F. TECHNICAL REFERENCES LIST

Index to Rulemaking File Underground Storage Tank Regulations Title 23, Waters Division 3, Water Resources Control Board Chapter 16, Underground Storage Tank Regulations 1985

1. American Society of Mechanical Engineers, "ASME Boiler Pressure Vessel Code, An American National Standard," Section VIII, 1977 ed., as cited in Technology For the Storage of Hazardous Liquids - A State of the Art Review, Department of Environmental Conservation, Albany, New York, January 1983

TECHNOLOGY FOR THE STORAGE OF HAZARDOUS LIQUIDS

A State-Of-The-Art Review

New York State
Department of Environmental Conservation

File C 225

TECHNOLOGY FOR THE STORAGE OF HAZARDOUS LIQUIDS

A State-Of-The-Art Review

NEW YORK STATE

DEPARTMENT OF ENVIRONMENTAL CONSERVATION
DIVISION OF WATER
BUREAU OF WATER RESOURCES

ALBANY, NEW YORK

JANUARY 1983

C. TYPES OF UNDERGROUND STORAGE TANKS

1. Bare Steel Tanks

Bare steel tanks constructed of mild carbon steel may be used in non-corrosive soil environments to store non-corrosive materials, such as gasoline and other petroleum derivative products. The compatibility of steel with various petroleum and chemical products is discussed in Part 1 and Appendix B. The degree of environmental protection provided by bare steel tanks is minimal and consequently their use has declined in recent years.

Please note that many bare steel tanks have a thin surface coating to protect against rust. This is essentially a cosmetic coating, and should not be confused with more substantial corrosion protection coatings.

Design Standards. The capacities, dimensions and construction details for bare steel tanks generally follow established standards. These include the following:

Underwriter Laboratories (UL) Inc.:
- UL 58 – *Steel Underground Tanks for Flammable and combustible Liquids* [6].

National Fire Protection Association (NFPA):
- NFPA 30 – *flammable and combustible Liquids Code* [19].

American Petroleum Institute (API):
- API Publication 1602 – *Recommended Standard for Underground Gasoline Tanks* [21].
- API Publication 1611 – *Service Station Tankage Guide* [20].
- API Publication 1615 – *Installation of Underground Petroleum Storage Systems* [1].

American Society of Mechanical Engineers:
- ASME/Pressure Vessel Code, Section VIII/[14].

Of these standards, the Underwriters Laboratories standards are the most detailed in that they specify many of the tank design details. These include steel thickness, tank head design, bracing requirements for multi-compartment tanks, the sizes of vent connections, and tank marking and testing requirements.

The American Society of Mechanical Engineers Pressure Vessel Code may be used for storage tanks intended for industrial service.

The thicknesses of horizontal, atmospheric-type steel tanks of various capacities as recommended in UL 58 are shown in Table 2.1-2. This standard also recommends that the length of the tank be no more than six times its diameter [6]. As a source of reference, the capacity per foot of length for tanks having diameters of 24 to 144 inches is given in Table 2.1-3.

Installation of Underground Steel Tanks. Sources of information and recommendations of installation practices for underground storage tanks include API Publication 1615 [1], NFPA 30 [19] and the New York State Department of Environmental Conservation (NYSDEC) manual covering standards of practice for bulk storage of hazardous liquids [30]. Most manufacturers supply step-by-step procedures for tank installation and require that these steps be followed to validate the guarantees and warrantees.

The installation recommendations given in the API publication identify tank clearance, depth of excavation, and anchoring and backfilling requirements. Examples of the recommendations given in API Publication 1615 include the following:

- At least 6 inches and preferably 12 inches of well-compacted sand or gravel placed underneath the tank.
- A minimum tank clearance of 12 inches in all horizontal directions.
- In areas not subject to traffic, the cover depth should be a minimum of 24 inches, or not less than 12 inches plus a reinforced concrete slab not less than 4 inches in thickness.
- Where tanks are subject to traffic, cover depths should be a minimum of 36 inches, or not less than 18 inches of well-tamped material plus at least 6 inches of reinforced concrete or 8 inches of asphaltic concrete.

It should be noted that the burial depth of a tank is dependent upon several factors, including local regulations, the type of finished surface to be applied, soil conditions, topography, and suction pumping lift requirement [1].

The recommendations of NFPA 30 concur with those of API Publication 1615, with the addition that steel underground tanks shall be set on firm foundations and surrounded with at least 6 inches of noncorrosive inert material, such as clean sand or gravel, well-tamped in place [19].

The backfill for steel tanks is typically a clean, noncorrosive, porous material such as clean washed sand or gravel. Backfilling operations are very important to the life of the installation. It is important that the backfill be well compacted to avoid undue stresses on the tank. Application and compaction of the backfill in layers is often specified to chieve optimum compaction (eliminate voids in the backfill).

References

1. American Petroleum Institute, *Installation of Underground Petroleum Storage Systems*, API Publication 1615, American Petroleum Institute, 2101 L Street N.W., Washington, D.C. 20037, November 1979.

2. Bixby, J.L., *Underground Steel Storage Tanks*. The Construction Specifier, The Construction Specifications Institute, Washington, D.C. 20036, October, 1973.

3. Fitzgerald, J.H., *Suggested Ways to Meet Protection Corrosion Codes for Underground Tanks and Piping*, The Hinchman Company, 1605 Mutual Building, Detroit, MI 48226, August 8, 1981.

4. Hasse Tank GmbH & Co., KG, *The Double Wall Self-Monitored Tank*, Betco Associates, P.O. Box 350, Closter, N.Y. 07624.

5. Owens-Corning Fiberglas Corp., *Fiberglas Tanks for Fuel Storage*, Pub. No. 3-PE-6312-L, Owens-Corning Fiberglas Corp., Non-Corrosive Products Division, Fiberglas Tower, Toledo, Ohio 43659, December 1980.

6. Underwriters Laboratories, Inc., *Steel Underground Tanks for Flammable and Combustible Liquids*, UL 58, Underwriters Laboratories, Inc., 333 Pfingsten Road, Northbrook, Illinois 60062, October 1976.

7. Anonymous, "Composite Tanks Fuse Fiberglass to Steel via Polyester Resin Bond," *Petroleum Marketer*, McKeand Publications, May-June 1979.

8. Anonymous, "Proper Installation is Vital to Long-Life of Fiberglass Tanks," *Petroleum Marketer*, McKeand Publications.

9. Anonymous, "Steel Tank Institute's 'Sti-P3' Tanks Combine Three-Way Protection," *Petroleum Marketer*, McKeand Publications, May-June 1973.

10. Fitzgerald, J.H., "Corrosion Control for Buried Services Station Tanks," Paper No. 52, The International Corrosion Forum Devoted Exclusively to the Protection and Performance of Materials, April 14-18, 1975, Toronto, Canada, National Association of Corrosion Engineers, Publications Department, 1440 South Creek, Houston, Texas 77084.

11. Standards of the Suffolk County Department of Health Services for the Administration of Article 12 (Toxic and Hazardous Materials Storage and Handling Control), of the Suffolk County Sanitary Code, County of Suffolk, Department of Health Services, Central Islip, N.Y. 11722 dated October 3, 1979.

12. Husock, B., *Corrosion Cathodic Protection and Common Sense*, Paper No. HC-3, Harco Corp., Cathodic Protection Division, 1055 West Smith Road, Medina, Ohio 44256.

13. Lifetime Fiberglass Tank Co., *Spec-Data Sheet 13P – Liquid and Gas Storage Tanks*, Lifetime Fiberglass Tank Co., 5000 Packing House Road, Denver, Colorado 80216, February 1981.

14. Perry, R.H., Chilton C. H., *Chemical Engineers' Handbook*, Fifth Ed, McGraw-Hill Book Co., 1221 Avenue of the Americas, New York, N.Y. 10020.

15. Owens-Corning Fiberglas Corp., *Fiberglas Tanks for Liquid Chemicals*, Pub. No. 5-PE-6398-G, Owens-Corning Fiberglas Corp., Non-Corrosive Products Division, Fiberglas Tower, Toledo, Ohio 43659.

16. Tator, K.B., *Protective Coatings*, Chemical Engineering Deskbook Issue, McGraw-Hill Book Co., 1221 Avenue of the Americans, New York, N.Y., 10020, December 4, 1972.

17. Falck, S.B., *Process Tank Linings*, Chemical Engineering Deskbook Issue, McGraw-Hill Book Co., 1221 Avenue of the Americans, New York, N.Y., 10020, December 4, 1972.

18. Telephone conversation with Dick Hugo, Ceramic Coating Corp., Newport, KY., October 14, 1981.

19. National Fire Protection Association, *Flammable and Combustible Liquids Code*, NFPA 30, National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.

20. American Petroleum Institute *Service Station Tankage Guide*, API Publication 1611, American Petroleum Institute, 2101 L Street N.W., Washington, D.C. 20037.

References Continued

21. American Petroleum Institute *Recommended Standard for Underground Gasoline Tanks*, API Publication 1602, American Petroleum Institute, 2101 L Street N.W., Washington, D.C. 20037.

22. Rothman, P.S., *Cathodic Protection of Tanks and Underground Structures*, The Harco Corporation, Hatboro, PA 19040, 1978.

23. Clemmer Industries, Ltd., *Double-Walled Storage Tanks*, Clemmer Industries (1964) Ltd. 446 Albert Street, P.O. Box 130, Waterloo, Ontario N2J4A1, August, 1981.

24. J&T Ecology Corp., *Industrial-Chemical Storage Tanks*, JTEC-979, J&T Ecology Corp., 200 Lambert Avenue, Copiague, New York 11726.

25. Crown Rotational Molded products, *Crown Tanks for the Industrial-Chemical Industries*, Marked Tree, AR.

26. Steel Tank Institute, *Reliable, Low Cost, Long Life Design in Underground Steel Storage Tanks*, Publication 15.8 (d)/St, Steel Tank Institute, 666 Dundee Road, Northbrook, Illinois 60062.

27. Husock, B., *Fundamentals of Corrosion Protection*, Paper No HC-2, Harco Corporation, Cathodic Protection Division, 1055 West Smith Road, Medina, Ohio 44256.

28. National Fire Protection Association, *Standards for Installation of Oil Burning Equipment*, NFPA 31, National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.

29. Anonymous, "Denver's Lifetime Co. Constructs Fiberglass Tanks 'Like Giant *Pills*'", *Petroleum Marketer*, McKeand Publications, March/April 1980.

30. New York State Department of Environmental Conservation, *Standards of Practice for the Bulk Storage of Hazardous Liquids*, to be written.

31. Bethlehem Steel Corp., *BT-10 Specifications*, Bethlehem Steel Corp., Buffalo Tank Division; Frankfurst Avenue, Fairfield, Baltimore, MD 21226.

32. Steel Structure Painting Council, 4400 Fifth Ave., Pittsburgh, PA 15213.

33. PACE, *Underground Tank Systems;* Review of State of the Art and Guidelines. Report No. 82-3. PACE, 1202 275 Slater St., Ottawa, Can. KIP 5H9.

2. American Petroleum Institute. Recommended Practice for Underground Petroleum Product Storage Systems Marketing and Distribution Facilities, Publication 1635, First Edition, April 1984

Recommended Practice for Underground Petroleum Product Storage Systems at Marketing and Distribution Facilities

API RECOMMENDED PRACTICE 1635
FIRST EDITION, APRIL 1984

American Petroleum Institute
1220 L Street, Northwest
Washington, D.C 20005

MAY 24 1984

Recommended Practice for Underground Petroleum Product Storage Systems at Marketing and Distribution Facilities

Marketing Department

API RECOMMENDED PRACTICE 1635
FIRST EDITION, APRIL 1984

American
Petroleum
Institute

FOREWORD

The prevention and detection of product leakage from petroleum storage and dispensing systems is important to both industry and the public This recommended practice is offered as a guide for voluntary use by architects, engineers, marketers, jobbers, and contractors in the design, use, and maintenance of such systems.

Federal, state, and municipal codes or laws may have specific restrictions or requirements that must be taken into account prior to the installation of underground tanks and piping.

The American Petroleum Institute takes no position as to whether any procedure, method, device, or product mentioned in this publication is covered by existing patent or copyright or as to the validity of such coverage. The publication does not grant the right, by implication or otherwise, to manufacture, sell, or use such procedures, methods, devices, or products so covered nor does it insure anyone against liability for infringement of such patents or copyrights.

This publication is available for general use by those interested, but the American Petroleum Institute shall not be responsible or liable in any way for loss or damage resulting from such use or for the violation of any federal, state, or municipal regulation with which it may conflict.

CONTENTS

PAGE

1—GENERAL
1.1 Scope 1
1.2 General Provisions 1

2—DEFINITIONS
2.1 Underground Petroleum Product Storage Tank Systems 1
2.2 Marketing and Distribution Facilities 1
2.3 Authority Having Jurisdiction 1
2.4 Combustible Liquid 1
2.5 Flammable Liquid 1
2.6 Listed 1
2.7 Operator 1
2.8 Owner 1
2.9 Product Line Leak Detector 2
2.10 Remote Pumping System 2
2.11 Suction Product System 2
2.12 Product Handling System 2
2.13 Observation Well 2
2.14 Secondary Containment 2

3—PREVENTION
3.1 Selecting and Installing Underground Tanks 2
3.1.1 New Facilities 2
3.1.2 Existing Facilities 2
3.2 Piping 3
3.2.1 New Facilities 3
3.2.2 Existing Facilities 3
3.3 Pumping Systems 3
3.3.1 New Facilities 3
3.3.2 Existing Facilities 3

4—DETECTION
4.1 Inventory Control for New and Existing Facilities 4
4.2 Testing 5
4.2.1 New Facilities 5
4.2.2 Existing Facilities 5
4.3 Observation Wells 5
4.3.1 New Facilities 5
4.3.2 Existing Facilities 6
4.4 Secondary Containment 6
4.4.1 New Facilities 6
4.4.2 Existing Facilities 6

Recommended Practice for Underground Petroleum Product Storage Systems at Marketing and Distribution Facilities

1—GENERAL

1.1 Scope

This recommended practice describes measures necessary to prevent and detect leaks from underground petroleum product storage tank systems, as defined in 2.1, at marketing and distribution facilities, as defined in 2.2.

1.2 General Provisions

1.2.1 This recommended practice applies to underground petroleum product storage tank systems at marketing and distribution facilities, except fuel oil containers of less than 1100 gallons capacity connected to burning equipment and underground storage tanks for liquefied petroleum or natural gases.

1.2.2 In particular installations, the provisions of this recommended practice may be altered at the discretion of the authority having jurisdiction after consideration of special features, such as, topographical conditions, barricades, walls, water tables, soil conditions, and proximity to buildings and adjoining property.

2—DEFINITIONS

2.1 Underground Petroleum Product Storage Tank Systems

Underground petroleum product storage tank systems are tanks totally buried underground and the related system composed of storage tank(s), product line(s) to dispensing pump(s), vent line(s), tank fill line(s), dispensing pump(s), dispenser(s), and appurtenances for the storage or dispensing of petroleum products. This recommended practice does not apply to aboveground storage tanks that are partially buried or below grade, which are in compliance with other fire and safety codes, or are excluded in 1.2.1.

2.2 Marketing and Distribution Facilities

Marketing and distribution facilities are retail, commercial, and private facilities that store and dispense flammable or combustible liquids to consumers. This recommended practice does not apply to distribution centers with aboveground tankage or to product pipelines, both of which are covered by other standards.

2.3 Authority Having Jurisdiction

Authority having jurisdiction shall mean the organization, office, or individual responsible for approving equipment, installations, or procedures.

2.4 Combustible Liquid

A *combustible liquid* is a liquid having a flash point at or above 100°F (37.8°C).

2.5 Flammable Liquid

A *flammable liquid* is a liquid having a flash point below 100°F (37.8°C) and having a vapor pressure not exceeding 40 pounds per square inch absolute at 100°F (37.8°C) and shall be known as a Class I liquid.

2.6 Listed

Listed shall mean equipment or materials included in a list published by a nationally recognized testing laboratory, inspection agency, or other organization concerned with product evaluation that maintains periodic inspection of the production of listed equipment or materials and whose listing states either that the equipment or material meets nationally recognized standards or has been tested and found suitable for use in a specified manner.

2.7 Operator

The *operator* is the lessee or person(s) in control of and having responsibility for the daily operation of the facility for the storage, use, or dispensing of flammable and combustible liquids.

2.8 Owner

The *owner* is the person(s) who owns the tank storage system used for the storage, use, or dispensing of flammable and combustible liquids.

2.9 Product Line Leak Detector

A *product line leak detector* is a device used to detect product or pressure losses in a pressurized product line or a remote pumping system.

2.10 Remote Pumping System

A *remote pumping system* is a pressurized product line system in which flammable or combustible liquids are supplied to a point(s) away from the tank(s) by means of a pumping unit(s) in or on the storage tank(s).

2.11 Suction Product System

A *suction product system* is a nonpressurized product line system in which flammable or combustible liquids are removed from the storage tank(s) by means of a pumping unit(s) located at a point(s) away from the storage tank(s).

2.12 Product Handling System

A *product handling system* is a system composed of storage tank(s), product line(s), vent line(s), tank fill line(s), pump(s), dispenser(s), and other apppurtances for the storage, use, or dispensing of flammable or combustible liquids.

2.13 Observation Well

An *observation well* is a dug or drilled, cased well that can be used for detecting the presence of flammable or combustible liquids and is drilled to a depth of approximately 24 inches below the tank bottom.

2.14 Secondary Containment

Secondary containment is an impervious barrier installed so that any volume of material leaked from the storage system is prevented from reaching the lands and/or water outside the impervious barrier for the anticipated period of time necessary to detect and recover the spilled material.

3—PREVENTION

3.1 Selecting and Installing Underground Tanks

3.1.1 NEW FACILITIES

3.1.1.1 Tanks shall be designed and built using noncorrosive material or cathodically protected steel.

3.1.1.2 A steel system as described in 3.1.1.1 shall be cathodically protected by an impressed current cathodic protection system, sacrificial anodes, or some other type of equivalent protection If a cathodic protection system is used, it shall be maintained in accordance with 4.2.2 5.

3.1.1.3 Cathodically protected steel or approved noncorrosive coated steel underground tanks shall be set on a firm base and surrounded with at least 12 inches of noncorrosive inert material, such as clean sand or gravel, well tamped in place. The tanks shall be placed in the hole with care. Dropping or rolling the tank into the hole can break welds, puncture or damage the tank, scrape off the protective coating of coated tanks, or damage attached cathodic protection.

3.1.1.4 Cathodically protected steel or approved noncorrosive coated steel underground tanks shall be covered with a minimum of 2 feet of sand or shall be covered with not less than 1 foot of sand on top of which shall be placed a slab of reinforced concrete not less than 4 inches thick. When tanks are, or are likely to be, subjected to traffic, they shall be protected from damage from vehicles passing over them by at least 3 feet of backfill, 18 inches of well-tamped backfill plus 6 inches of reinforced concrete or 8 inches of asphalt paving. When asphalt or reinforced concrete paving is used as part of the protection, it shall extend at least 1 foot horizontally beyond the outline of the tank in all directions.

3.1.1.5 Nonmetallic underground tanks shall be installed in accordance with the manufacturer's instructions. The minimum depth of cover shall be as specified in 3.1.1.4.

3.1.1.6 The entire installation shall comply with the latest requirements of the National Fire Protection Association (NFPA)[1] 30, *Flammable and Combustible Liquids Code*, or the International Conference of Building Officials[2] *Uniform Fire Code*, as applicable.

3.1.1.7 All temporary supports must be removed prior to final backfilling.

3.1.2 EXISTING FACILITIES

3.1.2.1 If it is necessary to replace or coat the interior of an underground steel tank that developed a corrosion-induced leak, consideration should be given to coating the interior

[1]National Fire Protection Association, Batterymarch Park, Quincy, Massachusetts 02269

[2]International Conference of Building Officials, 5360 South Workman Mill Road, Whittier, California

or replacing all other steel tanks at the facility whether or not they are leaking. Replacement tanks should meet the requirements of 3.1.1.1 through 3.1.1.7. If the interior of an underground steel tank is being coated and the soil resistivity is less than 10,000 ohms per centimeter, the tank should be provided with cathodic protection.

3.1.2.2 Determinations to replace unprotected steel tanks should be based on specific site and soil conditions.

3.1.2.3 Tanks constructed of corrosion-resistant materials, cathodically protected steel tanks, or noncorrosive coated steel tanks need not be replaced based on arbitrary factors, such as age, alone.

3.1.2.4 Cathodic protection systems for steel tanks should be monitored sufficiently to ensure that continuous protection is being provided as prescribed by the designer or the manufacturer or both.

3.1.2.5 Tanks to be abandoned or removed should be handled in accordance with API Recommended Practice 1604.

3.2 Piping

3.2.1 NEW FACILITIES

3.2.1.1 All underground piping shall be approved nonmetallic pipe or cathodically protected Schedule 40 steel pipe. If a cathodic protection system is used, it shall be maintained in accordance with 4.2.2.5.

3.2.1.2 Product lines shall be installed in a single trench between the tank area and the pump island. Similarly, underground vent lines shall be installed in a single trench. If secondary containment is provided, all lines should slope towards the tank area.

3.2.1.3 Before underground piping is installed, the trench shall receive as a minimum a 6-inch deep bed of well compacted noncorrosive material such as clean, washed sand or gravel. All trenches shall be wide enough to permit at least 6 inches of noncorrosive backfill material around all lines.

3.2.1.4 All piping shall be tested according to the requirements of 4.2.1.1.

3.2.1.5 All temporary supports must be removed prior to final backfilling.

3.2.2 EXISTING FACILITIES

3.2.2.1 Replacement of underground piping shall be done in accordance with 3.2.1.

3.2.2.2 Repair of underground piping shall be done in accordance with generally accepted industry practice.

3.3 Pumping Systems

3.3.1 NEW FACILITIES

3.3.1.1 Remote pumping systems shall be designed or equipped so that no part of the system will be subjected to pressures above allowable working pressures.

3.3.1.2 All new remote pumping systems shall be equipped with a product line leak detector. Leak detectors shall be tested in accordance with 4.2.1.3.

3.3.1.3 For remote pumping systems, a listed, rigidly anchored emergency shutoff valve, incorporating a fusible link or other thermally actuated device, designed to close automatically in the event of a severe impact or exposure to fire, shall be properly installed in the supply line at the base of each individual island-type dispenser. The automatic closing feature of this valve shall be checked at the time of initial installation and at least once a year thereafter by manually tripping the hold-open linkage.

3.3.1.4 Conventional suction systems may be used.

3.3.1.5 The operator shall advise the owner immediately should a leak detector signal a suspected product loss or a suction product system indicate a symptom of a potential leak [that is, a meter display jumping or skipping, liquid not being pumped when a pump is on, initial pump overspeed followed by slow pumping, erratic liquid flow (indicating an air and liquid mixture), continued loss of prime in the pumping unit, or others]. In no event shall the operator or his employees tamper with the leak detector.

3.3.1.6 When advised of a suspected leak by the operator, the owner shall take immediate action to verify the operation of the pumping system. Should a loss be determined, the owner shall take immediate corrective action. The affected pumping system shall be taken out of service until the necessary corrective action has been taken.

3.3.2 EXISTING FACILITIES

3.3.2.1 It is recommended that existing remote pumping systems be equipped with product line leak detectors. Leak detectors shall be tested in accordance with 4.2.2.6.

3.3.2.2 A listed, rigidly anchored emergency shutoff valve, incorporating a fusible link or other thermally actuated device, designed to close automatically in the event of a severe impact or exposure to fire, shall be properly installed in a remote pumping system supply line at the base of each

individual island-type dispenser. The automatic closing feature of this valve shall be checked at the time of initial installation and at least once a year thereafter by manually tripping the hold-open linkage.

3.3.2.3 The operator shall immediately advise the owner should a leak detector signal a suspected product loss or a suction product system indicate a symptom of a potential leak [that is, a meter display jumping or skipping, liquid not being pumped when a pump is on, initial pump overspeed followed by slow pumping, erratic liquid flow (indicating an air and liquid mixture), continued loss of prime in the pumping unit, and others]. In no event shall the operator or his employees tamper with the leak detector.

3.3.2.4 When advised of a suspected leak by the operator, the owner shall take immediate action to verify the operation of the pumping system. Should a loss be determined, the owner shall take immediate corrective action. The affected pumping system shall be taken out of service until the necessary corrective action has been taken.

4—DETECTION

4.1 Inventory Control for New and Existing Underground Facilities

4.1.1 Accurate daily inventory records shall be maintained and reconciled on all flammable and combustible underground liquid storage tanks for indication of possible leakage from tanks or piping. The records shall be made available for inspection by the enforcing authority and shall include, as a minimum, records showing by product, daily reconciliation between sales, use, receipts, and inventory on hand. If there is more than one system consisting of a tank(s), serving pump(s), or dispenser(s) for any product, the reconciliation shall be maintained separately for each tank system.

4.1.2 Daily inventory shall be maintained by the operator for each tank system at each location. The inventory records for the immediately preceding 12 months shall be kept at the premises.

4.1.3 Inventory shall be based on the actual daily measurement and recording of tank product and water levels and the daily recording of actual sales, use, and receipts. Daily measurements shall be made by gage or gage stick or by readout from an automated gaging system. The inventory records shall include a daily computation of gain or loss. The mere *recording of pump meter readings and product delivery* receipts shall not consistitute adequate inventory records.

4.1.4 The operator of the location shall be responsible for notifying the owner or person(s) in control of the facility to take action to correct any abnormal loss or gain not explained by spills, temperature variations, or other causes.

4.1.5 Failure to maintain inventory procedures and records as indicated in 4.1.1 through 4.1.4 may result in penalties by enforcing authorities.

4.1.6 As a minimum, the steps described in 4.1.6.1 through 4.1.6.8 shall be taken in an expeditious manner when daily inventory records indicate an abnormal loss.

4.1.6.1 The inventory records shall be checked for error.

4.1.6.2 If no error in inventory records is apparent, an independent calculation of apparent loss shall be made by a qualified person starting from a point in time where the records indicate a no-loss condition.

4.1.6.3 If the step described in 4.1.6.2 confirms an apparent loss, the readily accessible physical facilities on the premises shall be inspected carefully for evidence of leakage.

4.1.6.4 If the step described in 4.1.6.3 does not disclose a leak, the dispensers used with the particular product involved with the apparent loss shall be checked for calibration. The drain plugs within the dispenser should be sealed by drilling holes in plug protrusions and inserting wire lead seals. Fill pipe openings should be locked to prevent unauthorized product removal.

4.1.6.5 If the steps described in 4.1.6.1 through 4.1.6.4 do not explain the apparent loss and the regulatory reporting or testing requirements are not known, the situation shall be reported *promptly to the authority having jurisdiction.*

4.1.6.6 If the steps described in 4.1.6.1 through 4.1.6.4 do not explain the loss and if the piping system can be tested without excavation, the piping system between the storage tank and the dispenser(s) shall be tested in accordance with 4.2.1.1 for new facilities or 4.2.2.4 for existing facilities. If it is necessary to excavate to perform a piping test, such a test shall be conducted after a storage tank test has been performed in accordance with 4.1.6.7.

4.1.6.7 If the step described in 4.1.6.6 does not disclose a leak, the storage tank(s) shall be tested for tightness in

accordance with NFPA 329, *Underground Leakage of Flammable and Combustible Liquids*.

4.1.6.8 If the steps described in 4.1.6.1 through 4.1.6.7 do not confirm the apparent loss, the daily inventory shall be continued with a daily independent verification by a qualified person. Additional surveillance of the facility should be engaged to ensure against unauthorized removal of product.

4.1.7 Daily inventory need not be maintained on those days that an installation is not in operation. When the facility is not in operation, the daily inventory may be waived for periods not to exceed 15 days.

4.2 Testing

4.2.1 NEW FACILITIES

4.2.1.1 All piping shall be installed according to the manufacturer's recommendations. Before being covered, enclosed, or placed in use, the piping shall be hydrostatically tested to 150 percent of the maximum anticipated pressure of the system or pneumatically tested to 100 percent of the maximum anticipated pressure of the system, but not less than 50 pounds per square inch gage at the highest point of the system. If a pneumatic test is performed, all joints and connections shall be sprayed with a soap solution, and the test shall be maintained for a time sufficient to complete visual inspection of all joints and connections, but not less than 10 minutes.

4.2.1.2 New underground tanks shall be tested for tightness hydrostatically or with air pressure at not less than 3 pounds per square inch and not more than 5 pounds per square inch after installation but before being covered or placed in use.

NOTE Air pressure tests shall not be conducted after petroleum product has been placed in the tank

4.2.1.3 Product line leak detectors shall be tested for proper operation before the remote pumping system is used after initial installation.

4.2.2 EXISTING FACILITIES

4.2.2.1 The authority having jurisdiction may require the operator of an underground storage system to test the system for tightness, at the operator's expense, when accurate daily inventory records have not been maintained as specified in 4.1.2

4.2.2.2 The authority having jurisdiction may require the owner of an underground tank storage system to test the system for tightness at the owner's expense when inventory records reveal an unexplained loss as specified in 4.1.4 or when flammable or combustible liquids or their vapors have been detected in neighboring structures, sewers, wells, or other on- or off-property location.

4.2.2.3 Product tanks shall not be pressure tested with air.

4.2.2.4 Piping tests as required in 4.2.2.1 and 4.2.2.2 shall be by a pipeline test with liquid as specified in NFPA 329, *Underground Leakage of Flammable and Combustible Liquids*.

4.2.2.5 If a cathodic-protection system is installed, an ongoing preventive maintenance program shall be used. Where sacrificial anodes have been installed, their proper operation shall be confirmed by a qualified person within 6 to 12 months of installation and 1 year thereafter. If these tests confirm proper operation, subsequent inspection intervals can be extended to 5 years. However, if underground work is performed at a protected site, cathodic protection should be remonitored 6 to 12 weeks after work is completed and 1 year thereafter before again extending the inspection interval. If an impressed current cathodic-protection system is installed, the operator shall verify, at least once a month, that it is operating, and a qualified person shall conduct an on-site test and inspection, at least once a year, to measure the structure-to-soil and structure-to-structure potentials and the rectifier voltage and current output.

4.2.2.6 Product line leak detectors shall be tested for proper operation on an annual basis.

4.3 Observation Wells

4.3.1 NEW FACILITIES

4.3.1.1 When more than one tank is installed, observation wells, a minimum of 2 inches in diameter, are recommended for installation at two corners within tank hole excavations. If only one tank is installed, an observation well should be installed near each end of the tank.

NOTE: Observation wells should be adequately identified to avoid confusion with product fill openings

4.3.1.2 Observation wells shall be installed to a depth of 24 inches below the tank bottom or to the top of the concrete slab, if used for anchoring.

4.3.1.3 Observation wells shall be installed with a pipe section having 0.020-inch maximum slots with the slots extending to within approximately 12 inches of grade. This will allow detection of product leaks on a fluctuating water table and will eliminate well plugging under most soil conditions; blank well piping should extend the remainder of the distance

to grade. Observation wells should be capped and protected from traffic with a manhole and cover.

4.3.1.4 With secondary containment, only one observation well is required. This well should extend to within approximately 6 inches of the bottom of containment material and have pipe with 0.020-inch slots to 24 inches above the designed water level within the containment system.

4.3.2 EXISTING FACILITIES

4.3.2.1 Observation wells should not be arbitrarily required for existing tank installations.

4.3.2.2 Observation wells may be required where inventory controls are not maintained as recommended and a local authority required them as a result of a suspected tank failure or leakage.

4.3.2.3 Observation wells may be required where a high environmental risk exists as a result of the presence of sole-source aquifers or water reservoirs.

4.3.2.4 Observation wells, when required, should be installed in accordance with 4.3.1.1 through 4.3.1.3.

4.4 Secondary Containment

4.4.1 NEW FACILITIES

4.4.1.1 Secondary containment is recommended for new installations when sole-source aquifers are determined to need such protection or groundwater below the facility is within the cone of influence of municipal water wells. Where private potable water wells are within a minimum of 300 feet of a tank installation or hydrogeological conditions indicate that a potable water well could be contaminated by a tank leak, secondary containment is recommended.

4.4.1.2 Secondary containment should be engineered for specific site conditions using the best current engineering practices and petroleum-resistant materials.

4.4.1.3 Secondary containment for locations with water table elevations normally within the tank hole excavation should consist of an impervious barrier on the tank excavation walls. The bottom should not be enclosed with the impervious barrier because the water table will allow detection of any petroleum product leak via the observation well.

4.4.1.4 Where the water table is below the tank hole excavation, secondary containment may be accomplished by lining the tank hole. The secondary containment should be constructed to maintain a water depth to the top of the tanks and then allow excess water buildup to be discharged from the bottom of the containment area via overflow piping or other similar system. Any leaking tanks shall be readily detected by daily inventory control because the tank will be taking on water. Where feasible, the overflow water should be allowed to discharge into the ground outside the containment area, to a dry well, or to a storm drain or sanitary sewer, as appropriate.

4.4.1.5 Where required for new tank installations, secondary containment is recommended under all underground piping connected to the tank(s). The piping secondary containment shall provide for the collection and detection of any piping leak.

4.4.2 EXISTING FACILITIES

The technology for installing secondary containment for existing tanks, while they remain in place, is not sufficiently reliable or effective to be recommended or required.

3. American Petroleum Institute. Recommended Practice for Bulk Liquid Store Control at Retail Outlets, Marketing Department Publication 1621, Third Edition, 1977

Recommended Practice For Bulk Liquid Stock Control At Retail Outlets

Marketing Department

PUBLICATION 1621
THIRD EDITION 1977

American
Petroleum
Institute

TABLE OF CONTENTS

		Page
1.	Foreword	iv
2.	Introduction and Purpose	1
3.	Accounting Systems	2
4.	Sources of Losses	2
5.	Unavoidable Losses	2
6.	Magnitude of Normal Loss	3
7.	Controllable Losses	4
7.1	Leakage	4
7.2	Spillage	5
7.3	Theft	5
7.4	Product Used on Premises	5
8	Procedures for Reduction of Controllable Losses	5
9.	Summary	7
	Appendix A—Sample Daily Gasoline Inventory Record	8
	Appendix B—Procedure for Testing Accuracy of Gasoline-Dispensing Meters	9
	Appendix C—Leak Investigation Procedures	10
	Appendix D—Gaging Procedure for Underground Horizontal Tanks	11
	Appendix E—Water-Gaging Procedure	13

1. FOREWORD

The American Petroleum Institute takes no position as to whether any procedure, method, device, or product mentioned in this bulletin or its appendices is covered by an existing patent or copyright or as to the validity of such coverage. The bulletin does not grant the right, by implication or otherwise, to manufacture, sell, or use such procedures, methods, devices, or products so covered, nor does it insure anyone against liability for infringement of such patents or copyrights.

This bulletin is available for general use by those interested, but the American Petroleum Institute shall not be responsible or liable in any way for loss or damage resulting from such use or for the violation of any federal, state, or municipal regulation with which it may conflict.

This bulletin supersedes and replaces the previous bulletin entitled, "Recommended Practice for Bulk Liquid Stock Control in Service Stations, January 1973 Edition, Reprinted July 1976."

2. INTRODUCTION AND PURPOSE

Any merchandising operation in which a commodity is handled in bulk is susceptible to stock or inventory losses. This problem becomes even more critical at retail outlets selling motor fuels since the principal bulk commodity handled is volatile. Thus, *special care* must be exercised to hold product losses to a minimum so as to provide a safe environment for the operator, employees, customers, and neighbors; to minimize air and water pollution; and to maximize profits.

The negative effect of product losses on profits needs no explanation. However, the operator should understand that he, as well as the owner of the underground storage and dispensing equipment, may be subject to financial penalties imposed by governmental agencies if product leakage causes contamination. He may also be liable for personal injuries and property damage resulting from hazardous conditions caused by product leakage as a result of his negligence. Further, the Occupational Safety and Health Administration (OSHA) requires the operator to maintain and reconcile inventory records. Several states have similar regulations which contain penalties for noncompliance.

The purpose of this bulletin, then, is to assist the operator in reducing his bulk stock losses, thereby achieving a high level of safety and pollution control while also maximizing profits. This bulletin describes and explains practices and procedures needed to achieve good bulk stock control since it is the basic method for recognizing unaccounted-for losses. This control is achieved through the *daily preparation and review* of inventory control records.

3. ACCOUNTING SYSTEMS

The necessity of establishing and using an adequate accounting system, not only for inventory, but for the business in general, cannot be overstressed. Even a very simple system may be adequate to control inventory of bulk liquid stock, but it is of the utmost importance that it be used every day.

As a minimum, the system should clearly show each day the following information for each grade or type of bulk liquid product:

1. A record of all bulk liquid receipts (i.e., delivery invoices).
2. A record of all bulk liquid sales (obtained from the fuel dispensers).
3. A record of bulk liquid used other than that sold.
4. A daily reconciliation between sales, use, receipts, and inventory-on-hand.

Many different accounting systems are available. Most supplying oil companies will advise their operators as to the proper accounting procedures to be used, including the use of suitable accounting forms and where they may be obtained (a sample daily gasoline inventory record is included as Appendix A).

Once the operator has adopted a system, he should use it conscientiously and according to the instructions. In some cases, the circumstances of an individual operation may be such that after a reasonable period of use, the system can be simplified without impairing its purpose or augmented to provide additional accurate information. However, to be of full value the system, no matter how it is modified, must be used daily.

4. SOURCES OF LOSSES

For the purpose of this discussion, losses are divided into two categories: those which are unavoidable because of the nature of the business and the characteristics of the liquid, and those which can be controlled and reduced by following appropriate stock control procedures.

5. UNAVOIDABLE LOSSES

Any business involving the handling of merchandise is subject to unavoidable stock losses. The operator of a retail gasoline outlet is even more subject to unavoidable stock loss because of the volatile nature of the liquid product he handles. A portion of the product in the storage tanks will vaporize and occupy the empty portion of the tank as a vapor-air mixture. When product is received, an equivalent volume of vapor-air mixture is forced out through the vents by the incoming product. Where vapor emission control equipment is in use, the vapor-air mixture is returned to the tank truck making the delivery.

Regardless of whether the storage system is or is not equipped with vapor emission control equipment, vapor-air mixture is seldom, if ever, expelled from underground tanks except during deliveries. The only other times when this condition could occur are when the vapor-air mixture expands as a result of an increase in temperature or when the barometric pressure changes.

The temperature of the ground around underground tanks does not vary appreciably from day to day. Even if underground product temperatures increase, vapor-air mixture normally will not be expelled from the vent because increased space is created whenever product is pumped from the tank during a sale to a customer. As a result, air is drawn into the tank rather than vapor-air mixture being forced out.

It is reasonable to conclude that vapor losses other than those which occur when deliveries are made to the underground tanks are so small that they could not be detected by ordinary gaging methods.

Differences in temperature between the product being delivered and the product already in the tank will create volume changes after delivery. If the temperature of the stored product drops, the volume will decrease, resulting in a shrinkage loss. Conversely, a rise in temperature results in product expansion.

For day-to-day impossibility of calibrating the meters of gasoline dispensers to achieve and maintain 100% accuracy should be recognized. Understanding this, the National Conference on Weights and Measures has established ± 7 cubic inches per 5 gallon measure as the legal tolerance level of gasoline dispensing meters. Since meter calibration variances may be overages, as well as underages, customers, on balance, receive full measure (procedure for testing the accuracy of gasoline dispensing meters is described in Appendix B).

In addition to these normal losses, the operator should recognize that an apparent reduction of inventory will occur when a new outlet is opened or tanks and lines are replaced at an existing outlet and the dispensing pumps are then placed in operation. This is caused by the withdrawal of product necessary to fill the lines. The operator should gage the tanks and if necessary, make an adjustment to his records. Neither the line fill nor the unavailable product in the tank below the suction stub should be considered lost since the product remains at the outlet and can be reclaimed or accredited as necessary.

6. MAGNITUDE OF NORMAL LOSS

The variances which have been discussed cannot be controlled by the operator, as they are inherent in the retail outlet operation and in the characteristics of the product handled. Data from a Treasury Department survey of regional differences between the volume of gasoline received and the volume dispensed at retail outlets showed that average geographic variances were within the range of +0.27 percent to −0.40 percent. In the aggregate, these variances are small enough to fall within the limits of good business operating overhead and should be considered as such by the operator.

It is apparent from the foregoing that a single or absolute figure cannot be developed to characterize the unavoidable losses of gasoline at specific retail outlets due to shrinkage, vaporization, meter calibration, and other causes. An operator should expect small variations in his inventory control. However, losses generally should not exceed one half of one percent (0.5 percent) or five gallons of every 1,000 gallons delivered. Any outlet operator whose losses exceed this amount when measured over extended periods of time should carefully examine his operating practices. Of even greater concern should be *sudden, unexplained variances from the established pattern or small but growing daily losses* (the steps to be taken when inventory records indicate an unexplained variance are outlined in Appendix C).

7. CONTROLLABLE LOSSES

The largest stock losses in a service station operation occur from practices and conditions which are within the operator's control. These include leaks, spills, theft, and product used on the premises. The larger the operation and the more persons employed, the more necessary it becomes to adhere rigidly to established procedures for good stock control if the business is to be successful.

7.1 LEAKAGE

Leaks can occur in dispensing equipment, underground piping, or tanks. Losses from this source can be reduced by proper product accountability, by regular inspection of the visible parts of the product handling system, and by the prompt recognition of symptoms which indicate leaks in the underground portion.

The dispensing equipment should be inspected at least once a week. If possible, this inspection should be made while the equipment is operating. Whereas, the operator might tighten a leaking connection, he should not attempt to correct a condition requiring extensive repair. Under no circumstances should electrical connections be broken or disconnected. If repairs or adjustments are required, the operator should immediately notify those responsible for maintenance of the equipment.

Evidence of leakage from buried equipment can be gathered from inventory control records and from abnormal operation of pumping equipment. Some of the more obvious symptoms of such leaks are:

1. Loss of product in a tank during periods when product is not dispensed usually indicates a leaking tank, but might also indicate an unaccounted for withdrawal, theft, or extreme temperature change.
2. An unaccountable increase in water in an underground tank may be caused by a leak in the tank if the ground surrounding it is saturated. Under such circumstances, water may leak into the tank instead of product leaking out. The increase in water may also be caused by a leaking gage or fill cap, and these should be examined and made watertight, if necessary, before concluding that the tank is at fault.
3. Increasing differences between the amount of product received and dispensed may indicate a meter calibration problem, theft, or a leak in tanks or piping. In this case refer to Appendix C.
4. Where fill boxes are located remotely from the tanks, large differences appearing consistently between the amounts invoiced and the tank gages after deliveries may indicate a leak in the remote fill line. In such event, the line should be tested.
5. A hesitation in the delivery from a standard dispensing pump may indicate a leak in the suction piping, although such hesitation may also be caused by a leaking foot valve or, in warm weather, by vaporlock. Should this occur, the inventory control records may indicate whether the cause is mechanical or whether product is actually being lost.
6. In a remote pumping system, meter spin without product delivery may indicate a piping leak.
7. Gasoline odor in spaces below ground adjacent to the station may be evidence of underground leaks, whether in the tank or piping.

Should the operator observe any of the foregoing symptoms, he should immediately notify those responsible for maintaining the equipment. He should not attempt to correct the condition himself, as the operation may involve some hazard and may require special equipment. Further, in some locations, only specially licensed mechanics can work on station equipment.

If gasoline odors are detected in an off-property location or if there is evidence of leakage at the outlet, the local fire department and the owner(s) of underground storage and dispensing equipment should be notified immediately.

7.2 SPILLAGE

Spillage losses can occur during receipt of product if the truck hose connections are not properly made either at the truck or at the fill box. These connections should be observed by the operator at the beginning of the delivery and corrections made if necessary.

Inspection of the truck's compartments to be sure they are empty may prevent a spill caused by premature removal of the truck hose from the fill box when delivery is made from a calibrated compartment by gravity.

Care should be exercised to avoid overfilling the underground storage tanks. The "Procedure for Receipt of Product," (page 6, 8 B) if followed, will prevent spillages from this source.

7.3 THEFT

Although loss through theft will not commonly occur, it must be considered. The accounting system must provide for periodic checks of purchases, sales, and inventories. If excessive variations of inventory are revealed by such checks, the facilities of the outlet and the operating procedures should be scrutinized closely. If this examination does not indicate the cause of the variation, the possibility of theft must be explored. The stock-inventory control system should be designed to take into consideration the fact that the normal causes for loss may be utilized to cover up fraudulent operations. Therefore, to prevent loss by theft, the operator must maintain a constant and careful watch over the operation of the system and immediately investigate any abnormal losses.

7.4 PRODUCT USED ON PREMISES

A careful record should be kept of all product dispensed for use on the premises or for the personal use of the operator and his employees. Such withdrawals must be properly accounted for if the stock control record is to show a true picture of inventory and losses.

Losses cannot be ascertained with any degree of accuracy without good gaging procedures and properly adjusted dispensing meters. The procedure for gaging (outlined in the following section), for meter checking (Appendix B), and the instructions for the proper use of the gage stick (Appendix D) are designed to assist the dealer in accurately accounting for his bulk liquid stock.

8. PROCEDURES FOR REDUCTION OF CONTROLLABLE LOSSES

The following procedures are recommended for use in maintaining an accurate inventory of bulk liquid product. It is recognized that the frequency of these procedures will vary when applied to the wide range of retail outlet operations dispensing motor fuel, but, adherence to the basic principle of maintaining a sound inventory control system will minimize losses and provide early detection of losses in excess of normal unavoidable losses.

A. Daily Procedures

1. Opening or closing of business:

a. First, read all meter totalizers. If the outlet is operating on shifts, the incoming and outgoing shift supervisors should perform this duty together. If this is not practical, the incoming supervisor should make meter readings his first duty and should check any readings left him by the supervisor of the previous shift. If the outlet is closed at night, compare the opening reading with the previous closing reading.

b. Gage all tanks (detailed procedure is specified in Appendix D).

c. Check all tanks for water, compare with previous reading, and make necessary adjustment for any variation. An undetected change in the amount of water in the tank would change the level of the product and produce an erroneous reading (instructions for gaging for water are given in Appendix E).

d. Record all sales and other uses of product occurring during gaging period.

e. Prepare meter and tank reconciliation by product system, maintaining records in such a manner that trends over a period of time are easily discerned.

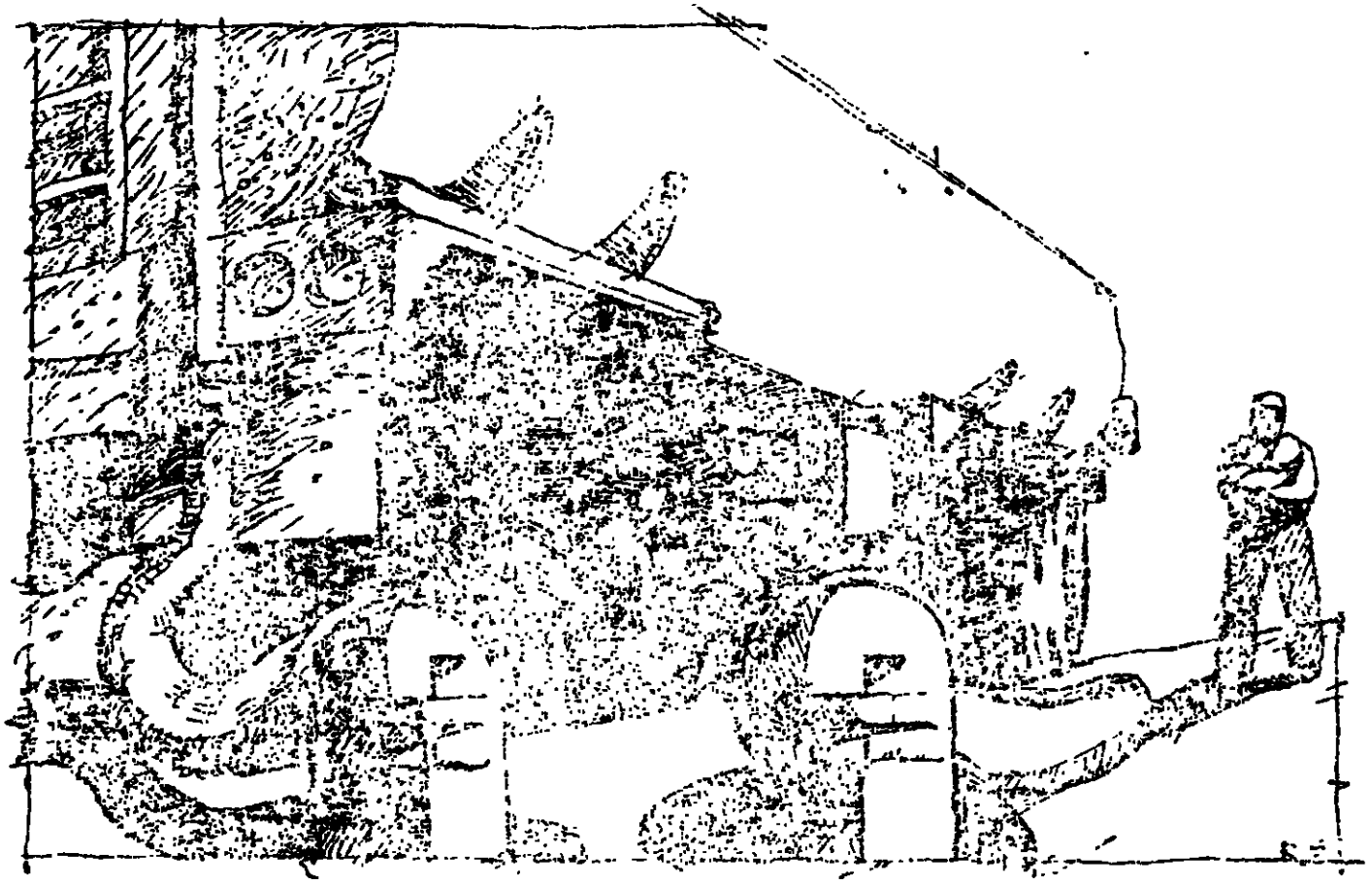
B. Procedure for Receipt of Product

1. Before and after delivery:

a. Although a few minutes might be saved in gaging tanks by limiting these procedures to those tanks involved with the anticipated receipt of product, it is recommended that all tanks be gaged. This will not only reveal any mistakes which might occur (dumping into wrong tanks, etc.) but will ensure accuracy when tanks are manifolded or when environmental requirements have necessitated a pressure/vacuum valve on the tanks.

b. All gaging should be completed as simultaneously as possible and as soon after the delivery has been completed so as to avoid delaying the truck. Should variations be experienced with interconnected tanks, a second gage should then be taken at least a half hour later when the product level has equalized. A record should be kept of all gages, but the last and more accurate gage should be used for inventory purposes.

c. Check all tanks for water before and after delivery. If this has been done in the preceding 12 hours, it need not be repeated *before* accepting the delivery, but it should always be done *after* the tanks are filled. No supplier willfully delivers water, but bulk plant operations and procedures sometimes result in water reaching the vehicle tanks without the knowledge of the loader. An increase in the water level will result in an erroneous calculation of the amount



received unless the water is detected and the records adjusted accordingly.

d. Reinstall all fill and gage caps. The delivery truck operator will make his own hook-ups.

CAUTION—Due to many changes in storage and dispensing facilities during recent years as necessitated by environmental protection considerations, the outlet operator must thoroughly understand his particular system. It should be recognized that a pressure or vacuum may exist under certain conditions, in which case necessary precautions should be observed. Most supplying oil companies will advise their retailers concerning such precautions when requested.

2. After delivery:
   a. Make adjustments for variation in water level, if any.
   b. Make adjustments for transactions during the delivery, if any
   c. Calculate amount of product received and compare with amount shown on the invoice
   d. Make sure fill and gage caps are tight and locked, if required.
3. Night deliveries with station closed:
   a. The difference between the closing gages and the opening gages of those tanks which were filled should be compared with the amount shown on the invoice.
   b. The tanks should be checked for water at the opening of business following the delivery and adjustments made for any variation in water level from the previous day.
   c. Make sure fill and gage caps are tight and locked, if required.

C. Special Circumstances

Tanks should be checked for water after a thaw or heavy rain, as under these circumstances, water may enter the tank through leaking fill or gage caps.

9. SUMMARY

Product losses can be controlled and reduced by following the procedures and methods described herein, coupled with the conscientious use of a suitable accounting system. Employees should be trained in these procedures and required to follow them. Whenever the trend in product variations significantly changes or exceeds that normally encountered in retail outlet operations, suitable corrective measures should be taken immediately and notification given to all concerned.

APPENDIX A

SAMPLE DAILY GASOLINE INVENTORY RECORD

At least weekly, review the past week's daily inventory records

A	B		C		D		E		F	G
Product	Opening Physical Inventory	—	Sales	+	Receipts	—	Inventory Balance	—	Closing Physical Inventory	Over (Short)
TOTAL										

F

CLOSING INVENTORY STICK READINGS

Tank	Feet/Inches	Product	Gallons
1	/		
2	/		
3	/		
4	/		
5	/		
6	/		
7	/		
8	/		

Initialed by _____

Date _____

NOTE: FORWARD CLOSING PHYSICAL INVENTORY F TO OPENING PHYSICAL INVENTORY B ON NEXT DAY'S RECORD.

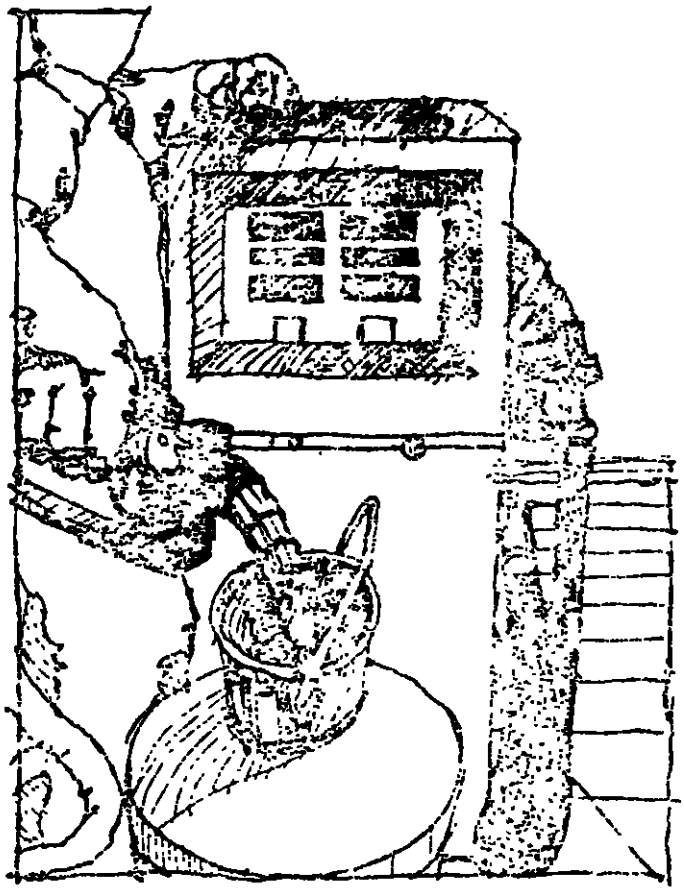
APPENDIX B

PROCEDURE FOR TESTING ACCURACY OF GASOLINE-DISPENSING METERS

EQUIPMENT

A proving can of 5-gallon capacity is the only special equipment required. The upper portion of this can consists of a neck approximately 4 inches in diameter having a sight glass with an adjacent scale graduated in cubic inches above and below a zero point. It indicates the number of cubic inches delivered by the meter greater or less than the amount indicated on the dispenser dial.

If local regulations require the station operator to periodically check the dispensing units, the local bureau of weights and measures should be consulted concerning the size and type of proving can to be used. Otherwise, a suitable can may be purchased from a reliable automotive equipment supplier. Each can should be checked for accuracy periodically and/or as may be required by local regulations.



PROCEDURE

1. Wet the can by filling with product to its full capacity and return the product to the storage tank.
2. Refill the can to the capacity indicated by the dispenser with the nozzle fully open (maximum filling rate).
3. Read on the graduated scale the number of cubic inches delivered greater or less than the quantity shown on the dispenser and note the difference.
4. Return the product in the can to storage.
5. Refill the can as in step 2 but with the nozzle partly closed to limit flow to approximately 5 gallons per minute.
6. Repeat steps 3 and 4.
7. If the quantity delivered in steps 2 or 5 varies by more than 7 cubic inches above or below the zero point, adjustment by a qualified pump mechanic should be arranged. The operator should not attempt to adjust the meter himself.
8. Note in the inventory record the changed meter readings caused by the delivery of the product used for the test, noting also whether the product was returned to storage or used for other purposes.
9. Keep records of calibrations to assist in reconciling inventory variations.

APPENDIX C

LEAK INVESTIGATION PROCEDURES

The following steps, as a minimum, should be taken in an expeditious manner when daily inventory records indicate excessive stock loss:

1. The records of inventory, receipts, and dispensing should be checked for error.
2. If no error is apparent, an independent calculation of apparent loss should be made by a qualified person starting from a point in time where the records indicate a no-loss condition.
3. If step 2 confirms an apparent loss, the readily accessible physical facilities on the premises should be carefully inspected for evidence of leakage and those responsible for the maintenance of the equipment should be notified immediately.
4. If step 3 does not disclose a leak, the dispensers used with the particular product involved with the apparent loss should be calibrated.
5. If step 4 does not explain the loss, the piping system between the storage tank and dispensers should be tested in an acceptable manner to determine if this segment of the system is leaking. If the tank has a remote fill and the variations occur at the time of deliveries, the remote fill line should also be tested (see item 4 under "Leakage").
6. If step 5 does not disclose a leak, the storage tank(s) should be tested in an acceptable manner to determine if there is a leak in the tank(s).
7. If steps 1 through 6 do not confirm the apparent loss, the daily inventory should be continued with a daily independent verification by a qualified person. Also, additional surveillance of the facility should be engaged to insure against unauthorized removal of product.

APPENDIX D

GAGING PROCEDURE FOR UNDERGROUND HORIZONTAL TANKS

EQUIPMENT

A pole made of varnished hardwood (maple) or other nonsparking material should be used. The pole should be long enough to reach the bottom of the tank (usually 6 feet to 10 feet), and should be about 1 inch wide by ¾ inch thick. The pole should not be warped. One side of the pole should be marked in inches with ⅛ inch subdivisions, the zero marking should be at the bottom or tip of the pole. If the pole is used for gaging gasoline or other volatile product, the side adjacent to the graduated side should be grooved every ⅛ inch in order to retard creepage.

The gage stick is used in conjunction with a calibration chart or charts furnished by the supplier. The chart shows the number of gallons for each inch on the gage stick. Each chart is calculated for a tank of particular dimensions and capacity, and the chart used must be the proper one for the tank being gaged.

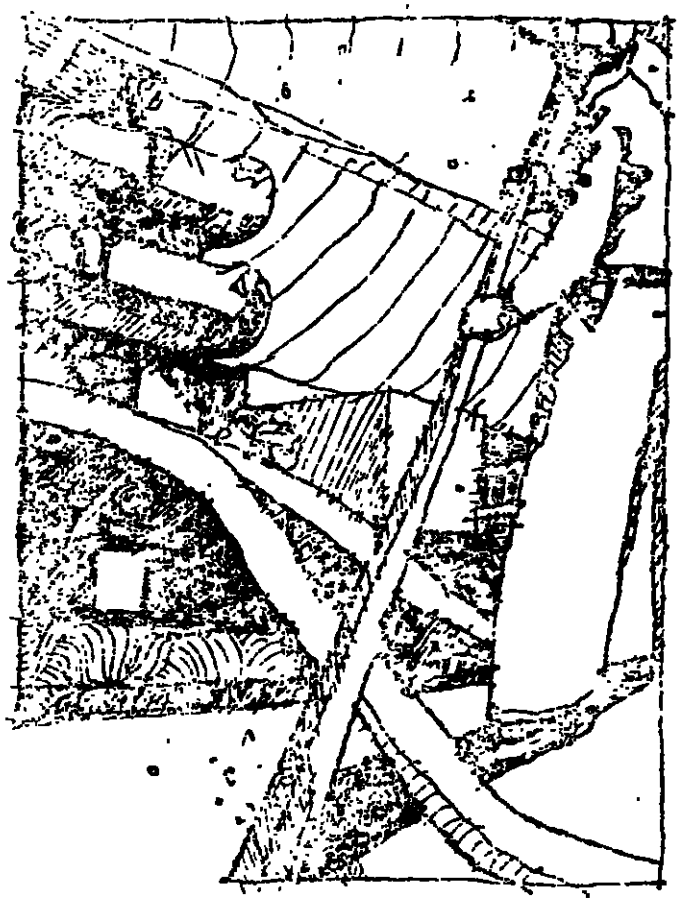
PROCEDURE

Insert the pole through the gage hole of the tank until the tip touches the tank bottom. The pole should be inserted at the same point in the gage hole each time a gage is taken and should be held in a vertical position. Be sure that it does not rest on a projection on the tank bottom. Withdraw the pole quickly to avoid creepage of the product, and read the product "cut" on the graduated scale to the nearest ⅛ inch. When gasoline or another volatile product is gaged, the reading adjacent to the "cut" or the grooved portion of the pole should be taken as the gage. Clean the pole at the "cut" by wiping with a cloth and repeat the procedure to check.

USE OF TANK CALIBRATION CHART

After gaging the tank, select the correct calibration chart and proceed as follows:

1. Read chart directly for all gages which are to the exact inch (tolerance plus or minus 1/16 inch).
2. For gages of ⅛ inch over or under the exact inch proceed as follows:
   a. Read chart for exact inch gage on scale above and below actual stick-gage reading --for example, if stick gage reads 46½ inches, read chart at 46 inches and 47 inches.



   b. Subtract gallonage shown on scale at these two readings, i.e., for the 1,000 gallon tank (diameter 64 inches; length 72 inches):

      Chart reading at 47 in. = 789 gallons
      Chart reading at 46 in. = 771 gallons
      Subtracting = 18 gallons

   c. Multiply this gallonage by the fraction of an inch, i.e.:

      18 gallons times ½ = 9 gallons

   d. Add the gallonage shown on the chart for the lower whole inch gage and the gallons calculated by step (c), i.e.:

      Gallons at 46 inches = 771 gallons
      Gallons at ½ inch = 9 gallons
      Adding 780 gallons

Therefore, the tank gage of 46½ inches represents 780 gallons of product in the 1,000 gallon tank (diameter 64 inches, length 72 inches).

If a water gage (see Appendix E) has been taken, the quantity of water contained in the tank is determined by the same procedures. The total amount of water should be subtracted from the total amount of liquid in the tank (as determined in step d) to determine the net gallons of product contained.

NOTE: Underground tanks are fabricated as production items. The tank manufacturer supplies charts intended to be used for all tanks of the same nominal dimensions and capacities. Depending on the fabricating method, these tanks are likely to vary by a fraction of an inch in diameter or length. Therefore, the charts cannot be considered as absolutely accurate although the amount of inaccuracy is usually too minute to be of consequence.

Some long tanks are equipped with a gage well at each end. These are installed for use if the tank settles unevenly with one end lower than the other. It is not necessary under ordinary circumstances to gage through both wells. It would be advisable, however, to check occasionally to determine that the product is approximately at the same level in both gage wells.

If the gage well is in the center of the tank, settlement will not affect the accuracy of the gage. But, if settlement occurs, the water will collect at the lower end, and a water gage taken at the center may not indicate the true condition.

To verify the accuracy of remote gages, tanks equipped with such devices should be periodically stick gaged.

APPENDIX E

WATER-GAGING PROCEDURE

A water-finding paste, which is unaffected by gasoline, but which will change color in water, is used to check for water at the bottom of storage tanks. Information on satisfactory paste may be obtained from the supplier

It is used as follows:

Coat the end of the gage stick on the graduated side with a light, even film of the paste for approximately 3 inches Insert the pole through the gage hole until the pole reaches the bottom of the tank. Be sure that the pole is kept in a *vertical* position and that it does not rest on an obstruction or other projection on the tank bottom. Keep the pole in this position for the time specified for the product. Then withdraw it and read the water "cut" (as noted by change in color of the paste) on the graduated scale to the nearest 1/8 inch.

The immersion time for a water "cut" is approximately 10 seconds for light products such as gasoline and kerosene, and 20 to 30 seconds for heavier products. If the test shows more than 1/2 inch of water, arrangements should be made for its immediate removal and the supplier notified.

NOTE: Occasionally, a submerged and/or suction pump will deliver water with the product, but no water will show when the tank is checked. This usually indicates that the tank is not level and the water has accumulated at the low end away from the gage well.

Similarly, a suction pump may dispense water with the product when there is an underground suction line leak and a coinciding high water table Such a condition must be checked out and corrected immediately.

Some long tanks are equipped with a gage well at each end and water may be found only under the lower end

A tank equipped with only a center gage well may not show accumulated water if the tank is not level.

4. American Petroleum Institute. Recommended Practice for Interior Lining of Existing Steel Underground Storage Tanks, Publication 1631, First Edition, 1983

Recommended Practice for the Interior Lining of Existing Steel Underground Storage Tanks

PUBLICATION 1631
FIRST EDITION 1983

American Petroleum Institute
2101 L Street, Northwest
Washington, D.C. 20037

Recommended Practice for the Interior Lining of Existing Steel Underground Storage Tanks

1.0 Scope

This publication recommends minimum requirements for the interior lining of existing steel underground tanks used for the storage of petroleum-based motor fuels and middle distillates. In general, it outlines requirements, procedures and operating conditions to be followed by contractors, mechanics and engineers. Methods for gas-freeing tanks, removing sediment and cleaning interior surfaces of steel tanks are also included. All work must be accomplished in accordance with the applicable federal, state and local requirements as well as accepted safety standards.

The interior lining process can be used to repair certain corroded tanks or to protect underground steel tanks from internal corrosion. The lining itself is not intended to replace the structural strength provided by the steel tank shell or prevent future external corrosion.

2.0 Permitting and Training

Where required, contractors must be approved by local authorities and all applicable permits must be obtained prior to beginning any work. Contractors should certify to the owner that employees and subcontractors responsible for tank lining have been trained in the following: (a) the handling and disposal of tetraethyl lead and its by-products; (b) the use of equipment and procedures for testing and gas-freeing tanks; (c) all applicable safety rules and regulations; and (d) the application and handling of the tank lining material.

In addition, contractors should certify that his employees and subcontractors are knowledgeable of:

- API Publication 2015, *Cleaning Petroleum Storage Tanks, Third Edition, 1983*;
- API Publication 2015A, *A Guide for Controlling the Lead Hazard Associated with Tank Entry and Cleaning, 1982*;
- API RP 2003, *Protection Against Ignitions Arising out of Static, Lightning and Stray Currents, Fourth Edition, 1982*;
- NFPA 327, *Cleaning Small Tanks and Containers*; and
- API RP 2027, *Ignition Hazards Involved in Abrasive Blasting of Tanks in Service, First Edition, 1982*.

Care should also be taken to use procedures and equipment necessary to comply with all applicable safety rules and regulations.

3.0 Coating (Lining) Specifications

Materials used for interior lining of underground tanks may be epoxy-based resins, isophthalic polyester-based resins or other acceptable coatings. CAUTION: Some coating materials are not acceptable due to incompatibility with petroleum products or product additives. Acceptable coating materials shall satisfy the following three requirements as certified by the manufacturer:

A. Bonding Coatings, when applied to properly-prepared steel surfaces (see Section 7.3), must maintain bond to the tank while in its designated service for the period of the tank lining's warranty.

B. Coefficient of Thermal Expansion The coating's coefficient of thermal expansion shall be compatible with steel, so that inordinate stresses will not result due to temperature change.

C. Immersion Tests Representative coating samples shall be tested to determine compatibility of the lining material with stored products. Samples shall be immersed in the liquids listed below at either 38°C (100°F) for periods of one, three and six months, or 23°C (74°F) for periods of one, three, six and twelve months. Upon completion of each immersion period, testing of the samples must verify that the coating has not substantially deteriorated in accordance with the following:

TEST	PURPOSE
ANSI-N512-1973	Bonding Strength
ASTM D790-71	Flexural Strength
ASTM D2794-69	Impact Resistance
ASTM D2583-67 or Barber Coleman GYZJ 935-1 and 934	Barcol Hardness
ASTM D543-67 Procedure 1	Film Integrity

LIQUIDS FOR IMMERSION TESTING:
ASTM Reference Fuel C
Unleaded Gasoline
Leaded Gasoline
No. 2 Fuel Oil or Diesel Fuel
Toluene
Xylene
Gasohol (10% Ethanol)
Distilled Water

NOTE: A warranty certifying chemical compatability is to be provided to the owner by the manufacturer before storage is permitted of liquids other than those listed.

Physical properties after the final immersion period shall be a minimum of 30% of the original physical properties before immersion with a stable trend indicating little or no further long-term deterioration for toluene, xylene, and distilled water; and 50% for all other listed materials.

4.0 Preparation for Opening the Tank

4.1 Safety Precautions

Sources of ignition must be removed from the area surrounding the tank(s) and vapor vents during periods when flammable vapors might be expelled. Work will not commence if the direction of the wind might carry vapors into areas where they could produce a hazardous condition (e.g. ignition, breathing).

A combustible gas indicator shall be used to check for hazardous vapors in the area. All open flame and spark-producing equipment within the vapor hazard area shall be shut down. Electrical equipment used in the area must be explosion-proof (Class 1, Division 1, Group D) or approved for the service.

4.2 Tank Isolation

Before any work on the exterior surface of the tank begins, tanks must be inspected to determine how the tank is to be isolated. If a tank is equipped with a manifolded vent or fill line or syphon assembly, necessary measures must be taken to isolate each tank. The vent for the tank being lined should be isolated from vents for other tanks which may still be in service. This may require a temporary separate vent for the tank being lined. All electrical switches supplying electrical current to submerged pumps and/or other equipment connected to the tank shall be disconnected and locked.

4.3 Removal of Liquid Product

As much product, water and sediment as possible shall be removed using explosion-proof or air driven pumps. Pump motors and suction hoses must be bonded to the tank to prevent electrostatic ignition hazards. A small quantity of water can be pumped into the tank to float the product from a low spot to where it can be pumped from the tank. Also, where possible, fill (drop) tubes shall be removed to allow for maximum removal of all liquid and to provide for adequate air ventilation.

4.4 Removal of Flammable Vapors (Gas Freeing)

The tank shall be thoroughly purged only with air to remove flammable vapors or residue capable of producing flammable vapors. The concentration of flammable vapors in a tank may go through the flammable range before a safe atmosphere is obtained. It therefore is necessary that precautions are taken to eliminate the possibility of the discharge of static electricity during gas freeing procedures.

Air pressure in the tank must not exceed 5 psig. To prevent excess air pressure the vent line must be checked to make certain it is free from obstructions and traps.

Ventilation of the tank can be accomplished by one of two methods which are listed below:

a. An eductor-type air mover (see Figure 1) usually driven by compressed air, shall be properly bonded to prevent the possibility of static electricity generation and discharge. When using this method, the fill (drop) tube should remain in place to ensure ventilation at the bottom of the tank. Tanks equipped with fill (drop) tubes which are not removable should be purged by this method. An extension shall be used to discharge vapors a minimum of twelve (12) feet above grade.
b. Diffused blown-air is illustrated in Figure 2. When using this purging method it is imperative that the air-diffusing pipe is properly bonded to prevent the discharge of a spark. Fill (drop) tubes must be removed to allow proper diffusion of the air in the tank. Air supply should be from a compressor, which has been checked to ensure a clean air supply, free from volatile vapors. Air pressure in the tank must not exceed 5 psig.

4.5 Testing Flammable Vapor Concentrations

An important phase of the operation is the testing for flammability of the vapor in the excavated area and in the tank. Such tests are to be made with a combustible gas indicator which is properly calibrated on hexane in air and thoroughly checked and maintained in accordance with manufacturer's instructions. Persons responsible for testing must be completely familiar with the use of the instrument and the interpretation of the instrument's readings.

The tank vapor space is to be tested by placing the combustible gas indicator probe into the fill opening with the fill (drop) tube removed. Readings should be taken at the bottom, middle and upper portions of the tank and the instrument should be cleared after each reading. If the tank is equipped with a non-removable fill tube, readings should be taken through another opening. Liquid product must not enter the probe. The vapors should be tested at the vent riser or eductor while the air mover is in operation and purging is in progress, and also in the tank itself with purge air shut off. Readings of 10 percent or less of the lower flammable limit (LFL), as indicated in the tank and at the vent riser or eductor, must be obtained before the tank is considered safe for opening.

5.0 Opening the Tank

If no manway exists, an opening with the minimum dimensions of 18" by 18" shall be cut in the tank top avoiding welded seams. The tank section to be removed should be marked with chalk and a hole drilled with an explosion-

INTERIOR LINING OF STEEL
UNDERGROUND STORAGE TANKS

TYPES OF TANK VENTILATION AIR MOVERS

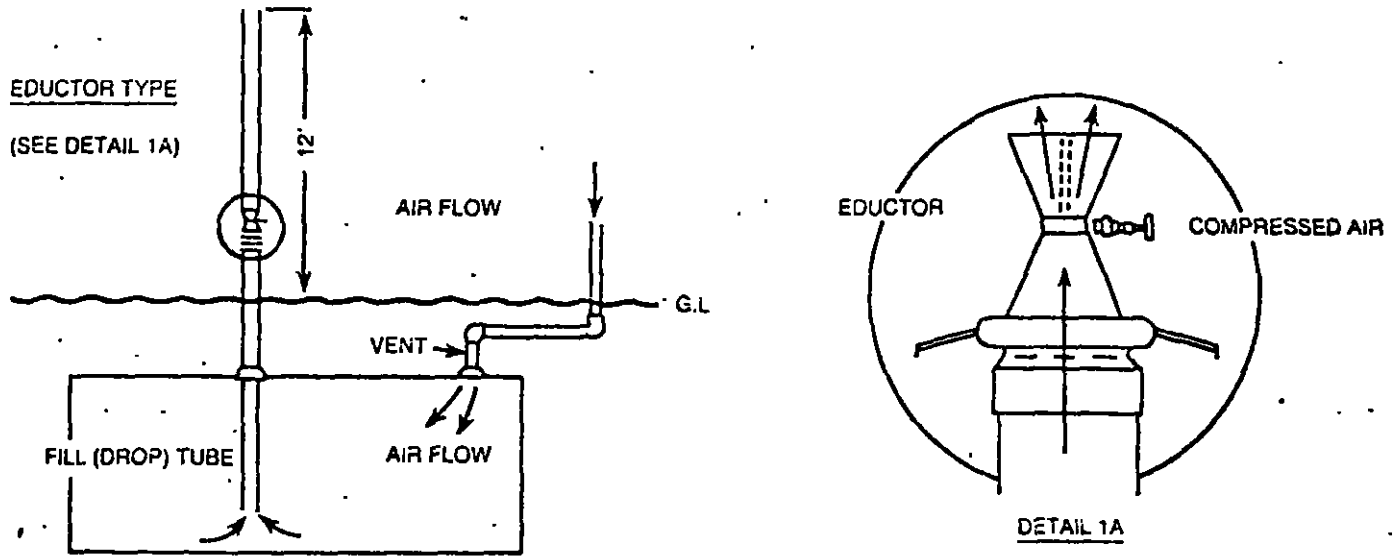
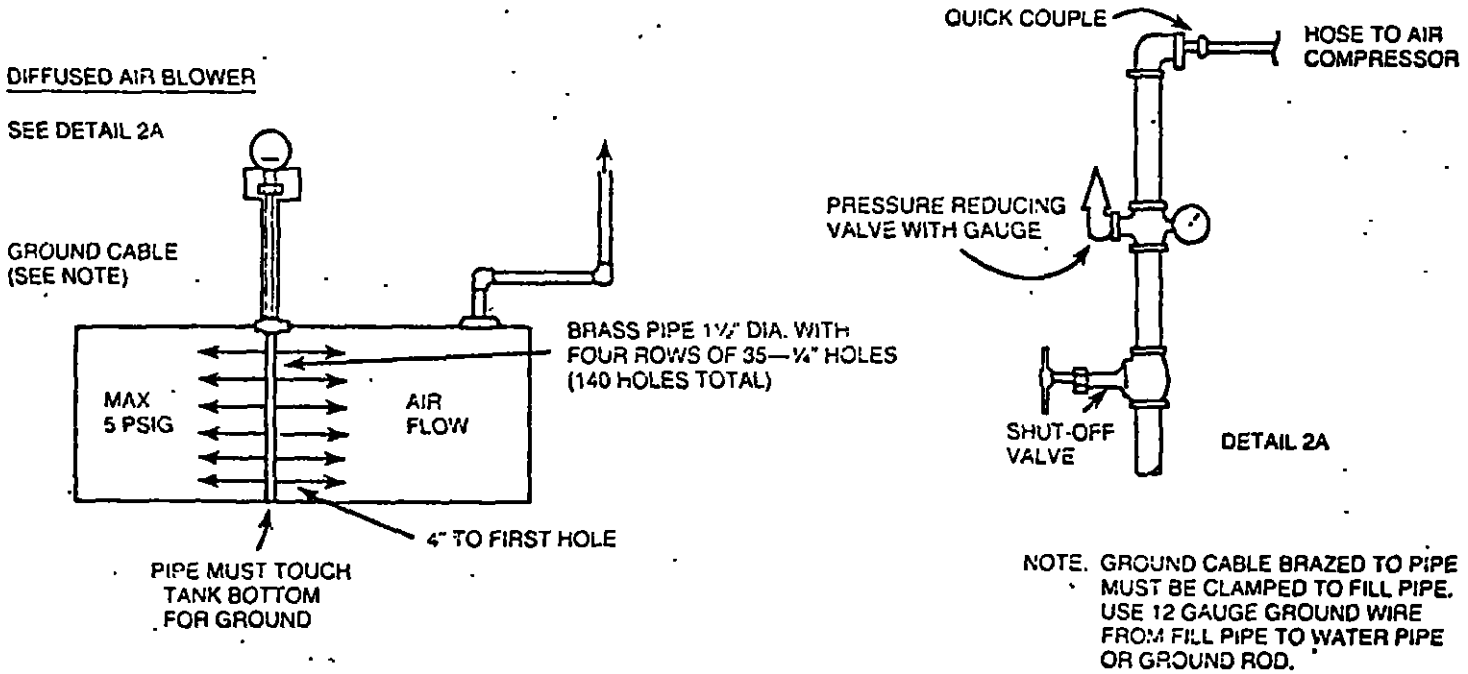


FIGURE 1



NOTE. GROUND CABLE BRAZED TO PIPE MUST BE CLAMPED TO FILL PIPE. USE 12 GAUGE GROUND WIRE FROM FILL PIPE TO WATER PIPE OR GROUND ROD.

FIGURE 2

proof (such as air-driven) drill at one corner of the section. After the hole is drilled, the tank vapors must again be tested by inserting the meter probe into the hole to verify that the vapor concentration does not exceed 10 percent LFL.

Note: It is important that the purging, air ventilation and testing continue throughout the entire lining operation. During the tank cutting operation minimal air pressure should be maintained to prevent a blow out.

The tank should be cut using an explosion-proof (such as air-driven) saber saw or snipper using lubricating oil to reduce friction, heat and possible sparks. Prior to the final cut, the plate should be supported to prevent its falling into the tank.

6.0 Tank Entry

Before entering tanks, the procedures described in API Publication 2015, "*Cleaning Petroleum Storage Tanks*", and 2015A, "*A Guide for Controlling the Lead Hazard Associated with Tank Entry and Cleaning*", should be followed This includes checking the oxygen content inside the tank with a properly calibrated oxygen monitor.

At all times, personnel entering the tank shall be equipped with positive pressure air supplied equipment with full face enclosure and safety harness connected to a safety line held by an attendant outside the tank. Oil and water-resistant rubber or neoprene boots and gloves shall be worn. Clothing shall cover the arms, legs, torso and head of tank entry personnel. Disposable clothing, impervious to product, is preferred. Clothing saturated with product shall be removed immediately. All personnel working inside the tank should be familiar with ANSI Z117.1, "*Confined Spaces Safety*".

Tests with the combustible gas indicator and oxygen monitor should be performed periodically in the tank to ascertain that the tank vapors and oxygen content are in the safe range. It should be recognized that if the tank is perforated, product or vapors which have leaked into the soil may re-enter the tank through a perforation. The vent line shall remain clear and unobstructed to allow continuous ventilation. All other lines and openings shall be plugged or capped off to insure no liquids or vapors may enter the tank during the lining operation.

7.0 Preparation of Tank Interior

7.1 Sludge Removal

Sludge accumulation on the bottom of the tank must be removed and placed in tightly sealed containers. It must be disposed of in accordance with local, state and federal regulations, which may require mandatory documentation as well as safe disposal.

Note: Tank sludge and scale are potentially hazardous as they may contain tetraethyl lead vapors which can be inhaled, or toxic liquid tetraethyl lead which may be absorbed through the skin. If the dry internal surface of the tank is scraped, the resulting atmosphere may contain dangerous quantities of lead. The quantity of lead in the tank atmosphere should be checked using a lead in air analyzer.

7.2 Tank Inspection

During inspection, the entire interior surface of the tank shall be inspected using a light fixture approved for Class 1, Division 1, Group D - Hazardous Locations. The structural integrity of the steel shell around perforations (holes) or areas of severe corrosion should be determined by tapping with a brass ballpeen hammer. Sufficient steel shell must remain intact (after abrasive blasting) to provide structural support for the interior lining. The following guidelines may be utilized to identify a tank that may be repaired.

1. A tank having an open seam or split no longer than three (3) inches; or
2. A tank having a perforation no larger than one and one-half (1 ½) inches in diameter except under the gauging opening where the perforation may be no larger than two and one half (2 ½) inches in diameter; or
3. A tank with less than five (5) perforations (none larger than one half inch in diameter) in any one square foot area.
4. A tank with less than twenty (20) perforations (none larger than one half inch in diameter) in a five hundred (500) square foot area.

Tanks that exceed any of the above should not be interior lined unless approved by the authority having jurisdiction.

To determine adherence to these guidelines, perforations and seams shall be brass ballpeen hammered (before and after abrasive blasting) to remove thin metal and obtain structurally sound edges. Perforations and seam splits shall be reamed until the edges of the hole or split are a minimum of ⅛" thick.

7.3 Surface Preparation

All blasting personnel should be familiar with the hazards described in API Publication 2027, "*Ignition Hazards Involved in Abrasive Blasting of Tanks in Service*". All perforations shall be plugged with boiler plugs or hydraulic cement prior to abrasive blasting; seams may be plugged with hydraulic cement

CAUTION: BEFORE ABRASIVE BLASTING, THE TANK SHOULD BE CHECKED AGAIN WITH THE COMBUSTIBLE GAS INDI-

CATOR TO ENSURE THAT NO FLAMMABLE VAPORS HAVE ENTERED THE TANK.

BLAST CLEANING OPERATIONS SHALL NOT BE CONDUCTED ON SURFACES THAT WILL BE WET AFTER BLASTING AND BEFORE APPLICATION OR WHEN THE SURFACE IS LESS THAN 5°F ABOVE DEW POINT, OR WHEN THE RELATIVE HUMIDITY OF THE AIR IS GREATER THAN 85%.

The entire internal tank surface shall be abrasive blasted completely free of scale, rust and foreign matter to SSPC-SP 5-63 (S.S.S.a3) (White Metal Blast Cleaning). When sand is used as the blast material a minimum of 90 psi and 18 mesh grit material should be used during blasting.

Note: A White Metal Finish is defined as a surface with a gray-white uniform metallic color, roughened to form 1 ½-2 Mil anchor profile pattern for coatings. The surface, when viewed without magnification, shall be free of all oil, grease, dirt, visible mill-scale, rust, corrosion products, oxides, paint or other foreign matter.

Abrasive blast operators shall wear approved helmets connected to sources of clean air. Bonding should be provided between the blasting nozzle and the work surface, or else the blasting nozzle should be effectively grounded to provide equivalent protection from static charges Separators and traps should be used to remove oil and water from compressed air. Following completion of the abrasive blasting operation, the surface shall be brushed with a clean hair, bristle, or fiber brush, blown with compressed air, then vacuumed. Boiler plugs and hydraulic cement plugs shall be covered with epoxy or polyester then covered with fiberglass cloth (minimum 1 ½ oz./yd^2, silane treated) which overlaps all sides of the plug with a minimum of two (2) inches. If perforation in a seam is present, the perforation shall be sealed with hydraulic cement then covered with glass cloth and resin, overlapping the perforation by six (6) inches.

8.0 Application of Lining

Prior to the application of lining material, a ¼" steel reinforcing plate rolled to the contour of the tank and with minimum dimensions of 8" by 8" shall be installed under the fill (drop) tube and gauging tube. This plate shall be covered with fiberglass cloth imbedded in resin. The blast-cleaned surface should be coated within eight hours after blasting and before any visible rusting occurs. Only those lining materials meeting the specifications in Section 3.0 shall be used. Manufacturer's instructions are to be followed on handling and mixing of resin compounds, and these compounds shall be applied to the entire interior surface of the tank by the manufacturer or his designated distributor following the specified method of application, to the designated thickness and at the recommended application temperature. If a heater is used to accelerate the curing process, all other work which might release flammable vapors must be halted and the heating unit must be attended whenever it is in operation. The coating shall be cured thoroughly to the manufacturer's specifications and checked for air pockets, and pinholes using a Holiday Detector. If any exceptions are found they shall be repaired to manufacturer's specifications. Contractor shall protect the coated surfaces from contamination by foreign matter. The coating thickness shall be checked with an Elcometer Thickness Gauge or equivalent and tested for hardness using a Barcol Hardness Tester or equivalent to ensure compliance with manufacturer's specifications.

Personnel safety and clothing requirements must comply with Section 6.0.

9.0 Tank Closing

If an opening has been cut, the tank shall be sealed as follows:

a. A ¼" thick steel cover plate, rolled to the contour of the tank, shall be made to overlap the hole at least two inches on each side (e.g., should measure at least 26" by 26" if manhole was cut 22" by 22").
b. The cover shall be used as a template to locate ¾" diameter holes not exceeding five inch centers, one inch from the edge of the cover.
c. The cover plate shall be sandblasted to White Metal on both sides and the entire inside surface shall be coated with coating material to act as a gasket.
d. Before the coating on the cover cures, the cover shall be fastened to the tank using ½" (minimum) diameter bolts. The bolt shafts are to be placed through the holes from the inside of the tank and held in place by spring clips, then fastened with local washers and nuts as illustrated in Figure 3.
e. After being bolted to the tank, the cover plate and surrounding tank surface shall be properly sandblasted, coated with coating material and allowed to cure before backfilling the hole.

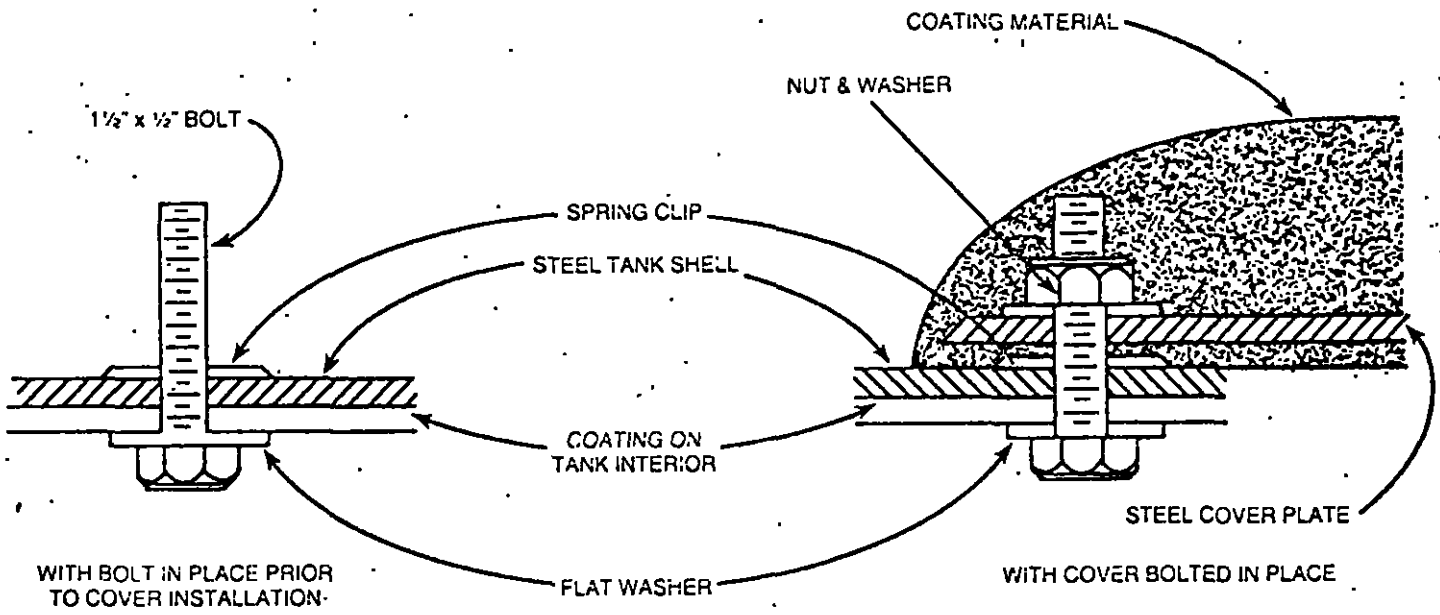
10.0 Tank Tightness Testing

Before backfilling, the tank should be tightness tested using locally acceptable methods. Particular attention should be paid to the cover plate and all exposed fittings.

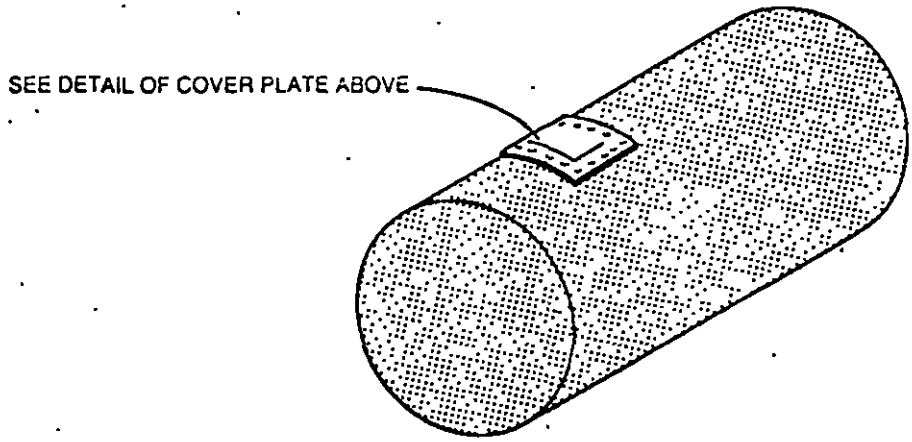
INTERIOR LINING OF STEEL
UNDERGROUND STORAGE TANKS

FIGURE 3

INSTALLATION OF TANK COVER PLATE



CROSS SECTION



1400 — 9 83 — 1M

5. American Petroleum Institute. "Installation of Underground Petroleum Storage System", Publication 1615, First Edition, 1979

Stephen A Fagenius

Installation of Underground Petroleum Storage Systems

PUBLICATION 1615
NOVEMBER 1979

American Petroleum Institute
2101 L Street, Northwest
Washington, D.C. 20037

FEB 1984
DIVISION OF
TECHNICAL SERVICES

Installation of Underground Petroleum Storage Systems

Marketing Department

PUBLICATION 1615
NOVEMBER 1979

OFFICIAL PUBLICATION

REG U.S. PATENT OFFICE

TABLE OF CONTENTS

Page

1. Foreword 1
2. Introduction 2
3. Tanks 3
4. Piping 4
5. Equipment 6
6. Prevention and Detection of Leakage 7

Figure 1—Typical Plot Plan Showing Possible Tank Locations 8
Figure 2—Tank Piping Details—Suction System 9
Figure 3—Tank Piping Details—Submerged System 9
Figure 4—Miscellaneous Details 10
Figure 5—Pump Island Piping—Suction and Submerged 11
Figure 6—Typical Remote Pumping Siphon System 11
Figure 7—Typical Suction Pump Siphon System 12

1. FOREWORD

The prevention and detection of product leakage from petroleum storage and dispensing systems is important to both industry and the public. In preparing this bulletin, careful consideration was given to:

1. Safety;
2. Protecting the environment;
3. Preventing tank and piping failures;
4. Minimizing maintenance;
5. Protecting product quality; and
6. Minimizing installation costs.

Furthermore, attention was also given to the applicable sections of National Fire Protection Association (NFPA) 30, Flammable and Combustible Liquids Code, NFPA 329, Underground Leakage of Flammable and Combustible Liquids, and Underwriters' Laboratories, Inc. (UL) 58, Specifications for Underground Storage Tanks.

This bulletin, covering the installation of underground gasoline, diesel fuel and waste oil systems, is offered as a guide for use by architects, engineers, marketers, jobbers and contractors. Its primary application is at retail and commercial facilities. It is not intended to cover specialized installations, such as airports, marinas, home-heating oil systems or tanks to be installed inside buildings.

Federal, state and municipal codes or laws may have specific restrictions, which must be taken into account prior to the installation of underground tanks and piping.

The information in this bulletin may be used by anyone desiring to do so, but the American Petroleum Institute shall not be held responsible or liable in any way, either for any loss or damage resulting therefrom, or for the violation of any federal, state or municipal regulations with which it may conflict.

Note: Vapor recovery systems have not been covered in this bulletin. Anyone preparing to make an underground gasoline tank and piping installation in an Environmental Protection Agency Air Quality Control Region should investigate the local requirements and current methods of compliance in that region

2. INTRODUCTION

Many underground storage tanks and piping systems installed in the United States have operated safely and free of leaks in excess of 30 years. Materials and procedures currently are available to help ensure that today's installations also can be operated without problems for the life of the facility. Success depends on a number of factors, including:

- Sound design of installation;
- Proper selection of materials for the specified location;
- Installation procedures in accordance with good engineering specifications and manufacturers' instructions;
- Capable and adequate supervision and inspection during installation;
- Thorough testing at appropriate stages of progress; and
- Appropriate monitoring and maintenance programs.

Prior to construction of a facility and the installation of underground equipment, a detailed analysis of the selected site is necessary. At a minimum, the analysis should include a determination of soil conditions, water table level and drainage. In addition, a review should be made of the corrosion history of the area. If sufficient data are not available and metal tanks and piping are to be used, a corrosion survey should be performed by a qualified person.

Uncontrolled corrosion can lead to product leakage. Corrosion is the result of a flow of direct electrical current, which removes metal from the surface. It can be caused by the corrosive nature of the soil, stray electrical currents and/or bimetallic cells.

- Corrosive nature of the soil: Several factors account for the corrosive nature of soils. These include low soil resistivity (the ability of the soil to conduct electrical charges), moisture content, acidity, and the presence of sulfides, as well as the differentials which exist within these factors. Probably the most significant of these is low soil resistivity. Other factors being equal, soil resistivity under 3,000 ohm-centimeters may indicate a very corrosive soil; 5,000 ohm-centimeters, a moderately corrosive soil; and over 10,000 ohm-centimeters, a relatively noncorrosive soil. However, a soil having both a high resistivity and a low pH (acidic) could be potentially corrosive.
- Stray electrical currents: Stray electrical currents that come from underground power lines or from improperly constructed electrical systems can be a source of corrosion.
- Bimetallic and galvanic cells: Corrosion cells which derive their driving voltage from the interaction of two different metals are called "bimetallic cells." Such cells are created when two dissimilar metals are connected. Typical examples might be found where a bronze check valve is joined to steel piping, or where galvanized piping is connected to a steel tank. In many cases, the circuit connection may be obscure. For instance, a copper water pipe crossing a service station property does not necessarily have to be in direct contact with a gasoline line for a "cell" to be created. If the electrical service in the station is grounded to the water service, a circuit can exist at the pump island, where both the electrical conduit cable and the gasoline piping reach a common junction point. Corrosion cells can also be created where the same metal is used, for example where there are impurities such as slag inclusions, or where weld metal is used that differs from the parent metal or piping has been scratched or cut.

Two important points should be kept in mind by persons planning on installing new tanks and piping systems, or replacing existing systems that are leaking due to corrosion:

First, unprotected steel tanks should be used only in non-corrosive areas. Otherwise, install either:

- A system constructed of non-corrosive materials such as fiberglass-reinforced plastic (FRP) or its equivalent; or
- A steel system cathodically protected by an impressed current cathodic protection system, sacrificial anodes, or some other type of equivalent protection.

Second, if it is necessary to replace or interior-coat an underground steel tank which developed a corrosion-induced leak, it is recommended that all other steel tanks at the facility—which are of the same age or older—also be treated similarly, even though they may not be leaking at that time. Newer tanks can be anodic to old steel. Therefore, they should be uncovered sufficiently to determine if additional protection or replacement is required.

Other factors to consider when making a choice between the use of metallic or nonmetallic tanks or piping would include initial and operating costs, and the availability of qualified personnel for the installation and maintenance of the selected corrosion control equipment.

If a cathodic protection system is used, an ongoing preventive maintenance program must be in effect. If sacrificial anodes have been installed, their proper

operation should be confirmed by a qualified person at least once a year.

If an impressed current cathodic protection system is used, it is necessary to verify—at least once a month—that the rectifier is operating. Such systems are subject to vandalism, and the electrical service may be disconnected by accident or on purpose, making periodic inspections mandatory. While it may be feasible for local personnel to monitor operation, a qualified person should conduct an on-site test and inspection of the facility no less than once a year to measure the structure-to-soil and structure-to-structure potentials, and the rectifier voltage and current output.

The installation of cathodically protected systems usually involves the use of wiring connections between anodes and test stations. The exact location of such wiring and anodes should be carefully identified on a plot plan of the facility, and a copy of this plan should be kept at the site. A notice board should be placed adjacent to the tank location reading:

CAUTION: THIS SITE HAS CATHODICALLY PROTECTED TANKS. BEFORE EXCAVATING, CONTACT:

_____

(Insert name and telephone number of company representative.)

3. TANKS

A number of factors must be considered in the (1) selection, (2) location, (3) installation, and (4) testing of tanks.

(1) Selection: Primary considerations in tank selection include the material required for the anticipated service, tank dimensions, and the capacity desired.

(a) As previously noted, the material to be used at a particular site will depend upon the conditions at that location (see "Introduction). Steel fabrication should comply with the latest issue of UL 58, Steel Underground Tanks for Flammable and Combustible Liquids. Both steel and FRP tanks should bear the applicable UL Label.

(b) Selection of tank dimensions is somewhat flexible. This can be of importance where a high water table exists or where rock conditions or suction pumping lift requirements dictate a shallow installation. Tanks of the same nominal capacity can be secured in many areas, with various diameters and lengths.

For example: 6,000 gallon steel tanks are available in the Eastern U.S. in diameter/length combinations of 95''/17'; 84''/21'; and 72''/29'.

The shorter lengths may be required to fit a site with restricted dimensions.

Note: Prior to installation, tanks should be measured to confirm the tank gauging chart(s) that should be supplied by the manufacturer It is necessary to have this information available for product purchase/sale transactions, as well as for testing and maintenance to determine any leakage that may occur as a result of installation or subsequent damage or corrosion.

(c) Tanks of the most commonly used capacities are available in most areas. FRP tanks are available in any size normally used at service stations Steel tanks can be secured for underground petroleum service in almost any capacity. The selection of tankage capacities and numbers for a particular site are discussed in detail in API Bulletin No. 1611, Service Station Tankage Guide, 1961.

(2) Location: Whenever possible, tank fill openings should be located so that a minimum amount of maneuvering will be required by the truck or transport making the product delivery. The driveway grade should be such that the tank truck will drain properly.

(a) Tanks should be located so that the parked tank truck will not be on the public right of way, block the driveway to consumer use, obstruct the motorist's view of the service station building, or interfere with the operator's use or visual control of the driveway.

(b) Regulations may permit underground tanks to be located closer than 10' to a building, but care should be taken to avoid possible damaging effects to the foundation of the building where this option is used.

(3) Installation: Tank excavations should be sufficiently large to provide a minimum clearance of 12'' (in the case of steel tanks) and 18'' (for FRP tanks) in all horizontal directions. The excavation should be deep enough to provide for a backfill below the bottom of the tank of at least 6'' for steel tanks and 12'' for FRP tanks. The burial depth of the tank is dependent on local regulations, the type of finished surface to be applied, soil conditions, topography, suction pumping lift requirements, and the piping cover needed.

In areas not subject to traffic, the cover depth of underground tanks should be a minimum of 24'', or not less than 12'' plus a reinforced concrete slab not less than 4'' in thickness. Where tanks are subject to or likely to be subject to traffic, cover depths should be a minimum of 36'', or not less than 18'' of well-tamped material plus at least 6'' of reinforced concrete or 8'' of asphaltic concrete.

(a) Backfill below, around and above tanks should be clean, noncorrosive porous material, such as clean washed sand or gravel for steel tanks and, for FRP tanks, must be in accordance with manufacturer's specifications.

Backfilling operations are most important to the life of the installation. The owner should continuously supervise these operations to ensure that only specified materials and installation methods are followed by the contractor.

(b) It is recommended that tanks be ballasted with product as soon as possible after backfilling. Water ballast may be used as an alternative, but it is necessary to defer installation of submerged pumping units in the tank until after the water ballast is removed. If ballasting is necessary in order to prevent tank flotation (from a high water table or from rain), the end-use product should be used as a first choice.

(c) With product ballast, attention is required in handling, inventory control, and safeguarding against accidents or thefts. All fill caps and pumps should be locked during unattended periods.

(d) Anchoring should be used to prevent tank flotation from a high water table. When a concrete slab is used for anchoring, tanks should be separated from the slab by no less than 12" of sand. Tanks should not be set directly on the concrete nor placed on hard or sharp material that could cause deformation or damage to either the tanks or tank coatings. Anchor straps should be installed so as not to damage tanks or tank coatings and to ensure that the tank is electrically isolated from the anchor straps. This can be accomplished by placing a section of rubber tire between the tank and anchor strap.

The entire installation should comply with the requirements of NFPA Code 30.

(4) Testing: Requirements for the testing of underground tanks vary with state and local regulations. Tests can be performed (1) at the time of the delivery of the tank to the site; (2) in hole prior to covering; (3) after installation but prior to completing the backfilling; and (4) after the paving and all piping has been installed.

(a) Since damage can occur to tanks at any stage of construction, specific testing requirements would be dictated by the degree of control the owner must exercise. Any damage to the exterior coating should be repaired using material of similar nature.

(b) Testing should comply with NFPA Code 30 requirements.

(c) As a minimum, it is recommended that all tanks be tested with air pressure prior to installation. PRESSURE MUST NOT EXCEED 5 POUNDS PER SQUARE INCH (psi). All fittings, seams and visible dents should be soaped during this period, and inspected for bubbling.

4. PIPING

As is the case with tanks, proper care must be taken in the (1) selection, (2) installation, and (3) testing of piping for underground tankage.

(1) Selection: The location of the piping will determine the type and size that should be used.

(a) Schedule 40 steel pipe, either galvanized or wrapped black iron, or UL approved nonmetallic pipe, is recommended for all underground piping; and Schedule 40 galvanized steel pipe should be used for aboveground vent piping. Piping with a 1½" or 2" diameter is generally used. As a minimum, couplings and fittings should be 150-lb. malleable iron.

(b) Delivery piping from tanks to dispensers should be sized according to the recommendation of the pump manufacturer. In determining size, consideration must be given to the length of runs, flow rates, and number of dispensers to be served.

(c) Siphons may be used to equalize product levels in two or more tanks storing the same product. Material for siphons may be galvanized iron, wrapped black iron or nonmetallic. It is recommended that siphon piping be the same size as the suction and/or delivery lines to the dispensers.

(d) Each tank should be vented through adequately sized piping. This is necessary to prevent the build-up of excessive pressure, or the blow-back of vapor or liquid at the fill opening, while the tank is being filled. The maximum rate of fill can be limited by the diameter of the vent line. Two-inch diameter vents (in lengths up to 150') should be adequate for flow rates incurred using 4" delivery equipment. If nonmetallic pipe is used for underground vent piping, special adapters are required at the point where this pipe connects with the steel swing joint. Such adapters are available from the pipe manufacturer.

(2) Installation: Product lines should be run in a single trench between the tank area and the pump island area. Similarly, vent lines, between the tank area and the building or other structure to which the aboveground vent lines are attached, should be placed in a single trench.

(a) Before any underground lines are laid, the trench or ditch for such piping should receive a minimum 6"-deep bed of well-compacted noncorrosive material, such as clean, washed sand or gravel. All trenches should be wide enough to permit at least 6" of such protection around all underground lines. This applies to both metallic and nonmetallic underground piping. Bedding and the covering backfill should be of the same material. This will be helpful for grading the lines, and in providing corrosion protection for any adapter fittings used with non-metallic piping.

(b) The actual location of pipe runs should be noted on as-built drawings, if there is a change from installation drawings. Photographs of underground piping are desirable as part of the permanent record of piping locations.

(c) Piping should be arranged so that lines do not cross over underground tanks.

(d) Underground product lines should have a uniform slope of not less than $^1/_8$" per foot toward the tank. Product lines should be at least 12" below the finished surface. Underground piping requires careful attention to the tightness of joints and pipe fittings. A pipe dope certified for petroleum service is to be used for galvanized or black iron pipe fittings, while the manufacturer's recommendation will apply for the cement to be used in nonmetallic piping joints.

(e) Possible breakage of underground piping and vent lines, or the loosening of pipe fittings resulting in product leaks, will be minimized through the use of swing joints. These should be installed in lines at points where the piping connects with the underground tanks, and where the piping ends at the pump islands and vent risers. Fiberglass piping, which is inherently flexible, does not require swing joints, if at least 4' of straight run is provided between any directional change exceeding 30 degrees.

Note: When nonmetallic piping (that has been approved for underground use) is selected, it is extremely important that it be installed strictly in accordance with the manufacturer's specifications.

(f) Occasionally, it is necessary or advisable to install more than one storage tank for a given grade of product. Such multiple tanks may be interconnected through a siphon connection. This permits the equalization of the product in the connected tanks. However, a siphon system will give reliable service only if care is taken to see that all joints in the siphon manifold are tight.

(g) Interconnected tanks should be the same diameter and be installed with the bottoms at the same depth. Although it is not recommended, if it is necessary to siphon-connect tanks of different diameters at a new installation, both the tank bottoms and the ends of the suction stub piping should be at the same level. Additionally, care should be taken to see that the vent line leaving the smaller diameter tank rises vertically to a point higher than the top of the larger tank before the horizontal section of the vent piping is installed.

(h) Remote pumps are available with a siphoning attachment, which can be connected to a siphon manifold. This permits one pump to draw the contents from two or more interconnected tanks. The manufacturer's installation instructions should be followed.

(i) Vent piping should be at least 12" below the finished surface beginning from the point where it rises vertically (or 4" in no-load areas), and slope uniformly towards the tank. The slope should be no less than $^1/_8$" per foot, and the piping laid so as to avoid sags or traps in the line in which liquid can collect. Just as with product piping, swing joints should be installed at the tank and vent riser ends of all underground steel vent piping. No swing joints are needed where fiberglass piping is used, provided at least 4' of straight run is used between any changes in direction exceeding 30 degrees.

(j) Vent piping aboveground should be located, or protected and anchored, so as to prevent damage from traffic and other sources of potential damage. Vent outlets should be located so as to prevent flammable vapors from entering building openings or reaching hazardous areas. Vent outlets must discharge upwards, and the discharge point must not be less than 12' above adjacent ground.

(3) Testing: It is essential that, during testing of piping, the piping be disconnected from the tanks, pumps and dispensers. Failure to disconnect the piping from the tanks could result in damage to the tanks and product loss. The piping should then be subjected to an air test of $1^1/_2$ times the working pressure but not less than 50 psi, and the pressure maintained for a minimum of 60 minutes, with only a minimal change. Leaks may be detected by soaping all joints, while the system is under pressure.

(a) After all piping has been tested and found to be tight, all exposed threads of galvanized pipe should be coated with a coal tar product or tape film. This prevents the formation of an electrolytic cell between the galvanized fitting and the threaded area where the protective galvanized layer has been removed. Electrolytic cells can cause premature pipe failure. Where sacrificial tank anode cathodic protection systems are installed, non-metallic tank bushings should be installed in tank openings at all points of connection of product and vent

piping to the tank, and separate protection provided for steel piping. When remote pumps are used, an insulating fitting should be installed in the electrical conduit at the pump.

(b) All piping must be covered with the same material used in the bedding. Depth of such material should not be less than 6".

5. EQUIPMENT

Although this bulletin is primarily a guide to underground tank and piping installations, consideration should be given also to the type of pumping system to be used, and to the tank fittings. The type of system selected (suction pumping, and remote or submerged pumping) has a direct bearing on the kind of tank and piping installed.

- Suction Pumping: This system usually consists of a pump at each dispenser on the pump island, with individual product suction lines running from each pump to the underground storage tank.

(a) When a suction type pumping system is used, the height to which the pumps can lift the product may be a critical factor.

(b) The tank diameter and the length of product piping between the tank and the pump should be kept to a minimum. This is especially important in warmer climates and at higher altitudes.

- Remote or Submerged Pumping: In this system, the pump is located in or above the underground storage tank. This permits the use of a single product line from each product pump to the dispensers on the pump islands. The system permits the use of more dispensers for each product, and a reduction in the quantity of buried piping. An impact valve, level with the top of the island, is to be installed at each dispenser.

(a) Leaks in these lines will result in an outward flow and loss of product, but leaks into the system are minimized.

(b) With submerged pumping systems, the delivery of product is not dependent on the diameter of the tank nor—within limits—on the length of product piping.

- Other Factors: Other factors to be considered in the selection and installation of pumps include the following:

(a) Pump construction, seals and trim should be designed for and be compatible with the liquids to be handled.

(b) Suction stubs in suction-type pumping systems should be the same diameter as the product line they serve. Such stubs and remote pumps should extend to within 3" of the bottom of the tank or as specified by the tank manufacturer.

(c) It is recommended that a double poppet (under the pump or angle check valve at the tank) be installed on each product line, where suction-type pumps are used. If the fitting is to be installed under concrete, an extractor angle valve manhole or concrete breakout can be used.

(d) With remote or submerged pumping systems, a leak detection device is required by NFPA Code 30.

(e) Pumping systems should be equipped with clearly identified and easily accessible electrical switches or circuit breakers. These should be located away from dispensers and pumps, and permit the shutting off of all dispensing devices, in the event of an emergency.

(f) Dispensers should be of an approved type, which meets requirements of UL 87, and bear the UL Label.

- Tank Fittings: Tanks should be constructed to recognized standards of design (such as UL 58/1971, Standards for Steel Underground Tanks for Flammable and Combustible Liquids), and equipped with the desired number and size of tank openings. Tank manufacturer's specifications and drawings must be checked to determine what types (steel or FRP), sizes and capacities are available, and whether they conform to recommended standards.

(a) Tank openings of 4" diameter are recommended, and most steel tanks will meet that specification. Fill pipes, fill caps, and fill tubes normally are also 4" in diameter. Submersible pumps, designed with the capacity to meet normal service station layout and operation requirements, are built to fit 4" tank openings. If greater capacity is needed, larger pumps and tank openings may be required.

(b) Double-tapped bushings are used to reduce the size of the tank opening, so that appropriate fittings can be attached, and connecting pipes inside and outside of the tank installed.

(c) At the time of installation, temporary plugs in unused openings should be removed and replaced with malleable iron plugs that are wrenched tight.

(d) Nonmetallic tanks are fitted with threaded openings to receive the same double-tapped bushings or plugs referred to above, or shown in the installation diagrams which follow.

(e) Fill pipes may be located at any opening in the tank.

(f) Tight fill connections are recommended. A fill tube should be inserted at the fill opening, and should

extend to within 6" of the tank bottom The use of tight fill connections and fill tubes will increase the rate of product flow during filling, and decrease turbulence and product vapor loss.

(g) A liquid-tight fill cap, equipped with a lock, should be installed. This may be used in conjunction with a manhole ring and cover (see Figure 2). The fill assembly or manhole ring should be marked with product identification and tank size. This can be done either by using a color code, or by having the product name stamped or applied to the fixed portion of the fill assembly, or both.

(h) A float activated vent valve should be installed in the tank to help prevent overfilling

(i) Vent caps should be installed, where required by local ordinances or special conditions, so as to not restrict the discharge of vapors from the outlet.

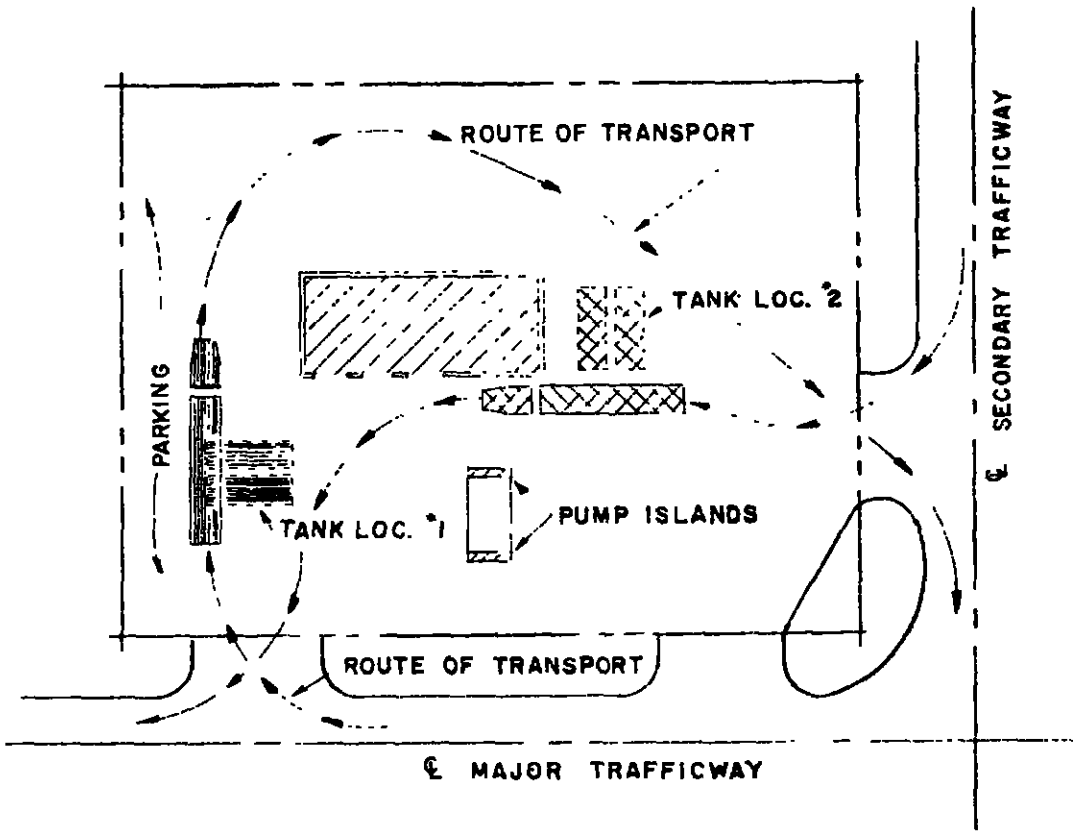
6. PREVENTION AND DETECTION OF LEAKAGE

The prevention of product leaks and overfills from storage and dispensing systems is necessary to provide a safe environment for the community, employees, customers and neighbors; and to minimize air and water pollution. Prevention of leaks should be given high priority. This can best be accomplished by properly installing and maintaining a tight storage and dispensing system, specifically designed and protected for its particular environment.

Should a leak develop, it must be detected promptly. This can be done through the daily preparation and reconciliation of inventory control records, and recognition of the symptoms of leaks. For inventory control procedures, the reader is directed to API Bulletin No. 1621, Recommended Practice for Bulk Liquid Stock Control at Retail Outlets.

FIGURE 1

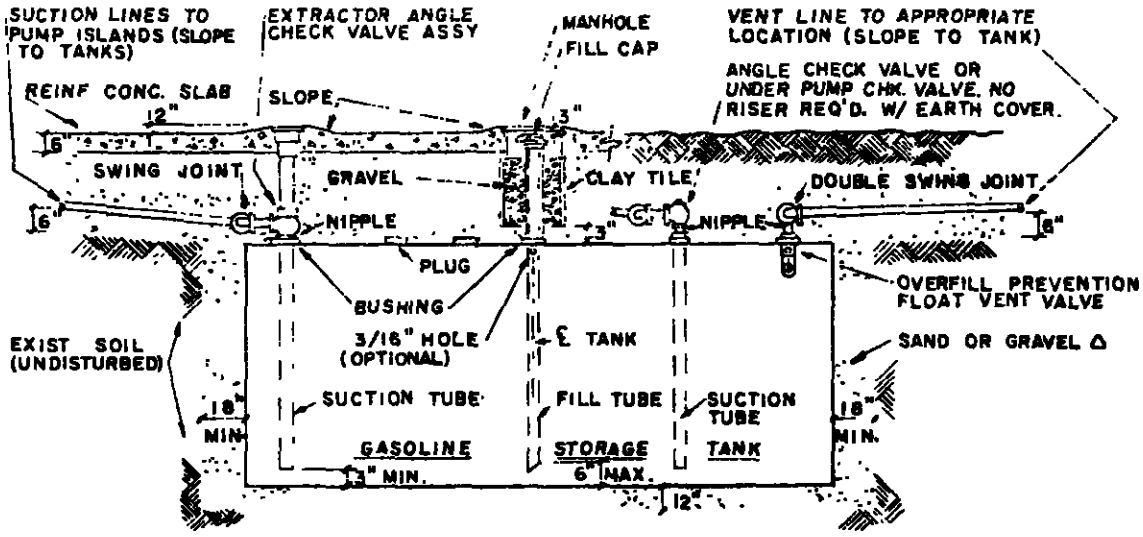
TYPICAL PLOT PLAN SHOWING POSSIBLE TANK LOCATIONS



1. ROUTE OF TRANSPORT REQUIRES MIN. 50' TURNING RADIUS.
2. NO "BACKING" REQUIRED FOR TRANSPORT.
3. PRODUCT LINES ARE A PRACTICAL LENGTH, FOR EITHER SUCTION OR REMOTE PUMPING.
4. RECOMMEND PAVING OVER TANKS AT EITHER LOCATION.

FIGURE 2

TANK PIPING DETAILS - SUCTION SYSTEM



PIPING DETAILS FOR TANKS — UNDER CONCRETE

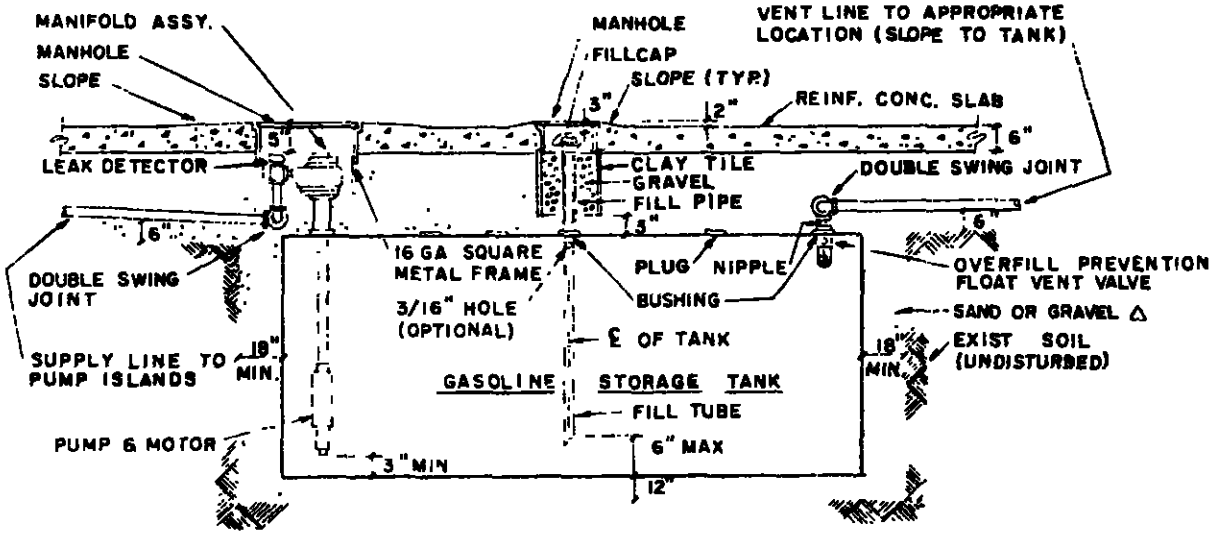
NO SCALE

△ PEA GRAVEL FOR NON-METALLIC TANKS (OR MFR. APPROVED ALTERNATE)

NOTE: ELIMINATE CONC. SLAB IN NON-TRAFFIC AREAS & CONSTRUCT CONC. PADS (ONLY) AROUND MANHOLES. THE EXTR. ANGLE CHECK RISER IS NOT REQ'D. W/ EARTH COVER

FIGURE 3

TANK PIPING DETAILS - SUBMERGED SYSTEM



PIPING DETAILS FOR TANKS — UNDER CONCRETE

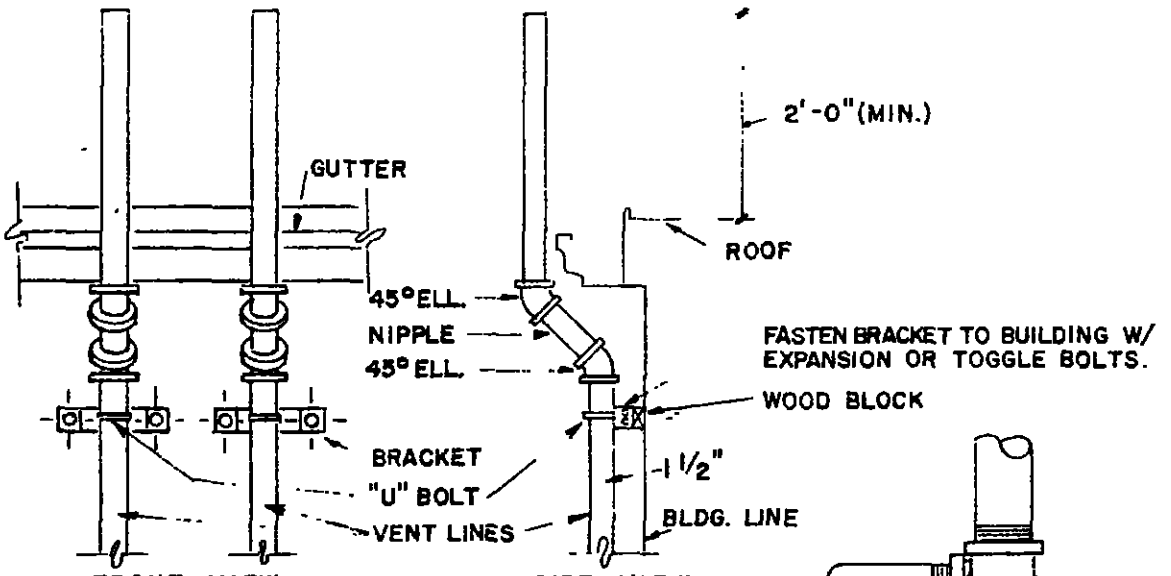
NO SCALE

△ PEA GRAVEL FOR NON-METALLIC TANKS (OR MFR APPROVED ALTERNATE)

NOTE: ELIMINATE CONC. SLAB IN NON-TRAFFIC AREAS & CONSTRUCT CONC PADS (ONLY) AROUND M.H.'S.

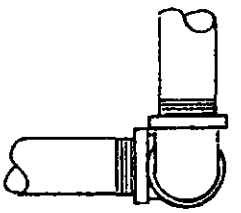
FIGURE 4

MISCELLANEOUS DETAILS



VENT DETAILS

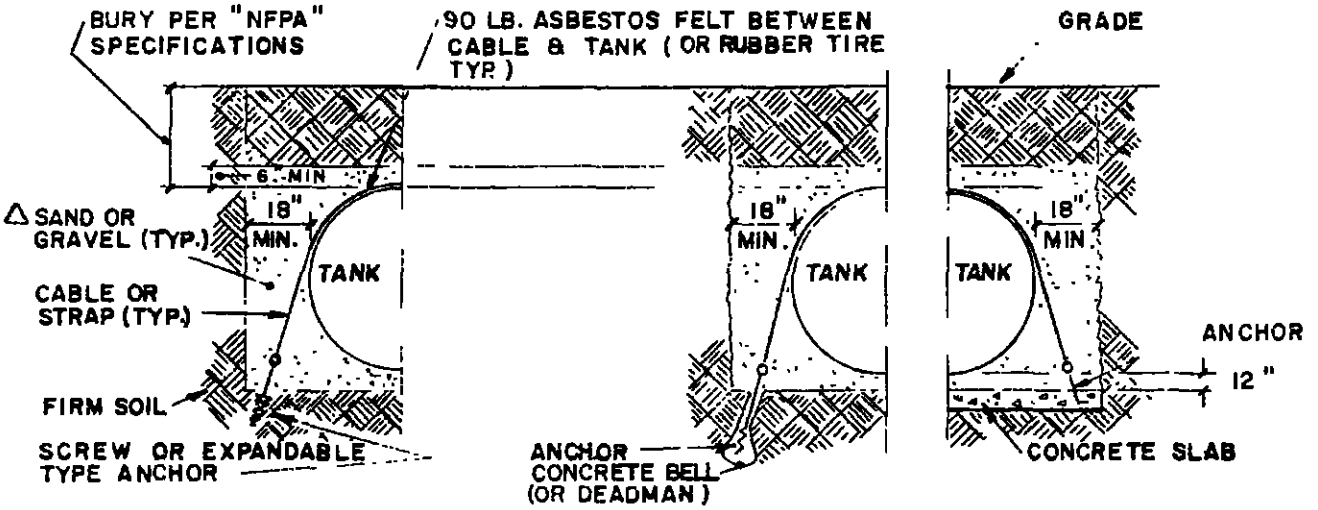
NO SCALE



TYPICAL SWING JOINT

(ISLAND & VENT TERMINAL)

NO SCALE



NOTE: SEE MANUFACTURERS RECOMMENDATIONS FOR ANCHOR AND INSTALLATION INSTRUCTIONS.

TANK INSTALLATION

(WHERE SUB-SURFACE WATER CONDITIONS EXIST.)

NO SCALE

△ PEA GRAVEL FOR NON-METALLIC TANKS (OR MFR. APPROVED ALTERNATE)

FIGURE 5

PUMP ISLAND PIPING - SUCTION & SUBMERGED

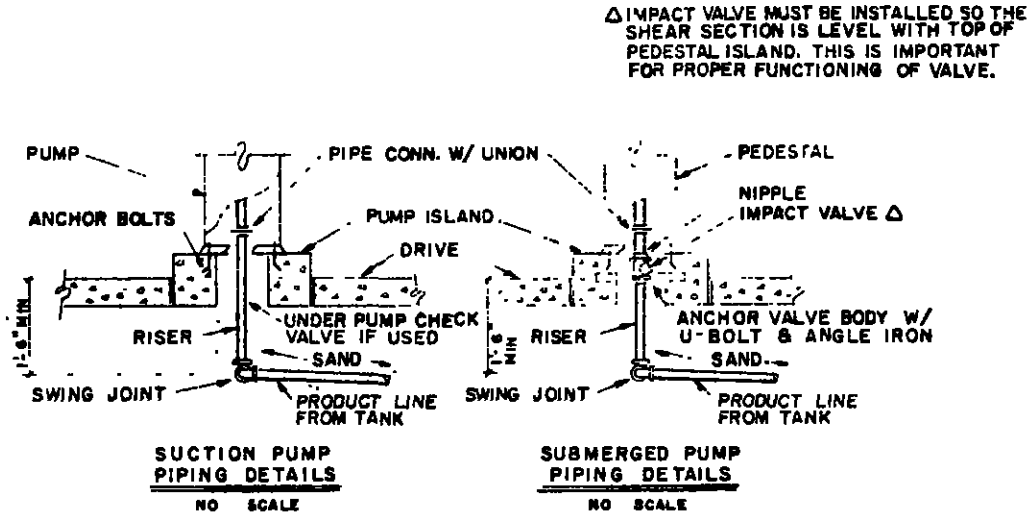
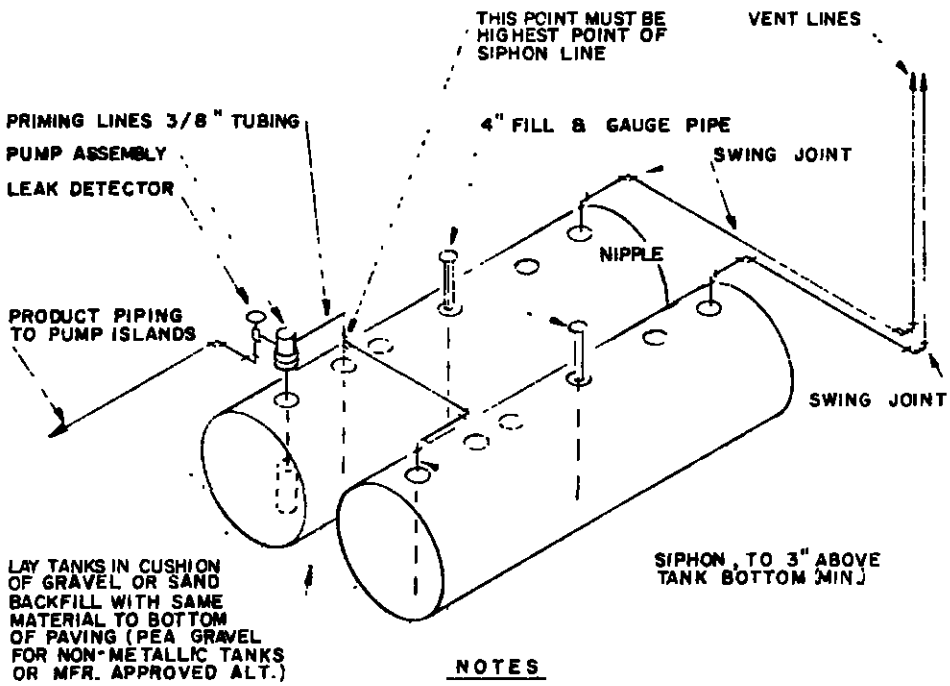


FIGURE 6

TYPICAL REMOTE PUMPING SIPHON SYSTEM

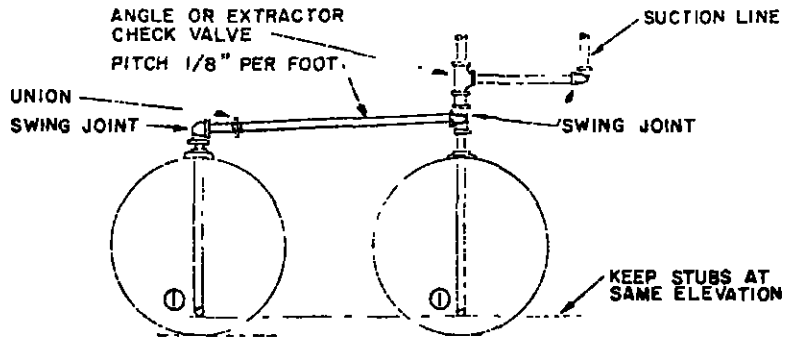


NOTES

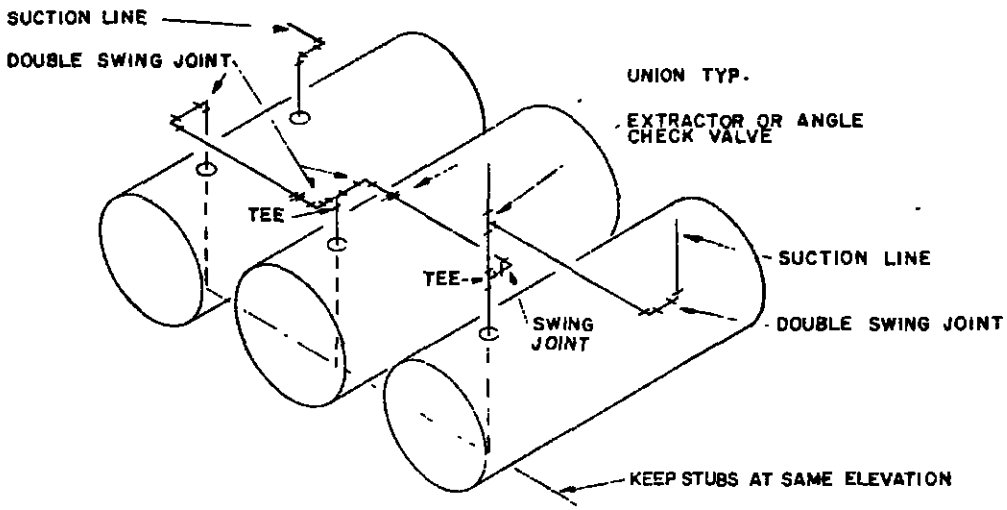
1. TANK BOTTOMS TO BE AT SAME ELEVATION
2. SWING JOINTS TO BE INSTALLED WITH APPROXIMATELY 45° BEND WITHOUT TWISTING.
3. BOTTOM OF SIPHON STUBS TO BE AT SAME ELEVATION.

FIGURE 7

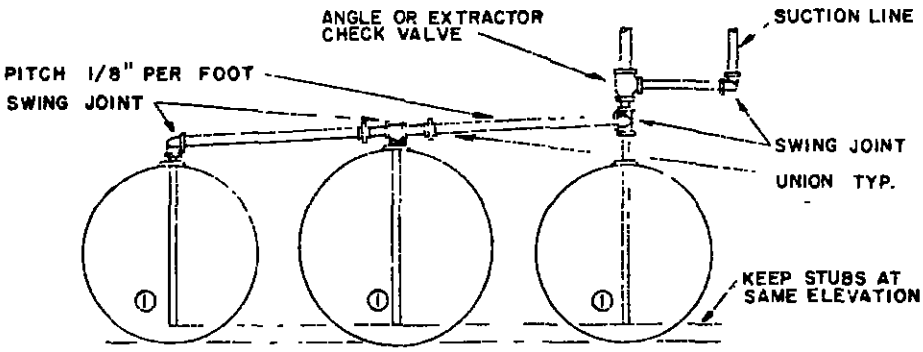
TYPICAL SUCTION PUMP SIPHON SYSTEM



2 - TANKS TO 1 - OR MORE PUMPS



ISOMETRIC OF 3 - TANKS TO 1 - OR MORE PUMPS



3 - TANKS TO 1 - OR MORE PUMPS

① WHEN EXISTING U.G. TANKS, THE BOTTOMS OF WHICH ARE NOT ON THE SAME LEVEL, ARE TO BE TWINNED, BOTTOMS OF SUCTION STUBS MUST BE ON THE SAME LEVEL.

1-1400-11/79-2M
1-1400- 1/80-4M
1-1400- 7/80-2M

6. American Petroleum Institute. "Cathodic Protection of Underground Petroleum Storage Tanks and Piping Systems", Publication 1632, First Edition, 1983

Stephen A. Figueroa

Cathodic Protection of Underground Petroleum Storage Tanks and Piping Systems

PUBLICATION 1632
FIRST EDITION 1983

American Petroleum Institute
1220 L Street, Northwest
Washington, D.C. 20005

Cathodic Protection of Underground Petroleum Storage Tanks and Piping Systems

PUBLICATION 1632
FIRST EDITION 1983

OFFICIAL PUBLICATION

REG. U.S. PATENT OFFICE

TABLE OF CONTENTS

		Page
I.	Foreword	1
II.	Scope	1
III.	Introduction	1
IV.	Sacrificial Anode Protection	7
V.	Impressed Current Protection	9

Cathodic Protection of Underground Petroleum Storage Tanks and Piping Systems

I. Foreword

Persons planning to construct an underground storage facility, replace existing underground storage tanks and piping system, or cathodically protect existing underground storage tanks and piping should refer to applicable local, state and federal fire, safety and environmental regulations as well as the following publications and material:

- API 1615, *Installation of Underground Petroleum Storage Systems*
- API 1621, *Recommended Practice for Bulk Liquid Stock Control at Retail Outlets*
- NFPA 30, *Flammable and Combustible Liquids Code*
- NACE RP-01-69, *Control of External Corrosion on Underground or Submerged Metallic Piping Systems*
- *National Electrical Code*

The information in this bulletin may be used by anyone desiring to do so, but the American Petroleum Institute shall not be held responsible or liable in any way, either for any loss or damage resulting therefrom, or for the violation of any federal, state or municipal regulations with which it may conflict.

II. Scope

This bulletin covers two methods for providing cathodic protection to buried steel petroleum storage and dispensing systems. Its intent is to provide information specific to steel structures buried at service stations such as motor fuel storage tanks and delivery piping, waste oil tanks, heating oil tanks, and automobile lifts. Information presented for service stations is not necessarily applicable to buried tanks and piping used for other purposes. This bulletin is meant to serve only as a general guide to marketers, architects and engineers interested in cathodic protection of underground petroleum storage and dispensing systems. Specific cathodic protection designs are not given. Such designs should be developed or reviewed by a qualified corrosion engineer or a person thoroughly familiar with cathodic protection practices.

III. INTRODUCTION

Corrosion may be defined as the deterioration of metal due to a reaction with its environment External corrosion of buried steel structures is an electrochemical process. For the process to occur, areas with different electrical potentials must exist on the metal surface. These areas must be electrically connected and they must also be in contact with an electrolyte. There are, therefore, four components in each electrochemical corrosion cell: an anode, a cathode, a metallic path connecting the anode and cathode, and an electrolyte (See Figure 1).

- At the anode the base metal goes into solution (corrodes) by releasing electrons and forming positive metal ions.
- No metal loss occurs at the cathode. However, other chemical reactions occur which consume the electrons released at the anode.
- The metal path connecting the anode and cathode conducts electrons generated by the chemical corrosion reactions at the anode to the cathode where they are consumed.
- Positive current flows through the electrolyte from the anode to the cathode to complete the electrical circuit. In the case of buried structures the electrolyte is moist soil.

Corrosion is usually not limited to a single point as shown in Figure 1. In the case of general corrosion, thousands of tiny micro corrosion cells may occur randomly over the metal surface resulting in relatively uniform metal loss. In pitting attack the individual corrosion cells tend to be larger, and distinct anode and cathode areas can often be identified. Metal loss may be concentrated within relatively small areas and substantial areas of the surface may be unaffected by corrosion.

Both metal composition and environmental factors may determine which areas on a metal surface become anodes or cathodes. Steel is an inherently nonhomogeneous material and for a particular environment, potential differences between adjacent areas can result from uneven distribution of alloying elements or contaminants within the metal structure Differences in weld material and the steel plate can also cause corrosion cells.

Physical and chemical properties of the soil electrolyte may also influence the location of anodic and cathodic areas on the metal surface. For example, differing oxygen concentrations at different areas on a buried steel structure may generate potential differences. Areas with low oxygen levels become anodic areas and areas with higher oxygen concentrations become cathodic areas. This may result in more severe corrosion attack at the bottom of a buried tank than at the top of the tank since oxygen concentration in soil is primarily dependent on diffusion processes (See Figure 2). The same mechanism can also contribute to corrosion in areas where clay or debris contact a steel tank buried in a

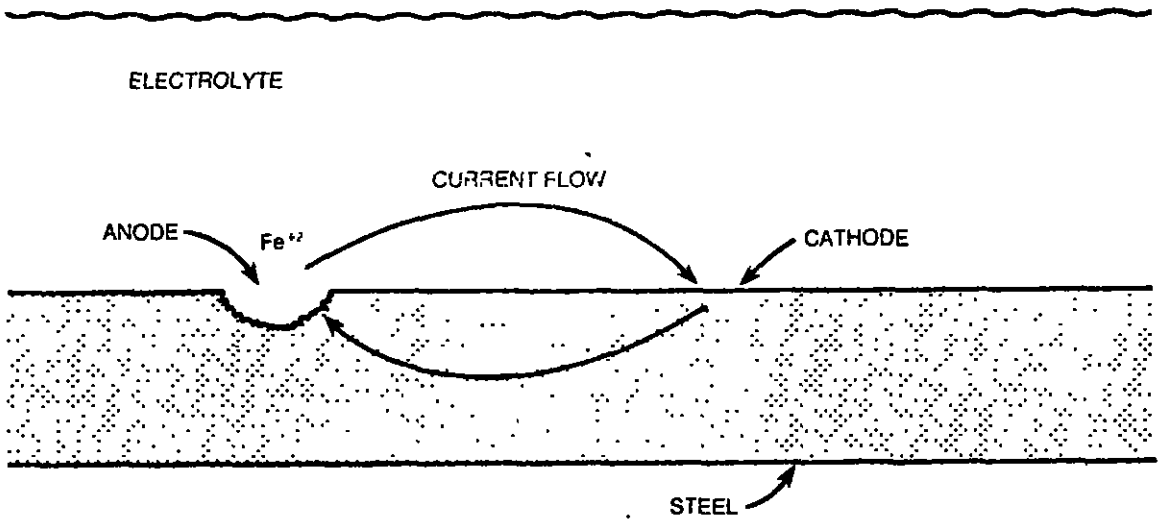


FIGURE 1 ELECTROCHEMICAL CORROSION CELL

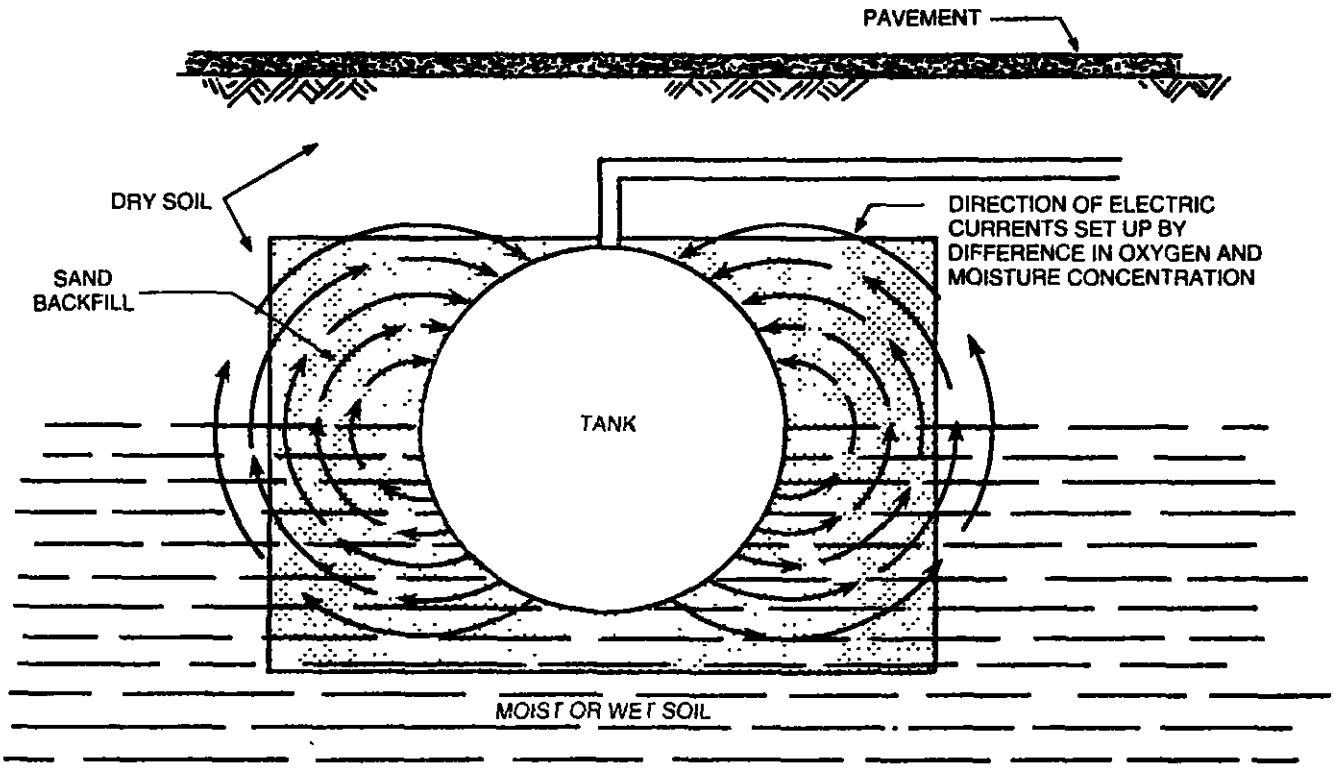


FIGURE 2 CORROSION CAUSED BY DIFFERENCES IN OXYGEN AND MOISTURE CONTENT OF SOILS

sand backfill or where a tank is buried in two different types of soil (See Figure 3)

Soil characteristics substantially affect the type and rate of corrosion occurring on buried structures For example, dissolved salts influence the current carrying capacity of the soil electrolyte and help determine reaction rates at anode and cathode areas Soil moisture content, pH (measure of acidity), and the presence of sulfides also influence corrosion These factors, and perhaps others, interact in a complex fashion to influence corrosion at each location.

Corrosion processes described above are often referred to as galvanic corrosion. In addition to galvanic corrosion stray current and bimetallic corrosion may also be encountered on buried steel structures. Like galvanic corrosion, these corrosion processes also involve electrochemical reactions.

- Stray currents are electric currents which travel through the soil electrolyte. Direct current (DC) stray currents are the most common and potentially the most damaging These currents are generated from grounded DC electric power operations including electric railroads, subways, welding machines and cathodic protection systems. Stray currents may enter a buried metal structure and travel through the low resistance path of the metal to an area on the structure closer to the current source. Current leaves the structure at this point to return to the source through the soil electrolyte. Corrosion occurs at the area where current leaves the structure (See Figure 4).
- Bimetallic corrosion occurs when two metals with different compositions are connected in a soil electrolyte. For example, bimetallic corrosion can occur where a bronze check valve is joined to steel piping or where galvanized pipe is connected to a steel tank. In the bronze check valve/steel pipe example, the steel pipe becomes the anode and the bronze check valve is the

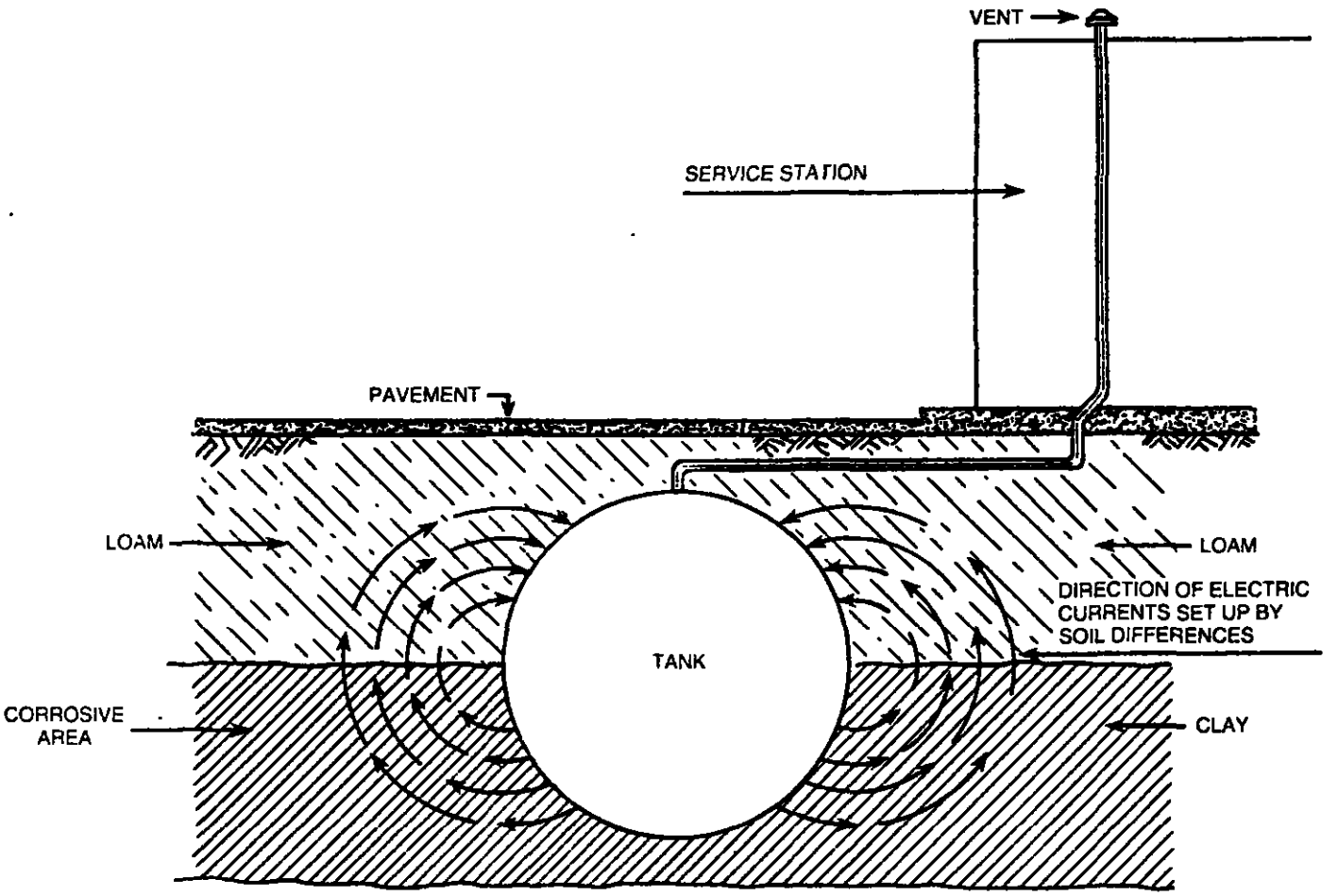


FIGURE 3 CORROSION CAUSED BY DISSIMILAR SOILS

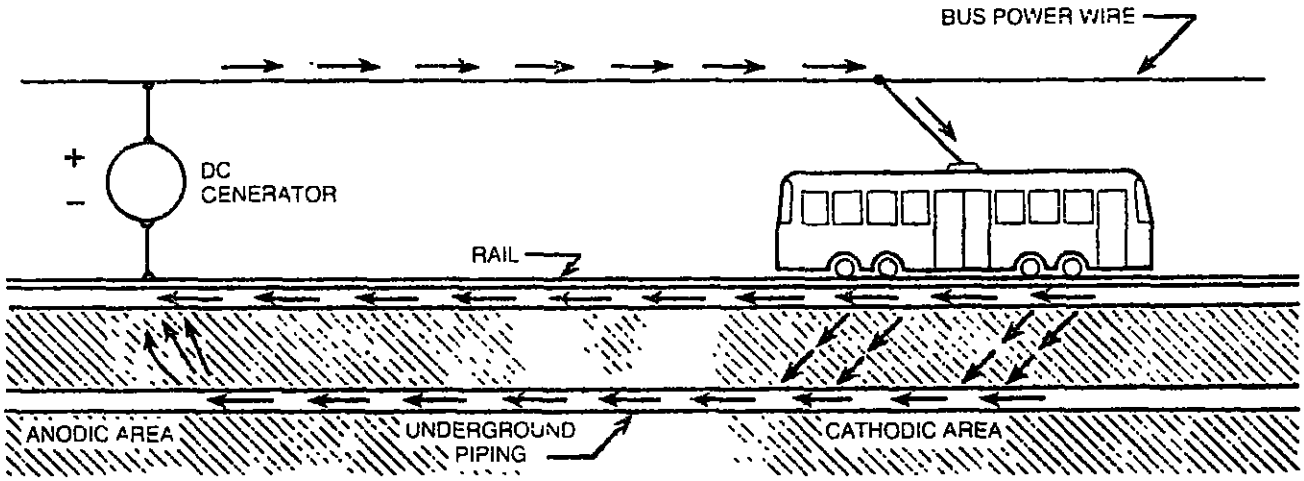


FIGURE 4 STRAY CURRENT CORROSION

cathode. Since current takes the path of least resistance, the most severe corrosion attack on the steel pipe occurs in the area immediately adjacent to the check valve (See Figure 5).

Corrosion of buried steel structures may be eliminated by proper application of cathodic protection. Cathodic protection is a technique for preventing corrosion by making the entire surface of the metal to be protected a cathode of an electrochemical cell. Corrosion is not eliminated. It is simply transferred from the metal surface to an external anode.

There are two methods of applying cathodic protection to underground metal structures:

- Sacrificial or galvanic anodes
- Impressed current

For sacrificial or galvanic anode systems, a metal anode more negative than steel in the galvanic series (see Table 1 for a partial galvanic series) is electrically connected to the structure to be protected and buried in the soil. A galvanic corrosion cell develops and the active metal anode corrodes (is sacrificed) while the structure becomes cathodic and is protected. As the protective current enters the structure it opposes, overcomes, and prevents the flow of any corrosion current from the metal structure. The protective current then returns to the sacrificial anode through a metallic conductor (See Figure 6).

Advantages of sacrificial anode cathodic protection systems include:

- No external power supply is necessary
- Installation is relatively easy
- Costs are low for low current requirement situations

Table 1
PRACTICAL GALVANIC SERIES
(Neutral Soils and Water)

METAL	VOLTS (REFERENCED TO COPPER/COPPER SULFATE)
Commercially pure Magnesium	−1.75
Magnesium Alloy (6%Al, 3%Zn, 0.15%Mn)	−1.6
Zinc	−1.1
Aluminum Alloy (5%Zn)	−1.0
Commercially pure Aluminum	−0.8
Mild Steel (Clean and Shiny)	−0.5 to −0.8
Mild Steel (Rusted)	−0.2 to −0.5
Cast Iron	−0.5
Lead	−0.5
Mild Steel in Concrete	−0.2
Copper, Brass, Bronze	−0.2
High Silicon Cast Iron	−0.2
Mill Scale on Steel	−0.2
Carbon, Graphite, Coke	+0.3

- Maintenance costs are minimal after installation
- Interference problems (stray currents) on foreign structures are rare
- Sacrificial anodes may be attached directly to new, coated tanks by tank manufacturers

Disadvantages of sacrificial anode cathodic protection systems are:

- Limited driving potential
- Low current output, preventing protection of other structures
- Subject to soil resistivity limitations

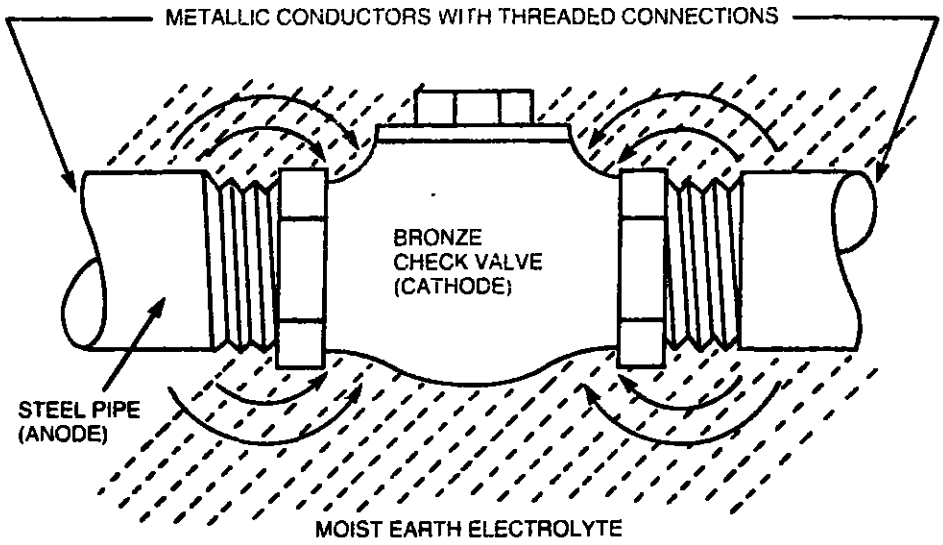


FIGURE 5 BIMETALLIC CORROSION

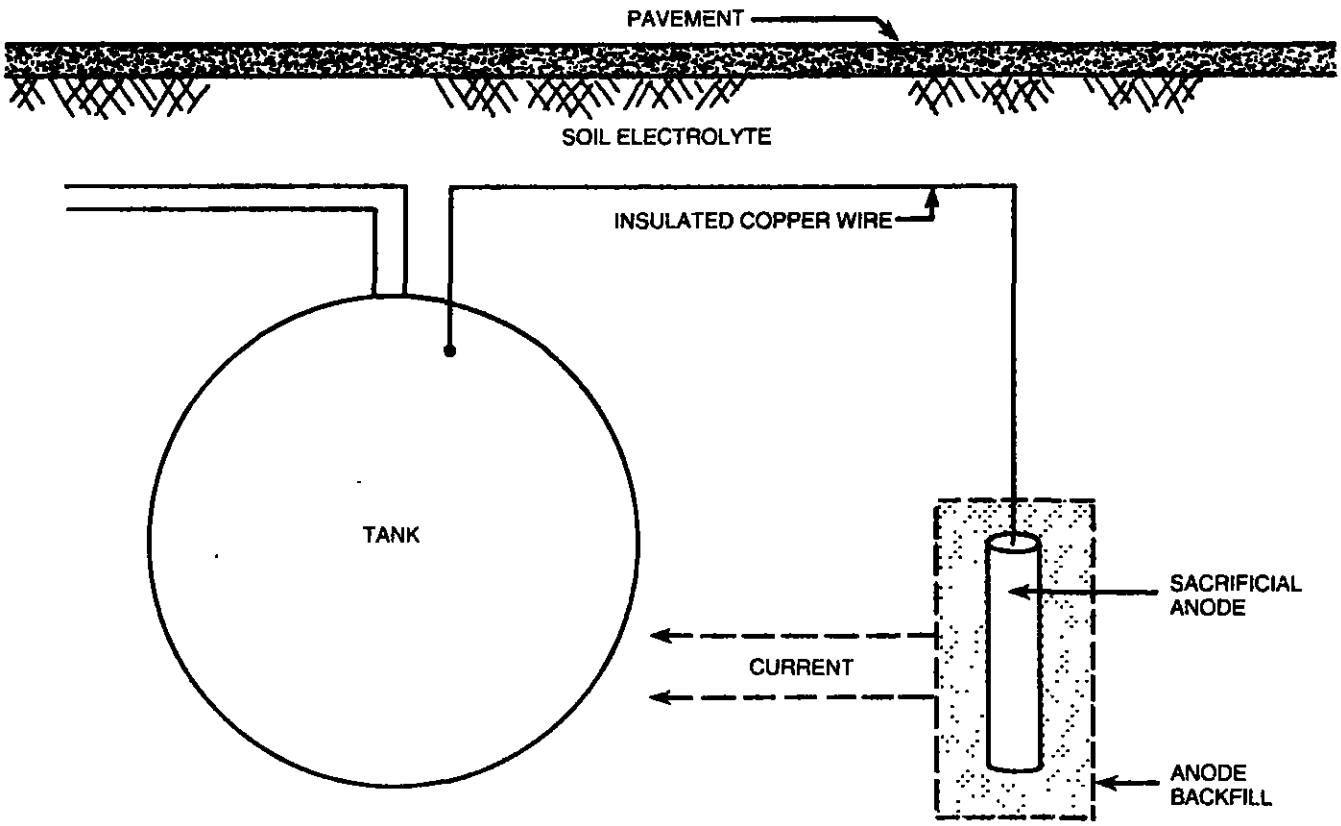


FIGURE 6 SACRIFICIAL ANODE CATHODIC PROTECTION

- Not applicable for protecting large bare steel structures
- Possibility of a short life

The second method of applying cathodic protection to a buried metal structure is to use impressed current from an external source. Figure 6 illustrates a typical installation of this type using an AC power supply with a rectifier. The DC current from the rectifier flows through the soil to the structure from a buried electrode. In this case there is no need for the anode itself to corrode to provide current to the structure, so impressed current anodes are typically made of relatively inert materials.

Advantages of impressed current cathodic protection systems are:

- Large driving potential
- High current output capable of protecting other underground steel structures with a low operating cost
- Possibility of flexible current output control
- Applicability to almost any soil resistivity
- Capable of protecting large bare steel structures

Impressed current cathodic protection systems have the following disadvantages:

- May cause interference problems (stray currents) on foreign structures
- Possible to deliberately or unintentionally switch off current and eliminate protection
- Systems must be monitored and maintained on a regular schedule

As indicated by the advantages and disadvantages of sacrificial and impressed current systems listed above, the type of system selected for a particular location may depend upon a number of factors. In general, systems and designs selected should provide corrosion protection while optimizing installation, maintenance and operation costs. New, coated

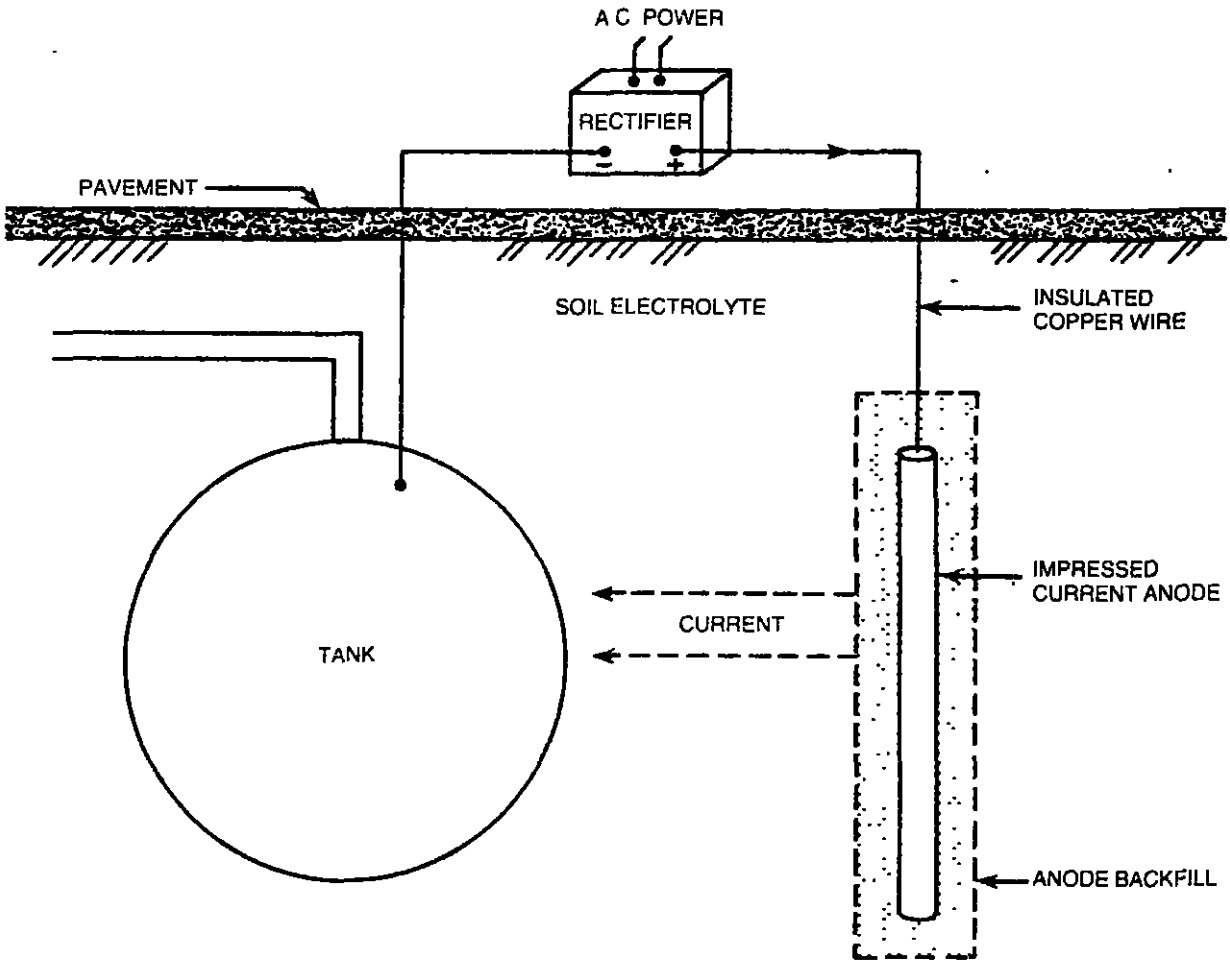


FIGURE 7. IMPRESSED CURRENT CATHODIC PROTECTION

tanks and piping may be protected by either system, whereas existing installations will normally require impressed current systems. Since complete corrosion protection of buried structures under cathodic protection depends upon proper system design, it is recommended that cathodic protection systems should be designed by qualified corrosion engineers or other persons thoroughly familiar with cathodic protection.

Consideration should be given to the following factors in developing cathodic protection designs for buried structures:

- Soil resistivity
- Present and future current requirements
- Life of the cathodic protection system in relation to the intended life of the structures to be protected
- Presence of stray currents
- Anode placement to provide uniform protective current
- Condition of the structures to be protected. Are they new or old, coated or bare
- Selection of a system to minimize excessive current output which can harm structure coatings or produce interferences with nearby buried structures
- Reliability of cathodic protection system components

In some instances on-site surveys may be required to obtain information necessary for specific designs. In other cases designs may be sufficiently versatile to cover the wide range of conditions normally encountered.

The installation of cathodic protection systems involves the use of wire conductors connecting anodes and structures, anodes and test stations, and anodes and rectifiers. The exact location of such wiring and anodes should be carefully identified on a plot plan of the facility, and a copy of this plan should be maintained by the owner.

IV. Sacrificial Anode Protection

Corrosion protection with sacrificial anodes may be used in preference to an impressed current system where current requirements are low. Magnesium anodes are most commonly used although zinc anodes may be employed to advantage in low resistivity soils. Low driving voltages and low current out-puts (usually less than 0.10 ampheres per anode) generally limit sacrificial anodes to cathodic protection of well coated structures. New installations involving coated tanks and/or distribution piping are particularly amenable to sacrificial anodes for providing corrosion protection.

Underground storage tanks are available from tank manufacturers with sacrificial anode cathodic protection systems already attached. Current requirements are minimized by plant application of long-lasting corrosion resistant coatings. Sacrificial anodes are attached at the plant with anode weight and size determined by the tank size. Non-conductive bushings and flanges are provided with each tank to insulate the tank from any extra current demand from associated metal piping. These bushings and flanges must be used to protect the tank and maintain the supplier's warranty. These tanks may also be obtained with plant installed test leads which facilitate field monitoring of anode current output and tank to soil potential.

These pre-engineered cathodic protection systems for new tanks were developed to satisfy requirements for most soil situations. In some instances, such as locations with low soil resistivity, the life of these systems may not be as long as expected. Conditions under which long term corrosion protection is afforded should be determined by purchasers and compared with conditions present at proposed installation sites.

Tanks with pre-engineered cathodic protection systems must be given careful handling during transportation and installation to protect against coating damage or rupture of anode packages. Anode wires, test leads, tank coating and tank isolation bushings should be inspected for obvious damage prior to final installation. As with any cathodic protection system, a regular monitoring program after installation is necessary to determine that corrosion protection is being maintained.

Field installed sacrificial anode cathodic protection systems may also be used to protect new or existing well-coated tanks and piping. In general, a coal tar coating routinely applied to steel petroleum storage tanks should not be considered to be an adequate coating for cathodic protection purposes. Many of the corrosion resistant coatings used on cathodically protected petroleum pipelines (see NACE RP-01-69) are applicable as coatings for buried petroleum storage tanks and dispensing piping. Effective coatings are needed to reduce current requirements of these structures to levels which can be supplied over a long term by sacrificial anodes.

With information on soil resistivity, total surface area to be protected and coating quality, current requirements for new or existing buried structures may be estimated. For existing structures, it is also possible to quantitatively determine current requirements by electrically connecting buried structures to a variable DC power source and measuring structure to soil potentials vs a copper-copper sulfate electrode. The observed current output needed to achieve a desired cathodic protection criteria may then be used for designing a cathodic protection system for the structures.

Three sacrificial anode materials are commonly used for soil installations:

- high potential magnesium alloy
- standard magnesium alloy
- zinc

Magnesium and zinc anodes prepackaged in chemical backfill are readily available in a number of size and weight

configurations to provide current output and anode life design flexibility. The use of a chemical backfill with anodes is necessary for reliable operation in soil environments. Chemical backfill promotes anode efficiency, lengthens anode life and keeps anodes moist.

The number of anodes required for providing cathodic protection to buried structures depends largely upon total current requirements, but current distribution factors should also be considered. Where several anodes are needed for a structure, better current distribution (more uniform polarization) may be achieved by distributing the anodes uniformly around the structure. In the case of new tank installations, sacrificial anodes are often placed parallel to the tank walls, at or near the level of the tank bottom. For petroleum distribution systems, anodes are typically installed below the piping at a depth of about five feet. Installation of anodes at these locations for tanks and piping serves two purposes:

- it helps assure anodes remain in a moist environment and
- it provides better current distribution to the lower portion of the buried structures where corrosion is typically most severe

A low resistance electrical connection must be made between the structure to be protected and the sacrificial anodes lead wire. For new installations and where safety considerations permit, powder weld connections; (e.g. Cadweld or Thermit type) should be used. In some situations, safety factors may dictate the use of mechanical connections. Such connections should be carefully made since poor electrical contact will increase the effective circuit wire resistance and limit the amount of useful current available from the anode. All exposed metal at structure-lead wire connections should be waterproofed and coated with electrical insulating material. This will prevent bimetallic corrosion between the copper wire and the steel tank if the sacrificial anode should fail at some time in the future.

Current output of sacrificial anodes is limited and cathodic protection designs typically do not provide sufficient current for protecting adjacent buried structures. For this reason, the structure to be protected should be electrically insulated from other buried metal structures including electrical conduit. Properly installed insulating unions and bushings are effective for accomplishing electrical isolation. Location of these insulating fittings will depend upon the cathodic protection design and the extent of the structure to be cathodically protected. These insulating fittings should be inspected after installation to insure no damage has occurred.

Where electrical isolation is essential for adequate corrosion protection, particular care should be taken to assure that the structure to be protected is insulated from any buried metallic powder conduit. For example, petroleum distribution piping protected by sacrificial anodes should have an insulating union at each dispensing unit, and protected underground storage tanks with submersible pumps should include insulating bushings between the pump riser pipe and the tank.

There are several criteria for determining if adequate cathodic protection has been achieved on buried structures. The most common criterion for underground petroleum storage tanks and piping systems with sacrificial anode protection is a negative voltage of at least 0.85 volts. This potential is measured between the structure and a saturated copper-copper sulfate reference electrode contacting the soil electrolyte and with sacrificial anodes attached.

Routine structure to soil potential measurements for evaluating the extent of corrosion protection are often difficult to obtain at petroleum storage and distribution sites because the buried structures are covered by asphalt or concrete pavement. While valid potential measurements are possible through asphalt or concrete, special equipment and trained personnel may be required to obtain and interpret these results. More reliable results can be obtained by installing permanent access manholes through the pavement to the soil at the time cathodic protection is installed. The number and location of soil access manholes will depend upon the cathodic protection design and placement of sacrificial anodes. In general, the access manholes should be placed to measure potentials over the structure at points farthest from the sacrificial anodes or in shielded areas.

As an alternative to making structure to soil potential measurements as described above, long-life reference cells should be permanently installed in the soil near protected structures. Specially designed copper-copper sulfate or packaged zinc reference cells are commercially available for this purpose. These reference cells are typically located within several inches of the structure in areas where current distribution may be poor, at points farthest from attached anodes, or under the tank. Acceptable potential readings at such locations, according to the criterion above, are a good indication that adequate corrosion protection has been achieved on the entire external structure surface.

Lead wires attached to the buried reference cells should be run to a permanent test station at the site to allow easy attachment to test instruments. It may also be convenient or necessary to attach a test lead to the buried structure and run it to the test station to facilitate periodic potential monitoring.

Structure to soil potential measurements are made by electrically connecting the buried structure to the negative terminal of a suitable high resistance voltmeter (e.g. 50,000 ohm internal resistance or higher). The positive terminal of the voltmeter is connected to a properly placed reference cell. When a buried zinc reference cell is used, a negative

1.1 volts must be added to the observed voltmeter reading to obtain a potential reading comparable to that which would result from using a copper-copper sulfate reference cell.

Where sacrificial anodes have been installed, their proper operation should be confirmed by a qualified person within six and twelve months of installation, and one year thereafter. If these tests confirm proper operation, subsequent inspection intervals can be extended to five years. However, if underground work is performed at the protected site, cathodic protection should be remonitored six to twelve weeks after work completion and one year thereafter before again extending the inspection interval. Procedures used and data obtained should be clearly recorded and included in permanent cathodic protection records for the location along with the name of the person making the measurements and the date measurements were made.

V. Impressed Current Protection

Impressed current cathodic protection is often the most economical means of controlling corrosion of existing buried steel petroleum storage tanks and distribution piping systems. It may also be used to provide corrosion protection for other buried structures at a location such as waste oil tanks, heating oil tanks and automobile lifts—often at minimal additional costs.

As indicated previously, cathodic protection requires a source of direct current. For impressed current systems, this direct current is typically provided by a rectifier attached to a conventional AC power source. (A rectifier is a device for converting alternating current to direct current). DC output from the rectifier flows to the buried impressed current anode, through the soil electrolyte and onto the surface of the structure as shown in Figure 6.

The usual cathodic protection rectifier has two major components: a step-down transformer to reduce the AC supply voltage and rectifying elements to provide DC output. Units may be obtained with either selenium or silicon rectifier elements. Both types of elements are widely used and provide dependable service. Either may show cost or performance advantages for a particular application. Small selenium units are often less expensive than similar silicon units but silicon rectifiers are generally more efficient. Silicon units are particularly susceptible to damage from power surges and protective devices should be included in these units to prevent lightning damage. Selenium rectifiers are not recommended if ambient temperatures are expected to exceed 130°F (55°C).

The rectifier output capacity selected will depend upon estimated or measured current requirements of the structure to be protected and upon the voltage needed to cause current to flow from the anodes to the buried structure. In general, moderate excess capacity should be allowed for all rectifiers to provide for adjustment flexibility during the life of the cathodic protection system and to prevent voltage overloads. All rectifiers may be damaged by voltage overloads. Excess rectifier voltage outputs of from 15% to 30% above expected needs are suggested to compensate for possible line voltage fluctuations. Some excess rectifier current output capacity is particularly suggested for coated structures. Coatings may degrade with time and increase current requirements of a structure.

Careful consideration should be given to locating rectifiers. Efforts should be made to place the units in areas not susceptible to accidental or malicious damage, since no corrosion protection is provided by an impressed current system if the rectifier is inoperative. Whenever possible rectifiers should be mounted within a secure building and in a spot which allows regular and convenient monitoring of meters and indicator lights. All wiring to rectifiers must comply with local and national electrical codes.

Rectifiers are available with optional equipment which facilitates periodic monitoring and provides an indication that power is available to impressed current anodes. It is suggested that the equipment listed below should be mounted on the front panel of each rectifier cabinet:

- Green and red signal lights to indicate proper/improper rectifier operation.
- A volt-ammeter for measuring rectifier voltage and current output.
- A non-resettable elapsed time meter with a minimum hour capacity of 99,999 hours.
- Warning sign stating that this is a cathodic protection rectifier and that corrosion of underground structures can result if power to the unit is shut off.

Optional audio alarm signals, which sound if a rectifier is not operating properly, may be useful in some situations.

The AC power source to a rectifier should be isolated to an individual circuit breaker on the main electrical panel. This breaker switch should have a tab-lockout bracket installed, if permitted by local code, to prevent inadvertent switching-off of the rectifier. Rectifier cabinets should be sealed or padlocked to prevent unauthorized entry to the on-off AC circuit breaker and other exposed high voltage contacts within the cabinet.

Several materials are used as impressed current anodes. The most common are:

- graphite
- high silicon cast iron
- platinized niobium, tantalum or titanium

Each anode material has an optimum current density which provides maximum anode service life. Anodes may be located in remote ground beds, in deep wells, or distributed closely about the structure to be protected. The latter two designs may be required to:

7. American Petroleum Institute. "Underground Survey Results" as reported by F. B. Killman to API to Underground Leak Task Force, API, Washington D.C. February 5, 1981, as cited in Technology for the Storage of Hazardous Liquids - A State of the Art Review, Department of Environmental Conservation, Albany, New York, January 1983

TECHNOLOGY FOR THE STORAGE OF HAZARDOUS LIQUIDS

A State-Of-The-Art Review

New York State
Department of Environmental Conservation

File Copy

TECHNOLOGY FOR THE STORAGE OF HAZARDOUS LIQUIDS

A State-Of-The-Art Review

NEW YORK STATE

DEPARTMENT OF ENVIRONMENTAL CONSERVATION
DIVISION OF WATER
BUREAU OF WATER RESOURCES

ALBANY, NEW YORK

JANUARY 1983

A good security system is helpful in preventing hazardous chemical spills or leaks due to vandalism, theft, sabotage or other improper and illegal use of storage plant facilities. The elements of such a system could include the following:

- Routine patrols of the plant by security personnel.
- Fencing.
- Good lighting.
- Vehicular traffic control.
- Controlled access to the plant.
- Locked entrances.
- Locks on drain valves and pumps for chemical storage tanks.
- Television monitoring.

3. Below Ground Storage Systems [1,5,10]

Underground storage systems are susceptible to leaks and spills from the same types of causes as aboveground storage systems, and, in general, the same methods of spill and leak control are applicable. In the case of thse systems however, data indicates that corrosion and poor installation are by far the most common causes of storage system leaks and spills [1,10]. For example, the American Petroleum Institute (API) conducted a survey of 1,717 underground tanks and piping systems that were known to be leaking. The data was collected via questionnaire from 1977 through 1980. A categorization of the reported leaks is displayed in Table 1.1-3. Since no data base exists in this study concerning the number or age of the various types of tanks in the ground at the time of this survey or the average ages of each type of tank, the use of the study for comparing types of tanks is meaningless. Much valuable data is contained in the study but any attempt to compare tank types would be a misuse of the data.

The life expectancy of any given tank is difficult to predict. Experience has shown that underground steel tanks have a finite life, but this life is variable between 5 and 45 years depending on the thickness of the steel, installation practices, soil resistivity, pH, soil moisture level, the presence of sulfides, the type of backfill material used, and the tank size. The average life expectancy of these tanks is about 15 years, but age by itself is a poor indicator of tank integrity.

The causes of leaks in steel tanks, as determined by the API Leak Survey, are shown in Table 1.1-4. Overall, roughly 91 percent of the leaks in steel tanks were caused by corrosion. Other causes included loose fittings and physical breakage. Of the 28 leaking fiberglass tanks included in the survey, 9 had dip stick punctures, 4 had breakage from improper handling, 1 had a backhoe puncture, and 14 had experienced physical breakage or separation due to other causes. For piping systems, corrosion was also the most common cause of leaks as shown in Table 1.1-5.

Table 1.1-3

Leaks by Source Categories

Source	Number	Percent of total
Unprotected Steel Tanks	913	62
Steel tanks with Impressed Current	13	0 9
Steel tanks with Sacrificial Anodes	0	0 0
Interior Coated Steel Tanks	7	0.5
Fiberglass tanks	28	1.9
Steel piping	454	30 8
Fiberglass piping	50	3.4
Steel piping with Impressed Current	7	0 5
Sub-Total	1472	100
Unspecified Tanks	216	
Unspecified Piping	29	
Total	1717	

Source Reference 10

Table 1.1-4

Causes of Leaks in Steel Tanks

Cause	Total	Percent of Total
Corrosion	775	90.7
Loose Fittings	10	1 2
Physical Breakage	14	1 6
Other	55	6.4
Sub-Total	854	99.9
Unknown or unanswered	59	

Table 1.1-5

Causes of Piping Leaks

Cause	Number	Percent of Total
Corrosion	343	66.6
Flex Connector Failure	31	6
Physical Breakage	34	6.6
Loose Fittings	57	11.1
Other	50	9.7
Sub-Total	515	100
Unknown or Unanswered	25	

Note: These tables emphasize the importance of corrosion as a cause of storage system leaks.

Source: Reference 10

Underground tanks which are connected together with siphoning pipes present unique problems. Leak testing becomes difficult, if not impossible, to accomplish. the ususal reason for siphoning between tanks is to add capacity to a system. When a small tank does not provide enough gallonage for increased business (usually after several years), a second tank is installed and is connected to the first with a siphon. The new tank and the new piping become targets for electrolytic corrosion from the old tank.

C. CORROSION [8,11,12,13,14,15,16,17,18,19,20]

The corrosion of tanks and piping systems is a complex phenomenon that may take one or more of several forms. Corrosion results from interactions betweeen the tanks and piping and their surroundings, both internal and external.

The deterioration of plastics and other non-metallic materials, which are susceptible to softening, cracking, swelling, etc., is essentially chemical in nature [11]. Non-metallic materials may deteriorate rapidly when exposed to corrosive elements. The corrosion of non-metallic storage system components can be controlled and essentially eliminated through proper selection and careful handling of tank and piping materials.

In metallic materials, corrosion is a chemical or electrochemical process. Corrosion control in these materials is therefore more complicated. The remainder of the discussion in this chapter focuses on the causes of internal and external corrosion of metals, the factors which influence this corrosion, and the steps which can be taken to protect against this form of deterioration.

1. Corrosion Mechanisms

As stated above, the corrosion of metals is primarily an electrical process; it may take the form of either galvanic or electrolytic corrosion. As shown in Figure 1.1-7, electrolytic corrosion is a result of direct current from outside sources entering and then leaving a particular metal structure by way of the electrolyte (surrounding material, such as soil for underground structures or water for submerged structures). The structure is usually unaffected or is provided with some degree of protection at the point the current enters (the cathodic area). Corrosion occurs where the current leaves the structure (the anodic area). In underground structures, this type of corrosion is often referred to as stray current corrosion, and is a result of current entering the ground from sources of DC current such as street railways or DC machinery.

The mechanisms of galvanic corrosion are illustrated in Figure 1.1-8. Galvanic corrosion is a self-generated activity resulting from differences in electrical potential that develop when metal is placed in an electrolyte. These differences in electrical potential can result from the direct coupling of dissimilar metals, or they can result from variations in conditions which exist upon the surface of a single metal. The variations could include:

- Variations resulting from non-homogeneity of the metal.
- Differences which exist within the electrolytes.

When two dissimilar metals are connected electrically and immersed in an electrolyte, as shown in Figure 1.1-8, current will be generated and galvanic corrosion will occur in one of the metals. Current from the corroding metal will flow into the electrolyte, over to the non-corroding metal, and then back through the connection between the two metals. The corroding metal (the one from which current leaves to enter the electrolyte) is known as the anode; the metal which receives current is known as the cathode. Table 1.1-6 shows the anodic-cathodic (galvanic) series of various metals.

Alternately, as stated previously, the same metal can develop differences in potential, and, as a result, portions of the surface of that metal become anodic with respect to the remainder of the surface. As shown in figure 1.1-8, corrosion will occur at these anodic locations.

Electrolytic and galvanic corrosion are similar in that corrosion always occurs at the anodes. The essential difference between the two is that in electrolytic corrosion it is the external current which generates the corrosion, whereas in galvanic corrosion it is the corrosion activity which generates the current.

Corrosion Allowance. Often corrosion is anticipated, and items are constructed with enough metal to allow for corrosion to proceed to a point without interfering with the normal function of that item. An example of such a corrosion allowance is a tank whose design thickness is such that appreciable corrosion can be tolerated before a leak or tank failure will occur.

Corrosion-Resistant Materials of Construction. Corrosion can also be controlled through the use of corrosion-resistant materials of construction. Examples of such items include special alloys, fiberglass reinforced plastic, and fiberglass reinforced plastic coatings. Special alloys are most often used when difficult-to-contain fluids are to be handled. Stainless steel is an example of such a material. Stainless steel is a family of alloys. The corrosion resistant properties of the specific material chosen for the containment vessel should be appropriate for the material being contained.

From the perspective of corrosion resistance, fiberglass reinforced plastic (FRP) tanks are an effective means of storing many fluids in underground storage systems, most notably petroleum products. These tanks are not subject to corrosion and are strong enough to withstand most soild and other loading stresses when they are properly installed. The importance of proper installation of FRP tanks is discussed in further detail in Part II. The FRP piping is also applicable in these types of situations.

Fiberglass reinforced plastic coatings are also available and generally consist of thick (on the order of ⅛ inch) coatings applied to steel tanks. The concerns expressed above and elsewhere in this document regarding the use of coatings apply to these types of coatings as well.

References

1. New York State Department of Environmental Conservation, *Bulk Storage of Hazardous Liquids Study Program – Problem Assessment Report*, Paper #5, New York State Department of Environmental Conservation, 50 Wolf Road, Albany, NY 12233, April, 1981.

2. New York State Department of Environmental Conservation, *New York State Bulk Storage Control – Study Program*, New York State Department of Environmental Conservation, 50 Wolf Road, Albany, NY 12233, May, 1980.

3. American Petroleum Institute, *Underground Spill Cleanup Manual*, API Publication, American Petroleum Institute, 2101 L Street, N W., Washington, DC 20037, June, 1980.

4. National Fire Protection Association, *Underground Leakage of Flammable and Combustible Liquids*, NFPA 329, National Fire Protection Association, Inc., Batterymarch Park, Quincy, Massachusetts 02269, 1977.

5. Pace Company Consultants & Engineers, Inc., Spill Control Manual prepared under EPA Training Grant No. T-900-175-02-2 to the Department of Environmental Science and Engineering, Rice University, Houston, TX, February, 1975

6. Annual Report of the New York State Oil Prevention, Control and Compensation Program, April 1, 1978 to March 30, 1979, New York State Department of Environmental Conservation, 50 Wolf Road, Albany, NY 12233

7. Annual Report of the New York State Oil Prevention, Control and Compensation Program, April 1, 1979 to March 30, 1980, New York State Department of Environmental Conservation, 50 Wolf Road, Albany, NY 12233.

8. American Petroleum Institute, *Guide for Inspection of Refinery Equipment, Chapter I – Introduction; Chapter XIII – Inspection of Atmosphere and Low-Pressure Storage Tanks*, American Petroleum Institute, 2101 L Street, N.W., Washington, DC 20037, 1976

9. U.S. Environmental Protection Agency, *NPDES Best Management Practices Guidance Document*, Draft, EPA-600/9-79-045, Industrial Environmental Research Laboratory, USEPA, Cincinnati, OH 45268, December, 1979.

10. American Petroleum Institute, Underground Leak Survey results as reported by F.B. Killman to API Underground Leak Task Force, American Petroleum Institute, 2101 L Street, N.W., Washington, DC 20037, February 5, 1981.

11. Perry, R.H., Chilton, C.H., *Chemical Engineers' Handbook*, Fifth Edition, McGraw-Hill Book Co., 1221 Avenue of the Americas, New York, NY 10020, 1973.

12. Husock, B., "Fundamentals of Cathodic Protection", Paper No. HC-2, Harco Corporation, Cathodic Protection Division, 1055 West Smith Road, Medina, Ohio 44256, March 6, 1962.

References, continued

13. Husock, B., "Cathodic Protection – One Way to Prevent Underground Corrosion", Paper No. HC-4, Harco Corporation, Cathodic Protection Division, 1055 West Smith Road, Medina, OH 44256.

14. Husock, B., "Corrosion and Cathodic Protection of Underground Tanks at Service Stations", Paper No. HC-15, Harco Corporation, Cathodic Protection Division, 1055 West Smith Road, Medina, OH 44256, February, 1965.

15. Husock, B., "Causes of Underground Corrosion", Paper No. NC-36, Harco Corporation, Cathodic Protection Division, 1055 West Smith Road, Medina, OH 44256, May, 1976.

16. Rothman, P.S., "Cathodic Protection of Tank and Underground Structures", Harco Corporation, Cathodic Protection Division, 244 East County Line Road, Hatboro, PA 19040, 1978.

17. U.S. Department of Agriculture, "Control of Underground Corrosion", Design Note No. 12, Soil Conservation Service, U.S. Department of Agriculture, Soil Conservation Service, Feb. 1, 1971.

18. National Association of Corrosion Engineers, *Recommended Practice – Control of External Corrosion on Underground or Submerged Metallic Piping Systems*, NACE Standard RP-01-69, National Association of Corrosion Engineers, 1440 South Creek, Houston, TX 77084, January, 1972.

19. Fitzgerald, J.H., "Corrosion Control for Buried Service Station Tanks", Paper No. 52, The International Corrosion Forum Devoted Exclusively to the Protection and Performance of Materials, April 14-18, 1975, Toronto, Canada, National Association of Corrosion Engineers, 1440 South Creek, Houston, TX 77084.

20. The Hinchman Company, *Suggested Ways to Meet Corrosion Protection Codes for Underground Tanks and Piping*, Job Number 1079-4542, The Hinchman Company, Corrosion Engineers, 1605 Mutual Building, Detroit, Michigan 48226, April 8, 1981.

21. Husock, B., "Use of Pipe-to-Soil Potential in Analyzing Underground Corrosion Problems", Paper No. HC-7, Harco Corporation, Cathodic Protection Division, 1055 West Smith Road, Medina, Ohio 44256.

22. Husock, B., "Pipe-to-Soil Potential Measurements and Cathodic Protection of Underground Structures", Paper No. HC-8, *Materials and Performance*, Vol. 10, No. 5, May, 1971.

23. Rizzo, F.E. "Detection of Active Corrosion", Paper No. HC-14, Harco Corporation, Cathodic Protection Division, 1055 West Smith Road, Medina, OH 44256.

24. Hosford, H.W. "Cathodic Protection of Marine Structures", Paper No. HC-16, Harco Corporation, Cathodic Protection Division, 1055 West Smith Road, Medina, OH 44256.

25. Rizzo, F.E., Miller, M., "New Technique for CP Monitoring of Offshore Pipelines", Paper No. HC-39, *Oil and Gas Journal*, February 13, 1978.

8. Annual Book of ASTM Standards, "Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens," pt. 10, G1-81, American Society for Testing and Materials, Philadelphia, Pennsylvania, 1981, pg. 829-834

Designation: G 1 – 81

Standard Practice for PREPARING, CLEANING, AND EVALUATING CORROSION TEST SPECIMENS[1]

This standard is issued under the fixed designation G 1; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last approval.

1. Scope

1.1 This practice gives suggested procedures for preparing bare, solid metal specimens for laboratory corrosion tests, for removing corrosion products after the test has been completed, and for evaluating the corrosion damage that has occurred. Emphasis is placed on procedures related to the evaluation of corrosion by mass-loss and pitting measurements.

NOTE 1: Caution—In many cases the corrosion product on the reactive metals titanium and zirconium is a hard and tightly bonded oxide that defies removal by chemical or ordinary mechanical means. In many such cases, corrosion rates are established by weight gain rather than weight loss.

2. Applicable Documents

2.1 *ASTM Standards:*

A 262 Recommended Practice for Detecting Susceptibility to Intergranular Attack in Stainless Steels[2]

D 1384 Corrosion Test for Engine Coolants in Glassware[3]

G 31 Recommended Practice for Laboratory Immersion Corrosion Testing of Metals[2]

G 46 Recommended Practice for Examination and Evaluation of Pitting Corrosion[4]

3. Significance and Use

3.1 A significance and use statement is not applicable to this practice.

4. Sampling

4.1 The bulk sampling of products is outside the scope of this practice.

5. Methods for Preparing Specimens for Test

5.1 *Surface Condition:*

5.1.1 For laboratory corrosion tests that simulate exposure to service environments, a commercial surface, closely resembling the one that would be used in service, will yield the most significant results.

5.1.2 For more searching tests of either the metal or the environment, standard surface finishes may be preferred. A suitable procedure might be:

5.1.2.1 Degrease in an organic solvent or hot alkaline cleaner.

NOTE 2—Hot alkalies and chlorinated solvents may attack some metals.

NOTE 3—Ultrasonic cleaning may be beneficial in both pre-test and post-test cleaning procedures.

5.1.2.2 Pickle in an appropriate solution (in some cases the chemical cleaners described in Section 7 will suffice) if oxides or tarnish are present.

5.1.2.3 Abrade with a slurry of an appropriate abrasive or with an abrasive paper (see Recommended Practices A 262, D 1384, and G 31). The edges as well as the faces of the specimens should be abraded to remove burrs.

5.1.2.4 Rinse thoroughly and dry.

5.2 *Metallurgical Condition*—When spec-

[1] This practice is under the jurisdiction of ASTM Committee G-1 on Corrosion of Metals and is the direct responsibility of Subcommittee G01.05 on Laboratory Corrosion Tests.

Current edition approved April 24, 1981. Published June 1981. Originally published as G 1 – 67. Last previous edition G 1 – 72 (1979).

[2] *Annual Book of ASTM Standards*, Parts 3 and 10.

[3] *Annual Book of ASTM Standards*, Part 30.

[4] *Annual Book of ASTM Standards*, Part 10.

men preparation changes the metallurgical condition of the metal, other methods should be chosen or the metallurgical condition must be corrected by subsequent treatment. For example, shearing a specimen to size will cold work and may possibly fracture the edges. Edges should be machined or the specimen annealed.

5.3 The clean, dry specimens should be measured and weighed. Dimensions determined to the third significant figure and mass determined to the fifth significant figure are suggested.

6. Method for Electrolytic Cleaning After Testing

6.1 Electrolytic cleaning is a satisfactory method for many common metals.

6.1.1 The following method is typical; after scrubbing to remove loosely attached corrosion products, electrolyze the specimen as follows:

Sulfuric acid (H_2SO_4, sp gr 1.84)	28 ml
Organic inhibitor	2 ml (see Note 4)
Water to make	1 litre
Temperature	75 C (167 F)
Time	3 min
Anode	carbon or lead (see Note 5)
Cathode	test specimen
Current density	20 A/dm^2

NOTE 4—Instead of using 0.2 volume percent of any proprietary inhibitor, about 0.5 g/litre of such inhibitors as diorthotolyl thiourea, quinoline ethiodide, or betanaphthol quinoline may be used.

NOTE 5—If lead anodes are used, lead may deposit on the specimen and cause an error in the mass loss. If the specimen is resistant to nitric acid, the lead may be removed by a flash dip in 1 + 1 nitric acid. Except for this possible source of error, lead is preferred as an anode as it gives more efficient corrosion-product removal.

6.2 It should be noted that this electrolytic treatment may result in the redeposition of metal, such as copper, from reducible corrosion products and, thus, lower the apparent mass loss.

7. Methods for Chemical Cleaning After Testing

NOTE 6: Caution—These methods may be hazardous to personnel. They should not be carried out by the uninitiated or without professional supervision.

7.1 *Copper and Nickel Alloys*—Dip in:

Hydrochloric acid (HCl, sp gr 1.19)	500 ml
Water to make	1 litre
Temperature	room
Time	1 to 3 min

NOTE 7—To avoid metal loss during cleaning, deaerate solution with purified nitrogen before cleaning specimens.

7.2 *Aluminum Alloys*—The following methods are suitable:

7.2.1 Dip in:

Chromic acid (CrO_3)	20 g
Phosphoric acid (H_3PO_4, sp gr 1.69)	50 ml
Water to make	1 litre
Temperature	80°C (176°F)
Time	5 to 10 min, or until clean

7.2.1.1 If a film remains, dip in:

Nitric acid (HNO_3, sp gr 1.42)	...
Temperature	room
Time	1 min

7.2.2 Dip in:

Nitric acid (HNO_3, sp gr 1.42)	...
Temperature	room
Time	15 min, or until clean

NOTE 8: Caution—Remove extraneous deposits as well as bulky corrosion products before the HNO_3 treatment to avoid violent reactions that may result in attack of the aluminum alloy (see 7.9).

7.3 *Tin Alloys*—Dip in:

Trisodium phosphate (Na_3PO_4)	150 g
Water to make	1 litre
Temperature	boiling
Time	10 min

7.4 *Lead Alloys*—Suitable methods include:

7.4.1 Preferably, use the electrolytic cleaning procedure of Section 6.

7.4.2 Dip in:

Acetic acid (99.5 percent)	10 ml
Water to make	1 litre
Temperature	boiling
Time	5 min

7.4.3 Alternatively dip in:

Ammonium acetate	50 g
Water to make	1 litre
Temperature	hot
Time	5 min

7.4.3.1 This removes lead oxide (PbO) and lead sulfate ($PbSO_4$).

7.5 *Zinc*—The following methods are suitable:

7.5.1 Dip in:

Ammonium hydroxide (NH_4OH, sp gr 0.90)	150 ml
Water to make	1 litre
Temperature	room
Time	several minutes

7.5.2 Then dip in:

Chromic acid (CrO_3)	50 g
Silver nitrate ($AgNO_3$)	10 g
Water to make	1 litre
Temperature	boiling
Time	15 to 20 s

NOTE 9—In making up the c... it is advisable to dissolve the si... and add it to the boiling chr... excessive crystallization of the si... chromic acid must be free from ... on the zinc.

7.5.2 Dip in:

Hydriodic acid (HI, sp gr 1.5)
Water to make
Temperature
Time

7.5.2.1 This procedure d... and corrections must be ma...

7.5.6 *Magnesium Alloys*—...

Chromic acid (CrO_3)
Silver chromate (Ag_2CrO_4)
Water to make
Temperature
Time

7.7 *Iron and Steel*—The fo... are suitable:

7.7.1 The hot sodium hy... cellent for cleaning iron a... the point of view of ease o... sion products and minim... metal.[5] Because of the hazard somewhat more sophistica... quired, other methods may ... alternative choice is electr... Section 6).

7.7.2 Dip in Clarke's sol...

Hydrochloric acid (HCl, sp gr 1.19) 1...
Antimony trioxide (Sb_2O_3) 2...
Stannous chloride ($SnCl_2$) 5...
Temperature r...
Time u...

7.7.2.1 Solution should b... or the specimen should be ru... abrasive implement of woo...

7.7.3 Dip in:

Sulfuric acid (H_2SO_4, sp gr 1.84)
Organic inhibitor
Water to make
Temperature

7.8 *Stainless Steels:*

7.8.1 Methods in 7.7.1 are ...

7.8.2 Dip in:

Nitric acid (HNO_3, sp gr 1.42)
Water to make
Temperature
Time

7.8.3 Alternatively dip i...

Ammonium citrate
Water to make

NOTE 9—In making up the chromic acid solution, it is advisable to dissolve the silver nitrate separately and add it to the boiling chromic acid to prevent excessive crystallization of the silver chromate. The chromic acid must be free from sulfate to avoid attack on the zinc.

7.5.2 Dip in:

Hydriodic acid (HI, sp gr 1.5)	85 ml
Water to make	1 litre
Temperature	room
Time	15 s

7.5.2.1 This procedure dissolves a little zinc and corrections must be made as noted in 8.1.

7.5.6 *Magnesium Alloys*—Dip in:

Chromic acid (CrO_3)	150 g
Silver chromate (Ag_2CrO_4)	10 g
Water to make	1 litre
Temperature	boiling
Time	1 min

7.7 *Iron and Steel*—The following methods are suitable:

7.7.1 The hot sodium hydride method is excellent for cleaning iron and steel both from the point of view of ease of removal of corrosion products and minimum attack on the metal.[5] Because of the hazard involved and the somewhat more sophisticated equipment required, other methods may be preferred. An alternative choice is electrolytic cleaning (see Section 6).

7.7.2 Dip in Clarke's solution:

Hydrochloric acid (HCl, sp gr 1.19)	1 litre
Antimony trioxide (Sb_2O_3)	20 g
Stannous chloride ($SnCl_2$)	50 g
Temperature	room
Time	up to 25 min

7.7.2.1 Solution should be vigorously stirred or the specimen should be rubbed with a nonabrasive implement of wood or rubber.

7.7.3 Dip in:

Sulfuric acid (H_2SO_4, sp gr 1.84)	100 ml
Organic inhibitor	1.5 ml
Water to make	1 litre
Temperature	50 C (120 F)

7.8 *Stainless Steels:*

7.8.1 Methods in 7.7.1 are also applicable.

7.8.2 Dip in:

Nitric acid (HNO_3, sp gr 1.42)	100 ml
Water to make	1 litre
Temperature	60 C (140 F)
Time	20 min

7.8.3 Alternatively dip in:

Ammonium citrate	150 g
Water to make	1 litre
Temperature	70 C (158 F)
Time	10 to 60 min

7.9 Mechanical cleaning in some cases may be used in place of, or as supplement to, chemical treatments to remove bulky adherent deposits. A relatively soft scraper or stiff fiber bristle brush should be used to avoid scratching or removal of metal from the surface of the specimen. However, this method may not remove all the products from pits.

NOTE 10—Such vigorous mechanical cleaning is applicable when mass losses are large and hence errors in mass loss will produce only small errors in corrosion rates. Blank corrections will be difficult to apply.

7.10 In all the foregoing methods, specimens should be rinsed following cleaning and scrubbed lightly with a bristle brush under running water. The cleaning dip may be repeated as necessary. After the final rinse, specimens should be dried and weighed.

8. Calculation of Corrosion Rate

8.1 Whatever cleaning method is used, the possibility of removal of solid metal is present: this results in error in the determination of the corrosion rate. To check this, one or more cleaned and weighed specimens may be recleaned by the same method and reweighed. Loss due to this second weighing may be used as an approximate correction to the first one (see Appendix X2 for a more exact method).

8.2 The initial total surface area of the specimen (making allowances for the change in area due to mounting holes) and the mass lost during the test are determined. The average corrosion rate may then be obtained as follows:

$$\text{Corrosion rate} = (K \times W)/(A \times T \times D)$$

where:

K = a constant (see 8.2.1),
T = time of exposure in hours to the nearest 0.01 h,
A = area in cm^2 to the nearest 0.01 cm^2,
W = mass loss in g, to nearest 1 mg, and
D = density in g/cm^3 (see Appendix X1).

8.2.1 Many different units are used to express corrosion rates. Using the above units for T, A, W, and D the corrosion rate can be

[5] *Technical Information Bulletin SP29-370* "DuPont Sodium Hydride Descaling Process Operating Instructions," available from E. I. duPont de Nemours & Co. (Inc.), Electrochemicals Dept., Wilmington, Del. 19898.

calculated in a variety of units with the following appropriate value of K:

Corrosion Rate Units Desired	Constant (K) in Corrosion Rate Equation
mils per year (mpy)	3.45×10^6
inches per year (ipy)	3.45×10^3
inches per month (ipm)	2.87×10^2
millimetres per year (mm/y)	8.76×10^4
micrometres per year (μm/y)	8.76×10^7
picometres per second (pm/s)	2.78×10^6
grams per square metre per hour (g/m²·h)	$1.00 \times 10^4 \times D^A$
milligrams per square decimetre per day (mdd)	$2.40 \times 10^6 \times D^A$
micrograms per square metre per second (μg/m²·s)	$2.78 \times 10^6 \times D^A$

[A] Density is not needed to calculate the corrosion rate in these units; the density in the constant K cancels out the density in the corrosion rate equation.

NOTE 11—If desired, these constants may also be used to convert corrosion rates from one set of units to another. To convert a corrosion rate in units X to a rate in units Y, multiple by K_Y/K_X for example:

$$15 \text{ mpy} = 15 \times (2.78 \times 10^6)/(3.45 \times 10^6) \text{ pm/s}$$

8.3 Corrosion rates calculated from mass losses can be misleading when deterioration is highly localized, as in pitting or crevice corrosion. If corrosion is in the form of pitting, it may be measured with a depth gage or micrometer calipers with pointed anvils (see Recommended Practice G 46). Microscopical methods will determine pit depth by focusing from top to bottom of the pit, when it is viewed from above (using a calibrated focusing knob) or by examining a section that has been mounted and metallographically polished. The pitting factor is the ratio of the deepest metal penetration to the average metal penetration (as measured by mass loss).

8.4 Other methods of assessing corrosion damage are:

8.4.1 *Appearance*—The degradation of appearance by rusting, tarnishing, or oxidation.

8.4.2 *Mechanical Properties*—An apparent loss in tensile strength will result if the cross-sectional area of the specimen (measured before exposure to the corrosive environment) is reduced by corrosion. Loss in tensile strength will result if a metasomatic change, such as parting has taken place. Loss in tensile strength and elongation will result from localized attack, such as cracking.

8.4.3 *Electrical Properties*—Loss in apparent conductivity will result from cracking or pitting.

8.4.4 *Microscopical Examination*—Parting, exfoliation, cracking, or intergranular attack may be measured by metallographic examination of suitably prepared sections.

9. Report

9.1 The report should include the compositions and sizes of specimens, their metallurgical conditions, surface preparations, and post-corrosion cleaning methods, as well as measures of corrosion damage such as corrosion rates (calculated from mass losses), maximum depths of pitting, or losses in mechanical properties.

10. Precision and Accuracy

10.1 A precision and accuracy statement cannot be made for this practice.

APPENDIXES

X1. DENSITIES FOR A VARIETY OF METALS AND ALLOYS

Aluminum Alloys	Density g/cm³
1100, 3004	2.72
1199, 5005, 5357, 6061, 6062, 6070, 6101	2.70
2024	2.77
2219, 7178	2.81
3003, 7079	2.74
5050	2.69
5052, 5454	2.68
5083, 5086, 5154, 5456	2.66
7075	2.80

Copper Alloys	Density g/cm³
Copper	8.94
Brasses:	
Commercial bronze 220	8.80
Red brass 230	8.75
Cartridge brass 260	8.52
Muntz metal 280	8.39
Admiralty 442, 443, 444, 445	8.52
Aluminum brass 687	8.33

Aluminum Alloys	Den g/c
Bronzes:	
Aluminum bronze, 5 percent 608	8.
Aluminum bronze, 8 percent 612	7.
Composition M	8.
Composition G	8.
Phosphor bronze, 5 percent 510	8.
Phosphor bronze, 10 percent 524	8.
85-5-5-5	8.
Silicon bronze 655	8.
Copper nickels 706, 710, 715	8.
Nickel silver 752	8.
Ferrous Metals	
Gray cast iron	7.
Carbon steel	7.
Silicon iron	7.
Low alloy steels	7.
Stainless steels:	
Types 201, 202, 302, 304, 304L, 321	7.
Types 309, 310, 311, 316, 316L, 317, 329, 330	7.
Type 347	8.
Type 410	7.
Type 430	7.
Type 446	7.
Type 502	7.
Durimet 20	8.

X2. METHOD FOR DETERMINING BASE ME

X2.1 Repeat the cleaning procedure a nu times. Weigh after each cleaning and plot t loss against the total time of cleaning or the of cleanings, see Fig. X2.1. The ordinate at t

Aluminum Alloys	Density g/cm³
Bronze:	
Aluminum bronze, 5 percent 608	8.16
Aluminum bronze, 8 percent 612	7.78
Composition M	8.45
Composition G	8.77
Phosphor bronze, 5 percent 510	8.86
Phosphor bronze, 10 percent 524	8.77
85-5-5-5	8.80
Silicon bronze 655	8.52
Copper nickels 706, 710, 715	8.94
Nickel silver 752	8.75
Ferrous Metals	
Gray cast iron	7.20
Carbon steel	7.86
Silicon iron	7.00
Low alloy steels	7.85
Stainless steels:	
Types 201, 202, 302, 304, 304L, 321	7.94
Types 309, 310, 311, 316, 316L, 317, 329, 330	7.98
Type 347	8.03
Type 410	7.70
Type 430	7.72
Type 446	7.65
Type 502	7.82
Durimet 20	8.02

Aluminum Alloys	Density g/cm³
Carpenter Stainless No. 20 Cb 3	8.05
Lead	
Antimonial	10.80
Chemical	11.33
Nickel Alloys	
Nickel 200	8.89
Monel Alloy 400	8.84
Inconel Alloy 600	8.51
Incoloy Alloy 825	8.14
Illium G	8.31
Hastelloy B	9.24
Hastelloy C	8.93
Hastelloy G	8.27
Other Metals	
Magnesium	1.74
Molybdenum	10.22
Platinum	21.45
Silver	10.49
Tantalum	16.60
Tin	7.30
Titanium	4.54
Zinc	7.13
Zirconium	6.53

X2. METHOD FOR DETERMINING MASS LOSS WHERE CLEANING MAY ATTACK THE BASE METAL OF THE SPECIMEN

X2.1 Repeat the cleaning procedure a number of times. Weigh after each cleaning and plot the mass loss against the total time of cleaning or the number of cleanings, see Fig. X2.1. The ordinate at the intersection of the two lines is the mass loss caused by removal of corrosion products alone. The method is particularly applicable to electrolytic cleaning, see Section 6.

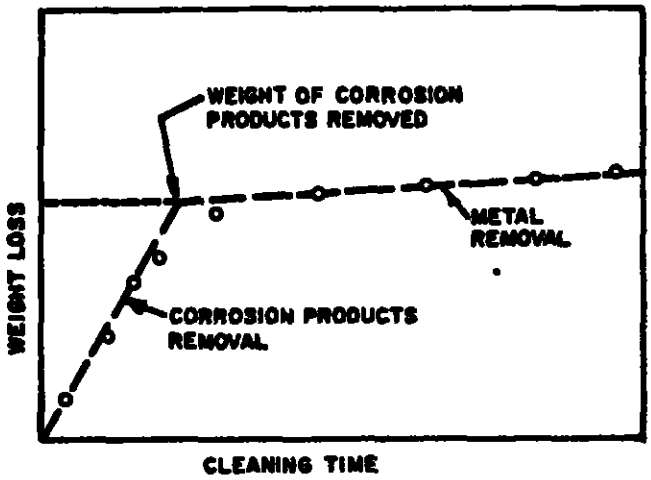


FIG. X2.1 Mass Loss Versus Exposure Time for Specimens During Cleaning

The American Society for Testing and Materials takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 1916 Race St., Philadelphia, Pa. 19103, which will schedule a further hearing regarding your comments. Failing satisfaction there, you may appeal to the ASTM Board of Directors.

Standard Prac
AQUEOUS C
ZIRCONIUM

This standard is issued under the fix
of original adoption or, in the case
reapproval.

1. Scope

1.1 This practice covers
ples of zirconium alloys in
elevated temperatures and p
tice includes a description
ration techniques, autocla
specified parameters when t
acceptance test in conjunct
tions for zirconium alloy p

1.2 This practice may be
products, castings, powde
ucts, and weld metal.

2. Summary of Method

2.1 Specimens of metal a
pressure water or steam at
tures to determine the oxida
is measured by the gain in w
and by the appearance of t

3. Significance and Use

3.1 This practice is pri
acceptance test for zircon
Typically specimens are e
750°F (399°C) and 1500 p
days. This practice has als
in development of new a
practices, and for evaluati
niques.

3.2 The specified param
met when the test is used
acceptance test are set fort
erances given elsewhere
laboratory practices.

3.3 Specimens are norm
ful pickling and rinsing
practice. Samples with a

9. Annual Book of ASTM Standards, "Standard Recommended Practice for Laboratory Immersion Corrosion Testing of Metals", pt. 10, G-31-72, American Society for Testing and Materials, Philadelphia, Pennsylvania, 1981, pp. 917-928

Designation: G 31 – 72 (Reapproved 1979)[1]

Standard Recommended Practice for LABORATORY IMMERSION CORROSION TESTING OF METALS[1]

This standard is issued under the fixed designation G 31; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

[1] NOTE—Editorial changes were made throughout in March 1979.

1. Scope

1.1 This recommended practice[2] describes accepted procedures for and factors that influence laboratory immersion corrosion tests, particularly mass loss tests. These factors include specimen preparation, apparatus, test conditions, methods of cleaning specimens, evaluation of results, and calculation and reporting of corrosion rates. This recommended practice also emphasizes the importance of recording all pertinent data and provides a checklist for reporting test data. Other ASTM procedures for laboratory corrosion tests are tabulated in the Appendix.

1.2 Corrosion testing by its very nature precludes complete standardization. This recommended practice, rather than a standardized procedure, is presented as a guide so that some of the pitfalls of such testing may be avoided.

1.3 Experience has shown that all metals and alloys do not respond alike to the many factors that affect corrosion and that "accelerated" corrosion tests give indicative results only, or may even be entirely misleading. It is impractical to propose an inflexible standard laboratory corrosion testing procedure for general use, except for material qualification tests where standardization is obviously required.

1.4 In designing any corrosion test, consideration must be given to the various factors discussed in this recommended practice, because these factors have been found to affect greatly the results obtained.

NOTE 1: Caution—In many cases the corrosion product on the reactive metals titanium and zirconium is a hard and tightly bonded oxide that defies removal by chemical or ordinary mechanical means. In many such cases, corrosion rates are established by weight gain rather than weight loss.

2. Applicable Documents

2.1 *ASTM Standards:*

A 262 Recommended Practices for Detecting Susceptibility to Intergranular Attack in Stainless Steels[3, 4]

E 8 Tension Testing of Metallic Materials[3]

G 1 Recommended Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens[4]

G 16 Recommended Practice for Applying Statistics to Analysis of Corrosion Data[4]

G 46 Recommended Practice for Examination and Evaluation of Pitting Corrosion[4]

3. Significance and Use

3.1 A significance and use statement is not applicable to this practice.

4. Interferences

4.1 The methods and procedures described herein represent the best current practices for conducting laboratory corrosion tests as devel-

[1] This recommended practice is under the jurisdiction of ASTM Committee G-1 on Corrosion of Metals and is the direct responsibility of Subcommittee G01.05 on Laboratory Corrosion Tests.

Current edition approved May 30, 1972. Published July 1972.

[2] This recommended practice is based upon NACE Standard TM-01-69, "Test Method-Laboratory Corrosion Testing of Metals for the Process Industries", with modifications to relate more directly to Recommended Practices G 1 and G 4 and Methods A 279.

[3] *Annual Book of ASTM Standards*, Part 3.

[4] *Annual Book of ASTM Standards*, Part 10.

oped by corrosion specialists in the process industries. For proper interpretation of the results obtained, the specific influence of certain variables must be considered. These include:

4.1.1 Metal specimens immersed in a specific hot liquid may not corrode at the same rate or in the same manner as in equipment where the metal acts as a heat transfer medium in heating or cooling the liquid. If the influence of heat transfer effects is specifically of interest, specialized procedures (in which the corrosion specimen serves as a heat transfer agent) must be employed (1).[5]

4.1.2 In laboratory tests, the velocity of the environment relative to the specimens will normally be determined by convection currents or the effects induced by aeration or boiling or both. If the specific effects of high velocity are to be studied, special techniques must be employed to transfer the environment through tubular specimens or to move it rapidly past the plane face of a corrosion coupon (2). Alternatively, the coupon may be rotated through the environment, although it is then difficult to evaluate the velocity quantitatively because of the stirring effects incurred.

4.1.3 The behavior of certain metals and alloys may be profoundly influenced by the presence of dissolved oxygen. If this is a factor to be considered in a specific test, the solution should be completely aerated or deaerated in accordance with 8.7.

4.1.4 In some cases, the rate of corrosion may be governed by other minor constituents in the solution, in which case they will have to be continually or intermittently replenished by changing the solution in the test.

4.1.5 Corrosion products may have undesirable effects on a chemical product. The amount of possible contamination can be estimated from the loss in mass of the specimen, with proper application of the expected relationships among (*1*) the area of corroding surface, (*2*) the mass of the chemical product handled, and (*3*) the duration of contact of a unit of mass of the chemical product with the corroding surface.

4.1.6 Corrosion products from the coupon may influence the corrosion rate of the metal itself or of different metals exposed at the same time. For example, the accumulation of cupric ions in the testing of copper alloys in intermediate strengths of sulfuric acid will accelerate the corrosion of copper alloys, as compared to the rates that would be obtained if the corrosion products were continually removed. Cupric ions may also exhibit a passivating effect upon stainless steel coupons exposed at the same time. In practice, only alloys of the same general type should be exposed in the testing apparatus.

4.1.7 Coupon corrosion testing is predominantly designed to investigate general corrosion. There are a number of other special types of phenomena of which one must be aware in the design and interpretation of corrosion tests.

4.1.7.1 Galvanic corrosion may be investigated by special devices which couple one coupon to another in electrical contact. The behavior of the specimens in this galvanic couple are compared with that of insulated specimens exposed on the same holder and the galvanic effects noted. It should be observed, however, that galvanic corrosion can be greatly affected by the area ratios of the respective metals, the distance between the metals and the resistivity of the electrolyte. The coupling of corrosion coupons then yields only qualitative results, as a particular coupon reflects only the relationship between these two metals at the particular area ratio involved.

4.1.7.2 Crevice corrosion or concentration cell corrosion may occur where the metal surface is partially blocked from the corroding liquid as under a spacer or supporting hook. It is necessary to evaluate this localized corrosion separately from the overall mass loss.

4.1.7.3 Selective corrosion at the grain boundaries (for example, intergranular corrosion of sensitized austenitic stainless steels) will not be readily observable in mass loss measurements unless the attack is severe enough to cause grain dropping, and often requires microscopic examination of the coupons after exposure.

4.1.7.4 Dealloying or "parting" corrosion is a condition in which one constituent is selectively removed from an alloy, as in the dezincification of brass or the graphitization of cast iron. Close attention and a more sophisticated evaluation than a simple mass loss measurement is required to detect this phenomenon.

4.1.7.5 Certain metals and alloys are subject to a highly localized type of attack called pitting

[5] The boldface numbers in parentheses refer to the list of references at the end of this recommended practice.

corrosion. This cannot b
loss alone. The reporting
rosion is discussed below.
ciated that pitting is a st
and that the incidence of p
related to the area of m
ample, a small coupon is
pitting as a large one and
the phenomenon altoge
testing of certain alloys,
300 series stainless steels
nated environments.

4.1.7.6 All metals and
stress corrosion cracking
stances. This cracking oc
of applied or residual ten
or may not be visible t
upon casual inspection. A
amination may confirm th
corrosion cracking. It is im
this usually occurs with n
mass of the test coupon.
fractory metals are an exc
vations. Generally, if cra
the coupon, it can be tal
tion of susceptibility, wh
this phenomenon simply
occur under the duratio
tions of the test. Separ
niques are employed for th
of the susceptibility of m
stress corrosion cracking

5. Apparatus

5.1 A versatile and c
should be used consisting
suitable size (usually 50
condenser with atmosph
controlling atmosphere or
well and temperature-regu
ing device (mantle, hot
specimen support syste
quired, the apparatus can
a suitable stirring mech
netic stirrer. A typical r
type test is shown in Fi

5.2 The suggested co
ified, simplified or mod
fit the needs of a partic
suggested apparatus is
is limited only by the j
of the investigator.

5.2.1 A glass reactio

corrosion. This cannot be evaluated by mass loss alone. The reporting of nonuniform corrosion is discussed below. It should be appreciated that pitting is a statistical phenomenon and that the incidence of pitting may be directly related to the area of metal exposed. For example, a small coupon is not as prone to exhibit pitting as a large one and it is possible to miss the phenomenon altogether in the corrosion testing of certain alloys, such as the AISI Type 300 series stainless steels in chloride contaminated environments.

4.1.7.6 All metals and alloys are subject to stress corrosion cracking under some circumstances. This cracking occurs under conditions of applied or residual tensile stress, and it may or may not be visible to the unaided eye or upon casual inspection. A metallographic examination may confirm the presence of stress corrosion cracking. It is imperative to note that this usually occurs with no significant loss in mass of the test coupon, although certain refractory metals are an exception to these observations. Generally, if cracking is observed on the coupon, it can be taken as positive indication of susceptibility, whereas failure to effect this phenomenon simply means that it did not occur under the duration and specific conditions of the test. Separate and special techniques are employed for the specific evaluation of the susceptibility of metals and alloys to stress corrosion cracking (see Ref. (3)).

5. Apparatus

5.1 A versatile and convenient apparatus should be used, consisting of a kettle or flask of suitable size (usually 500 to 5000 ml), a reflux condenser with atmospheric seal, a sparger for controlling atmosphere or aeration, a thermowell and temperature-regulating device, a heating device (mantle, hot plate, or bath), and a specimen support system. If agitation is required, the apparatus can be modified to accept a suitable stirring mechanism, such as a magnetic stirrer. A typical resin flask setup for this type test is shown in Fig. 1.

5.2 The suggested components can be modified, simplified, or made more sophisticated to fit the needs of a particular investigation. The suggested apparatus is basic and the apparatus is limited only by the judgment and ingenuity of the investigator.

5.2.1 A glass reaction kettle can be used where the configuration and size of the specimen will permit entry through the narrow kettle neck (for example, 45/50 ground-glass joint). For solutions corrosive to glass, suitable metallic or plastic kettles may be employed.

5.2.2 In some cases a wide-mouth jar with a suitable closure is sufficient when simple immersion tests at ambient temperatures are to be investigated.

5.2.3 Open-beaker tests should not be used because of evaporation and contamination.

5.2.4 In more complex tests, provisions might be needed for continuous flow or replenishment of the corrosive liquid, while simultaneously maintaining a controlled atmosphere.

6. Sampling

6.1 The bulk sampling of products is outside the scope of this practice.

7. Test Specimen

7.1 In laboratory tests, uniform corrosion rates of duplicate specimens are usually within ± 10 percent under the same test conditions. Occasional exceptions, in which a large difference is observed, can occur under conditions of borderline passivity of metals or alloys that depend on a passive film for their resistance to corrosion. Therefore, at least duplicate specimens should normally be exposed in each test.

7.2 If the effects of corrosion are to be determined by changes in mechanical properties, untested duplicate specimens should be preserved in a noncorrosive environment at the same temperature as the test environment for comparison with the corroded specimens. The mechanical property commonly used for comparison is the tensile strength. Measurement of percent elongation is a useful index of embrittlement. The procedures for determining these values are shown in detail in Methods E 8.

7.3 The size and shape of specimens will vary with the purpose of the test, nature of the materials, and apparatus used. A large surface-to-mass ratio and a small ratio of edge area to total area are desirable. These ratios can be achieved through the use of square or circular specimens of minimum thickness. Masking may also be used to achieve the desired area ratios but may cause crevice corrosion problems. Circular specimens should preferably be cut from sheet and not bar stock, to minimize the exposed end grain. Special coupons (for

example, sections of welded tubing) may be employed for specific purposes.

7.3.1 A circular specimen of about 38-mm (1.5-in.) diameter is a convenient shape for laboratory corrosion tests. With a thickness of approximately 3 mm (0.125-in.) and an 8-mm (5/16-in.) or 11-mm (7/16-in.) diameter hole for mounting, these specimens will readily pass through a 45/50 ground-glass joint of a distillation kettle. The total surface area of a circular specimen is given by the following equation:

$$A = \pi/2(D^2 - d^2) + t\pi D + t\pi d$$

where:

t = thickness,
D = diameter of the specimen, and
d = diameter of the mounting hole.

7.3.1.2 If the hole is completely covered by the mounting support, the last term ($t\pi d$) in the equation is omitted.

7.3.2 Strip coupons 50 by 25 by 1.6 or 3 mm (2 by 1 by 1/16 or 1/8 in.) may be preferred as corrosion specimens particularly if interface or liquid line effects are to be studied by the laboratory tests (see Fig. 1), but the evaluation of such specific effects are beyond the scope of this recommended practice.

7.3.3 All specimens should be measured carefully to permit accurate calculation of the exposed areas. A geometric area calculation accurate to ±1 percent is usually adequate.

7.4 More uniform results may be expected if a substantial layer of metal is removed from the specimens to eliminate variations in condition of the original metallic surface. This can be done by chemical treatment (pickling), electrolytic removal, or by grinding with a coarse abrasive paper or cloth such as No. 50, using care not to work harden the surface (see 5.7). At least 0.0025 mm (0.0001 in.) or 1.55 to 2.33 mg/cm.^{2} (10 to 15 mg/in.^{2}) should be removed. (If clad alloy specimens are to be used, special attention must be given to ensure that excessive metal is not removed.) After final preparation of the specimen surface, the specimens should be stored in a desiccator until exposure, if they are not used immediately. In special cases (for example, for aluminum and certain copper alloys), a minimum of 24 h storage in a desiccator is recommended. The choice of a specific treatment must be considered on the basis of the alloy to be tested and the reasons for testing. A commercial surface may sometimes yield the most significant results. Too much surface preparation may remove segregated elements, surface contamination, etc., and therefore not be representative.

7.5 Exposure of sheared edges should be avoided unless the purpose of the test is to study effects of the shearing operation. It may be desirable to test a surface representative of the material and metallurgical conditions used in practice.

7.6 The specimen can be stamped with an appropriate identifying mark. If metallic contamination of the stamped area may influence the corrosion behavior, chemical cleaning must be employed to remove any traces of foreign particles from the surface of the coupon (for example, by immersion of stainless steel coupons in dilute nitric acid following stamping with steel dies).

7.6.1 The stamp, besides identifying the specimen, introduces stresses and cold work in the specimen that could be responsible for localized corrosion or stress-corrosion cracking, or both.

7.6.2 Stress-corrosion cracking at the identifying mark is a positive indication of susceptibility to such corrosion. However, the absence of cracking should not be interpreted as indicating resistance (see 4.1.7.6).

7.7 Final surface treatment of the specimens should include finishing with No. 120 abrasive paper or cloth or the equivalent, unless the surface is to be used in the mill finished condition. This resurfacing may cause some surface work hardening, to an extent which will be determined by the vigor of the surfacing operation, but is not ordinarily significant. The surface finish to be encountered in service may be more appropriate for some testing.

7.7.1 Coupons of different alloy compositions should never be ground on the same cloth.

7.7.2 Wet grinding should be used on alloys which work harden quickly, such as the austenitic stainless steels.

7.8 The specimens should be finally degreased by scrubbing with bleach-free scouring powder, followed by thorough rinsing in water and in a suitable solvent (such as acetone, methanol, or a mixture of 50 percent methanol and 50 percent ether), and air dried. For relatively soft metals (such as aluminum, magnesium, and copper), scrubbing with abrasive powder is not always needed and can mar the

surface of the specimen. Prope
cedures are an acceptable alte
towels for drying may intr
through contamination of the
grease or lint.

7.9 The dried specimens sh
on an analytical balance to a
least ±0.5 mg. If cleaning depo
scouring powder) remain or
dryness is suspected, then
drying is performed until a c
attained.

7.10 The method of speci
should be described when rep
to facilitate interpretation of
sons.

7.11 The use of welded sp
times desirable, because son
cathodic or anodic to the pare
affect the corrosion rate.

7.11.1 The heat-affected z
portance but should be studi
cause welds on coupons do no
duce heat input or size effect
ments.

7.11.2 Corrosion of a weld
reported by description and t
ments rather than a mils per
the attack is normally localiz
sentative of the entire surfac

7.11.3 A complete discus
testing of welded coupons o
treatment on the corrosion re
is not within the scope of
practice.

8. Test Conditions

8.1 Selection of the cond
tory corrosion test will be
purpose of the test.

8.1.1 If the test is to b
selection of a material for a
the limits of the controllin
must be determined. These
ygen concentration, tempe
pH value, composition, &
characteristics of the soluti

8.2 An effort should be
all pertinent service condit
test.

8.3 It is important that
controlled throughout the
sure reproducible results.

surface of the specimen. Proper ultrasonic procedures are an acceptable alternate. The use of towels for drying may introduce an error through contamination of the specimens with grease or lint.

7.9 The dried specimens should be weighed on an analytical balance to an accuracy of at least ±0.5 mg. If cleaning deposits (for example, scouring powder) remain or lack of complete dryness is suspected, then recleaning and drying is performed until a constant weight is attained.

7.10 The method of specimen preparation should be described when reporting test results, to facilitate interpretation of data by other persons.

7.11 The use of welded specimens is sometimes desirable, because some welds may be cathodic or anodic to the parent metal and may affect the corrosion rate.

7.11.1 The heat-affected zone is also of importance but should be studied separately, because welds on coupons do not faithfully reproduce heat input or size effects of full-size weldments.

7.11.2 Corrosion of a welded coupon is best reported by description and thickness measurements rather than a mils per year rate, because the attack is normally localized and not representative of the entire surface.

7.11.3 A complete discussion of corrosion testing of welded coupons or the effect of heat treatment on the corrosion resistance of a metal is not within the scope of this recommended practice.

8. Test Conditions

8.1 Selection of the conditions for a laboratory corrosion test will be determined by the purpose of the test.

8.1.1 If the test is to be a guide for the selection of a material for a particular purpose, the limits of the controlling factors in service must be determined. These factors include oxygen concentration, temperature, rate of flow, pH value, composition, and other important characteristics of the solution.

8.2 An effort should be made to duplicate all pertinent service conditions in the corrosion test.

8.3 It is important that test conditions be controlled throughout the test in order to ensure reproducible results.

8.4 The spread in corrosion rate values for duplicate specimens in a given test probably should not exceed ±10 percent of the average when the attack is uniform.

8.5 *Composition of Solution:*

8.5.1 Test solutions should be prepared accurately from chemicals conforming to the Specifications of the Committee on Analytical Reagents of the American Chemical Society[6] and distilled water, except in those cases where naturally occurring solutions or those taken directly from some plant process are used.

8.5.2 The composition of the test solutions should be controlled to the fullest extent possible and should be described as completely and as accurately as possible when the results are reported.

8.5.2.1 Minor constituents should not be overlooked because they often affect corrosion rates.

8.5.2.2 Chemical content should be reported as percentage by weight of the solutions. Molarity and normality are also helpful in defining the concentration of chemicals in some test solutions.

8.5.3 If problems are suspected, the composition of the test solutions should be checked by analysis at the end of the test to determine the extent of change in composition, such as might result from evaporation or depletion.

8.5.4 Evaporation losses may be controlled by a constant level device or by frequent addition of appropriate solution to maintain the original volume within ±1 percent. Preferably, the use of a reflux condenser ordinarily precludes the necessity of adding to the original kettle charge.

8.5.5 In some cases, composition of the test solution may change as a result of catalytic decomposition or by reaction with the test coupons. These changes should be determined if possible. Where required, the exhausted constituents should be added or a fresh solution provided during the course of the test.

8.5.6 When possible, only one type of metal should be exposed in a given test (see 4.1.6).

8.6 *Temperature of Solution:*

---

[6] "Reagent Chemicals, American Chemical Society Specifications," Am. Chemical Soc., Washington, D. C. For suggestions on the testing of reagents not listed by the American Chemical Society, see "Reagent Chemicals and Standards," by Joseph Rosin, D. Van Nostrand Co., Inc., New York, N. Y., and the "United States Pharmacopeia."

8.6.1 Temperature of the corroding solution should be controlled within ±1 C (±1.8 F) and must be stated in the report of test results.

8.6.2 If no specific temperature, such as boiling point, is required or if a temperature range is to be investigated, the selected temperatures used in the test, and their respective duration, must be reported.

8.6.3 For tests at ambient temperature, the tests should be conducted at the highest temperature anticipated for stagnant storage in summer months. This temperature may be as high as from 40 to 45 C (104 to 113 F) in some areas. The variation in temperature should be reported also (for example, 40 ± 2 C).

8.7 *Aeration of Solution:*

8.7.1 Unless specified, the solution should not be aerated. Most tests related to process equipment should be run with the natural atmosphere inherent in the process, such as the vapors of the boiling liquid.

8.7.2 If aeration is employed, the specimen should not be located in the direct air stream from the sparger. Extraneous effects can be encountered if the air stream impinges on the specimens.

8.7.3 If exclusion of dissolved oxygen is necessary, specific techniques are required, such as prior heating of the solution and sparging with an inert gas (usually nitrogen). A liquid atmospheric seal is required on the test vessel to prevent further contamination.

8.7.4 If oxygen saturation of the test solution is desired, this can best be achieved by sparging with oxygen. For other degrees of aeration, the solution should be sparaged with air or synthetic mixtures of air or oxygen with an inert gas. Oxygen saturation is a function of the partial pressure of oxygen in the gas.

8.8 *Solution Velocity:*

8.8.1 The effect of velocity is not usually determined in normal laboratory tests, although specific tests have been designed for this purpose.

8.8.2 Tests at the boiling point should be conducted with the minimum possible heat input, and boiling chips should be used to avoid excessive turbulence and bubble impingement.

8.8.3 In tests below the boiling point, thermal convection generally is the only source of liquid velocity.

8.8.4 In test solutions with high viscosity, supplemental controlled stirring with a magnetic stirrer is recommended.

8.9 *Volume of Test Solution:*

8.9.1 The volume of the test solution should be large enough to avoid any appreciable change in its corrosivity during the test, either through exhaustion of corrosive constituents or by accumulation of corrosion products that might affect further corrosion.

8.9.2 Two examples of a recommended minimum "solution volume-to-specimen area" ratio are 20 ml/cm^2 (125 ml/in.^{2}) of specimen surface (Recommended Practice A 262), and 40 ml/cm^2 (250 ml/in.^{2}).

8.9.3 When the test objective is to determine the effect of a metal or alloy on the characteristics of the test solution (for example, to determine the effects of metals on dyes), it is desirable to reproduce the ratio of solution volume to exposed metal surface that exists in practice. The actual time of contact of the metal with the solution must also be taken into account. Any necessary distortion of the test conditions must be considered when interpreting the results.

8.10 *Method of Supporting Specimens:*

8.10.1 The supporting device and container should not be affected by or cause contamination of the test solution.

8.10.2 The method of supporting specimens will vary with the apparatus used for conducting the test, but should be designed to insulate the specimens from each other physically and electrically and to insulate the specimens from any metallic container or supporting device used within the apparatus.

8.10.3 Shape and form of the specimen support should assure free contact of the specimen with the corroding solution, the liquid line or the vapor phase as shown in Fig. 1. If clad alloys are exposed, special procedures will be required to ensure that only the cladding is exposed, unless the purpose is to test the ability of the cladding to protect cut edges in the test solution.

8.10.4 Some common supports are glass or ceramic rods, glass saddles, glass hooks, fluorocarbon plastic strings, and various insulated or coated metallic supports.

8.11 *Duration of Test:*

8.11.1 Although duration of any test will be determined by the nature and purpose of the test, an excellent procedure for evaluating the effect of time on corrosion of the metal and also on the corrosiveness of the environment in

laboratory tests has been p
and Treseder (4). This te
"planned interval test," a
evaluation of results are g
procedures that require
corrosion products betw
will not measure accurate
of corrosion with time.

8.11.2 Materials that
rosion generally do not o
tests to obtain accurate
ever, there are cases wh
not valid. For example, h
acid corrodes at an extre
while building a protecti
decrease considerably so
is negligible. The phen
protective film is obser
sion-resistant materials. T
on such materials woul
rosion rate and be com

8.11.3 Short-time test
ing results on alloys th
such as stainless steels. W
tions, a prolonged test n
breakdown of the passi
more rapid attack. Co
long periods are cons
than those conducted f
statement must be q
corrosion should not p
the original specimen
is drastically reduced o
perforated.

8.11.4 If anticipate
moderate or low, the
the suggested test dur

Hours = 2000/(c

where mpy = mils p
Note 2 for conversion t

8.11.4.1 *Example*—
is 10 mpy, the test sh
h.

8.11.4.2 This meth
ration is useful only a
a test has been ma
desirable to repeat th
The most common te
h (2 to 7 days).

8.11.5 In some cas
know the degree of co
the products of corr

laboratory tests has been presented by Wachter and Treseder (4). This technique is called the "planned interval test," and the procedure and evaluation of results are given in Table 1. Other procedures that require the removal of solid corrosion products between exposure periods will not measure accurately the normal changes of corrosion with time.

8.11.2 Materials that experience severe corrosion generally do not ordinarily need lengthy tests to obtain accurate corrosion rates. However, there are cases where this assumption is not valid. For example, lead exposed to sulfuric acid corrodes at an extremely high rate at first, while building a protective film; then the rates decrease considerably so that further corrosion is negligible. The phenomenon of forming a protective film is observed with many corrosion-resistant materials. Therefore, short tests on such materials would indicate a high corrosion rate and be completely misleading.

8.11.3 Short-time tests also can give misleading results on alloys that form passive films, such as stainless steels. With borderline conditions, a prolonged test may be needed to permit breakdown of the passive film and subsequent more rapid attack. Consequently, tests run for long periods are considerably more realistic than those conducted for short durations. This statement must be qualified by stating that corrosion should not proceed to the point where the original specimen size or the exposed area is drastically reduced or where the metal is perforated.

8.11.4 If anticipated corrosion rates are moderate or low, the following equation gives the suggested test duration:

$$\text{Hours} = 2000/(\text{corrosion rate in mpy})$$

where mpy = mils per year (see 11.2.1 and Note 2 for conversion to other units).

8.11.4.1 *Example*—Where the corrosion rate is 10 mpy, the test should run for at least 200 h.

8.11.4.2 This method of estimating test duration is useful only as an aid in deciding, after a test has been made, whether or not it is desirable to repeat the test for a longer period. The most common testing periods are 48 to 168 h (2 to 7 days).

8.11.5 In some cases, it may be necessary to know the degree of contamination caused by the products of corrosion. This can be accomplished by analysis of the solution after corrosion has occurred. The corrosion rate can be calculated from the concentration of the matrix metal found in the solution and it can be compared to that determined from the mass loss of the specimens. However, some of the corrosion products usually adhere to the specimen as a scale and the corrosion rate calculated from the metal content in the solution is not always correct.

8.12 The design of corrosion testing programs is further discussed in Recommended Practice G 16.

9. Methods of Cleaning Specimens after Test

9.1 Before specimens are cleaned, their appearance should be observed and recorded. Location of deposits, variations in types of deposits, or variations in corrosion products are extremely important in evaluating localized corrosion, such as pitting and concentration cell attack.

9.2 Cleaning specimens after the test is a vital step in the corrosion test procedure and if not done properly, can cause misleading results.

9.2.1 Generally, the cleaning procedure should remove all corrosion products from specimens with a minimum removal of sound metal.

9.2.2 Set rules cannot be applied to specimen cleaning, because procedures will vary, depending on the type of metal being cleaned and on the degree of adherence of corrosion products.

9.3 Cleaning methods can be divided into three general categories: mechanical, chemical, and electrolytic.

9.3.1 Mechanical cleaning includes scrubbing, scraping, brushing, mechanical shocking, and ultrasonic procedures. Scrubbing with a bristle brush and mild abrasive is the most popular of these methods. The others are used principally as a supplement to remove heavily encrusted corrosion products before scrubbing. Care should be used to avoid the removal of sound metal.

9.3.2 Chemical cleaning implies the removal of material from the surface of the specimen by dissolution in an appropriate chemical solution. Solvents such as acetone, carbon tetrachloride, and alcohol are used to remove oil, grease, or resin and are usually applied prior to other methods of cleaning. Chemicals are chosen for

application to a specific material. Methods for chemical cleaning after testing of specific metals and alloys are described in Recommended Practice G 1.

9.3.3 Electrolytic cleaning should be preceded by scrubbing to remove loosely adhering corrosion products. A method of electrolytic cleaning is described in Recommended Practice G 1.

9.3.3.1 *Precautions must be taken to ensure* good electrical contact with the specimen, to avoid contamination of the solution with easily reducible metal ions, and to ensure that inhibitor decomposition has not occurred.

9.4 Whatever treatment is used to clean specimens after a corrosion test, its effect in removing metal should be determined and the mass loss should be corrected accordingly. A "blank" specimen should be weighed before and after exposure to the cleaning procedure to establish this mass loss (see also Recommended Practice G 1). Careful observation is needed to *ensure that pitting does not occur during cleaning.*

9.4.1 Following removal of all scale, the specimen should be treated as discussed in 5.8.

9.4.2 The description of the cleaning method should be included with the data reported.

10. Interpretation of Results

10.1 After corroded specimens have been cleaned, they should be reweighed with an accuracy corresponding to that of the original weighing. The mass loss during the test period can be used as the principal measure of corrosion.

10.2 After the specimens have been reweighed, they should be examined carefully for the presence of any pits. If there are any pits, the average and maximum depths of pits are determined with a pit gage or a calibrated *microscope which can be focused first on the* edges and then on the bottoms of the pits. The degree of lateral spreading of pits may also be noted.

10.2.1 Pit depths should be reported in millimeters or thousandths of an inch for the test period and not interpolated or extrapolated to millimeters per year, thousandths of an inch per year, or any other arbitrary period because rarely, if ever, is the rate of initiation or propagation of pits uniform.

10.2.2 The size, shape, and distribution of pits should be noted. A distinction should be made between those occurring underneath the supporting devices (concentration cells) and those on the surfaces that were freely exposed to the test solution (see Recommended Practice G 46).

10.3 If the material being tested is suspected of being subject to dealloying forms of corrosion such as dezincification or to intergranular attack, a cross section of the specimen should be microscopically examined for evidence of such attack.

10.4 The specimen may be subjected to simple bending tests to determine whether any embrittlement attack has occurred.

10.5 It may be desirable to make quantitative mechanical tests, comparing the exposed specimens with uncorroded specimens reserved for the purpose, as described in 7.2.

11. Calculating Corrosion Rates

11.1 Calculating corrosion rates requires several pieces of information and several assumptions:

11.1.1 The use of corrosion rates implies that all mass loss has been due to general corrosion and not to localized corrosion, such as pitting or intergranular corrosion of sensitized areas on welded coupons. Localized corrosion is reported separately.

11.1.2 The use of corrosion rates also implies that the material has not been internally attacked as by dezincification or intergranular corrosion.

11.1.3 Internal attack can be expressed as a corrosion rate if desired. However, the calculations must not be based on weight loss (except in qualification tests such as Recommended Practice A 262), which is usually small but on microsections which show depth of attack.

11.2 Assuming that localized or internal corrosion is not present or is recorded separately in the report, the average corrosion rate can be calculated by the following equation:

$$\text{Corrosion rate} = (K \times W)/(A \times T \times D)$$

where:

K = a constant (see below)
T = time of exposure in hours to the nearest 0.01 h,
A = area in cm² to the nearest 0.01 cm²,
W = mass loss in g, to nearest 1 mg (corrected for any loss during cleaning (see 9.4)),

and
D = density in g/cm³, (see Appen
Recommended Practice G 1).

11.2.1 Many different units are
press corrosion rates. Using the abo
T, A, W, and D, the corrosion r
calculated in a variety of units with
ing appropriate value of K:

Corrosion Rate Units Desired	Co C
mils per year (mpy)	3.4
inches per year (ipy)	3.4
inches per month (ipm)	2.8
millimetres per year (mm/y)	8.7
micrometres per year (μm/y)	8.7
picometres per second (pm/s)	2.7
grams per square metre per hour (g/m²·h)	1.0
milligrams per square decimetre per day (mdd)	2.4
micrograms per square metre per second (μg/m²·s)	2.7

[A] Density is not needed to calculate the
these units. The density in the constant K
density in the corrosion rate equation.

NOTE 2—If desired, these constant
used to convert corrosion rates from
to another. To convert a corrosion ra
a rate of units Y, multiply by K_Y/K_X

$$15 \text{ mpy} = 15 \times [(2.78 \times 10^6)/(3.45$$
$$= 12.1 \text{ pm/s}$$

12. Reporting the Data

12.1 The importance of report
completely as possible cannot b
sized.

12.2 Expansion of the testing
future or correlating the results
other investigators will be possi
pertinent information is properly

12.3 The following checklist
mended guide for reporting all
formation and data.

12.3.1 Corrosive media and
(any changes during test).

(1) Fisher, A. O. and Whitney, Jr
tory Methods for Determining
Under Heat Flux Conditions
15, No. 5, May 1959, p. 257t.
(2) U.S. Patent 3,228,236, 1969

and

D = density in g/cm³, (see Appendix X1 of Recommended Practice G 1).

11.2.1 Many different units are used to express corrosion rates. Using the above units for T, A, W, and D, the corrosion rate can be calculated in a variety of units with the following appropriate value of K:

Corrosion Rate Units Desired	Constant (K) in Corrosion Rate Equation
mils per year (mpy)	3.45×10^6
inches per year (ipy)	3.45×10^3
inches per month (ipm)	2.87×10^2
millimetres per year (mm/y)	8.76×10^4
micrometres per year (μm/y)	8.76×10^7
picometres per second (pm/s)	2.78×10^6
grams per square metre per hour (g/m²·h)	$1.00 \times 10^4 \times D$[a]
milligrams per square decimetre per day (mdd)	$2.40 \times 10^6 \times D$[a]
micrograms per square metre per second (μg/m²·s)	$2.78 \times 10^6 \times D$[a]

[a] Density is not needed to calculate the corrosion rate in these units. The density in the constant K cancels out the density in the corrosion rate equation.

NOTE 2—If desired, these constants may also be used to convert corrosion rates from one set of units to another. To convert a corrosion rate in units X to a rate of units Y, multiply by K_Y/K_X for example:

$$15 \text{ mpy} = 15 \times \{(2.78 \times 10^6)/(3.45 \times 10^6)\} \text{pm/s} = 12.1 \text{ pm/s}$$

12. Reporting the Data

12.1 The importance of reporting all data as completely as possible cannot be overemphasized.

12.2 Expansion of the testing program in the future or correlating the results with tests of other investigators will be possible only if all pertinent information is properly recorded.

12.3 The following checklist is a recommended guide for reporting all important information and data.

12.3.1 Corrosive media and concentration (any changes during test).

12.3.2 Volume of test solution.

12.3.3 Temperature (maximum, minimum, average).

12.3.4 Aeration (describe conditions or technique).

12.3.5 Agitation (describe conditions or technique).

12.3.6 Type of apparatus used for test.

12.3.7 Duration of each test.

12.3.8 Chemical composition or trade name of metals tested.

12.3.9 Form and metallurgical conditions of specimens.

12.3.10 Exact size, shape, and area of specimens.

12.3.11 Treatment used to prepare specimens for test.

12.3.12 Number of specimens of each material tested, and whether specimens were tested separately or which specimens tested in the same container.

12.3.13 Method used to clean specimens after exposure and the extent of any error expected by this treatment.

12.3.14 Initial and final masses and actual mass losses for each specimen.

12.3.15 Evaluation of attack if other than general, such as crevice corrosion under support rod, pit depth and distribution, and results of microscopical examination or bend tests.

12.3.16 Corrosion rates for each specimen.

12.4 Minor occurrences or deviations from the proposed test program often can have significant effects and should be reported if known.

12.5 Statistics can be a valuable tool for analyzing the results from test programs designed to generate adequate data. Excellent references for the use of statistics in corrosion studies include Ref. (5) through (7) and in Recommended Practice G 16.

13. Precision and Accuracy

13.1 A precision and accuracy statement cannot be made for this standard.

REFERENCES

(1) Fisher, A. O. and Whitney, Jr., F. L., "Laboratory Methods for Determining Corrosion Rates Under Heat Flux Conditions," *Corrosion*, Vol 15, No. 5, May 1959, p. 257t.

(2) U.S. Patent 3,228,236, 1969.

(3) "Stress Corrosion Test Environments and Test Durations," *Symposium on Stress Corrosion Testing, ASTM STP 425*, ASTTA, Am. Soc. Testing Mats, 1967.

(4) Wachter, A. and Treseder, R. S., "Corrosion

Testing Evaluation of Metals for Process Equipment," *Chemical Engineering Progress*, CEPRA, Vol 43, June 1947, pp. 315–326.

(5) Mickley, H. S., Sherwood, T. K., and Reed, C. E. editors, *Applied Mathematics in Chemical Engineering* 2nd Edition, McGraw-Hill Book Co., New York, N. Y. 1957.

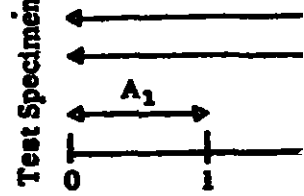
(6) Youden, W. J., *Experimentation and Measurement*, National Science Teachers Assn., Washington, D. C., 1962.

(7) Booth, F. F. and Tucker, G. E. G., "Statistical Distribution of Endurance in Electrochemical Stress-Corrosion Tests," *Corrosion*, Vol 21, No. 5, May 1965, pp. 173–177.

(8) Champion, F. A., *Corrosion Testing Procedures*, 2nd Edition, John Wiley & Sons, Inc., New York, N. Y., 1965.

T

(Reprinted by pe



Identical specimens all placed in the
1. Letters, A_0, A_1, A_{i+1}, B, represent corr
from A_{i+1}.

Occurrences D
Liquid corrosiveness
Metal corrodibility

Liquid corrosiveness
1. unchanged
2. unchanged
3. unchanged
4. decreased
5. decreased
6. decreased
7. increased
8. increased
9. increased

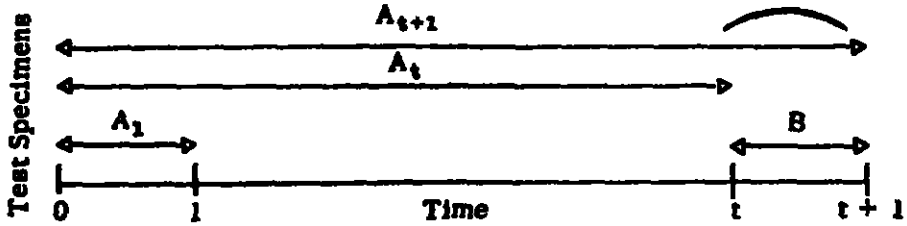
Example; Conditions: Duplicate strip
percent $SbCl_3$ mixture through which d

	Int d
A_1	0–1
A_i	0–3
A_{i+1}	0–4
B	3–4
A_2	calc

Example: $A_2 < B < A_1$
$0.05 < 0.11 < 1.69$
Therefore, liquid markedly decreased in
indicated.

TABLE 1 Planned Interval Corrosion Test

(Reprinted by permission from Chemical Engineering Progress, June 1947.)



Identical specimens all placed in the same corrosive fluid. Imposed conditions of the test kept constant for entire time $t + 1$. Letters, A_1, A_t, A_{t+1}, B, represent corrosion damage experienced by each test specimen. A_2 is calculated by subtracting A_t from A_{t+1}.

Occurrences During Corrosion Test		Criteria
Liquid corrosiveness	unchanged	$A_1 = B$
	decreased	$B < A_1$
	increased	$A_1 < B$
Metal corrodibility	unchanged	$A_2 = B$
	decreased	$A_2 < B$
	increased	$B < A_2$

Combinations of Situations

Liquid corrosiveness	Metal corrodibility	Criteria
1. unchanged	unchanged	$A_1 = A_2 = B$
2. unchanged	decreased	$A_2 < A_1 = B$
3. unchanged	increased	$A_1 = B < A_2$
4. decreased	unchanged	$A_2 = B < A_1$
5. decreased	decreased	$A_2 < B < A_1$
6. decreased	increased	$A_1 > B < A_2$
7. increased	unchanged	$A_1 < A_2 = B$
8. increased	decreased	$A_1 < B > A_2$
9. increased	increased	$A_1 < B < A_2$

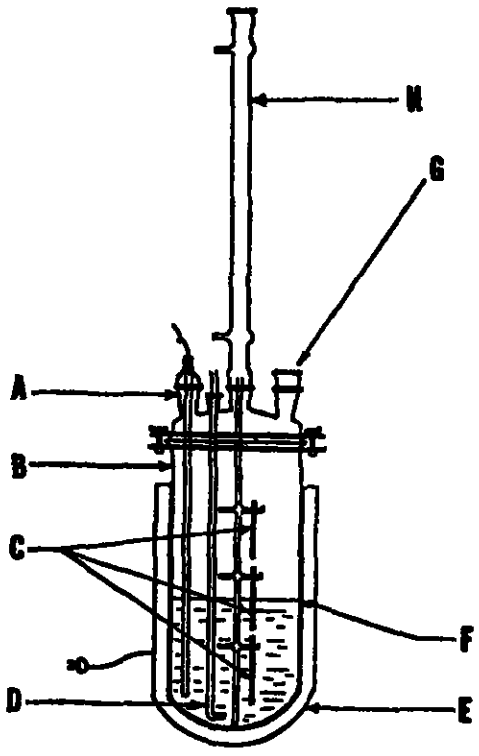
Example: Conditions: Duplicate strips of low-carbon steel, each ¾ by 3 in., immersed in 200 ml of 10 percent $AlCl_3$-90 percent $SbCl_3$ mixture through which dried HCl gas was slowly bubbled at atmospheric pressure. Temperature 90 C.

	Interval, days	Mass Loss, mg	Penetration, mils	Apparent Corrosion Rate, mpy
A_1	0-1	1080	1.69	620
A_t	0-3	1430	2.24	270
A_{t+1}	0-4	1460	2.29	210
B	3-4	70	0.11	40
A_2	calc. 3-4	30	0.05	18

Example: $A_2 < B < A_1$

$0.05 < 0.11 < 1.69$

Therefore, liquid markedly decreased in corrosiveness during test, and formation of partially protective scale on the steel was indicated.



NOTE—The flask can be used as a versatile and convenient apparatus to conduct simple immersion tests. Configuration of top to flask is such that more sophisticated apparatus can be added as required by the specific test being conducted. *A* = thermowell, *B* = resin flask, *C* = specimens hung on supporting device, *D* = air inlet, *E* = heating mantle, *F* = liquid interface, *G* = opening in flask for additional apparatus that may be required, and *H* = reflux condenser.

FIG. 1 Typical Resin Flask.

APPENDIX

X1. LISTING OF ASTM LABORATORY CORROSION TESTS

A 262 Recommended Practices for Detecting Susceptibility to Intergranular Attack in Stainless Steels[4,6]

B 117 Salt Spray (Fog) Testing[6,7,8]

B 287 Acetic Acid-Salt Spray (Fog) Testing[6,7,8]

B 368 Copper-Accelerated Acetic Acid-Salt Spray (Fog) Testing (CASS Test)[7,8]

B 380 Corrosion Testing of Decorative Chromium Plating by the Corrodkote Procedure[7]

D 2251 Test for Metal Corrosion by Halogenated Organic Solvents and Their Admixtures[9]

G 2 Recommended Practice for Aqueous Corrosion Testing of Samples of Zirconium and Zirconium Alloys[4]

G 5 Recommended Practice for Standard Reference Method for Making Potentiostatic and Potentiodynamic Anodic Polarization Measurements[4]

[7] *Annual Book of ASTM Standards*, Part 9.
[8] *Annual Book of ASTM Standards*, Part 27.
[9] *Annual Book of ASTM Standards*, Part 30.

The American Society for Testing and Materials takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 1916 Race St., Philadelphia, Pa. 19103, which will schedule a further hearing regarding your comments. Failing satisfaction there, you may appeal to the ASTM Board of Directors.

AMERICAN NATIONAL STANDARD

Standard Metho
VIBRATORY C

This standard is issued under the fixed
year of original adoption or, in the case of
reapproval.

Cavitation erosion
modern high-speed
propellers, hydrofoil
Cavitation erosion is
guiding high speed fl
Ever since Gaines
vibrating piston, thi
screening materials.
tee on Cavitation re
art then existent (2)
has taken place. Re
initiated a round-r
specifications and r
ASTM round-robin
Those who are in
ters including the
standard procedure
materials. Adheren
tion of the test re
rational specificatio

1. Scope

1.1 This method covers
of rate of cavitation erosion
ferent materials. It is based
of cavitation bubbles that c
of a test specimen vibrating
in the test liquid under sp
tions. This method may be
the relative resistance of di
cavitation erosion. Some
used this method as a scree
impingement erosion in ser

2. Applicable Document

2.1 *ASTM Standard*:
D 1193 Specification fo

10. Annual Book of ASTM Standards, "Standard Test Method for Resistance of Plastics to Chemical Reagents," pt. 35, D-543-67, American Society for Testing and Materials, Philadelphia, Pennsylvania, 1981, pg. 191-197

Standard Test Method for RESISTANCE OF PLASTICS TO CHEMICAL REAGENTS[1]

This standard is issued only under the fixed designation D 543, the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

This method has been approved for use by agencies of the Department of Defense and for listing in the DoD Index of Specifications and Standards.

1. Scope

1.1 This method covers the testing of all plastic materials, including cast, hot-molded, cold-molded, laminated resinous products, and sheet materials, for resistance to chemical reagents (Note 2). This method includes provisions for reporting changes in weight, dimensions, appearance, and strength properties (Note 3). Standard reagents are specified to establish results on a comparable basis. Provisions are made for various exposure times and exposure to reagents at elevated temperatures.

NOTE 1 – The values stated in SI units are to be regarded as the standard.

NOTE 2 – The resistance of plastic films to extraction by chemicals shall be determined in accordance with Method D 1239.

NOTE 3 – The effect of chemical reagents on other properties shall be determined by making measurements on standard specimens for such tests before and after immersion in the reagents specified.

2. Applicable Documents

2.1 *ASTM Standards*:

D 13 Specification for Spirits of Turpentine.[2]

D 396 Specification for Fuel Oils[3]

D 618 Conditioning Plastics and Electrical Insulating Materials for Testing[4]

D 883 Definitions of Terms Relating to Plastics[4]

D 1040 Specification for Uninhibited Mineral Insulating Oil for Use in Transformers and in Oil Circuit Breakers[5]

D 1239 Test for Resistance of Plastic Films to Extraction by Chemicals[4]

D 1898 Recommended Practice for Sampling of Plastics[4]

E 177 Recommended Practice for Use of the Terms Precision and Accuracy as Applied to Measurement of a Property of a Material[4]

3. Significance and Use

3.1 The limitations of the results obtained from this test should be recognized. The choice of types and concentrations of reagents, duration of immersion, temperature of the test, and properties to be reported is necessarily arbitrary. The specification of these conditions provides a basis for standardization and serves as a guide to investigators wishing to compare the relative resistance of various plastics to typical chemical reagents.

3.2 Correlation of test results with the actual performance or serviceability of plastics is necessarily dependent upon the similarity between the testing and end-use conditions. For applications involving continuous immersion, the data obtained in short time tests are of interest only in eliminating the most unsuitable materials or indicating a probable relative order of resistance to chemical reagents.

---

[1] This method is under the jurisdiction of ASTM Committee D-20 on Plastics and is the direct responsibility of Subcommittee D-20 50 on Permanence Properties.

Current edition effective Aug 24, 1967. Originally issued 1939. Replaces D 543–65.

[2] *Annual Book of ASTM Standards*, Part 29.

[3] *Annual Book of ASTM Standards*, Part 23.

[4] *Annual Book of ASTM Standards*, Part 35.

[5] *Annual Book of ASTM Standards*, Part 40.

3.3 Evaluation of plastics for special applications involving corrosive conditions should be based on the particular reagents and concentrations to be encountered. The selection of test conditions should take into account the manner and duration of contact with reagents, the temperature of the system, and other performance factors involved in the particular application.

4. Apparatus

4.1 *Balance*—An accurate chemical balance.

4.2 *Micrometers*—Micrometers capable of measuring dimensions of test specimens to 0.025 mm (0.001 in.).

4.3 *Room*, or enclosed space capable of being maintained at the Standard Laboratory Atmosphere, as prescribed in Methods D 618.

4.4 *Containers*—Suitable containers for immersing specimens in chemical reagents. They must be resistant to the corrosive effects of the reagents being used. Venting should be provided, especially when using volatile reagents at elevated temperaures.

4.5 *Oven or Constant-Temperaure Bath*, capable of maintaining temperature within ± 2°C of the specified test temperatures.

4.6 *Testing Devices*—Testing devices for determining specific strength properties of specimens before and after immersion, conforming to the requirements prescribed in the ASTM test methods for the specific properties being determined.

5. Reagents and Materials

5.1 The following list of standard reagents is intended to be representative of the main categories of pure chemical compounds, solutions, and common industrial products. Chemicals used in this test shall be of technical grade or greater purity. All solutions shall be made with freshly prepared distilled water. Specified concentrations are on a weight percent or specific gravity basis. Mixing instructions are based on amounts of ingredients calculated to produce 1000 ml of solution of the specified concentration.

5.2 The list of standard reagents is not intended to preclude the use of other reagents pertinent to particular chemical resistance requirements. It is intended to standardize on typical reagents, solution concentrations, and industrial products for general testing of the resistance of plastics to chemical reagents. Material specifications in which chemical resistance is indicated shall be based on reagents and conditions selected from those listed herein except by mutual agreement between the seller and the purchaser.

5.3 The standard reagents are as follows:

5.3.1 *Acetic Acid (sp gr 1.05)*—Glacial acetic acid.

5.3.2 *Acetic Acid; (5 %)*—Add 48 ml (50.5 g) of glacial acetic acid (sp gr 1.05) to 955 ml of water.

5.3.3 *Acetone.*

5.3.4 *Ammonium Hydroxide (sp gr 0.90)*—Concentrated ammonium hydroxide (NH_4OH).

5.3.5 *Ammonium Hydroxide (10 %)*—Add 375 ml (336 g) of NH_4OH (sp gr 0.90) to 622 ml of water.

5.3.6 *Aniline.*

5.3.7 *Benzene.*

5.3.8 *Carbon Tetrachloride.*

5.3.9 *Chromic Acid (40 %)*—Dissolve 549 g of chromic anhydride (CrO_3) in 822 ml of water.

5.3.10 *Citric Acid (1 %)*—Dissolve 104 g of citric acid crystals in 935 ml of water.

5.3.11 *Cottonseed Oil*, edible grade.

5.3.12 *Detergent Solution, Heavy Duty (0.025 %)*—Dissolve 0.05 g of alkyl aryl sulfonate and 0.20 g of trisodium phosphate in 1000 ml of water.

5.3.13 *Diethyl Ether.*

5.3.14 *Dimethyl Formamide.*

5.3.15 *Distilled Water*, freshly prepared.

5.3.16 *Ethyl Acetate.*

5.3.17 *Ethyl Alcohol (95 %)*—Undenatured ethyl alcohol.

5.3.18 *Ethyl Alcohol (50 %)*—Add 598 ml (482 g) of 95 % undenatured ethyl alcohol to 435 ml of water.

5.3.19 *Ethylene Dichloride.*

5.3.20 *2-Ethylhexyl Sebacate.*

5.3.21 *Heptane*, commercial grade, boiling range 90 to 100°C.

5.3.22 *Hydrochloric Acid (sp gr 1.19)*—Concentrated hydrochloric acid (HCl).

5.3.23 *Hydrochloric Acid (10%)*—Add 239 ml (283 g) of HCl (sp gr 1.19) to 764 ml of water.

5.3.24 *Hydrofluoric Acid (40 %*
add 748 ml (866 g) of hydrofluo
to 55 percent HF) to 293 ml of w

5.3.25 *Hydrogen Peroxide So*
or USP 100 Volume).

5.3.26 *Hydrogen Peroxide So*
or USP 10 Volume)—Add 98
commercial grade (100 vol or
gen peroxide (H_2O_2) to 901 ml

5.3.27 *Isooctane (2,2,4-Trim*
tane).

5.3.28 *Kerosine*—No. 2 fuel oi
tion D 396.

5.3.29 *Methyl Alcohol.*

5.3.30 *Mineral Oil, White, US*
to 0.860; Saybolt @ 100°F, 125 to

5.3.31 *Nitric Acid (sp gr 1.4*
trated nitric acid (HNO_3).

5.3.32 *Nitric Acid (40 %)*
(710 g) of HNO_3 (sp gr 1.42)
water.

5.3.33 *Nitric Acid (10 %)*
(153 g) of HNO_3 (sp gr 1.42)
water.

5.3.34 *Oleic Acid*, cP.

5.3.35 *Olive Oil*, edible grade

5.3.36 *Phenol Solution (5*
47 g of carbonic acid crystals, US
of water.

5.3.37 *Soap Solution (1 %)*
hydrated pure white soap flakes
105°C) in water.

5.3.38 *Sodium Carbon*
(20 %)—Add 660 g of sodium ca
$CO_3 \cdot 10H_2O$) to 555 ml of water

5.3.39 *Sodium Carbonate*
Add 55 g of $Na_2CO_3 \cdot 10H_2O$ to

5.3.40 *Sodium Chloride S*
Add 107 g of sodium chlorid
ml of water.

5.3.41 *Sodium Hydrox*
(60 %)—Slowly dissolve 971 g
droxide (NaOH) in 649 ml of w

5.3.42 *Sodium Hydrox*
(10 %)—Dissolve 111 g of Na
water.

5.3.43 *Sodium Hydroxide S*
Dissolve 10.1 g of NaOH in 9

5.3.44 *Sodium Hypochlo*
tional Formulary (4 to 6 %)[6]—
tion of this solution can b

5.3.24 *Hydrofluoric Acid (40 %)*—Slowly add 748 ml (866 g) of hydrofluoric acid (52 to 55 percent HF) to 293 ml of water.

5.3.25 *Hydrogen Peroxide Solution (28%, or USP 100 Volume).*

5.3.26 *Hydrogen Peroxide Solution (3 %, or USP 10 Volume)*—Add 98 ml (108 g) of commercial grade (100 vol or 28 %) hydrogen peroxide (H_2O_2) to 901 ml of water.

5.3.27 *Isooctane (2,2,4-Trimethyl Pentane).*

5.3.28 *Kerosine*—No. 2 fuel oil, Specification D 396.

5.3.29 *Methyl Alcohol.*

5.3.30 *Mineral Oil, White, USP (sp gr 0.830 to 0.860; Saybolt @ 100°F, 125 to 135 s).*

5.3.31 *Nitric Acid (sp gr 1.42)*—Concentrated nitric acid (HNO_3).

5 3.32 *Nitric Acid (40 %)*—Add 500 ml (710 g) of HNO_3 (sp gr 1.42) to 535 ml of water.

5.3.33 *Nitric Acid (10 %)*—Add 108 ml (153 g) of HNO_3 (sp gr 1.42) to 901 ml of water.

5.3.34 *Oleic Acid,* cP.

5.3.35 *Olive Oil,* edible grade.

5.3.36 *Phenol Solution (5 %)*—Dissolve 47 g of carbonic acid crystals, USP, in 950 ml of water.

5.3.37 *Soap Solution (1 %)*—Dissolve dehydrated pure white soap flakes (dried 1 h at 105°C) in water.

5.3.38 *Sodium Carbonate Solution (20 %)*—Add 660 g of sodium carbonate ($Na_2CO_3 \cdot 10H_2O$) to 555 ml of water.

5.3.39 *Sodium Carbonate Solution (2 %)*—Add 55 g of $Na_2CO_3 \cdot 10H_2O$ to 964 ml of water.

5.3.40 *Sodium Chloride Solution (10 %)*—Add 107 g of sodium chloride (NaCl) to 964 ml of water.

5.3.41 *Sodium Hydroxide Solution (60 %)*—Slowly dissolve 971 g of sodium hydroxide (NaOH) in 649 ml of water.

5.3.42 *Sodium Hydroxide Solution (10 %)*—Dissolve 111 g of NaOH in 988 ml of water.

5.3.43 *Sodium Hydroxide Solution (1 %)*—Dissolve 10.1 g of NaOH in 999 ml of water.

5.3.44 *Sodium Hypochlorite Solution, National Formulary (4 to 6 %)*[8]—The concentration of this solution can be determined as follows: Weigh accurately in a glass-stoppered flask about 3 ml of the solution and dilute it with 50 ml of water. Add 2 g of potassium iodide (KI) and 10 ml of acetic acid, and titrate the liberated iodine with 0.1 *N* sodium thiosulfate ($Na_2S_2O_3$), adding starch solution as the indicator. Each ml of 0.1 *N* $Na_2S_2O_3$ solution is equivalent to 3.7222 mg of sodium hypochlorite.

5.3.45 *Sulfuric Acid (sp gr 1.84)*—Concentrated sulfuric acid (H_2SO_4).

5.3.46 *Sulfuric Acid (30 %)*—Slowly add 199 ml (366 g) of H_2SO_4 (sp gr 1.84) to 853 ml of water.

5.3.47 *Sulfuric Acid (3 %)*—Slowly add 16.6 ml (30.6 g) of H_2SO_4 (sp gr 1.84) to 988 ml of water.

5.3.48 *Toluene.*

5.3.49 *Transformer Oil,* complying with the requirements of Specification D 1040.

5.3.50 *Turpentine*—Gum spirits or steam distilled wood turpentine conforming to Specification D 13.

6. Precautions

6.1 Safety precautions should be taken to avoid personal contact, to eliminate toxic vapors, and to guard against explosion hazards in accordance with the hazardous nature of the particular reagents being used.

7. Test Specimens

7.1 The type and dimensions of test specimens to be used depend upon the form of the material and the tests to be performed (Note 4). At least three specimens shall be used for each material being tested and for each reagent involved. The specimens shall be as follows:

7.1.1 *Molding and Extrusion Materials*—Specimens shall be molded to shape or cut from molded slabs as required below. The cut edges of specimens shall be made smooth by sharp cutting, machining, or by finishing with No. 0 or finer sandpaper or emery cloth. Molding shall conform to conditions recommended by the manufacturer of the material (Note 5). The shape and dimensions of specimens shall

[8] Available from Fisher Scientific Co., Code No. SO-S-290.

depend on the test to be performed and shall conform to the following:

7.1.1.1 *Weight and Dimension Changes*—Standard specimens shall be in the form of disks 50.80 mm (2 in.) in diameter and 3.175 mm (0.125 in.) in thickness molded or cut from molded slabs. The nominal surface area of this standard disk is 45.60 cm^2 (7.068 $in.^2$).

7.1.1.2 *Mechanical Property Changes*—Standard tensile specimens shall be used according to the method of test prescribed in the appropriate specification for the material being tested, or by agreement among those concerned. Where the determination of other mechanical properties is agreed upon by the seller and the purchaser, standard specimens prescribed in the appropriate standard methods of test shall be used.

7.1.2 *Sheet Materials*—Specimens from sheet materials shall be cut from a representative sample of the material (Note 6) in a manner depending on the tests to be performed and the thickness of the sheet as follows (see 7.1.1 regarding preparation of cut edges):

7.1.2.1 *Weight and Dimension Changes*—Standard specimens shall be in the form of bars 76.20 mm (3 in.) in length by 25.40 mm (1 in.) in width by the thickness of the material. The nominal surface area of the standard bar, having a thickness of 3.175 mm (0.125 in.), is 45.16 cm^2 (7.0 $in.^2$). Circular disk specimens 50.80 mm (2 in.) in diameter by the thickness of the material are permissible under mutual agreement between the seller and the purchaser. Permissible variations in thickness of both types of specimens are ± 0.18 mm (0.007 in.) for hot molded and ± 0.30 mm (0.012 in.) for cold molded or cast materials.

7.1.2.2 *Mechanical Property Changes*—Standard machined, sheared, or cut tensile specimens shall be used according to the methods of test prescribed in the appropriate specifications of the material being tested, or by agreement among those concerned (see 7.1.1.2).

NOTE 4—Specimen surface area greatly affects the weight change due to immersion in chemical reagents. Thickness influences percentage dimension change as well as percentage change in mechanical properties. In addition, molded specimens may not agree with specimens cut from molded or otherwise formed sheet of a given material. Consequently, comparison of materials should be made only on the basis of results obtained from specimens of identical dimensions and like methods of specimen preparation.

NOTE 5—Molding conditions can affect the resistance of plastics to chemical reagents. Compression moldings should be prepared in a manner that will disperse external lubricants and result in complete fusion of the particles. Injection molding should be accomplished in a manner that results in a minimum of molecular orientation and thermal stresses or a controlled level of both depending upon the conditions being simulated.

NOTE 6—For certain products, such as laminates, in which edge effects are pronounced, larger coupons may be exposed from which standard specimens can be cut after immersion for determining the effects of reagents on mechanical properties. This may be allowed in provisions of material specifications by mutual agreement between the seller and the purchaser and should be reported as such.

8. Sampling

8.1 For Procedure I, sample in accordance with the pertinent considerations outlined in Method D 1898.

8.2 For Procedure II, sample in accordance with the ASTM test methods for the specified properties to be determined.

9. Conditioning

9.1 *Conditioning*—Condition the test specimens at 23 ± 2°C (73.4 ± 3.6°F) and 50 ± 5 % relative humidity for not less than 40 h prior to test in accordance with Procedure A of Methods D 618 for those tests where conditioning is required. In cases of disagreement, the tolerances shall be 1°C (1.8°F) and ± 2% relative humidity.

9.2 *Test Conditions*—Conduct tests in the Standard Laboratory Atmosphere of 23 ± 2°C (73.4 ± 3.6°F) and 50 ± 5 % relative humidity, unless otherwise specified in the test methods or in this specification. In cases of disagreements, the tolerances shall be 1°C (1.8°F) and ± 2 % relative humidity.

10. Procedure I. Weight and Dimension Changes (See Note 7 and 5.2).

10.1 Weigh each conditioned specimen separately and measure its thickness at the center and its length and width, or two diameters at right angles to each other, to the nearest 0.025 mm (0.001 in.). In the case of

laminates, edge swellin
under certain conditior
may be necessary to me
at the center and at the
percentage change separa

10.2 Place the specime
tainers for the reagents
the specimens to be tota
reagent for 7 days in the
Atmosphere. Suspend t
any contact with the w
container. For specime
those having a lower de
it may be necessary to
such as nichrome wire
curling. Several specim
may be immersed in th
vided sufficient reagent
surface area exposed an
touch each other. For sp
able and relatively in
quantity of reagent sha
ml/in.^{2} of specimen s
mens that tend to dis
extraction of plasticize
agent shall be approxim
imen surface area. Whe
these matters, use the
tests at other than ro
recommended that th
50°C, 70°C, or othe
mended in Methods D
the reagent be at the e
before the specimens a

10.3 *Stir the reage*
erate manual rotatio
other suitable means (

10.4 After 7 days,
period of time, individ
imen from the reagen
a weighing bottle, an
sions. Wash with ru
removed from acid,
solutions, wipe then
tissue, and immediat
reagents such as co
may remain adsorbe
specimen even after
diate special handl
pickup before and
specimens removed f
ter-soluble organic li

reagents at elevated temperature, unless, they are to be tested at the elevated temperature, they shall be placed in another container of the reagent at the Standard Laboratory Temperature for approximately 1 h to effect cooling prior to testing (Note 10).

NOTE 9—While tensile tests are more generally applicable and preferred for assessing mechanical property changes due to the effects of chemical reagents, other mechanical properties may be more significant in special cases. For example, flexural properties of rigid materials, which are not appreciably softened by the reagents under study, may be extremely sensitive to surface attack such as crazing. Consequently, in the use of this method for establishing chemical resistance levels in material or product specifications, consideration should be given to the choice of mechanical properties that properly characterize the effects of exposure to chemical reagents.

NOTE 10—To isolate the effects of certain chemical reagents on the mechanical properties of some plastics, it is necessary to test identical specimens that have been immersed in water. This is especially true of tests to determine the effects of aqueous solutions, where these may not differ greatly from the effects of immersion in water alone (see References (3) and (4) at the end of this method). When tests are run with a variety of aqueous solution reagents, the effects due to water alone should be established for better comparison of results. Similar behavior may result when tests are run at elevated temperatures, requiring knowledge of the effects of temperature alone to properly assess the effects due to the chemical reagents.

12 Report

12.1 *Procedure I:*

12.1.1 Complete identification of the material tested including type, source, manufacturer's code, form, and previous history,

12.1.2 Method of preparing test specimens,

12.1.3 Conditioning procedure used,

12.1.4 Temperature of tests,

12.1.5 Chemical reagents,

12.1.6 Duration of immersion,

12.1.7 Initial length, width or two diameters, and thickness of each specimen, in inches, measured to the nearest 0.025 mm (0.001 in.) (see 7.1),

12.1.8 Initial weight of each specimen in grams to ±0.0005 g.

12.1.9 Length, width, and thickness after immersion.

12.1.10 Weight after immersion.

12.1.11 Average percentage increase or decrease in length and width, or in the two diameters, and in the thickness, calculated to the nearest 0.1%. Calculations shall be based upon the corresponding dimensions of the conditioned specimen.

12.1.12 Average percentage gain or loss in weight calculated to the nearest 0.01 %. Calculations shall be based upon the weight of the conditioned specimen.

12.1.13 General appearance of specimens after immersion.

12.2 *Procedure II:*

12.2.1 Items 11.1.1 through 11.1.6 as for Procedure I, and the following:

12.2.2 Specimen type and dimensions,

12.2.3 Method of test,

12.2.4 Conditions of test,

12.2.5 Mechanical properties of identical nonimmersed and immersed specimens, and

12.2.6 Average percentage increase or decrease in mechanical properties, taking the properties of the conditioned nonimmersed specimens as 100 %.

13. Precision and Accuracy

13.1 *Procedure I:*

13.1.1 *Precision*—In view of the wide differences possible in the reactions of specific plastics to particular reagents, it is impossible to prepare statistically meaningful general statement of precision for this procedure. If necessary, a precision for a specific plastic/reagent system should be prepared in accordance with the considerations presented in Recommended Practice E 177.

13.1.2 *Accuracy*—For the reasons outlined in 13.1.1, no statement of accuracy has been prepared.

13.2 *Procedure II:*

13.2.1 *Precision and Accuracy*—No statements of precision and accuracy are applicable to this procedure: these are dependent upon the ASTM test methods for the specific properties to be determined.

(1) Kline, G. M., Rinke
F., "Resistance of P
agents," *Proceedings*, A
Vol 41, 1941, p. 12
Vol 19, December, 1
(2) Delmonte, J. "Effect
Organic Plastics," *In*
Chemistry, Vol 34, Ju
(3) Tyrie, W. R., "Chem
lic Laminates," *Tra*
chanical Engrs., Vol
795.
(4) Crouse, W. A., Caricko
Margaret A., "Effec

The American Society for Te
connection with any item me
validity of any such patent ri

This standard is subject t
years and if not revised, eith
for additional standards and sh
at a meeting of the responsib
a fair hearing you should m
19103, which will schedule a
ASTM Board of Directors.

REFERENCES

(1) Kline, G. M., Rinker, R. C., and Meindl, H. F., "Resistance of Plastics to Chemical Reagents," *Proceedings*, Am Soc. Testing Mats., Vol 41, 1941, p. 1246; and *Modern Plastics*, Vol 19, December, 1941, p. 59.

(2) Delmonte, J. "Effect of Solvents Upon Solid Organic Plastics," *Industrial and Engineering Chemistry*, Vol 34, June, 1942, p. 764.

(3) Tyrie, W. R., "Chemical Resistance of Phenolic Laminates," *Transactions*, Am. Soc. Mechanical Engrs., Vol 69, October, 1947, p. 795.

(4) Crouse, W. A., Carickoff, Margie, and Fischer, Margaret A., "Effect of Fuel Immersion on Laminated Plastics," *Transactions*, Am. Soc. Mechanical Engrs. Vol 72, February 1950, p. 175.

(5) Adams, W. H., and Lebach, H. H., "New Corrosion Test for Plastics," *Chemical Engineering*, Vol 56, July, 1949, pp. 98–101.

(6) Reinhart, Frank W., and Williams, Harry C., Jr., "Resistance of Representative Plastic Materials to Hydrofluoric Acid," ASTM BULLETIN, No. 167, July 1950, p. 60.

(7) Meyerhans, Konrad, "Resistance of Ethoxyline Resins to Chemical Attacks. The Behavior of Araldite Casting Resin B towards Chemicals," *Kunststoffe*, Vol 44, 1954, pp. 135–42.

The American Society for Testing and Materials takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, is entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 1916 Race St., Philadelphia, Pa. 19103, which will schedule a further hearing regarding your comments. Failing satisfaction there, you may appeal to the ASTM Board of Directors.

11. Annual Book of ASTM Standards, "Standard Test Method for Rubber Property-Durometer Hardness pt. 35, D-2240-75, American Society for Testing and Materials, Philadelphia, Pennsylvania, 1981, pg. 708-711

AMERICAN NATIONAL STANDARD

ASTM D 2240 – 75

Standard Test Method for
RUBBER PROPERTY—DUROMETER HARDNESS[1]

This Standard is issued under the fixed designation D 2240; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

This method has been approved for use by agencies of the Department of Defense to replace methods 5311.1 and 5321 of Federal Test Method Standard 601 and method 1084 of Federal Test Method Standard 406, and for listing in the DoD Index of Specifications and Standards.

1. Scope

1.1 This method covers two types of durometers, A and D, and the procedure for determining the indentation hardness of homogeneous materials ranging from soft vulcanized rubbers to some rigid plastics. Type A is used for measuring the softer materials, and Type D for the harder materials (see Note 7, Section 7). This method permits measurements either of initial indentations or of indentations after specified periods of time, or both.

1.2 This method is not applicable to the testing of coated fabrics.

2. Significance

2.1 This method is based on the penetration of a specified indentor forced into the material under specified conditions. The indentation hardness is inversely related to the penetration and is dependent on the elastic modulus and viscoelastic behavior of the material. The shape of the indentor and the force applied to it influence the results obtained so that there may be no simple relationship between the results obtained with one type of durometer and those obtained with either another type of durometer or another instrument for measuring hardness. This method is an empirical test intended primarily for control purposes. No simple relationship exists between indentation hardness determined by this method and any fundamental property of the material tested. For specification purposes, it is recommended that ASTM Method D 1415, Test for Rubber Property—International Hardness,[2] be used for soft materials and Method A of ASTM Methods D 530, Testing Hard Rubber Products,[2] or ASTM Method D 785, Test for Rockwell Hardness of Plastics and Electrical Insulating Materials[3] be used for hard materials.

3. Apparatus

3.1 The durometer shall consist of the following components:

3.1.1 *Presser Foot* with a hole between 2.5 and 3.2 mm (0.10 and 0.13 in.) in diameter, centered at least 6 mm (0.25 in.) from any edge of the foot.

3.1.2 *Indentor* formed from hardened steel rod between 1.15 and 1.40 mm (0.045 and 0.055 in.) in diameter to the shape and dimensions shown in Fig. 1 for Type A durometers or Fig. 2 for Type D durometers.

3.1.3 *Indicating Device* on which the amount of extension of the point of indentor may be read in terms of graduations ranging from zero for full extension of 2.46 to 2.54 mm (0.097 to 0.100 in.) Note 1) to 100 for zero extension obtained by placing presser foot and indentor in firm contact with a flat piece of glass.

NOTE 1—Type A Shore Durometers serial numbers 1 through 16,300 and 16,351 through 16,900 and Type A-2 Shore Durometers numbers 1 through 8077 do not meet the requirement of 2.46 to 2.54 mm (0.097 to 0.100 in.) extension of the

[1] This method is under the jurisdiction of ASTM Committee D-11 on Rubber and is the direct responsibility of Subcommittee D11.10 on Physical Tests.

Current edition approved March 29, 1975. Published April 1975. Originally published as D 2240 – 64 T. Last previous edition D 2240 – 68.

[2] *Annual Book of ASTM Standards*, Part 37.

[3] *Annual Book of ASTM Standards*, Part 39.

zero reading. These duro
which are low by amou
at 30 hardness to 1 unit

4 *Calibrated Spring* for appl
indentor in accordance w
following equations:

$$\text{Force, N} = 0.550 - 0.075\,H_A$$

where H_A is the hardness reading
durometer, and

$$\text{Force, N} = 0.44\,H_D$$

where H_D is the hardness reading
durometer.

4. Test Specimen

4.1 The test specimen shall be
(0.25 in.) in thickness unless i
identical results are obtaine
specimen (Note 2). A spec
composed of thinner pieces
necessary thickness, but deter
on such specimens may not
made on one-piece specimen
surfaces between plies may
complete contact. The lateral dim
specimen shall be sufficient
measurements at least 12 mm (0.5
edge unless it is known tha
results are obtained when measure
made at a lesser distance from an e
The surface of the specimen sh
sufficient area to permit the pr
contact the specimen over an ar
radius of at least 6 mm (0.25 in.)
indentor point. A suitable hardness
cannot be made on a rou
or rough surface.

NOTE 2—The minimum requireme
of the specimen is depende
of penetration of the indentor int
that is, thinner specimens may b
materials having hardness values at the
the scale. The *minimum distance fro*
which measurements may be made h
as the hardness increases. For
hardness values above 50 Type
the thickness of the specimen sh
3 mm (0.12 in.) and measureme
be made closer than 6 mm (0.25
in.).

5. Calibration

5.1 The *spring can be calibrated*
the durometer in a vertical
resting the point of the inden

ntor at zero reading. These durometers will give readings which are low by amounts ranging from 3 units at 30 hardness to 1 unit at 90 hardness.

3.1.4 *Calibrated Spring* for applying force to the indentor in accordance with one of the following equations:

$$\text{Force, N} = 0.550 + 0.075\,H_A \quad (1)$$

where H_A is the hardness reading on a Type A durometer, and

$$\text{Force, N} = 0.44\,H_D \quad (2)$$

where H_D is the hardness reading on a Type D durometer.

4. Test Specimen

4.1 The test specimen shall be at least 6 mm (0.25 in.) in thickness unless it is known that identical results are obtained with a thinner specimen (Note 2). A specimen may be composed of thinner pieces to obtain the necessary thickness, but determinations made on such specimens may not agree with those made on one-piece specimens because the surfaces between plies may not be in complete contact. The lateral dimensions of the specimen shall be sufficient to permit measurements at least 12 mm (0.5 in.) from any edge unless it is known that identical results are obtained when measurements are made at a lesser distance from an edge (Note 3). The surface of the specimen shall be flat over sufficient area to permit the presser foot to contact the specimen over an area having a radius of at least 6 mm (0.25 in.) from the indentor point. A suitable hardness determination cannot be made on a rounded, uneven, or rough surface.

NOTE 2—The minimum requirement for the thickness of the specimen is dependent on the extent of penetration of the indentor into the specimen, that is, thinner specimens may be used for materials having hardness values at the upper end of the scale. The minimum distance from edge at which measurements may be made likewise decreases as the hardness increases. For materials having hardness values above 50 Type D durometer, the thickness of the specimen should be at least 3 mm (0.12 in.) and measurements should not be made closer than 6 mm (0.25 in.) to any edge.

5. Calibration

5.1 The spring can be calibrated by supporting the durometer in a vertical position and resting the point of the indentor on a small spacer at the center of one pan of a chemical balance as shown in Fig. 3 in order to prevent interference between presser foot and pan (Note 3). The spacer shall have a small cylindrical stem approximately 2.5 mm (0.1 in.) in height and 1.25 mm (0.05 in.) in diameter, and shall be slightly cupped on top to accommodate the indentor point. Balance the mass of the spacer by a tare on the opposite pan of the balance. Add weights to the opposite pan to balance the force on the indentor at various scale readings. The measured force shall equal the force calculated by either Eq 1 within ± 0.08 N or Eq 2 within ± 0.44 N.

NOTE 3—Instruments specifically designed for calibration of durometers may be used. Zwick & Co., Control Equipment 7501, can be used for calibration as it is capable of measuring or applying a force on the point of the indentor within 0.004 N for a Type A durometer and within 0.02 N for a Type D durometer. Zwick Control Equipment 7501 with serial numbers higher than WA-20301 are satisfactory for this work. Instruments with lower serial numbers must be modified.[4]

6. Conditioning

6.1 Tests shall be made at 23 ± 2 C (73.4 ± 3.6 F) if the temperature of test is not specified. When tests are made at other temperatures, it is recommended that they be made at one or more of the standard temperatures given in ASTM Recommended Practice D 1349, for Rubber—Standard Temperatures and Atmospheres for Testing and Conditioning,[2] or Procedure A of ASTM Methods D 618, Conditioning Plastics and Electrical Insulating Materials for Testing.[3] The durometer and specimens shall be conditioned at the temperature of test for at least 1 h before test for materials whose hardness is not dependent on the relative humidity (Note 4). For materials whose hardness is dependent on the relative humidity, the specimens shall be conditioned in accordance with Procedure A of Methods D 618 and tested at the same conditions.

NOTE 4—When a durometer is moved from a chamber below room temperature to a higher temperature, the durometer shall be placed in a suitable desiccator or airtight container immediately

[4] The standardization of one type of instrument is described by Lewis Larrick, "The Standardization of Durometers," *Rubber Chemistry and Technology*, RCTEA, Vol 13, 1940, p 969.

upon removal and allowed to remain there until the temperature of the durometer is above the dew point of the air in the new environment.

7. Procedure

7.1 Place the specimen on a hard, horizontal surface. Hold the durometer in a vertical position with the point of the indentor at least 12 mm (0.5 in.) from any edge of the specimen, unless it is known that identical results are obtained when measurements are made with the indentor at a lesser distance. Apply the presser foot to the specimen as rapidly as possible without shock, keeping the foot parallel to the surface of the specimen. Apply just sufficient pressure to obtain firm contact between presser foot and specimen.

NOTE 5—Better reproducibility may be obtained by using either a durometer stand or a weight centered on the axis of the indentor or both to apply the presser foot to the specimen. Recommended weights are 1 kg for the Type A durometer and 5 kg for the Type D durometer.

7.2 Unless otherwise specified, read the scale within 1 s after the presser foot is in firm contact with the specimen, unless the durometer has a maximum indicator, in which case the maximum reading is taken. If a reading after a time interval is specified, hold the presser foot in contact with the specimen without change in position or pressure and read the scale after the period specified.

NOTE 6—Durometers having only a maximum indicator cannot be used to obtain hardness values at various time intervals, nor in testing vinyl plastics which require the reading to be taken at 15 s.

7.3 Make five measurements of hardness at different positions on the specimen at least 6 mm (0.25 in.) apart and determine the median value or the arithmetic mean.

NOTE 7—It is recommended that measurements be made with the Type D durometer when values above 90 are obtained with the Type A durometer and that measurements be made with the Type A durometer when values less than 20 are obtained with the Type D durometer.

8. Report

8.1 The report shall include the following:

8.1.1 Complete identification of material tested,

8.1.2 Description of specimen, including thickness and number of pieces plied,

8.1.3 Temperature of test if other than 23 C, and relative humidity when hardness of material is dependent on humidity,

8.1.4 Type and manufacture of durometer,

8.1.5 Indentation hardness time interval at which reading was taken, and data designating basis, median or mean value (Note 8).

8.1.6 Date of test.

NOTE 8—Readings may be reported in the form: A/45/15 where A is the type of durometer, 45 the reading, and 15 the time in seconds that the pressure foot is in firm contact with the specimen. Similarly, D/60/1 indicates a reading of 60 on the Type D durometer obtained either within 1 s or from a maximum indicator.

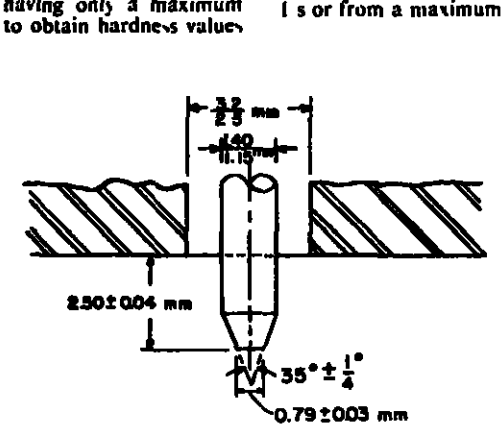


FIG. 1 Indentor for Type A Durometer.

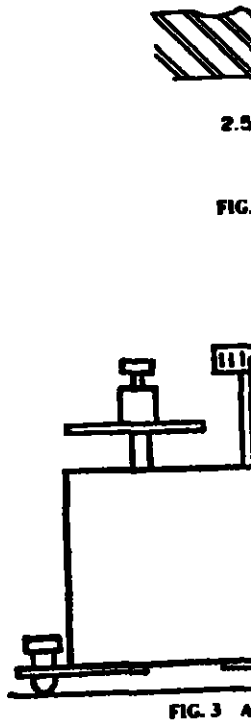


FIG. 3 A

The American Society for Testing and
in connection with any item mentioned in
of the validity of any such patent rights, a

This standard is subject to revision at a
years and if not revised, either reapproved
for additional standards and should be add
at a meeting of the responsible technical
received a fair hearing you should mak
Philadelphia, Pa. 19103, which will sche
may appeal to the ASTM Board of Directo

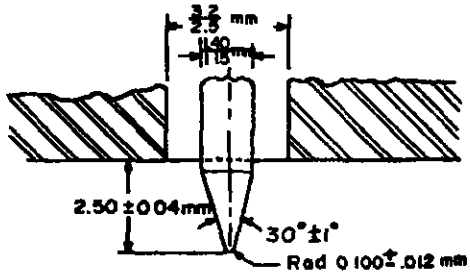


FIG. 2 Indentor for Type D Durometer.

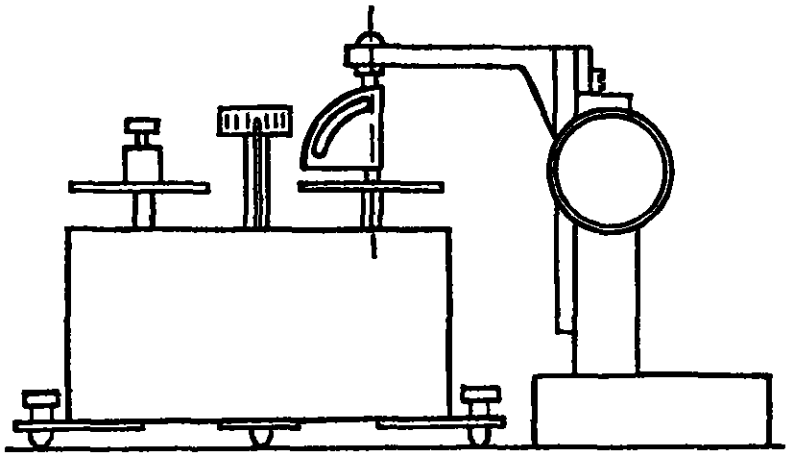


FIG. 3 Apparatus for Calibration of Durometer Spring.

The American Society for Testing and Materials takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, is entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 1916 Race St., Philadelphia, Pa. 19103, which will schedule a further hearing regarding your comments. Failing satisfaction there, you may appeal to the ASTM Board of Directors

12. Annual Book of ASTM Standards, "Standard Recommended Practice for Determining Permeability of Thermo-plastic Containers", D-2684-73, American Society for Testing and Materials, Philadelphia, Pennsylvania, 1979, pp. 552-556

Designation: D 2684 – 73 (Reapproved 1979)

Standard Recommended Practice for DETERMINING PERMEABILITY OF THERMOPLASTIC CONTAINERS[1]

This Standard is issued under the fixed designation D 2684, the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

1. Scope

1.1 This recommended practice covers procedures for determining the permeability of thermoplastic containers to packaged reagents or proprietary products under specified conditions of exposure. The exposures used are intended to simulate the normal and elevated temperature-storage conditions that might be encountered in end-use application.

1.2 The recommended practice is applicable only to those types of containers designed to allow positive, leakproof closure.

1.3 Two procedures are provided:

1.3.1 *Procedure A* is specific to testing only with a standard design container. This procedure provides for determinations of rate of weight loss (or gain) and for calculation of a permeability factor.

1.3.2 *Procedure B* applies to tests of all other container designs. Permeability data by this procedure are expressed only in terms of rate of weight loss (or gain) for the particular container tested.

NOTE 1—The values stated in SI units are to be regarded as the standard.

2. Summary

2.1 Test bottles are filled with the test product and, after sealing, are exposed at 23 C (73.4 F) and 50 C (122 F) conditions for 28 days or longer. Measurements of weight are made at intervals to determine the average rate of weight change.

3. Significance

3.1 With the proper precautions and background experience, results can be useful for estimation of the loss of a packaged product through the walls of a container during shelf storage. The test is also useful for isolating the effects of a container design and materials, and is applicable for development and research and for specification purposes.

3.2 In the absence of adequate supporting data, extrapolations or correlations of results to conditions beyond those of the test are not recommended because of possible product alteration, solvency, or chemical effects on the plastic, etc.

4. Definition

4.1 *permeability factor*, P_t—the permeability of a given plastic to a given product at temperature t, in degrees Celsius, expressed in units of g · cm/day · m^2, as determined by Procedure A. The permeability factor under 23 C test conditions, for example, is signified by the notation P_{23}.

4.1.1 Determination of P_t is based on an averaged wall thickness over the entire area of the container and an assumption that permeation rate is inversely proportional to the thickness. Precaution in the extent of allowable variations of these factors is recommended, and use of P_t should take into consideration that wall thickness of the containers varies, that the estimate of average thickness from density, area, and weight is not exact, and that permeability of the product through the plastic material may not be directly proportional to the thickness.

[1] This recommended practice is under the jurisdiction of ASTM Committee D-20 on Plastics and is the direct responsibility of Subcommittee D20.12 on Olefin Plastics.

Current edition approved Jan. 29, 1973. Published March 1973. Originally published as D 2684 - 68 T. Last previous edition D 2684 - 68 T.

5. Apparatus

5.1 *Enclosure* or room with provision [illegible] maintaining the Standard Laboratory [illegible] sphere of 23 ± 2 C (73.4 ± 3.6 F) [illegible] 5 percent relative humidity, as defin[illegible] ASTM Methods D 618, Condition[illegible] Plastics and Electrical Insulating Materi[illegible] Testing.[2]

5.2 *Circulating-Air Oven*, consistent w[illegible] in accordance with Specification E 1[illegible] for Gravity-Convection and Forced-Vent[illegible] Ovens,[3] capable of maintaining a t[illegible] perature of 50 ± 1 C (122 ± 1.8 F) and [illegible] flow rate of 8.5 to 17.0 m^3/min (300 [illegible] ft^3/min), and with provisions for deter[illegible] of the relative humidity. The lim[illegible] of 25 ft^3 on oven size can be overlook[illegible] provided all other requirements are met.

NOTE 2—Only explosionproof equipment [illegible] provision for adequate exhaust of vapors sh[illegible] used for tests with potentially hazardou[illegible] products.

NOTE 3—Relative humidity variation can [illegible] affect permeability loss in many [illegible] especially water-based products in va[illegible] thermoplastics.

5.3 *Balance*, accurate to 0.01 percen[illegible] weight of test container and cont[illegible]

5.4 *Container Seals*, suitable heat-se[illegible] laminate[4] and polyethyle or other su[illegible] lined screw-type closures for sealing the [illegible] tainers.

5.5 *Heat Sealer*.[5]

5.6 *Torque Wrench*.[6]

6. Reagents and Materials

6.1 The reagent or proprietary pr[illegible] as specified for testing.

7. Test Specimens

7.1 The test specimen for Procedu[illegible] shall be the 4-oz cylindrical bottle des[illegible] specified in Fig. 1, having a nominal ex[illegible] surface area of 154 cm^2 (23.8 in^2).

7.2 The test specimen for Procedure [illegible] be any thermoplastic container, as sp[illegible] or selected for test evaluation, provide[illegible] designed to allow positive closure.

7.3 For each procedure, a minim[illegible] three specimens shall be tested at eac[illegible] perature. Three additional specime[illegible] required for Procedure A for determina[illegible] the plastic density.

5. Apparatus

5.1 *Enclosure* or room with provision for maintaining the Standard Laboratory Atmosphere of 23 ± 2 C (73.4 ± 3.6 F) and 50 ± 5 percent relative humidity, as defined in ASTM Methods D 618, Conditioning Plastics and Electrical Insulating Materials for Testing.[2]

5.2 *Circulating-Air Oven*, consistent with requirements in accordance with Specification E 145, for Gravity-Convection and Forced-Ventilation Ovens,[3] capable of maintaining a temperature of 50 ± 1 C (122 ± 1.8 F) and an air-flow rate of 8.5 to 17.0 m^3/min (300 to 600 ft^3/min), and with provisions for determination of the relative humidity. The limitation of 25 ft^3 on oven size can be overlooked, provided all other requirements are met.

NOTE 2—Only explosionproof equipment with provision for adequate exhaust of vapors should be used for tests with potentially hazardous or toxic products.

NOTE 3—Relative humidity variation can significantly affect permeability loss in many products, especially water-based products in various thermoplastics.

5.3 *Balance*, accurate to 0.01 percent of the weight of test container and contents.

5.4 *Container Seals*, suitable heat-sealing laminate[4] and polyethylene or other suitably lined screw-type closures for sealing the containers.

5.5 *Heat Sealer*.[5]

5.6 *Torque Wrench*.[6]

6. Reagents and Materials

6.1 The reagent or proprietary product as specified for testing.

7. Test Specimens

7.1 The test specimen for Procedure A shall be the 4-oz cylindrical bottle design as specified in Fig. 1, having a nominal external surface area of 154 cm^2 (23.8 $in.^2$).

7.2 The test specimen for Procedure B may be any thermoplastic container, as specified or selected for test evaluation, provided it is designed to allow positive closure.

7.3 For each procedure, a minimum of three specimens shall be tested at each temperature. Three additional specimens are required for Procedure A for determination of the plastic density.

NOTE 4—Trim and finish the containers, if needed, to ensure a smooth contacting surface for positive seal.

8. Conditioning

8.1 *Conditioning*—Condition the test specimens at 23 ± 2 C (73.4 ± 3.6 F) and 50 ± 5 percent relative humidity for not less than 40 h prior to test in accordance with Procedure A of Methods D 618, for those tests where conditioning is required. In cases of disagreement, the tolerances shall be ±1 C (±1.8 F) and ±2 percent relative humidity.

8.2 *Test Conditions*—Conduct tests in the Standard Laboratory Atmosphere of 23 ± 2 C (73.4 ± 3.6 F) and 50 ± 5 percent relative humidity, unless otherwise specified in the test methods or in this specification. In cases of disagreements, the tolerances shall be ±1 C (±1.8 F) and ±2 percent relative humidity.

9. Procedure A (Standard Container)

9.1 With specimens taken from the sidewalls of three of the containers, determine the average plastic density by ASTM Method D 1505, Test for Density of Plastics by the Density-Gradient Technique,[2] or by an alternative method of equivalent accuracy.

9.2 For each test temperature, select a minimum of three containers. Weigh each when empty, without the closure. Also weigh the empty containers with their corresponding closures and appropriately sized laminate pieces.

9.3 Fill the containers to nominal capacity with the test product.

9.4 Make a thorough check for any drippage or spill of product on the outside surface of the containers. If any is noted, replace the container with a new specimen.

9.5 Heat seal the containers with the laminate (plastic to plastic), check for leaks, and then cap the containers with screw-type clo-

[2] *Annual Book of ASTM Standards*, Part 35.

[3] *Annual Book of ASTM Standards*, Part 41.

[4] One such laminate suitable for polyethylene containers: MIL-B-131C Class 2, a polyethylene-aluminum foil-paper laminate, available from the Robertson Co., Jamaica, N.Y.

[5] Sealector Hand Sealing Iron (165 W) made by Sealector, Shelton, Conn., or Super Sealer made by Cleveland Lathe and Machinery Co., Cleveland, Ohio, are suitable.

[6] Model 25 Owens-Illinois Torque Tester, Owens-Illinois, Toledo, Ohio, is suitable.

sures, using sufficient torque to provide positive seal. Avoid distorting the container when capping.

NOTE 5—One method of testing for a poor seal is to immerse an upright test container in a beaker filled to the base of the cap with a liquid that will not attack the plastic. When a vacuum of 15 in. Hg is applied to the entire system, a poorly sealed bottle will give off bubbles from the sealed area.

NOTE 6—Any deformation of the container during sealing may result in a volume change which will affect the final test pressure. An application torque of 1.7 N·m (15 lbf·in.) has been found sufficient for the standard container in Fig. 1.

9.6 Weigh the sealed containers.

9.7 Unless otherwise specified, expose one set of containers in the Standard Laboratory Atmosphere, 23 ± 2 C (73.4 ± 3.6 F) and 50 ± 5 percent relative humidity, and another set in a circulating-air oven controlled at 50 ± 1 C (122 ± 1.8 F). Place the containers upright on an inert metal screen or perforated sheet support to allow air circulation. Place a tray beneath the container support to collect leakage of product, if failure occurs. Provide enough spacing between the containers so they do not touch each other. Also, take precautions as necessary to prevent any possible cross-contamination in the test chamber from other agents.

NOTE 7—For certain relatively unstable or spoilable products, the use of elevated temperature exposures may not be applicable.

9.8 Weigh the containers after 1 day, 7 days, 14 days, 21 days, and 28 days. In certain cases, a steady rate of weight change may be reached in either a shorter or longer period. Other intervals can then be used. They should be regular and reported.

9.8.1 If the weight change appears abnormal for any of the containers during exposure, inspect the containers to ensure that a positive seal exists. If a leak is detected, retest with a new specimen.

9.8.2 Cool in the Standard Laboratory Atmosphere until consistent weighings are obtained. Resume oven exposure within 6 h from removal time.

9.8.3 In elevated-temperature tests, rotate the locations of the specimens in the oven when re-exposing after each interval to minimize possible bias due to variations of air flow and temperature within the oven.

9.9 *Calculations:*

9.9.1 Calculate the percentage weight loss or gain after a given exposure time as follows:

Weight loss (at time x), percent $= [(G_u - G_x)/N_u] \times 100$

Weight gain (at time x), percent $= [(G_x - G_u)/N_u] \times 100$

where:

G_u = gross weight of unexposed bottle, closure, and contents, g,

G_x = gross weight of exposed bottle, closure and contents, g, and

N_u = net weight of unexposed test product in the bottle, g.

9.9.2 *Rate of Average Weight Change*—Plot the weight changes, $G_u - G_x$ for losses or $G_x - G_u$ for gains, versus time in days on rectilinear graph paper. Draw the best straight line through the points, eliminating those points of initial and eventual deflection from equilibrium rate conditions; and from the slope of the line determine the rate of average weight change, R, in grams per day. Note whether it is loss or gain. (See Fig. 2 for example plot.)

Weight change per day, percent $= (R/N_u) \times 100$

9.9.3 *Permeability Factor* (see 4.1)— Calculate the permeability factors as follows:

$$P_t = RT/A$$

For P_t in metric units, g · cm/day · m².

R = rate of average weight change, g/day, from 9.9.2, and

T = average bottle wall thickness, cm, calculated from bottle weight, area in cm², and density of the bottle material, for example:

$$T = \frac{\text{weight of bottle (g)}}{\text{density (g/cm}^3) \times \text{area (cm}^2)}$$

A = bottle surface area, m².

NOTE 8—For Procedure A, where the standard 4-oz Boston Round Bottle is used (23.8-in.² area), the following equations can be used:

To calculate P_t in metric units:

$$P_t = RT/A = \frac{R\ \text{(g/day)} \times \text{weight of bottle (g)}}{\text{density (g/cm}^3) \times 2.358}$$

10. Procedure B (Nonstandard Containers)

10.1 Follow the procedure of test given in 9.2 through 9.8.

NOTE 9—If not feasible to heat seal the c[illegible]ner due to design, etc., any other means for [illegible]viding an equivalent, nonpermeable, leakp[illegible] closure would be an acceptable alternative.

10.2 *Calculations:*

10.2.1 Calculate the percentage weight [illegible] or gain after a given exposure time as [illegible]tailed in 9.9.1.

10.2.2 Calculate the rate of average we[illegible] change as shown in 9.9.2.

11. Report

11.1 The report shall include the fo[illegible]ing:

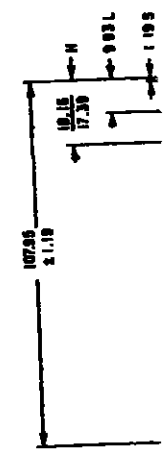
11.1.1 Complete bottle and test pr[illegible] identification and description,

11.1.2 Complete closure identification [illegible] description,

11.1.3 Exposure conditions,

11.1.4 Calculated permeation data,

11.1.5 Any occurrences of container [illegible]age, failure, etc.,



NOTE-

FIG 1 St[illegible]

NOTE 9—If not feasible to heat seal the container due to design, etc., any other means for providing an equivalent, nonpermeable, leakproof seal would be an acceptable alternative.

9.2 *Calculations:*

9.2.1 Calculate the percentage weight loss or gain after a given exposure time as described in 9.9.1.

9.2.2 Calculate the rate of average weight change as shown in 9.9.2.

11. Report

11.1 The report shall include the following:

11.1.1 Complete bottle and test product identification and description,

11.1.2 Complete closure identification and description,

11.1.3 Exposure conditions,

11.1.4 Calculated permeation data,

11.1.5 Any occurrences of container leakage, failure, etc.,

11.1.6 Date of test,

11.1.7 Duration of test, and

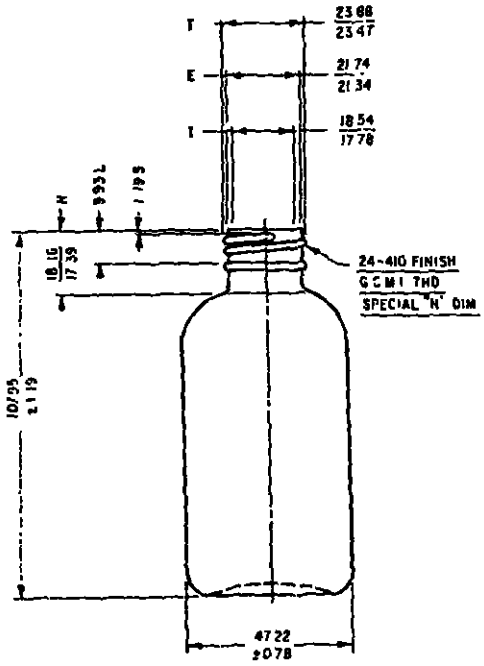
11.1.8 Regular weighing intervals.

12. Precision

12.1 Round-robin testing[7] among six laboratories by Procedure A was performed with containers of Type I polyethylene in accordance with ASTM Specification D 1248, for Polyethylene Plastics Molding and Extrusion Materials,[8] and a variety of liquid reagents. P_t values ranged from 0.02 to about 200 mg · cm/day m^2. Over this wide range, the standard deviations of the results between laboratories increased with increased values of P_t. For 18 levels of P_t, the interlaboratory coefficients of viariation remained relatively constant with the over-all average being 14 percent.

[7] Supporting data have been filed at ASTM Headquarters as RR 50 D-20

[8] *Annual Book of ASTM Standards*, Parts 34 and 36



NOTE—Dimensions are in millimeters

FIG 1 Standard Container for Permeability Test.

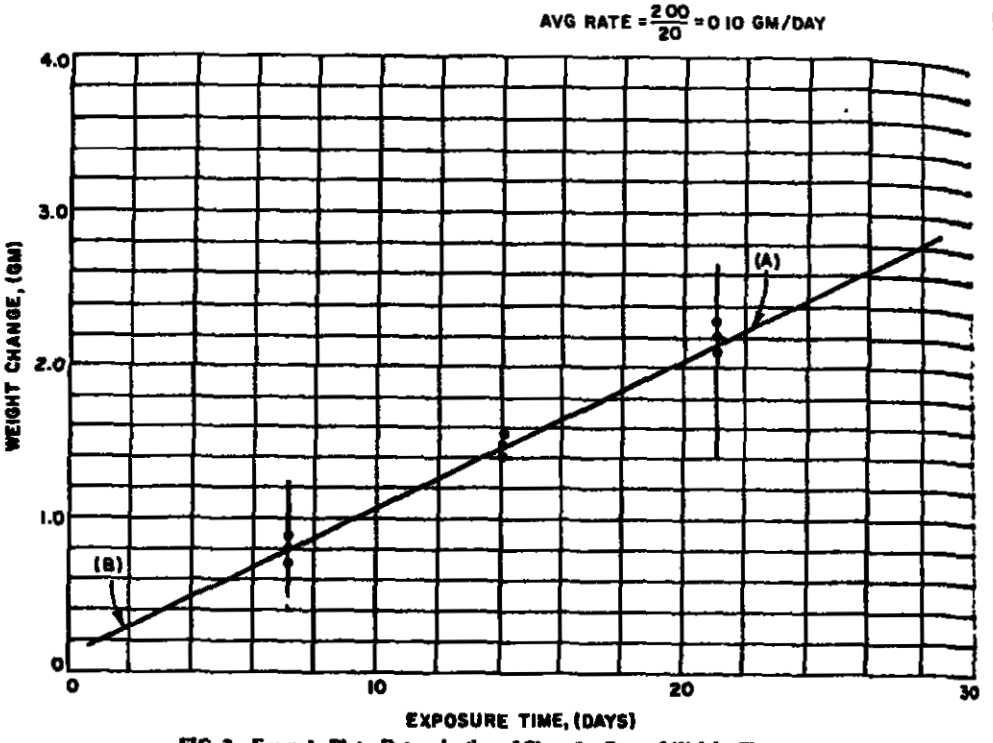


FIG. 2 Example Plot—Determination of Slope for Rate of Weight Change.

APPENDIX

A1. Mixed U.S. Customary-Metric Units and Conversion Factors

A1.1 For P_t in mixed U.S. customary-metric units, g · mil/day · 100 in.^{2}.

R = rate of average weight change, g/day, from 9.9.2.

T = average bottle wall thickness, mils, calculated from bottle weight, area in in.^{2}, and density, for example:

$$T = \frac{\text{weight of bottle (g)} \times 1000 \text{ (mils/in.)}}{\text{density (g/cm}^3) \times 16.39 \text{ (cm}^3\text{/in.}^3)} \times \text{area (in.}^2)$$

A = bottle surface area in units of 100 in.^{2}; for example, if bottle surface area is 23.8 in.^{2}, A = 0.238.

NOTE A1—The mixed U.S. customary-metric units are not recommended for general use, but are included to establish a relationship with work that has been previously accomplished in this area.

A1.2 To convert P_t values between systems use the following equations:

P_t (metric units) = 0.0394 P_t (mixed U.S. customary-metric units)

P_t (mixed U.S. customary-metric units) = 25.4 P_t (metric units)

The American Society for Testing and Materials takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, is entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 1916 Race St., Philadelphia, Pa. 19103, which will schedule a further hearing regarding your comments. Failing satisfaction there, you may appeal to the ASTM Board of Directors.

Standard Test Method for SAG FLOW OF HIGHLY V

This standard is issued under the fixed designation D 2730, ... of original adoption or, in the case of revision, the year o ... revision.

Scope

1.1 This method[2] covers the determinatior ... the *flow* properties of highly viscous mate ... ls and pastes. The test procedure is applica ... e to mixed and curing systems, as well as t ... dividual resin and hardener component ... Testing of low-viscosity materials by this pr ... edure is generally not practical. Low viscosi ... aterials should be tested in accordance wi ... Method D 2393.

1.2 The values stated in SI units are to ... regarded as the standard.

2. Applicable Documents

2.1 *ASTM Standards*:

D 2393 Test for Viscosity of Epoxy Re ... and Related Components[3]

D 2471 Test for Gel Time and Peak E ... thermic Temperature of Reacting T ... mosetting Resins[3]

E 1 Specification for ASTM Thermome

3. Significance

3.1 The procedure described can be us ... a quality control and acceptance test for t ... viscous materials and pastes. The metho ... termines the maximum thickness to wh ... material can be applied without sagging. ... provides a means of measuring the amo ... sag flow at a given thickness.

4. Apparatus

4.1 *Sag Flow Board*, as pictured in F

4.2 *Temperature-Controlled Bath*, co ... ble to 0.1°C (0.2°F), either oil or wate

4.3 *Thermometer*, Celsius, with 0.1 ... sions, or Fahrenheit, with 0.2°F divi ... suitable thermometer is ASTM Ther ... 91°C, 20 to 50°C range, with 0.1°C

13. Annual Book of ASTM Standards, "Standard Test Method for Rubber Property-Vapor Transmission of Volatile Liquids," pt. 37, D-814-81, American Society for Testing and Materials, Philadelphia, Pennsylvania, 1981, pp. 181-183

Designation: D 814 – 81

An American National Standard

Standard Test Method for RUBBER PROPERTY— VAPOR TRANSMISSION OF VOLATILE LIQUIDS[1]

This standard is issued under the fixed designation D 814, the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

1. Scope

1.1 This method covers the measurement of the rate of vapor transmission of volatile liquids through a rubber sheet, disk, or diaphragm.

2. Applicable Document

2.1 *ASTM Standard*:

D 3767 Practice for Rubber—Measurement of Dimensions[2]

3. Significance

3.1 The rate of transmission of a liquid through a rubber sheet, that acts as a barrier, is important in rubber diaphragm performance and other similar industrial applications. This transmission is referred to as vapor transmission since the liquid diffuses through the rubber in a molecular sense and escapes into free atmosphere in vapor form.

3.2 The test is applicable only to the materials in sheet form of moderate thickness and is principally useful for comparing the relative vapor transmission of different liquids in the same rubber or of the same liquid through different rubbers. Comparisons should not be made in which both different rubbers and different liquids are used.

4. Apparatus

4.1 The test apparatus shall consist essentially of glass vapor transmission jars (4.2) for each liquid, on which the test specimens are mounted, and a suitable rack for supporting the jars in an inverted position in such a way as to allow free circulation of air over the surface of the specimen. The apparatus shall be kept in a constant temperature cabinet or room at 23 ± 2°C (73.4 ± 3.6°F).

4.2 *Vapor Transmission Jar*—A glass jar of approximately 236-cm³ (½-pt) capacity with an opening of 60.3 ± 0.4 mm (2.375 ± 0.015 in.) in inside diameter and a wall 3.2 mm (0.125 in.) in thickness at the opening, which shall be ground flat without rounded edges to a smooth ground-glass finish at the contact surface. The opening shall be equipped with a metal screw ring clamp holding a smooth-edged, flat, sheet-metal ring 55.6 ± 0.4 mm (2.188 ± 0.015 in.) in inside diameter and approximately 68.3 mm (2.69 in.) in outside diameter. The ring clamp and ring serve as a clamping device for holding the specimen against the ground-glass-edge of the jar with a circular specimen area 55.6 mm (2.188 in.) in diameter exposed to the air while permitting the screw clamp to be tightened to form a leak-proof seal without subjecting the specimen to torsional strain. When testing extensible materials, a circular disk of 16- to 20-mesh screen shall be placed inside the screw ring clamp between it and the flat metal ring to prevent stretching of the specimen during the test. The screen disk may be soldered in place on top of the sheet metal ring if desired.

---

[1] This method is under the jurisdiction of ASTM Committee D-11 on Rubber and is the direct responsibility of Subcommittee D11.10 on Physical Testing.

Current edition approved Jan. 8, 1981. Published April 1981. Originally published as D 814 - 44 T. Last previous edition D 814 - 55 (1976)[1].

[2] *Annual Book of ASTM Standards*, Part 37.

NOTE 1—A suitable vapor transmission jar may be prepared from a ½-pt Mason jar equipped with a Kerr-type screw cap, provided the edge of the jar is properly ground and finished with fine emery and the cap is cut with smooth, flattened edges to form the required circular opening.

4.3 *Dial Micrometer*—The dial micrometer shall conform to the requirements of Method A of Practice D 3767.

4.4 *Balance*—The balance shall be of suitable capacity capable of weighing to 0.005 g.

5. Test Specimens

5.1 The test specimens shall consist of circular disks 68 mm (2.69 in.) in diameter, cut with a sharp-edged die from a sheet of the material being tested. The thickness of the sheet, which shall not exceed 3.2 mm (0.125 in.), shall be measured using the dial micrometer described in 4.3.

5.2 For evaluating the vapor transmission of a particular liquid with respect to a given rubber, three specimens having the same nominal thickness within a tolerance of ±3 % shall be tested. The vapor transmission of the liquid shall be taken as the average of the values obtained from the two rubber specimens giving the lowest results, providing these check within ±20 % of the average so determined.

6. Procedure

6.1 With the vapor transmission jar in an upright position, place 200 cm^3 of the test liquid in it, after which fit the test specimen over the mouth of the jar, place the ring and wire screen in position, and screw down the screw ring clamp lightly. Hold the assembly in the constant temperature cabinet or room at 23 ± 2°C (73.4 ± 3.6°F) with the test disk lightly in place until temperature equilibrium is obtained. Then screw down the ring tightly and allow the assembly to stand in an upright position for 2 h. Make a tare assembly using a duplicate jar and a test specimen of the same size but without the addition of the test liquid. Place suitable weighting material such as lead shot in the tare jar to bring its mass to approximately that of the assembled jar and contents. Condition the tare jar at the test temperature, seal it, and handle throughout the test in a manner similar to that used for the test jar. Place the test jar on a balance of suitable capacity capable of weighing to 0.005 g, and counterbalance it against the tare jar, adding weights as required to equilibrium. Take the original mass of the test assembly as that of the tare corrected for the added weights and record to the nearest 0.005 g.

6.2 *After weighing, invert each test jar assembly* and place on the rack, supporting each in such a way that the entire inner surface of the specimen remains in contact with the liquid throughout the test. If the rack is located in a conditioning cabinet, take care to remove diffused vapors from the chamber and to assure free circulation of fresh air by means of a fan or other suitable device. Twenty-four hours after inverting the jar, again weigh it against the tare jar. Any excessive loss of mass indicates that leakage due to improper seal is occurring. Remove such test assemblies and replace them by new assemblies properly prepared. Return the test assembly to the rack and reweigh against the tare after periods of 120 ± 2 h and 192 ± 2 h from the initial inversion. Consider the difference in mass between those obtained at 120 h (5 days) and at 192 h (8 days) divided by 3 as the average mass of liquid lost per 24 h.

NOTE 2—In this test, the specimens are allowed to remain in contact with the liquid for 5 days before starting measurement of the loss in order to permit the rate of diffusion of the liquid to become uniform.

7. Calculation

7.1 Express the vapor transmission rate (VTR) of each test liquid with respect to the rubber employed and calculate as follows:

$$\text{Vapor transmission rate (VTR), mg/s}\cdot\text{m}^2 = 4.05 \times \text{average mass in grams of liquid lost per 24 h}$$

8. Report

8.1 The report shall include the following:

8.1.1 Identification of the test rubber,

8.1.2 Thickness of the test rubber to the nearest 0.025 mm (0.001 in.),

8.1.3 Identification of the test liquid, and

8.1.4 Vapor transmission rate (VTR) of the liquid, expressed in milligrams per second per square metre of wetted area.

Precision
A program is currently be
on precision data. Approp
Society for Testing and M
item mentioned in this
rights, and the risk of in
standard is subject to revision at a
reviewed, either reapproved or with
should be addressed to ASTM
technical committee, which you ma
known to the ASTM Co
regarding your comments Fa

Precision

A program is currently being organized [illegible] precision data. Appropriate precision statements will be incorporated into this document when this program is completed.

[illegible] Society for Testing and Materials takes no position respecting the validity of any patent rights asserted in [illegible] with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity [illegible] patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

[illegible] standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years [illegible] revised either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional [illegible] and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the [illegible] technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should [illegible] your views known to the ASTM Committee on Standards, 1916 Race St., Philadelphia, Pa. 19103, which will schedule a [illegible] hearing regarding your comments. Failing satisfaction there, you may appeal to the ASTM Board of Directors.

14. Annual Book of ASTM Standards, "Standard Methods of Testing Coated Fabrics," pt. 38, D-751-79, American Society for Testing and Materials, Philadelphia, Pennsylvania, 1981, pp. 170-183

AMERICAN NATIONAL STANDARD

ASTM D 751 – 79

Standard Methods of Testing
COATED FABRICS[1]

This Standard is issued under the fixed designation D 751, the number immediately following the designation indicates the year of original adoption or, in the case of revision the year of last revision. A number in parentheses indicates the year of last reapproval.

These methods have been approved for use by agencies of the Department of Defense and for listing in the DoD Index of Specifications and Standards.

1. Scope

1.1 These methods describe procedures for the testing of coated fabrics.

CONDITION

2. Standard Condition

2.1 *Test Condition*—Coated fabrics shall be tested in standard condition, unless otherwise specified.

2.2 *Standard Condition*—Standard condition of coated fabrics shall be that reached by the fabric when in moisture equilibrium with a standard atmosphere having a relative humidity of 65 percent at 21 C (70 F). A tolerance of ±2 percent is permitted in relative humidity and 1.1 C (±2 F) in temperature.

2.3 *Moisture Equilibrium*—It shall be considered that moisture equilibrium is reached when, after free exposure to air in motion, there is no progressive increase in weight. Moisture equilibrium shall be approached from the dry side (not moisture-free). Certain coatings may greatly retard moisture penetration into the fabric and, therefore, fabrics coated on both sides may require 24 h or more to reach equilibrium.

3. Time Lapse Between Vulcanization and Testing

3.1 For all test purposes, the minimum time between vulcanization and testing should be 16 h.

3.2 For non-product tests, the maximum time between vulcanization and testing should be 4 weeks and for evaluations intended to be comparable, the tests, as far as possible, should be carried out after the same time interval.

3.3 For product tests, wherever possible, the time between vulcanization and testing should not exceed 3 months. In other cases, tests should be made within 2 months of the date of receipt by the customer.

NOTE 1—Section 3 is not applicable for coated fabrics not requiring vulcanization

DIMENSIONS AND WEIGHT

4. Length

4.1 *General Method*—Lay the coated fabric out smooth, without tension, on a horizontal surface and measure the length parallel to the selvage; or, measure successive portions, each at least 4.57 m (5 yd) in length, under the same conditions.

4.2 *Drum Method*—Run the coated fabric over a measuring drum with just enough uniform tension to keep it running flat and true. Determine the length from the dial or counter on the drum and its calibration.

5. Width

5.1 Measure the width with the coated fabric laid out smooth on a horizontal surface but without tension in either direction. Report the average of at least five different measurements uniformly distributed along the full length of a roll or piece as the average width of the roll or piece.

[1] These methods are under the jurisdiction of ASTM Committee D-11 on Rubber and are the direct responsibility of Subcommittee D11.3 on Coated Fabrics and Rubber Thread.

Current edition approved Oct. 26, 1979. Published December 1979. Originally published as D 751 – 43 T. Last previous edition D 751 – 73.

Thickness

6.1 *Thickness Gage*—The gage us[illegible] ment of thickness shall b[illegible] weight type equipped with a [illegible] to read directly to 0.025 mm [illegible] presser foot shall be circ[illegible] of 9.52 ± 0.03 mm (0.37[illegible] The presser foot and moving [illegible] therewith shall be weight[illegible] a total force of 1.7 ± 0.1 N (6[illegible] equivalent to a pressure of 23.5 ± 0.[illegible] to the specimen. The presser foot [illegible] shall be plane to within [illegible] in.) and parallel to each ot[illegible] in. The gage shall be calib[illegible] total load exerted by the presse[illegible] of any device so arranged [illegible] total vertical force exerted by t[illegible] at the several gage readings o[illegible] selected for calibration. The [illegible] be brought to each calibration [illegible] higher one.

NOTE 2—It is suggested that the cali[illegible] accomplished by supporting the pres[illegible] horizontal strap suspended from a [illegible] arranged that it may be rais[illegible] gradually and leveled at any required p[illegible]

6.2 *Procedure*—Place the c[illegible] upon the anvil of the gage smoot[illegible] tension. Lower the presser foo[illegible] material gradually (without impact) [illegible] rest upon it for 10 s, and the[illegible] reading of the dial. Make sim[illegible] ments at not less than five diff[illegible] uniformly distributed over the [illegible] coated fabric exclusive of the are[illegible] either selvage and within one tenth [illegible] the fabric or within 2.5 m (100 in.) [illegible] of a roll or piece. Report the aver[illegible] or more measurements as the a[illegible] ness.

7. Mass

7.1 *Method Applicable to a [illegible] Roll*—Weigh the full piece, cut [illegible] calibrated scale accurate to 0.25 [illegible] ure the length and width of the [illegible] and calculate the mass, reporti[illegible] per square metre (ounces per s[illegible] the nearest 2.8 g (0.1 oz).

7.2 *Method Applicable to a S[illegible]* specimen having an area of at le[illegible]

Thickness

Thickness Gage—The gage used for the measurement of thickness shall be of the dial type equipped with a dial graduated to read directly to 0.025 mm (0.001 in.). The presser foot shall be circular with a diameter of 9.52 ± 0.03 mm (0.375 ± 0.001 in.). The presser foot and moving parts connected therewith shall be weighted so as to exert a total force of 1.7 ± 0.1 N (6 ± 0.1 oz) equivalent to a pressure of 23.5 ± 0.5 kPa (3.4 psi) on the specimen. The presser foot and anvil surfaces shall be plane to within 0.0025 mm (0.001 in.) and parallel to each other to within 0.001 in. The gage shall be calibrated for the total load exerted by the presser foot by means of any device so arranged as to measure the total vertical force exerted by the presser foot at the several gage readings or presser foot levels selected for calibration. The presser foot shall be brought to each calibration level from a higher one.

NOTE 2—It is suggested that the calibration may be accomplished by supporting the presser foot on a vertical strap suspended from a weighing device so arranged that it may be raised or lowered at will and leveled at any required position.

7.2 *Procedure*—Place the coated fabric on the anvil of the gage smooth, but without tension. Lower the presser foot upon the material gradually (without impact), allow it to rest upon it for 10 s, and then observe the reading of the dial. Make similar measurements at not less than five different places uniformly distributed over the surface of the coated fabric exclusive of the area adjacent to the selvage and within one tenth the width of the fabric or within 2.5 m (100 in.) of either end of roll or piece. Report the average of the five or more measurements as the average thickness.

8. Mass

8.1 *Method Applicable to a Piece, Cut or Roll*—Weigh the full piece, cut or roll, on a calibrated scale accurate to 0.25 percent, measure the length and width of the coated fabric, and calculate the mass, reporting it in grams per square metre (ounces per square yard) to the nearest 2.8 g (0.1 oz).

8.2 *Method Applicable to a Sample*—Cut a specimen having an area of at least 125 cm² (20 in.²), or a number of specimens not less than 50 mm (2 in.) square and having a total area of at least 125 cm² (20 in.²), from the coated fabric, weigh on a calibrated scale accurate to 0.25 percent, and calculate the mass, reporting it in grams per square metre (ounces per square yard). Unless a specimen the full width of the fabric is used, take no specimen nearer the selvage than one tenth the width of the fabric.

NOTE 3—This method is intended for use when a small sample of coated fabric is sent to the laboratory for test. The result is considered to be applicable to the sample, but not to the piece or lot of goods from which the sample was taken unless the number of samples and method of sampling are specified and agreed upon by those concerned. If this is done, each sample should be tested in accordance with 7.2 and the results averaged to obtain the average mass in grams per square metre (or ounces per square yard).

BREAKING STRENGTH

8. Breaking Strength

8.1 Breaking strength shall be determined by the Grab Method, unless the Strip Method is specified. In the case of coated knit fabrics, the breaking strength may be more satisfactorily determined by the bursting strength method which shall be used when specified.

A—Grab Method

9. Testing Machine

9.1 The machine shall consist of three main parts:

9.1.1 Straining mechanism,

9.1.2 Clamps for holding specimen, and

9.1.3 Load and elongation recording mechanism(s).

9.2 *Staining Mechanism*—A machine wherein the specimen is held between the two clamps and strained by a uniform movement of the pulling clamp shall be used. Unless otherwise specified in the material specification, the machine shall be adjusted so that the pulling clamp shall have a uniform speed of 5 ± 0.2 mm/s (12 ± 0.5 in./min).

9.3 *Load and Elongation Recording Mechanism(s)*—Calibrated dial, scale, or chart to indicate applied load and elongation. Unless otherwise specifed for load determination, the machine shall be adjusted or set so that the maximum load required to break the specimen will remain indicated on the calibrated dial or

scale after the test specimen has ruptured.

9.4 *Capacity*—If the machine is of the pendulum type, it shall be of such capacity that the maximum load required to break the specimen shall be not greater than 85 percent or less than 15 percent of the rated capacity.

9.5 *Machine Efficiency*—The error of the machine shall not exceed 2 percent up to and including a 200-N (50-lbf) force and 1 percent over 200 N and 1 percent at any reading within its loading range.

10. Clamps for Fabrics

10.1 The clamps for holding a specimen of coated fabric shall have metallic gripping surfaces sufficiently smooth, flat, and parallel as to prevent the test specimen from slipping or moving between the gripping surfaces when held under the pressure normal to operation. The dimension of all gripping surfaces parallel to the direction of application of the load shall be 25 mm (1 in.); the dimension perpendicular to this direction shall be 1 in. for the face jaw and 50 mm (2 in.) or more for the other. All edges that might cause a cutting action shall be rounded to a radius of not over 0.4 mm (1/64 in.). The design of the clamp shall be such that one gripping surface shall be an integral part of the rigid frame of the clamp while the other shall be on a part hinged or swiveled to the movable member of the clamp. The pressure between the gripping surfaces, sufficient to clamp the specimen firmly before the testing load is applied and to prevent slippage during the progress of the test, shall be secured by any suitably constructed mechanical device operating on the movable member of the clamp. The distance between the clamps at the start of the test shall be 75 mm (3 in.).

NOTE 4—As a practical method of determining the degree of fatness and parallelism of the assembled clamp mechanism it is recommended that a sheet of thin white paper, between two thin sheets of carbon paper, be placed between the gripping surfaces, and the jaws then brought together with a light pressure

11. Test Specimens

11.1 Specimens 100 mm (4 in.) in width and not less than 150 mm (6 in.) in length shall be cut from the coated fabric for test. Two sets of five specimens each will be required, one set for longitudinal breaking strength having the longer dimension parallel to the lengthwise direction of the goods, and the other set for transverse breaking strength, having the longer dimension parallel to the crosswise direction of the goods. No two specimens shall contain the same threads of the fabric in the direction to be tested. Unless otherwise specified, specimens shall be taken no nearer the selvage than one-tenth the width of the coated fabric.

12. Procedure

12.1 Place the specimen symmetrically in the clamps of the machine (see Fig. 1) with the longer dimension parallel to and the shorter dimension at right angles to the direction of application of the force. Report the average of the results of the five individual tests in each direction as the longitudinal breaking strength and the transverse breaking strength of the fabric, respectively. If a specimen slips in the clamps, breaks in the clamps, breaks at the edges of the clamps, or if for any reason attributable to faulty operation, the result falls markedly below the average for the set of specimens, discard the result, take another specimen, and include the result of this break in the average.

B—Cut Strip Method

13. Procedure

13.1 Make the breaking strength test by the cut strip method in accordance with the directions for the grab method (Sections 9 to 12), with the exception that the specimens shall be cut 25 mm (1 in.) in width (or other width when specified).

ELONGATION

14. Procedure

14.1 Unless otherwise specified, obtain the elongation of a coated fabric at any stated force when the breaking strength (Sections 8 to 12) is determined and for the same specimens by means of a suitable autographic recording device on the testing machine. The elongation shall be the average of the results obtained for five specimens, and it shall be expressed as the percentage increase in length. Since the initial length and, therefore, the measured elongation depend upon the load applied in placing the specimen in the clamps of the machine, place

[illegible] tial load of 1.7 N (6 ozf), or other [illegible] specified for the particular mat[illegible] [illegible] on the specimen before grippi[illegible] [illegible]cimen in the lower clamp of the [illegible] [illegible]culate the elongation from the start [illegible] as shown on the graphic record.

BURSTING STRENGTH

15. Testing Machine

15.1 The machine used for det[illegible] [illegible]sting strength shall be either of the [illegible] [illegible] types:

15.2 *Tension Testing Machine wi[illegible] Clamp*—The tension testing mach[illegible] [illegible]ribed in Section 9 shall be equipped [illegible] [illegible]sting attachment of such design th[illegible] [illegible]pecimen held securely by a ring-clam[illegible] [illegible]sm 44.0 ± 0.05 mm (1.750 ± 0.002 [illegible] [illegible]nternal diameter with the center of the [illegible] [illegible]men pressed against a polished stee[illegible] [illegible] 25.00 ± 0.025 mm (1.000 ± 0.002 i[illegible] [illegible]diameter until a burst is produced. The [illegible] [illegible]tion of motion of the ring clamp sh[illegible] [illegible]right angles to the initial plane of the s[illegible] The capacity of the machine shall be [illegible] [illegible]red suitable if, when the specimen bu[illegible] [illegible]angle which the pendulum makes wi[illegible] [illegible]vertical is between 9 and 45 deg.

15.3 *Diaphragm Bursting Tester*—R[illegible] [illegible]ments for a diaphragm bursting test [illegible] [illegible]outlined in 15.3.1, 15.3.2 and 15.3.3; ho[illegible] [illegible]any machine that operates on the same [illegible] [illegible]ple and has coaxial apertures of 31.2 ± [illegible] [illegible](1.24 ± 0.02 in.) in diameter in the cl[illegible] [illegible]surfaces is a valid machine for this test

15.3.1 The testing machine to be us[illegible] [illegible]be either mechanically or manually op[illegible] [illegible]It shall permit the clamping of the mai[illegible] [illegible]be tested between two circular clamp[illegible] [illegible]than 75 mm (3 in.) in diameter havi[illegible] [illegible]apertures of their centers 31.2 ± 0.5 m[illegible] [illegible]± 0.02 in.) in diameter. The surfac[illegible] [illegible]clamps between which the specimen[illegible] [illegible]placed shall be concentrically groo[illegible] [illegible]grooves shall be spaced not less tha[illegible] [illegible](0.031 in.) apart and of a depth not [illegible] [illegible]0.15 mm (0.006 in.). The grooves shall [illegible] [illegible]closer than 3.2 mm (0.125 in.) from t[illegible] [illegible]the aperture The surfaces of the cl[illegible] [illegible]be metallic and any edge which mig[illegible] [illegible]cutting action shall be rounded to a [illegible] [illegible]not over 0.4 mm (1/64 in.). The lower cl[illegible]

- ial load of 1.7 N (6 oz/f), or other initial ... specified for the particular material in ... on the specimen before gripping the ... in the lower clamp of the machine. ... late the elongation from the start of the ... shown on the graphic record.

BURSTING STRENGTH

Testing Machine

... 1 The machine used for determining ... ing strength shall be either of the following ... types.

... 2 *Tension Testing Machine with Ring ... p*—The tension testing machine de... ed in Section 9 shall be equipped with a ... ing attachment of such design that the ... men held securely by a ring-clamp mecha... 44.0 ± 0.05 mm (1.750 ± 0.002 in.) in ... nal diameter with the center of the speci... pressed against a polished steel ball of ... 0 ± 0.025 mm (1.000 ± 0.002 in.) in ... eter until a burst is produced. The direc... of motion of the ring clamp shall be at ... angles to the initial plane of the specimen. ... capacity of the machine shall be consid... suitable if, when the specimen breaks, the ... which the pendulum makes with the ... cal is between 9 and 45 deg.

... 3 *Diaphragm Bursting Tester*—Require... for a diaphragm bursting tester are ... ned in 15.3.1, 15.3.2 and 15.3.3; however, ... machine that operates on the same princi... and has coaxial apertures of 31.2 ± 0.5 mm ... ± 0.02 in.) in diameter in the clamping ... aces is a valid machine for this test.

... 3.1 The testing machine to be used may ... either mechanically or manually operated. ... shall permit the clamping of the material to ... sted between two circular clamps not less ... 75 mm (3 in.) in diameter having coaxial ... ertures of their centers 31.2 ± 0.5 mm (1.24 ... 02 in.) in diameter. The surfaces of the ... ps between which the specimen is to be ... ed shall be concentrically grooved. The ... es shall be spaced not less than 0.8 mm ... 31 in.) apart and of a depth not less than ... 5 mm (0.006 in.). The grooves shall not start ... er than 3.2 mm (0.125 in.) from the edge of ... aperture. The surfaces of the clamps shall ... metallic and any edge which might cause a ... ing action shall be rounded to a radius of ... over 0.4 mm (1/64 in.). The lower clamp shall be integral with the chamber in which a screw shall operate to force a liquid pressure medium at a uniform rate of 1.64 ± 0.07 cm³/s (6.00 ± 0.25 in.³/min) against a rubber diaphragm fitted to expand through the aperture exerting its force against the coated fabric set between the two clamps. (In the manually operated machine, this shall correspond to approximately 2 rps of a hand wheel turning the displacement screw.)

15.3.2 In the mechanically operated machine, means shall be provided for stopping, at the instant of the rupture of the specimen, any further application of the loading pressure, and for holding unchanged the contents of the pressure chamber until the gross bursting pressure and tare diaphragm pressure indicated on the gage have been recorded. The machine shall be fitted with a Bourdon tube gage, maximum-reading type, having a dial 114 mm (4.5 in.) in diameter, and the scale divided to read in 2-N (0.5-lbf) units, with a range of from 0 to 500 N (0 to 100 lbf). Accuracy shall be within ±2 N (0.5 lbf). When the gage is calibrated, it shall be mounted in the same relative position as on the bursting tester. If calibrated with a dead-weight tester, the weights shall be spun slowly to ensure free action of the piston.

NOTE 5—A higher capacity gage may be used provided it meets the accuracy requirements.

15.3.3 Provision shall be made for applying to the specimen, before clamping, a slight initial tension, which shall be uniform in all directions.

16. Test Specimens

16.1 At least ten specimens shall be cut, the smallest dimension of which shall be at least 12.5 mm (0.5 in.) greater than the outside diameter of the ring-clamp mechanism of the testing machine.

17. Procedure

17.1 When the pendulum machine is used, mount the test specimen in the ring clamp and move it at a rate of 5 mm/s (12 in./min.) against the steel ball until rupture occurs. Record the pounds pressure as the bursting strength of the specimen.

17.2 When the diaphragm tester is used, mount the specimen between the ring clamp

and the base surface with a uniform tension. Apply the pressure at a constant rate as prescribed in 15.2.1 until rupture occurs. Record the pounds pressure and then release the upper clamp completely, allowing the tare of the diaphragm to register on the pressure gage. Report the bursting strength of the material as the gross pressure minus the tare of the diaphragm.

NOTE 6—When the diaphragm bursting tester is used, it is recommended that the difference between the gross bursting pressure and the tare diaphragm pressure be reported as the bursting strength of the material.

18. Calculation

18.1 The average bursting strength of the material shall be the arithmetic mean of the results of ten tests and reported in pascals or pounds per square inch.

TEARING STRENGTH

19. Scope

19.1 The tearing strength of the coated fabrics shall be determined by either the pendulum method, or the tongue tear method.

A—Pendulum Method

20. Testing Machine

20.1 Pendulum-type machine wherein the specimen is held between a pair of clamps, one movable and one stationary, and torn by the fall of a pendulum through the force of gravity. The machine shall consist of the following:

20.1.1 Pendulum carrying a circumferential graduated scale so as to indicate the force used in tearing the specimen.

20.1.2 Movable clamp carried on a pendulum, preferably formed by a sector of a wheel or circle free to swing on a ball or other substantially frictionless bearing, and a stationary clamp. The gripping surface of the jaws in each clamp shall be not less than 25 mm (0.98 in.) wide and 16.5 mm (0.650 in.) deep. The clamps shall be separated by a distance of 2.5 mm (0.1 in.).

20.1.3 Pointer and pointer stop to record the maximum arc of swing of the sector pendulum.

20.1.4 Sector release to hold the pendulum in a raised position during the mounting of the specimen and to permit it to fall through the force of gravity.

20.1.5 Knife attachment for initial slitting of the specimen.

21. Adjustment of Apparatus

21.1 For apparatus having a sector as a pendulum, and which tears the specimen as it moves toward the right, draw a pencil line on the base of stop mechanism 25 mm (1 in.) to the right of the edge of the sector stop. With the sector raised to its initial position and the pointer set against its stop, on releasing the sector and holding the stop down, the sector should make at least 20 complete oscillations before the edge of the sector that engages with the stop no longer passes to the left of the pencil line. Otherwise, the bearing shall be oiled and adjusted.

21.2 Level the instrument so that, with the sector free, the line on the sector indicating the vertical from the point of suspension coincides with the corresponding point on the base of the instrument, usually placed on the stop mechanism. After leveling, operate the instrument several times with nothing in the jaws, and movable jaw being closed, to ascertain if the pointer registers zero with no load. If zero is not registered, the pointer stop should be suitably adjusted until the zero reading is obtained. If it is necessary to move the pointer stop, the pointer friction should be checked as follows. Set the pointer at the zero reading on the scale before releasing the sector and after release see that the pointer is not pushed more than three scale divisions beyond the zero. A reading of more than three divisions indicates excessive pointer friction and the pointer should be removed, the bearing wiped clean, and a trace of oil or petroleum jelly applied. When the pointer friction has been reduced, finally adjust the point stop.

22. Calibration of Apparatus

22.1 Level and adjust the instrument on a level sheet of plate glass and clamp a known mass in grams, W, to the radial edge of the sector beneath the jaws. The center of gravity of the mass (including means of attaching) shall be previously marked by a punched dot on the face of the mass that is to be in the front of the instrument.

22.2 Raise and set the sector as for tearing a specimen and, by means of a surface gage or convenient means, measure the hei[illegible] the center of gravity of the mass ab[illegible] plate. Then release the sector, allo[illegible] and note the pointer reading. W[illegible] touching the pointer, raise the sector [illegible] edge of the pointer just meets with its s[illegible] which position again determine the h[illegible] centimetres, h, of the center of gravity o[illegible] above the glass plate.

22.3 The work done is $W(H - h)$ g[illegible] metres. The pointer reading for [illegible] standard instrument and method spe[illegible] should be as follows:

$$W(H - h)/137.6$$

22.4 Five forces from 75 to 400 g fo[illegible] table range for the calibration, one or [illegible] being clamped on the edge of the sect[illegible] different positions, the work done in r[illegible] each being calculated and added togethe[illegible]

22.5 Make a record of deviations [illegible] indicated readings and make correspo[illegible] corrections in the test results.

22.6 It is unnecessary to repeat the ca[illegible] tion of the instrument provided it is k[illegible] adjustment and no parts become chan[illegible] worn, but the tearing distance, which eq[illegible] mm (1.7 in.) shall be checked prior t[illegible] series of tests and adjusted if necessary.

23. Test Specimen

23.1 The standard test specimen sha[illegible] rectangle of cloth approximately 100 m[illegible] in.) long and exactly 63 mm (2.50 in. [illegible] with the slit to be cut 20 mm (0.8 in [illegible] leaving a distance of exactly 43 mm ([illegible] between the end of the slit and the edg[illegible] specimen.

NOTE 7—Precautionary measures sh[illegible] taken to prevent or minimize the raveling o[illegible] last yarns and to ensure their being torn d[illegible] test. For preparing the specimen, a die or [illegible] conforming to Fig. 2 is useful.

24. Procedure

24.1 Place the specimen securely [illegible] clamps. Locate the knife attachment [illegible] slit the specimen midway between th[illegible] at right angles to the upper edge of the [illegible] Make a slit extending from the botton[illegible] the specimen to a point 4 mm (0.157 i[illegible] the top edge of the clamps leaving a di[illegible] 43 mm (1.7 in.) of uncut specimen pe[illegible] lar to the long dimension of the speci[illegible]

convenient means, measure the height, the center of gravity of the mass above the plate. Then release the sector, allow it to swing and note the pointer reading. Without touching the pointer, raise the sector until the tip of the pointer just meets with its stop. In this position again determine the height in metres, h, of the center of gravity of the mass above the glass plate.

The work done is $W(H - h)$ gram-metres. The pointer reading for the standard instrument and method specified shall be as follows:

$$W(H - h)/137.6$$

Five forces from 75 to 400 g form a suitable range for the calibration, one or more weights clamped on the edge of the sector in different positions, the work done in raising being calculated and added together.

Make a record of deviations of the indicated readings and make corresponding corrections in the test results.

It is unnecessary to repeat the calibration of the instrument provided it is kept in adjustment and no parts become changed or worn, but the tearing distance, which equals 43 mm (1.7 in.) shall be checked prior to each series of tests and adjusted if necessary.

Test Specimen

The standard test specimen shall be a rectangle of cloth approximately 100 mm (4.00 in.) long and exactly 63 mm (2.50 in.) wide, with the slit to be cut 20 mm (0.8 in.), thus leaving a distance of exactly 43 mm (1.7 in.) between the end of the slit and the edge of the specimen.

NOTE 7—Precautionary measures should be taken to prevent or minimize the raveling out of the yarns and to ensure their being torn during the test. For preparing the specimen, a die or template conforming to Fig. 2 is useful.

Procedure

Place the specimen securely in the clamps. Locate the knife attachment so as to place the specimen midway between the clamps at right angles to the upper edge of the clamps. Make a slit extending from the bottom edge of the specimen to a point 4 mm (0.157 in.) above the top edge of the clamps leaving a distance of 43 mm (1.7 in.) of uncut specimen perpendicular to the long dimension of the specimen. The accuracy of the readings obtained with the apparatus depends to a great extent on the exactness of this 43 mm (1.7 in.) of uncut specimen.

24.2 With the pendulum in the raised position, the movable clamps shall lie in the same plane as the fixed clamp forming an extension to the fixed clamp. This plane shall be perpendicular to the plane of oscillation of the pendulum.

24.3 The perpendicular from the line formed by the top edge of the clamps to the axis of suspension shall be 104 mm (4.09 in.) and shall make an angle of 27.5 deg with the plane of the specimen.

24.4 Press the sector release, causing the sector to fall, thus moving the pendulum clamp away from the fixed clamp so as to tear the specimen. Read from the scale, to the nearest division, the force required to tear the specimen.

24.5 Reject readings obtained where the tear deviates more than 10 mm (0.4 in.) away from the initial slit. Likewise, if the side of the specimen above the movable jaw rubs against the sector as the tear is made, reject the reading.

24.6 The machine, when used for a given specimen, shall be of such capacity that the maximum force required to tear the specimen is not greater than 85 percent or less than 15 percent of the rated capacity.

24.7 Make not less than five tests in each principal direction of the coated fabric.

25. Calculation and Report

25.1 Report the results as the force in newtons or pounds-force required to tear a specimen. If the Elmendorf Tear Tester is used, refer to Table I for calculating values in newtons or pounds-force.

25.2 Report the average, maximum and minimum results for both principal directions of the coated fabric. Designate these as longitudinal tear resistance and transverse tear resistance.

B—Tongue Tear Method

26. Testing Machine

26.1 The testing machine used for this test shall conform to the requirements of the machine used in the grab method for breaking

strength (see Section 9) with the following modifications: The face of the jaws shall measure 25 by 50 mm (1 by 2 in.) or more with the long dimension perpendicular to the direction of application of the load. All machine attachments for determining maximum loads shall be disengaged during this test.

27. Test Specimen

27.1 The specimen shall be a rectangle of 75 by 200 mm (3 by 8 in.) cloth. Five specimens from each of the warp and filling directions shall be tested. The short distance shall be parallel to the warp yarns for the warp tests, and parallel to the filling yarns for the filling tests. No two specimens for warp tests shall contain the same warp yarns, nor shall any two specimens for the filling tests contain the same filling yarns. A 75-mm cut shall be made at the center of and perpendicular to a short side of the specimen forming the tongues or cut strips.

28. Procedure

28.1 The machine, when used for a given specimen, shall be of such capacity that the maximum force required to tear the specimen is not greater than 85 or less than 15 percent of the rated capacity.

28.2 Center the specimen in the machine with one tongue or cut strip in each clamp. Start the machine and observe by means of an autographic recording device the force necessary to tear the cloth a distance of 75 to 100 mm (3 to 4 in.).

28.3 If a specimen slips between the jaws, breaks or tears in a direction other than that of the original cut, or if for any reason attributable to faulty technique, an individual measurement falls markedly below the average test result for the sample unit, discard and test another specimen.

29. Report

29.1 The tearing strength of the test specimen shall be the average of the five highest peak loads of resistance (not including the initial peak) registered during the separation of the tear. The tearing strength of the sample unit shall be the average of the results obtained from the five specimens tested in each of the warp and filling directions and shall be reported separately to the nearest 0.5 N (0.1 lbf).

HYDROSTATIC RESISTANCE

30. Hydrostatic Resistance

30.1 The hydrostatic resistance of a coated fabric shall be determined by Method A which uses a Mullen-type hydrostatic tester or, when specified, by Method B which uses the hydrostatic pressure of a rising column of water (Suter test).

Method A—Pressure Application by Mullen-Type Hydrostatic Tester

31. Testing Machine

31.1 Requirements for the testing machine are outlined in 31.2; however, any machine that operates on the same principle and has coaxial apertures of 31.2 ± 0.5 mm (1.24 ± 0.02 in.) in diameter in the clamping surfaces is a valid machine.

31.2 The testing machine to be used may be either mechanically or manually operated. It shall permit the clamping of the material to be tested between two circular clamps about 75 mm (3 in.) in diameter having coaxial apertures of their centers 31.2 ± 0.5 mm (1.24 ± 0.02 in.) in diameter. The surfaces of the clamps between which the specimen is to be placed, shall be concentrically grooved. The grooves shall be spaced 0.8 mm (0.031 in.) apart and of a depth not less than 0.15 mm (0.006 in.). The grooves shall not start closer than 3.18 mm (0.125 in.) from the edge of the aperture. The lower clamping surface shall have a recession concentric to the aperture capable of accepting an O-ring having a cross-sectional diameter of 4.7 ± 0.1 mm (0.187 ± 0.004 in.). The machine shall have means of applying hydraulic pressure to the underside of the clamped specimen until the specimen fails. The pressure shall be generated by means of a piston forcing water into the pressure chamber of the apparatus at the rate of 1.4 ± 0.1 cm^3/s (5.2 ± 0.3 $in.^3/min.$). The machine shall be fitted with a Bourdon gage, maximum-reading type, with the scale divided to read 2-N (0.5-lbf) units. Accuracy shall be within 2 N on readings from 0 to 180 N (0 to 100 lbf) and to 1.0 percent on any reading over 180 N. When the gage is calibrated, it shall be mounted in the same relative position as on the bursting tester.

NOTE 8—Any machine that operates on the

ciple and maintains the specified
of 85 ml/min. and in addition po
on the upper clamping surface of 3
24 ± 0.01 in.), is a valid machine for

Test Specimens

1 The test specimen cut from th
shall be of such size that the
sion is at least 12.5 mm (0.5 in.
the outside diameter of the ri
anism of the testing machine.

Procedure

33.1 Before clamping the specime
ing machine, bring the water leve
h the top of the rubber gasket so t
ket may exist between the wate
d the coated fabric being teste
herwise specified in the case of
ated on one side only, place the c
t to the water level. In the case
ated fabrics or double-texture fabr
rface may be used unless the side
facing downward against the wat
definitely specified. The temperat
water shall be the same as the a
temperature of the testing room. C
test in accordance with one of th
two procedures, except that when
and glass support is employed, only
2 shall be used.

33.1.1 *Procedure 1*—Increase t
steadily at the rate of displacement
15.3.1 and take a dial reading
appearance of water through the c
being tested. Make ten different
tions and take the average as the
resistance of the coated fabric.
isolated high or low result that is
in duplicate when a consistent ave
obtained without the abnormal
substitute a retest.

33.1.2 *Procedure 2*—Apply
pressure held constant within 1
against the test specimen for a pe
Any appearance of water throu
fabric that can be detected duri
will indicate failure to meet th
least ten specimens from any s
rial. The coated fabric will hav
met the required test if at least
tests show no leakage at the pre

NOTE 9—Any material that fail

...ple and maintains the specified displace-...of 85 ml/min, and in addition possesses an ...the upper clamping surface of 31 5 ± 0 25 ... 0 01 in), is a valid machine for this test

... Test Specimens

... The test specimen cut from the coated ... shall be of such size that the smallest ...on is at least 12 5 mm (0 5 in.) greater ... outside diameter of the ring-clamp ...ism of the testing machine.

... Procedure

... Before clamping the specimen into the ...g machine, bring the water level up flush ...the top of the rubber gasket so that no air ...may exist between the water surface ...the coated fabric being tested. Unless ...wise specified in the case of materials ...d on one side only, place the coated side ... to the water level. In the case of double-...d fabrics or double-texture fabrics, either ...e may be used unless the side to be put ...g downward against the water level is ...ely specified. The temperature of the ...r shall be the same as the atmospheric ...erature of the testing room. Conduct the ... in accordance with one of the following ... procedures, except that when the screen ...d glass support is employed, only Procedure ... shall be used.

...1 1 *Procedure 1*—Increase the pressure ...dily at the rate of displacement indicated in ...1 and take a dial reading at the first ...earance of water through the coated fabric ...g tested Make ten different determina-...ns and take the average as the hydrostatic ...stance of the coated fabric Discard an ...ated high or low result that is not repeated ...duplicate when a consistent average has been ...ained without the abnormal reading and ...stitute a retest

...1 2 *Procedure 2*—Apply a specified ...ssure held constant within 14 kPa (2 psi) ...inst the test specimen for a period of 5 min. ... appearance of water through the coated ...ric that can be detected during that period ...l indicate failure to meet the test. Test at ...st ten specimens from any sample of mate-...l The coated fabric will have satisfactorily ...t the required test if at least eight out of ten ...s show no leakage at the pressure specified

NOTE 9—Any material that fails to give a value of at least 35 kPa (5 psi) as measured by either procedure of testing shall be regarded as having too low a hydrostatic resistance to be measured by this method, and the alternate Method B of using the hydrostatic pressure of a rising column of water shall be tried

34. Report

34 1 The report shall include the following:

34 1.1 Statement of the method and procedure used and whether or not the screen and glass support was employed.

34.1 2 With Procedure 1, all observed and recorded data together with the average value of the hydrostatic resistance in kilopascals (pounds per square inch).

34.1.3 With Procedure 2, statement of the number of specimens tested, the specified pressure applied, and the number of specimens that withstood the pressure

Method B—Pressure Application by a Rising Column of Water

35. Testing Machine

35.1 The machine shall consist of a clamp for holding the specimen and a means of providing a column of water whose level can be raised. Figure 3 shows a suitable apparatus.

35 2 The clamp shall consist of a lower ring about 170 mm (6.75 in.) in outside diameter by 115 mm (4.5 in.) in inside diameter held in a fixed position and provided with a channel 9.5 mm (0.375 in.) in width into which a rubber gasket seats, and also a movable upper plate which shall be about 170 mm in outside diameter and shall carry the rubber gasket. A water chamber on top of the upper plate shall have a water opening into the clamp, and a vent pipe A suitable mechanism shall be provided to close the clamp with the specimen of fabric between the ring and plate.

35 3 The water leveler shall be provided with a water inlet, water outlet, and overflow pipe It shall be connected to the clamp by means of a rubber hose. The overflow pipe provides a means of maintaining a constant level of water. A suitable mechanism for raising the water leveler uniformly at the required rate and lowering it again shall be provided A chain and sprocket device driven by a motor and controlled by a suitable disk clutch has been found satisfactory.

35.4 A steel scale for measuring the height of the water column shall be attached to the water leveler in such a way that the zero is in the same horizontal plane as the constant water level at all times. A reference pointer in fixed position at the level of the face of the lower ring of the clamp shall be provided for measuring the distance of travel of the water leveler above the face of the clamp. The scale shall be graduated in millimeters (or sixteenths of an inch).

35.5 A mirror shall be provided under the clamp in order to observe any leaks in the fabric being tested.

36. Test Specimens

36.1 The test specimen of the coated fabric shall be at least 200 mm (8 in.) square. The specimen may include a seam if desired since the rubber gasket provides a means of obtaining a tight seal in the clamp. At least five specimens from any sample of material shall be tested.

37. Procedure

37.1 Conduct the test according to one of the following two procedures:

37.1.1 *Procedure 1*—Lay the specimen smoothly on the face of the lower ring of the clamp, and lower and fasten the upper plate in place. This shall form a watertight compartment. When the specimen is coated on only one side, place the coated side next to the water column, unless otherwise specified. With the leveler at the zero position, turn the water on and keep it running at such a rate as to overflow continuously. Raise the column at a rate of 10 mm/s until the first drop of water appears through the coated fabric. Read on the scale the height of the water column above the level of the specimen.

37.1.2 *Procedure 2*—An alternative procedure is placing the specimen in the clamp and raising the water column to a predetermined height and recording the time required for the first drop of water to penetrate the coated fabric.

38. Report

38.1 The report shall include the following:

38.1.1 Statement of the method and procedure used and the number of specimens tested.

38.1.2 With Procedure 1, the height of the column of water to the nearest 0.01 kPa (or to the nearest 1/16 in.), at which the first drop appeared on the underside of each of the coated fabric specimens, also the average value for all specimens.

38.1.3 With procedure 2, the preset height of the column of water and the time elapsed before the first drop of water appeared on the under side of each specimen of the coated fabric, also the average value for all specimens.

ADHESION OF COATING TO FABRIC[13]

39. Testing Machine

39.1 A testing machine as described in Section 9 shall be used, except that the speed of the pulling clamp shall be *either* 0.85 ± 0.05 mm/s (2.0 ± 0.1 in./min) or 5.00 ± 0.02 m/s (12 ± 0.5 in./min). The faces of the clamps shall measure 25 by 75 mm (1 by 3 in.), with the short dimensions parallel to the direction of application of the load. The distance between the clamps at the start shall be 25 mm. If the machine is of the pendulum type, the pendulum shall be disengaged from the ratchet. A pendulum-type machine shall be considered to be of proper capacity for the test, if, when the coating separates from the fabric, the angle that the pendulum makes with the vertical is between 9 and 45 deg.

40. Test Specimens

40.1 Specimens 50 mm (2 in.) in width and 200 mm (8 in.) in length shall be cut from the coated fabric. Two sets of two specimens each will be required, one set for adhesion in the longitudinal direction having the longer dimension parallel to the lengthwise direction of the fabric, and the other set for adhesion in the transverse direction having the longer dimension parallel to the crosswise direction of the fabric. These specimens shall be prepared for test as follows:

40.1.1 When the strength of the coating film exceeds the adhesive bond to the fabric, as with thick films, the specimen shall be prepared for test by carefully cutting the coating through the fabric on two parallel cuts *A* and *B*, 25 mm (1 in.) apart running lengthwise of the specimen as shown in Fig. 4. Cut *A* shall extend from the end of the specimen, *E*, to within 1 in.

...opposite end, *D*. Cut *B* shall extend f...
...within 50 mm (2 in.) of end *D*.
...of cuts *A* and *B* shall be joined toge...
...diagonal cut *C* which shall also...
...cut through the coating to the fa...
...edge of a knife shall be worked unde...
...formed by cuts *A* and *C* and the co...
...25-mm strip separated from the bac...
...distance of 50 mm from that point.

...1.2 With thin films or in cases wher...
...ng is not sufficiently strong to be stri...
...the fabric as described in 40.1.1,...
...mens of the coated fabric shall be...
...ed together face to face with an adh...
...ble for adhering the type of coating t...
...ated. The cuts shown in Fig. 4 shall...
...ade from one side being careful to...
...only through one layer of fabric an...
...ure the other fabric layer. The fabric...
...side shall then be stripped down...
...ance of 50 mm (2 in.). This will allo...
...ing fabric to be inserted in one jaw...
...chine, and a double thickness of coatin...
...backing fabric from the other piece...
...erted in the other jaw of the machine...
...aration between the coating and the...
...g fabric can then be measured as no...
...0.1.1.

NOTE 10—In case the fabric is too weak...
...ted in a 25-mm (1-in.) width, the specimen...
...at 75 mm (3 in.) in width and the st...
...duation cut 50 mm (2 in.) in width. The...
...ll then be recorded as newtons (pounds-f...
...mm) strip.

41. Procedure

41.1 Clamp the separated portion...
...25-mm (1 in.) strip in the lower jaw...
...esting machine and end *D* of the spec...
...the upper jaw so that the movement...
...lower jaw will separate the coating f...
...backing. The rate of travel of the lo...
...shall be one of the two speeds specified...
...The distance of separation of the co...
...piles shall be a minimum of 76 mm (...

42. Report

42.1 The report shall include the f...

42.1.1 Type of testing machine and...
...of travel of the lower jaw, and

42.1.2 The average test value for...
...two specimens cut in the longitudinal...
...and two specimens cut in the transve...

opposite end, *D*. Cut *B* shall extend from within 50 mm (2 in.) of end *D*. The cuts *A* and *B* shall be joined together diagonal cut *C* which shall also be cut through the coating to the fabric. of a knife shall be worked under the ed by cuts *A* and *C* and the coating 25-mm strip separated from the backing stance of 50 mm from that point.

.1.2 With thin films or in cases where the is not sufficiently strong to be stripped the fabric as described in 40.1.1, two ens of the coated fabric shall be ce- d together face to face with an adhesive le for adhering the type of coating being ated The cuts shown in Fig. 4 shall then ade from one side being careful to pene- only through one layer of fabric and not ure the other fabric layer. The fabric from side shall then be stripped down for a tance of 50 mm (2 in.). This will allow the ing fabric to be inserted in one jaw of the chine, and a double thickness of coating and acking fabric from the other piece to be ted in the other jaw of the machine. The aration between the coating and the back- fabric can then be measured as noted in .1.1

NOTE 10—In case the fabric is too weak to be d in a 25-mm (1-in.) width, the specimen may be 75 mm (3 in.) in width and the strip for ation cut 50 mm (2 in.) in width. The results then be recorded as newtons (pounds-force per in) strip.

41. Procedure

41.1 Clamp the separated portion of the 25-mm (1 in.) strip in the lower jaw of the ting machine and end *D* of the specimen in upper jaw so that the movement of the er jaw will separate the coating from the cking The rate of travel of the lower jaw all be one of the two speeds specified in 39.1. e distance of separation of the coating or es shall be a minimum of 76 mm (3 in.).

42. Report

42.1 The report shall include the following:

42.1.1 Type of testing machine and the rate travel of the lower jaw, and

42.1.2 The average test value for at least o specimens cut in the longitudinal direction d two specimens cut in the transverse direction. The averages of the five high peaks and the five low peaks shall be used to determine the pull in newtons (or pounds-force) for reporting the adhesion of the coating or plies

NOTE 11—When a test for hydrogen permeability is required, reference should be made to ASTM Method D 815, Testing Coated Fabrics—Hydrogen Permeance.[2]

TACK-TEAR RESISTANCE

43. Scope

43.1 This method covers the measurement of the resistance of a coated fabric to tearing under conditions simulating an installation that has been tacked in place. It is intended primarily for testing vinyl plastic coated fabrics for furniture or automotive applications.

44. Apparatus

44.1 The apparatus shall consist of the device illustrated in Fig. 5 and a testing machine conforming to the requirements of Section 9.

45. Test Specimens

45.1 The specimens shall be 50 mm (2 in.) in width and 150 mm (6 in.) in length. Two sets of five specimens each are required, one set for warp tack-tear strength, having the longer dimension parallel to the filling yarns, and the other set for filling tack-tear strength having the longer dimension parallel to the warp yarn.

46. Procedure

46.1 Clamp the device shown in Fig. 5 in the upper jaw of the testing machine and adjust the machine to compensate for its weight. Impinge the specimen on the needles, taking care that the line of needles is parallel to the threads to be tested and exactly 12.5 mm (0.5 in.) from the top edge of the specimen. Clamp the specimen in the lower clamp. Operate the machine as for a tension test with the distance from the bottom of the needles to the top of the lower clamp 75 mm (3 in.) and the rate of jaw separation 5 mm/s (12 in./min) with no load. The faces of the bottom clamp shall measure 25 by 75 mm (1 by 3 in.) or more. If the machine is of the pendulum type, disengage the pawls on the pendulum from the ratchet.

[2] *Annual Book of ASTM Standards*, Part 38.

Record the average force necessary to tear the fabric, preferably with an autographic recording device.

47. Report

47.1 Report the median of the results of the five individual tests on the warp as the warp tack-tear strength, and the median of the five individual tests on the filling as the filling tack-tear strength.

LOW-TEMPERATURE BEND TEST

48. Procedure

48.1 Determine the resistance of the material to low-temperature bending in accordance with ASTM Method D 2136, Testing Coated Fabrics—Low-Temperature Bend Test.[3]

LOW-TEMPERATURE IMPACT TEST

49. Procedure

49.1 Determine the resistance of the material to low-temperature impact in accordance with ASTM Method D 2137, Rubber Property—Brittleness Point of Flexible Polymers and Coated Fabrics.[3]

SEAM STRENGTH

50. Scope

50.1 The strength of coated fabric seams (lapped, lapped and bonded, and sewn seams) shall be tested by the modified grab method.

51. Significance

51.1 This method is intended to determine the seam strength for comparison with the strength of the coated fabric.

52. Testing Machine

52.1 The testing machine used for this test shall conform to the requirements of the machine used in the grab method for breaking strength (see Section 9) with the following modification: The face of the jaws shall measure 25 by 75 mm (1 by 3 in.) or more with the long dimension perpendicular to the direction of application of the load. The machine shall be adjusted to pull the clamps at a uniform rate of 5 mm/s (12 in./min).

53. Test Specimen

53.1 The specimen shall be a rectangle 50 by 200 mm (2 by 8 in.) with the seam horizontally across the center, perpendicular to the long direction. Unless otherwise specified in the material or product specification, three individual specimens shall be tested and the median of the three test results shall be recorded.

54. Procedure

54.1 The machine shall be of such capacity that the maximum force required to tear the seam of the specimen is not greater than 85 % or less than 15 % of the rated capacity.

54.2 Place the specimen symmetrically in the jaws of the testing machine with the seam centered between and parallel to the jaws and the shorter dimension at right angles to the direction of application of the force. Start the machine and observe by means of an autographic recording device the force or load necessary to slip the seam or rupture the fabric.

54.3 If a specimen slips between the jaws, breaks or tears in a direction other than parallel to the seam, or, if for any reason attributable to faulty technique an individual measurement falls 20 % below the median test results for the sample unit, discard and test another specimen.

55. Calculation and Report

55.1 The seam strength of the test specimen shall be reported as the median of all the individual results in kN/m (lbf/2 in.) to the nearest 0.01 kN/m (0.1 lbf/2 in.). The report shall include whether failure occurred in the seam or in the fabric.

[3] *Annual Book of ASTM Standards*, Parts 37 and 38.

TABLE I Factors for Ca

Instrument
[illegible]-dard instrument
W[illegible]out augmenting weight)
[illegible]-d instrument
W[illegible] NBS augmenting consisting of we[illegible]
[illegible]ctor fitted into the opening of the pendul[illegible]
[illegible]-dard instrument
W[illegible]th two augmenting weights consisting c[illegible]
[illegible]NBS weighted sector fitted into the open[illegible]
[illegible] the pendulum and another weighed section [illegible]
[illegible]to the first augmenting weight)
[illegible]-duty instrument
W[illegible]thout NBS augmenting weight)
[illegible]-duty instrument
[illegible]With one augmenting weight consisti[illegible]
[illegible]eighted sector fitted into the opening [illegible]
[illegible]ndulum)
[illegible]-duty instrument
[illegible]With two augmenting weights consisting [illegible]
[illegible]eighted sector fitted into the opening [illegible]
[illegible]endulum, and two weighted sectors fitted [illegible]
[illegible]eriphery of the pendulum)

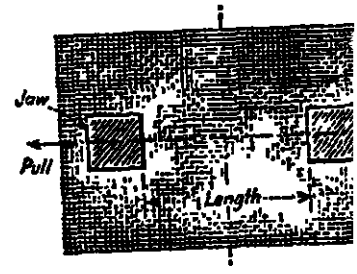


FIG. 1 Illustration of Grab Tes

TABLE 1 Factors for Calculating Tearing Force in Newtons (or Pounds-Force)

Instrument	Scale	Percentage Scale	Factor, N	Percentage Scale	Factor, lbf
[illegible] instrument [illegible] augmenting weight)	1	16	15.7	0.0353	3.53
[illegible] instrument [illegible] NBS augmenting consisting of weighted [illegible] fitted into the opening of the pendulum)	1	32	31.4	0.0706	7.06
[illegible] instrument [illegible] two augmenting weights consisting of the [illegible] weighted sector fitted into the opening of [illegible] pendulum and another weighed section fitted [illegible] the first augmenting weight)	1		62.8		14.12
[illegible] instrument [illegible] NBS augmenting weight)	1		62.8		14.12
[illegible] instrument [illegible] one augmenting weight consisting of [illegible] ghted sector fitted into the opening of the [illegible] dulum)	1		89.9		20.23
[illegible] instrument [illegible] two augmenting weights consisting of the [illegible] ghted sector fitted into the opening of the [illegible] dulum and two weighted sectors fitted on the [illegible] ery of the pendulum)	1		224.45		50.46

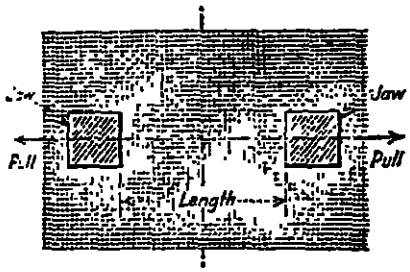


FIG. 1 Illustration of Grab Test

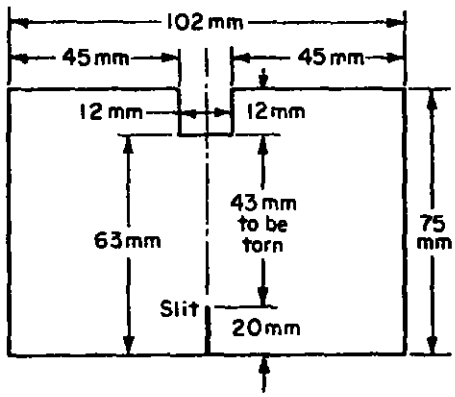


FIG. 2 Dimensions of Die or Template for Cutting Notched Specimens

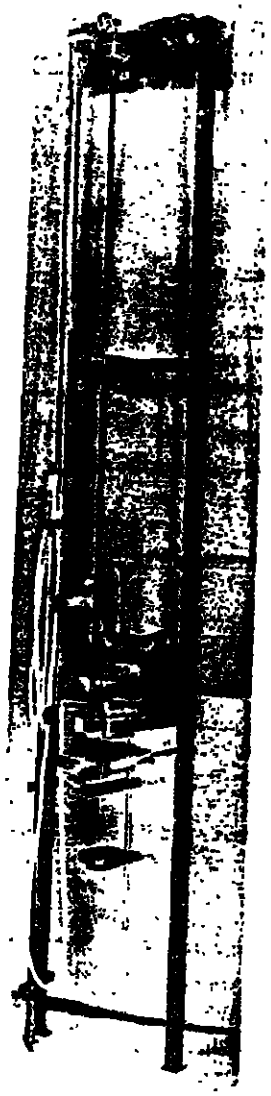
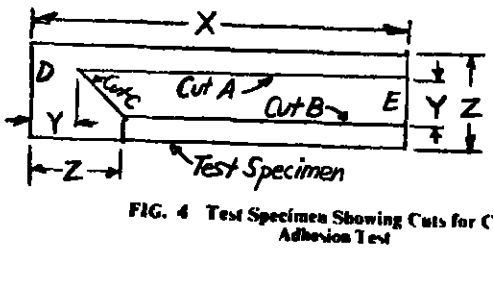
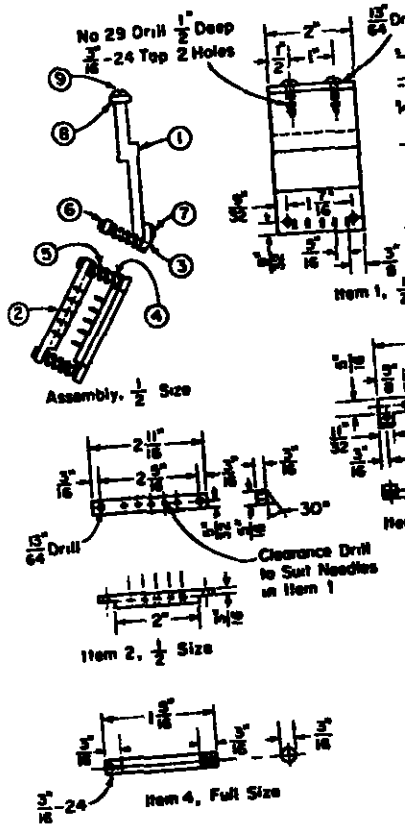


FIG. 3 Machine for Measuring Hydrostatic Resistance of a Coated Fabric by Using the Pressure of a Rising Column of Water



		mm	in
X	-	200	8
Y	-	25	1
Z	-	50	2

FIG. 4 Test Specimen Showing Cuts for Coating Adhesion Test

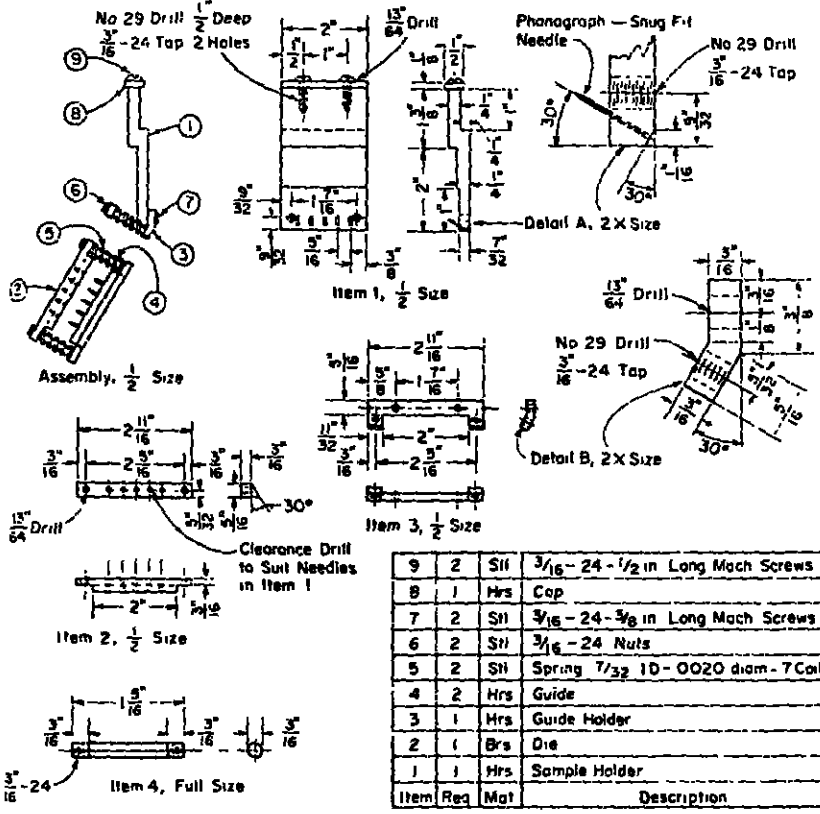


in.	mm
	1.159
1/16	3.175
1/8	3.969
5/32	4.762
3/16	5.159
13/64	5.556
7/32	6.350
1/4	7.144
9/32	7.938
5/16	8.731
11/32	

Fig. 5 Tack

The American Society for Testing and Material
nnection with any item mentioned in this standar
alidity of any such patent rights, and the risk of infr

This standard is subject to revision at any tim
ears and if not revised, either reapproved or wit
or additional standards and should be addressed
at a meeting of the responsible technical committe
a fair hearing you should make your views know
19103, which will schedule a further hearing re
ASTM Board of Directors.



Item	Req	Mat	Description
9	2	Stl	3/16 – 24 – 1/2 in Long Mach Screws
8	1	Hrs	Cap
7	2	Stl	3/16 – 24 – 3/8 in Long Mach Screws
6	2	Stl	3/16 – 24 Nuts
5	2	Stl	Spring 7/32 ID – 0020 diam – 7 Coil – 1 in
4	2	Hrs	Guide
3	1	Hrs	Guide Holder
2	1	Brs	Die
1	1	Hrs	Sample Holder

in	mm	in	mm
1/16	1 159	5/8	9 525
1/8	3 175	1/2	12 700
5/32	3 969	5/8	15 875
3/16	4 762	1	25 400
13/64	5 159	1 3/16	33 338
7/32	5.556	1 3/8	34 925
1/4	6 350	1 7/16	36 512
9/32	7.144	2	50 800
5/16	7,938	2 5/16	58 735
11/32	8 731	2 11/16	68 262

Fig 5 Tack-Tear Tester for Coated Fabrics

The American Society for Testing and Materials takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, is entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 1916 Race St., Philadelphia, Pa 19103, which will schedule a further hearing regarding your comments. Failing satisfaction there, you may appeal to the ASTM Board of Directors.

15. Annual Book of ASTM Standards, "Standard specification for Glass-Fiber-Reinforced Polyester Underground Petroleum Storage Tanks," D4021-81, American Society for Testing and Materials, Philadelphia, Pennsylvania, 1981, pp. 1-13

From Paul Robinson
OCF

Designation: D 4021 – 81

AMERICAN SOCIETY FOR TESTING AND MATERIALS
1916 Race St., Philadelphia, Pa. 19103
Reprinted from the Annual Book of ASTM Standards, Copyright ASTM
If not listed in the current combined index, will appear in the next edition.

Standard Specification for GLASS-FIBER-REINFORCED POLYESTER UNDERGROUND PETROLEUM STORAGE TANKS[1]

This standard is issued under the fixed designation D 4021, the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

1. Scope

1.1 This specification covers glass-fiber-reinforced horizontal, cylindrical, and spherical-type underground tanks for atmospheric pressure storage of petroleum based fuels and oils.

1.2 The values given in parentheses are provided for information purposes only.

2. Applicable Documents

2.1 *ASTM Standards*:

C 33 Specification for Concrete Aggregates[2]

C 581 Test for Chemical Resistance of Thermosetting Resins Used in Glass Fiber Reinforced Structures[3]

D 471 Test for Rubber Property—Effect of Liquids[4]

D 618 Conditioning Plastics and Electrical Insulating Materials for Testing[5]

D 698 Tests for Moisture—Density Relations of Soils and Soil-Aggregate Mixtures Using 5.5-lb (2.49-kg) Rammer and 12-in. (305-mm) Drop[6]

D 790 Test for Flexural Properties of Plastics and Electrical Insulating Materials[7]

D 883 Definitions of Terms Relating to Plastics[8]

D 1600 Abbreviations of Terms Relating to Plastics[9]

D 2583 Test for Indentation Hardness of Rigid Plastics by Means of a Barcol Impressor[7]

D 2584 Test for Ignition Loss of Cured Reinforced Resins[9]

D 3299 Specification for Filament-Wound Glass Fiber Reinforced Polyester Chemical-Resistant Tanks[10]

F 412 Definitions of Terms Relating to Plastic Piping Systems[10]

2.2 *Other Documents*:

ANSI B2.1 American Standard Tapered Pipe Threads[11]

ANSI B16.5 Steel Pipe Flanges, Flanged Valves, and Fittings[11]

ASME Boiler and Pressure Vessel Code Section III, Division I—Sub Section ND[12]

3. Descriptions of Terms

3.1 *General*—Definitions are in accordance with Definitions D 883 and F 412, and abbreviations with Abbreviations D 1600, unless otherwise indicated.

3.2 *cylinder wall*—that portion of the tank that forms the main body of the tank, and that part that lies horizontal in the ground after installation. (See Fig. 1 for further clarification.)

3.3 *tank heads*—that portion of the tank that closes the ends of the cylinder, making the tank into a container. Each tank has two tank heads (See Fig. 1 for further clarification.)

---

[1] This specification is under the jurisdiction of ASTM Committee D-20 on Plastics and is the direct responsibility of Subcommittee D20.23 on Reinforced Plastic Piping Systems and Chemical Equipment.

Current edition approved Aug. 31, 1981. Published September 1981.

[2] *Annual Book of ASTM Standards*, Parts 14 and 15.

[3] *Annual Book of ASTM Standards*, Parts 34 and 35.

[4] *Annual Book of ASTM Standards*, Part 37.

[5] *Annual Book of ASTM Standards*, Parts 22, 35, and 39.

[6] *Annual Book of ASTM Standards*, Part 19.

[7] *Annual Book of ASTM Standards*, Part 35.

[8] *Annual Book of ASTM Standards*, Parts 34, 35, and 36.

[9] *Annual Book of ASTM Standards*, Part 36.

[10] *Annual Book of ASTM Standards*, Part 44.

[11] Available from American National Standards Institute, Sales Dept., 1430 Broadway, New York, N.Y. 10018.

[12] Available from American Society of Mechanical Engineers, United Engineering Center, 345 E. 47th St., New York, N.Y. 10017.

3.4 *spherical tanks*—tanks that are spherical or near sperhical in shape. These tanks may be formed in one piece or may be formed by joining two hemispherical like tank heads together.

3.5 *fittings*—openings used to provide a means to fill, extract, or vent the contents of the tank.

3.6 *fill tubes*—devices attached to the tank to assist in filling. These devices normally attach to the tank top and convey the liquid to or near to the tank bottom.

3.7 *lifting device*—hook-on type device attached to the tank to provide means of lifting the tank.

3.8 *manways*—entrance ways installed in the tank for the purpose of access into the tank.

4. Materials

4.1 *Resin*—The resin used shall be a commercial-grade unsaturated polyester resin.

4.2 *Reinforcing Materials*—Reinforcing materials shall be commercial-grade "E" type glass in the form of mat, continuous roving, chopped roving, or roving fabric, or combination of these, having a coupling agent that will provide a suitable bond between the glass reinforcement and the resin.

4.3 *Surfacing Materials*—If reinforcing material is used on the surface exposed to the contained substance, it shall be a commercial-grade chemical-resistant glass or organic surfacing mat, having a coupling agent that will provide a suitable bond with the resin.

4.4 *Fillers and Additives*—Fillers, when used, shall be inert to the environment and the tank materials of construction. Additives, such as thixotropic agents, catalysts, promoters, etc., may be added as required by the specific manufacturing process to be used to meet this standard. The resulting glass-fiber-reinforced plastic material must meet the requirements of this specification.

5. Manufacture

5.1 One-piece spherical-type tanks, tank cylinders, tank heads, reinforced-plastic flanged and gusseted nozzles, manways, and fill tubes shall be produced from glass-fiber-reinforced plastic, with the construction determined by the particular process of manufacture and configuration. The manufacturing process may include contact-molding, compression-molding, pultrusion, centrifugal-casting, filament-winding, etc., or combination of these processes. Manway covers or manway blinds shall be constructed from steel plate.

5.2 *Lifting Device*—Each tank shall be provided with a means of lifting, by having one or more "hook-on"-type devices attached to the tank.

5.3 *Fittings*—Each tank shall be provided with openings. These openings shall be steel-threaded, glass-fiber-reinforced plastic flanged nozzles, or fiber-reinforced plastic flanged and gusseted nozzles.

5.3.1 Fittings may be installed in any location on the tank except at assembly joints, and in any quantity, provided they meet all the requirements of this specification. Care shall be taken to avoid installing fittings at rib locations.

5.4 Fill tubes or other interior projections fixed at the tank "top" shall clear the tank bottom by a minimum of 3 % of the tank inside diameter.

5.5 Manways may be of any shape or size, provided the requirements of this specification are met.

5.6 *Assembly Joints*—Product segments for horizontal cylindrical- and spherical-type tanks may be joined together to form a complete tank. Allowable joint types shall be butt with overlay, and bell-spigot with overlay.

5.7 *Anchor System Loading*—Each tank shall be capable of being anchored.

NOTE 1—The tank anchor system (straps, cables, turnbuckles, etc.) should have the strength of at least 1½ times the maximum uplift force of the empty tank without backfill in place.

6. Requirements

6.1 *Workmanship*:

6.1.1 *Exterior Surface*—The exterior surface shall be relatively smooth, with no sharp projections. Hand work finish is acceptable if enough resin is present to eliminate fiber show. The exterior surface shall be free of blisters larger than ½ in. (13 mm) in diameter, delamination, and fiber show.

6.1.2 *Interior Surface*—The interior surface shall be resin-rich with no exposed fibers. The surface shall be free of crazing, delamination, blisters, and wrinkles of ⅛ in. (3.2 mm) or greater in depth. Surface pits shall be permitted up to 6/ft² (65/m²), if they are less than ¾ in. (19 mm) in diameter and less than 1/16 in. (1.6

mm) deep. Voids entirely beneath the surface of the laminate, that cannot be broken with finger pressure, shall be permitted up to 4/ft² (43/m²), if they are less than ½ in. (13 mm) in diameter.

6.2 *Repairs*—Any tank may be repaired prior to shipment, provided the repaired tank meets all requirements of this specification.

6.3 *Dimensions*—The dimensions shall be as provided in this specification when measured in accordance with 8.3.1.

6.3.1 *Inside Diameter*—Nominal inside diameters shall be 48 in. (1219 mm), 72 in. (1828 mm), 90 in. (2296 mm), 92 in. (2337 mm), 118 in. (2997 mm), 120 in. (3048 mm), and 138 in. (3505 mm). Tolerance shall be ±1 % of nominal inside diameter. Other diameters, as agreed upon between the purchaser and the manufacturer, may be specified.

6.3.1.1 The cylinder wall of the tank may be tapered but shall not exceed 0.5° per side. The taper, if any, shall be additive to the nominal inside diameter.

NOTE 2—The cylinder wall of the tank may have ribs added which will increase the outside diameter substantially.

6.3.2 *Thickness*—The minimum cylinder wall thickness and minimum tank-head thickness shall be 0.20 in. (5 mm).

6.3.3 *Tank Head*—The tank head shall have a knuckle radius (KR) equal to or greater than 0.03 times the head diameter (D), but never less than 1½ in. (38 mm). The tank head radius (DR or HR) shall be equal to or less than the head diameter (D). Typical tank heads are shown in Figs. 2 through 6. Other head shapes are allowed provided all other performance requirements are achieved.

6.3.4 *Steel Fitting Diameters*—Standard threaded steel (NPT) fitting diameters shall be ¾ in., 1.0 in., 1¼ in., 1½ in., 2.0 in., 2½ in., 3.0 in., 4.0 in., 6.0 in., and 8.0 in. Typical tank fittings are shown in Fig. 7.

6.3.5 *Reinforced Plastic Fitting Diameters*—Standard fiberglass reinforced plastic (FRP) flanged fitting diameters shall be 2.0 in., 3.0 in., 4.0 in., 6.0 in., 8.0 in., 10.0 in., 12.0 in., 14.0 in., 16.0 in., 18.0 in., and 20.0 in. Typical FRP flanged fittings are shown in Fig. 7 and dimensions are listed in Tables 1 and 2.

6.4 *External Load Requirements*—The complete tank with fittings, manways, fill tube, etc. attached, shall meet the load requirements when tested in accordance with 8.4.

6.4.1 *Earth Load*—The tank when installed with a 36 ± 3 in. (914 ± 76 mm) cover on top of the tank, shall not leak, fail, or deflect more than 2 % of the unbackfilled, unloaded tank vertical diameter when measured at a fitting near the center of the tank.

6.4.2 The tank when installed with a 36 ± 3 in. (914 ± 76 mm) cover on top of the tank, and with a concentrated load of 22 400 lb (10 168 kg) applied at the surface of the cover, shall not leak, fail, or deflect more than 2 % of the unbackfilled, unloaded tank vertical diameter when measured at a fitting near the center of the tank.

6.4.3 *External Hydrostatic Pressure*

6.4.3.1 For tanks to be installed at depths of cover to 36 ± 3 in. (914 ± 76 mm) the tank shall withstand, when installed with 36 ± 3 in. (914 ± 76 mm) of cover on top of the tank, an external water-pressure load equal to the diameter of the tank plus 36 ± 3 in. (914 ± 76 mm). This external water pressure shall be held for 24 h. The tank shall not leak, fail, or deflect more than 2 % of the unbackfilled, unloaded tank vertical diameter when measured at a fitting near the center of the tank.

6.4.3.1.1 For tanks to be installed at depths of cover to 36 ± 3 in. (914 ± 76 mm), the tank shall withstand after the 24-h hold detailed in 6.4.3.1, an external water-pressure head-load equal to the diameter of the tank plus 36 ± 3 in. (914 ± 76 mm), and an additional superimposed negative internal pressure of 5.3 in. Hg (18 kPa). The tank shall not leak or fail by other means after holding this superimposed negative internal pressure for 1 min.

6.4.3.2 For tanks to be installed at depths of cover greater than 36 ± 3 in. (914 ± 76 mm), the tank shall withstand when installed with the desired depth in inches ± 3 in. (desired depth in millimetres ± 76 mm) of cover on the top of the tank, an external water-pressure load equal to the diameter of the tank plus the desired depth of cover. This external water pressure shall be held for 24 h. The tank shall not leak, fail, or deflect more than 2 % of the unloaded, unbackfilled tank vertical diameter when measured at a fitting near the center of the tank. As an alternative, the tank shall withstand, when installed with 36 ± 3 in. (914 ± 76 mm) of cover on the top of the tank, an external

water-pressure load equal to the tank diameter plus 36 ± 3 in (914 ± 76 mm) and an additional superimposed negative internal pressure equal to the [(depth of cover in feet − 3 ft) × 0 8826 in of Hg/ft] ([depth of cover in metres − 0.914 m) × 9 78 kPa/m]) This total external water pressure plus the superimposed negative internal pressure shall be held for 24 h. The tank shall not leak, fail, or deflect more than 2 % of the unbackfilled, unloaded vertical diameter when measured at a fitting near the center of the tank.

6.4.3 2 1 For tanks to be installed at depths of cover greater than 36 ± 3 in. (914 ± 76 mm) the tank shall withstand, after the 24 h hold as detailed in 6.4.3.2, an external water-pressure head equal to the tank diameter plus desired depth of cover in inches ± 3 in. (desired depth of cover in millimetres ± 76 mm) and an additional superimposed negative internal pressure of 5.3 in Hg (18 kPa). The tank shall not leak or fail by other means after holding this superimposed negative internal pressure for 1 min. As an alternative, the tank shall withstand after the 24-h hold detailed in 6 4.3.2, an external water-pressure head equal to the tank diameter plus 36 ± 3 in. (914 ± 76 mm) and an additional superimposed negative internal pressure equal to the [(depth of cover in feet − 3 ft) × 0 8826 in. of Hg/ft] ([(depth of cover in metres − 0.914 m) times 9.78 kPa/m]) plus 5.3 in. Hg (18 kPa). The tank shall not leak or fail of other means after holding this superimposed internal pressure for 1 min.

6 5 *Internal Pressure*—Tanks of diameter 120 in. (3048 mm) and less shall withstand 25 psig (172.5 kPa) and tanks greater than 120 in (3048 mm) in diameter shall withstand 15 psig (103.5 kPa) when tested in accordance with 8.5.

6.6 *Fitting Moment Load Rating*—Fittings 2 in. and smaller shall withstand, without damage, a moment load of 1000 lbf·ft (1356 N·m) and fittings greater than 2 in shall withstand, without damage, a moment load of 2000 lbf·ft (2712 N·m) when tested in accordance with 8.6. After the test the fitting shall not leak when tested in accordance with 8.8.

6.7 *Fitting Torque Load Rating*—Each installed fitting shall withstand, without damage, the loads in Table 3 when tested in accordance with 8.7. After the test, the fitting shall not leak when tested in accordance with 8.8.

6 8 *Leakage*—When tested in accordance with 8.8, tanks of 120 in. (3048 mm) diameter and less, complete with attachments, shall not leak at a pressure level of 5 psig (34.5 kPa), and tanks greater than 120 in. (3048 mm) diameter, complete with attachments, shall not leak at a pressure level of 3 psig (20.7 kPa).

6.9 *Internal Impact Resistance*—The internal tank wall surface shall withstand, without visible damage, the impact of an 0.8 lb (0.36 kg) steel ball when tested in accordance with 8.9.

6.9.1 After impact with the steel ball as described in 6.9, the tank shall not leak when tested in accordance with 8 8.

6.10 *Lifting Lug Loading*—All lifting lugs must meet or exceed a load rating equal to two times the weight of the empty tank when tested in accordance with 8.10. The tank, as a result of the test, must not leak or suffer other damage. If the tank has more than one lifting device, the devices shall meet the requirement in combination.

6 11 *Negative Pressure*—The tank shall withstand negative pressure of −2.5 psig (−17.3 kPa) when tested in accordance with 8.11

6.12 *Material Properties*—The following properties shall be established for each type of construction used in the tank using test specimens obtained in accordance with 8.12.

6.12.1 Material composition in percent by weight shall be determined in accordance with 8.12.1.

6.12.2 Flexural strength in the hoop and axial direction shall be determined in accordance with 8 12.2.

6 12.3 Flexural modulus in the hoop and axial direction shall be determined in accordance with 8.12 2

6 12.4 Surface hardness shall be determined in accordance with 8.12.3. The minimum value shall be not less than 90 % of the resin manufacturer's minimum value for the cured resin.

6.13 *Chemical Resistance*—When tested in accordance with 8.13, the log of percent retention of each property after immersion testing, when plotted against the log of immersion time and extrapolated to 100 000 h, shall assure retention of at least 50 % of the initial properties

NOTE 3—Chemical testing is conducted to determine the applicability of the tank materials of construction to specific use conditions It is not considered to be a quality control procedure

7. Quality Control

7.1 *Examination*—Each tank component shall be examined for dimensional requirements, hardness, and workmanship.

7.2 *Leakage*—Each tank shall be tested in accordance with 8.8 to determine conformance with 6.8

7.3 *Negative Pressure*—Each tank shall be tested in accordance with 8.11 to determine conformance with 6.11.

7.4 *Composition Control*—Controls on glass, resin, fillers, and additives shall be maintained for all manufacturing processes and for each portion of tank fabrication. Records shall be maintained of these control checks. Proper composition may be shown by glass usage checks, by glass and resin application rate checks, or in accordance with the material composition test in 8.12 1.

NOTE 4—Weighing of finished parts and periodic testing for material properties may provide additional assurance of quality.

8. Test Methods

8.1 *Conditioning*—Conditioning of the test specimen is not required unless otherwise specified by the test method referenced. When required, conditioning of the specimen prior to test shall be at 73.4 ± 3.6°F (23 ± 2°C) and 50 ± 5 % relative humidity for not less than 40 h, in accordance with Procedure A of Methods D 618.

8.2 *Test Conditions*—Tests shall be conducted at ambient temperatures without any special controls on temperature or humidity, unless otherwise specified in the test method referenced.

8.3 *Dimensions*:

8 3.1 Measure dimensions other than thickness with a steel tape with graduations of ⅛ in (3 mm) or less

8 3 2 *Thickness*—Measure to the nearest 0 01 in (0 25 mm) with a micrometer, caliper gage, or other suitable instrument. Make a minimum of one thickness determination in each 10 ft² (1 m²) of tank wall surface and tank head surface. Through regions of taper, make sufficient checks to establish actual thickness

8 4 *External Load Tests*.

8 4.1 *Tank Sample*—Test tanks of each diameter used. In the case of tanks with the equal diameter, but of different lengths, testing of the longest tank shall confirm performance of shorter lengths provided the wall thickness is constant If wall thickness varies with length, test each tank to prove conformance.

8.4.2 *Test Preparation*—Install the tank in a pit large enough to allow a minimum of 12 in. (305 mm) distance from the sides of the pit and the tank surface. The pit may be one with rigid walls, such as concrete, or may be an excavation in the ground with a soil-bearing pressure capacity of greater than 3500 lbf/ft² (168 kPa). Determine the depth of the pit by adding to the tank diameter a backfill bed of 12 in. (305 mm) and a backfill cover of 36 ± 3 in. (914 ± 76 mm).

8.4.2.1 The bed, side support, and cover material shall be a naturally rounded aggregate with particle size not less than ⅛ in. or more than ¾ in. (3.2 to 19.0 mm) in diameter and shall be classified as free flowing As alternatives, either an angular material, clean and free flowing, with particle size not less than ⅛ in. or more than ½ in. (3 2 to 13 mm) in diameter or a clean, well-graded sand with maximum particle size of ⅛ in. (3 2 mm) with no more than 8 % fines passing a 200-mesh sieve may be used. In the case of sand, take care to compact the material to a density of at least 85 % of the maximum, as determined by Method D 698. These materials shall meet the requirements of Specification C 33 for quality and soundness.

8.4 2.2 Place the tank on a 12-in. (305-mm) bed composed of the material described in 8.4 2.1. Take care to ensure that the tank is no closer than 12 in (305 mm) to the sides of the pit.

8.4.2.3 Anchor the tank to prevent float-out during testing. Place the anchoring at the positions provided on the tank.

8.4.2.4 After anchoring, place the material described in 8.4 2 1 around the tank uniformly around to the top of the tank. Take care to ensure that the material is placed under the tank and tank heads.

8.4.2.5 Use the material described in 8 4.2.1 as the cover for the tank and place it to the ground surface or top of the pit. The depth of the cover shall be 36 ± 3 in (914 ± 76 mm).

8 4.2.6 The tank shall be fitted with a vent, fill tube, and outlet prior to beginning the test.

8 4 3 *Cover Load Test*—Subject the tank to a load imposed by the cover over the top of the tank as described in 8.4 2.5. Measure the change in vertical tank diameter at a fitting

near the center of the tank before and after cover.

8.4.4 *Concentrated Load Test*—Subject the tank to a concentrated load of 22 400 lb (10 168 kg). Apply this load to a load-bearing plate 20 by 20 in. (500 by 500 mm) at the top of the cover material. Measure the change in vertical tank diameter at a fitting near the center of the tank.

8.4.5 *External Hydrostatic Pressure Load Test*:

8.4.5.1 For tanks to be installed with 36 ± 3 in. (914 ± 76 mm) of cover, flood the pit with water to a distance 36 ± 3 in. (914 ± 76 mm) above the top of the tank. The tank shall be empty and anchored. Leave the tank in the fully flooded pit for 24 h. Measure the change in vertical diameter at a fitting near the center of the tank.

8.4.5.1.1 For tanks to be installed with 36 ± 3 in. (914 ± 76 mm) of cover, flood the pit with water as described in 8.4.5.1. After the 24 h have elapsed, superimpose a negative internal pressure of 5.3 in. Hg (18 kPa) on the tank and hold for 1 min. At the end of the 1-min hold, terminate the test.

8.4.5.2 For tanks to be installed at depths of cover greater than 36 ± 3 in. (914 ± 76 mm), install the tank in a pit deep enough to allow for the pit to be flooded with water to a height above the top of the tank equal to the depth of cover desired. In this test, the pit should be deep enough to allow for a bed, as described in 8.4.2, plus the depth of cover desired. The tank shall be empty and anchored. Flood the pit with water to a distance equal to the depth of cover desired ± 3 in. (±76 mm). Leave the tank in the fully flooded pit for 24 h. Measure the change in vertical diameter at a fitting near the center of the tank. Alternatively, this test may be run as described in 8.4.5.1 with a superimposed negative internal pressure equal to the (depth of cover in feet − 3 ft) × 0.8826 in. of Hg/ft ([(depth of cover in millimetres − 0.914 m) × 9.78 kPa/m]) added. In this alternative test, maintain both the 36 ± 3 in. (914 ± 76 mm) of water over the top of the tank and the superimposed negative internal pressure for 24 h. Measure the change in vertical diameter at a fitting near the center of the tank.

8.4.5.2.1 For tanks to be installed at depths of cover greater than 36 ± 3 in. (914 ± 76 mm), install the tank as described in 8.4.5.2. After the 24 h have elapsed, superimpose a negative internal pressure of 5.3 in. Hg (18 kPa) on the tank and hold for 1 min. Terminate the test at the end of 1 min.

8.5 *Internal Pressure Tests*:

8.5.1 *Tank Sample*—Test each tank of a specific diameter, wall thickness, or configuration and head thickness, or configuration or combination of these. In the case of tanks with the same diameter but different lengths, testing of the longest tank shall confirm performance of the other lengths, provided the wall thickness is constant.

8.5.2 *Test Procedure*—Test each size of tank to be tested to the required pressure level, holding the pressure for a period of 1 min. Run the test using a pressure gage graduated in increments of 1 psig (6.9 kPa) or less. Failure to hold the required pressure, with a 10 % drop allowed for pressure settlement, is indication of failure. The test may be performed by two different methods, hydrostatic or aerostatic.

8.5.2.1 *Hydrostatic Test* (Preferred Method)—Fill the tank with water and impose an air surcharge to produce the required total pressure. Take care to ensure that the tank is supported in a manner to prevent the development of high bending stresses.

8.5.2.2 *Aerostatic Test*—Place the tank on a horizontal plane surface with no additional support. Take care by performing the test in an isolated area.

8.6 *Fitting Moment Test*—Apply moment loads to tank fittings through a pipe attached to the fitting. The moment arm shall be such that the required loads can be applied in increments of 100 lb (45.4 kg). Apply the loads in at least the tank circumferential and longitudinal direction.

8.7 *Fitting Torque Test*—Apply torque loads to the tank fittings. Transmit the applied loads to the fittings through a fitting plug attached to the fitting in increments of 50 lb (22.7 kg).

8.8 *Leakage Test*—Subject the tank to an aerostatic test to the required pressure level above ground without special support, using a pressure gage graduated in 0.25-psig (1.75-kPa) increments or less. While holding at the required pressure level, soap the entire tank with a liquid composed of water and leak-test fluid or detergent. After soaping, check the tank visually for leaks, giving special attention to tank openings.

8.8.1 The pressure may drop in this test as the tank makes a temperature adjustment. Do not start the leakage test until the pressure settles and the tank holds the pressure. Make adjustments to the tank pressure to maintain the required pressure during this settling period.

8.9 *Internal Impact Resistance Test*—Bed the tank on a sand bed. Compact the bed well and take care to ensure that the tank bottom is in full contact with the bed. Position an 0.8-lb (0.36-kg) steel ball at a distance equal to the diameter of the tank above the tank bottom. Release the steel ball and allow it to free fall to the tank bottom.

8.10 *Lifting Lug Strength Test*—Test a tank with the lifting lug installed. Place a force to the required level on the lifting lug. Apply this force in a vertical plane, taking care to ensure that no load, other than in the vertical plane, is applied. If the tank has more than one lifting lug, test them in combination with the total load equal to the required load in accordance with the manufacturer's recommendation on spreader bars, etc.

8.11 *Negative Pressure Test*—Perform this test on a tank lying in a horizontal plane without special side support, using a vacuum pump capable of reaching the required negative test pressure and a mercury manometer graduated in increments of 0.1 psig (70 kPa) or less. The test level need only be reached to prove conformance.

8.12 *Material Properties*—Specimens taken from a tank should be used, if possible, to establish material properties. If it is not possible to take the specimens from a tank because of dimensional requirements for testing or the need of flat specimens for strength property tests, the specimens shall be made independently of the tank but, in any case, must be consistent in all respects with the construction of the tank.

8.12.1 *Material Composition*—Determine composition in accordance with Method D 2584. For specimens with fillers or additives, or both, separate the residue into its components (glass, sand, etc.) in order to determine the glass content.

8.12.2 *Flexural Strength and Modulus*—Determine the flexural strength and modulus in accordance with Method D 790.

8.12.3 *Surface Hardness*—Determine the hardness in accordance with Method D 2583. The frequency of checks shall be no less than four random points per component part.

8.13 *Chemical Resistance*—The testing procedure for measuring chemical resistance shall conform to Method C 581 with the exceptions noted below.

8.13.1 *Test Specimen Construction*—The basic test specimen shall be fabricated in a manner consistent in every way with the tank construction. Factors to be considered include percent glass, type of glass, resin, catalyst system, post-cure, fillers and additives, and whether or not air is excluded from the specimen surfaces during cure.

8.13.1.1 If the specimen is to be tested in an environment simulating a contained substance, a resin-rich layer may be added to the exterior portion of the specimen. This second resin-rich surface, not present in the tank itself, shall be of the same construction and thickness and made with the same considerations, (that is, exclusion of air) as the primary layer on the opposite side of the specimen. Where a dual-resin construction is used, this second resin-rich layer should employ the same resin as the first. Cut edges shall be sealed with the resin used in the resin-rich surfaces.

8.13.1.2 If the specimen is to be tested in an environment simulating soil conditions, it shall be that described in 8.13.1. Cut edges of the specimen shall be sealed with that resin used in the outer surface of the tank.

8.13.2 Test intervals for the specimens shall be determined by test temperature selected. When testing at 37.8°C (100°F) specimens shall be drawn and tested after 1 month, 3 months, and 6 months of immersion in each test medium. When testing at 23°C (73.4 °F) specimens shall be drawn and tested after 1 month, 3 months, 6 months, and 12 months of immersion in each test medium. It may be advisable to include an extra specimen in the test at the time of the initial immersion in the event it becomes necessary to extend the test interval because of inconclusive results. For applications that will require heated fuel or oils, the test interval shall be 1 month, 3 months, and 6 months.

8.13.3 *Test Media*—Test media shall be those specified in Table 4. For application that

will require heated fuel or oils, an additional test media shall be the materials stored in the tank.

8.13.4 The temperature for the test media in Table 4 shall be 23 ± 2°C (73.4 ± 3.6°F) or 37.8 ± 2°C (100 ± 3.6°F) and is dependent upon the testing interval selected from 8.13.2. For fuel or oils that require elevated temperatures, testing shall be at least at the maximum service temperature.

8.13.5 *Interpretation of Results*:

8.13.5.1 Properties to be determined initially and after each test period are flexural strength and flexural modulus (both in accordance with Method D 790, Method I, Procedure A), and Barcol hardness (in accordance with Method D 2583) of both the interior and exterior of the laminate. In the case of soil conditions testing, no exterior Barcol hardness is required. The specimen should be fully cured before initial properties are obtained.

8.13.5.2 Note any effect upon the immersion medium or specimen observed during visual inspection and use to augment physical data determining the suitability of the tank in any given medium.

8.13.5.3 Plot the log of percent retention of each property (see 8.13.5.1) after immersion testing (versus initial) against the log of immersion time in hours (see Fig. 8).

9. Inspection

9.1 Inspection of the material shall be made as agreed upon between the purchaser and the supplier as part of the purchase contract.

10. Rejection and Rehearing

10.1 Tanks that fail to conform to the requirements of this specification may be rejected. Rejection should be reported to the manufacturer or supplier promptly and in writing. In case of dissatisfaction with the results of any test, the manufacturer or supplier may make a claim for a rehearing.

11. Certification

11.1 When requested by the purchaser on his order, a certification shall be made the basis of acceptance. This shall consist of a copy of the manufacturer's test report, or a statement by the supplier, accompanied by a copy of the test results, that the tank has been sampled, tested, and inspected in accordance with the provisions of this specification and meets all requirements. Each certification so furnished shall be signed by an authorized agent of the supplier or manufacturer.

12. Marking

12.1 The tanks shall be marked with the following information:

12.1.1 This ASTM designation

12.1.2 Manufacturer's name or trademark.

12.1.3 Manufacturing serial number.

12.1.4 Installation instructions (to be printed and adhered, at the manufacturer's option, to the tank. Printing shall be typewritten size or larger).

12.1.5 Warning and caution statements:

12.1.5.1 Keep tank vented,

12.1.5.2 Maximum test pressure, 5 psig or 3 psig,

12.1.5.3 Do not drop tank, and

12.1.5.4 Caution: Do not fill before backfilling.

TABLE 1 Pipe for FRP Fittings

NOTE—Pipe wall thicknesses as outlined in this table, are in accordance with Specification D 3299

Pipe Size in	Pipe Size mm	Minimum Wall Thickness in	Minimum Wall Thickness mm
Contact-Molded FRP Pipe Minimum Wall Thickness			
2	51	3/16	4.8
3	76	3/16	4.8
4	102	3/16	4.8
6	152	3/16	4.8
8	203	3/16	4.8
10	254	3/16	4.8
12	305	3/16	4.8
14	356	1/4	6.4
16	406	1/4	6.4
18	457	1/4	6.4
20	508	1/4	6.4
Filament-wound FRP Pipe Minimum Wall Thickness			
2	51	0.140	3.6
3	76	0.140	3.6
4	102	0.180	4.6
6	152	0.180	4.6
8	203	0.200	5.1
10	254	0.200	5.1
12	305	0.200	5.1

TABLE 2 Minimum Flange Thickness for FRP Fittings

NOTE 1—These values are based on flat-faced flanges with full-face gaskets suitable for petroleum-based oils and fuels

NOTE 2—Flange dimensions (except thickness) and bolting conform to ANSI B16.5 for 150-lb steel flanges

NOTE 3—Flange thicknesses as outlined in this table are in accordance with Specification D 3299

NOTE 4—This table is based on a safety factor of 8 to 1 and a flexural strength of 20,000 psi (140 MPa)

Pipe Size in	Pipe Size mm	Minimum Flange Thickness in	Minimum Flange Thickness mm
2	51	1/2	12.7
3	76	1/2	12.7
4	102	1/2	12.7
6	152	1/2	12.7
8	203	9/16	14.3
10	254	11/16	17.5
12	305	3/4	19.0
14	356	13/16	20.3
16	406	7/8	22.2
18	457	15/16	23.4
20	508	1	25.4

TABLE 3 Fitting Torque Load Requirements

Fitting Size in	Fitting Size mm	Torque Load lbf·ft	Torque Load N·m
0.75	19	167	226
1.00	25	200	271
1.25	32	242	328
1.50	38	258	350
2.00	51	275	373
2.25	64	292	396
3.00	76	300	407
4.00	102	317	430
6.00	152	350	475
8.00	203	383	519

TABLE 4 Test Media for Chemical Resistance Test

Interior Surface
ASTM Reference Fuel C (as specified in Method D 471)
Commercial unleaded premium gasoline
Unleaded gasoline, ethyl alcohol 90 to 10 % blend gasohol
No. 2 Fuel Oil
Distilled water
Sodium carbonate-sodium bicarbonate solution (pH = 10)
Potassium biphthalate buffer (pH = 4)
Material to be contained in the tank if other than above
Exterior Surface
Sodium chloride saturated solution
Sodium carbonate-sodium bicarbonate solution simulating alkaline soil (pH = 10)
Potassium biphthalate buffer simulating acidic soil (pH = 4)

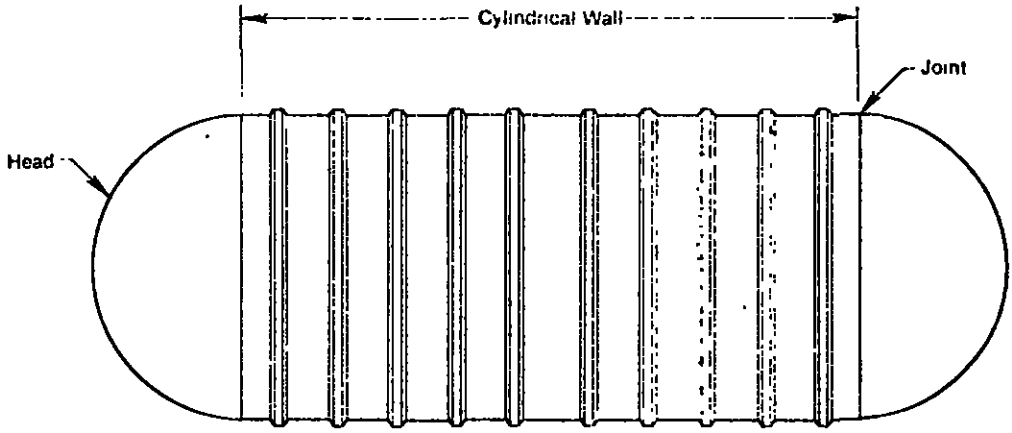


FIG. 1 Typical Tank

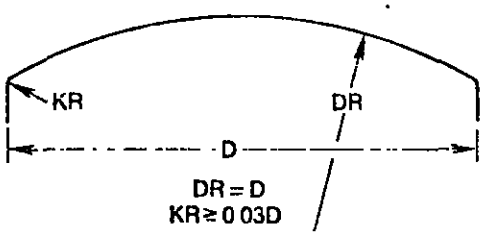


FIG. 2 Standard Dish Tank Head

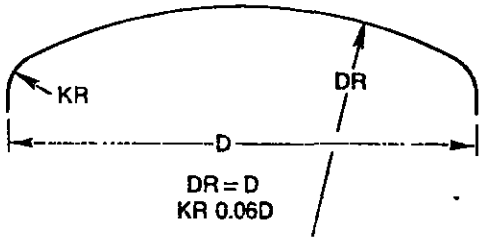


FIG. 3 ASME[12] Dish Tank Head

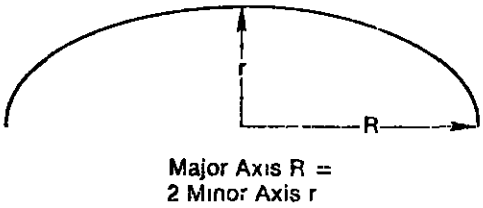


FIG. 4 Elliptical Tank Head

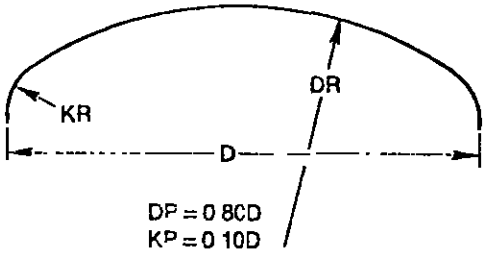


FIG. 5 80-10 Dish Tank Head

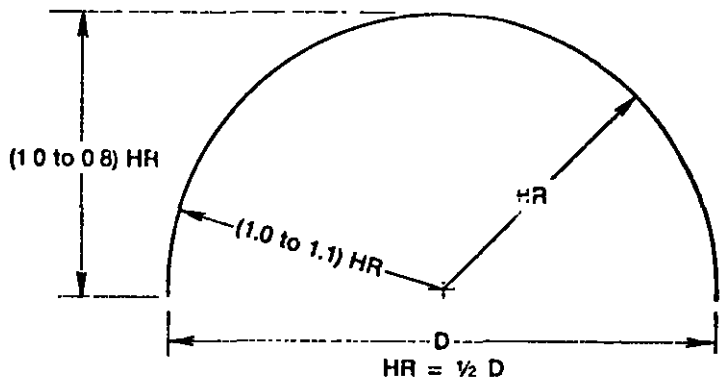


FIG. 6 Hemispherical-Like Tank Head

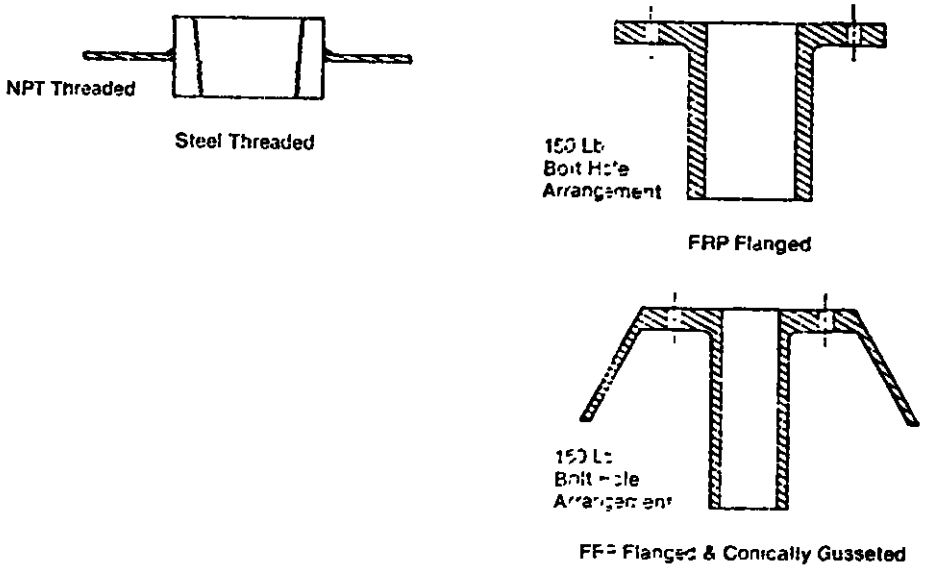


FIG. 7 Typical Tank Fittings

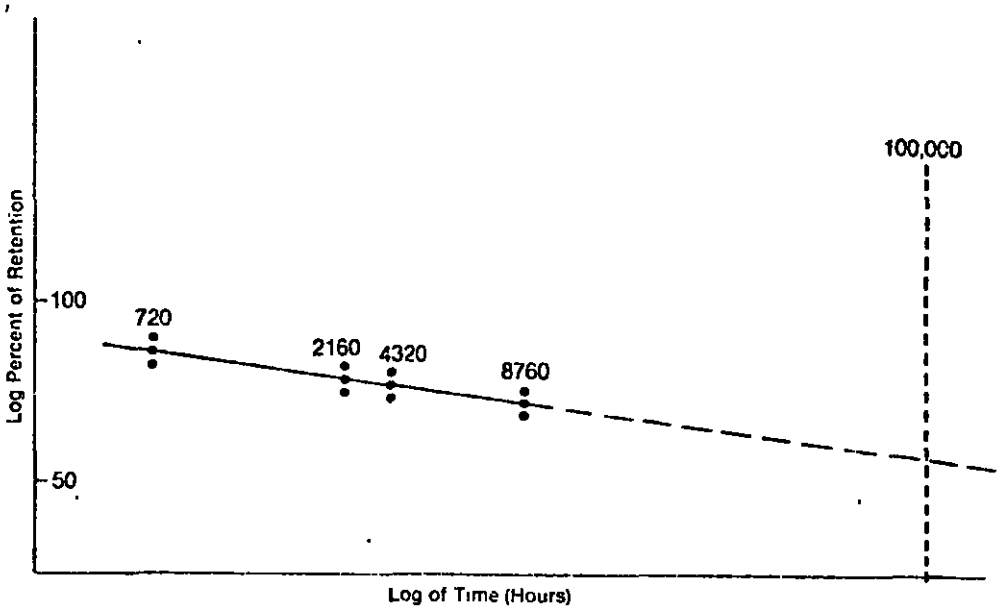


FIG. 8 Chemical Resistance Test Property Retention

The American Society for Testing and Materials takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 1916 Race St., Philadelphia, Pa. 19103, which will schedule a further hearing regarding your comments. Failing satisfaction there, you may appeal to the ASTM Board of Directors.

MAR 1 3 1984

16. Blake S.B., et al. "Underground Oil Recovery Ground Water Monitoring Review, Spring 1983, pp. 40-46

2641
2645
2646
2647
2648

UNDERGROUND OIL RECOVERY

Discusses various product recovery alternatives including their relative advantages and disadvantages.

by Steven B Blake and
Richard W. Lewis

Product Migration

Once hydrocarbons are lost through leaks or spills to the ground, their behavior and ultimate fate become dependent on the local hydrogeologic conditions. Petroleum products tend to follow the most permeable zones, such as artificial fills, pipeline trenches, foundation fills, etc. These backfilled excavations are commonly filled with more permeable material than the native soils, thus they offer a low-resistance migration route. A spill which might otherwise have contaminated a relatively localized area can spread laterally through these zones of artificially high permeability and make identification of the source difficult.

In general, the spilled product will migrate downward through the unsaturated zone with some lateral spreading. The rate of this downward migration will be dependent on the physical properties of the soil, the type of product and the volume of product spilled. The greater the permeability and volume of the spill and the lower the viscosity of the product, the more rapid the migration of the spill. The downward migration of the product will eventually be stopped either by retention in the soils, an impermeable barrier or the water table.

If the migrating product encounters a large enough volume of soil, all of the product may become pellicular and effectively immobilized before it reaches the water table. The immediate hazard of ground-water contamination in this instance is reduced, however, subsequent recharge from precipitation will transport mobile components of the hydrocarbon to the aquifer. The volume of product retained by the soil will be dependent upon the soil characteristics (i e. porosity and pore size distribution) and the type of petroleum. Some general guidelines for the estimation of residual saturation have been presented by the API (American Petroleum Institute 1972). Based upon a "typical" soil with a porosity of 30 percent, the API gives residual saturation values of 0.10 for light oil and gasoline, 0.15 for diesel and light fuel oil, and 0.20 for lube and heavy fuel oils. These residual saturation values are given as a percentage of the total porosity of the soil.

If the hydrocarbon encounters an impermeable barrier, it may spread along this layer and gradually be retained by the soil until it reaches an immobile state. However, if the leak continues or if the volume of product is large enough, it will accumulate on this layer and flow down dip until it reaches an outcrop and forms a surface seep or encounters the water table.

If the product manages to reach the water table, several things may take place. According to the API (1980), as the oil encounters the capillary zone it cannot displace much of the capillary water and migrates around the water-filled pores. When it encounters water, which it cannot bypass, the weight of the oil begins to depress the water table. The water in the capillary zone tends to inhibit the oil's movement, thus the oil spreads over and through the capillary zone. With enough time and no addition of new product, the oil will spread to a critical thickness and stop moving. This critical thickness is only a fraction of the thickness of the capillary zone, with the oil forming a pancake-shaped layer over the water table. However, field observations indicate that the behavior of the migrating product is sometimes quite different from that described in the API article. If a large volume of oil is spilled or if the downward migration of the oil is quite rapid and localized, the oil will depress the water table and a lens of oil will be formed. The oil will then flow with the water and move downgradient as a unit. These lenses can be several feet thick and have a very limited dispersion front.

Spill Evaluation

The procedure used in evaluating a spill will vary depending on

site-specific conditions. Thus, a methodology used in one location may not apply to a different hydrogeologic environment. Variables such as the mobility of the product, the location of the spill relative to man-made structures and the potential hazard imposed by the spill will all play a role in selecting the procedure to be followed.

In general the first step to be taken is to locate and remove the source of the hydrocarbon contamination. Normally the source of the product is located near the area where the product has been detected on the water table. Since ground-water movement is generally quite slow (on the order of a few inches to a few feet per day), it takes several years for the product to travel a significant distance. However, in some instances the contamination may not be detected for years and the product can migrate hundreds of feet from its origin, making the location of the source extremely difficult.

A physical survey of the area should be made to identify facilities which could be contributing to the problem. Utilities and petroleum companies should be contacted as to the location of any underground lines, storage tanks or surface impoundments. These facilities should then be plotted on topographic maps. Although this initial field survey may not locate the source exactly, it should provide the location of several suspected sources which can be evaluated more closely. In addition, the locations of any existing wells penetrating the contaminated aquifer should be located. These wells can be used to determine the ground-water gradient in the area and to provide information on pumping wells which might influence the migration of the product.

The next step in the evaluation should be the installation of monitoring wells to provide information on: 1) the areal extent and thickness of the product, 2) the type of product spilled, 3) ground-water quality, 4) the local ground-water gradient and 5) the general hydrogeology of the site.

Monitoring Well Design

Placement of the screened portion of the well is critical when monitoring for the presence of hydrocarbons. The wells should be installed such that the screened portion extends several feet beneath the ground-water table and is still open to the water surface so that product is free to migrate into the well. The screens should be long enough to compensate for seasonal fluctuations in water-table levels, and should be constructed of materials which are resistant to hydrocarbons. The size of the monitoring wells will be dependent on their expected current and future use. If the wells are to be installed only for contaminant sampling, determination of fluid levels, and collection of formation samples during drilling; 2-inch diameter wells are sufficient. However, if the wells are to be used for future recovery of the product, they must be large enough to house pumping equipment.

Well Placement

Monitoring wells should be installed initially at the location where the contamination is first detected and then upgradient in an attempt to delineate the source of the contamination. In addition, monitoring wells should be placed on the periphery of the spill to monitor any further migration of the product. All monitoring wells should be surveyed in and a bench mark established so that fluid-surface elevations can be determined and ground-water gradients established.

Sampling and Product Detection

When large amounts of oil are present on the water table, their thicknesses can be determined by using a steel tape with water- and oil-finding pastes or with electronic resistivity probes. Both the level of the fluid surface and the oil-water interface should be recorded so that the shape of the hydrocarbon pool and potential migration routes can be evaluated. If large accumulations of product are not present on the surface, the presence of product in the ground water can normally be detected in the field by smell. Most refined petroleum products have a characteristic odor. An experienced person can even tell with some accuracy the type of product by its smell.

Samples should be taken to determine both the nature of the hydrocarbon and its concentration in the water. The solubility of the hydrocarbon in water will be dependent on the product type; however gasoline has a solubility of between 20 and 80 mg/L (McKee et al. 1972). Samples to determine the concentration of dissolved hydrocarbons should be taken in glass containers. The sample bottle should be only partially filled to avoid the loss of any floating oil and to permit the entire sample to be extracted if necessary. For extraction-type analysis, samples should be at least one liter or larger. If the sample cannot be analyzed the day it is taken, it should be preserved to prevent biological degradation of the product. This can be accomplished by acidifying the sample to a pH of two or less with either hydrochloric or sulfuric acid (API 1972).

Determining the nature of the hydrocarbon is also very important when trying to trace the source of the contamination. Methods are available for determining hydrocarbon type from dissolved, vapor or recovered samples. However, when the results of these or other tests are interpreted, the possible effects of weathering of the product must be considered. For instance: 1) certain components of gasoline may volitalize, 2) some of the components (particularly aromatics) will dissolve in water, 3) straight chain paraffins are susceptible to decomposition by bacteria, and 4) olefins may be oxidized in the presence of sunlight (API 1972). Thus, the interpretation and identification of the hydrocarbons should be done by personnel experienced in these procedures. Although the weathering of the product can make identification difficult, it can also provide information on the length of time the product has been in the ground and the direction of migration. Since certain components of the hydrocarbon will be preferentially retained on the soils and others will be dissolved in the ground water, these losses can be identified as the product moves downgradient, giving an indication as to the proximity of the sample to the contaminant source.

Recovery Alternatives

Due to the many and varied conditions which can affect the migration and recovery of a product spill, recovery systems must be tailored to each specific site. The hydrogeologic conditions, the extent and volume of the spill, the type of product, the potential and/or immediate hazard imposed by the spill and the available equipment will all play a part in the selection of an appropriate recovery system. A discussion of some of the available recovery alternatives and their

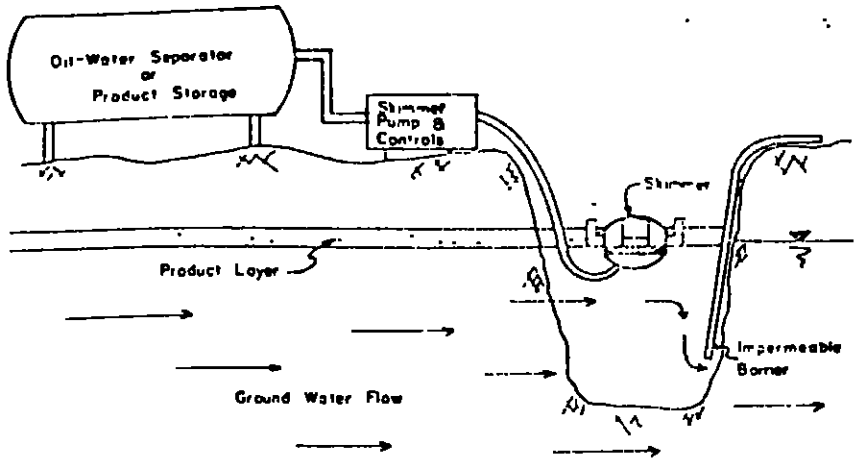


Figure 1. Open interceptor trench utilizing a Skimmer Pump

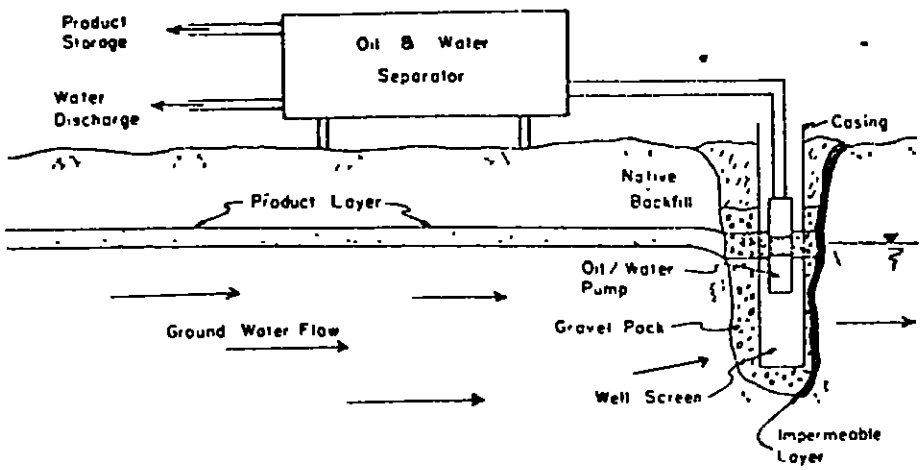


Figure 2. Interceptor trench utilizing a recovery well and single-pump unit

advantages and disadvantages follows.

Interceptor Trenches

Small spills encountering a shallow ground-water table or a barrier to vertical migration can be contained and recovered with a trench or drain system designed to intercept the product. The materials and equipment necessary to install the system are generally locally available, the system is not complicated and it can be installed relatively quickly. There are several factors to evaluate when considering an interceptor system: 1) the trench must bisect the entire width of the spill in order to contain it so the spill must be of relatively limited extent; 2) due to soil instability, the volume of material which must be removed, and the excavation equipment available, the depth of the trench systems is normally limited to 6 to 8 feet; 3) skimming or pumping equipment must operate continuously or the product will accumulate and migrate around the ends of the trench.

Once the trench has been excavated, an impermeable barrier should be installed on the downgradient side of the trench to stop the migration of the floating product but allow the water to pass underneath. The trench can then be left open and skimmer systems employed to remove the floating product (Figure 1). Alternately, the trench can be backfilled with very porous material and a French drain or large-diameter well installed (Figure 2). The use of a skimmer system has the advantage of producing very limited amounts of water for disposal. However, the rate of recovery is slow since the system relies mainly on the natural gradient to transport the oil to the trench. The pumped trenches are more effective and provide for more rapid recovery, because a gradient is created toward the trench. However, much larger volumes of water which may contain unacceptable concentrations of dissolved hydrocarbons must be disposed.

Recovery Wells

Recovery wells are by far the most popular means of product recovery from water-table aquifers. If designed properly, they will provide for an efficient and normally faster recovery of spilled product than a trench system. By creating a cone of depression in the water table, a gradient is established toward the well and product within this cone is directed to the well and can be removed.

Well Design and Operation

Design and operation of the recovery well or well system is critical to the rate of recovery and the total volume of product removed. The well should be designed to maximize efficiency while avoiding the pumping of sand. Field experience has shown that the rate of product recovery is directly related to the efficiency of the pumping well. Standard water well design procedures should be implemented for the sizing of the screen and gravel pack with only slight modifications. The screen length will normally be longer in a product recovery well to allow for the entry of floating hydrocarbons. If the screened zone is placed too deep and drawdown is not sufficient to depress the water surface to the screened zone, free floating hydrocarbons may not enter the well, or product withdrawal from the well will be delayed until enough oil accumulates outside the well to depress the oil-water interface to the level of the screened zone.

Another aspect of recovery well design which must be considered is the type and size of screen to be installed. Continuous-slot wire-wrap screen is recommended so that the percentage of open area can be maximized. Field experience has shown that hydrocarbons provide a good medium for bacterial growth and that bacterial growth and clogging of screens is accelerated in hydrocarbon recovery wells. The more open area you can provide initially, the longer the well can be in operation before maintenance is required to clean and redevelop the well to restore its efficiency. The size of the casing and screen required for the pumping well will be dependent upon the pumping equipment which is to be installed. Field experience indicates that for most single pump systems the smallest reasonable diameter for the screen and

casing is 6 inches, while the smallest workable diameter for a two-pump system is 10 inches.

Operation of the well is also extremely important to the final results of the recovery effort. The cone of depression should be adjusted such that it is just large enough to contain and recover the spilled product. Pumping water at an accelerated rate in hopes of steepening the gradient to the pumping well and increasing the rate of recovery is not necessarily a good procedure. Although this may increase the rate of recovery for some period, it will also result in decreasing the total amount of product which can be recovered. Excessive drawdown will result in the oil having to migrate through a larger thickness of sands. As the product migrates through the dewatered sand, portions of it will become pellicular and will not be recoverable. Even if the pumping rate is decreased and the water level is allowed to rise, studies have shown that this pellicular hydrocarbon will not be removed by this water flushing (McKee et al. 1972 and Raymond et al. 1976). The amount of hydrocarbon retained in the aquifer matrix will depend on the type of product and the aquifer properties. Studies done by McKee et al. (1972) with unconsolidated sands having a porosity of 23 percent had a gasoline retention of 7.7 percent of the pore volume or 1.77 percent of the bulk volume. Similar studies done by Engineering Enterprises Inc. on products of lower API gravities (i.e. gravities between 34 and 42) show that specific retention for heavier products can range between 10 percent and 16 percent of the bulk volume. Thus, the loss due to retention in the aquifer as the product migrates to the recovery well can be significant.

Pumping Arrangements

Various pumping arrangements can be employed for the recovery of hydrocarbons in water-table aquifers. The selection of a pumping system will be dependent upon the hydrogeologic conditions, the equipment available, the volume and extent of the spill and the design of existing wells which might be employed in the recovery operation. Some of the options available include: 1) single-pump systems utilizing one recovery well; 2) single-pump systems utilizing multiple wells; 3) two-pump systems utilizing two recovery wells; and 4) two-pump systems utilizing one recovery well.

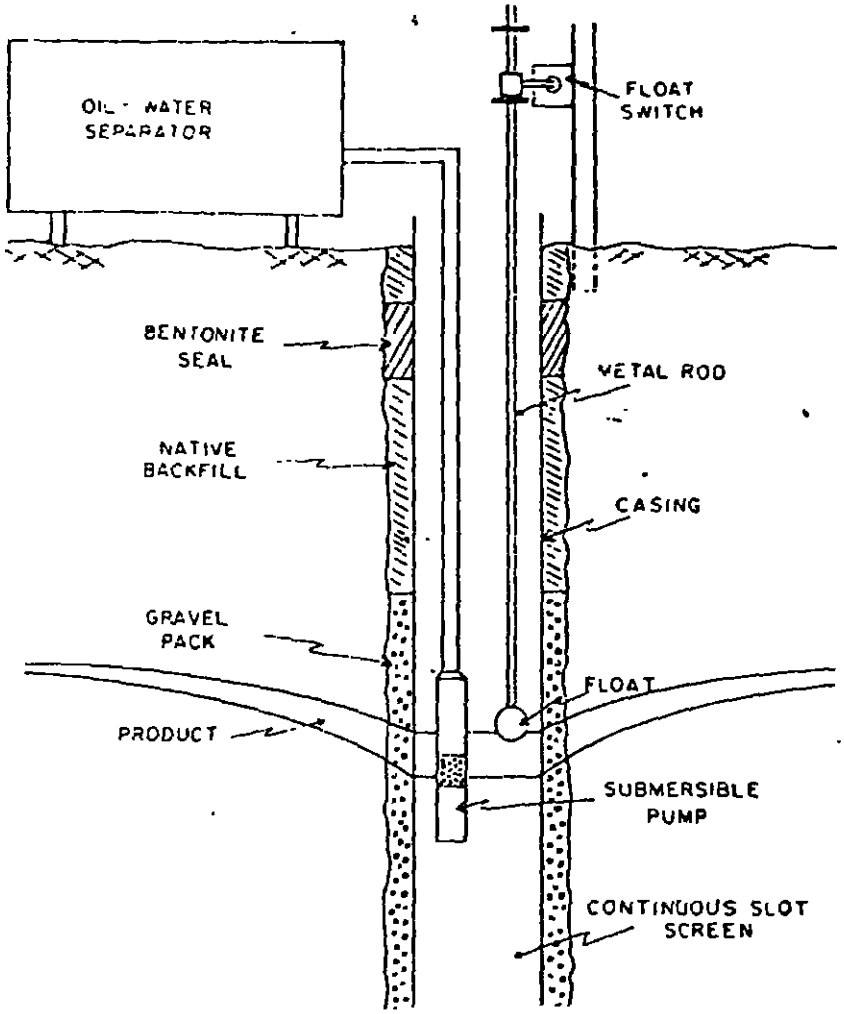


Figure 3 Schematic of one-pump system utilizing a submersible pump and float controls

Single-pump systems using one well have several advantages over other systems (Figure 3). They are normally cheaper to construct than multiple pump systems because only one pump is required and complicated electronic controls are not needed to regulate pumping levels. A simple mechanical float can be installed to ensure that the pumping level is maintained close to the pump intake to facilitate recovery of the hydrocarbons. Also, smaller diameter wells can be used for the recovery system. However, there are several disadvantages to single-pump systems. Separators must be installed to recover the product at the surface. They are normally not as efficient as two-pump systems because the pump must cycle. The agitation of the product during recovery may emulsify the product and make separation from the water difficult. The mixing of the product and water can result in an increase in the amount of soluble hydrocarbon components retained in the waste water. Although the one-pump system can be utilized effectively for hydrocarbon recovery, these disadvantages make them a less desirable alternative.

One-pump systems utilizing multiple well points are plagued by the same problems as the single-well arrangements. However, in tight formations of low permeability this arrangement may be the only feasible recovery alternative.

Two-pump systems using two wells are normally employed when a small-diameter well not capable of accepting two pumps is already in existence at the site of the spill. If a well already exists which is screened in the lower portion of the contaminated aquifer, another small-diameter well capable of housing a product recovery pump, screened higher in the aquifer, can be installed nearby. Water can then be withdrawn from the well screened in the lower portion of the aquifer to create the cone of depression, and the accumulating product can be skimmed from the other well (Figure 4). However, care must be taken to assure that extensive product accumulations do not occur in the water well, resulting in the discharge of product through the water pump.

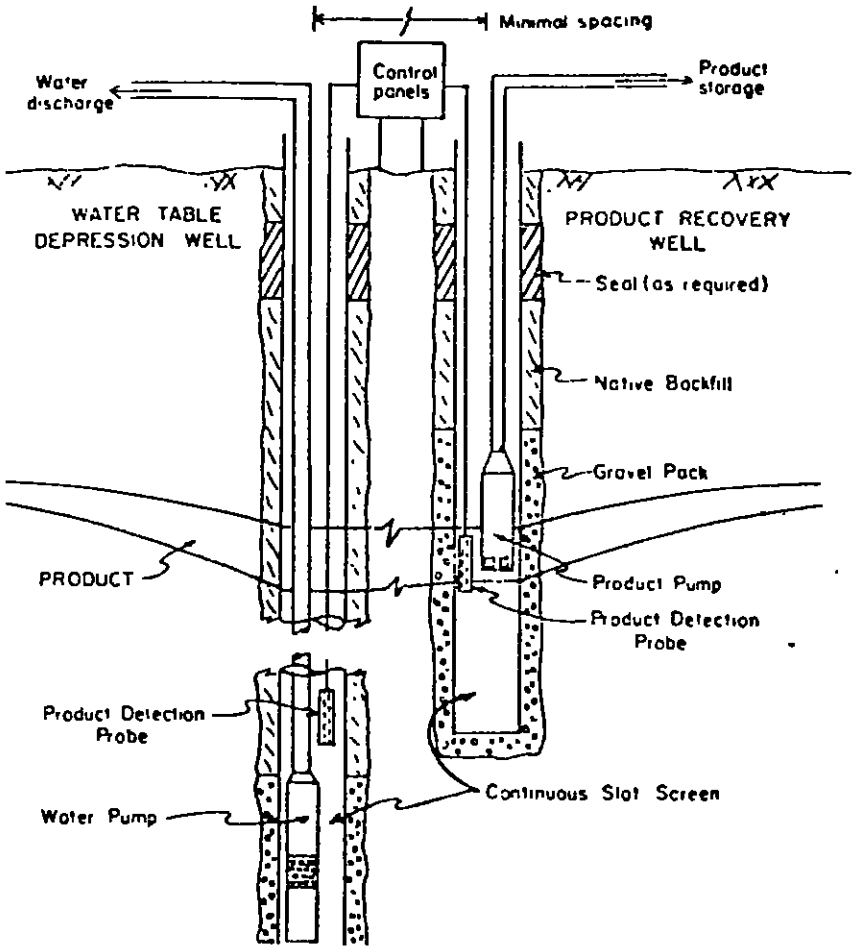


Figure 4 Schematic of two-pump system utilizing two small-diameter wells

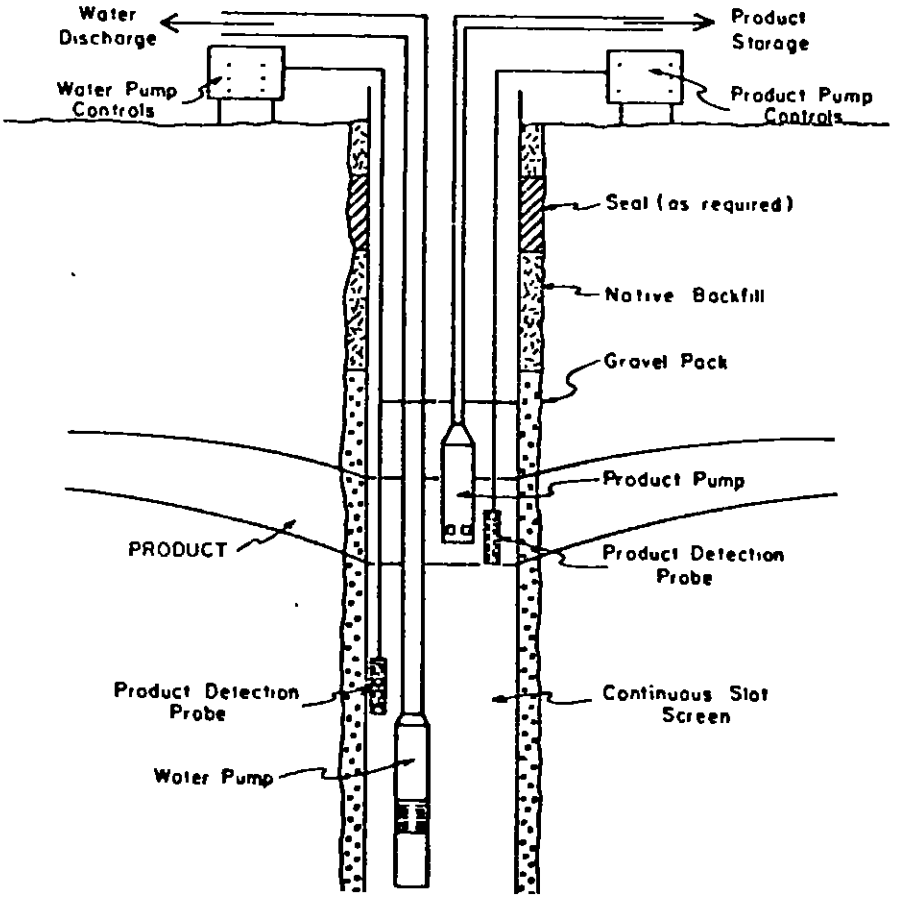


Figure 5 Schematic of two-pump system utilizing one recovery well

Electronic controls should be installed in the water well which will shut the water pump off if product accumulations become severe, or if the product pump in the recovery well fails.

Two-pump systems utilizing one well are generally the most desirable recovery arrangement. A water pump is installed with the intake near the bottom of the well and water is withdrawn at a controlled rate to create the cone of depression. A product pump suspended on a cable is placed above the water pump, and adjusted so that the intake is at or below the oil-water interface (Figure 5). Automatic controls are attached at the product pump intake to cycle the product pump as product is accumulated and removed. In addition, controls are installed on the water pump which will stop the pump if product accumulates in the well and approaches the level of the water pump intake.

There are several significant advantages to this type of system. The product is separated from the water in the well and surface separators are not normally necessary. In some instances the product can be recovered, reblended and sold without any additional refining. Addition of soluble hydrocarbon components to the waste water is minimized, since the water and oil are not mixed when recovered. The system is fully automated and can be operated continuously, thus maximizing the efficiency of the system and speed of recovery.

Although this recovery system is normally the most efficient and preferred alternative, there are several disadvantages which must be considered. A larger diameter casing and screen must be installed to house both pumps. The equipment required to operate a two-pump system, mainly due to the complex electronic controls, is much more expensive than that in the one-pump systems. If resistivity probes are used to detect the product in the well and operate the product pump, they require periodic maintenance and cleaning. Particularly when used in heavy products, the probes can become coated with hydrocarbon and will not sense the water interface. Control panels, although not overly sensitive, are subject to malfunctions. The most common problem is fuse failure, followed by failure of control switches, failure of the time delay module used to control the cycling period of the pumps.

and failure of the power supply module which drives the control panel and its sensors. With the exception of fuse blowouts, the control repairs are not simple to perform and require the services of an experienced electrician. This can result in significant loss of time of operation, thus it is recommended that spare controls be kept on hand. These systems cannot be left unattended for long periods of time and be expected to operate efficiently. The systems must be inspected at least weekly and preferably more often.

In addition, extreme care must be exercised during the initial start up and adjustment of the two-pump system. The water pumping rate and product pump location in the well must be adjusted so that the oil-water interface is maintained at a constant level in the well. Thus, the well must be gauged routinely for several days following start up to assure that pumping levels are stabilized. The stabilization of pumping levels in low-yield wells can be extremely difficult and well shutdown due to over pumping is a common problem. Thus, the installation, start up and operation of two pump recovery wells should be left to personnel experienced in this method of oil recovery and all of its pitfalls.

Recovery Equipment

Extreme care must be taken in the selection of equipment to be used in the recovery of spilled hydrocarbons. The safety of the equipment is the overriding factor to be considered when selecting oil recovery equipment. The use of equipment not specifically designed or modified for use in recovery of flammable petroleum products can result in hazardous situations and the endangerment of project personnel. Thus, the selection and installation of recovery equipment should be left to experienced professionals familiar with the precautions required when working with hazardous materials. The following discussion will present some of the general guidelines which should be considered when selecting pumping systems, but these criteria are not all inclusive.

Before any water pump is purchased for use in a recovery system, factors affecting this selection must be considered. The type of pump, the materials used in construction of the pump and the pump's electrical system must all be evaluated. Some of the criteria which the water pump should meet are:

- All parts coming in contact with the water should be resistant to the effects of hydrocarbons. Plastic impellers, bowls or rubber bearings which are not resistant to hydrocarbons should be avoided. These components can swell when brought into contact with oil, resulting in excessive wear or seizure of the pump. Even in pumps used only as dewatering pumps in a two-pump well, soluble hydrocarbons contained in the water can cause swelling of nonresistant parts.
- Discharge hoses from the pump, assuming the pump is a submersible pump, must also be hydrocarbon resistant, preferably oilfield discharge hose. If the correct hose is not selected, it can become brittle from contact with hydrocarbons.
- Electrical wiring to the pump must also be resistant to the effects of hydrocarbons. Teflon- or viton-coated wire is recommended. The wire should also have additional protection to assure that it is not frayed or damaged during installation or routine maintenance. Splicing of the wire between the pump and the top of the well should be avoided.
- Submersible water pumps are not manufactured to meet specifications for explosion-proofness. Thus, every precaution must be taken to assure that the water pump does not pump pure hydrocarbons during its operation. Controls to protect the pump from this possibility should be installed.

The same criteria listed for water pumps also apply to product pumps used for skimming the oil from the surface of the water. The pumping unit selected should be explosion-proof. Several manufacturers market explosion-proof product pumps and they are relatively inexpensive. Another criterion which must be considered when selecting a product pump is the viscosity of the product. Some product pumps have a limited range of viscosities which they will handle. This factor should be explored thoroughly before a selection is made.

Safety

Safety should be a primary concern during the design, installation and operation of any hydrocarbon recovery system. In working with a flammable contaminant, every precaution should be taken to minimize the chance of fire or explosion. Safety personnel familiar with work involving flammable materials should be contacted for their recommendations before work begins. In addition all personnel involved in the installation and operation of the recovery system should be briefed on the proper safety and emergency procedures.

Before any drilling begins, each site should be cleared to assure that no underground lines might be hit. Utilities which might have lines in the area should be contacted so that the lines can be accurately located. If the drilling is to be done in a highly congested area, such as a refinery, the site should be cleared with a backhoe as a final precaution before drilling. The location of old underground product lines or abandoned lines which might contain explosive vapors are usually not known even by refinery personnel.

During the drilling and development operation, some of the hydrocarbons encountered in the aquifer are forced to the surface and present a hazard. Any machinery capable of producing heat or a spark that might ignite flammable vapors should be kept upwind and as far removed from the well as possible. The drilling rig should be grounded to prevent the possibility of static electricity producing a spark. Smoking should be prohibited within the area surrounding the well, and fire extinguishers approved for use on petroleum fires should be available. Air rotary drilling of hydrocarbon recovery wells should be avoided, especially in areas of heavy accumulations: the injection of air into the hydrocarbons present can produce an extremely flammable mixture.

During the drilling and development phase of well installation, the borehole and mud pit should be tested for the presence of flammable vapors with a combustible gas indicator. If high-pressure jetting and air-lifting are being used for development, the well and air-lift discharge should be checked for vapors routinely. If flammable concentrations of hydrocarbon vapor are detected, this method of development should be abandoned immediately. Jetting with simultaneous air-lifting can produce hazardous conditions, due to the aeration of the hydrocarbons and the static charges which may build up in the air-lift system.

During the installation of the pumping system, care should be taken to avoid the production of any

sparks which might ignite vapors in the well. The control panels and power supply to the well should all be grounded properly. In addition, lightning protection should be provided at the installation. It is recommended that all electrical equipment and enclosures meet explosion proof specificiations, i.e. NEMA 7, Division 1, Class 1, Group C and D.

Summary

The effective recovery of spilled hydrocarbons present on the ground-water table is not a simple task and requires the use of specialized procedures and equipment. There are numerous alternative recovery systems which can be employed. The selection of an alternative will be dependent upon the existing hydrogeologic conditions and the nature of the spill.

Once installed, the proper operation and maintenance of the recovery system is crucial to the success of the recovery effort. Initial start up of the systems to stabilize pumping levels should be performed by personnel experienced in the field of hydrocarbon recovery. The systems require routine inspection and adjustment to provide for an efficient recovery. When electronic pump controls are employed, the systems must have a continuous maintenance program as they are prone to malfunctions.

Safety should be the overriding concern when designing, installing and operating a hydrocarbon recovery system. All personnel involved in the installation and operation of the system should be briefed on the proper safety and emergency procedures to be followed.

References

_____. 1972. The migration of petroleum products in soil and ground water—principles and countermeasures. API publication 4149. American Petroleum Institute. Washington.

_____. 1980. Underground spill cleanup manual. API publication 1628. American Petroleum Institute. Washington.

McKee, J.E., F.B. Laverty and R.M. Hertel. 1972. Gasoline in ground water. J. Water Pollution Contr. Fed. 44, pp. 293-302.

Raymond, R.L., J.O. Hudson and V.W. Jamison. Bacterial growth in and penetration of consolidated and unconsolidated sands containing gasoline. API Project 307-76.

Biographical Sketches

Steven B. Blake is currently a senior hydrologist for Engineering Enterprises Inc., Norman, Oklahoma, where he is coordinator of oil recovery operations. He's also involved in monitoring and evaluation of hazardous waste sites and ground-water modeling.

Blake received his B.S. in hydrology from Colorado State University in 1978 and his M.S. in watershed hydrology from the University of Arizona in 1980. His previous work experience includes work with the USGS, evaluating the effects of strip mining on ground-water quality and work with the U.S. Forest Service, evaluating the effects of clear-cutting and slash-burning on surface-water quality.

Richard W. Lewis is currently a senior hydrogeologist for Ground Water Technology, a division of Oil Recovery Systems Inc. in its Needham, Massachusetts, office where he is project manager in charge of aquifer evaluations and aquifer restoration from petroleum spills and other industrial-related activities. He received his B.S. in both geology and biology from the State University of New York at Brockport in 1975, and his M.S. in geology from the State University of New York at Fredonia in 1977. Lewis attended post graduate courses in hazardous waste management and toxicology at Oklahoma University. From 1979 to 1980 Lewis was senior hydrogeologist at Engineering Enterprises, Norman, Oklahoma. In 1978 and part of 1979 he served as staff geologist for the Industrial Waste Division of Oklahoma's State Department of Health where he was in charge of hazardous waste site permit reviews and pollution investigations.

17. Bosch, C. T. and B. A. Valde. "Consultants' Report on DPA/PACE Special Task Force on Underground Storage Tanks," The Orley Group, Inglewood, California, February 1978

CONSULTANTS' REPORT

TO

THE OPA/PACE SPECIAL TASK FORCE ON UNDERGROUND STORAGE TANKS

Prepared by

C. T. Bosch,
B. A. Valde, P. Eng.

February 1978

THE ORLEY GROUP
ORLEY H. LINDGREN, Ph.D.
429 WEST MANCHESTER BLVD.
INGLEWOOD, CALIFORNIA 90301
TELEPHONE (213) 673-7470

ABSTRACT

Results of a six-month investigation of unprotected steel underground tank removals are reviewed and documented.

Investigations were carried out from May 30th to November 30th, 1977 and during this period, on-site physical inspections were made of 235 tanks removed at 74 sites in Southern Ontario. Soil conditions were analyzed, and observations were made on the quality of installations and on safety procedures for the removal, handling and disposal of tanks.

Details were also analyzed of an additional 271 tanks removed at 105 sites from other locations across Canada.

TABLE OF CONTENTS

		Page
1.	Summary	1
2.	Introduction	3
3.	Methodology	5
4.	Discussion	7
5.	Recommendations	23
6.	Appendix A - Sites Reported	25
7.	Appendix B - Leaking Tank Chart	27
8.	Appendix C - Average Age Vs. Soil Aggressiveness Value	29
9.	Appendix D - Summary of Tank Removals	31
10.	Appendix E - Tank Failures by Age and Company	33
11.	Appendix F - Tank Failures by Age	35
12.	Appendix G - Tank Failures by Soil Aggressiveness Value	37
13.	Appendix H - Physiography Vs. Soil Aggressiveness Value	39
14.	Appendix I - Internal Corrosion Details	41
15.	Appendix J - Tanks Adjacent to Leakers	43
16.	Appendix K - Heating Oil Tank Details	45
17.	Appendix L - Waste Oil Tank Details	47
18.	Appendix M - Thorco Tank Lining Letter	49
19.	Appendix N - Proposed Tank Removal Report	51
20.	Appendix O - Details of Tank Removals Attended by Consultants	53
21.	Appendix P - Details of Tank Removals Reported by Others	59
22.	Appendix Q - Bibliography	67

SUMMARY

This study, believed to be the first of its kind, has revealed factual information that should be useful to the Petroleum Industry.

Results of the study show that there is a definite relationship between tank life and soil aggressiveness. For example, of the 108 tanks shown on the leaking tank chart, Appendix B, only one tank failed in less than 15 years in other than aggressive soil. The chart supports the theory that an unprotected steel tank, in less aggressive or mild soil, should normally last well in excess of 15 years.

The average age of all the 108 tank failures was 19.1 years, even though 71 percent of them were in aggressive or highly aggressive soils.

During the study period, a total of 506 tanks were removed across Canada, 124 of which had one or more perforations, and therefore, classed as leakers. One hundred eight of these tanks appear on the leaking tank chart, Appendix B. The remaining 16 are not charted because soil samples were not made available for analysis.

It should be pointed out that in some cases, perforations were self sealed by the products of corrosion and did not necessarily show evidence of product loss.

Detailed on-site investigations were made of 235 tanks in Southern Ontario, 68 of which were classed as leakers, although only 31 of these had been reported as leakers. This leads to the assumption that there may be some question as to the reliability of bulk inventory control at retail outlets.

With very few exceptions, all tanks removed exhibited varying degrees and types of corrosion. External corrosion was by far the most common, and at about half of the sites such corrosion could be attributed to contaminated backfill - evidence of a sub-standard installation.

Tank removal procedures revealed a number of unsafe and illegal practices. Tanks were not always fully stripped of product, gas-freeing of tanks was questionable, and openings were not always cut to render tanks unfit for further use. Some tanks were hauled away intact without knowledge of their future use. Company technical representatives were seldom in attendance at removal sites to ensure safe practices.

In some cases, the leaking tank only was replaced without checking all other tanks at the site.

There seems to be little attention paid to the condition of heating oil and waste oil tanks. Leaks in heating oil tanks are usually discovered when there is an unaccountable increase in consumption, or by repeated furnace shutdowns due to water in the product. Leaks in waste oil tanks are rarely, if ever, discovered until they are removed when the service station is closed.

INTRODUCTION

Two consultants were appointed to carry out a detailed study of steel unprotected underground tank removals. The field work covered a six-month period commencing on May 30, 1977. Objectives and duties were outlined as follows:

Objectives:

1. Coordinate and carry out an intensive six months investigation of underground tank removals to analyze conditions contributing to tank corrosion and failure.

2. Compile complete and significant data to form the background for development of an industry position for replacement or upgrading of underground tank systems.

Duties:

1. Make on-site inspections of all tank removals in Southern Ontario.

2. Determine conditions responsible for corrosion and failure by sampling and electrochemical analysis of soil conditions, and by evaluation of other contributing factors.

3. Carry out thorough and detailed physical examination of all tanks to determine type and location of corrosion, both internal and external.

4. Compile and analyze reports on tank removals from all areas across Canada in relation to location, soil conditions, age of tank, and type and location of corrosion.

5. Obtain from participating oil companies all available data on history of past leakers.

6. Procure government soil classification data for Ontario, and if required, for other provincial areas.

7. Maintain contact with system analysis consultant to ensure significant data is being obtained and compiled in a manner required by the system analysis.

8. Submit regular progress reports to the OPA/PACE Task Force.

9. Consult as necessary with tank suppliers and corrosion consultants.

METHODOLOGY

For tank removals in Southern Ontario, one of the consultants was in attendance during all phases of the tank removal process.

While the tanks were being removed, observations were made on the soil conditions, including backfill material, groundwater, native soil, and quality of the installation. Upon removal of the tanks, detailed inspections were made to determine the degree, type, and location of corrosion. This was done by removal of material adhering to the tanks, followed by hand scraping and wire brushing. In many cases, tanks were opened permitting visual internal inspection.

Photographs were taken of various types and patterns of internal and external corrosion.

Samples were taken of the native soil in three different locations within the excavated area. Samples were then analyzed for resistivity, moisture, pH, and bacterial content.

For tank removals elsewhere in Ontario and in the rest of Canada, reports and soil samples sent to the consultants were analyzed and recorded. In these cases, of course, detailed physical tank inspections could not be made by the consultants, but a general description of tank conditions was usually included in the submitted reports.

Three soil samples were taken from each site, and were analyzed using the following equipment:

- Agra Mark II Soil Box and multimeter, to determine soil resistivity in ohm-centimeters.
- Beckmann pHistol for analysis of soil acidity or alkalinity.
- Hydrochloric acid and lead acetate paper, to determine presence of sulfides--an indicator of bacterial activity.
- Hand rolling of sample to determine moisture content of soil.

Following the above analysis, an evaluation was made of the soil aggressiveness value (S.A.V.) using the criteria outlined below:

1. Basic Characteristics

		Points
Soil Resistivity	under 300 ohm-centimeters	12
	300 - 1,000	10
	1,000 - 2,000	8
	2,000 - 5,000	6
	5,000 - 10,000	3
	10,000 - 25,000	1
	over 25,000	0

Soil pH	under 3.0	8
	3.0 - 5.0	6
	5.0 - 6.5	4
	6.5 - 7.5	2
	7.5 - 9.0	1
	over 9.0	0
Soil Moisture	saturated	3
	moist	2
	dry	0

2. Differential Characteristics

Resistivity Ratios	over 10	3
	over 5	2
	over 3	1
	under 3	0
pH Difference	over 3.0	2
	1.5 - 3.0	1
	0 - 1.5	0

3. Indicator of Bacterial Activity

Sulfides	Positive	4
	Negative	0

4. Classification of Soil Aggressiveness Values

Sum of the above selected point values:	over 12	Highly Aggressive
	10 - 12	Aggressive
	7 - 9	Less Aggressive
	4 - 6	Mild
	under 4	Innocuous

DISCUSSION

1. Communications

Instructions were sent to all participating companies to give ample prior notice of tank removals so that arrangements could be made for one of the consultants to be in attendance. During the first two months, there was limited response. This may have been due to the time lag for communications to reach all field personnel, or to a lack of understanding of the objectives of the project. There was also some resistance from the field in completing the six page "*Leaking Tank System Report*" form. Reports generally were slow in coming in, necessitating in some cases, one or more follow ups. Reports were not well prepared except for a few isolated cases.

During the latter half of the project, there was a considerable improvement in removal advice, and the consultants' field activity during this period was maintained at a brisk pace.

Advice on tank removals was received in some cases from a company representative, but more often, directly from the contractor. The latter proved to be the most reliable, simply because the contractor was in a better position to know exactly when the removal was taking place. At least one company made the contractor responsible for removal advice by including it as one of the conditions of his contract.

Unfortunately, there were twenty-two sites in Southern Ontario for which prior advice was not received even though they were well within the area that could have been attended by the consultants. As a result, detailed tank inspections were not made, although in some cases, soil samples were sent to the consultants for analysis.

2. Tank Corrosion

a) External Corrosion

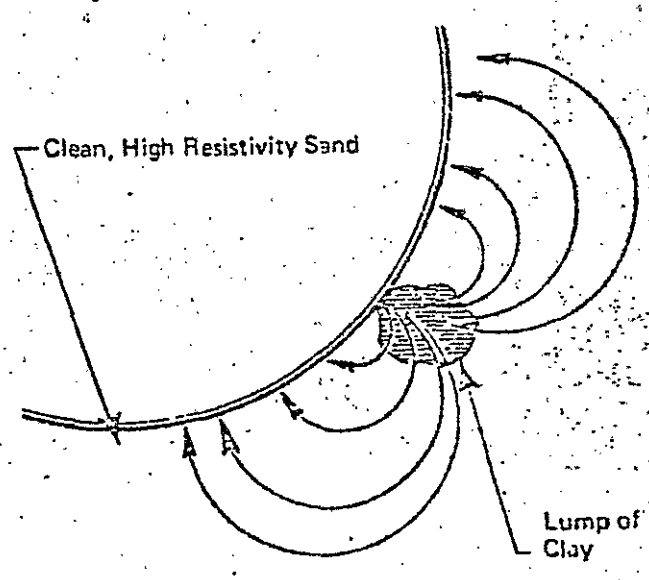
By far, the most common type of corrosion was external and it occurred in many different forms and from a variety of causes:

(1) *Lumps of Clay*

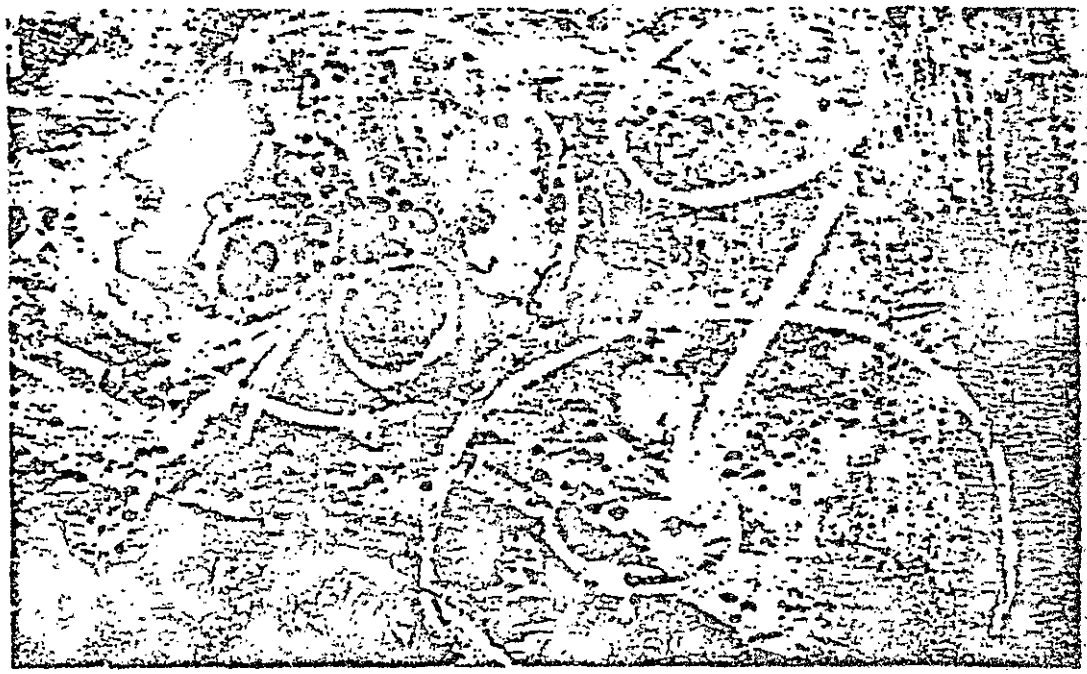
The most frequent cause of pitting was where lumps of clay were found adhering to the tank in the presence of sand or granular backfill. In this case, the clay creates a corrosion cell by shutting off the oxygen, causing the clay contact area to become anodic to its surroundings.

This condition is illustrated in Figure 1 and in Photograph P1.

Figure 1



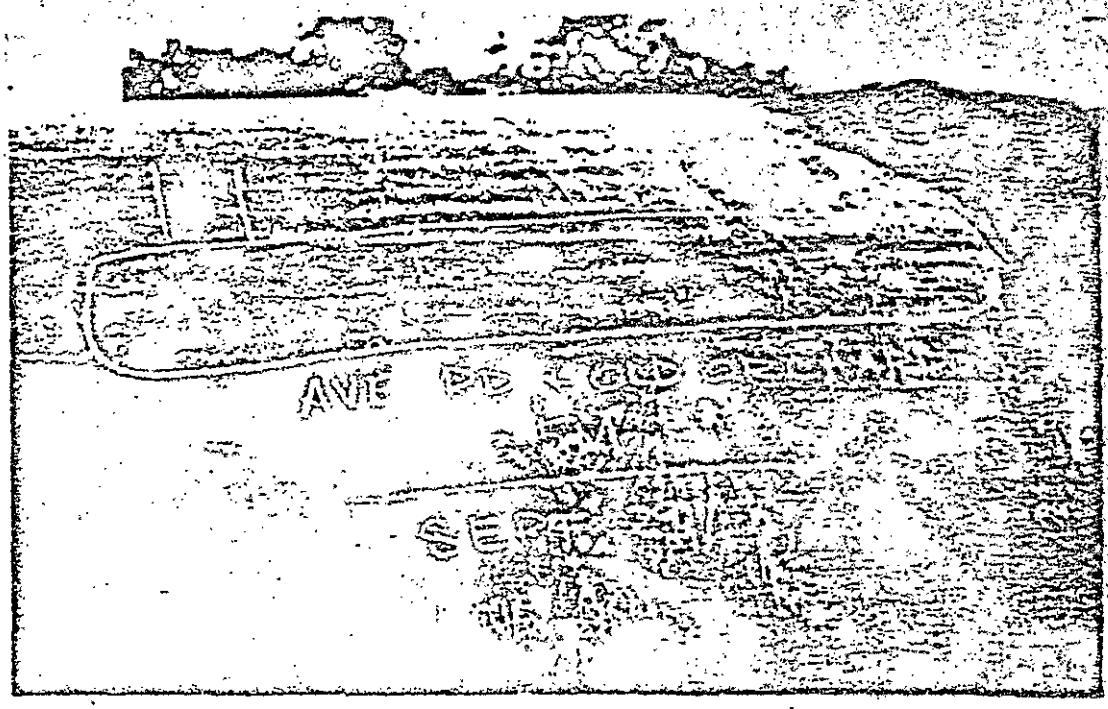
Photograph P1



(2) Contaminated Backfill

Many more cases of pitting were observed where contaminated backfill had been used. Such contamination included tin cans, old tires, straw, cinders, pieces of wood, bricks, scraps of pipe, and other construction debris. An excellent example of corrosion caused by scrap pipe in contact with the tank is shown in Photograph P2. The electrolytic action is similar to that shown in Figure 1, where the area of the tank in contact with the pipe becomes anodic to its surroundings.

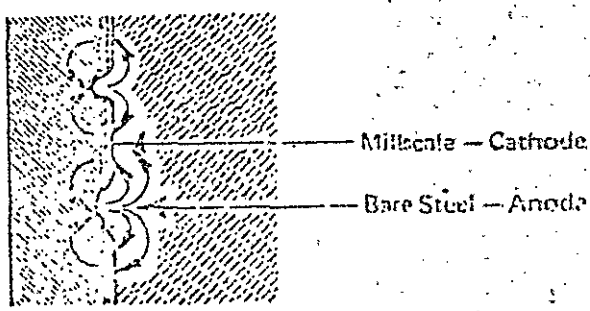
Photograph P2



(3) Millscale Damage

When the millscale on an unprotected tank is removed in localized areas, a corrosion system is activated. Because millscale is a relatively good electrical conductor, it is cathodic to the bare steel areas and a galvanic cell is created similar to Figure 2 with a bare steel anode and a millscale cathode.

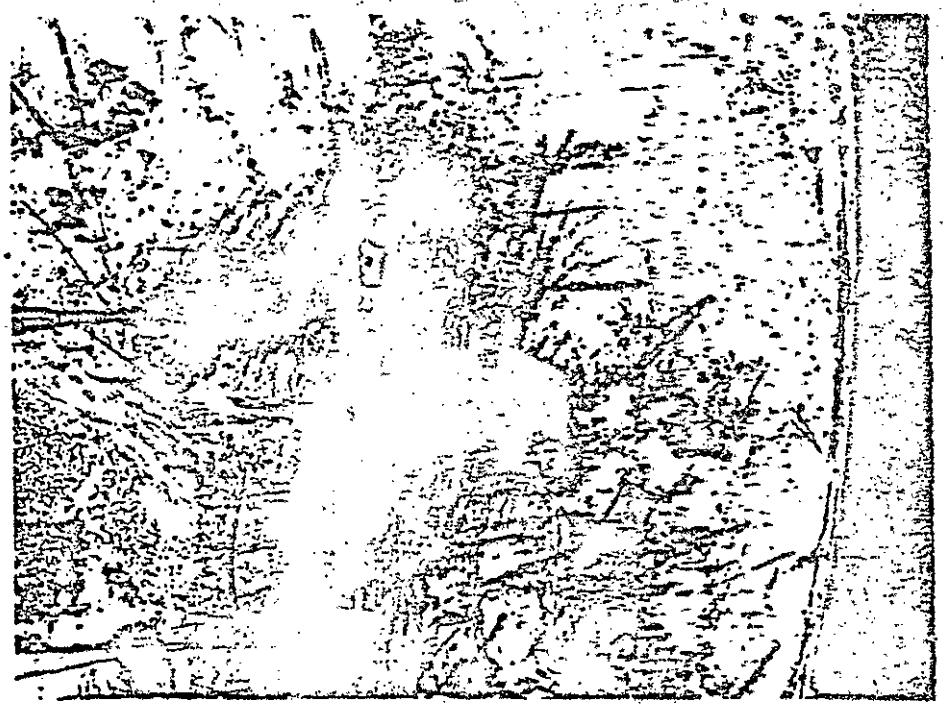
Figure 2



Several such examples were observed where chains or slings caused millscale abrasion during handling of the tank. Similar disturbance of the millscale was evident where hold-down straps without insulation had been used.

An example of corrosion caused by sling damage is shown in Photograph P3.

Photograph P3

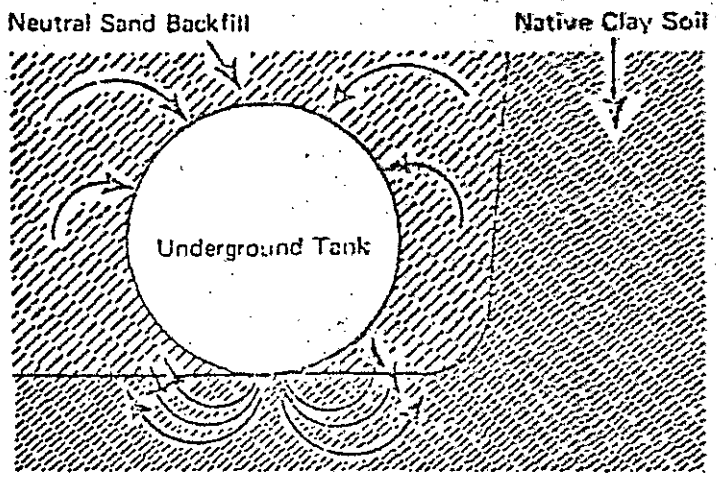


(4) Direct Contact With Other Than Backfill

If a tank is installed directly on the bottom of an excavation and backfilled with sand, a strip along its bottom could very likely be exposed to low oxygen concentration, to an acid soil condition, and to a soil of high ion concentration; while the remainder of the tank would be exposed to better aerated neutral sand with lower ion concentration. All three corrosion conditions would be working together to make the strip at the bottom anodic to the rest of the tank. Several such situations were observed, and the condition is

illustrated in Figure 3.

Figure 3



Strip Along Bottom of Tank

Anodic { Low Oxygen Concentration, More Acid Electrolyte, High Ion Concentration

Remainder of Tank Surface

Cathodic { Higher Oxygen Concentration, Neutral Electrolyte, Lower Ion Concentration

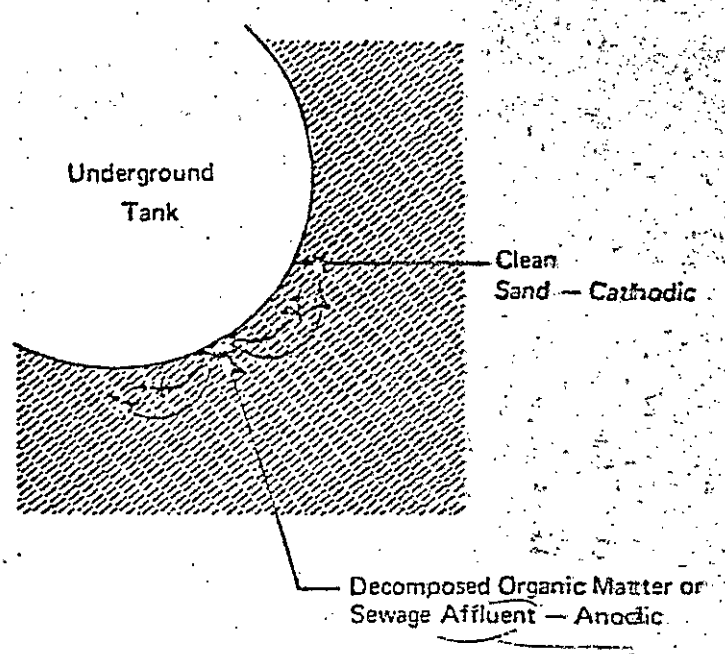
A similar condition exists when part of a tank is installed in direct contact with concrete. A good example is shown in Photograph P4 where the bottom portion of the tank was set in concrete.

Photograph P4

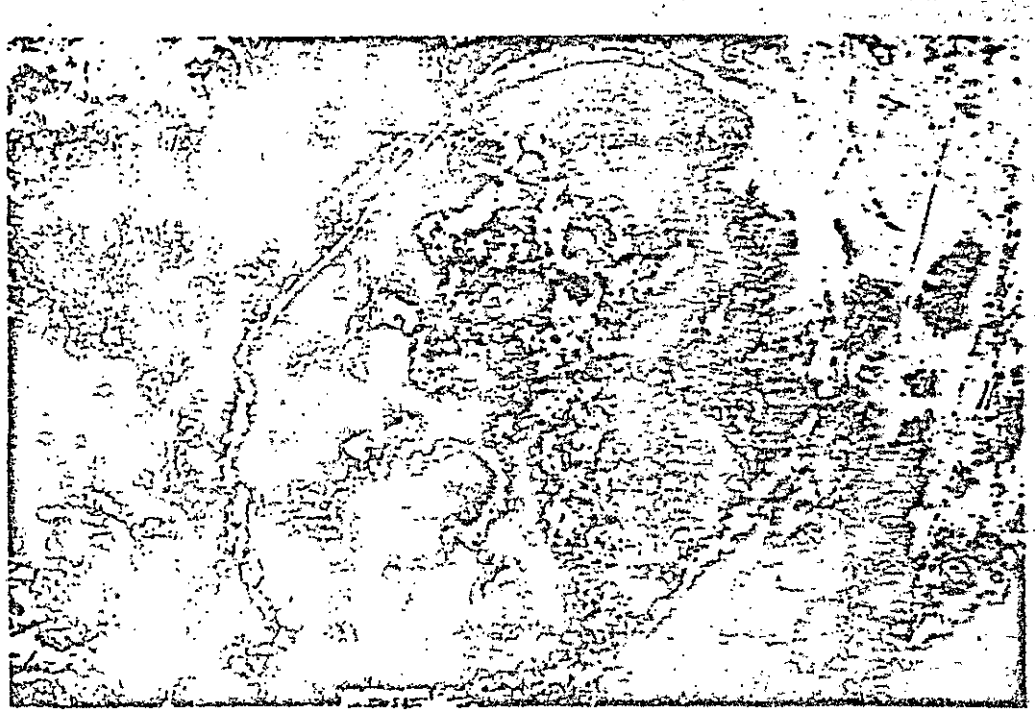
(5) Organic Matter

Organic matter in the backfill around a tank can produce pockets of acid residue, creating highly corrosive acid conditions around parts of the tank as illustrated in Figure 4. Several such examples were observed, and one of them is shown in Photograph P5.

Figure 4



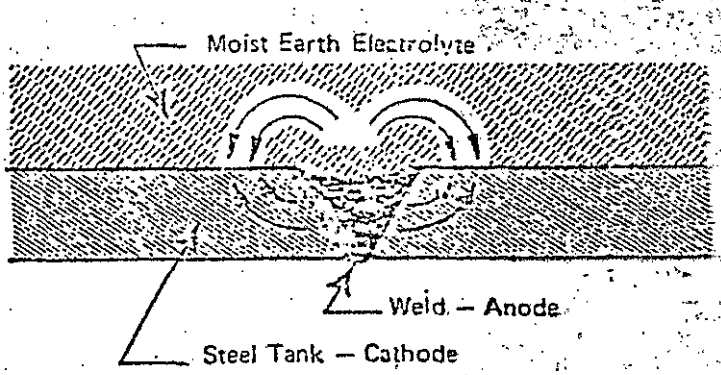
Photograph P5



(6) Welded Joints

Weld metal may be anodic or cathodic to the tank steel depending on the selection of welding rod and welding procedure. Because of the area relationship involved, a weld which is anodic to the base metal as illustrated in Figure 5, would be subject to highly localized corrosion, a condition which was observed in some cases. One example is shown in Photograph P6.

Figure 5

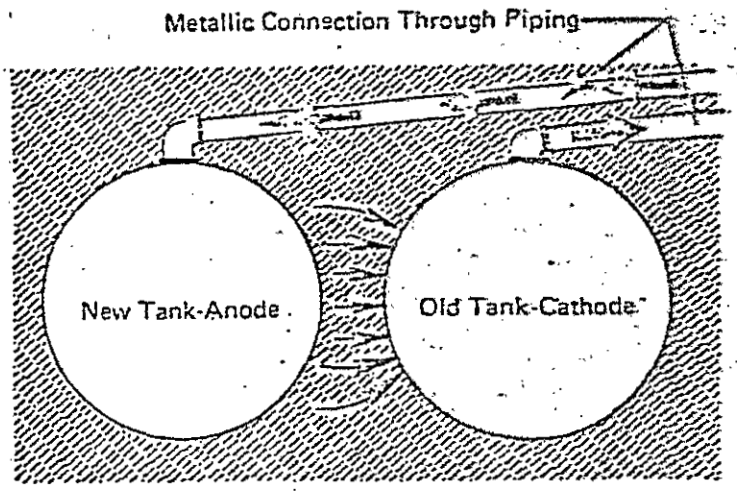


Photograph P6

(7) New Tank Adjacent to Old

When a new unprotected underground tank is installed adjacent to old tanks and connected to them through the product piping, the new tank becomes the anode of a corrosion cell in which the older tanks are the cathodes. This condition is illustrated in Figure 6 and a few examples were observed.

Figure 6



(8) Protected Tank Adjacent to Old

One case was encountered where a new cathodically protected tank had been installed two years ago, adjacent to three unprotected 10-year old tanks. Here, the side of the tank next to the protected tank was severely corroded while the other two old tanks were in good condition. It would appear here that the cathodic protection system on the new tank lowered the resistivity of the electrolyte at the side of the old tank.

b) Internal Corrosion

Of the 235 tanks inspected on site, 80 were opened and examined for internal corrosion. Other than some cases of sludge accumulation, most tanks were found to be in quite good condition. Where corrosion was observed, it occurred as follows:

(1) Overall Scaling

In these cases, a thin layer of overall fine rust scale was observed, and this was probably due to condensation within the tank. No serious pitting was found where this condition existed.

(2) Below Fill Pipe

There were two cases where perforations occurred directly below the fill pipe. One of these is shown in Photograph P7 where the 1/4-inch round internal perforation was the only corrosion discovered. The exterior of the tank was in near perfect condition. Some authorities suggest that this condition is caused by the repeated impact of a brass-tipped dip stick. In this study, there was not enough evidence to support this theory.

Photograph P7

(3) Below Vent Pipe

One tank was discovered to have a 1/8-inch perforation directly below the vent pipe. Since this was an isolated case, it can only be assumed that the location of the perforation was simply a coincidence.

Three more cases of perforations due to internal corrosion were discovered, all in very old galvanized tanks. The tank design involved embossed heads and ribbed shells. Perforations occurred mainly in the ribs, although in one case, there were perforations in the flat area of the shell. No perforations were found in the heads.

3. Quality of Installations

Other than the effect of the soil aggressiveness, most of the examples of external corrosion were to some degree due to the quality or type of installation. It seems clear that the results of a poor installation can override many of the other factors that contribute to corrosion. It should be recognized that a variety of corrosive forces are acting on underground tanks. Where failures occur, however, it is nearly always a result of those forces being concentrated in relatively small areas and the higher concentrations usually occur as a result of foreign matter in the backfill.

In this study, about half of all the sites visited were discovered to have sub-standard tank installations. Cases were found where the sand backfill was mixed with clay, construction debris, cinders, and other contaminating material. In most cases, these situations probably contributed to premature failure of the tanks.

A good example was seen at a site in an urban area where the native clay soil was highly aggressive. Four tanks had been installed with clean sand backfill and were in good condition. On the same site, in another location, two other tanks had been installed, but the backfill was contaminated with clay and construction debris. Both of these tanks were severely corroded and were leaking. This is the classic case of the benefits of good installation practices.

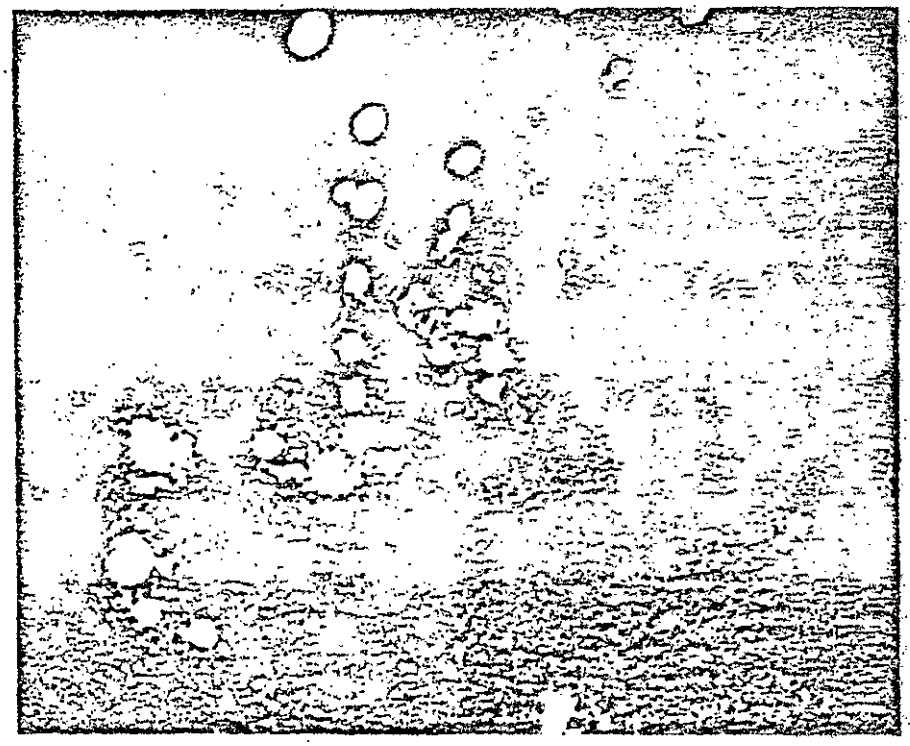
Unless there is continuous supervision during the tank installation procedure, there is no way of knowing if it was a good one because the work is covered over and so it remains for years to come or until premature tank failure occurs. Unlike many other components of a service station facility where the workmanship can be inspected after completion, the quality of the tank installation is hidden and will never be known until the tanks are removed.

4. Other Tanks

It appears that little, if any, attention is paid to the condition of heating oil and waste oil tanks at service stations.

Leaks in heating oil tanks are usually discovered only when there is an unaccountable increase in oil consumption, or by repeated furnace shutdowns due to water in the product. Even then, prompt action is not always taken to examine the tank. For example, one operator said that he had reason to believe his heating oil tank had been leaking for about five years before action was taken to replace it. He said he had repeatedly reported these conditions during these five years. The tank in question was removed during the period of this study, and was found to have countless perforations all over the tank. Photograph P8 is an interior view showing a group of perforations on

Photograph P8



one side of the tank. Photograph P9 shows one of several groups of external perforations on the other side, and Photograph P10 shows several of many more external perforations on the top of the tank. The backfill around this tank was badly contaminated with construction debris and bacterially-active material.

Photograph P9

Photograph P10

Leaks in waste oil tanks are rarely, if ever, discovered. It should be obvious to the operator that the tank may be leaking if there is an unaccountable reduction in the pump-out frequency. However, there is little incentive for the operator to report such a situation and a leaking tank could go undetected for years. Two cases were observed where the tanks were so badly corroded and perforated that it would be impossible for them to retain any waste fluids. The only waste oil tanks removed during the study period were at purification sites, and none had been reported as leakers. Waste oil tanks can contain a variety of oils, gasoline, anti-freeze, alcohol, road salt and acid.

5. Handling and Disposal of Used Tanks

Although the Ontario Gasoline Handling Act clearly sets out requirements for the safe and legal handling, stripping, gas-freeing, transporting, and disposing of used tanks, many deviations were observed.

For example, tanks were not always completely stripped, and when they were removed, some or all of the remaining product escaped on the ground.

In many cases, tanks were not gas-freed either before ripping them open, or before hauling them away. In those cases where dry ice was used for gas-freeing, it was seldom in the quantities required.

Tanks that were ripped open and rendered unfit for further use were usually taken away by a scrap dealer. However, many tanks were hauled away intact without any knowledge of their ultimate destination or future use.

6. Leak Discoveries

During the six month study period, 235 tanks in Southern Ontario were inspected by the consultants. These tanks were removed for various reasons, such as identified leakers, upgrading, tank age, and close out of the property.

Of all the tanks inspected, 31 had been reported as leakers. Upon detailed examination of all other tanks, 37 more were found to have perforations. Not all of the tanks in this group showed actual evidence of product loss, because in some cases, the perforations were sealed either by the surrounding material, or by the products of corrosion.

7. Inventory Control

Good inventory control appears to be lacking at most retail outlets. Of 35 leaker sites reported across Canada, only 2 were discovered because of identified product loss. All the others

were discovered by other indicators, such as water in the product, fumes in the neighboring basements, and in one case, by product in a nearby manhole. Furthermore, an additional 25 sites were discovered to have leaking tanks that had not been reported.

8. Physiography

An attempt was made to determine if there was any correlation between available physiographic data and the soil aggressiveness data acquired during the course of the study.

Physiography maps were obtained from the Ontario Government offices, and tank removal sites were plotted on these maps. It should be pointed out, however, that the physiography maps deal primarily with surface soil conditions for agricultural purposes, whereas soil samples at tank removal sites were taken at depths varying from 3 feet to 10 feet. Nevertheless, there was some general relationship, as evidenced below:

Of 16 sites located in Till Plains, 14 were aggressive.

Of 26 sites located in Clay Plains, all were aggressive.

However, of 33 sites located in Sand Plains, 3 were mild and 13 were highly aggressive, indicating a wide range of conditions in the Sand Plains area.

In total, of the 93 sites plotted, 70 of them were classed as aggressive, and 62 of these were in the Till Plains, Sand Plains, and Clay Plains areas. Since these three areas cover a major portion of Southern Ontario, a high percentage of soils in this part of the province can be classified as aggressive. These areas are defined on the map, "Physiography of Southern Ontario", (Appendix Q). This map may be useful in determining possible soil aggressiveness of sites located within these areas.

Details of physiography and soil aggressiveness relationships are shown in Appendix H.

9. Past History Data

Information was obtained from some of the participating companies on past history of leaking tanks. However, there was not enough reliable data, either in scope or in detail, to prepare a meaningful or factual analysis.

10. Contacts With Tank Manufacturers

Contact was made with one of the leading manufacturers who advised that neither they nor any other manufacturer had assembled reliable information or data relating to this study. They did state, however, that their association had discussed the possibility of developing a program to study this subject.

11. Government Contacts

Several contacts were made with related Government offices. Except for the material obtained on physiographic data, it was found that no other material was available that could contribute to the study.

12. Contacts With Contractors

One of the glass lining contractors proved to be most cooperative by providing information on tanks that he had repaired in the Toronto area since 1971. His conclusions generally support the data gathered in this study. A copy of his covering letter is shown in Appendix M.

It was also found that all of the tank removal contractors were very cooperative in providing prior advice on tank removals, as well as assisting the consultants during on-site inspections.

13. Removal of Protected Tanks

A few tanks were removed that were equipped with corrosion protection using ULC Method A - Taping. None of these tanks were leakers, but in every case, the protective green tape had separated, and when the tanks were removed, most of the tape either remained in the excavation or hung in shreds from the tank.

RECOMMENDATIONS

1. That Industry take steps to ensure that operators maintain accurate daily inventory records, so that product losses from leaking tanks can be immediately detected.

2. That Industry take action to improve supervisory procedures for tank installations. Such action could be accomplished by ensuring supervisory attendance during the entire tank installation procedure. In addition, programs should be initiated to ensure that all supervisory personnel, as well as contractors, are fully acquainted with the consequences of poor handling and installation practices.

3. That whenever a leaking tank is removed, all other tanks at the same site should be protected or replaced.

4. That all tank removals be fully supervised by Industry to ensure compliance with legal and safety requirements.

5. That operators be made aware of the necessity and importance of noting and reporting any changes in waste oil tank pump-out cycles.

6. That Industry maintain accurate records of all tanks showing number, size and type of tanks at each outlet as well as date of installation.

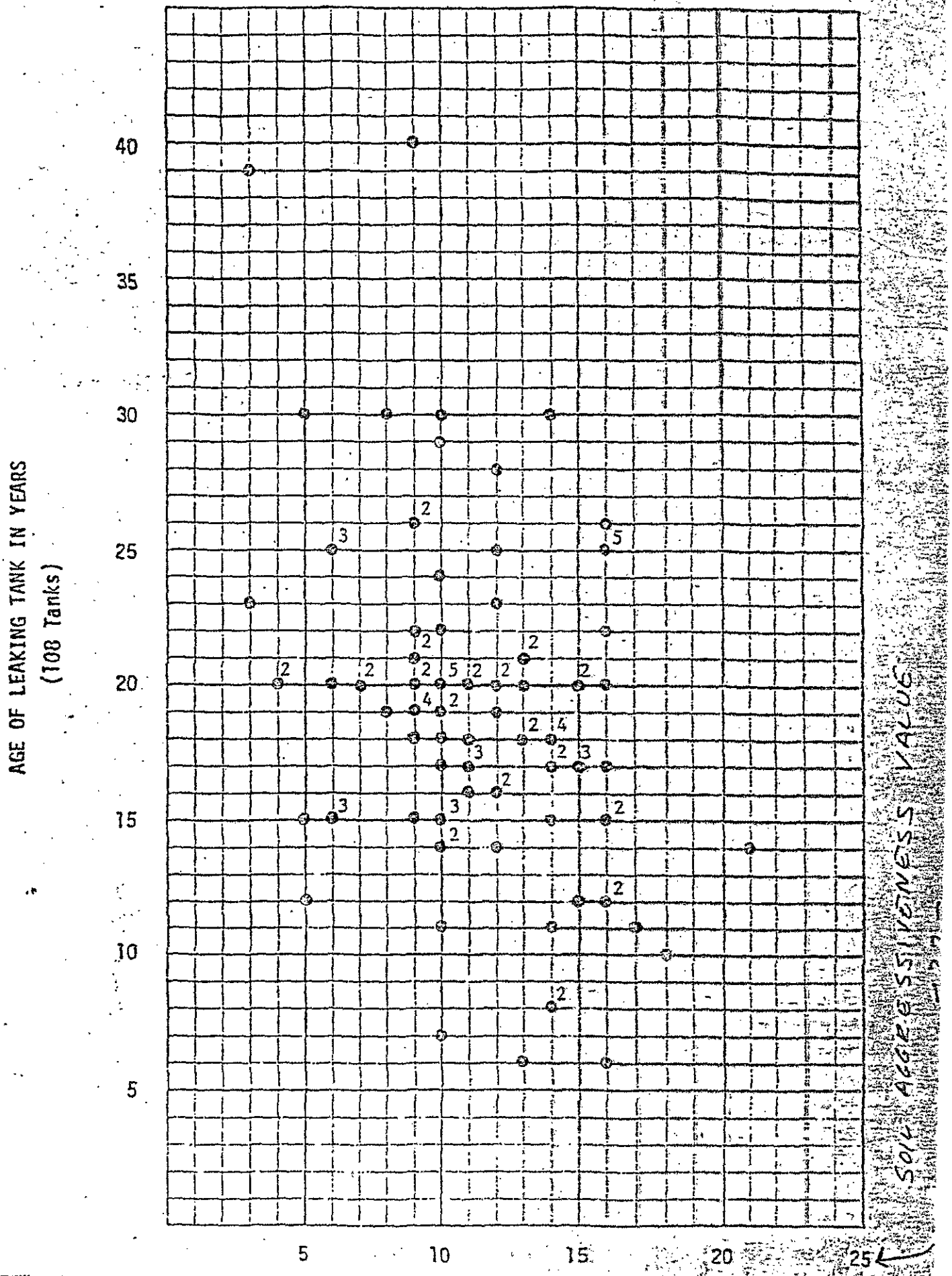
7. That every tank removal be completely documented using a standard form, such as that recommended in Appendix N.

SITES REPORTED - MAY 30 TO NOVEMBER 30, 1977

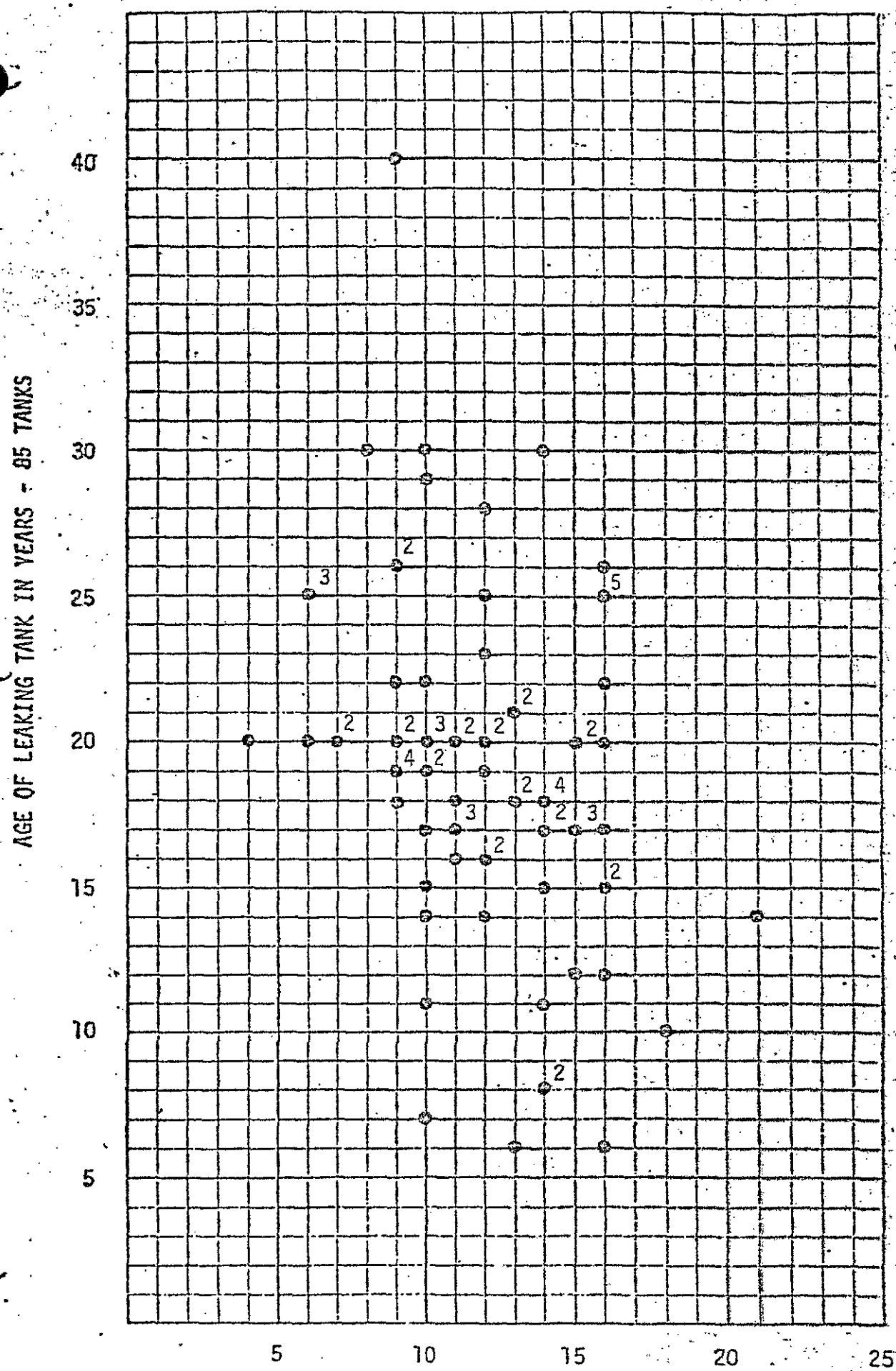
COMPANY	ONT.	B.C.	ALTA.	SASK.	MAN.	QUE.	N.B.	N.S.	P.E.I.	NFLD.	TOTALS
Company A	13	-	-	-	-	0	-	-	-	-	13
Company B	21	2	0	0	3	5	0	1	0	0	32
Company C	16	6	0	0	0	6	5	6	3	1	43
Company D	16	-	-	-	-	1	0	0	0	-	17
Company E	18	1	0	0	0	1	0	0	0	0	20
Company F	18	-	-	-	-	2	-	-	-	-	20
Company G	9	1	1	0	0	2	12	7	0	1	33
Company H	1	-	-	-	-	-	-	-	-	-	1
TOTALS	112	10	1	0	3	17	17	14	3	2	179

LEAKING TANK CHART

AGE VS. SOIL AGGRESSIVENESS

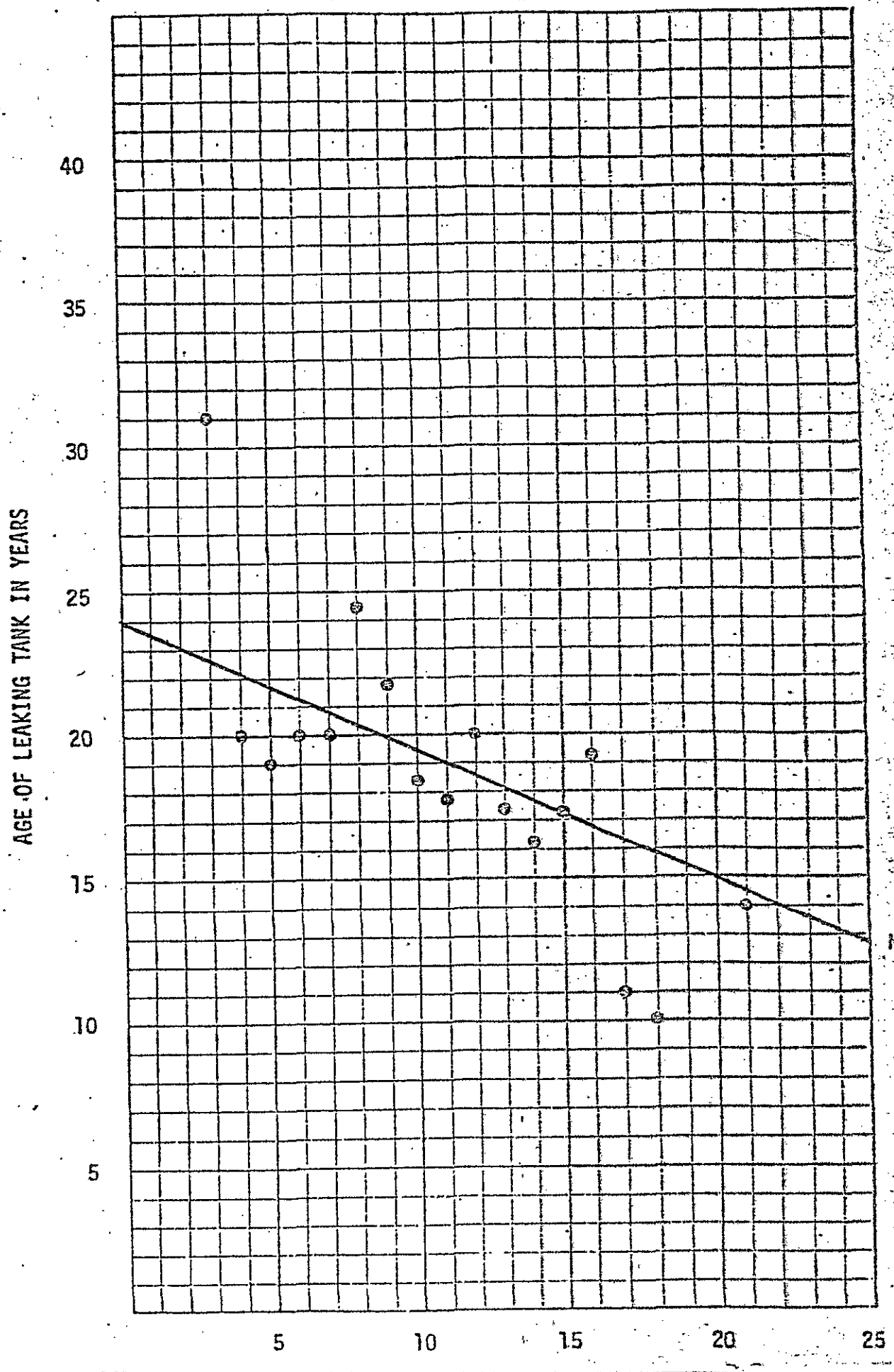


LEAKING TANK CHART
ONTARIO ONLY



LEAKING TANK CHART

AVERAGE AGE VS. S.A.V.



SUMMARY OF TANK REMOVALS

(All Canada)

Age in Years	Number of Tanks Removed	Number of Non-Leakers	Number of Leakers
1	25	25	0
2	5	5	0
3	10	10	0
4	19	18	1
5	5	5	0
6	16	14	2
7	10	9	1
8	20	18	2
9	8	8	0
10	14	12	2
11	16	13	3
12	36	31	5
13	16	14	2
14	14	9	5
15	37	24	13
16	5	2	3
17	20	10	10
18	36	25	11
19	24	15	9
20	72	51	21
21	11	7	4
22	8	5	3
23	5	2	3
24	8	7	1
25	34	24	10
26	11	8	3
28	3	2	1
29	1	0	1
30	12	8	4
31	1	0	1
35	2	1	1
39	1	0	1
40	1	0	1
TOTALS	506	382	124

TOTAL TANK FAILURES BY AGE AND COMPANY - ALL CANADA

Age in Years	Company A	Company B	Company C	Company D	Company E	Company F	Company G	Total	Cumulative Total	Cumulative Percent
4	-	-	1	-	-	-	-	1	1	0.8%
6	1	-	1	-	-	-	-	2	3	2.4
7	-	-	-	-	-	1	-	1	4	3.2
8	-	-	1	1	-	-	-	2	6	4.8
10	-	-	-	1	1	-	-	2	8	6.5
11	-	1	-	-	-	2	-	3	11	8.9
12	-	2	-	-	1	1	1	5	16	12.9
13	-	1	-	-	-	-	1	2	18	14.5
14	-	-	1	-	1	1	2	5	23	18.6
15	-	2	7	-	3	-	1	13	36	29.0
16	-	2	-	1	-	-	-	3	39	31.5
17	1	1	6	2	-	-	-	10	49	39.5
18	8	-	-	2	-	-	1	11	60	48.4
19	-	-	4	-	-	-	5	9	69	55.6
20	-	7	2	4	2	3	3	21	90	72.6
21	1	-	-	-	-	1	2	4	94	75.8
22	-	-	-	1	1	1	-	3	97	78.2
23	-	-	2	-	-	-	1	3	100	80.6
24	-	-	-	-	-	1	-	1	101	81.5
25	-	1	-	1	8	-	-	10	111	89.5
26	-	2	-	-	-	1	-	3	114	91.9
28	-	-	1	-	-	-	-	1	115	92.7
29	-	-	-	-	-	1	-	1	116	93.5
30	1	-	2	-	-	1	-	4	120	96.8
31	-	1	-	-	-	-	-	1	121	97.6
35	-	1	-	-	-	-	-	1	122	98.4
39	-	-	-	-	1	-	-	1	123	99.2
40	-	-	-	-	-	-	1	1	124	100.0
TOTALS	12	21	28	13	18	14	18	124		

Average Age of All Leakers = 18.9 Years

TANK FAILURES BY AGE

(Includes Only Tanks Where Soil Aggressiveness Known)

Age in Years	No. of Failures	Cumulative Total	Cumulative Percent
6	2	-	-
7	1	3	2.6%
8	2	5	4.6
10	1	6	5.6
11	3	9	8.3
12	4	13	12.0
14	4	17	15.7
15	11	28	25.9
16	3	31	28.7
17	10	41	38.0
18	9	50	46.3
19	8	58	53.7
20	20	78	72.2
21	4	82	75.9
22	3	85	78.7
23	2	87	80.6
24	1	88	81.5
25	9	97	89.8
26	3	100	92.6
28	1	101	93.5
29	1	102	94.4
30	4	106	98.1
39	1	107	99.1
40	1	108	100.0

Average Age of All Leakers = 19.1 Years

TANK FAILURES BY
SOIL AGGRESSIVENESS VALUES

S.A.V.	No. of Failures	Shortest Life	Longest Life	Average Age
3	2	23 Years	39 Years	31.0
4	2	20	20	20.0
5	3	12	30	19.0
6	7	15	25	20.0
7	2	20	20	20.0
8	2	19	30	24.5
9	14	15	40	21.8
10	20	7	30	18.5
11	7	16	20	17.8
12	9	14	28	20.0
13	6	6	21	17.4
14	11	8	30	16.2
15	6	12	20	17.2
16	14	6	26	19.3
17	1	11	11	11.0
18	1	10	10	10.0
21	1	14	14	14.0

SOUTHERN ONTARIO PHYSIOGRAPHY RELATED TO SOIL AGGRESSIVENESS VALUES
(Includes All Sites Where Soil Aggressiveness Analyzed)

Soil Class	Innocuous		Mild			Less Aggressive			Aggressive			Highly Aggressive						Totals
S.A.V. Number	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	18	21	
Escarpment								1										1
Kame Moraines	1								1									2
Shale								1		1		1						3
Limestone Plains							1		1			1						3
Spillways		1		1					2									4
Beaches and Bars	1		2					1							1			5
Till Plains					1	1			5	2	1	2	3	1				16
Clay Plains									3	3	5	3	5	1	5	1		26
Sand Plains			1	1	1	1	1	6	3	3	3	2	5	1	4		1	33
Totals	2	1	3	2	2	2	2	9	15	9	9	9	13	3	10	1	1	93

INTERNAL CORROSION DETAILS

Consultants' Chart No.	Company	S.A.V.	No. and Size	Age	Product	Tank Material	No. of Perforations	Location of Corrosion
29	B	9	1-1000	26		Galv.	8	Bottom
34	E	16	1-3000	12	No Lead	Steel	1-1/4"Ø	Directly below fill
36	F	9	1-3000	22	Regular	Steel	1-1/8"Ø	Bottom below vent
45	A	10	1-3000	17	Regular	Steel	1-1/4"Ø	Directly below fill
54	F	14	1-1000	30	Regular	Galv.	Few Pinholes	Bottom in ribs
72	G	9	1- 500	40	No Lead	Galv.	3	Holes on bottom of ribs
Others								
2	B (Que.)	17	1-5000	11	No Lead	Steel	1-1/2"Ø	Below fill pipe
33	B (Ont.)		1- 500	31	Premium	Galv.		Each rib along bottom
81	C (N.B.)		1-1000	4	Gas	Steel		Bottom of tank
103	B (B.C.)	9	2-3000	21	Premium	Steel	1 pinhole	Hole in bottom

DETAILS ON TANKS ADJACENT TO LEAKERS IN SOUTHERN ONTARIO

(Includes Only Reported Leakers Where Adjacent Tankage Also Removed)

Consult.	Reported Leakers					Adjacent Tanks				
Chart No.	No. & Size	Age	Product	Type of Corrosion	Corrosion Extent	No. & Size	Age	Type of Corrosion	Corrosion Extent	Leaker
1	1-4000	20	Premium	External	Local	1-2000	26	External	Local	Yes
						2-2000	26	Minor		No
2	1-3000	19	No Lead	External	Severe pitting	2-2000	19	External	Some pitting	No
3	1-5000	8	Regular	External	Severe pitting	3-5000	8	External	Severe pitting	No
5	1-5000	20	Regular	External	Severe pitting	1-3000	20	External	Severe pitting	Yes
7	1-5000	14	Regular	External	Severe local	1-4000	14	External	Deep severe	No
8	1-3000	19	Regular	External	Severe local	1-3000	19	External	Severe local	Yes
						1-2000	19	External	Severe local	Yes
						1-2000	19	External	Very little	No
11	1-3000	21	Gas	External	Severe local	2-3000	22	External	Severe local	No
12	1-3000	17	No Lead	External	Severe	2-3000	17	External	Severe	Yes
13	1-3000	25	Regular	External	Severe	2-2000	25	External	Severe	Yes
20	1-3000	20	Regular	External	Local	1-2000	25	External	Local	Yes
						1-1000	25	None		No

DETAILS ON TANKS ADJACENT TO LEAKERS IN SOUTHERN ONTARIO

(Includes Only Reported Leakers Where Adjacent Tankage Also Removed)

Consult.	Reported Leakers					Adjacent Tanks				
Chart No.	No. & Size	Age	Product	Type of Corrosion	Corrosion Extent	No. & Size	Age	Type of Corrosion	Corrosion Extent	Leaker
21	1-2000	18	Premium	External	Very local	2-2000	18	External	Slight	No
34	1-3000	12	No Lead	Internal	Below fill	2-3000	12	External	Some slight	No
36	1-3000	22	Regular	Internal	Below vent	2-3000	22	No corrosion		No
	1-4000	20	Premium	External	Severe pitting	1-4000	11	No corrosion		No
39	1-1000	17	Heating Oil	External	Numerous	1-5000	17	External	Local pitting	No
	1-3000	17	Premium	External	Numerous					
	1-4000	17	No Lead	External	Numerous					
42	1-3000	15	No Lead	External	2 Perforations	1-3000	15	External	Local pitting	No
	1-3000	15	Regular	External	12 Perforations					
57	1-1000	18	No Lead	External	6 Perforations	2-3000	18	External	Very minor	No
70	1-3000	11	Regular	External	3 Perforations	1-3000	11	External	Minor	No
	1-2000	29	No Lead	External	5 Perforations	1-4000	20	External	Minor	No

HEATING OIL TANK REMOVAL DETAILS

Consultants' Chart No.	Size of Tank	Age	Leaking		Reason for Removal	Degree of Corrosion
			Yes	No		
2	1000	19		X	Close out	Not noted
17	1000	10	X		Water in tank	External - 5 perforations in bottom, 1 near top
39	1000	17	X		Part of leaking tank removal	Perforations on bottom and side
51	500	18	X		Water in tank	Dozens of perforations all over tank
52	500	16	X		Water in tank	One perforation on end at bottom
56	500	12	X		Close out	3 perforations in top 1/2 of tank
63	500	22	X		Water in tank	5 perforations top and bottom
68	1000	20	X		Water in tank	Perforations both ends - top 1/2 of tank
73	500	22	X		Close out	Perforations all over - mainly top 1/2 of tank
Others						
14	500	17		X	Close out (B.C.)	No corrosion
23	636	20		X	Close out (B.C.)	No corrosion
35	500	18	X		Water in tank (Ontario)	External - bottom of tank
51	1000		X		Water in tank (Quebec)	External - perforations in bottom and side

WASTE OIL TANK REMOVAL DETAILS

Consultants' Chart No.	Size of Tank	Age	Leaking		Reason for Removal	Degree of Corrosion
			Yes	No		
2	1000	19		X	Close out	Not noted
23	500	26		X	Close out	No corrosion
30	500	20		X	Close out	External - slight pitting
31	500	25		X	Close out	No corrosion
47	500	25		X	Close out	External - surface corrosion
53	1000	20	X		Close out	Completely perforated all over
61	500	6		X	Close out	Very minor external pitting
68	500	20	X		Close out	Completely perforated all over
69	500	18		X	Close out	No corrosion
71	500	20		X	Close out	External - slight scaling and shallow pits
Others						
14	500	17		X	Close out (B.C.)	No corrosion
23	500	20		X	Close out (B.C.)	No corrosion
48	500	14		X	Close out (B.C.)	No corrosion
53	500	20	X		Close out (Ontario)	Several perforations
54	500	13	X		Close out (Ontario)	Perforated
63	500	25		X	Close out (Ontario)	
64	500	20		X	Close out (Ontario)	
78	500	15	X		Water in tank (N.S.)	Sides of tank severely rusted
87	500	18	X		Close out (B.C.)	Completely perforated

Thorco
TANK LINING COMPANY
1700 MIDLAND AVENUE
SCARBOROUGH, (TORONTO) ONT.
M1P 3C2
TELEPHONE: 751-8747

January 12, 1978

P A C E,
c/o Sunoco Inc.,
56 Wellesley Street West,
Toronto, Ontario
M5S 2S4

Attention: Mr. Bert A. Valde

Dear Sir,-

Attached is a summary of Service Station tanks lined by Thorco in the Toronto area between 1971 and 1977, along with a general assessment of the condition of the tanks at the time that they were Glass Armor lined.

Our records indicate that the following general conclusions can be drawn concerning the condition of the tanks which we have Glass Armor lined in the past:

a) The location of most serious corrosion has been in the bottom portion of the tanks.

b) Outside corrosion working towards the inside has occurred in the majority of instances where holes have been found at the time of sandblasting the interior of the tanks in preparation for Glass Armor lining. The number of cases of internal corrosion of serious magnitude has been minimal.

c) Corrosion has often occurred in the bottom portion of the tanks in close proximity to the seams.

d) In a high percentage of the tanks lined a few isolated corrosion areas resulted in holes through the tank shell. These holes were a result of outside corrosion working inwards causing a hole through the metal.

We trust the attached will be useful. If we can be of further assistance, please contact me directly.

Yours very truly,
THORCO TANK LINING COMPANY,

J.D. Thordarson,
General Manager.

Distributor of GLASS ARMOR for Corrosion Control

PROPOSED TANK REMOVAL REPORT

Location:		Date:
Supplying Company:	Contact:	Tel. No:
Contractor:		Tel. No:

REASON FOR REMOVAL

Details of Tanks Removed:

Tank No.	Size	Product	Age	Tank Material	Type and Extent of Corrosion	Leaker Yes	Leaker No
1							
2							
3							
4							
5							
6							

LEAK DETAILS

Date Leak Discovered:

Product Lost:	Product Recovered:

How Was Leak Discovered?

Were Proper Records Maintained?

SOIL CONDITIONS

Native Soil:	Soil Aggressiveness Value:

Backfill Material:

Water Table:

REMARKS

DETAILS OF TANK REMOVALS ATTENDED BY CONSULTANTS

Company and Site Location	Soil Resistivity	pH	Moist	Sulfide	S.A.V.	Internally Inspected	Leaking Tanks: No. & Size	Leaking Tanks: Age	Leaking Tanks: Product	Leaking Tanks: Reason for Removal	Leaking Tanks: Corrosion Details	Other Tanks: No. & Size	Other Tanks: Age	Other Tanks: Product	Other Tanks: Corrosion Details	Remarks
Company A Bloor & Islington Etobicoke	2,400	7.6	Moist	No	9	No	1-2,000	18	Premium	Taking on water; upgrade of storage.	External: localized pitting on clean tank; 2 perf. in shell bottom.	1-2,000 1-2,000	18 18	No Lead Regular	Slight external pitting only.	Native soil: wet, muddy clay. Backfill: wet sand mixed with clay.
Company A Southdown & Truscott Mississauga	21,300	8.2	Moist	Yes	11	No				Upgrade of storage due to re-development.		1-5,000 1-5,000 1-4,000 1-3,000	2 12 12 12	Regular Regular No Lead Premium	No corrosion; near perfect condition.	Native soil: clay. Backfill: sand. Good installation.
Company A 83 Hunter Street Peterborough	13,000	8.7	Moist	Yes	10	No	1-3,000	12	Regular	Dip records indicate 1,330 gallons lost over 22-hour period.	Internal: 1/4-in. perf. below fill pipe. Exterior of tank covered with coating and surface pitting.					Native soil: sandy soil with smooth stones; heavy clay at 15-ft. Backfill: sand. Water table: 11½-ft.
Company A Hwy. #9 & Hwy. #27 Schomberg	3,000	8.7	Sat.	Yes	16	No	1-3,000	18	Premium	Upgrade of storage.	External: localized pitting; 1 perf. in seam at tank bottom vent end.	2-3,000	18	Regular	External: localized pitting at seam and where clay stuck to tank.	Native soil: moist clay. Backfill: sand but tank bottom set on clay.
Company A Stanley & Dalhousie Brantford	3,300	7.4	Moist	Yes	14	No	1-3,000 1-3,000	18 18	Regular Regular	Upgrade of storage due to re-development.	External: 3 perf. and deep localized pitting. External: 1 perf. and deep localized pitting.	1-2,000	18	No Lead	External: localized deep pitting.	Native soil: sandy/clay. Backfill: was native soil.
Company A 219 Sheppard Ave. E. North York	3,200	8.1	Moist	Yes	14	No	1-1,000	18	No Lead	Water in tank and in cart.	External: 1 perf. at top and 3 at bottom, all at fill end.	1-1,000	18	Regular	External: very minor pitting along bottom.	Native soil: heavy sandy coloured clay. Backfill: clean sand.
Company A St. Clair & Kennedy Scarborough	2,400	8.5	Moist	Yes	13	Yes	1-3,000	18	Premium	Upgrade of storage due to re-development.	External: 12 perf. in bottom and side of tank nearest other tanks.	1-4,000 1-3,000 1-2,000	18 18 18	Regular Regular No Lead	External: minor localized pitting.	Native soil: moist clay. Backfill: was native soil.
Company B (Consumer) 501 Fairview Rexdale	1,700	6.8	Sat.	Yes	16	Yes	1-2,000	6	Regular	Close out.	External: severe pitting with 5 perforations.					Native soil: clay. Backfill: sand and clay with debris. Tire and plank in contact with tank.
Company A (Consumer) 149 Norfinch Rexdale	19,300	6.5	Moist	Yes	11	Yes				Close out.		1-7,000	4	Regular	External: tank in perfect condition.	Native soil: land fill site. Backfill: sand.
Company C Bathurst & Drewry North York	3,200	7.8	Moist	Yes	14	Yes	1-5,000	9	Regular	Water in tank.	External: localized pitting with 4 perforations.	1-5,000 1-5,000 1-5,000	8 8 8	Regular Premium No Lead	External: badly pitted and gouged.	Native soil: clay. Backfill: sand but tank bottom set on clay.
Company C 300 Lindsay Street Cornwall	2,200	7.4	Moist	No	18	No	1-5,000	14	Regular	Water in tank.	External: localized pitting on bottom with 6 perforations.	1-4,000	14	Regular	External: deep and severe localized pitting on bottom.	
Company C Clarke & Trafalgar London	1,000	8.0	Moist	No	[illegible]	No	1-3,000 1-3,000 1-8,000	10 10 10	Regular Regular Premium	Water in tank. Age. Age.	External: 1 perforation. External: 3 perforation. External: 3 perforations.	1-2,000	10	Premium	External: very minor.	
Company C Fanny & Bathurst Toronto	[illegible]	[illegible]	Moist	No	[illegible]	[illegible]	1-5,000 1-3,000	[illegible]	Regular No Lead	Product and water in store basement and owners site closed out.	External: various perf. ranging from pinhole to [illegible]-in.					Backfill: sand close to tank with rubble, clay, etc. to roadway.

Appendix C

DETAILS OF TANK REMOVALS ATTENDED BY CONSULTANTS

Company and Site Location	Soil Resistivity	pH	Moist	Sulfide	S.R.V	Internally Inspected	Leaking Tanks: No & Size	Leaking Tanks: Age	Leaking Tanks: Product	Leaking Tanks: Reason for Removal	Leaking Tanks: Corrosion Details	Other Tanks: No. & Size	Other Tanks: Age	Other Tanks: Product	Other Tanks: Corrosion Details	Remarks
Company A Elder & Islington Etobicoke	2,400	7.6	Moist	No	9	No	1-2,000	18	Premium	Taking on water; upgrade of storage.	External: localized pitting on clean tank; 2 perf. in shell bottom.	1-2,000 1-2,000	18 18	No Lead Regular	Slight external pitting only.	Native soil: wet, muddy clay. Backfill: wet sand mixed with clay.
Company A Southdown & Truscott Mississauga	21,300	8.2	Moist	Yes	11	No				Upgrade of storage due to re-development.		1-5,000 1-5,000 1-4,000 1-3,000	2 12 12 12	Regular Regular No Lead Premium	No corrosion; near perfect condition.	Native soil: clay. Backfill: sand. Good installation.
Company A 83 Hunter Street Peterborough	13,000	8.2	Moist	Yes	10	No	1-3,000	17	Regular	Dip records indicate 1,130 gallons lost over 22-hour period.	Internal: 1/4-in. perf. below fill pipe. Exterior of tank covered with coating and surface pitting.					Native soil: sandy soil with smooth stones; heavy clay at 15-ft. Backfill: sand. Water table: 11½-ft.
Company A Hwy. #9 & Hwy. #27 Schomberg	3,000	8.7	Sat.	Yes	14	No	1-3,000	18	Premium	Upgrade of storage.	External: localized pitting; 1 perf. in seam at tank bottom west end.	2-3,000	18	Regular	External: localized pitting at seam and where clay stuck to tank.	Native soil: moist clay. Backfill: sand but tank bottoms set on clay.
Company A Stanley & Dalhousie Brantford	3,300	7.4	Moist	Yes	18	No	1-3,000 1-3,000	18 18	Regular Regular	Upgrade of storage due to re-development.	External: 3 perf. and deep localized pitting. External: 1 perf. and deep localized pitting.	1-2,000	18	No Lead	External: localized deep pitting.	Native soil: sandy/clay. Backfill: was native soil.
Company A 219 Sheppard Ave. E. North York	3,700	8.1	Moist	Yes	14	No	1-1,000	18	No Lead	Water in tank and in cars.	External: 3 perf. at top and 3 at bottom, all at fill end.	2-3,000	18	Regular	External: very minor pitting along bottom.	Native soil: heavy sandy coloured clay. Backfill: clean sand.
Company A St. Clair & Kennedy Scarborough	2,400	8.5	Moist	Yes	13	Yes	1-3,000	18	Premium	Upgrade of storage due to re-development.	External: 12 perf. in bottom and side of tank nearest other tanks.	1-4,000 1-3,000 1-2,000	18 18 18	Regular Regular No Lead	External: minor localized pitting.	Native soil: moist clay. Backfill: was native soil.
Company A (Consumer) 501 Fairway Rexdale	2,700	6.0	Sat.	Yes	16	Yes	1-2,000	4	Regular	Close out.	External: severe pitting with 5 perforations.					Native soil: clay. Backfill: sand and clay with debris. Tile and plank in contact with tank.
Company A (Consumer) 169 Hartlands Rexdale	10,300	6.5	Moist	Yes	11	Yes				Close out.		1-2,000	4	Regular	External: tank in perfect condition.	Native soil: land fill site. Backfill: sand.
Company C Bathurst & Drewry North York	3,200	7.8	Moist	Yes	14	Yes	1-5,000	8	Regular	Water in tank.	External: localized pitting with 5 perforations.	1-5,000 1-5,000 1-5,000	8 8 8	Regular Premium No Lead	External: badly pitted and gouged.	Native soil: clay. Backfill: sand but tank bottoms set on clay.
Company C 369 Lindsay Street Cayuga	2,200	7.4	Moist	No	10	No	1-5,000	14	Regular	Water in tank.	External: localized pitting on bottom with 5 perforations.	1-4,000	14	Regular	External: deep and severe localized pitting on bottom.	
Company C Clarke & Grafalgar London	5,000	8.0	Moist	No	9	No	1-3,000 1-5,000 1-4,000	19 19 19	Regular Regular Premium	Water in tank. Age. Age.	External: 1 perforation. External: 1 perforation. External: 3 perforations.	1-2,000	19	Premium	External: very minor.	
Company C Yonge & Dundurn Toronto	8,000	9.2	Moist	No	11	Yes	2-3,000 1-5,000	17 17	Regular No Lead	Product and odour in store basement near dump site placed out.	External: various perf. ranging from pinhole to 1/8-in. x 2-in.					Backfill: sand close to tanks with rubble, clay, etc. in remainder.

DETAILS OF TANK REMOVALS ATTENDED BY CONSULTANTS

Company and Site Location	Soil Resistivity	pH	Moist	Sulfide	S.A.V	Internally Inspected	Leaking Tanks: No. & Size	Age	Product	Reason for Removal	Corrosion Details	Other Tanks: No. & Size	Age	Product	Corrosion Details	Remarks
Company B 2801 Jerry Road Malton	2,400	5.7	Sat.	Yes	16	No	1-500	22	Fuel Oil	Water in tank.	External: 5 perforations 1/8-in. to 1-in.					Native soil: clay. Backfill: sand and clay with some cinders.
Company B (Consumer) 499 Lakeshore Blvd. Toronto	51,000	6.7	Moist	No	4	Yes	1-2,000	20	Regular	Close out.	External: 1 1/2-in. diameter perforation in bottom.					Native soil: sand. Backfill: sand with some cinders.
Company B Spadina & Richmond Toronto	3,300	6.3	Moist	No	12	No	2-2,000	16	Premium	Close out.	External: several perf. and badly pitted.	1-3,000 1-5,000	11 7	Regular No Lead	No corrosion. External: slightly pitted	Native soil: hard clay. Backfill: clean sand at regular tanks, sand and clay mixed with cinders at premium tank.
Company B 640 St. Clair Ave. W. Toronto	3,600	6.8	Moist	No	14	No				Close out.		2-2,000 1-2,000 1-3,000	18 14 7	Regular Premium No Lead	External: many pitted areas along bottom.	Backfill: sand, clay and debris.
Company B Lincoln & Southworth Welland	1,300	7.1	Moist	No	12	No	1-3,000 1-2,000	20 25	Regular No Lead	Water in tank. Age.	External: 1 perf. in bottom and localized pitting; 2 perf. in bottom and localized pitting.	1-1,000 (Galv.)	25	Premium	No corrosion.	Native soil: land fill over marsh. (Fill came from Union Carbide Plant). Top 3-ft. black, grey clay, remainder is light brown clay. Backfill: native soil.
Company B Stanley Avenue Niagara Falls	2,700	6.7	Moist	Yes	14	No				Close out.		1-3,000 1-3,000 1-3,000	20 20 20	Regular Premium Diesel	External: very clean with light generalized surface pitting; one tank had deep pits from clay.	Native soil: brown dry clay. Backfill: sand.
Company B Queen & Scarborough Rd. Scarborough	14,300	6.7	Moist	Yes	7	No	1-1000	26		Close out.	Internal: 8 perf. in bottom ribs of galvanized tank.	1-1,000 2-2,000	26 26		External: very slight surface pitting.	Native soil: sand. Backfill: sand.
Company B (CFIO) McEwan & Hwy. #401 North York	3,700	8.1	Sat.	Yes	11	No				Relocation of tanks.		1-2,000 1-3,000	6 6	Regular No Lead	External: very slight surface pitting.	Native soil: clay. Backfill: sand.
Company B Avenue Rd. & Lawrence Toronto	10,800	6.6	Moist	Yes	10	Yes				Close out.		1-5,000 1-4,000 1-3,000 1-500	4 8 11 10	Regular Premium No Lead Waste Oil	No corrosion.	Backfill: sand.
Company B Kingston Rd. & Harding Scarborough	13,000	6.1	Moist	Yes	9	Yes				Close out.		1-2,000 1-3,000 1-2,000 1-500	20 20 20 20	Premium Regular Regular Waste Oil	External: slight scaling and localized shallow pitting.	Native soil: sandy silt. Backfill: sand.
Company B Wellesley & Sherbourne Toronto	6,500	7.8	Moist	No	4	Yes	1-2,000 1-2,000 1-3,000	25 25 25	Regular Regular Regular	Product in nearby building.	External: 4 perf. bottom 3 end welds, disintegrated; 2 perf. in weld 3 1/2-in. dia. perf. in bottom; 2 1/8-in. dia. perf. in bottom & 2 1/4-in. dia. perf. in weld; respectively.					Native soil: sand. Backfill: sand.
Company B Hwy. #27 & Pikton Rd. Brodale	1,300	5.9	Moist	Yes	18	No	1-1,000	18	Fuel Oil	Furnace stopped; water in tank.	External: badly corroded 5 perf. along bottom; gas vent top.					Native soil: clay. Water table: high.
Company B Bathurst & York Mills Toronto	2,000	6.0	Moist	Yes	16	No				Close out.		1-2,000 1-2,000 1-2,000 1-1,000 1-500	26 26 26 26 26	No Lead Regular Premium Regular Waste Oil	No corrosion.	Native soil: clay. Backfill: sand. Sacrificial anodes installed 1969.

Appendix O

DETAILS OF TANK REMOVAL AS GIVEN BY CONSULTANTS

Company and Site Location	Soil Resistivity	pH	Moist.	Sulfide	S.A.R.	Internally Inspected	Existing Tanks: No. & Size	Age	Product	Reason for Removal	Corrosion Details	Other Tanks: No. & Size	Age	Product	Corrosion Details	Remarks
Company E Danforth & Drayton Toronto	10,000	7.8	Moist	No	[illegible]	No				Close out.		2-10,000 1-5,000	8 6	Gas Gas	External: slight localized shallow pitting.	Native soil: clay. Backfill: sand.
Company E Jarvis & Richmond Toronto	900	6.1	Moist	Yes	.21	No	1-3,000	18	Regular	Water in tank and in cars.	External: 5 perf. at bottom.					Native soil: clay fill to 4-ft.; grey, blue clay from 4-ft. to 7-ft.; heavy brown clay below 7-ft. Backfill: sand Water table: 1' tank bottom.
Company E Church & McGill Toronto	5,200	6.3	Moist	Yes	13	No				Close out.		2-5,000 1-500	28 20	Gas Waste Oil	External: slight pitting.	Native soil: clay. Backfill: sand.
Company E Dundas & Coxon Mississauga	1,600	6.6	Moist	No	12	No				Close out.		3-5,000 1-2,000 1-500	25 25 25	Gas Gas Waste Oil	No corrosion.	Native soil: blue clay. Backfill: sand.
Company E Airport & Slough Malton	1,500	6.9	Moist	Yes	16	No	1-3,000	12	No Lead	Water in tank and in cars.	Internal: 1/4-in. perf. directly below fill pipe.	1-3,000 1-3,000	12 12	Premium No Lead	External: some pitting especially tank nearest the other protected tank.	Native soil: red and blue clay. Backfill: sand. Water table: 6-in. above tank bottoms.
Company E Eglinton & Lloyd Manor Islington	9,800	9.6	Moist	Yes	13	Yes				Upgrade in storage due to re-development.		1-5,000 2-3,000 2-3,000 1-3,000	6 12 12 2	Premium No Lead Regular Regular	External: several pitted areas over lower half of tank.	Native soil: clay. Backfill: sand with some clay.
Company E Spadina & Wellington Toronto	1,600	7.7	Moist	Yes	16	Yes	1-3,000 1-3,000	15 15	No Lead - Regular	Water in tank.	External: 2 perf. External: severe corrosion with 12 perf.	1-3,000	16	Regular	External: pitting in several areas.	Native soil: blue clay. Backfill: sand containing cinders, building debris, etc.
Company E Pine & Cosburn Toronto	6,200	7.6	Moist	Yes	16	No	1-2,000 1-1,000	25 25	Gas Gas	Close out.	External: one or more perforations in each tank.	1-500	25	Waste Oil	External: minor pitting.	Native soil: clay. Backfill: sand mixed with clay.
Company E 571 Maple Grove Oakville	6,300	8.4	Moist	Yes	18	No				Upgrade in storage due re-development.		2-5,000 1-5,000 1-5,000	20 14 6	Regular Premium No Lead	External: severe pitting over bottom quarter and both ends.	Native soil: shale 4-ft. to 5-ft. below grade. Backfill: sand.
Company E Bay & Dalton Toronto	1,100	8.1	Moist	Yes	15	No	1-1,000 1-500	20 20	Fuel Oil Waste Oil	Water in tank; close out	External: perf. and deep pits over top half and both ends. External: perforated all over whole tank.	1-5,000 2-3,000 1-3,000	4 20 29	No Lead Regular	External: very minor pitting.	Native soil: clay. Backfill: sand.
Company E 1757 Eglinton Ave. E. Scarborough	5,100	8.5	Moist	Yes	18	Yes	1-1,000	22	Fuel Oil	Close out.	External: perforations all over tank but mainly in top half.	1-5,000 2-3,000 1-2,000	10 22 15	Gas Gas Diesel	External: localized pitting along bottom quite deep in places.	Native soil: sandy clay. Backfill: sand.
Company E Concession & Hamilton Hamilton	2,900	7.2	Moist	No	9	Yes	1-4,000 1-2,000	20 16	Premium Regular	Water in Premium tank; close out.	External: localized pitting where clay adhered to tanks.	2-2,000	28	Regular	No corrosion.	Native soil: rock. Backfill: sand with some clay.
Company E Hwy. 401 Wasaga Beach	89,600	7.8	Moist	No	4	No				Energy Board ordered removal due to contaminated well on property		1-3,000	12	Premium	No corrosion; air test above ground held.	Native soil: sand.

DETAILS OF TANK REMOVALS ATTENDED BY CASTLE TANKS

Company and Site Location	Soil Resistivity	pH	Moist	Sulfide	S.A.V	Internally Inspected	Leaking Tanks: No. & Size	Age	Product	Reason for Removal	Corrosion Details	Other Tanks: No. & Size	Age	Product	Corrosion Details	Remarks
Company F Dundas & Gooch Etobicoke	28,500	8.4	Dry	No	7	Yes				Upgrade in storage.		3-2,000 1-2,000	19 19	Regular Premium	External: surface coating but no pitting.	Native soil: sand.
Company F 158 Talbot Street Leamington	5,000	7.8	Moist	Yes	13	No	1-3,000	21	Gas	Water in tank.	External: surface pitting under heavy coating; localized pitting and 1 perforation in bottom.	2-3,000	21	Gas	External: surface pitting and deep localized pitting under heavy coating	Native soil: sand over clay. Backfill: sand.
Company F Hwy. 211 & Innisfil Street	8,000	6.8	Moist	No	7	No				Upgrade in storage.		1-4,000 1-1,000 (Galv.)	20 30	Regular Premium	External: slight pitting. No corrosion.	Native soil: clay and sand. Backfill: sand.
Company F Hwy. 427 & Evans Mississauga	3,400	5.4	Moist	No	16	No				Tank in way of new canopy footing.		1-5,000	9	No Lead	External: slight localized pitting.	
Company F Hwy. 65 & Walker's Line Waterdown	2,600	6.8	Moist	Yes	16	No	1-4,000	11	Premium	Close out.	External: 1 perf. in bottom with numerous deep localized pits.	1-4,000	11	Regular	External: localized deep pitting and grooves along bottom.	Native soil: heavy brown clay. Backfill: granular rock dust/pebbles fills formed thick blisy granular coating over tanks Water table: near tank bottoms.
Company F Victoria Avenue Ottawa	60,000	7.2	Dry	No	7	No				Close out.		1-6,000 1-6,000	20 20	Premium Regular	External: deep localized pitting on bottom plate and welds.	Native soil: sandy type soil with roots, debris and clay mixed in.
Company F Dixon & Lipling Etobicoke	4,100	8.0	Moist	Yes	13	No				Upgrade in storage.		2-5,000 1-5,000 1-5,000	8 8 8	Regular Premium No Lead	No corrosion.	Native soil: clay. Backfill: sand.
Company F North Service Rd. & Easley Mississauga	17,200	8.2	Moist	Yes	9	Yes	1-3,000 1-4,000	22 20	Regular Premium	Water in tank. Some water problems.	External: 1 perf. in bottom of tank; no extensive corrosion. External: 4 perf. and heavily pitted in top half of tank	2-3,000 1-4,000	22 11	Regular No Lead	No corrosion.	Native soil: layered sandy clay with grey clay and shale at 12-ft. Backfill: sand. Water table: at 7-ft. or 8-ft.
Company F Niagara Stone Road Niagara	3,500	8.1	Moist	Yes	12	No	1-1,000	14	No Lead	Water in tank.	External: 4 perf. found on end plate; localized pitting on bottom and plate.					Native soil: heavy wet clay. Backfill: sand.
Company F Hwy. 401 Wainfleet	6,000	7.6	Dry	No	10	No	1-500	7	No Lead	Close out.	External: 1 perf. in weld at end plate near top; localized pitting on plate.	1-2,000	7	Regular	External: slight surface rust on top of tank.	
Company F Main Street Milton	1,500	7.6	Wet	Yes	14	No	1-1,000	20	Waste Oil	Close out.	External: hundreds of perforations all over tank.	1-1,000 1-1,000 1-1,000	10 10 10	Regular Regular No Lead	External: minor pitting. External: deep pitting on bottom. External: minor pitting.	Native soil: clay mixed with rubble, landfill Backfill: sand at gas tanks, rubble at waste oil tank; top of gas tanks very rust pitted and the bottoms were clean.
Company F Hwy. 11 Barrie	2,000	8.0	Wet	Yes	14	No	1-1,000 (Galv.)	30	Regular	Upgrade in storage.	Internal: perforations on bottom in ring. External: minor.	1-1,000 1-1,000	30 30	Regular No Lead	External: minor corrosion.	Native soil: plastic clay.
Company F Lytle & Dexter North Bay	9,000	8.1	Moist	Yes	16	No	1-500	12	Fuel Oil	Upgrade in storage due to re-development.	External: 5 perf. in top half of tank.	1-5,000 2-5,000 1-5,000	3 12 12	No Lead Regular Premium	External: slight surface corrosion.	Native soil: sandy clay. Backfill: sand. 3-year old tank had heavier corrosion than others.

DETAILS OF TANK REMOVAL SUPPLIED BY CONSULTANTS

Company and Site Location	Soil Resistivity	pH	Moist	Sulfide	S.R.V.	Internally Inspected	Leaking Tanks: No. & Size	Age	Product	Reason For Removal	Corrosion Details	Other Tanks: No. & Size	Age	Product	Corrosion Details	Remarks
Company F Sheppard & Woodbine North York	3,400	6.3	Sat.	Yes	14	Yes				Upgrade in storage due to re-development.		2-5,000 1-5,000 1-5,000	11 11 4	Regular Premium No Lead	External: severe pitting; very deep in places.	Native soil: land fill 3-ft. to 4-ft. deep over clay. Water table: at 6-ft.
Company F Dundas & Fay Woodstock	5,800	7.2	Moist	Yes	10	No				Close out		1-5,000 1-4,000 1-4,000 1-4,000	3 15 15 15	No Lead Premium Regular Regular	External: slight surface rust. External: slight pitting. External: minor pitting. External: deep local. pitting.	Native soil: backfill material--rubble, bricks, clay and loam. Backfill: sand.
Company F Avenue Rd. & Woburn North York	6,200	8.9	Moist	Yes	10	Yes	1-3,000 1-2,000	11 29	Regular No Lead	Water in tank. Water in tank.	External: 1 perf. in bottom. External: 3 perf. in end plate & 2 perf. in bottom	1-3,000 1-4,000	11 20	Regular Premium	External: minor pitting.	Native soil: clay. Backfill: sand. Water table: 3-ft. above tank bottom.
Company G Viper & Walmer Toronto	2,900	8.0	Moist	No	9	No	1-3,000	19	No Lead	Water in tank; gas in drill manhole.	External: severe pitting and 3/8-in. diameter perforations.	2-2,000 1-1,000 1-1,000	19 19 19	Regular Fuel Oil Waste Oil	External: some localized pitting.	Native soil: fill of sand to 11-ft. over glacial silt till. Backfill: sand.
Company G Trafalgar Rd. South of G.I.W Oakville	4,100	7.5	Moist	No	10	No	1-2,000 1-2,000	20 20	Gas Gas	Upgrade in storage due to re-development.	External: numerous perf. in bottom. External: 2 perf. in end plate weld at tank bottom	2-2,000	20	Gas	External: numerous deep pits and gouges.	Native soil: red clay to 3-ft ; gray clay to 7-ft. and shale below. Backfill: granular. Tanks set 3-ft. deep in concrete slab and encircled with ring straps.
Company G Bulk Plant Hwy. 427 Schomberg	1,800	7.5	Moist	No	12	Yes				Upgrade in storage.		1-500 1-2,000 1-5,000	25 25 25	Gas & Distillates	External: some shallow localized pitting on 2 tanks.	Native soil and backfill: heavy clay. 3-2,000 gal. tanks had sides touching each other.
Company G Woodbine & Crawley Side Rd. Crawley	2,600	9.2	Moist	Yes	14	No				Basement sump contained gasoline.		1-5,000	8	Regular	External: deep localized pitting on bottom.	Native soil: clay with sand. Backfill: sand. Suspected leaker removed but no perforations found. Further testing to be done.
Company G Lowbanks	14,200	7.6	Moist	Yes	9	Yes	1-500 (fuel)	40	No Lead	Dip records indicated leak.	Internal: perforations in bottom of ribs.					Native soil and backfill: beach sand. Water table: varies Tank 100-ft. ± from Lake Erie.
Company G Upper James & Fennell Hamilton	5,600	8.5	Moist	Yes	12	No	1-3,000	19	Regular	Water in tank.	External: 6 perf. 1/8-in to 3/4-in. in bottom with severe pitting.					Native soil: clay. Backfill: sand mixed with clay.

DETAILS OF TANK REMOVALS REPORTED BY OTHERS

Company and Site Location	Soil Resistivity	pH	Moist	Sulfide	S.A.V.	Internally Inspected	Leaking Tanks: No. & Size	Age	Product	Reason for Removal	Corrosion Details	Other Tanks: No. & Size	Age	Product	Corrosion Details	Remarks
Company G 8105 Argyll Road Edmonton, Alberta							1-3000	20	Regular	Water in tank; no product lost.	Tank capped and isolated so details unavailable.					Backfill: sand & dirt.
Company C 8346 - 120th Street Surrey, B. C.	18,000	6.8	Moist	No	5							1-6000 1-6000	9 9	Regular No Lead	External: pitting along sides about 1/4-inch up from bottom.	
Company C Hwy 99 & Thorpe Richmond, B. C.	3,300	6.8	Moist	No	12							1-6000 1-6000 1-500 1-500	17 17 17 17	Regular No Lead Fuel Oil Waste Oil	External: gas tanks badly pitted on one end only; pits varied in depth from 1/16-in. to 3/16-in.	6000 gal. tanks were glass lined in 1977 due to leak in Regular tank. (Internal - perf. in end plate and directly below fill).
Company C 676 Front Street Quesnel, B. C.	18,000				5							2-4000	20	Regular	Corrosion free.	
Company C 4727 Willingdon St. Burnaby, B. C.	4,900	6.1	Sat.	Yes	17							1-4000 1-4000 1-636 1-500	20 20 20 20	Regular No Lead Fuel Oil Waste Oil	Corrosion free.	Native soil: wet clay. Backfill: wet clay.
Company C Bassano, B. C.	Inf.	6.2	Dry	No	6							1-6000 1-6000 1-500	14 14 14	Regular Premium Waste Oil	Corrosion free.	Native soil: 20-ft. of dry sand fill
Company C 1045 Terminal Ave. Nanaimo, B. C.	19,100	7.8	Moist	No	5							1-3000 2-3000 1-2000 1-2000 1-500	19 5 8 8 7	Premium Regular Premium Marine No Lead		Native soil: granular fill.
Company B 575 Rockland Ave. Trail, B. C.	61,000	6.8	Moist	No	6							1-3000 1-3000	12 12	Regular Premium	Corrosion free.	
Company B Cadboro Rd. & Fowl Bay Road Victoria, B. C.	3,350	7.8	Moist	No	9		2-3000	21	Premium	Close out.	Internal: perforation in bottom.	1-3000	21	Regular	Corrosion free.	Native soil: blue clay and rock. Backfill: very little sand and gravel. Water table: 7-feet.
Company C Celtic Salt Plant Vancouver, B. C.	33,000				7		1-4000	39	Regular	Upgrading of storage.	External: perforation in bottom of tank.					Native soil: sandy soil Water table: below tank
Company C 3770 Boundary Rd. Surrey, B. C.	3,600	6.2	Sat.	No	18		1-2000 1-500	16 18	Regular Waste Oil	Water in tank. Close out.	Internal: perf. in top. near fill pipe. External: perf. all over tank.	2-2000 1-2000 1-5000	18 18 4	Premium Regular Regular	Very little corrosion.	
Company B Sutherland & Lettemond Winnipeg, Manitoba	8,600	6.5	Moist	No	10		1-2000 1-2000	20 20	Regular No Lead	Water in tank.	External: several perf. on bottom and 2 perf. on side.	1-2000	20	Premium	External.	Native soil: clay. Backfill: sand.
Company B 2267 Main Ave. & Bliss Winnipeg, Manitoba							1-2000	12	Premium	Water in tank.	External: 1 perf. in bottom at fill; ends badly pitted along bottom and both ends.	1-5000 1-5000	8 12	No Lead Regular	External: badly pitted each end. External: excessive pitting almost through.	Native soil: silty soil and gumbo clay. Backfill: sand. Water table: 8-ft.

DETAILS OF TANK REMOVALS REPORTED BY OWNERS

Company and Site Location	Soil Resistivity	pH	Moist.	Sulfide	S.A.V.	Internally Inspected	Leaking Tanks: No. & Size	Age	Product	Reason for Removal	Corrosion Details	Other Tanks: No. & Size	Age	Product	Corrosion Details	Remarks
Company B 1216 Grant Avenue Winnipeg, Manitoba	2,500	8.2	Sat.	No	19		1-5000 1-5000	15 15	Regular Premium	Site upgrading.	External: perforations in bottom and welds badly pitted along bottom.	1-5000 3-5000	15 10	No Lead Regular	External: badly pitted. External: slightly pitted.	Native soil: heavy highly plastic clay soil. Backfill: sand. Water table: 4-ft. to 5-ft. below grade.
Company A Lyndon, Ontario	4,000	8.1	Moist	Yes	13		1-1000	21		Upgrading of storage.						
Company A 1492 Wellington Rd. London, Ontario							1-4000	18	Regular	Water in tank.	External: perforation in bottom of tank.					Native soil: clay Backfill: sand. Water table: 8-ft. below grade.
Company A Berlton Bulk Plant Dockton, Ontario	10,900	8.3	Sat.	Yes	10		1-5000	30	Diesel	Water in tank; inventory records show 2,121 gal. lost.	External: 2-in. split in bottom plate at weld.					Native soil: sand and gravel. Backfill: sand.
Company A 119 Durham Street Port Colborne, Ont.							1-1000	18	Regular	Water in tank.	External: perforations in bottom.					Native soil: rock at 4-ft. below grade Backfill: sand.
Company C Fairhurst & Wilson Toronto, Ontario	3,000	7.6	Moist	Yes	12		1-1000	28	Regular	Upgrading of storage.	External: 2 perf. in bottom of tank.	1-5000 1-2000 1-3000 1-2000 1-2000	6 12 15 24 28	Regular Regular No Lead Premium Regular	Corrosion free. Corrosion free. Very little corrosion. External: some pitting. External: deep pits in bottom.	
Company C Lakeshore & Sawlter Toronto, Ontario												1-5000 2-5000 1-3000 [Protected]	15 15 3	No Lead Regular Premium		
Company C Montreal & Rideau Kingston, Ontario	5,300	7.9	Moist	Yes	8		1-1000	30	Premium	Close out.		1-2000 1-1000	30 30	Regular Premium	External: severe pitting.	
Company D Hwy. 118 & Albert Haliburton, Ontario	8,900	6.4	Moist	No	11		1-2000	20	Regular	Water in cars.	External: 1/2-in. perf. on bottom of tank and several pitted areas.	1-2000	20	No Lead		Native soil: clay. Backfill: sand and gravel. (Bottom of tanks in clay).
Company D 1019 Queen St. E. Toronto, Ontario	5,200	6.1	Moist	Yes	15							1-3000 1-3000	15 15	No Lead Regular	External: pitting on bottom of tank. Corrosion free.	Backfill: sand.
Company D 542 Scarlet Road Etobicoke, Ont.	2,800	6.5	Moist	Yes	16		1-2000 1-3000	17 17	Premium Regular	Water in tank.	External: perf. 3/4 down side of tank. External: 20 small perf. in tank bottom.					Native soil: pea gravel
Company D 2241 Mountainside Dr. Burlington, Ont.	8,000	7.2	Moist	Yes	11		1-500	18	Fuel Oil	8-inches water in tank.	External: perforations in bottom of tank.					
Company D 1616 Pitt Street Cornwall, Ontario	8,700	8.0	Moist	Yes	10							2-2000 1-3000	20 20	Regular No Lead	Corrosion free. External: slight pitting on bottom.	

DETAILS OF TANK REMOVALS REPORTED BY OWNERS

Company and Site Location	Soil Resistivity	pH	Moist	Sulfide	S.R.N	Internally Inspected	Leaking Tanks: No. & Size	Age	Product	Reason for Removal	Corrosion Details	Other Tanks: No. & Size	Age	Product	Corrosion Details	Remarks
Company D Belmont, Ontario	3,700	8.0	Sat.	Yes	14		1-2000	8	No Lead	Water in cars; 4-in. in tank.	External: perforations in bottom					Native soil: gravel and clay. Backfill: gravel and clay.
Company D 432 Boundary Rd. Pembroke, Ontario	2,800	7.4	Moist	No	10							1-2000	20	Regular	External: severe pitting along top of tank.	
Company D R.R. 65 Spencerville, Ont.	8,200	7.5	Sat.	Yes	17							1-2000 1-5000	17 17	Premium Regular	Corrosion free.	
Company D Hwy 138 Thermosville, Ont.							1-2000	25	Regular	Water in cars.	External: perforations in bottom and one side of tank					Native soil: limestone shale rock. Backfill: sand.
Company D R.R. #3 Peterborough, Ont.	5,300	8.3	Moist	Yes	10							1-1000		No Lead	Corrosion free.	
Company B Agency Fenlon Falls, Ont.	16,000	7.5	Moist	No	4		1-5000	20	Fuel Oil	Inventory record.	External: perforations about half way up side of tank.					Native soil: 3-ft. of sandy gravel over rock. Backfill: granular.
Company B 171 John Street Hawkesbury, Ont.	6,200	6.4	Sat.	Yes	16		1-2000	17	Premium	Water in cars.	External: perforations and pitting along side of tank.	1-5000	17	Regular	External: extensive pitting along sides.	Native soil: 3-ft. to 5-ft. of loam over clay. Backfill: gravel. Water table: 5-ft. below grade.
Company B Cumberland & Ahmose Thunder Bay, Ont.	22,500	7.4	Moist	Yes	32		1-3000	20	Premium	Water in cars.	External: partially collapsed on bottom; seam opened at weld.					Native soil: sandy loam to 6-ft. below grade Grey clay and loam beneath. Backfill: gravel.
Company B Syndicate & Arthur Thunder Bay, Ont.	1,900	6.8	Moist	Yes	16		1-2000	26	Regular	Water in cars.	External: perforations in line along side of tank.					Backfill: sand and gravel. Water table: 6-ft. below grade.
Company B City Road 1 Lambeth, Ontario							1-400	31	Premium	Close out.	Internal: perforations in each rib along bottom of tank.	1-1000	21	Regular	External: pitting along bottom and sides.	Native soil: loam with boulders.
Company B 114 Sterling Ave. Ottawa, Ontario	5,000	6.0	Moist	Yes	33							2-5000 1-1000 (Replaced)	28 [illegible]	Regular No Lead	External: pitting along bottom. Corrosion free but very separated from tank.	
Company B Shrewsford, Ont.	55,000	9.0	Moist	No	3							1-2000 1-3000	24 16	No Lead Regular	External: extensive pitting.	
Company B Sioux Lookout, Ont.							1-1000	35		Water in tank.	External: perforation in bottom.	1-1000	35			Backfill: clay.

Appendix

DETAILS OF TANK REMOVALS - FILLED BY OTHERS

Company and Site Location	Soil Resistivity	pH	Moist	Sulfide	S.R.V.	Internally Inspected	Leaking Tanks					Other Tanks				Remarks
							No. & Size	Age	Product	Reason for Removal	Corrosion Details	No. & Size	Age	Product	Corrosion Details	
Company B Hwy. #69 Mackey, Ontario												1-2000 1-3000 1-5000 (Protected)	7 7 2	No Lead Premium Regular	Corrosion free.	Backfill: sand.
Company A Hwy. #11 Finch, Ontario	5,800	7.7	Sat.	Yes	11		1-500	20	Waste Oil	Close out.	External: several perforations in bottom at fill end	1-5000 1-5000 (Protected)	4 1	Regular No Lead	External: minor corrosion. Corrosion free but 70 percent of tape peeled off.	Native soil: grade to 5-ft. - gravel and loam fill; 5-ft. to 7-ft. - loam; 7-ft. to 12-ft. - clay. Backfill: sand. Water table: 6-ft. below grade.
Company E Front & Ontario Sturgeon Falls, Ont.							1-500	13	Waste Oil	Close out.	External	1-3000 1-3000 1-3000	13 13 13	Premium Regular No Lead	Corrosion free.	Native soil: clay Backfill: sand at gas tank; clay at waste oil tanks.
Company F 1153 Plainer St. Burlington, Ont	7,800	8.6	Moist	Yes	10							1-2000 1-2000	8 8	Solvent Solvent		
Company B Hwy. #7 Pembroke, Ontario	16,000	8.8	Sat.	No	5							1-2000 1-1000	15 14	Regular No Lead	External: minor corrosion along sides and on ends but no pitting.	Native soil: gravel. Water table: 5-ft. below grade.
Company I Sparingville, Ont	7,700	6.5	Moist	No	10		1-3000	15	No Lead	Close out.		1-5000	15	Regular	Corrosion free.	Backfill: sand.
Company L Dundas & Carlaw Toronto, Ontario												2-2000 1-3000 1-500	25 25 25	Gasoline Gasoline Waste Oil		
Company E Bayview & Moore Toronto, Ontario												1-5000 4-2000 1-100	20 20 20	Gasoline Gasoline Waste Oil		
Company A Main & Ashford Hamilton, Ontario	2,800	7.4	Moist	No	9											
Company G 113 Lent St. W. Lindsay, Ontario							1-5000	15	Regular	Water in cars.	External: 5 perf. in bottom.					Native soil: sand. Backfill: sand with cinders mixed in.
Company G 2151 Baseline Rd. Ottawa, Ontario							1-2000	19	No Lead	Water in cars.						
Company G Hay Street Thunder Bay, Ont.	6,300	7.8	Sat.	No	10		1-3000 1-2000	19 19	Regular Regular	Water in tanks.	External: perforations in top and bottom of tank.	1-3000 1-2000	19 19	No Lead Premium	External: extensive pitting.	Native soil: clay. Backfill: sand with clay mixed in. Water table: approx. 8-ft. below grade.
Company H Emerson, Ontario	3,100	6.5	Moist	No	9							3-10000 1-5000 1-3000 1-3000	25 25 25 25	Fuel Oil Gasoline Gasoline Stove Oil	Corrosion free.	Native soil: clay. Backfill: clay.

DETAILS OF TANK REMOVALS REPORTED BY OTHERS

Company and Site Location	Soil Resistivity	pH	Moist	Sulfide	S.A.V	Internally Inspected	Leaking Tanks					Other Tanks				Remarks
							No. & Size	Age	Product	Reason for Removal	Corrosion Details	No. & Size	Age	Product	Corrosion Details	
Company C Rte. 133 South Pike River, Quebec	24,000	8.0	Moist	No	3		1-2000	23	Regular	Water in cars.	External: both sides and bottom of tank corroded.					Backfill: mixed sand and screening. Water table: below bottom of tank
Company C St. Benoit, Quebec	8,200	7.5	Moist	No	2							2-2000	4		Corrosion free.	Backfill: sand.
Company C 2470 Boisvert Blvd. Montreal, Quebec	15,000	8.1	Moist	No	3							1-2000 2-5000 1-8000	13 13 8		External: pitting over 40 percent of tanks.	Backfill: sand.
Company C 1010 Laurentide Blvd. Laval, Quebec	14,100	6.7	Moist	No	5							1-5000 2-2000	10 10		Internal: slight pitting.	Backfill: sand.
Company C 475 Blvd Labelle Fabreville, Quebec	42,500	8.5	Moist	Yes	9							2-2000 1-4000	8 6	Gasoline Gasoline	Corrosion free.	Backfill: sand.
Company C 2261 Henri Bourassa Montreal, Quebec	15,000	8.1	Moist	No	3							1-5000 1-4000 2-2000	3 21 21		Corrosion free. External: generalized pitting.	Backfill: sand.
Company D 416 Chapleau Bois des Filions, Q.							1-5000	10	Regular	Water in cars: tank being lined.						Native soil: rock. Backfill: sand Water table: 5-ft below grade.
Company B 2010 Montfield Kahnawake, Quebec	500	7.2	Moist	Yes	17		1-5000	13	No Lead	Contaminated soil and product odors in subway.	Internal: 1/2-in. perf. in bottom below fill pipe.					Native soil: blue clay. Backfill: sand.
Company B Bulk Plant Joliette, Quebec	1,320	6.1	Moist	No	13		1-5000	20	Regular	Water in tank.	External: 3/8-in. perf. and several pitted areas along bottom of tank.					Native soil: 6-ft. of sand on top of blue clay. Backfill: sand.
Company B 195 Chemin Ste. Foy, Quebec												1-4000 1-4000	20 20	Regular Premium	Corrosion free.	Native soil: solid rock.
Company B 411 Winchester St. Quebec City, Quebec	2,600	6.4	Moist	Yes	16		1-4000	12	Gasoline	Close out.	External: 2 perf. in bottom.	1-4000	12	Gasoline	External: pitted along bottom.	Native soil: clay. Backfill: sand.
Company B Pointe Du Rhe Ste. Charlemagne, Que	30,700	8.3	Moist	No	3							1-1000 1-1500	12 12	Regular No Lead	External: severe deep pitting all over tanks.	Native soil: sand.
Company B 7887 St. Laurent B Ville Ray Montreal, Quebec							1-1000		Fuel oil	Water in tank.	External: perforations in bottom and sides of tank.					Native soil: mud and sand. Backfill: sand.

Appendix P

DETAILS OF TANK REMOVALS REPORTED BY BTHIPS

Company and Site Location	Soil Resistivity	pH	Moist	Sulfide	S.A.V	Internally Inspected	Leaking Tanks: No. & Size	Age	Product	Reason for Removal	Corrosion Details	Other Tanks: No. & Size	Age	Product	Corrosion Details	Remarks
Company F Laurentian Blvd St. Laurent, Quebec	3,100	7.5	Moist	No	10		1-2000	24	Regular	Inventory records indicated product loss.	External: perforations and pitting along bottom of tank.	1-2000 1-4000	24 24	Regular Premium		Backfill: screening material. Water table: not visible.
Company F 1135 Sources Rd Dollard Des Ormeaux Quebec	2,500	8.7	Moist	Yes	13							1-5000 2-5000 1-5000	12 12 9	Premium Regular No Lead	External: slight corrosion only	
Company G John Monier St. Jean Dollard Des Ormeaux Quebec							1-4000	13	Regular	Water in tank.	External: numerous perforations in bottom of tank.	1-5000 1-4000	13 13	Premium Regular	External: pitting along bottom.	Native soil: blue clay. Backfill: sand. Water table: 14-in. above bottom of tanks Tanks resting on concrete slab.
Company G 515 rue D Or Quebec City, Quebec							1-3000	23	Premium	Water in tank.	External: perforation in bottom.	1-2000 1-3000	23 23	No Lead Regular	External: very slight corrosion.	Native soil: clay and quick sand. Backfill: sand and gravel. Water table: 15-ft. below grade.
Company C Agency Albert, N.B.	14,000	7.1	Moist	No	5		1-9000	30	Regular							
Company C Dorchester, N.B.	8,300	6.9	Moist	No	-8		1-2000	19	Regular							
Company C Church Avenue Saint John, N.B.	9,900	5.1	Moist	No	8							1-4000 1-4000 1-5000	15 15 15	Regular Premium No Lead	External: very little pitting.	
Company C Greenfield Street, N.B.	170,000	5.4	Moist	No	2							2-1000 1-500	10 30	Gasoline Gasoline	External: very little pitting.	
Company C (Consumer) Sussex, N.B.							1-3000	8	Gasoline	Inventory records indicated product loss.	Internal: bottom of tank.					Native soil: clay. Backfill: fine gravel.
Company G Rosencrow Street Campbellton, N.B.							1-5000	14	Regular	Water in cars.	External: perforation in bottom of tank with severe pitting.	1-4000	14	Premium		Native soil: shale rock. Backfill: gravel. Water table: 6-in below grade.
Company G Spring River, N.B.	20,000	6.0	Moist	No	7							1-3000 (FRP) 1-2000 1-3000	1 6 6	Regular No Lead No Lead		
Company G Leech, N.B.	213,000	6.[illegible]	Moist	No	7							1-3000 1-2000 1-4000 (FRP)	3 3 1	No Lead No Lead Regular		
Company G Tabusintac, N.B.	54,000	7.4	Dry	No	2							1-2000 1-3000 1-3000 (FRP)	10 10 3	No Lead No Lead Regular		

DETAILS OF TANK REMOVALS REPORTED BY OTHERS

Company and Site Location	Soil Resistivity	pH	Moist	Sulfide	S.A.V	Internally Inspected	Leaking Tanks: No. & Size	Leaking Tanks: Age	Leaking Tanks: Product	Leaking Tanks: Reason for Removal	Leaking Tanks: Corrosion Details	Other Tanks: No. & Size	Other Tanks: Age	Other Tanks: Product	Other Tanks: Corrosion Details	Remarks
Company G Cape Pele, N.B.	14,300	7.0	Dry	No	3							1-2000 (FRP) 1-4000	1 11	Regular No Lead		
Company G Bathurst, N.B.	10,000	7.0	Dry	No	2							1-4000 1-3000 1-2000 (FRP)	15 15 1	No Lead Regular Regular		
Company G Chatham, N.B.	30,700	6.9	Dry	No	2							2-5000 1-4000 1-5000 1-5000 (FRP)	13 13 3 1	Regular Premium No Lead Diesel		
Company G Route 11 Petit Rocher, N.B.	57,000	6.3	Moist	No	9							2-2000 1-2000 (FRP)	12 1	No Lead Regular		
Company G Route 11 Little Rickman, N.B.	28,000	6.8	Dry	No	5							2-2000 1-2000	12 1	No Lead Regular		
Company G Shediac, N.B.	10,700	6.5	Dry	No	6							1-2000 1-1000 1-3000 1-2000 (FRP)	28 18 9 4	Premium No Lead No Lead Regular		
Company G Sheila, N.B.	10,000	6.9	Dry	No	7							1-3000 1-1000 1-2000 (FRP)	4 4 .1	No Lead No Lead Regular		
Company G Hwy. #325 Bertrand, N.B.	83,300	6.8	Dry	No	2							1-3000 1-2000 1-2000	3 2 1	No Lead No Lead Regular		
Company E Nicholsville Rd. Bear Lake, Nfld.	28,500	7.6	Dry	No	4							1-4000 1-2000	7 7	Regular Premium	Corrosion free. External: uniform surface corrosion at fill pipe.	
Company E Water Street St. John's, Nfld.	[illegible]	6.9	Dry	No	[illegible]		1-5000	12	Regular	301 gallons discovered missing over one month.	Unable to locate perforation.					
Company E Hwy 8 Patterson Grand, N.S.	[illegible]	[illegible]	Moist	No	[illegible]		1-2000	15	Regular							
Company E Grand Pelee, N.S.	[illegible]	8.2	Moist	No	[illegible]		1-1000 1-2000	15 15	Regular Premium							
Company E King's Rd. & Morgan Sydney, N.S.	[illegible]	[illegible]	Wet	No	[illegible]		1-500	15	Waste Oil	Water in tank.	External: severe corrosion in sides of tank.					Backfill: partly sand.

Appendix P

DETAILS OF TANK REMOVALS REPORTED BY OWNERS

Company and Site Location	Soil Resistivity	pH	Moist	Sulfide	S.R.V	Internally Inspected	Leaking Tanks: No. & Size	Age	Product	Reason for Removal	Corrosion Details	Other Tanks: No. & Size	Age	Product	Corrosion Details	Remarks
Company C Pleasant St. & Exton Road Dartmouth, N.S.	12,800	7.7	Sat.	No	8							1-2000 1-2000 1-2000	19 19 19	Regular Premium No Lead	External: uniform surface corrosion.	Backfill: mixture of clay, sandy soil and small stones.
Company C 165 Union Street Glace Bay, N.S.	4,000	7.7	Moist	No	9							2-2000 2-2000 1-3000	18 18 7	Regular Premium No Lead	External: severe pitting Corrosion free.	
Company C Aulds Cove, N.S.	22,300	7.4	Moist	No	5							1-2000 1-2000 1-2000	4 4 4	Premium Regular No Lead	External: surface rust only.	
Company R Bear River, N.S.	3,500	6.9	Moist	No	12							2-1000 1-1000	15 15	Regular Premium	External: minor pitting with surface rust.	
Company G Petit Etang, N.S.	17,000	7.3	Moist	No	5							2-2000 1-5000 (Protect) 1-5000 (Protect)	10 1 d) 1 d)	Regular Regular No Lead		
Company G Central West River, Nova Scotia	39,000	8.1	Moist	No	4							1-1000 1-2000 1-2000 (Protect)	13 13 3 d)	No Lead No Lead Regular		
Company G Dist. III Port Hood, N.S.	1,700	7.5	Moist	Yes	16							2-2000 1-5000 (Protect) 1-5000 (Protect)	17 1 d) 1 d)	Regular Regular No Lead		
Company G Dist. III Inverness, N.S.	11,000	7.1	Moist	No	5							1-3000 1-2000 1-500 1-2000 (Protect)	8 8 8 1 d)	No Lead No Lead Premium Regular		
Company G West Bristol, N.S.	2,200	8.1	Moist	No	7							2-2000 1-500 (Protect) 1-2000 (Protect)	9 1 d) 1 d)	No Lead Premium Regular		
Company G Route 4 St. Peters, N.S.	7,000	8.1	Moist	No	6							1-2000 1-5000 (Protect) 1-5000 (Protect)	13 1 d) 1 d)	Regular Regular No Lead		
Company G Amherstburg, N.S.	155,000	7.4	Moist	No	5							2-2000 1-800 (FRP)	8 1	No Lead Regular		
Company E Carleton, P.E.I.	2,000	6.7	Moist	No	9		1-1000	15	No Lead							
Company E Alberton, P.E.I.	39,300	7.1	Dry	No	4		1-500	20	Regular							
Company E Tignish, P.E.I.							1-2000	15	Premium	Product/odors in well.		1-2000 1-2000	15 15	Premium Regular		Backfill: clay and sand mixture.

BIBLIOGRAPHY

1. API Bulletin 1615 - "Installation of Underground Gasoline Tanks and Piping at Service Stations"

2. API Bulletin 1611 - "Service Station Tankage Guide"

3. PACE Report - "Petroleum Industry Meeting on Underground Storage and Dispensing Systems"

4. The Hinchman Company - "The Investigation of Internal Corrosion of Steel Fuel Storage Tanks"

5. The Hinchman Company - "An Evaluation of Unbonded Polyethylene Wrapping for Underground Steel Tanks"

6. The Hinchman Company - "Evaluation of Corrosion Resistance of Fiberglass Reinforced Plastics Vs. Conventional Material for Underground Storage Tanks"

7. API Bulletin 1621 - "Recommended Practise for Bulk Liquid Stock Control at Service Stations"

8. National Fire Code of Canada (1975) Part 4 - "Flammable and Combustible Liquids"

9. National Fire Protection Association-NFPA 329 - "Underground Leakage of Flammable and Combustible Liquids."

10. API Publication 4149 - "The Migration of Petroleum Products in Soil and Ground Water"

11. PACE/PPA Brief to the Manitoba Clean Environment Commission - "Pollution of Underground Water Resources by Petroleum Products"

12. Manitoba Clean Environment Commission, Preliminary Report - "Contamination of Underground Water Resources by Refined Petroleum Products"

13. D. W. Hoffman, B. C. Matthews, R. E. Wicklund - "Soil Associations of Southern Ontario"

14. L. J. Chapman, D. F. Putnam - "The Phyiography of Southern Ontario"

15. Province of Ontario - "The Gasoline Handling Act and The Gasoline Handling Code"

18. Bridgeport Chemical Corp. Glass Armor Repair of Gasoline Storage Tanks, GA27 P Armor Spray

GLASS ARMOR

EPOXY RESINS

TECHNICAL INFORMATION BULLETIN

SPECIFICATIONS

GLASS ARMOR REPAIR OF GASOLINE STORAGE TANKS
(GASOHOL)

"GA27 P ARMOR SPRAY"
(GASOHOL COATING)

SOUTHWEST TANK MAKERS, Inc.
J. R. [illegible]
[illegible]
[illegible]
El Centro, CA [illegible]
(619) 352-[illegible]

BRIDGEPORT CHEMICAL CORPORATION
2610 N.E. 5th Avenue
Pompano Beach, Florida 33064
305/781-3700

TECHNICAL INFORMATION BULLETIN
THE GA27 P (ARMOR SPRAY)

GA27 P is a specially formulated, chemically resistant, epoxy resin-based product, structurally reinforced with glass fibers. It is specifically designed for building a new tank in a steel storage tank, using Bridgeport Chemical's FUSION BONDING process. It eliminates corrosion from within the tank and retards corrosion from outside elements in the soil.

This technical bulletin outlines the specifications of Bridgeport Chemical Corporation's Glass Armor method for solving the extremely serious, costly, and hazardous problem of replacing leaking underground gasoline storage tanks in the service station.

Gasoline by itself cannot cause corrosion, but water and oxygen that gasoline picks up does the damage. At high-product temperatures, gasoline is more heavily saturated with air and water than at lower temperatures. Then as the product cools, the solubility of water in gasoline decreases and droplets of water form and settle out on the tank metal. When the gasoline temperatures drop from 140°F. to 80°F., as much as 0.5 lbs. of water comes from 100 lbs. of hydrocarbon (about 1,616 lbs. of gasoline). These figures indicate a 6,000 gallon tank could have approximately 23 gallons of water in each load.

The rate of corrosion also depends on the type of gasoline and the type of crude used in the refining process. The most highly aromatic fuels have a greater water solubility and are more corrosive (premium is more corrosive than regular which in turn is more corrosive than kerosene).

CHEMICAL PROPERTIES:

Films cured for 7 days @ 75°F. are unaffected by the following reagents after 30 days immersion @ 75°F.

Reagent	Visible Affects
ASTM reference Fuels A and C	No Affect
Unleaded Gasoline	No Affect
Premium Leaded Gasoline	No Affect
Diesel Fuel	No Affect
Benzene	No Affect
Toluene	No Affect
Xylene	No Affect
Mineral Spirits	No Affect
Gasohol 10% ethyl alcohol	No Affect
Gasohol 50% ethyl alcohol	No Affect
Ethyl alcohol	No Affect
Isopropyl alcohol	No Affect
Propyl alcohol	No Affect
Tertiary butyl alcohol (TBA)	No Affect
10% Ethanol gasoline	No Affect
10% Methanol gasoline	No Affect

15% Methanol gasoline	No Affect
30% Methanol gasoline	No Affect
50% Methanol gasoline	No Affect
100% Methanol	No Affect
Distilled water	No Affect
10% Sulfuric acid	No Affect
Sodium Hydroxide 10-30%	No Affect
5% Sodium Chloride	No Affect

The Glass Armor epoxy resins have long been recognized by corrosion engineers as a superior material unique in properties that make them one of the most valued tools to combat corrosion.

Bridgeport Chemical Corporation, who pioneered the process of lining leaking gasoline tanks, has factory trained franchise applicators serving the petroleum industry from coast to coast. All Glass Armor applicators follow this specification using the GA 27P line of epoxy coatings.

GA 27P bonded to the interior surface of the steel storage tank results in a structurally strong tank built within a tank. This material gives a solid glass hard inner protective wall to the leaking vessel. The corrosion-proof inner tank seals off the leaks and becomes completely bonded to the entire tank.

The Glass Armor procedure for the repair of underground gasoline storage tanks include the following:

1. Isolating the tank.
2. Gas freeing the tank.
3. Entering the tank.
4. Cleaning and sandblasting the tank.
5. Application of GA 27P.
6. Sealing the tank.

To be certain that all Applicators take all the necessary action required to succeed in this program, the following specifications have been written.

1. SCOPE:

This specification covers the requirements for the Glass Armor process for the repair of gasoline storage tanks. This specification outlines the method to be followed for the safeguarding of gasoline tank atmospheres for the purpose of conducting the Glass Armor Process for such tanks. It outlines the methods to be followed for flushing the interior of gasoline tanks for the removal of combustible vapor preparatory to the removal of sediment, rust, etc. Instructions are included for cleaning interior surfaces of steel tanks, and for the application of protective coating. This specification outlines in general the requirements, procedure, and operating conditions for the above work to be followed by Bridgeport Chemical Corporation's Franchised Applicators and Dealers. All work must be done in accordance with the current Federal Occupational Safety and Health Administration Codes. (OSHA).

2. SITE INSPECTION:

The Applicator must visit the site, ascertain local conditions and scope of work. Where necessary, approval from local authorities should be obtained prior to application. Where no such approval exists, the applicator must notify Bridgeport Chemical Corporation in writing. See Annex D.

3. SPECIFICATION FOR COATING:

Glass Armor GA27 P shall be applied to the entire inner surface to be protected on the storage vessel.

4. INSPECTION OF STORAGE VESSEL:

The storage vessel should be inspected by a competent person to determine how long the tank has been in service, approximate amount of gasoline and sediment in the tank, and the physical condition of the tank. If the tank does not appear structurally sound and has wide open seams or extremely porous metal, the tank should not be glass armor coated. Sources of ignition should be removed from surrounding area. Work should not be started if the direction of the wind might carry vapors into areas where they could produce a hazardous condition. All open flame and spark equipment within the vapor hazard area should be shut down. **Electric equipment used in the area must be explosion-proof, i.e., Class 1 D. Division 1.** See Annex A and B.

4-1 Isolation of the Vessel:

The tank must be completely isolated before any work begins. This means suction lines, pumps, and other connecting lines should be blanked.

5. REMOVAL OF FLAMMABLE VAPORS:

5-1 Displacement With Air: Purging and Ventilating:

Gas freeing the tank is accomplished by purging with fresh air, and a safe atmosphere can be maintained by continuous ventilation. In air purging, the concentration of vapor in air in the tank may go through the flammable range before a safe atmosphere is obtained, therefore all precautions shall be taken to insure that the air moving apparatus be bonded to the tank in order to minimize the hazard of ignition.

Ventilation of the tank is accomplished by the use of air movers of the eductor type. Air movers of this type are actuated with compressed air, fans and blowers by electric motors or air, or gasoline motor driven. We recommend the use of the Bridgeport Chemical Purging Aerator Method. **(Motor must be explosive proof.)**

5-2 Bridgeport Chemical Purging Method

Each applicator will insure all precautions will be taken as per these instructions, and the GA27 P specifications for the repair of steel storage tanks.

A. Preparations:

1. Remove as much gasoline as possible. (Use explosion-proof pumps and lines). Lines at the pump should be closed and blanked so that no vapors or gasoline can issue from the lines during the maintenance operation.

2. Syphon lines must be cut as well as any connections to a common fill line.

3. A small quantity of water can be pumped into the tank to float the gasoline from a low spot to where it can be removed from the tank.

B. Purging:

The tank will be thoroughly purged for the removal of flammable vapor atmostphere, or any residue capable of producing flammable vapors in the tank and connected distribution lines, so that subsequent natural ventilation will not result in the reinstatement of a flammable atmosphere, prior to any storage vessel.

A safe working atmosphere within the tank is obtained as follows:

Glass Armor Purging Aerator Method

1. Set up the Glass Armor Aerator as shown in drawing #1. Safety precautions must be taken as follows:

   a. Suitable grounding must be provided to prevent a spark from igniting any gasoline vapors in the immediate area.

   b. Air pressure in the tank must not exceed Five (5) psi. Air supply must be from a diesel compressor that has been safety checked to assure a clean air supply without volatile flammable fumes feeding the air hose. (Diesel or equivalent).

2. To provide a suitable ground against static electricity, be sure the copper purging pipe is resting on the bottom of the tank, and that the "Ground" wire from the copper pipe is attached to the fill line and to the nearest water meter.

3. To prevent excess air pressure from building up in the tank, set the pressure reducing valve to 5 psi until you are positive that the vent is free and open.

4. Increase air volume to remove as much air as possible without building up pressure in the tank.

SPECIAL CAUTION:

Occasionally tanks are equipped with inner fill pipes. It is necessary to make sure that the air from the copper purging pipe is going down the long fill line, into the tank, and out the vent. The air should not be blowing back out the fill pipe, thus, not purging the tank. If exhaust from the vent line is negligible, but considerable from the fill pipe, the open area around the pipe leading into the fill can be plugged up with rags to force air out the vent pipe.

The fill line should not be plugged in this manner unless the two conditions mentioned above exist. (That is, tanks equipped with inner fills and vent not exhausting adequately). See drawing #1 - Glass Armor Aerator.

6. TESTING THE VAPOR CONCENTRATION:

The test for flammability is the most important phase of the entire operation. These tests are made with a combustible gas indicator such as the Model 5 Explosive Meter (Mine Safety Appliance Company). Persons responsible for testing must be thoroughly instructed in handling and reading the vapor indications. Bridgeport Chemical Corporation technical personnel will check, approve, and supervise all newly trained personnel.

6-1 Testing Procedure

Testing the tank for vapors is accomplished in the following manner.

1. The MSA Model 5 Explosive Meter must be thoroughly checked as per instruction manual.

2. The meter will be checked by placing the probe in a known source of gasoline vapors such as a gas tank. After the meter reading has been checked, the probe is cleared with fresh air.

3. The tank will be checked by placing the probe in the fill line and taking separate readings at the bottom, middle, and upper portions of the tank, clearing the probe after each reading: Be sure and prevent liquid product from entering the probe. (Check MSA instruction manual.) The vapors should be tested with the air mover temporarily off at the tank. However, periodic tests should be made at the vent rise, while the air mover is in operation and purging is in progress.

4. When the meter reading is 40% of the Lower Explosive Limit (LEL) range at the three levels of the tank, a number of readings of the vapor content leaving the tank at the vent riser should be taken.

5. Safe reading of 20% or less of the Lower Explosive Limit (LEL) range as indicated on the Model 5 Explosive Meter must be obtained at both the tank and vent riser before the tank is considered safe.

6. See Annex B for further information.

7. OPERATING PROCEDURE

7-1 Opening the Tank

After it is determined that a safe atmosphere has been established, the tank may be opened. If cutting and drilling are necessary, the tools, where possible, are to be air operated or run by explosion-proof motors and bonded to the tanks. It is noted that some tools are not available with air operated or explosion-proof motors and when used, testing for flammable vapors in the work area becomes even more critical. Therefore, when using electric tools with open switches, the work area is to be tested continuously during the operation.

Where no hatch exists, a manhole may be cut out approximately 22" x 22". This is accomplished by outlining the area to be cut out with chalk, and drilling out two holes in the diagonal corners of the square with an air driven drill. (The cover plate can be used as a template). When the first hole is drilled into the tank the test probe will be placed into the hole to again verify that the tank is still safe. It is important that purging is continued throughout this entire operation. The test reading should be lower than 20% Lower Explosive Limits (LEL) on the test meter. The tank should then be cut by an air driven sniper or with an explosive-proof saber saw or equivalent.

A man with complete positive air displacement equipment with face mask and the proper protective clothing can then enter the tank. Tests with the explosive meter should be performed by the man in the tank to ascertain that the tank vapors are in the proper Lower Explosive Limits (LEL) range.

7-2 Removal of Sludge

The volatile lead compounds in the sludge and in the scale are a source of danger to workers. Sludge is a potential hazard because it is a source of Tetraethyl lead vapors which may be inhaled, because liquid tetraethyl lead in contact with the skin may be absorbed into the body and is highly poisonous. If the dry internal surface of the tank is scraped, the resulting atmospheres may contain dangerous quantities of lead. Poor health and fatigue accentuates the foregoing hazards. No one with a punctured ear drum should enter such a tank because vapor laden air will pass through this abnormal opening. Tanks of bulk storage capacity over 50,000 gallons must have a safety inspector from Du Pont or Ethyl Corporation approve entry into a tank. Before entering all leaded gasoline tanks follow the procedure as prescribed in American Petroleum Institute Bulletin #RP2015: "Cleaning Petroleum Storage Tanks."

Employees entering the tank and those handling tank sludge will be clothed so that arms, legs, head and torso are protected from contact with the tank residue and the coating resins. They shall wear oil and water resistant boots and gloves. In addition, protective respiratory equipment providing positive air pressure in a full facepiece mask will be worn by those entering the tank before and during Bottom Sediment and Water removal, sandblasting, and removal of residue and during the coating application. Protective equipment shall be provided, used and maintained in a sanitary reliable condition. Persons working in the tank when respirators are required will be equipped with safety harnesses and safety lines and standby employees.

Pumps used for the removal of Bottom Sediment and Water shall be explosion-proof. Shovels used to remove solid sludge shall be of the non-ferrous or sparkproof type.

7-3 Inspection of Tank Prior to Surface Preparation

Inspection of the interior may be made with one of several forms of internal inspection lamps or flashlights approved for Class I, Group D-Hazardous Locations.

Visual inspection of the tank should be made to insure that no liquid gas or fumes are reentering the tank. Any foot valves shall be removed or covered tightly with plastic and taped. Submerged pumps should be isolated. Suction lines should be removed and openings plugged with rubber test plugs or equivalent. The vent opening should be left clear freely exposed from the inside.

During inspection, the extent of corrosion (both internal and external) should be determined. The entire interior surface of the tank shall be visually inspected. Areas around holes or suspected severe corrsion and other randomly selected areas within the tank should be tested by tapping with a ballpeen hammer to determine structural integrity of the steel shell. A tank having extremely porous steel, a split seam or holes too large to be repaired, shall not be Glass Armor lined. In all cases, sufficient steel shell must remain intact (after sandblasting) to provide structural support for the interior lining.

The following guidelines shall be utilized to determine whether a tank may be repaired:

a. A tank having an open seam or split no longer than 3 inches, or
b. Perforation no larger than 1½" diameter except under the gauging opening where the perforation may be no larger than 2½ inches in diameter, or
c. A tank with less than five (5) perforations none larger than ½ inch in diameter) in any one square foot area,
d. A tank with less than twenty perforations (none larger than ½ inch in diameter) in a 500 square foot area.

Tanks that exceed any of the above should not be interior lined unless approved by an authority having jurisdiction.

To determine adherence to these guidelines, perforations and seams shall be ballpeen hammered (before and after sandblasting) to remove thin metal and obtain structurally sound edges. Perforations and seam splits shall be reamed out until the edges of the hole or split are a minimum of ⅛" thick.

7-4 Surface Preparation of Storage Tanks

All holes should be plugged with plugs or screws of non-corrosive plastic (e.g. nylon or teflon), epoxy putty, or hydraulic cement. Seams may be plugged with hydraulic cement or lead wool. The use of plugs and hydraulic cement are used only as temporary measures to prevent water products, fumes, foreign matter from entering the tank during sandblasting.

The entire tank shall be sandblasted completely free of rust, scale, and foreign matter to SSPC-SP5-63 "White Metal Blast".

SANDBLASTING: "BEFORE BEGINNING THE SANDBLASTING OPERATION, IT IS IMPERATIVE THAT THE AIR HOSE BE CHECKED TO BE SURE THAT CLEAN AIR FREE OF FLAMMABLE VAPORS IS COMING OUT OF THE AIR HOSE." After the surface has

been sandblasted to White Metal, it shall be brushed with clean brushes made of hair, bristle or fiber, blown off with compressed air or cleaned by vacuum. Adequate separators and traps shall be used to remove oil and water from compressed air. The blast cleaned surface shall be coated within 8 hours after blasting when practical. But in any event, not later than 24 hours after blasting and also before any visible rusting occurs. Contact Bridgeport Chemical Corporation for recommended sandblasting equipment and procedures.

After sandblasting, all perforations and or open/split seams shall be permanently repaired as follows:

a. All holes less than ¾" diameter shall be plugged with plugs or screws made of non-corrosive plastic (e.g. nylon or teflon). The plugs shall be covered with Glass Armor and fiberglass cloth, which overlaps all sides of the plug a minimum of 2".

b. Holes up to 1½" diameter shall first be plugged with either steel or plastic plugs. In addition, a 6"x6" steel plate (10 gauge min.) must be placed over the flattened plug and extend all sides by 2". This steel plate shall be sandblasted to white metal on both sides and bonded to the tank with Glass Armor epoxy. A laminate of epoxy and fiberglass cloth shall cover this plate on all sides by a minimum of 2".

c. An open or split seam (less than 3" long) shall be repaired using either fiberglass or steel plate epoxied in place and overlapping the seam by a minimum of 6" on all sides.

Sandblasting Safety Precautions:

1. Blast operators shall wear U.S. Bureau of Mines approved helmet connected to a source of clean compressed air.

2. Blast hose shall be grounded to dissipate static charges.

7-5 Application of GA27 P Protective Coating

GA27 P is a specially developed heavy built coating, designed specifically for special spray equipment which makes the coating easily applicable. A GA27 P unit will cover 40 square feet at approximately 125 mil thickness. The following procedure should be carefully followed.

1. Prepare the substrate for coating.

2. To assure the proper coverage, the tank must be marked off with chalk into 40 square foot sections.

3. Mix activator and resin for 3 minutes using mixing blade #A275. Scrape sides of can with a long pointed trowel and mix for another minute, total mixing time, 4 minutes. Material must be thoroughly mixed and uniform in color.

4. Place mixed material under spray gun pump and spray tank until completely coated.

5. Product temperature should be 80° F. - 90° F. for best spray pattern.

6. Heat cure with hot air (Union Chill Mat Indirect Heater Ultramatic III) for three hours or until fully cured to obtain maximum chemical and physical properties.

The coated area must be checked for any pinholes with a Holiday Detector, and coated over, if any are found. The coating thickness should be checked with an Elcometer Thickness Gauge or Branson Coatingage. Follow the instructions on standardizing the Elcometer Model Mark I Type A Scale 14, 0-¼". Check various areas of the tank for proper thickness as per meter reading. If any areas are not proper thickness, apply GA to the proper thickness. See Annex E.

Curing the coating completely before replacing the product into the tank is accomplished by either of the following methods:

Fast Cure:

1. The ambient air within the tank is heated to 140° F.-160° F. by means of a 250,000 BTU indirect heater. This is accomplished by placing a flexible hose from the heater inside the opening and directing it at either end first for a 1-1½ hours, then at opposite end for an equal time or until coating cured. (See 4 below) Check thoroughly before closing tank.

2. Allow to air cure 72 hours at 90° F.

3. Allow to air cure 7 days at 77° F. ambient.

4. See Annex C for cure testing procedures.

7-6 Coverage

Theoretically, 1 pound cover 0.94 square feet @125 mils:

GA27P unit covers: 45 sq. ft. @ 125 mils
37 sq. ft. @ 150 mils
30 sq. ft. @ 187 mils

A 10% allowance should be made for product loss due to pores of steel and product left in the can.

The average coating thickness should be 150 mils with a minimum thickness of 125 mils, and a maximum thickness of 187 mils.

Where no hatch cover exists, and a manhole has been cut out, the tank should be sealed in the following way:

The cover plate should overlap the hole at least 2" on each side and should measure at least 27"x27". Fastening the cover to the tank can be accomplished by punching ¾" diameter holes on 5" centers, 1" from the edge. The cover should be rolled to the contour of the tank. (See cover specifications drawing #2).

An alternate cover plate may be used and should overlap the hole at least 2" on each side and should measure 24"x24". The hole may be cut to 18"x18". Using 18 bolts, follow the same procedure as mentioned on previous page.

Whenever authorities require, the tank may be tested by either method as follows:

1. After the tank has been closed, but before the excavation is filled, the tank may be tested for tightness with air pressure at not less than 3 pounds per square inch and not more than 5 poundsper square inch. The test pressure shall hold, without fluctuation, for a period of 1 hour.

2. A Hydrostatic test may be applied, but the test pressure should be not less than 3 pounds per square inch and not more than 5 pounds per square inch.

8. OPERATIONS AFFECTING EXISTING WORK

The operation shall be conducted with care not to damage work which is to remain in place, and all existing work damaged by such operations shall be rectified promptly without additional expense to the owner.

Every reasonable precaution is taken in the manufacture of all Glass Armor products and compilation of data to assure that they comply with Bridgeport Chemical Corporation's exacting standards. As, however, the effectiveness of each product depends in part, upon correct methods of use, no guarantee of such products or data can be given.

ANNEX A

PERSONNEL EQUIPMENT REQUIRED:

a. Personnel working on such tanks will wear rubber boots, fresh air masks, life lines, and clean clothing with no metal buttons or fittings. A copper rivet will be driven into the heels of rubber boots to provide a ground or discharge of static electricity which may accumulate on personnel wearing safety equipment.

b. Fresh air will be supplied to the mask through a hose with a positive displacement air blower to the windward side of manhole in tank. Adequate power operated blowers are responsible for the air supply until personnel wearing mask have left tank and removed face piece. Securely attach one end of rope to the harness or body of the individual with the other end being held by an attendant stationed on the tank to assist in his removal, if necessary.

EQUIPMENT REQUIREMENTS:

a. Canister type masks will not be used in lieu of masks equipped with hose supplying fresh air.

b. Use non-ferrous tools for cleaning surfaces of rust, sediment, etc.

c. Use only cotton cloths for cleaning purposes. Other cloths tend to generate static electricity.

d. Lights of approved explosion-proof type only will be used.

e. Discontinue cleaning operations while electric storm is threating or in progress.

f. Personnel on this operation are prohibited from wearing wool, nylon, silk, rayon, and/or other static producing materials. Cotton cloth, is the only recommended type of clothing.

ANNEX B

DEFINITIONS:

EXPLOSIVE LIMITS: There is a minimum concentration of flammable vapor in air or oxygen below which propagation of flame does not occur on contact with source of ignition. There is also a maximum proportion of vapor or gas in air above which propagation of flame does not occur. "These boundary line mixtures of vapor or gas in air, which if ignited, will just propagate a flame, are known as the lower and upper explosive or flammable limits." Usually expressed in terms of percent by volume of gas in air.

FLAMMABILITY RANGE: The difference between the lower and upper explosive or flammable limits expressed in percent of vapor in air is known as the "flammable range." For example, the lower limits of flammability of gasoline, at ambient temperature, is approximately 1.4% vapor in air by volume, while the upper limit is about 7.6%. By difference, the explosive or flammability limit of gasoline is 6.2%.

Maximum Permissable 0_2 percentages and minimum inert gas concentration for aircraft fuel tanks.

TYPE OF FUEL	MAXIMUM 0_2	MINIMUM $C0_2$
Aviation Gas 115		
145	11.6	33.5
JP 3	11.4	35.0
JP 4	11.4	34.8

COMBUSTIBLE GAS INDICATORS: Readings from most indicators give the percentage of the lower flammable limit of the vapor in an atmosphere. Readings may be misleading where the atmosphere contains less than 5% by volume of 2_2 in an inert container.

ANNEX C

TESTS FOR DETERMINING COATING CURE

Either of the two following test methods may be used to check the degree of cures of the applied coating.

1. M-14 Pencil Hardness Test

General: Pencils of increasing hardness are drawn across the film until one is found which will not cut the film but will leave a black pencil mark on the surface whereas the next harder pencil will cut through the film without leaving a black mark. The number of the harder pencil is then used to express or designate the hardness.

Procedure: Strip wood from the lead for a distance of approximately ¼", using care not to nick the lead. Square the exposed lead by a gentle rotary motion against a No. 400 carbide abrasive paper.

Hold pencil in writing position, that is, at approximately 45°, and push forward against the film. Use pressure short of breaking the lead. By turning pencil after a test. a new edge is available for use and three or four trials may be made with one dressing of the lead.

Clean the marks with a soap or artgum eraser. Any marring of the surface, visible at an oblique angle in strong light, indicates that the pencil is harder than the film. The hardness is expressed as the grade of next softer pencil.

GA27 P should have a pencil hardness between 3H and 4H.

* 2. Barcol Hardness Tester GYZJ935 (Barber Colman Company, Rockford, Illinois) "This method, however, leaves a void in the coating, therefore the tested area must be recoated to eliminate this void."

The design of the Impressor is such that operating experience is not essential. It is only necessary to exert a light pressure against the instrument to drive the spring loaded indenter into the material to be tested. The indenter must be perpendicular to the surface. The instrument can be used in any position and in any space that will allow for the operator's hand. The hardness reading is instantly indicated on the dial which is conveniently divided into one hundred graduations. No waiting, preloading or separate measurements. On very soft materials, highest reading should be used since cold flow permits spring loaded indenter to continue penetration.

Barcol on GA27 P should read 65-75

* Preferred method

ANNEX D

The contractor's supervisor will be familiar and comply with the procedures established in the following publications:

1. Recommended Practice for Cleaning Petroleum Storage Tanks (API RP2015 - 2nd Edition 1976)

2. Cleaning Small Tanks and Containers NFPA 327,1976

3. Recommended Practice for Protection Against Ignitions arising out of static, lighting, and stray currents. (API RP2003, 3rd Edition 1974)

4. NIOSH "Working in Confined Spaces" - December, 1979

The contractor is also to be familiar and comply with the rules and regulations of the Occupational Safety and Health Administration as published in the Federal Register, Volume 36, No. 105, Part II, and in particular:

Subpart H -	Hazardous Materials par. 1910, 106 Flammable and Combustible Liquid.
Subpart I -	Personal Protective Equipment par. 1910, 132 general requirements par. 1910, 134 respiratory protection
Subpart J -	General Environment Controls par. 1910, 145 specifications for accident prevention signs & tags
Subpart L -	Fire Protection par. 1910, 157 portable fire extinguishers

ANNEX E

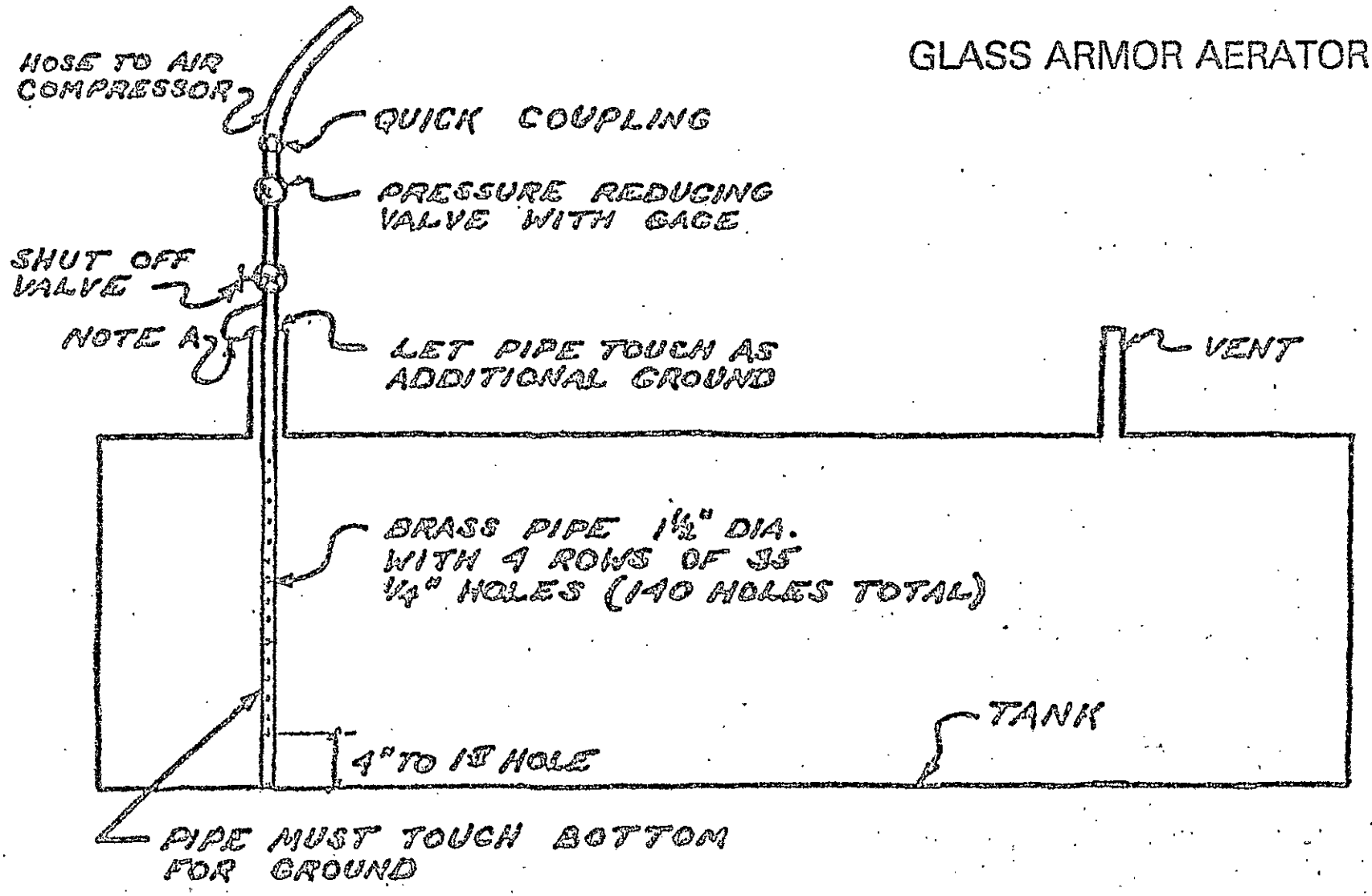
TESTS FOR DETERMINING COATING THICKNESS

Use a thickness gauge such as an Elcometer Model 1, Type A Scale 14, 0-¼" (Ferro Corporation, Cleveland, Ohio) or equivalent.

Follow the manufacturers instructions for standardizing the thickness gauge.

Check the various areas of the coated tank for proper film thickness as per meter reading. If any areas are not proper thickness, apply Glass Armor coating to the proper thickness and allow to cure.

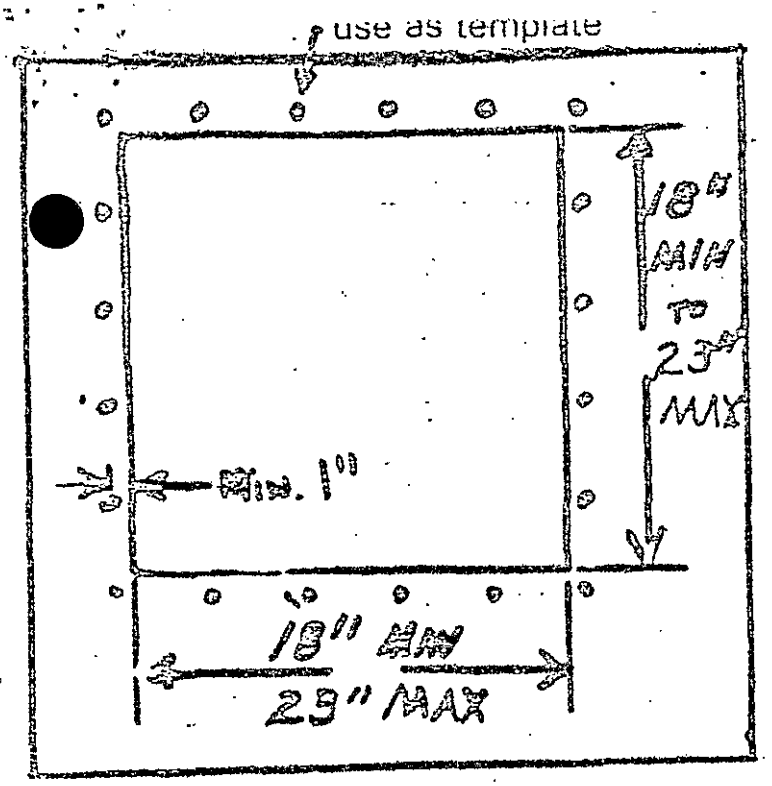
GLASS ARMOR AERATOR



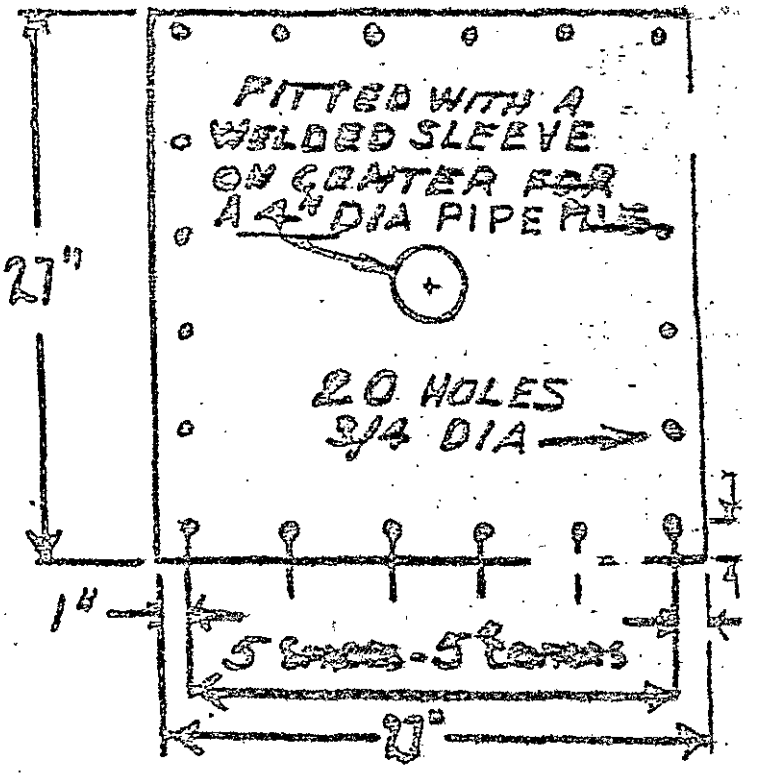
NOTE A GROUND CABLE BRAZED TO PIPE MUST BE CLAMPED TO FILL PIPE. USE 12 GAUGE WIRE FROM PIPE TO WATER PIPE.

DRAWING - 1

8/80

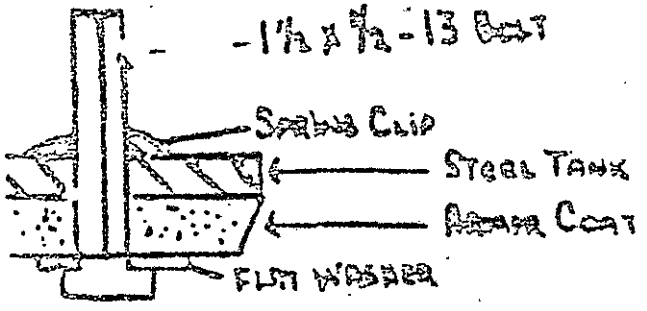


Plan of Tank Opening

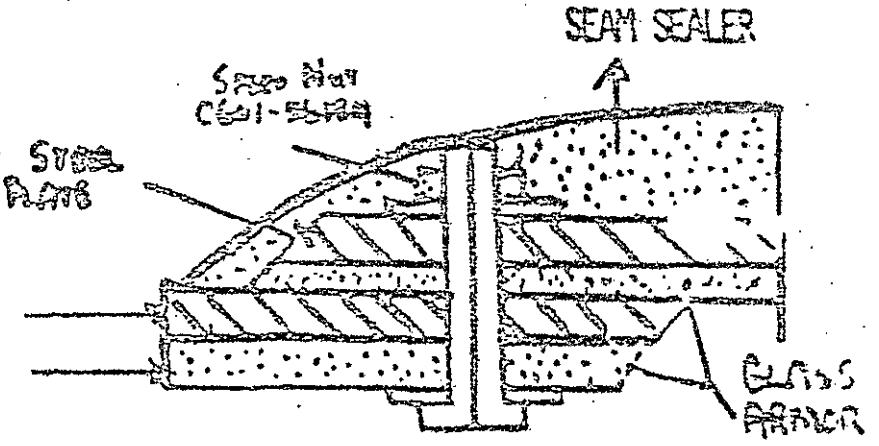


Plan of Tank Cover

NOTE: Make cover of same thickness as steel tank.



Section thru Bolt



Section thru Sealed Joint

Bridgeport Chemical Corp.
Glass Armor Systems
Seal for a buried Gasoline Storage Tanks
DRAWING - 2

8/80

19. Buono, Anthony and Elaine Packard. "Delineation and Hydrologic Effects of a Gasoline Leak at Stovepipe Wells Hotel, Death Valley National Monument California", USGS Water Resources Invert 82-45, 1982

2640

PB83-127548

Delineation and Hydrologic Effects of a Gasoline Leak at Stovepipe Wells Hotel Death Valley National Monument, California

(U.S.) Geological Survey
Sacramento, CA

Jul 82

U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
NTIS

50272-101

REPORT DOCUMENTATION PAGE	1. Sequential submission number: USGS/WRD/WRI/82-074	3. Recipient's Accession No. PB83 127548
4. Title and Subtitle Delineation and Hydrologic Effects of a Gasoline Leak at Stovepipe Wells Hotel, Death Valley National Monument, California		5. Report Date July 1982 6.
7. Author(s) Anthony Buono and Elaine M. Packard		8. Performing Organization Rept. No. USGS/WRI 82-45
9. Performing Organization Name and Address U.S. Geological Survey, Water Resources Division California District 2800 Cottage Way, Room W-2235 Sacramento, California 95825		10. Project/Task/Work Unit No. 11. Contract(C) or Grant(G) No. (C) (G)
12. Sponsoring Organization Name and Address U.S. Geological Survey, Water Resources Division California District 2800 Cottage Way, Room W-2235 Sacramento, California 95825		13. Type of Report & Period Covered Final 14.

15. Supplementary Notes

Prepared in cooperation with the National Park Service

16. Abstract (Limit: 200 words)

Ground water is the only local source of water available to the Stovepipe Wells Hotel facilities of the Death Valley National Monument, California. A leak in a service station storage tank caused the formation of a gasoline layer overlying the water table, creating the potential for contamination of the water supply. The maximum horizontal extent of the gasoline layer was mathematically estimated to be 1,300 feet downgradient from the leaky gasoline tank. Exploratory drilling detected the gasoline layer between 900 and 1,400 feet downgradient and between 50 and 150 feet upgradient from the source. Traces of the soluble components of gasoline were also found in the aquifer 150 feet upgradient, and 250 feet distant from the source perpendicular to the direction of ground-water movement. The gasoline leak is not likely to have an effect on the supply wells located 0.4 mile south of the leak source, which is nearly perpendicular to the direction of ground-water movement and the primary direction of gasoline movement in the area. No effect on phreatophytes 2 miles downgradient from the layer is likely, but the potential effects of gasoline vapors within the unsaturated zone on local xerophytes are not known.

17. Document Analysis a. Descriptors

Gasoline, Fuels, Path of Pollutants, Sewage, Dissolved Solids, Soil Contamination Effects, Water Supply, Groundwater, Alluvial Aquifer, Oil-Water Interface, Organic Compounds, Leakage, Infiltration, Movement, Percolation

b. Identifiers/Open-Ended Terms

California, Layer, Spread, Residual Saturation, Extent, Magnitude, Death Valley National Monument, Stovepipe Wells Hotel

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
No restriction on distribution	UNCLASSIFIED	28
Prepared for NTIS by U.S. Geological Survey, WRD	20. Security Class (This Page) UNCLASSIFIED	22. Price

(See ANSI-Z39.18)

REPRODUCED BY
NATIONAL TECHNICAL INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

DELINEATION AND HYDROLOGIC EFFECTS OF A GASOLINE LEAK AT STOVEPIPE WELLS HOTEL, DEATH VALLEY NATIONAL MONUMENT, CALIFORNIA

By ANTHONY BUONO and ELAINE M. PACKARD

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 82-45

Prepared in cooperation with the

NATIONAL PARK SERVICE

7218-21

July 1982

I

UNITED STATES DEPARTMENT OF THE INTERIOR

JAMES G. WATT, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

District Chief
U.S. Geological Survey
2800 Cottage Way, Room W-2235
Sacramento, Calif. 95825

CONTENTS

	Page
Abstract	1
Introduction	2
Geography and climate	2
Purpose and scope	2
Approach	5
Previous investigations	5
Well-numbering system	5
Acknowledgments	5
Ground-water hydrology	6
Determining the extent of gasoline contamination	12
Movement of a gasoline leak in a porous medium	12
Locating exploratory drilling sites	14
Gasoline losses from service station records	15
Exploratory drilling and subsurface soil sampling	17
Hydrologic effects of the gasoline leak	20
Summary and conclusions	22
Selected references	23

FIGURES

	Page
Figures 1-3. Maps showing:	
1. Location of study area in Death Valley National Monument, Calif.	3
2. Location of wells	4
3. Water-table configurations, April 1977 and June 1980	9
4. Hydrographs of selected wells in the Stovepipe Wells Hotel area, 1968, 1973-80	10
5. Map showing the estimated horizontal extent of the gasoline layer, based on test drilling, May 1980	16
6. Diagrammatic cross section of trace A-A' through the gasoline contaminated area	21

TABLES

	Page
Table 1. Water-level data, well data, and dissolved-solids concentrations in the Stovepipe Wells Hotel area	7
2. Gasoline concentrations in soil and water samples, Stovepipe Wells Hotel area	18

DELINEATION AND HYDROLOGIC EFFECTS OF A GASOLINE LEAK AT STOVEPIPE WELLS HOTEL, DEATH VALLEY NATIONAL MONUMENT, CALIFORNIA

By Anthony Buono and Elaine M. Packard

ABSTRACT

Ground water is the only local source of water available to the Stovepipe Wells Hotel facilities of the Death Valley National Monument, California. A leak in a service station storage tank, probably totaling more than 19,000 gallons, caused the formation of a gasoline layer overlying the water table, creating the potential for contamination of the water supply.

For the purpose of site selection for exploratory drilling, the horizontal extent of the gasoline layer was mathematically estimated to be 1,300 feet downgradient from the leaky gasoline tank. Exploratory drilling detected the gasoline layer extending between 900 and 1,400 feet downgradient and 50 and 150 feet upgradient from the source. Traces of the soluble components of gasoline were also found in the aquifer 150 feet upgradient and 250 feet distant from the source perpendicular to the direction of ground-water movement.

The gasoline leak is not likely to have an effect on the supply wells located 0.4 mile south of the leak source, which is nearly perpendicular to the direction of ground-water movement and the primary direction of gasoline movement in the area. No effect on phreatophytes 2 miles downgradient from the layer is likely, but the potential effects of gasoline vapors within the unsaturated zone on local xerophytes are not known.

INTRODUCTION

Stovepipe Wells Hotel is a National Park Service facility on State Highway 190 in the western part of Death Valley about 200 miles northeast of Los Angeles in southern California (fig. 1). In May 1979 the odor of gasoline was detected in unused well 15S/44E-36K1 (fig. 2) near the Stovepipe Wells Hotel gasoline station. Analysis of a sample collected from the well indicated that a layer of gasoline had accumulated above the water table. The gasoline had leaked from one of the station's two 8,000-gallon storage tanks located about 75 feet south of the well (fig. 2).

The National Park Service requested the U.S. Geological Survey to assess the spreading and the hydrologic effects of the gasoline leak on the ground water and vegetation of the area. Of primary concern were the hotel's supply wells 15S/44E-36Q2 and 16S/44E-1C1 about 0.4 mile south (fig. 2) of the contamination source. A map of the water-table configuration in August 1977 (Lamb and Downing, 1979, p. 7) indicated that a local pumping depression might surround the supply wells. The depression could cause the movement of gasoline toward those wells and jeopardize the area's only water supply.

Geography and Climate

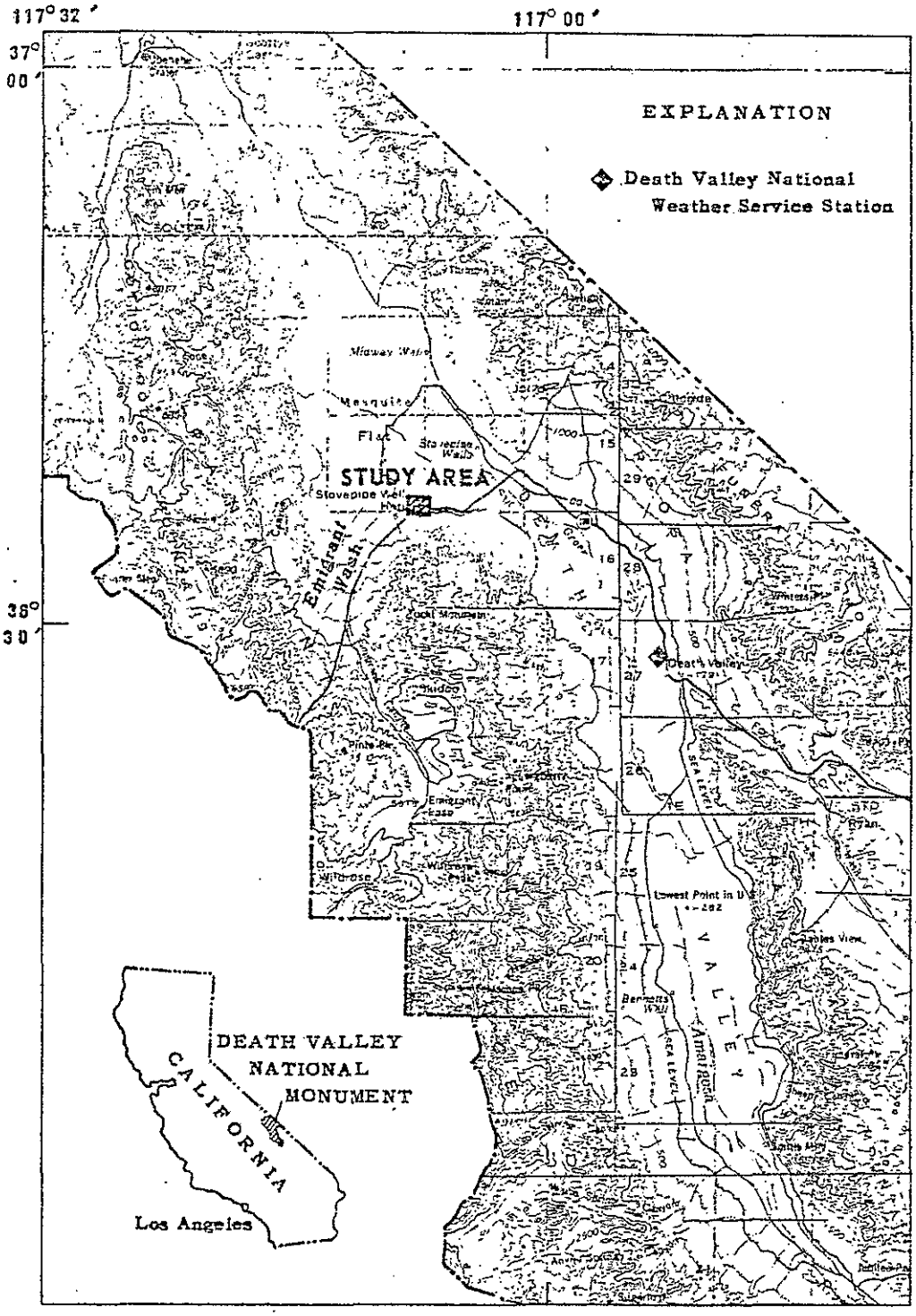
Death Valley is a 140-mile-long northwestward-trending desert basin in the southwestern part of the Great Basin. The valley, bounded on the east by the Amargosa Range and on the west by the Panamint Range, is famous as the site of the lowest point in the United States at 282 feet below sea level (fig. 1).

The climate in Death Valley is arid, with an average annual rainfall of less than 2 inches and an average monthly temperature ranging from 52°F in January to 102°F in July. Measurements have been recorded since 1913 at the National Weather Service Station at Death Valley, Calif., altitude 194 feet below sea level, about 18 miles southeast of the study area (fig. 1). The highest temperature recorded at this station was 134°F on July 10, 1913.

Purpose and Scope

The purposes of the investigation were to delineate the horizontal extent of the gasoline layer overlying the water table, to assess the effects of the gasoline layer on the ground water and vegetation of the area, with emphasis on the potential effects on water supply, and to determine what measures may be needed to insure continued safe use of local ground water.

The area of investigation was less than 1 mi^2 surrounding the Stovepipe Wells Hotel. The study involved the evaluation of ground-water levels and water-quality information, and exploratory drilling for the collection and analysis of soil samples for gasoline content above and below the water table in the vicinity of the gasoline leak.

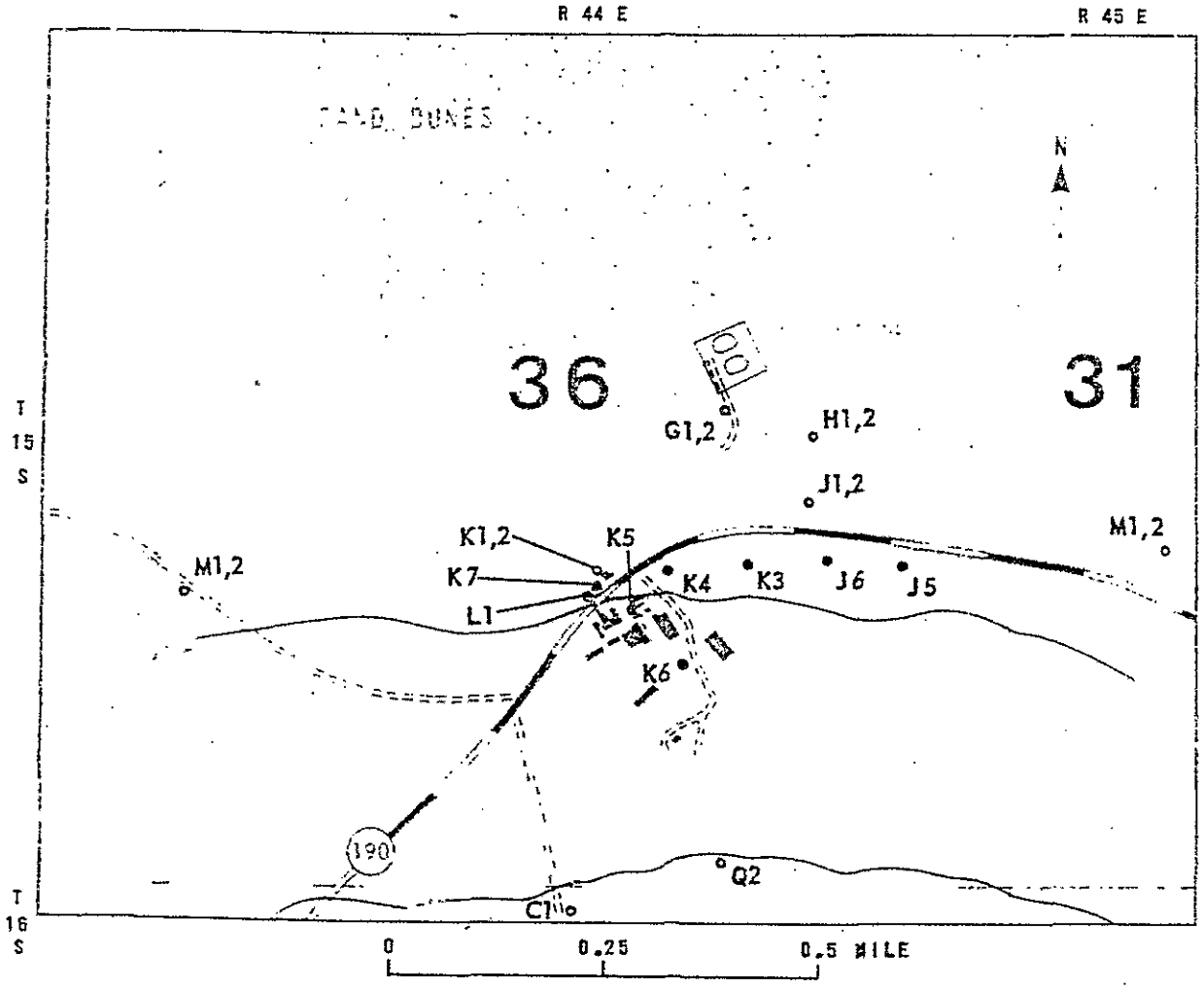


Base from U.S.Geological Survey, California (South half) 1:500,000, 1970

0 10 20 30 MILES

CONTOUR INTERVAL 500 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

FIGURE 1.--Location of study area in Death Valley National Monument, California.



TOPOGRAPHIC CONTOUR INTERVAL 80 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

EXPLANATION

WELL--

M1,2 Drilled prior to May 1980

J5 Drilled May 1980

FIGURE 2.--Location of wells.

Approach

The objectives of the investigation were accomplished by the evaluation of ground-water levels, water-quality information, well-construction information, well logs, and gasoline station operation records; determination of the direction of ground-water movement; test-hole drilling with split-spoon soil sampling above and below the water table; and the conversion of test holes to monitor wells for the collection of periodic water-level and water-quality data for the detection of continued gasoline movement.

Previous Investigations

Information from previous studies in Death Valley used during this investigation included: General background information concerning the climatic, hydrologic, and geologic setting from Hunt, Robinson, Bowles, and Washburn (1966); ground-water quality data from Miller (1977); and ground-water level and quality data from Lamb and Downing (1979).

Well-Numbering System

Wells are numbered according to their location in the rectangular system for the subdivision of public lands. For example, in the number 15S/44E-36K1, the part of the number preceding the slash indicates the township (T. 15 S.), the part between the slash and the hyphen indicates the range (R. 44 E.), the number between the hyphen and the letter indicates the section (sec. 36), and the letter indicates the 40-acre subdivision of the section, as shown in the diagram below. Within the 40-acre tract, wells are numbered serially as indicated by the final digit.

D	C	B	A
E	F	G	H
M	L	K	J
N	P	Q	R

Acknowledgments

The authors express their appreciation for the cooperation of the National Park Service personnel during the investigation, in particular, Gerard S. Witucki of the Western Regional office; and George Von der Lippe, Bob Quesenberry, and Richard S. Rayner of Death Valley National Monument.

The local water supply is obtained from two wells, 15S/44E-36Q2 and 16S/44E-1C1 (fig. 2), that penetrate the unconfined aquifer composed of unconsolidated gravelly sandy silt. Aquifer transmissivity was estimated to be 3,400 ft^2/d based on the Jacob and Lohman straight line solution for well recovery data (Lohman, 1972, p. 26-27) from a specific capacity test run by the Park Service on well 1C1 in 1973. The specific capacity of the well is about 7 (gal/min)/ft of drawdown in the well.

Each supply well produces about 25,000 gal/d during peak seasonal use at a pumping rate of 65 gal/min in well 15S/44E-36Q2 and 23 gal/min in well 16S/44E-1C1. Well 36Q2 supplies most of the area's nonpotable uses, and well 1C1 supplies all potable and some nonpotable uses after reverse-osmosis treatment at the well site. The wells penetrate deeper in the aquifer than other local wells and produce the best quality water in the area, although the dissolved-solids concentration of about 3,000 mg/L (table 1) is six times the recommended limit for drinking water (U.S. Environmental Protection Agency, 1976, p. 205-206). Table 1 shows water-level, well-construction, and dissolved-solids information for all local wells.

According to a 1977 water-table map (Lamb and Downing, 1979, p. 7) the direction of ground-water movement in the study area was southward toward the local supply wells. This direction of ground-water movement was the cause of great concern over the possible impact of the gasoline leak on the supply wells 0.4 mile to the south. During the present investigation, altitudes of well-measuring points were more accurately determined by use of a surveyor's leveling instrument. Using this information, new water-table maps were drawn, and a better understanding of the direction of local ground-water movement was obtained.

Figure 3 shows a comparison of the water-table configurations for April 1977 and June 1980. The map indicates that ground-water movement is eastward, nearly perpendicular to the alinement of the leak site and the supply wells. The figure also shows a general decline in water levels of about 0.25 foot, indicated by the westward shift of contours, and no change in the direction and pattern of ground-water movement. Hydrographs of several wells (fig. 4) show a declining trend over the period of record along with seasonal fluctuations in water levels. Included is a hydrograph of well 15S/44E-34D1 (off fig. 2 to west), 2.5 miles northwest of the supply wells, which also shows a declining trend in water levels. The hydrographs indicate that part of the decline observed in figure 3 resulted from seasonal fluctuations, because measurements were made in different months in 1977 and 1980, and part from regional decline. Together these data indicate that the present rate of withdrawal from the supply wells has had no noticeable effect on water levels or patterns of ground-water movement in the area.

TABLE 1. - Water-level data, well data, and dissolved-solids concentrations in the Stovepipe Wells Hotel area

[Analyses by the U.S. Geological Survey Central Laboratory, Arvada, Colo., unless otherwise noted]

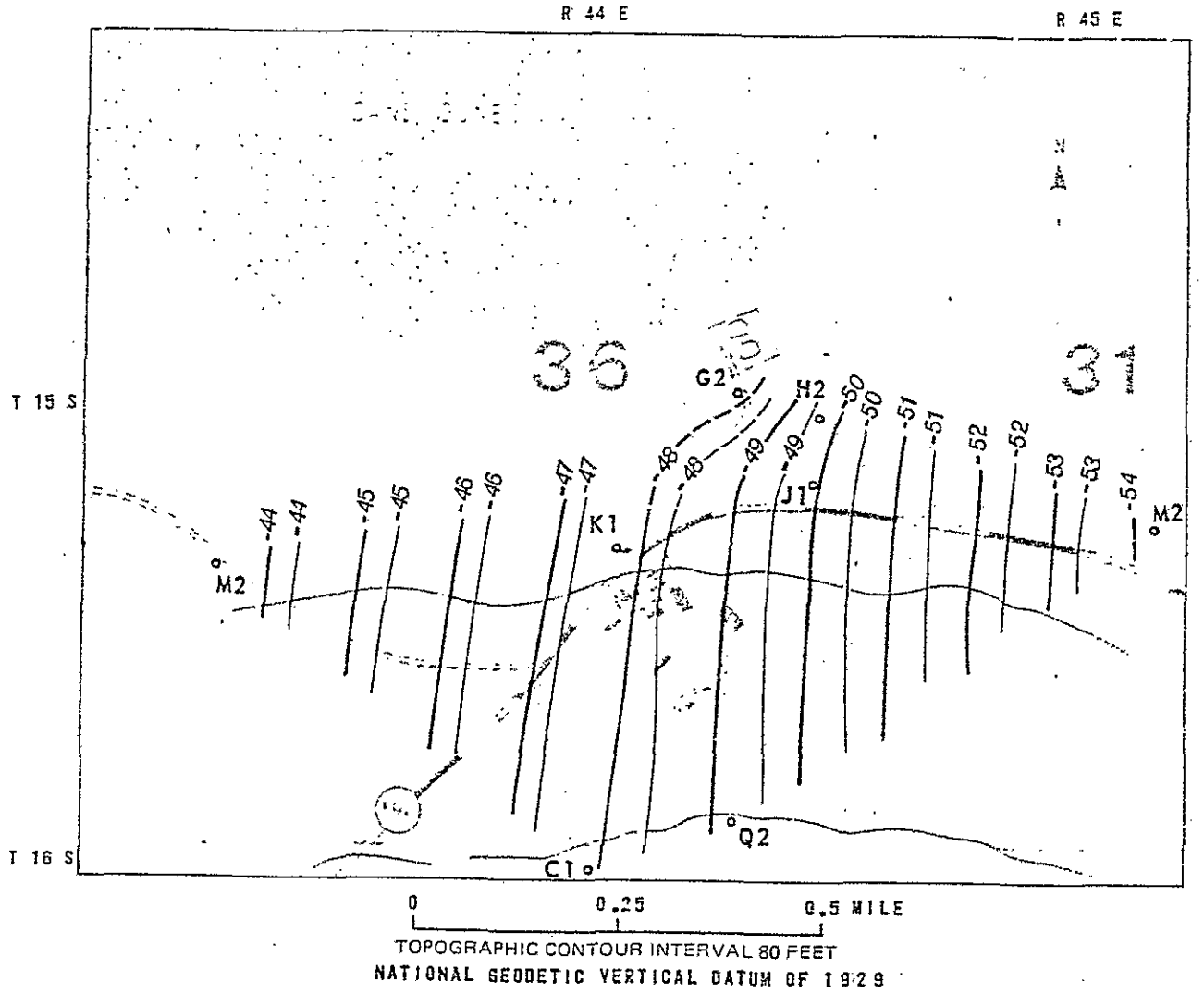
Site / Date	Altitude of lsd (feet above or below (-) sea level)	Depth to water (feet below lsd)	Perforated interval (feet below lsd)	Depth of well (feet below lsd)	Dissolved solids, calculated sum (mg/L)
15S/44E-34D1					
3-26-68[1]	15.41	38.17	51.0-53.0	53	3,290
15S/44E-36G1					
6-17-80	-25.21	22.78	44.9-46.9	46.9	--
15S/44E-36G2					
6-17-80	-25.31	22.46	24.7-27.7	27.7	8,080
15S/44E-36H1					
11-03-73	-26.20	22.25	49.2-51.2	51.2	5,430
6-17-80	--	23.53	--	--	5,580
15S/44E-36H2					
6-17-80	-26.10	23.80	25.2-28.2	28.2	--
15S/44E-36J1					
6-17-80	-22.76	27.22	48.2-50.2	50.2	6,410
15S/44E-36J5					
6-17-80	-15.30	36.26	32.6-44.3	44.3	8,260
15S/44E-36J6					
6-17-80	-12.64	37.42	36.0-46.0	46.0	5,390
15S/44E-36K1					
3-21-67	-9.84	--	37(?)-65(?)	65	9,170
2-14-74	--	37.57	--	--	--
2-27-75	--	37.67	--	--	--
6-23-76	--	37.66	--	--	--
4-05-77	--	37.61	--	--	--
5-10-78	--	37.57	--	--	11,200
5-09-79[1]	--	37.55	--	--	10,000
6-18-80	--	37.86	--	--	8,790
15S/44E-36K2					
2-14-74	-9.98	37.37	Unknown	50	--
2-27-75	--	37.53	--	--	--
6-23-76	--	37.49	--	--	--
4-06-77[1]	--	37.51	--	--	3,270
5-10-78	--	37.53	--	--	3,570
5-09-79	--	37.60	--	--	3,770
15S/44E-36K3					
6-17-80	-9.66	39.42	37.4-45.4	45.4	5,250
15S/44E-36K4					
6-17-80	-7.98	40.53	38.0-47.0	47.0	5,570
15S/44E-36K5					
6-18-80	.73	49.06	49.8-59.8	59.8	6,400

See footnotes at end of table.

TABLE 1. - Water-level data, well data, and dissolved-solids concentrations in the Stovepipe Wells Hotel area--Continued

Site / Date	Altitude of lsd (feet above or below (-) sea level)	Depth to water (feet below lsd)	Perforated interval (feet below lsd)	Depth of well (feet below lsd)	Dissolved solids, calculated sum (mg/L)
15S/44E-36K6					
6-18-80	14.46	63.62	62.0-71.7	71.7	6,790
15S/44E-36K7					
6-17-80	-5.23	42.53	37.0-54.0	54.0	7,650
15S/44E-36L1					
6-17-80	-1.85	45.07	44.3-54.4	54.4	6,370
15S/44E-36M1					
11-03-73	-15.22	28.1	43.7-45.7	45.7	6,610
2-26-76	--	--	--	--	6,490
4-06-77[1]	--	27.88	--	--	6,620
5-10-78	--	27.84	--	--	6,570
9-21-78	--	28.04	--	--	6,230
5-09-79[1]	--	28.01	--	--	6,580
6-18-80	--	28.20	--	--	6,220
15S/44E-36M2					
11-03-73	-15.33	18.46	30.4-33.4	33.4	7,260
15S/44E-36Q2					
5-08-67[1]	81.05	--	Unknown	>300	2,980
9-09-73[2]	--	130.25	--	--	--
6-19-75	--	--	--	--	2,780
2-26-76	--	--	--	--	2,840
4-06-77[1]	--	129.98	--	--	2,910
5-10-78	--	130.02	--	--	2,720
5-10-79[1]	--	130.23	--	--	2,920
6-18-80	--	130.25	--	--	2,730
15S/45E-31M1[3]					
2-26-76	-26.50	27.57	35.7-37.7	37.7	2,990
4-06-77[1]	--	27.25	--	--	5,540
5-10-78	--	27.29	--	--	9,260
9-21-78	--	27.45	--	--	8,340
5-10-79[1]	--	27.42	--	--	8,830
6-18-80	--	27.67	--	--	8,180
15S/45E-31M2[4]					
6-17-80	-26.64	27.59	28.3-30.3	30.3	--
16S/44E-1C1					
9-09-73	97.19	145.4	264-294	294	--
4-06-77[1]	--	144.84	--	--	2,870
5-10-78	--	144.67	--	--	2,960
5-10-79[1]	--	144.90	--	--	2,890

[1]Analysis by California Department of Water Resources.
[2]Analysis by National Park Service.
[3]Formerly 15S/44E-36J3.
[4]Formerly 15S/44E-36J4.



EXPLANATION

M2 WELL AND NUMBER

WATER-TABLE CONTOUR--Shows altitude of water table. Dashed where approximately located. Contour interval 1 foot. National Geodetic Vertical Datum of 1929

-53 April 1977

-54 June 1980

FIGURE 3.--Water-table configurations, April 1977 and June 1980.

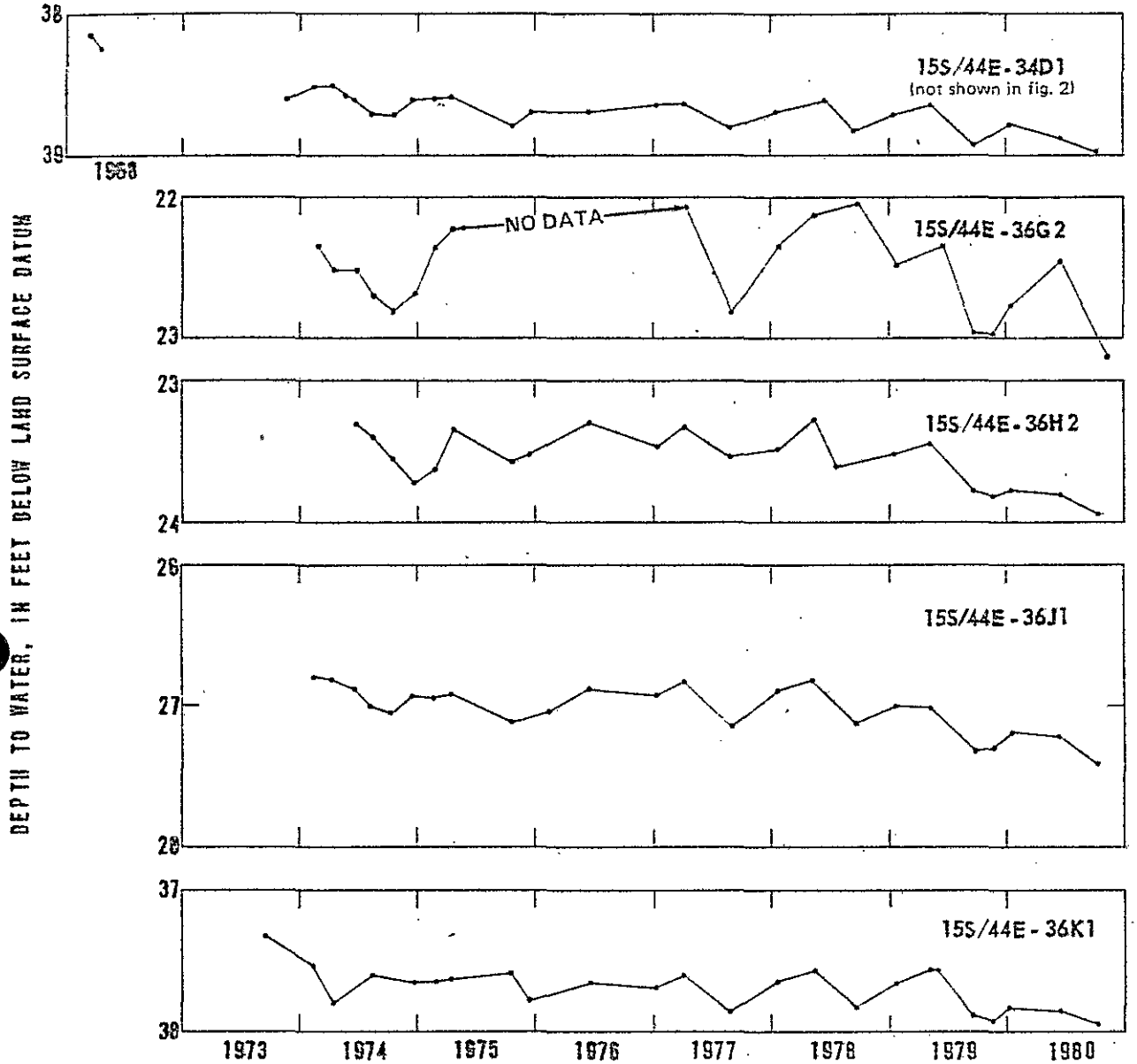


FIGURE 4.–Hydrographs of selected wells in the Stovepipe Wells Hotel area ,1968,1973–80.

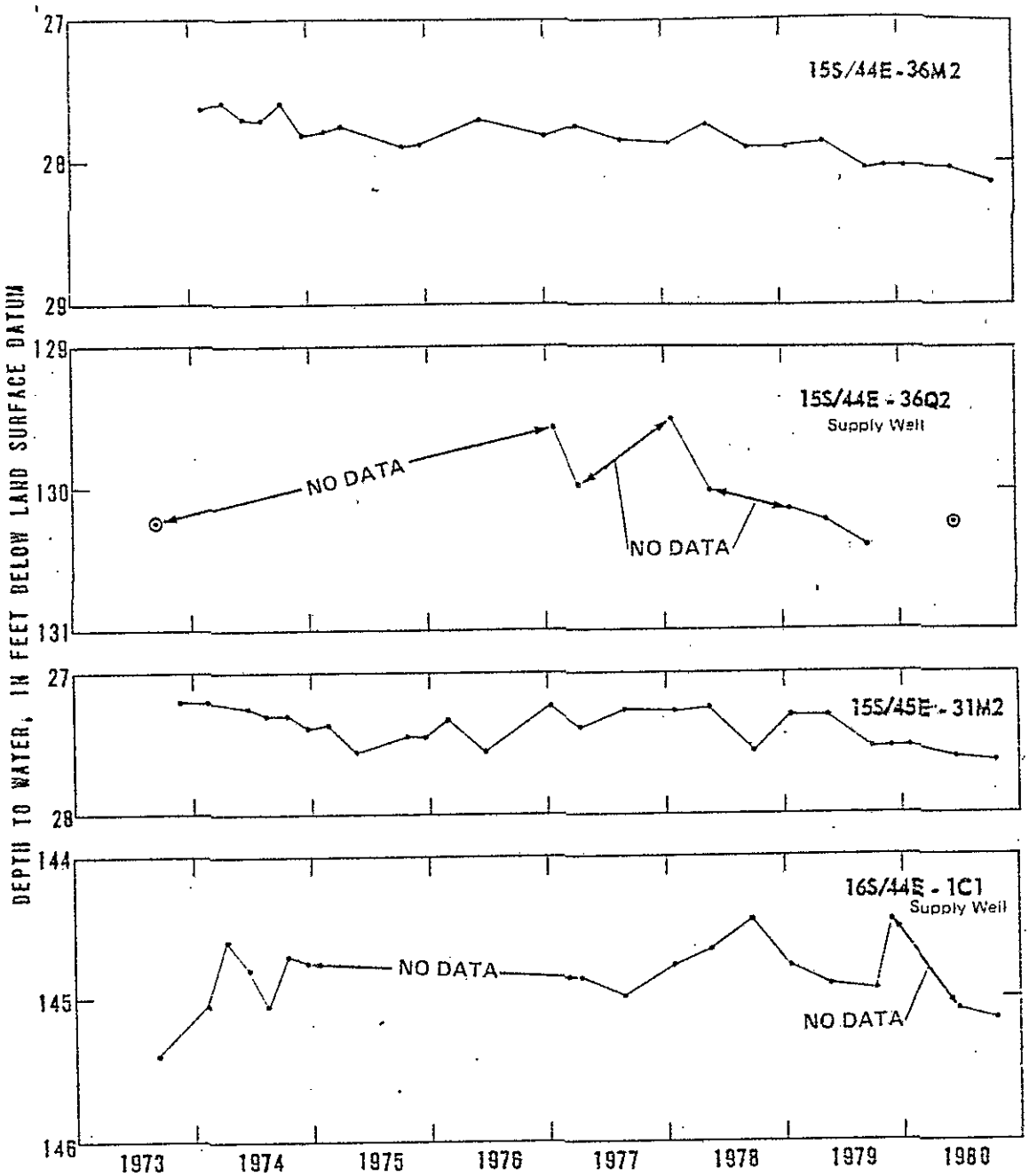


FIGURE 4.--Continued.

After the detection of a gasoline odor in well 15S/44E-36K1 (fig. 2) in May 1979, a gas chromatograph mass spectrometry analysis for hydrocarbon concentration was run on a sample taken at the liquid surface in the well. The sample was determined to be undiluted gasoline, indicating that a layer of gasoline had formed overlying the water table in the area. The well is directly behind the hotel's grocery store/gasoline station. Pressure testing of the station's two gasoline storage tanks in August 1979 indicated a leak in the upper part of the tank containing unleaded gasoline, 30-35 feet above the water table. Use of the tank was discontinued immediately.

Movement of a Gasoline Leak in a Porous Medium

The movement of gasoline in a porous medium, as with any liquid in the unsaturated zone, is controlled by a combination of the force of gravity and the capillary characteristics of the medium and liquid. These factors cause vertical (gravitational plus capillary forces) and lateral (capillary forces) movement of the gasoline away from the leak site. In the zone of gasoline leakage, gravitational forces are predominant, resulting in primarily vertical movement of the gasoline toward the water table.

Continued movement of the gasoline depends on the maintenance of a level of saturation exceeding the residual saturation of the medium. Residual saturation of an oil product is analogous to the specific retention of a medium for water. Specific retention is defined as "the ratio of (1) the volume of water which the porous rock or soil, after being saturated, will retain against the pull of gravity, to (2) the volume of rock or soil" (Lohman, 1972, p. 12). This retention can most easily be illustrated by water held suspended in a sponge by capillary forces against the pull of gravity. The volume of liquid retained by a medium is an inverse function of the grain and pore size of the medium. According to Schwille (1967, p. 35) the residual saturation for oil products will rarely exceed 5 percent of the volume of the medium. This value corresponds closely to values proposed by Dietz (1971, p. 132-133).

Dietz' discussion uses the porosity of the medium multiplied by the immobile oil saturation, a percentage of the porosity, which yields the oil saturation as a percentage of the total volume of the material affected by the leak. Immobile oil saturations ranged from 10 percent for light oil (gasoline) to 20 percent for heavy oil (lube oil, heavy fuel oil). For an assumed porosity of 35 percent for unconsolidated sands, 10-20 percent immobile oil saturation yields between 3.5 and 7 percent saturation of the total volume of the medium.

When a leak is sufficiently large to sustain the movement of gasoline to the water table, a layer will form overlying the water table. Gasoline, generally considered insoluble and immiscible in water even though certain components of gasoline are slightly soluble in water, has a specific gravity of 0.7 times that of water. This combination of physiochemical properties causes gasoline to float as a layer above the water surface in an unconfined aquifer. The layer will move primarily downgradient, controlled by the force of gravity and the capillary forces of the medium. Horizontal and vertical movement will continue through the unsaturated zone until the degree of gasoline saturation in the layer decreases to the residual saturation of the medium.

In addition to the movement of gasoline within the layer above the water table, the volatile nature of gasoline will cause the diffusion of gasoline vapors in the unsaturated zone, and the slight solubility of certain gasoline components in water can cause the degradation of the aquifer. The slightly soluble components are primarily the aromatic constituents of the gasoline, such as benzene and toluene (Frank Allen, U.S. Environmental Protection Agency, Athens, Ga., *oral commun.*, Dec. 1980). The exploratory objective of this investigation was limited to delineating the horizontal extent of the gasoline layer overlying the water table in the hotel area. Future monitoring of local wells will determine the extent of continued movement of the gasoline layer in addition to the concentration of the slightly soluble gasoline components in the aquifer. Diffusion of the soluble components in aquifer water results in a continuous dilution to lower concentrations as distance increases from the gasoline layer.

Two local conditions that will reduce the horizontal extent of the gasoline layer overlying the water table through increased residual gasoline saturation are the poorly sorted silty composition of the medium and the low soil-moisture content because of the arid climate. The silty medium causes a relatively high residual saturation through the associated higher capillarity. Both the fine-grained fraction of the medium and low soil moisture increase the grain surface area available for adsorption (molecular attraction forces) of the gasoline. These factors reduce the volume of gasoline available to reach the water table and increase the thickness of the layer overlying the water table.

Of additional benefit to the local ground-water system is the expected complete biodegradation and evaporation of the suspended gasoline and the gasoline layer within 15 years of the leak. According to Schwille, heavier oil products may remain in the soil for tens of years, whereas gasoline will not. Case histories of leaks show that gasoline has never remained in the soil for more than 15 years (Schwille, 1967, p. 38).

Locating Exploratory Drilling Sites

In November 1979, after a leveling survey determined precise altitudes of well measuring points, water levels were measured, and a generalized map of the configuration of the water table (similar to fig. 3) was drawn for field use. Based on the water-table map and an understanding of how gasoline spreads in the subsurface (Freeze and Cherry, 1979; Fried and others, 1979; Holzer, 1976; McKee and others, 1972; Dietz, 1971; Schwille, 1967; Van Dam, 1967; and Williams and Wilder, 1971), the extent of the spread of the gasoline was estimated to help in selecting sites for exploratory drilling. The estimate was based on assumptions concerning the volume of gasoline leakage, residual saturation of the alluvial material above the water table, and thickness of the gasoline layer above the water table. Gasoline leakage was assumed to be 5,000 gallons, the volume of the storage tank first reported by station operators. The residual saturation for the alluvium was assumed to be 0.05, based on geologists' and drillers' logs reporting poorly sorted gravelly silty sand. Finally, the thickness of the gasoline layer was assumed to be 0.117 inch (3 mm). Case histories of oil product leaks (Schwille, 1967, p. 36-37) indicate that where leaks have reached the final stages of spreading or have ceased spreading, layer thicknesses have never been less than 3-5 mm and are more likely to be several tens of millimeters. Using the thinnest layer thickness from case histories produced a maximizing of the spreading estimate used for locating exploratory drilling sites.

A basic estimate was made, using the stated values in the following equation, which assumes an even radius of spreading about the source of the gasoline:

$$r_s = \sqrt{\frac{V}{S_r L_t \pi}} = \sqrt{\frac{668}{(0.05)(0.01)\pi}} = 650 \text{ feet},$$

where

r_s = radius of spread, in feet,

V = volume of gasoline loss, in cubic feet, 668 ft^3 (5,000 gal),

S_r = residual saturation of the alluvium, 0.05, and

L_t = gasoline layer thickness, in feet, 0.01 foot (3 mm).

The radius of spread calculated was about 650 feet. It was realized, however, that much of the gasoline would be trapped by capillary and molecular forces in the unsaturated zone between the tank and the water table. Disregarding this fact, and therefore assuming that all gasoline reached the water table, would cause a further maximization of the value of r_s. It was also known that the gasoline that reached the water table would move primarily down the ground-water gradient. The r_s value was therefore doubled to 1,300 feet and considered a very rough estimate, leaving the option to relocate test-hole sites as exploratory drilling proceeded. This maximizing approach allowed for large error in making the estimate. For example, if 50,000 gallons of gasoline were actually lost and the layer thickness was actually 1.4 inches (36 mm), the spread should still be restricted within the 1,300-foot down-gradient estimate. Layer thicknesses in a silty alluvium, according to a rough guide offered by Dietz (1971, p. 132), will be much thicker than the 1.4 inches used in the above example. Dietz' guide is as follows:

Sand	Average grain size, in millimeters (inches)	Thickness of layer, in centimeters (inches)
Extremely coarse to very coarse	2 to 0.5 (0.08 to 0.02)	1.8 to 9.0 (0.71 to 3.54)
Very coarse to moderately coarse	0.5 to 0.2 (0.02 to .008)	9.0 to 22.4 (3.54 to 8.82)
Moderately coarse to moderately fine	0.2 to 0.05 (.008 to 0.002)	22.4 to 28.1 (8.82 to 11.06)
Moderately fine to very fine	0.05 to 0.015 (0.002 to 0.0006)	28.1 to 45.0 (11.06 to 17.72)

Eight exploratory sites were selected in three directions from the gasoline source, including sites extending as far down ground-water gradient as well 15S/44E-36K3 (fig. 5), 900 feet to the east. Site locations were selected subject to change as exploratory drilling proceeded. Each site was surveyed for altitude and plotted on the field water-table contour map to obtain an estimated depth to the water table. These estimates of depth insured sampling of the soil immediately above the water table, and therefore detection of the gasoline layer if present.

Gasoline Losses From Service Station Records

In December 1979, service station operation records of purchases and sales of unleaded gasoline were obtained from Fred Harvey, Inc., concessionaire for Stovepipe Wells Hotel. Records indicate that leakage during the period October 7, 1978, to September 4, 1979, may have been as much as 19,000 gallons. Prior to October 1978 the hotel was privately owned and records were not made available to the authors; therefore, an accurate estimate of the total volume of gasoline leakage was not possible. The losses from October 7, 1978, to November 2, 1978, averaged about 74 gal/d; the losses from October 7, 1978, to September 4, 1979, averaged about 57 gal/d. Because the average losses for the first 27 days of record were more than the average losses for the entire period of record, the indication is that leakage began prior to October 7, 1978.

With the additional information concerning the volume of gasoline losses, it was realized that the original estimate of downgradient spreading of the gasoline layer was based on too small a volume. No modification of the exploratory sites staked in November was assumed necessary at that time, however, because the option to relocate exploratory wells could be exercised in the field as new data were obtained from drilling results.

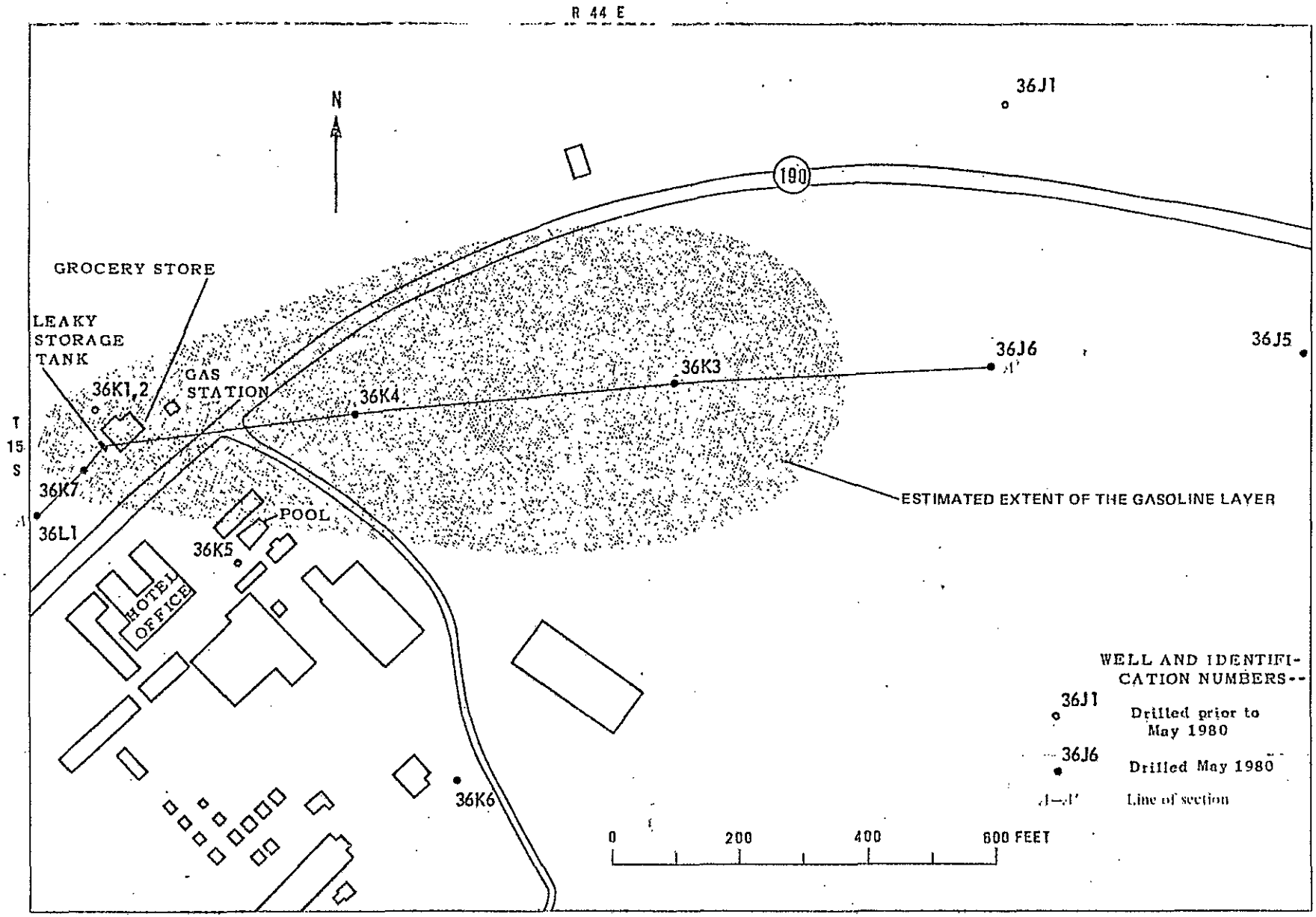


FIGURE 5.-- Estimated horizontal extent of the gasoline layer, based on test drilling, May 1980.

Exploratory Drilling and Subsurface Soil Sampling

Exploratory drilling was done using an 8-inch hollow-stem auger and a split spoon soil sampler. Each hole was drilled to a depth of 2 to 3 feet above the estimated water table at seven sites and to 11 feet above at site 15S/44E-36K7 (fig. 5), the closest well to the gasoline source. A step-by-step drilling and soil-sampling operation was then begun in 1-foot increments to a maximum depth of 3.5 feet below the estimated water table. The procedure used was to collect 1 foot of soil from below the auger bit, drill to the bottom of the sample interval, and then collect another sample below the bit. This was repeated until the final sampling depth was reached. Soil samples were collected in metal sleeve inserts to the sampler. This technique minimized evaporation of the gasoline from the soil following collection and during shipment to the laboratory, and minimized contamination from previous samples. The test holes were then drilled to completion between 6 and 11 feet below the water table and converted to monitor wells. Two-inch PVC blank and slotted casings were installed to the well's final depth, and the perforated sections were enveloped in a clean sand pack and set to intersect above and below the water table. This setting of the perforations insured that any gasoline above the water table would flow into the well.

Table 2 shows the details of all soil samples collected, concentrations of gasoline in the sample, and descriptions of gasoline presence. A strong gasoline odor was detected in soil samples collected from the first test hole, 15S/44E-36K4 (fig. 5), located about 400 feet east and down ground-water gradient from the gasoline source. The second hole, site 36K3, 900 feet east of the source, had a layer of gasoline possibly more than 1 foot in thickness, according to two consecutive 1-foot thick gasoline-saturated samples. Gasoline was poured from the top of the sampler into glass bottles and allowed to settle for several hours with no observable separation of gasoline and water. The layer thickness prompted the selection of a new site for the third test hole, site 36J5, about 1,900 feet east of the source. No field-detectable gasoline was discovered at the site. Site 36J6, 1,400 feet east of the source, was drilled next, but no gasoline was detected there. The downgradient extent of the gasoline layer was then judged to be between 900 and 1,400 feet from the source. Test holes 36K6 and 36K5, 750 feet and 250 feet southeast of the source, respectively, were drilled next but showed no field detection of gasoline. The last two test holes, 36K7 and 36L1, were drilled 50 feet and 150 feet southwest of the source, respectively. Undiluted gasoline was found in 36K7, but no field-detectable gasoline was found in 36L1.

TABLE 2. - Gasoline concentrations in soil and water samples, Stovepipe Wells Hotel area

[Description of gasoline presence: CGI, concentrated gasoline, ignitable; GW, gasoline and water; SGO, strong gas odor; FGO, faint gas odor; and NGO, no gas odor]

State well No. (fig. 5)	Date	Water level (feet below lsd)	Sample depth (feet below lsd)	Gasoline concentration (μg/L)	Description of gasoline presence
			Soil samples		
15S/44E-36J5	5-13-80	36.26	33.0-35.5	------	NGO
			35.5-36.0	(1)	NGO
			36.0-38.0	------	NGO
15S/44E-36J6	5-14-80	37.90	36.0-37.4	------	NGO
			37.4-37.9	(1)	NGO
			38.0-38.5	------	NGO
15S/44E-36K3	5-13-80	39.42	37.0-38.0	------	NGO
			38.1-38.5	(1)	NGO
			38.5-39.0	(1)	NGO
			39.0-40.0	------	CGI
			40.0-41.0	------	CGI
			41.0-42.0	------	GW
			42.0-43.0	------	SGO
15S/44E-36K4	5-13-80	40.53	35.0-36.0	------	NGO
			37.0-37.5	7.29×10^5	NGO
			37.5-38.0	------	NGO
			39.0-39.5	------	NGO
			39.5-40.0	------	SGO
			40.0-40.5	------	SGO
			41.1-41.6	------	NGO
			42.3-42.8	------	NGO
15S/44E-36K5	5-14-80	49.06	46.0-49.3	------	NGO
			49.3-49.8	1.12×10^4	NGO
			50.0-50.5	------	NGO
			50.5-51.0	1.57×10^4	NGO
			51.0-52.0	------	NGO
15S/44E-36K6	5-14-80	63.62	61.0-61.5	------	NGO
			61.5-62.0	(1)	NGO
			62.0-62.5	------	NGO
			62.5-63.0	(1)	NGO
			63.0-65.0	------	NGO

See footnote at end of table

TABLE 2. - Gasoline concentrations in soil and water samples, Stovepipe Wells Hotel area--continued

State well No. (fig. 5)	Date	Water level (feet below lsd)	Sample depth (feet below lsd)	Gasoline concentration (μg/L)	Description of gasoline presence
			Soil samples		
15S/44E-36K7	5-18-80	42.53	30.0-36.5	------	NGO
			36.5-37.0	(1)	NGO
			37.0-37.5	------	NGO
			37.5-38.0	(1)	NGO
			38.0-38.4	------	NGO
			38.4-38.9	(1)	NGO
			39.0-39.4	------	NGO
			39.4-39.9	(1)	NGO
			40.0-40.3	------	FGO
			40.3-40.8	(1)	FGO
			41.0-41.4	3.65×10^5	FGO
			41.4-41.9	------	FGO
			42.0-42.5	------	SGO
			42.5-43.0	2.71×10^6	SGO
			43.0-44.0	------	CGI
			44.0-45.0	------	FGO
15S/44E-36L1	5-15-80	45.07	42.0-44.5	------	NGO
			44.5-45.0	1.7×10^4	NGO
			45.0-45.5	(1)	NGO
			45.5-47.0	------	NGO
			Water sample		
15S/44E-36K1	5-30-79	37.56	37.56-38.56	undiluted gasoline[2]	

[1]Soil sample analyzed for hydrocarbons. No gasoline detected. Limit of detection is about 3×10^3 μg/L.

[2]Undiluted gasoline equals 6.72×10^8 μg/L.

Selected soil samples, primarily from zones where no field-detectable gasoline was found, were sent to the U.S. Geological Survey's Central Laboratory for analysis for hydrocarbon concentration. The samples, having been collected in metal sleeve inserts to the split-spoon sampler, were sealed with aluminum foil and tape, placed in sealable plastic bags, and refrigerated for shipment to the laboratory. A vial of gasoline was collected from test hole 15S/44E-36K3 for use as a laboratory standard. Hydrocarbons were extracted into acetone-hexane and then analyzed by gas chromatograph/mass spectrometry. Table 2 includes analyzed concentrations of gasoline found in the soil samples. Laboratory analyses detected gasoline in very low concentrations at two test sites where no field detection was made. Test holes 36K5 contained 1.12×10^4 μg/L and 36L1 contained 1.7×10^4 μg/L in samples collected at the water table. The concentrations are less than 0.002 percent hydrocarbons in water, and probably represent the diffusion of water-soluble components of gasoline into the aquifer, not the gasoline layer. The estimated horizontal spread of the gasoline layer was mapped (fig. 5) on the basis of field detection and sample analyses. Figure 6 shows a diagrammatic cross section of trace A-A' shown in figure 5. The purpose for the cross section is to graphically demonstrate how the subsurface zones are affected by the leaky gasoline storage tank. The size and boundaries of affected areas are not representative of the actual contamination at Stovepipe Wells Hotel but were meant for schematic purposes only.

Hydrologic Effects of the Gasoline Leak

No major impact on the area's water supply is expected from the gasoline leak unless a significant change occurs in the direction of ground-water movement. The direction of ground-water movement is the primary factor controlling the direction of movement of both the gasoline layer and the gasoline solutes in the aquifer water. Ground-water movement in the area is eastward (fig. 2); and supply wells 16S/44E-1C1 (reverse-osmosis supply well) and 15S/44E-36Q2 are about 0.4 mile south 5° west and south 23° east, respectively, of the gasoline leak site, not within the expected path of movement of the gasoline. The low hydrocarbon concentrations found in soil samples from test well 15S/44E-36K5 (table 2) indicate that the soluble gasoline components have migrated farther toward the supply wells than the gasoline layer has. Future monitoring of wells 15S/44E-36K5 and 15S/44E-36K6 will determine if either the gasoline layer or the solutes migrate farther toward those wells. In the unlikely event that low concentrations of gasoline solutes should reach the supply wells, their effects, such as disagreeable taste and odor, could be eliminated by a combination of aeration and activated charcoal filtration (Williams and Wilder, 1971, p. 51, 56).

Effects on phreatophytic plants would be of major concern if they were present in the area of the gasoline layer. The roots of these plants, in obtaining a water supply from below the water table, would penetrate through the gasoline layer. Fortunately, the nearest phreatophytes are located upgradient, about 0.3 mile northwest of the leak. Downgradient the nearest phreatophytes are located about 2 miles east of the leading edge of the gasoline layer as estimated in May 1980 (off fig. 5 to east). Future movement of the gasoline layer is not expected to extend that far. Monitoring of wells 15S/44E-36J5 and 36J6 would reveal any continued migration of the gasoline layer to the east. If gasoline extends past these wells, additional wells installed farther east would be required to continue the monitoring.

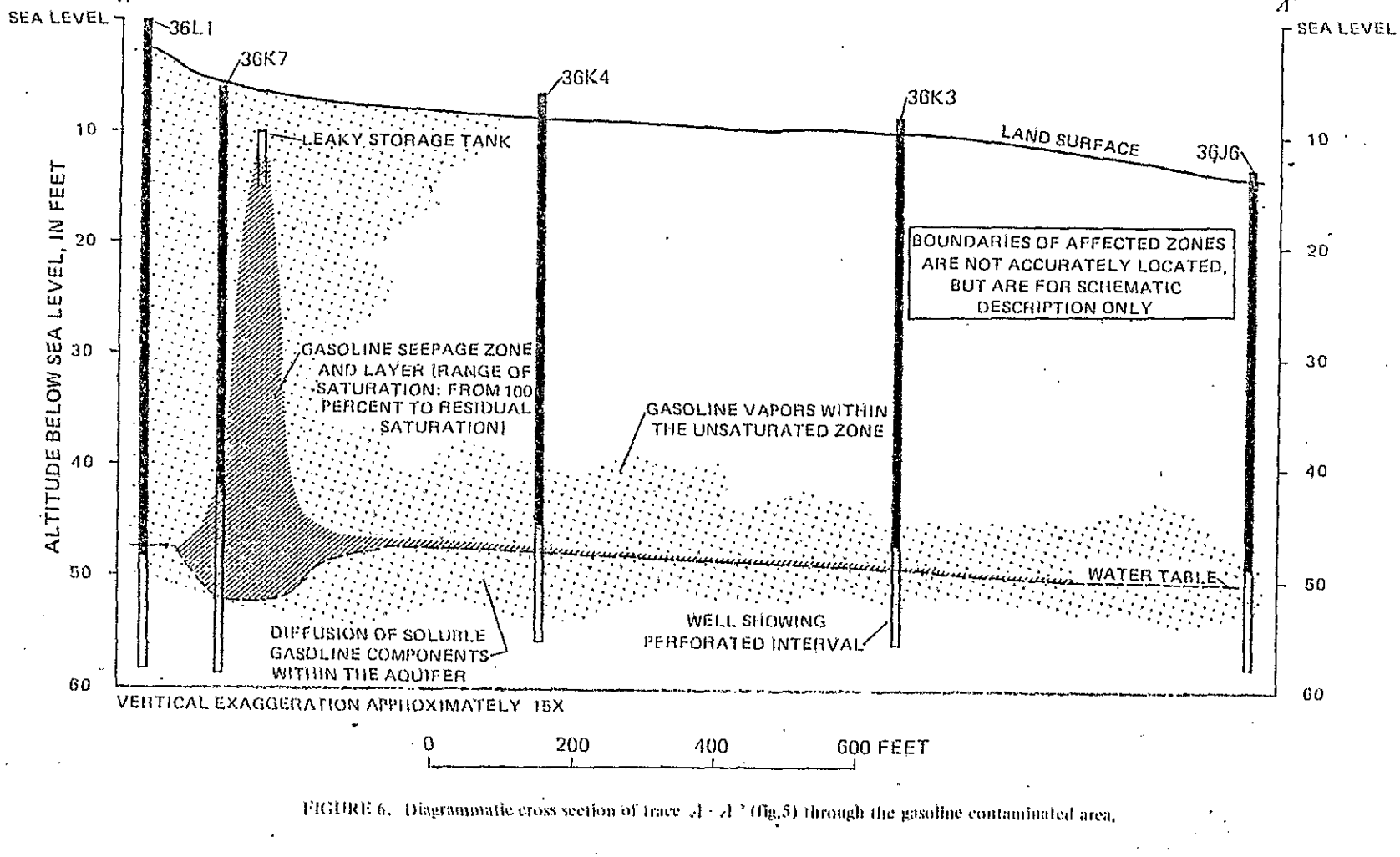


FIGURE 6. Diagrammatic cross section of trace A - A' (fig.5) through the gasoline contaminated area.

Xerophytic plants throughout the study area obtain water from soil moisture above the water table and will therefore not come in contact with the gasoline layer. What effect the gasoline vapors will have on these plants as the vapors continue to diffuse through the unsaturated zone is not known. No effects have been observed so far.

Complete biodegradation and evaporation of the gasoline will probably occur within 15 years of the leak. This would limit the duration of possible effects on both the water supply and the vegetation.

SUMMARY AND CONCLUSIONS

Following the detection of gasoline in an unused well at Stovepipe Wells Hotel, Calif., the horizontal extent of a gasoline layer overlying the water table was delineated by exploratory drilling and split-spoon soil sampling. The gasoline layer was found to extend between 900 and 1,400 feet downgradient (east) and between 50 and 150 feet upgradient from the leak source. Traces of hydrocarbons resulting from the diffusion of the slightly soluble gasoline components were also found in the aquifer 150 feet upgradient and 250 feet normal to the direction of ground-water movement (south) from the leak. Future monitoring of local wells, especially in the direction of the supply wells (south), will be necessary to determine the extent of continued movement of both the gasoline layer and the slightly soluble gasoline components within the aquifer.

Because of the present direction of ground-water movement in the area, no effects on the local water supply or phreatophytes are expected. The supply wells are about 0.4 mile south of the leak site, nearly perpendicular to the direction of ground-water movement and the primary direction of gasoline movement in the area. Should traces of gasoline solutes reach the supply wells, aeration and activated charcoal filtration of the water could alleviate adverse effects on taste and odor. The nearest phreatophytes are upgradient, 0.3 mile northwest of the leak site. Phreatophytes downgradient are about 2 miles east of the leading edge of the gasoline layer, as estimated in May 1980, farther from the leak site than the layer is ever expected to extend.

The potential effects on xerophytes of the diffusion of gasoline vapors within the unsaturated zone is not known. Xerophytes grow throughout the study area, but so far no effects from the gasoline leak have been noticed.

Complete evaporation and biodegradation of the gasoline above the water table will probably occur within 15 years of the leak. This would limit the duration of its possible adverse effects on both the water supply and the vegetation.

SELECTED REFERENCES

Dietz, D. N., 1971, Pollution of a permeable strata by oil components, in Hepple, Peter, ed., Water pollution by oil: Amsterdam, Elsevier, p. 128-142.

Freeze, R. A., and Cherry, J. A., 1979, Groundwater: Englewood Cliffs, New Jersey, Prentice Hall, Inc., 604 p.

Fried, J. J., Muntzer P., and Zilliox, L., 1979, Ground-water pollution by transfer of oil hydrocarbons: Ground Water, v. 17, no. 6, p. 586-594.

Holzer, T. L., 1976, Application of ground-water flow theory to a subsurface oil spill: Ground Water, v. 14, no. 3, p. 138-145.

Hunt, C. B., 1966, Plant ecology of Death Valley, California, with a section on Distribution of fungi and algae, by C. B. Hunt and L. W. Durrell: U.S. Geological Survey Professional Paper 509, 68 p.

Hunt, C. B., Robinson, T. W., Bowles, W. A., and Washburn, A. L., 1966, Hydrologic basin, Death Valley, California: U.S. Geological Survey Professional Paper 494-B, 138 p.

Lamb, C. E., and Downing, D. J., 1979, Hydrologic data, 1974-77, Stovepipe Wells Hotel area, Death Valley National Monument, Inyo County, California: U.S. Geological Survey Open-File Report 79-203, 19 p.

Lohman, S. W., 1972, Ground-water hydraulics: U.S. Geological Survey Professional Paper 708, 69 p.

McKee, J. E., Laverty, F. B., and Hertel, R. M., 1972, Gasoline in ground water: Water Pollution Control Federation Journal, v. 44, no. 2, p. 293-302.

Meyer, C. B., 1951, Water resources of California: [California] State Water Resources Board Bulletin no. 1, pl. 3.

Miller, G. A., 1970, Ground water in Death Valley, California, in Geologic guide to the Death Valley area, California: Sacramento Geological Society Annual Field Trip Guidebook, p. 33-39.

_____1977, Appraisal of the water resources of Death Valley, California-Nevada: U.S. Geological Survey Open-File Report 77-728, 68 p.

Moyle, W. R., Jr., 1974, Geohydrologic map of southern California: Menlo Park, Calif., U.S. Geological Survey Water-Resources Investigations 48-73, map.

National Academy of Sciences, National Academy of Engineering, 1973 [1974], Water quality criteria 1972: U.S. Environmental Protection Agency, EPA R3 73 033, 594 p.

National Oceanic and Atmospheric Administration, Environmental Data Service, 1978, Annual summary: 1978, v. 82, no. 13, 27 p.

_____1969-78, Climatological data, v. 73-82.

Robinson, T. W., 1958, Phreatophytes: U.S. Geological Survey Water-Supply Paper 1423, 84 p.

Schwille, Friedrich, 1967, Petroleum contamination of the subsoil--A hydrological problem, in Joint problems of oil and water industries: Amsterdam, Elsevier, p. 23-53.

U.S. Environmental Protection Agency, 1976 [1978], Quality criteria for water: U.S. Government Printing office, 256 p.

U.S. Geological Survey, 1978, Water resources data for California--Volume 1, Colorado River basin, southern Great Basin from Mexican border to Mono Lake basin, and Pacific slope basins from Tijuana River to Santa Maria River: U.S. Geological Survey Water-Data Report CA 78-1, 628 p.

Van Dam, J., 1967, The migration of hydrocarbons in a water-bearing stratum, in Joint problems of oil and water industries: Amsterdam, Elsevier, p. 55-96.

Williams, D. E., and Wilder, D. G., 1971, Gasoline pollution of a ground-water reservoir--A case history: Ground Water, v. 9, no. 6, p. 50-56.

20. Burkland, P. W. et al. "Method to Avoid Ground Water Mixing Between Two Aquifers During Drilling and Well Completion Procedures," Ground Water Monitoring Review., Fall 1983, pp. 48-45

METHOD TO AVOID GROUND-WATER MIXING BETWEEN TWO AQUIFERS DURING DRILLING AND WELL COMPLETION PROCEDURES

The authors describe a new cost-effective approach utilizing temporarily placed casing.

by Patrick W. Burklund and Ellen Raber

Introduction

Many hazardous waste landfill sites are underlain by multiple aquifers isolated from one another by layers of fairly impermeable bedrock (possible confining beds). In cases where aquifer contamination is believed to have occurred, it is important to know the actual distribution of contamination in both a vertical and lateral sense. To do this, one must be able to effectively isolate and sample the ground water from within the individual aquifers. This involves avoiding any mixing between the suspected contaminated aquifer and other, it is hoped, uncontaminated aquifer(s) during drilling and well completion procedures. This is important for two main reasons: (1) to avoid creating a pathway for the spread of contaminants, and (2) to be able to determine whether contamination has actually spread to deeper aquifers. Also, it is very time consuming, costly and sometimes impossible to remove all contamination incurred as a result of temporary aquifer interconnection.

An alternative procedure which could be employed to avoid ground-water mixing involves the use of a multi-cased well designed to seal off the upper contaminated zone before deeper drilling is performed (Edwards et al. 1983). This is achieved by drilling a relatively large-diameter borehole, inserting a permanent steel casing sealed at the bottom with grout, and then drilling through the grout to the lower level. This type of approach, although effective, requires an individual monitoring well for each specific zone to be sampled. Additionally, costs are increased due to the expense of the permanent steel casing required for each well.

Another approach would be to drill a larger diameter borehole for packer emplacements to isolate the individual aquifers. Problems associated with this method are packer blowouts and formation water leakage past the packer bladders. Expense may be prohibitive due to the costs of packers and associated equipment for installation.

Where the water table is relatively deep, the most cost-effective approach to ground-water monitoring is to install multi-level sampling wells. This article reports a method that has been developed which avoids mixing of ground water between two different aquifers (water-table and underlying confined) within a single borehole during the entire drilling and well completion operation. This eliminates problems associated with potential cross-contamination of ground water between aquifers, and allows valid multi-level ground-water sampling. The method assumes that some knowledge of the local hydrogeologic conditions already exists. However, it does allow for the identification of previously undetected perched aquifer conditions.

The basic approach utilizes a combination of air-rotary and continuous wire-line core drilling, although other drilling methods may be employed. Both aquifers are isolated by the use of temporarily placed casing while instrumentation is installed. Water sampling devices and pressure transducers are then permanently emplaced at the appropriate depths: first in the lower aquifer and then in the upper aquifer. Each set of instrumentation is isolated from the other using a combination of bentonite seals and cement grout. If desired, a standpipe piezometer may be placed in the uppermost aquifer. Although not discussed here, more than two aquifers could be isolated by this method. This would involve several temporarily placed casings (one inside the other) which would be installed in the same manner and removed sequentially (from the bottom up). However, this would require drilling a much larger diameter initial borehole.

An illustrated step-by-step explanation of this approach is presented. Additionally, a cost comparison is made between this approach and the alternative two-borehole method. The total depth of boreholes drilled ranged from 200 to 400 feet. This method of completion was used in three boreholes and was successful in two.

It has proven effective and relatively simple except for some problems encountered due to very unstable borehole conditions in a lower aquifer.

Description of the Method

Drilling Procedure

Boreholes were drilled using an Ingersoll-Rand TH-60 Cone Drill, although other drilling equipment should be just as effective. This is a very versatile piece of equipment that permits drilling with high pressure air (750 CFM at 250 psi) as well as with water and/or mud and is capable of both rotary drilling and continuous coring. Prior to any drilling activities, the drill rig and all drilling equipment were thoroughly cleaned by steam cleaning and washing. The equipment included hollow-stem augers, drill steel, casing, core rods, core barrels, tri-cone drill bits and any other associated equipment that would go downhole. This cleaning process was repeated after each borehole was drilled and before moving to the next location. Although time consuming, this effort was necessary to minimize the potential for introducing contamination into the subsurface. Additionally, special precautions were employed to minimize the use of drilling lubricants, since these are sometimes used in large quantities and they may contain many of the priority pollutants to be monitored.

Depending on the chemical constituents to be monitored, an assessment regarding the best drilling approach should be made. Additives or proprietary drilling muds and/or foams have been found to cause contamination problems in previous investigations as they remain in the borehole despite vigorous attempts to flush the well clean (Absalon and Starr 1980). Therefore, for our studies, the methods employed were augering, rotary and wire-line core drilling using air or water only. There are, however, some problems which may be encountered when drilling with high-pressure air. First, the possibility of entrained oil and/or lubricant from the drill rig air compressor exists, so this must be monitored. The equipment used in this investigation was relatively new and we did not experience any such problems. Second, one must expect that substantial aeration will occur downhole, especially in the uppermost water-bearing formation. Depending on the yield of the aquifer, it may take several months for certain parameters to reach steady-state equilibrium values. This will also be true when drilling with water if injection is into a more reducing environment. However, the amount of area affected by water-injection will usually be less than with air injection.

For this investigation, boreholes were started in unconsolidated material by using an 8.0-inch continuous flight, hollow-stem auger to advance holes and obtain soil samples. Once augering through the unconsolidated materials was completed, drilling was continued by using a combination of air rotary drilling and HQ wire-line core drilling. Rotary drilling with air and coring using air was successfully accomplished to depths of between 60 and 100 feet below ground surface in both unconsolidated and indurated materials. In this manner, the borehole was advanced down through the first aquifer into the confining bed.

After the top of the confining bed beneath the water-table aquifer was reached and identified, the wire-line core tools were removed and the borehole was then reamed to a 6.75-inch diameter down to the confining bed using a standard tri-cone roller bit (Figure 1). Geophysical logs were run in the borehole at this time. In our investigations, these included natural gamma, gamma-gamma density, self-potential, resistivity and

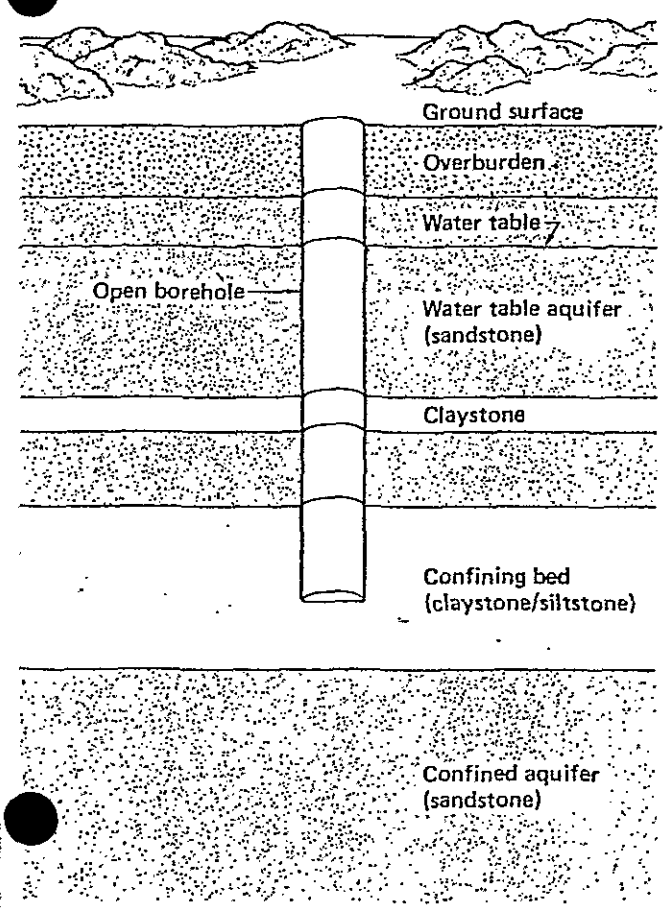


Figure 1. Borehole drilled to confining bed

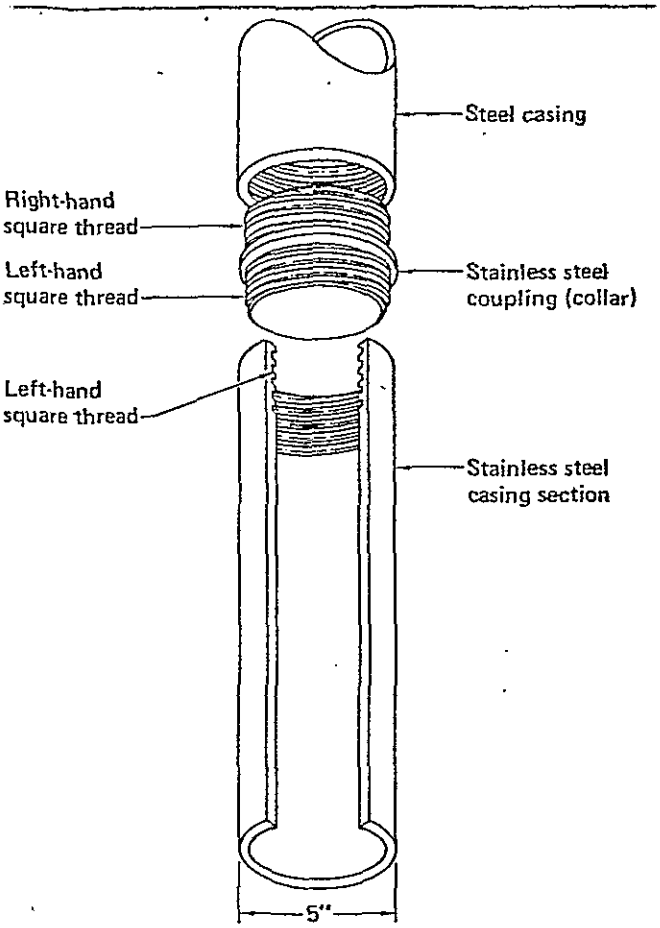


Figure 2. Right-hand/left-hand square thread casing

caliper logs. Temporary casing was then set to within 6 inches of the bottom of the borehole in the manner described below.

The lowermost casing section consisted of flush-joint stainless steel with a left-hand, square thread. It was connected to a right-hand square thread, flush-joint carbon steel casing by a stainless steel coupling threaded right-hand at the upper end and left-hand at the lower end. An illustration of this casing design is shown in Figure 2. The stainless steel casing section is the same inside and outside diameter as the carbon steel casing and 8 feet in length including the right-hand thread to left-hand thread coupling. Thin wall casing was selected in order to maximize working room inside the casing and to minimize borehole diameter. Flush joint casing was used to facilitate casing removal from the borehole. It is possible that casing couplings could cause problems during casing removal, if borehole swelling or borehole collapse occurred during the drilling or completion of the lower aquifer. Steel casing is recommended for this method rather than PVC since PVC casing could be broken by the drill rods while drilling inside of it (i.e., by rod whip or chatter).

The lower stainless steel casing section (threaded left-hand) was hand-tightened to the left-hand threaded end of the coupling. The coupling and stainless steel casing section were then attached to the carbon steel casing and the coupling was wrench-tightened to the temporary steel casing. All of the remaining casing sections were then wrench-tightened as the casing was lowered down the borehole (Figure 3). After the casing was in place, a quick-setting expansive grout plug (Cal-seal, a trademark of Halliburton Corp.) was poured via a tremie pipe into the borehole and allowed to circulate both inside and outside the stainless steel casing section. The amount of grout was calculated to encase only 6 feet of the 8-foot casing section (Figure 4). The grout was allowed to set two to four hours.

Before drilling was resumed, all standing water in the casing was removed. The well was then allowed to stand for at least one hour to determine whether there were any leaks in the casing or the grout seal through which formation water could enter the borehole. Once it was determined that there were no leaks in either the casing or the grout seal, drilling resumed. Wire-line core drilling was resumed by drilling through the grout plug and out the bottom of the casing through the confining layer into the lower aquifer to total depth (Figure 5). When total depth was reached, drilling tools were removed from the borehole and geophysical logs were run in the bottom section of the hole. By using the stratigraphic information obtained from the geophysical logs and geological cores, instrument locations were determined.

Well Completion Procedure

Most available instruments may be used in conjunction with this method, including bundle-type piezometers and various multi-level sampling devices. Borehole sizes may vary depending on the instrument selected. The ground-water sampling devices used in this investigation, which was primarily concerned with toxic inorganic constituents, were gas-drive type (Barcad, a trademark of Barcad Systems Inc.) samplers. In addition, vibrating-wire type strain gauge transducers were placed at each sampling point to determine piezometric pressure. Each transducer was attached to the tubing just above the sampler. The entire assembly

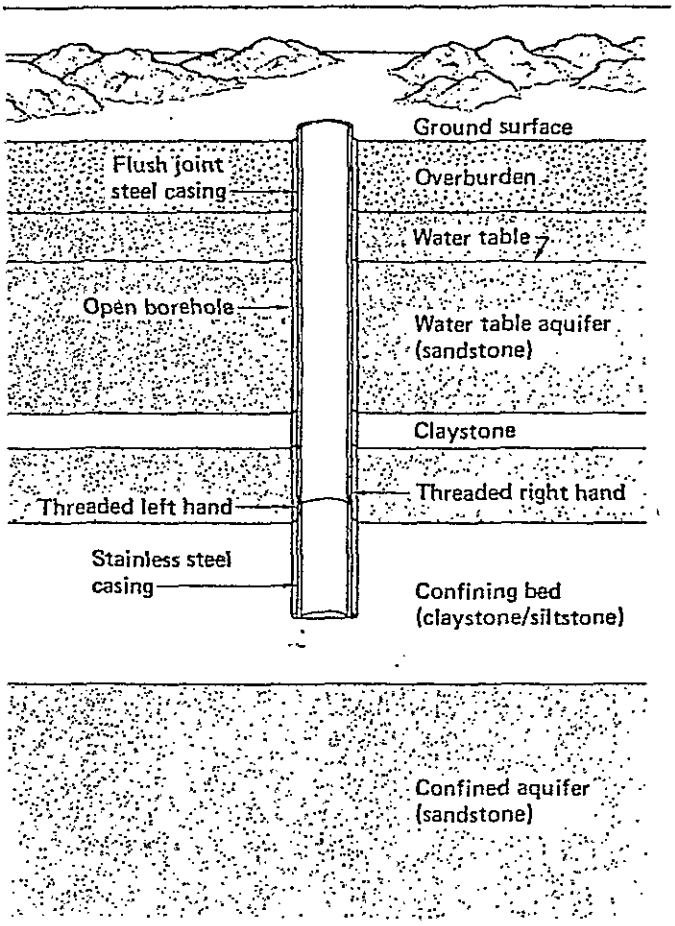


Figure 3. Temporary casing set in open borehole drilled to confining layer

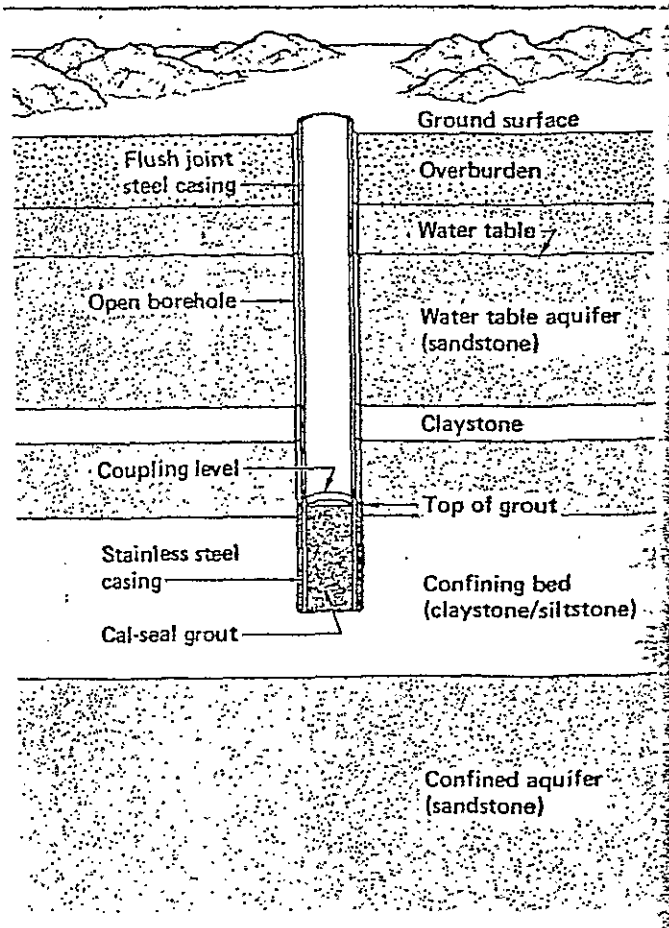


Figure 4. Grouted lower stainless steel casing joint

was then placed in a polypropylene filter "sock" and backfilled with No. 3 sand (Figure 6). All instrumentation was tested on the surface for proper operation before being installed in the borehole.

Well completion of the lower confined aquifer was ready to begin. A No. 3 sand footing was placed on the bottom of the borehole through the tremie pipe. The first sampler-transducer assembly was then lowered down the borehole and landed on the sand footing. Once the sampler-transducer assembly was in place, No. 3 sand was placed in the borehole through the tremie pipe to completely cover the unit. It should be noted that all instrument and backfill material locations were measured with a weighted tag line and that all stemming materials were placed with the use of tremie pipe. The sand quantities varied based on the vertical length of the borehole to be sampled. After the sampler-transducer assembly was completely covered with the No. 3 sand, a fine sand "cap" was placed on top of the No. 3 sand. No. 0 sand was used in this case; 2 feet was found to be sufficient. The purpose of the fine sand is to prevent bentonite and grout intrusion into the No. 3 sandpack. With the No. 0 fine sand "cap" in place, the area above the sampler was then sealed with a 5-foot bentonite plug. This was accomplished by washing ⅜-inch diameter bentonite pellets down the tremie pipe. The borehole was then grouted to 2 feet below the next sampler-transducer location and the above procedure was repeated.

After the appropriate number of sampler-transducer units were installed, the borehole was grouted back into the stainless steel casing section, sealing off the underlying aquifer(s) (Figure 7). After the grout had cured, any standing water in the casing was removed and the borehole was monitored for at least one hour to determine if there was any leakage into the temporary casing from the lower formation. When it had been determined that there were no leaks, the temporary casing was removed from the borehole. Removing the casing was accomplished by turning the entire casing string to the right (clockwise) and unscrewing from the left-hand threaded, stainless steel casing joint. The carbon steel casing sections were then removed from the borehole (Figure 8).

The upper part of the borehole was then open to the formation and could be instrumented. The well completion in the upper aquifer was similar to the lower aquifer except that a standpipe piezometer was installed as the uppermost (water-table) aquifer sampling point. The standpipe piezometer was constructed of 3 ½-inch diameter PVC with square threads and flush joints. No glues or solvents were used during piezometer assembly to avoid problems associated with degradation and leaching of contaminants from organic coupling cements (Baker 1980). The slotted sections of casing were typically 5-foot lengths with 0.020 slot width; 15 feet of slotted section was commonly used. The slotted section was packed with the No. 3 sand over its entire length. A 2-foot No. 0 sand "cap" was placed on top of the No. 3 sand to prevent bentonite or grout intrusion into the No. 3 sand pack. The borehole was then grouted to the surface. The subsurface portion of the monitoring well was now complete (Figure 9).

The surface completions for all multiple-completion

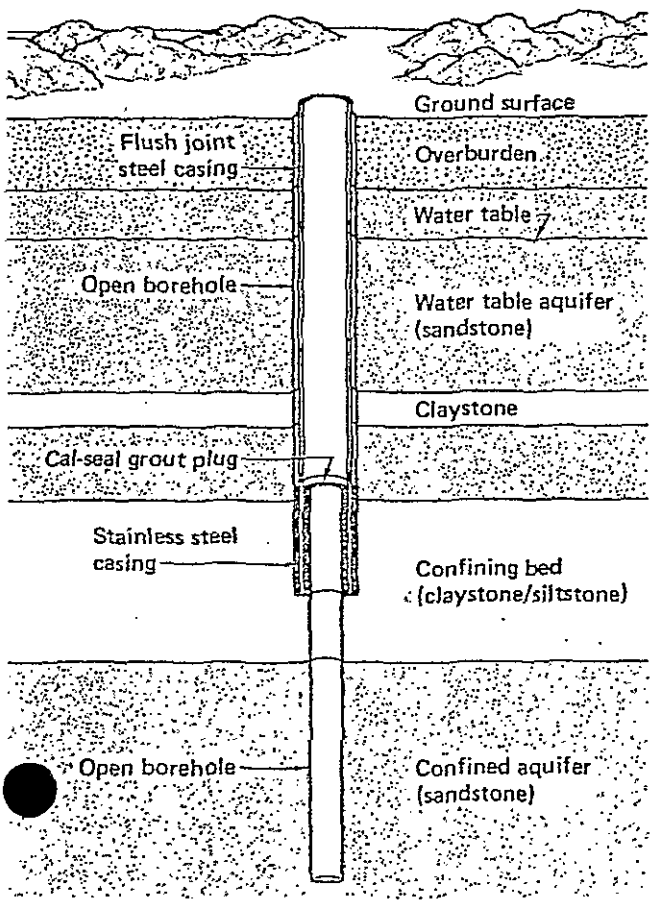


Figure 5. Borehole drilled to underlying confined aquifer

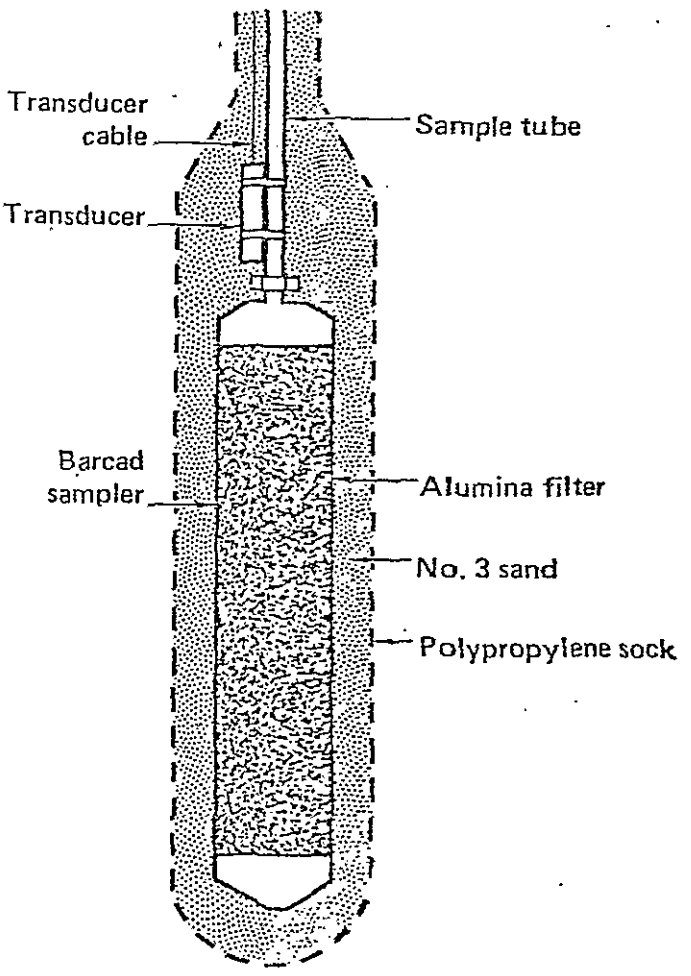


Figure 6. Instrumentation package

wells consisted of labeled, weather-tight enclosures mounted on steel support legs. The support legs were anchored into the ground with concrete a few feet from the well-head. The sampler tubes and pressure transducer cables were passed through a flexible conduit which serves as protection. The conduit is grouted to the top of the well and attached to the enclosure with weather-proof seals. The sampler tubes are plumbed to a prefabricated manifold mounted in the enclosure. These tubes are labeled with aluminum tags and kept inside the enclosure until used, protecting them from weather and vandalism. The surface completion is illustrated in Figures 10 and 11.

Field Problems Encountered

The procedure to isolate ground-water flow between two aquifers was relatively trouble free. However, there were a few problems encountered. As previously stated, this procedure was used in three boreholes with two successful completions.

Rotary drilling with air and coring using air was usually successfully accomplished. However, once the water table was encountered, wash boring was usually necessary to prevent mud collar buildup on the drill rods. This was due to the high clay content of the formations encountered at the project site. The main problem was associated with unstable borehole conditions below the temporary casing. Once the borehole was drilled to total depth and the wire-line core rods were removed to install instrumentation, the uncased lower portion of the borehole would often collapse.

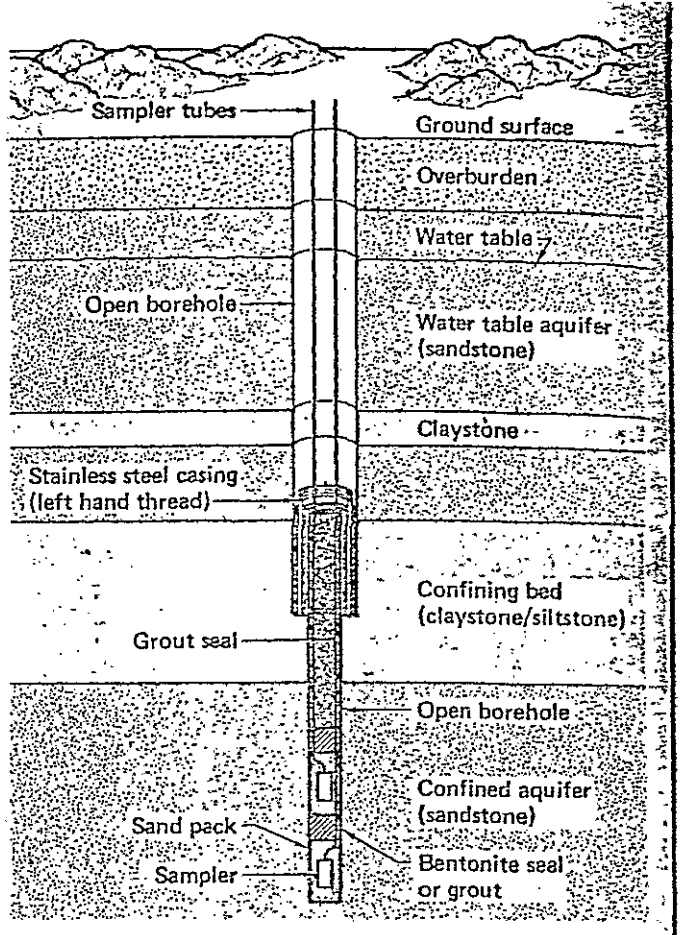


Figure 8. Steel casing sections removed from borehole

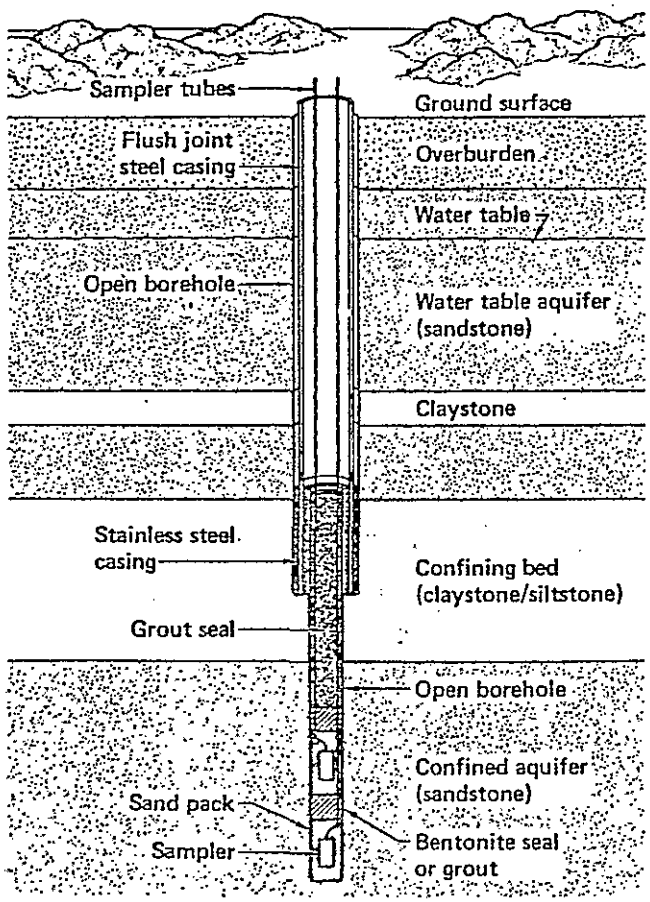


Figure 7. Instrumentation placed in lower aquifer

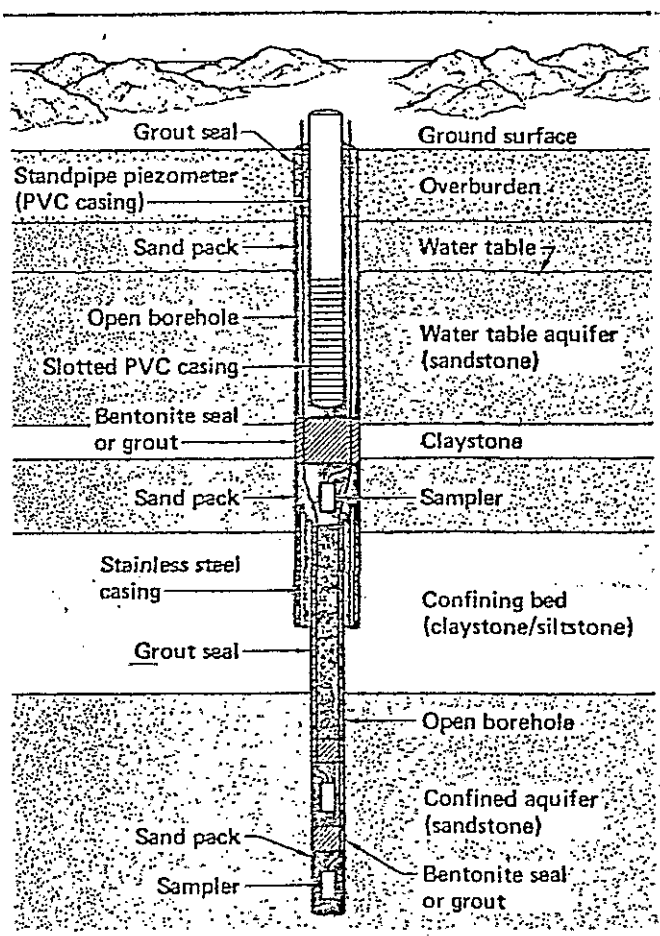


Figure 9. Completed monitoring well

When collapse occurred, the borehole was re-entered with the wire-line core drilling rods (no core bit) by using water injection (low flow rate) to "wash" the rods down to the bottom of the borehole. After reaching total depth with the wire-line drill rods, the transducer-sampler unit and sandpack were emplaced through the drill rods. The rods were then carefully pulled back, using a light water injection to avoid binding. By completing the borehole in this manner, using a tag line to measure borehole depth, the bottom part of the borehole was instrumented and stemming materials emplaced. Tag-line measurements are imperative to verify satisfactory placement of backfill materials and to detect collapse following wire-line rod withdrawal. If it is suspected that unstable borehole conditions exist, it may be desirable to initially plan to complete through the rods. Wire-line coring in unconsolidated materials is an effective way to advance an unstable borehole. Although core recovery was minimal at times, the borehole is protected from collapse while drilling, since the rods always remain in the hole.

A more critical problem arises when the borehole collapses just below the confining layer, shortly after the grout has been poured. This displaces the grout plug up into the temporary carbon steel casing. This was the case with the one unsuccessful completion. After the grout had cured (two to four hours) and the temporary casing was removed, the sampler-transducer tubes, which were grouted into the temporary casing were pulled apart. Therefore, there was no way to salvage the lower instrumented portion of the borehole.

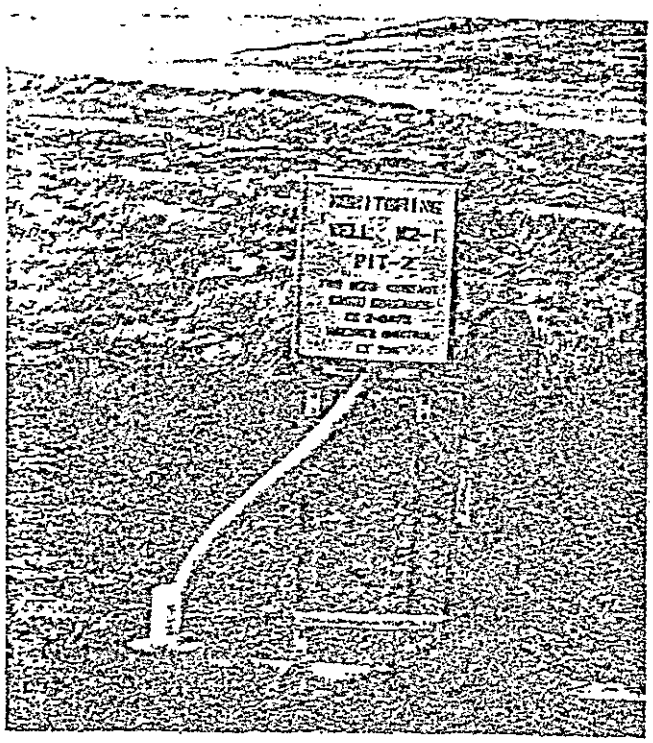


Figure 10. Typical wellhead completion

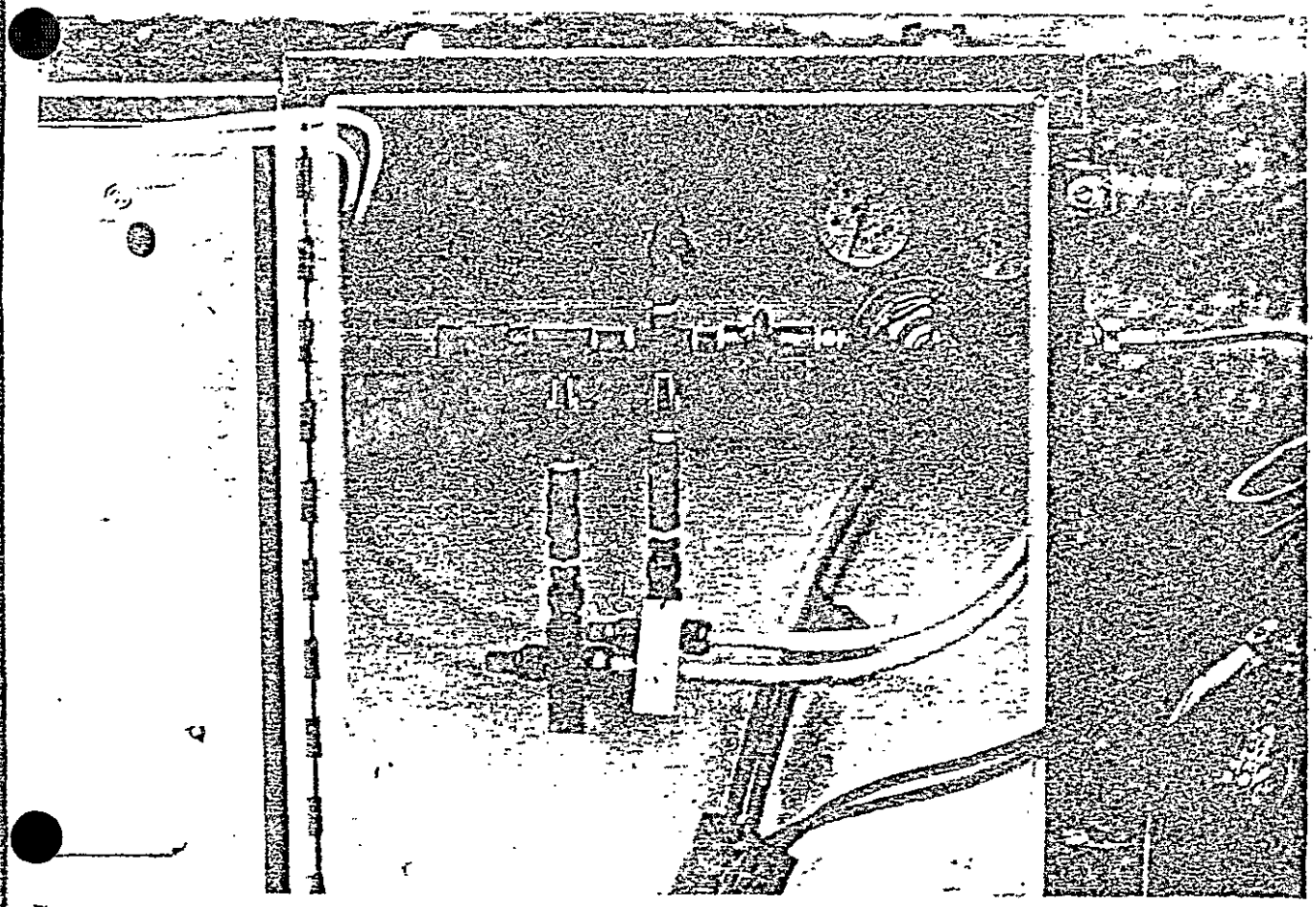


Figure 11. Closeup of wellhead enclosure

Improvements

It is suggested that the stainless steel casing section be longer in well completions of this type. Based upon this study, we recommend that it be at least 12 feet in length so that a good seal is ensured and grout quantities do not have to be as precise. With a 12-foot casing section and a 6- to 8-foot grout stage, this would allow more room in the stainless steel casing for the grout. This is important in the event that the bottom portion of the borehole collapses and grout is displaced upwards or grout quantities are slightly miscalculated.

Cost Comparison

A comparison was made between this method and an alternative approach to isolate two separate aquifers. This comparison is based on a 400-foot deep borehole. To accomplish the same sampling strategy discussed in this article, without the use of the retrievable casing method, two individual boreholes would need to be drilled. One well would be similar to the multi-cased well design described by Edwards et al. (1983). Figure 12 illustrates the two-borehole approach which can be compared directly to the single-borehole method illustrated in Figure 9. The two boreholes necessary would be as follows: One borehole is drilled to 180 feet total depth to sample the water-table aquifer. The second borehole is then drilled to 400 feet total depth to sample the confined aquifer only, isolating it from the water-table aquifer. This is accomplished by drilling through the water-table aquifer into the confining bed above the confined aquifer. A permanent casing must then be set into the confining bed at the base of the water-table aquifer and grouted in place. Then drilling would continue through the bottom of the permanent casing into the lower confined aquifer, which could then be instrumented.

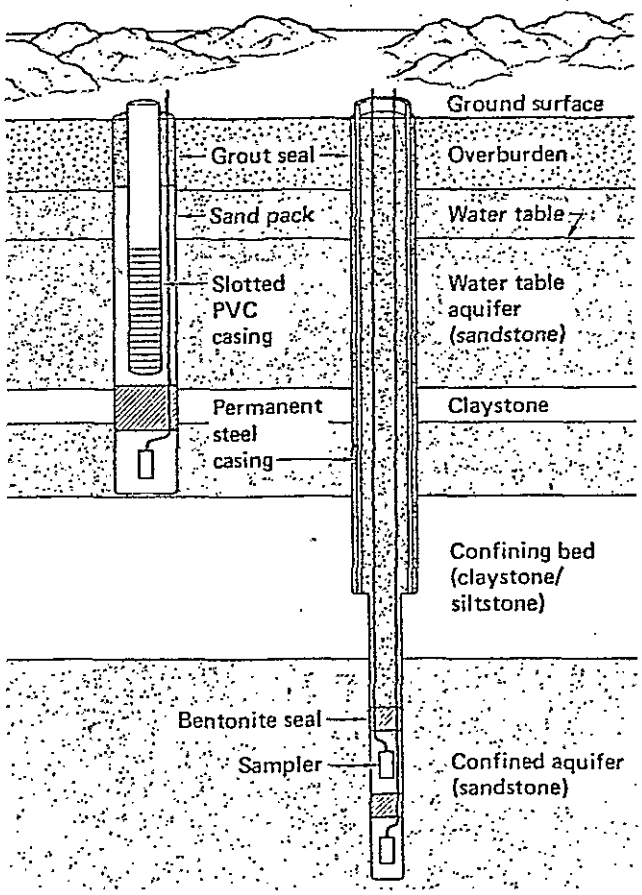


Figure 12. Two borehole completion method

The dollar values in Table 1 are based on the actual costs of materials and services, except where otherwise stated. The labor charges are estimated at $35. per person per hour and may need to be adjusted depending on actual labor costs. As Table 1 illustrates, the single borehole method is definitely more cost-effective, representing a savings of approximately 30 percent.

	Single borehole method*	Two borehole method**
Total drilling cost ($27.60/foot includes drillers labor)	11,040	16,560
Sampler/transducer	3,662	3,662
Completion materials	2,401	4,134
Surface completion	581	1,163
Labor costs ($35.00 per person per hour)	5,250	7,875
Total cost	$22,935	$33,394

* Based on 400 ft deep borehole
** Based on one borehole at 180 ft and the second borehole at 400 ft

Table 1. Cost Comparisons

Conclusions

This borehole drilling and completion method has proven to be very useful in instrumenting relatively deep water-table aquifers with underlying confined aquifers. The method avoids mixing of ground water between two different aquifers within a single borehole, eliminating potential cross-contamination of aquifers and biasing of sampling points. It is a cost-effective approach which does not require the drilling and completing of two separate monitoring wells. Also, since this method can be accomplished in a relatively small borehole, overall drilling costs are minimized. With good field planning, this can be an extremely useful monitoring well completion method for hazardous waste landfill investigations.

Acknowledgment

The authors would like to thank both D.W. Carpenter, D.G. Wilder, and D.O. Emerson of Lawrence Livermore National Laboratory for their contributions in the initial planning of this method and for their technical review of this document.

References

Absalon, J.R. and R.S. Starr. 1980. Practical aspects of ground-water monitoring at existing disposal sites. U.S. EPA Conference on Management of Uncontrolled Hazardous Waste Sites. October 15-17. Washington. D.C.

Baker, J. 1980. Field methods in contaminant hydrogeology. University of Waterloo, Canada. Short course notes.

Edwards, R.E., N.A. Speed and D.E. Verwoert. February 21, 1983. Cleanup of chemically contaminated sites. Chemical Engineering, pp. 73-81.

Biographical Sketches

Patrick W. Burklund joined the Lawrence Livermore National Laboratory in 1977 and is a senior technologist assigned to the Nuclear Test Engineering Division. As lead technician for many geotech-

nical field projects, he has substantial experience on many nuclear waste and energy-related projects. His current interests are design, development and installation of unique downhole instrumentation for geotechnical subsurface investigations, including ground-water monitoring, subsidence, slope stability and large-diameter hole drilling.

Ellen Raber received an M.S. in geochemistry/geology from the University of Massachusetts, Amherst in 1978. She joined the Lawrence Livermore National Laboratory, University of California, in 1978 and is currently a project leader involved with geochemical and hydrogeological site investigations. Her primary research activities are in environmental and energy-related geochemistry and include problems relating to nuclear waste isolation, geothermal and hazardous waste site investigations.

Disclaimer

This work was performed under the auspices of the U.S. Department of Energy under contract number W-7405-ENG-48. Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the Department of Energy to the exclusion of others that may be suitable.

21. California Hazardous Waste Control Law. Chapter 6.5 of Division 20 of California Health and Safety Code, commencing with Section 25100

West's

ANNOTATED CALIFORNIA CODES

HEALTH AND SAFETY CODE

Sections 18200 to 25699

Official California Health and Safety Code Classification

ST. PAUL, MINN.
WEST PUBLISHING CO.

Library References

Health and Environment ⇐37.
C.J.S. Health and Environment §§ 48, 113, 114, 155.

Chapter 6.5

HAZARDOUS WASTE CONTROL

Article		Section
1.	Findings and Declarations	25100
2.	Definitions	25110
3.	Hazardous Waste Technical Advisory Committee	25130
4.	Listings	25140
4.5.	State Regulation of Existing Hazardous Waste Facilities	25146
5.	Standards	25150
5.5.	Coordination with Federal Acts	25159
6.	Transportation	25160
6.5.	Hazardous Waste Haulers	25167.1
7.	Treatment, Recycling, and Disposal Technology	25170
8.	Enforcement	25180
8.5.	Hazardous Waste Testing Laboratories	25198
9.	Permitting of Facilities	25200
9.5.	Hazardous Waste Management Council [Repealed]	25206
10.	Prohibited Chemicals	25210
11.	Hazardous Waste Disposal Land Use	25220
12.	Financial Responsibility and Closure and Maintenance of Facilities	25245

Chapter 6.5 was added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973.

Law Review Commentaries

Emergency environmental health protection in California. (1982) 16 U.S.F.L.Rev. 539.

Article 1

FINDINGS AND DECLARATIONS

Section
25100. Legislative findings.
25101. Legislative declaration.
25105. Enforcement authority of state and local agencies.

Article 1 was added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973.

Cross References

Hazardous Substances Act, see § 28740 et seq.
Nejedly-Z'berg-Dills Solid Waste Management and Resource Recovery Act of 1972, see Government Code § 66700 et seq.
Radiation Control Law, see § 25800 et seq.
Radioactivity control, see § 25600 et seq.

§ 25100. Legislative findings

The Legislature finds that:

(a) Increasing quantities of hazardous wastes are being generated in the state, for which the generators of the hazardous waste must provide safe disposal.

(b) Long-term threats to public health and to air and water quality are posed by the landfill disposal of many types of untreated hazardous wastes and by the inappropriate handling, storage, use, and disposal of hazardous wastes.

(c) Extensive technology exists for the safe treatment, neutralization, and destruction of many types of hazardous wastes prior to disposal.

(d) Numerous opportunities exist to reduce the amount of hazardous waste generated in the state and to conserve resources through the application of existing source reduction and recycling technology.

(e) The people of the state face immense costs as a result of improper hazardous waste handling and disposal practices.

(Added by Stats.1982, c. 89, § 2, eff. March 2, 1982.)

Historical Note

Former § 25100, added by Stats.1972, c. 1236, p. 2388, § 1, amended by Stats.1977, c. 1039, p. 3142, § 1.3, relating to similar subject matter, was repealed by Stats.1982, c. 89, § 1, eff. March 2, 1982.

Derivation: Former § 25100, added by Stats.1972, c. 1236, p. 2388, § 1, amended by Stats.1977, c. 1039, p. 3142, § 1.3.

Cross References

Z'berg-Kapiloff Solid Waste Control Act of 1976, enforcement agency, see Government Code § 66796.

Law Review Commentaries

Hazardous waste materials: legislative review. (1973) 4 Pacific L.J. 508.

Health and Environme
C.J.S. Health and Env
seq., 106 et seq., 131

1. In general
The Hazardous Waste
section et seq.) which be
July 1, 1973, preempts

§ 25101. Legisla

The Legislature t

(a) In order to pr
conserve natural r
regulations and inc
ous waste employ
handling, treatment,
prior to disposal.

(b) In order to ass
responsibility for th
establish the Hazar

(c) The Legislatur
of this state and pa
are treated and disp
people injured or da
sary that the Hazar
to Section 25206, m
ance and mechanis
required by subdivis

(d) It is in the be
the State of Californ
to administer a sta
program pursuant t
Resource Conserva
Therefore, it is the
those powers necess
zation for the state
ments of Section 30
and Recovery Act
program in lieu of t

(Added by Stats.1982;

[1] 42 U.S.C.A. § 6926.

Library References

Health and Environment ⟹25.5(5).
C.J.S. Health and Environment §§ 91 et seq., 106 et seq., 131.

Notes of Decisions

1. In general

The Hazardous Waste Control Law (this section et seq.) which became operative on July 1, 1973, preempts existing local ordinances and regulations pertaining to the processing, handling and disposal of hazardous and extremely hazardous waste materials. 57 Ops.Atty.Gen. 159, 4-4-74.

§ 25101. Legislative declaration

The Legislature therefore declares that:

(a) In order to protect the public health and the environment and to conserve natural resources, it is in the public interest to establish regulations and incentives which ensure that the generators of hazardous waste employ technology and management practices for the safe handling, treatment, recycling, and destruction of their hazardous wastes prior to disposal.

(b) In order to assist the generators of hazardous waste in meeting the responsibility for the safe disposal of hazardous waste it is necessary to establish the Hazardous Waste Management Council.

(c) The Legislature further declares that in order to protect the public of this state and particularly the communities where hazardous wastes are treated and disposed, it is essential to assure full compensation of all people injured or damaged by hazardous wastes. It is therefore necessary that the Hazardous Waste Management Council, created pursuant to Section 25206, make recommendations regarding a system of insurance and mechanisms establishing liability to achieve this result, as required by subdivision (e) of Section 25208.

(d) It is in the best interest of the health and safety of the people of the State of California for the state to obtain and maintain authorization to administer a state hazardous waste program in lieu of the federal program pursuant to Section 3006 of Public Law 94-580, as amended, the Resource Conservation and Recovery Act of 1976 (42 U.S.C. 6926).[1] Therefore, it is the intent of the Legislature that the director shall have those powers necessary to secure and maintain interim and final authorization for the state hazardous waste program pursuant to the requirements of Section 3006 of Public Law 94-580, the Resource Conservation and Recovery Act of 1976 (42 U.S.C. 6926), and to implement such program in lieu of the federal program.

(Added by Stats.1982, c. 89, § 4, eff. March 2, 1982.)

[1] 42 U.S.C.A. § 6926.

Historical Note

Former § 25101, added by Stats.1972, c. 1236, p. 2388, § 1, amended by Stats.1977, c. 1039, p. 3143, § 2, relating to similar subject matter, was repealed by Stats.1982, c. 89, § 3, eff. March 2, 1982.

Derivation: Former § 25101, added by Stats.1972, c. 1236, p. 2388, § 1, amended by Stats.1977, c. 1039, p. 3143, § 2.

Notes of Decisions

1. In general

The Hazardous Waste Control Law (§ 25100 et seq.) which became operative on July 1, 1973, preempts existing local ordinances and regulations pertaining to the processing, handling and disposal of hazardous and extremely hazardous waste materials. 57 Ops.Atty.Gen. 159, 4-4-74.

§ 25105. Enforcement authority of state and local agencies

No provision of this chapter shall limit the authority of any state or local agency in the enforcement or administration of any provision of law which it is specifically permitted or required to enforce and administer.

(Formerly § 25172, added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973. Renumbered § 25105 and amended by Stats.1982, c. 89, § 16, eff. March 2, 1982.)

Historical Note

The 1982 amendment renumbered the section without change in the text.

Notes of Decisions

1. In general

The Hazardous Waste Control Law (§ 25100 et seq.) which became operative on July 1, 1973, preempts existing local ordinances and regulations pertaining to the processing, handling and disposal of hazardous and extremely hazardous waste materials. 57 Ops.Atty.Gen. 159, 4-4-74.

Article 2

DEFINITIONS

Section
25110. Construction of chapter.
25110.5. Business.
25111. Department.
25112. Director.
25113. Disposal.
25114. Disposal site.
25115. Extremely hazardous waste.
25116. Handling.
25117. Hazardous waste.
25117.3. Hazardous waste property.
25117.4. Border zone property.
25117.5. Infectious waste; etiologic agent.

Section
25117.6. Wastewate
25117.8. Natural re
25117.11. Offsite fac
25117.12. Onsite fac
25118. Person.
25119. Processing
25120. Producer.
25121. Recycle.
25121.5. Retrograde
25122. Waste.
25122.5. Recyclable
25122.6. Small quai
25123. Storage.
25123.3. Storage fa
25123.5. Treatment.
25124. Repealed.

Article 2 wc operative July

Hazardous substance ta and Taxation Code § 4

Words and Phrases (P

§ 25110. Constr

Unless the conte govern the construc

(Added by Stats.1972,

§ 25110.5. Busir

"Business" mean commercial or prop

(Added by Stats.1977,

§ 25111. Departr

"Department" me

(Added by Stats.1972, Stats.1973, c. 142, p. Stats.1977, c. 1252, p.

Section
25117.6. Wastewater and wastewater sludges; properly treated not infectious.
25117.8. Natural resources.
25117.11. Offsite facility.
25117.12. Onsite facility.
25118. Person.
25119. Processing.
25120. Producer.
25121. Recycle.
25121.5. Retrograde material.
25122. Waste.
25122.5. Recyclable material.
25122.6. Small quantity producer.
25123. Storage.
25123.3. Storage facility.
25123.5. Treatment.
25124. Repealed.

Article 2 was added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973.

Cross References

Hazardous substance tax, governed by definitions contained in this chapter, see Revenue and Taxation Code § 43002.

Library References

Words and Phrases (Perm. Ed.)

§ 25110. Construction of chapter

Unless the context indicates otherwise the definitions in this article govern the construction of this chapter.

(Added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973.)

§ 25110.5. Business

"Business" means the conduct of activity and is not limited to a commercial or proprietary activity.

(Added by Stats.1977, c. 1039, p. 3143, § 2.5.)

§ 25111. Department

"Department" means the State Department of Health Services.

(Added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973. Amended by Stats.1973, c. 142, p. 402, § 42.7, eff. June 30, 1973, operative July 1, 1973; Stats.1977, c. 1252, p. 4422, § 311, operative July 1, 1978.)

Historical Note

The 1973 amendment substituted "State Department of Health" for "State Department of Public Health".

The 1977 amendment added the word "Services".

§ 25112. Director

"Director" means the State Director of Health Services.

(Added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973. Amended by Stats.1973, c. 142, p. 402, § 42.8, eff. June 30, 1973, operative July 1, 1973; Stats.1977, c. 1252, p. 4422, § 312, operative July 1, 1978.)

Historical Note

The 1973 amendment substituted "Director of Health" for "Director of Public Health".

The 1977 amendment substituted "State Director of Health Services" for "Director of Health".

§ 25113. Disposal

"Disposal" means to abandon, deposit, inter or otherwise discard waste.

(Added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973. Amended by Stats.1977, c. 1039, p. 3143, § 3.)

Historical Note

The 1977 amendment rewrote the section which as added read:

"'Disposal' means to abandon, deposit, inter or otherwise discard waste as a final action after their use has been achieved or a use is no longer intended."

§ 25114. Disposal site

"Disposal site" means the location where any final deposition of hazardous waste occurs.

(Added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973. Amended by Stats.1977, c. 1039, p. 3143, § 4.)

Historical Note

The 1977 amendment substituted, at the end of the section "hazardous waste occurs." for "solid waste occurs."

§ 25115. Extremely hazardous waste

"Extremely hazardous waste" means any hazardous waste or mixture of hazardous wastes which, if human exposure should occur, may likely result in death, disabling personal injury or serious illness caused by the

hazardous waste or
concentration, or c
(Added by Stats.1972
Stats.1977, c. 1039, p

The 1977 amendment
illness caused by the
mixture of hazardous

List of extremely hazar

§ 25116. Handli

"Handling" mear
another, or pumpi
waste, but does n
becomes a waste.

(Added by Stats.1972,
Stats.1977, c. 1039, p

The 1977 amendment
which had read:

"'Handling' means t
fer from one place to an
of hazardous and ex
waste."

§ 25117. Hazar

"Hazardous wast
because of its quan
characteristics may

(a) Cause, or sig
increase in serious

(b) Pose a substa
environment when
of, or otherwise m

Unless expressly
shall be understood

(Added by Stats.1972,
Stats.1977, c. 1039,

hazardous waste or mixture of hazardous wastes because of its quantity, concentration, or chemical characteristics.

(Added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973. Amended by Stats.1977, c. 1039, p. 3143, § 5.)

Historical Note

The 1977 amendment substituted "serious illness caused by the hazardous waste or mixture of hazardous wastes" for "illness during, or as a proximate result of, any disposal of such waste or mixture of waste".

Administrative Code References

List of extremely hazardous wastes, see 22 Cal.Adm.Code 60283.

§ 25116. Handling

"Handling" means the transporting or transferring from one place to another, or pumping, processing, storing, or packaging of hazardous waste, but does not include the handling of any substance before it becomes a waste.

(Added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973. Amended by Stats.1977, c. 1039, p. 3143, § 6; Stats.1980, c. 878, p. 3756, § 1.)

Historical Note

The 1977 amendment rewrote the section which had read:

" 'Handling' means the transport, transfer from one place to another, or packaging of hazardous and extremely hazardous waste."

The 1980 amendment deleted, following the second use of the word "waste", the words "and does not include the storage of hazardous waste on the contiguous property of the producer of the waste.".

§ 25117. Hazardous waste

"Hazardous waste" means a waste, or combination of wastes, which because of its quantity, concentration, or physical, chemical, or infectious characteristics may either:

(a) Cause, or significantly contribute to an increase in mortality or an increase in serious irreversible, or incapacitating reversible, illness.

(b) Pose a substantial present or potential hazard to human health or environment when improperly treated, stored, transported, or disposed of, or otherwise managed.

Unless expressly provided otherwise, the term "hazardous waste" shall be understood to also include extremely hazardous waste.

(Added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973. Amended by Stats.1977, c. 1039, p. 3143, § 7; Stats.1982, c. 89, § 5, eff. March 2, 1982.)

Historical Note

The 1977 amendment rewrote the section which had read:

"'Hazardous waste' means any waste material or mixture of wastes which is toxic, corrosive, flammable, an irritant, a strong sensitizer, which generates pressure through decomposition, heat or other means, if such a waste or mixture of wastes may cause substantial personal injury, serious illness or harm to wildlife, during or as a proximate result of any disposal of such wastes or mixture of wastes. The terms 'toxic', 'corrosive', 'flammable', 'irritant' and 'strong sensitizer' shall be given the same meaning as in the California Hazardous Substances Act (Chapter 13 (commencing with Section 28740) of Division 21)."

The 1982 amendment added the last paragraph.

Cross References

Discharge,
- Offense and civil liability, see Water Code § 13265.
- Penalty for false report or withholding material information, see Water Code § 13261.
- Without technical or monitoring program reports, or giving false information, offense, see Water Code § 13268.

Hazardous substances, highway spill containment and abatement, see Vehicle Code § 2452.

Administrative Code References

List of hazardous wastes, see 22 Cal.Adm.Code 60281.

§ 25117.3. Hazardous waste property

(a) "Hazardous waste property" means land which is either of the following:

(1) Any hazardous waste facility or portion thereof, required to be permitted pursuant to this chapter, which has a permit for disposal from the department or has submitted an application for such a permit.

(2) A portion of any land designated as a hazardous waste property pursuant to Section 25229 where a significant disposal of hazardous waste has occurred on, under, or into the land resulting in a significant existing or potential hazard to present or future public health or safety.

(b) "Hazardous waste property" does not mean residential land that has never received waste chemicals from an industrial, commercial, agricultural, research, or business activity.

(Added by Stats.1980, c. 1161, p. 3899, § 1.)

§ 25117.4. Border zone property

"Border zone property" means any property designated as border zone property pursuant to Section 25229 which is within 2,000 feet of a significant disposal of hazardous waste, and the wastes so located are a significant existing or potential hazard to present or future public health or safety on the land in question.

(Added by Stats.1980, c. 1161, p. 3900, § 2.)

§ 25117.5.

(a) "Infecti

(1) Laborat
pose a substa

(2) Patholo
elements, exc
attendant dis

(3) Surgical
removed surg
attendant dis

(4) Equipm
which are like
or the enclos
suspected or

(5) Human
zate membrar

(6) Carcass
present a sul

(7) Any oth
infection cont
it is contamin
ed with, etiol

(b) As used
ganism, helm
the cause of,

(Added by Stat

Former § 2511
1039, p. 3143,
was repealed by
eff. Sept. 15, 198

§ 25117.6.

Wastewate
to comply w
Services and
considered in

(Added by Stat
1952, § 171.)

§ 25117.5. Infectious waste; etiologic agent

(a) "Infectious waste" means:

(1) Laboratory wastes, including cultures of etiologic agents, which pose a substantial threat to health due to their volume and virulence.

(2) Pathologic specimens, including human or animal tissues, blood elements, excreta, and secretions which contain etiologic agents, and attendant disposable fomites.

(3) Surgical specimens, including human or animal parts and tissues removed surgically or at autopsy which contain etiologic agents, and attendant disposable fomites.

(4) Equipment, instruments, utensils, and other disposable materials which are likely to transmit etiologic agents from the rooms of humans, or the enclosures of animals, which have been isolated because of suspected or diagnosed communicable disease.

(5) Human dialysis waste materials including arterial lines and dialyzate membranes.

(6) Carcasses of animals infected with etiologic agents which may present a substantial hazard to public health if improperly managed.

(7) Any other material which, in the determination of the facility infection control staff, presents a significant danger of infection because it is contaminated with, or may reasonably be expected to be contaminated with, etiologic agents.

(b) As used in this section, "etiologic agent" means a type of microorganism, helminth, or virus which causes, or significantly contributes to the cause of, increased morbidity or mortality of human beings.

(Added by Stats.1982, c. 1060, § 2, eff. Sept. 15, 1982.)

Historical Note

Former § 25117.5, added by Stats.1977, c. 1039, p. 3143, § 8, defining "infectious", was repealed by Stats.1982, c. 1060, § 1, eff. Sept. 15, 1982.

Derivation: Former § 25117.5, added by Stats.1977, c. 1039, p. 3143, § 8.

§ 25117.6. Wastewater and wastewater sludges; properly treated not infectious

Wastewater and wastewater sludges which have been properly treated to comply with the regulations of the State Department of Health Services and the regional water quality control boards shall not be considered infectious for the purposes of Section 25117.5.

(Added by Stats.1977, c. 1039, p. 3144, § 8.1. Amended by Stats.1980, c. 676, p. 1952, § 171.)

Historical Note

The 1980 amendment substituted "State Department of Health Services" for "State Department of Health".

§ 25117.8. Natural resources

"Natural resources" includes, but is not limited to, disposal site capacity and substances which are hazardous waste, or which are in hazardous waste, the reuse of which is technologically and economically feasible.

(Added by Stats.1982, c. 89, § 6, eff. March 2, 1982.)

§ 25117.11. Offsite facility

"Offsite facility" means a hazardous waste facility that is not an onsite facility.

(Added by Stats.1982, c. 1121, § 2.)

Historical Note

Section 1 of Stats.1982, c. 1121, provides:

"The Legislature finds that persons producing hazardous waste can be encouraged to reduce their production of that waste by regulatory and financial incentives. The Legislature further finds and declares that the provisions of this act are intended to provide these needed incentives."

§ 25117.12. Onsite facility

"Onsite facility" means a hazardous waste facility at which a hazardous waste is produced and which is owned by, leased to, or under the control of, the producer of the waste.

(Added by Stats.1982, c. 1121, § 3.)

Historical Note

Legislative findings, declarations, and intent concerning Stats.1982, c. 1121, see Historical Note under § 25117.11.

§ 25118. Person

"Person" means an individual, trust, firm, joint stock company, corporation, including, but not limited to, a government corporation, partnership, and association. "Person" also includes any city, county, district, and the state or any department or agency thereof, and the federal government or any department or agency thereof to the extent permitted by law.

(Added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973. Amended by Stats.1977, c. 1039, p. 3144, § 9; Stats.1982, c. 1121, § 4.)

The 1977 amendme
sentence.

The 1982 amendmer
first sentence, "includ
to, a government corp
ing a government co
wrote the second sent
in 1972, had read:

Statement regarding f
section other than a

1. In general

The Hazardous W
(§ 25100 et seq.) which
July 1, 1973, preempts

§ 25119. Proce

"Processing" me

(Added by Stats.1972
Stats.1977, c. 1039, p

The 1977 amendmer
the word "department'
junction with any othe
to regulate or control

The 1980 amendment
which as amended in 1

§ 25120. Produ

"Producer" mea

(Added by Stats.1982

Former § 25120, add
1236, p. 2388, § 1, defi

§ 25121. Recycl

"Recycle" means
stance from a haza
a hazardous waste

(Added by Stats.1972
Stats.1977, c. 1039, p

Historical Note

The 1977 amendment inserted the first sentence.

The 1982 amendment substituted, in the first sentence, "including, but not limited to, a government corporation" for "(including a government corporation)"; and rewrote the second sentence which, as added in 1972, had read:

"'Person' also includes any city, county, district, the state or any department or agency thereof.".

Legislative findings, declarations, and intent concerning, Stats.1982, c. 1121, see Historical Note under § 25117.11.

Cross References

Statement regarding failure to recycle hazardous waste, issuance by entity listed in this section other than an individual, see § 25175.

Notes of Decisions

1. In general

The Hazardous Waste Control Law (§ 25100 et seq.) which became operative on July 1, 1973, preempts existing local ordinances and regulations pertaining to the processing, handling and disposal of hazardous and extremely hazardous waste materials. 57 Ops.Atty.Gen. 159, 4-4-74.

§ 25119. Processing

"Processing" means treatment, as defined in Section 25123.5.

(Added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973. Amended by Stats.1977, c. 1039, p. 3144, § 10; Stats.1980, c. 878, p. 2756, § 2.)

Historical Note

The 1977 amendment deleted following the word "department" the words "in conjunction with any other agency authorized to regulate or control hazardous waste.".

The 1980 amendment rewrote the section which as amended in 1977 had read:

"'Processing' means to treat, detoxify, neutralize, incinerate, biodegrade, or otherwise process a hazardous waste to remove its harmful properties or characteristics for disposal in accordance with regulations established by the department.".

§ 25120. Producer

"Producer" means any person who generates a waste material.

(Added by Stats.1982, c. 496, § 1, eff. July 12, 1982.)

Historical Note

Former § 25120, added by Stats.1972, c. 1236, p. 2388, § 1, defining "processing facility", was repealed by Stats.1980, c. 878, p. 2756, § 3.

§ 25121. Recycle

"Recycle" means to redirect or utilize a hazardous waste or a substance from a hazardous waste, and includes recovery of resources from a hazardous waste.

(Added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973. Amended by Stats.1977, c. 1039, p. 3144, § 11; Stats.1980, c. 878, p. 2756, § 4.)

Historical Note

As added in 1972, this section read:

" 'Recycle' means to process, alter, or otherwise treat a hazardous waste for subsequent use."

The 1977 amendment rewrote the section to read:

" 'Recycle' means to redirect or utilize a waste or substance from a waste in a manner that, in the judgment of the department, will not result in a substantial hazard to the health or safety of persons, domestic livestock or wildlife.".

The 1980 amendment rewrote the section to read as it now appears.

§ 25121.5. Retrograde material

"Retrograde material" means any hazardous material which is not to be used, sold, or distributed for use in an originally intended or prescribed manner or for an originally intended or prescribed purpose for any of the following reasons:

(a) It has undergone chemical, biochemical, physical, or other changes.

(b) It has exceeded a specified or recommended shelf life.

(c) It is banned by law, regulation, ordinance, or decree.

(d) It cannot be used for reasons of economics, health or safety, or environmental hazard.

(e) It is mislabeled or is not adequately labeled, or is otherwise not identified or identifiable.

(f) It is packaged in deteriorated or damaged containers.

(Added by Stats.1980, c. 878, p. 2757, § 5.)

§ 25122. Waste

"Waste" means either of the following:

(a) Any material for which no use or reuse is intended and which is to be discarded.

(b) Any recyclable material.

(Added by Stats.1972, c. 1236, p. 2389, § 1. Amended by Stats.1980, c. 878, p. 2757, § 6.)

Historical Note

The 1980 amendment rewrote the section which previously read:

" 'Waste' means any material for which no use or reuse is intended and which is to be discarded.".

Section 13 of Stats.1980, c. 878, p. 2759, provided:

"The amendment of Section 25122 of the Health and Safety Code by this act is intended to clarify the intent of the previously existing definition of waste and is not a change in that definition."

§ 25122.5. Recyclable material

(a) "Recyclable material" means any material that would be considered a hazardous waste but for the fact that both of the following conditions exist:

(1) Some use
demonstrated.

(2) Such mat

(A) A spent,
residue, which
effluent, or res
following purp

(i) Recycling

(ii) Subseque

(B) Any ret
through treatm
the following c

(i) One year
material.

(ii) One year

(b) "Recycla

(1) A chemic

(2) A byprod
requirements:

(A) Has a co

(B) Is ordina
agricultural co

(C) The recl
health and safe

(3) A materi
the original ma

(4) A materi
of such materi
original manuf

(Added by Stats.

§ 25122.6. S

"Small quant
1,000 kilograms

(Added by Stats.

Legislative findi
tent concerning Sta
torical Note under

(1) Some use or reuse of such material may be intended and can be demonstrated.

(2) Such material is either of the following:

(A) A spent, contaminated, or used material, or a process effluent or residue, which has been transferred by the producer of such material, effluent, or residue to an unrelated or unaffiliated person for both of the following purposes:

(i) Recycling or treatment.

(ii) Subsequent sale.

(B) Any retrograde material that has not been used or reclaimed through treatment by the original manufacturer or owner by the later of the following dates:

(i) One year of the date when such material became a retrograde material.

(ii) One year after return to the original manufacturer.

(b) "Recyclable material" does not include any of the following:

(1) A chemical intermediate.

(2) A byproduct that in its existing state meets all of the following requirements:

(A) Has a commercial use.

(B) Is ordinarily used as a commodity in trade by the industrial or agricultural community.

(C) The reclamation operation poses no significant hazard to public health and safety, or to domestic livestock, wildlife, or the environment.

(3) A material that is routinely reclaimed by a third party for reuse by the original manufacturer of the material.

(4) A material that is routinely reclaimed by an original manufacturer of such material, provided the reclamation is only a portion of such original manufacturer's normal production of such material.

(Added by Stats.1980, c. 878, p. 2757, § 7.)

§ 25122.6. Small quantity producer

"Small quantity producer" means a person who produces less than 1,000 kilograms of hazardous waste in any month.

(Added by Stats.1982, c. 1121, § 5.)

Historical Note

Legislative findings, declarations, and intent concerning Stats.1982, c. 1121, see Historical Note under § 25117.11.

§ 25123. Storage

"Storage" means the containment of hazardous wastes, either on a temporary basis or for a period of years, in such a manner as not to constitute disposal or use of such hazardous waste.

(Added by Stats.1977, c. 1039, p. 3144, § 12.)

§ 25123.3. Storage facility

"Storage facility" means a hazardous waste facility at which hazardous waste is contained for periods greater than 96 hours at an offsite facility or for periods greater than 90 days at an onsite facility.

(Added by Stats.1982, c. 1121, § 6.)

Historical Note

Legislative findings, declarations, and intent concerning Stats.1982, c. 1121, see Historical Note under § 25117.11.

§ 25123.5. Treatment

"Treatment" means any method, technique, or process which changes the physical, chemical, or biological character or composition of any hazardous waste or any material contained therein, or removes or reduces its harmful properties or characteristics for any purpose.

(Added by Stats.1980, c. 878, p. 2758, § 8.)

§ 25124. Repealed by Stats.1980, c. 878, p. 2758, § 9

Historical Note

The repealed section, added by Stats. 1977, c. 1039, p. 3144, § 12.1, defined use.

Article 3

HAZARDOUS WASTE TECHNICAL ADVISORY COMMITTEE

Section

25130. Establishment; consultation, advice and recommendations.
25131. Membership.
25132. Representation of public interest; financial interest.
25133. Compensation; per diem and travel expenses.

Article 3 was added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973.

§ 25130. Est
ti

The departme
committee to pr
covered by the
the developmen
waste managem
ods by which e
laws regulating
administration f

(Added by Stats.1

§ 25131. Me

The committe
director who sh
The members s
public, local and
try, local healt

(Added by Stats.1

§ 25132. Rep

At least two n
the public and sl
tions or studies
but not be limite
waste disposal,
disposal, or as a
hazardous waste

(Added by Stats.1

§ 25133. Con

Members of t
serve without c
reimbursement f
mittee business.

(Added by Stats.1

Section

25140. Listing c
25141. Identific

§ 25130. Establishment; consultation, advice and recommendations

The department shall establish a hazardous waste technical advisory committee to provide consultation to the department concerning matters covered by the chapter. The committee shall advise the department on the development of standards, rules, and regulations for hazardous waste management, and shall supply recommendations concerning methods by which existing hazardous waste management practices and the laws regulating them may be supplemented and improved and their administration financed.

(Added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973.)

§ 25131. Membership

The committee shall consist of seven members appointed by the director who shall be knowledgeable in hazardous waste management. The members shall insofar as possible represent the interests of the public, local and regional government, agriculture, manufacturing industry, local health departments, and the waste management industry.

(Added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973.)

§ 25132. Representation of public interest; financial interest

At least two members of the committee shall represent the interests of the public and shall have no financial interest in any of the recommendations or studies of the committee. Such financial interest shall include, but not be limited to, service as a consultant to any person specializing in waste disposal, as a tenant or landlord of property used for waste disposal, or as an attorney of a party with a direct financial interest in hazardous waste disposal.

(Added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973.)

§ 25133. Compensation; per diem and travel expenses

Members of the hazardous waste technical advisory committee shall serve without compensation, but shall be entitled to per diem and reimbursement for travel expenses incurred as a result of official committee business.

(Added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973.)

Article 4

LISTINGS

Section

25140. Listing of wastes.
25141. Identification of wastes; criteria and guidelines.

Section
25142. Handling, storage, use, etc. of wastes prior to citation in list.
25143. Waiver of provisions; geothermal wastes.
25144. Effluent produced by biological process and discharged into navigable waters under federal permit; exemption; exception.
25145. Construction of chapter; powers of state and regional boards.
25145.4. Violations; Attorney General's authority to bring action.

Article 4 was added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973.

§ 25140. Listing of wastes

The department shall prepare, adopt and may revise when appropriate, a listing of the wastes which are determined to be hazardous, and a listing of the wastes which are determined to be extremely hazardous. When identifying such wastes the department shall consider, but not be limited to, the immediate or persistent toxic effects to man and wildlife and the resistance to natural degradation or detoxification of the wastes.

(Added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973.)

Library References

Health and Environment ⇐25.5.
C.J.S. Health and Environment §§ 61 to 66, 69, 71 to 73, 78 to 80, 82 to 86, 88 to 90, 94, 104, 110, 115 to 126, 128, 129, 132, 133, 135, 137 to 140, 142, 144 to 153.

§ 25141. Identification of wastes; criteria and guidelines

The department shall develop and adopt by regulation criteria and guidelines for the identification of hazardous wastes and extremely hazardous wastes.

(Added by Stats.1977, c. 1039, p. 3145, § 13.)

§ 25142. Handling, storage, use, etc. of wastes prior to citation in list

Any waste which conforms to a criterion adopted pursuant to Section 25141 shall be handled, stored, used, processed, and disposed of in accordance with permits, orders, and regulations issued or promulgated by the department pursuant to this chapter and building standards published in the State Building Standards Code relating to hazardous waste facilities, or recycled consistent with the list of hazardous wastes which the department, pursuant to Section 25175, finds are economically and technologically feasible to recycle, until such waste is cited in a list adopted by the department pursuant to Section 25140.

(Added by Stats.1977, c. 1039, p. 3145, § 14. Amended by Stats.1979, c. 1152, p. 4310, § 189; Stats.1982, c. 89, § 7, eff. March 2, 1982.)

The 1979 amendme
"Section 25141" the
ter"; and added foll
words "and building s
the State Building Sta
to hazardous waste fa
The 1982 amendmen
tions" for "requireme

§ 25143. Waive

Pursuant to reg
this chapter may
department deter
hazard to human
processing, or di
governmental age
exempt from the
geothermal waste
boards.

(Added by Stats.197
p. 4123, § 2.)

The 1978 amendme
sentence.

§ 25144. Efflue
intc
exc

A biological pro
products, and wa
discharged to na
pursuant to Sectic
U.S.C. 1342)[1] sh
However, residues
removed that conf
of this code shall

(Added by Stats.197

[1] 33 U.S.C.A. § 1342.

§ 25145. Const
boa

This chapter sh
powers or duties
and each regional

Historical Note

The 1979 amendment deleted, following "Section 25141" the words "of this chapter"; and added following "chapter" the words "and building standards published in the State Building Standards Code relating to hazardous waste facilities".

The 1982 amendment substituted "regulations" for "requirements"; and inserted, following "facilities" the words "or recycled consistent with the list of hazardous wastes which the department, pursuant to Section 25175, finds are economically and technologically feasible to recycle,".

§ 25143. Waiver of provisions; geothermal wastes

Pursuant to regulations adopted by the department, the provisions of this chapter may be waived by the department for any waste which the department determines is insignificant or unimportant as a potential hazard to human health, domestic livestock, or wildlife or the handling, processing, or disposal of which is adequately regulated by another governmental agency. Any drilling for geothermal resources shall be exempt from the requirements of this chapter because the disposal of geothermal wastes is regulated by the regional water quality control boards.

(Added by Stats.1977, c. 1039, p. 3145, § 14.1. Amended by Stats.1978, c. 1270, p. 4123, § 2.)

Historical Note

The 1978 amendment added the second sentence.

§ 25144. Effluent produced by biological process and discharged into navigable waters under federal permit; exemption; exception

A biological process on the property of the producer treating oil, its products, and water, and producing an effluent which is continuously discharged to navigable waters in compliance with a permit issued pursuant to Section 402 of the Federal Water Pollution Control Act (33 U.S.C. 1342)[1] shall be exempt from the provisions of this chapter. However, residues produced in the treatment process and subsequently removed that conform to any criterion adopted pursuant to Section 25141 of this code shall not be exempt.

(Added by Stats.1977, c. 1039, p. 3145, § 14.2.)

[1] 33 U.S.C.A. § 1342.

§ 25145. Construction of chapter; powers of state and regional boards

This chapter shall not be construed to limit, abridge, or supersede the powers or duties granted to the State Water Resources Control Board and each regional water quality control board by Division 7 (commencing

with Section 13000) and Division 7.5 (commencing with Section 14000) [1] of the Water Code.

(Added by Stats.1977, c. 1039, p. 3145, § 14.3. Amended by Stats.1982, c. 89, § 7.5, eff. March 2, 1982.)

[1] Repealed.

Historical Note

The 1982 amendment inserted the words "or supersede".

§ 25145.4. Violations; Attorney General's authority to bring action

No provision of this chapter, or any ruling of the department or director, shall be construed to limit or abridge the power of the Attorney General, at the request of the department or director, or upon his or her own motion, to bring an action in the name of the people of the State of California to enjoin any violation of the provisions of this chapter, seek necessary remedial action by any person who violates any of the provisions of this chapter, or seek civil and criminal penalties against any person who violates any of the provisions of this chapter.

(Added by Stats.1982, c. 496, § 2, eff. July 12, 1982.)

Article 4.5

STATE REGULATION OF EXISTING HAZARDOUS WASTE FACILITIES

Section

25146. Legislative finding and declaration.
25146.5. Further legislative findings and declarations.
25147. Intent not to preempt local land use regulation.
25147.5. Construction of definitions.
25148. Existing hazardous waste facility.
25148.5. Solid waste.
25149. Public notice and hearing; regulation of hazardous waste facilities.
25149.1. City, county, or city and county which has issued conditional use permit; limitation on additional restriction; modification or revocation of permit; procedure; application of section to existing facility.
25149.3. Examination and determination of significant existing or potential hazards; notice; hearing; costs; special accounts; action by local jurisdiction; stay of action upon building permit application; application of section.
25149.5. General law city or county; imposition and enforcement of license tax; limitation on amount.
25149.6. Recommendation by local agency to protect against hazards.
25149.7. Construction of article; right to maintain civil action.

Article 4.5 was added by Stats.1981, c. 244, p. 1295, § 3, eff. July 21, 1981.

§ 25146. Legi

The Legislatu
waste disposal f
and that under p
ply and demand
This problem is
urban, suburban

(Added by Stats.19

Health and Enviro
C.J.S. Health and
seq., 106 et seq.,

§ 25146.5. Fu

The Legislatur

(a) It is a matt
the number of
extent feasible.

(b) The availab
hazardous waste

(c) Any decrea
increases the dis
in order to prope

(d) An increase
to properly disp

(Added by Stats.19

§ 25147. Inter

Except as exp
this article to pr
waste facilities.

(Added by Stats.19

§ 25147.5. Co

The definitions
only this article.

(Added by Stats.19

§ 25148. Exist

(a) Except as
ous waste facilit

§ 25146. Legislative finding and declaration

The Legislature finds and declares that the number of hazardous waste disposal facilities is decreasing in the face of increasing demand, and that under present circumstances and law, imbalance between supply and demand is likely to further increase in the foreseeable future. This problem is general in nature, and does and will continue to exist in urban, suburban, and rural areas.

(Added by Stats.1981, c. 244, p. 1295, § 3, eff. July 21, 1981.)

Library References

Health and Environment ⟹25.5(4, 5).
C.J.S. Health and Environment §§ 91 et seq., 106 et seq., 130, 131, 132.

§ 25146.5. Further legislative findings and declarations

The Legislature further finds and declares that:

(a) It is a matter of urgent public necessity and statewide concern that the number of existing hazardous waste facilities be retained to the extent feasible.

(b) The availability of land suitable and capable of being developed as hazardous waste disposal sites is decreasing.

(c) Any decrease in the number of existing hazardous waste facilities increases the distance that it is necessary to transport hazardous waste in order to properly dispose of it.

(d) An increase in the distance which it is necessary to travel in order to properly dispose of hazardous waste encourages illegal disposal.

(Added by Stats.1981, c. 244, p. 1295, § 3, eff. July 21, 1981.)

§ 25147. Intent not to preempt local land use regulation

Except as expressly provided in Section 25149, it is not the intent of this article to preempt local land use regulation of existing hazardous waste facilities.

(Added by Stats.1981, c. 244, p. 1295, § 3, eff. July 21, 1981.)

§ 25147.5. Construction of definitions

The definitions contained in this article shall govern the construction of only this article.

(Added by Stats.1981, c. 244, p. 1295, § 3, eff. July 21, 1981.)

§ 25148. Existing hazardous waste facility

(a) Except as otherwise provided in subdivision (b), "existing hazardous waste facility" means a Class I disposal site, as defined in Section

2510 of Title 23 of the California Administrative Code on the effective date of this article, and which, in addition, is either:

(1) A facility operating as of May 1, 1981, pursuant to a valid hazardous waste facility permit issued by the department pursuant to Section 25200.

(2) A facility operating as of May 1, 1981, pursuant to a grant of interim status by the department pursuant to Section 25200.5.

(b) An "existing hazardous waste facility" does not include a facility which treats, disposes, stores, or recycles on the production site only hazardous wastes produced by the owner or lessee of such a facility.

(Added by Stats.1981, c. 244, p. 1295, § 3, eff. July 21, 1981.)

Cross References

Z'berg-Kapiloff Solid Waste Control Act of 1976, enforcement agency, see Government Code § 66796.

§ 25148.5. Solid waste

"Solid waste" means all putrescible and nonputrescible solid, semisolid, and liquid wastes, including garbage, trash, refuse, paper, rubbish, ashes, industrial wastes, demolition and construction wastes, abandoned vehicles and parts thereof, discarded home and industrial appliances, manure, vegetable or animal solid and semisolid wastes, and other discarded solid and semisolid wastes, but shall not include hazardous waste as defined in Section 25117.

(Added by Stats.1981, c. 244, p. 1295, § 3, eff. July 21, 1981.)

Library References

Health and Environment ⟹25.5(5).
C.J.S Health and Environment §§ 91 et seq., 106 et seq., 131.

§ 25149. Public notice and hearing; regulation of hazardous waste facilities

Notwithstanding any provision of law to the contrary, except as provided in Section 25149.5 or 25181 of this code or Section 731 of the Code of Civil Procedure, no city, county, city and county, whether chartered or general law, or district may enact, issue, enforce, suspend, revoke, or modify any ordinance, regulation, law, license, or permit relating to an existing hazardous waste facility so as to prohibit or unreasonably regulate the disposal, treatment, or recovery of resources from hazardous waste or a mix of hazardous and solid wastes at that facility, unless after public notice and hearing the director determines that the operation of the facility may present an imminent and substantial endangerment to health and the environment. However, nothing in this section shall authorize an operator of that facility to violate any

term or conditio
not in conflict w
(Added by Stats.1

§ 25149.1. Ci

(a) No city, c
chartered, which
waste facility sh
issue or amend
imposes addition
previously have
or storage unde
conditional use p

(b) This sectio
permit which is
permit, or to aba
public health or
permit may only
the facility opera
public health or
opportunity to a
health or safety,
enforcement or a

(c) This sectio
as defined in Sec
(Added by Stats.19

Health and Enviro
C.J.S. Health and
seq., 106 et seq.,

§ 25149.3. Ex

(a) Upon the r
examine and dete
one of the purp
Section 25232 co
present or futur

term or condition of a local land use permit or any other provision of law not in conflict with this section.

(Added by Stats.1981, c. 244, p. 1295, § 3, eff. July 21, 1981.)

§ 25149.1. City, county, or city and county which has issued conditional use permit; limitation on additional restriction; modification or revocation of permit; procedure; application of section to existing facility

(a) No city, county, or city and county, whether general law or chartered, which has issued a conditional use permit for a hazardous waste facility shall thereafter adopt an ordinance, rule, or regulation, or issue or amend any permit, which adoption, issuance, or amendment imposes additional restrictions on the types of hazardous waste which previously have been authorized to be accepted for disposal, treatment, or storage under the terms and conditions of any previously issued conditional use permit for that facility.

(b) This section does not apply to a modification or revocation of a use permit which is necessary to enforce the terms and conditions of the use permit, or to abate a nuisance, or to prevent an immediate threat to the public health or safety. Modification or revocation of an existing use permit may only occur after the city, county, or city and county orders the facility operator to abate the nuisance or correct the threat to the public health or safety, the facility operator has been afforded adequate opportunity to abate the nuisance or correct the threat to the public health or safety, and the facility operator has failed to comply with the enforcement or abatement order.

(c) This section does not apply to an existing hazardous waste facility, as defined in Section 25148.

(Added by Stats.1982, c. 1357, § 1.)

Library References

Health and Environment ⇐25.5(5).
C.J.S. Health and Environment §§ 91 et seq., 106 et seq., 131.

§ 25149.3. Examination and determination of significant existing or potential hazards; notice; hearing; costs; special accounts; action by local jurisdiction; stay of action upon building permit application; application of section

(a) Upon the request of any interested person, the department shall examine and determine whether or not the use of any property for any one of the purposes set forth in paragraph (1) of subdivision (b) of Section 25232 constitutes a significant existing or potential hazard to present or future health or safety because of the proximity of the

property to an existing hazardous waste facility as defined in this article. If the department determines that a significant existing or potential hazard to present or future public health or safety exists on the property, it shall give notice and hold a hearing pursuant to Article 11 (commencing with Section 25220). If the department determines that there is no significant existing or potential hazard to present or future public health or safety on the property, it shall so notify the person who requested the determination and the local jurisdiction.

(b) All costs incurred by the department pursuant to this section shall be borne by the person making the request. The authority conferred on the department, pursuant to this section, shall be in addition to its authority with respect to the regulation of hazardous waste property and border zone property. A special account administered by the department shall be established for each request made to the department for the examination and determination specified in subdivision (a). The department shall provide the requesting person an estimate of the amount of money which would be necessary to accomplish the examination and determination by the department pursuant to that request. The estimated amount, which shall be paid to the department before the department undertakes any activity pursuant to subdivision (a), shall be deposited in the special account. Expenditures from this special account shall not be made in excess of the total amount of money in that special account at any time. Expenditures in excess of the initial deposit may be made only when additional money is received from the requesting person and deposited into the account.

Notwithstanding any other provision of law, the department may enter into contracts for any action taken, or to be taken, pursuant to subdivision (a). These contracts do not require approval by the Department of General Services pursuant to Article 1 (commencing with Section 14780) of Chapter 6[1] of Part 5.5 of Division 3 of Title 2 of the Government Code.

(c) A local jurisdiction shall not take any action with respect to the uses of land for any of those purposes, including, but not limited to, a general plan amendment, zoning change, or the imposition of conditions on the use of property, which land is subject to an existing zoning classification which permits the uses set forth in paragraph (1) of subdivision (b) of Section 25232 for which an examination and determination has been requested pursuant to subdivision (a), solely on the basis of a health hazard due to the property's proximity to an existing hazardous waste facility, unless the department has made a determination, pursuant to subdivision (a), that those uses of the property constitute a significant existing or potential hazard to present or future public health or safety.

(d) No application for a building permit or for the use of property which is the subject of a request pursuant to subdivision (a) shall be acted upon pending a determination by the department, unless the permit or use is not for a purpose set forth in paragraph (1) of subdivision (b) of Section 25232.

The departme

(e) This sectic
than one mile f
existing hazard

(Added by Stats.1

[1] Repealed.

§ 25149.5. G

A general la
purposes, a lice
facility; provid
percent of the
disposal facility.

(Added by Stats.1

§ 25149.6. R

A city, county
facility is locate
additional permi
necessary to pr
health, domestic

(Added by Stats.1

§ 25149.7. C

No provision
director, shall b
maintain a civil
731 of the Code

(Added by Stats.1

Section
25150. Adoptio agene
25150.1. Regulat testin waste
25150.5. Time fo
25151. Variance
25152. Public h

The department shall act upon the request within 90 days.

(e) This section shall not apply to any land or property which is more than one mile from a significant disposal of hazardous waste within an existing hazardous waste facility, as defined in this article.

(Added by Stats.1982, c. 496, § 3, eff. July 12, 1982.)

[1] Repealed.

§ 25149.5. General law city or county; imposition and enforcement of license tax; limitation on amount

A general law city or county may impose and enforce, for revenue purposes, a license tax on the operation of an existing hazardous waste facility; provided that, the license tax imposed shall not exceed 10 percent of the annual gross receipts of the existing hazardous waste disposal facility.

(Added by Stats.1981, c. 244, p. 1295, § 3, eff. July 21, 1981.)

§ 25149.6. Recommendation by local agency to protect against hazards

A city, county, or city and county in which an existing hazardous waste facility is located may at any time recommend to the director any new or additional permit or interim status conditions as the local agency deems necessary to protect against hazards within its boundaries to the public health, domestic livestock, wildlife, or the environment.

(Added by Stats.1981, c. 244, p. 1295, § 3, eff. July 21, 1981.)

§ 25149.7. Construction of article; right to maintain civil action

No provision of this article, or any ruling by the department or director, shall be construed as a limitation on the right of any person to maintain a civil action to enjoin or abate a nuisance pursuant to Section 731 of the Code of Civil Procedure.

(Added by Stats.1981, c. 244, p. 1295, § 3, eff. July 21, 1981.)

Article 5

STANDARDS

Section

25150. Adoption and revision of standards and regulations; consultation with agencies of interested local governments.
25150.1. Regulation of construction, operation, maintenance, monitoring, and testing of underground storage tanks for storage of hazardous wastes.
25150.5. Time for adoption of standards and regulations.
25151. Variance; factors considered.
25152. Public hearings.

Section
25153. Disposal of extremely hazardous waste; notice to department.
25154. Unlawful handling, storage, use, processing or disposal of hazardous waste.
25155. Disposal of extremely hazardous waste; removal of harmful properties or as specified by regulations.
25156. Hazardous waste disposal land use; regulations and standards; recommendations.
25157. Treatment of extremely hazardous waste at site of production prior to transportation; disposal of hazardous waste at site of production.
25157.3. Emergency regulations for management of infectious waste as hazardous waste.

Article 5 was added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973.

§ 25150. Adoption and revision of standards and regulations; consultation with agencies of interested local governments

(a) Except as provided in Section 18930, the department shall adopt, and revise when appropriate, standards and regulations for the handling, processing, use, storage, and disposal of hazardous wastes to protect against hazards to the public health, to domestic livestock, to wildlife, or to the environment.

(b) The department shall apply the standards and regulations adopted pursuant to subdivision (a) to the use and operation of facilities for handling, treating, storing and disposing of hazardous waste and, except as provided in Section 18930, may adopt, and revise when appropriate, additional standards and regulations for the use and operation of such facilities to protect against hazards to public health, domestic livestock, wildlife, or the environment posed by such facilities.

(c) The department shall adopt, and revise when appropriate, regulations for the recycling of hazardous waste to protect against hazards to the public health, domestic livestock, wildlife, or to the environment and to encourage the best use of natural resources.

(d) The department shall adopt and submit building standards relating to hazardous waste facilities for approval pursuant to Chapter 4 (commencing with Section 18935) of Part 2.5 of Division 13 of this code for the purposes described in this section.

(e) Before preparation of such building standards or adoption of such other regulations, the department shall consult with all agencies of interested local governments, including, but not limited to, local governing bodies, local planning agencies, local health authorities, and local building inspection departments, and secure technical assistance from the Department of Food and Agriculture, the Department of the California Highway Patrol, the Department of Fish and Game, the Department of Industrial Relations, the Division of Industrial Safety, the State Air Resources Board, the State Water Resources Control Board, the State

Fire Marshal, reg
Standards Commi

(Added by Stats.197
Stats.1974, c. 545, p.
1397, p. 4622, § 11;
March 2, 1982.)

As added in 1972 th

"The department sh
revise when appropri
dards and regulations
cessing, and disposal c
tremely hazardous
against hazards to th
domestic livestock, and
adoption of such stand
the department shall c
cies of interested loc
secure technical assist
partment of Agricultur
the California Highway
ment of Fish and Game
Industrial Relations, D
Safety, the State Air R
State Water Resources
the State Fire Marshal.

The 1974 amendmen
partment of Food and A
partment of Agricultur

The 1977 amendment
to read:

"The department sh
revise when appropria
dards and regulations f
cessing, use, storage, a
the recovery of resourc
and extremely hazardou
against hazards to th
domestic livestock, or t

"The department sh
dards and requirement
operation of facilities fo
ing, storing, and disp
waste, and for the rec
from hazardous waste.

"Before adoption of
regulations the depart
with all agencies of inte
ments and secure techni
the Department of Foo
the Department of the
Patrol, the Department
the Department of Indu
vision of Industrial Sa

Fire Marshal, regional water quality control boards, the State Building Standards Commission, and the State Solid Waste Management Board.

(Added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973. Amended by Stats.1974, c. 545, p. 1292, § 79; Stats.1977, c. 1039, p. 3145, § 15; Stats.1978, c. 1397, p. 4622, § 11; Stats.1979, c. 1152, p. 4311, § 190; Stats.1982, c. 89, § 8, eff. March 2, 1982.)

Historical Note

As added in 1972 the section read:

"The department shall adopt, and may revise when appropriate, minimum standards and regulations for the handling, processing, and disposal of hazardous and extremely hazardous wastes to protect against hazards to the public health, to domestic livestock, and to wildlife. Before adoption of such standards and regulations the department shall consult with all agencies of interested local governments and secure technical assistance from the Department of Agriculture, the Department of the California Highway Patrol, the Department of Fish and Game, the Department of Industrial Relations, Division of Industrial Safety, the State Air Resources Board, the State Water Resources Control Board and the State Fire Marshal.".

The 1974 amendment substituted "Department of Food and Agriculture" for "Department of Agriculture".

The 1977 amendment rewrote the section to read:

"The department shall adopt, and may revise when appropriate, minimum standards and regulations for the handling, processing, use, storage, and disposal of, and the recovery of resources from, hazardous and extremely hazardous wastes to protect against hazards to the public health, to domestic livestock, or to wildlife.

"The department shall establish standards and requirements for the use and operation of facilities for handling, processing, storing, and disposal of hazardous waste, and for the recovery of resources from hazardous waste.

"Before adoption of such standards and regulations the department shall consult with all agencies of interested local governments and secure technical assistance from the Department of Food and Agriculture, the Department of the California Highway Patrol, the Department of Fish and Game, the Department of Industrial Relations, Division of Industrial Safety, the State Air Resources Board, the State Water Resources Control Board, the State Fire Marshal, regional water quality control boards, and the State Solid Waste Management Board.".

The 1978 amendment substituted, at the end of the first paragraph [now subd. (a)], "to wildlife, or the environment" for "or to wildlife".

The 1979 amendment added the exception relating to § 18930 to the first paragraph [now subd. (a)]; added the exception relating to § 18930 to the second paragraph; added the third paragraph [now subd. (b)]; and in the last paragraph [now subd. (e)], substituted "Before preparation of such building standards or adoption of such other regulations" for "Before adoption of such standards and regulations" and added, to the end of that paragraph, "the State Building Standards Commission".

The 1982 amendment rewrote the first paragraph which previously read:

"Except as provided in Section 18930, the department shall adopt and may revise when appropriate, minimum standards and regulations for the handling, processing, use, storage, and disposal of, and the recovery of resources from, hazardous and extremely hazardous wastes to protect against hazard to the public health, to domestic livestock, to wildlife, or the environment."; designated the former first paragraph as subd. (a); added subds. (b) and (c); deleted the former second paragraph which had read:

"Except as provided in Section 18930, the department shall establish standards and requirements for the use and operation of facilities for handling, processing, storing, and disposal of hazardous waste, and for the recovery of resources from hazardous waste."; designated the former third paragraph as subd. (d); designated the former last paragraph as subd. (e); and inserted in subd. (e) following "local governments", the words "including, but not limited to, local governing bodies, local planning agencies,

local health authorities, and local building inspection departments,".

Cross References

Department or officers authorized to enforce standards and regulations adopted pursuant to this section, see § 25180.

Library References

Health and Environment ⇐25.5.
C.J.S. Health and Environment §§ 61 to 66, 69, 71 to 73, 78 to 80, 82 to 86, 88 to 90, 94, 104, 110, 115 to 126, 128, 129, 132, 133, 135, 137 to 140, 142, 144 to 153.

Notes of Decisions

1. In general

The Hazardous Waste Control Law (§ 25100 et seq.) which became operative on July 1, 1973, preempts existing local ordinances and regulations pertaining to the processing, handling and disposal of hazardous and extremely hazardous waste materials. 57 Ops.Atty.Gen. 159, 4-4-74.

§ 25150.1. Regulation of construction, operation, maintenance, monitoring, and testing of underground storage tanks for storage of hazardous wastes

The requirements in Sections 25284 and 25284.1 apply to the construction, operation, maintenance, monitoring, and testing of underground storage tanks, as defined in subdivision (m) of Section 25280, which are required to obtain hazardous waste facilities permits from the department. The department shall adopt regulations implementing the requirements of Sections 25284 and 25284.1, for regulating the construction, operation, maintenance, monitoring, and testing of underground storage tanks used for the storage of hazardous wastes which standards and regulations are necessary to protect against hazards to the public health, to domestic livestock, to wildlife, or to the environment. The regulations department shall adopt the regulations by January 1, 1985. If the regulations are not adopted by that date, the regulations adopted by the board implementing Section 25284.1 shall be deemed to be the regulations of the department pursuant to this section until new regulations are adopted by the department pursuant to this section.

(Added by Stats.1983, c. 1046, § 2.)

Historical Note

Legislative findings and declarations of Stats.1983, c. 1046, see note under § 25280.

§ 25150.5. Time for adoption of standards and regulations

The department shall adopt all standards and regulations required to be adopted by any provision of this chapter, and shall revise any standard or regulation required to be revised by the act which enacted

this section duri
the Legislature,
(Added by Stats.1

§ 25151. Var
The departme
25150, other tha
depending on po
hazardous waste
nology available
waste handling,
(Added by Stats.1
Stats.1979, c. 115

The 1979 amendm
ing requirements ot
dards" for "varying
The 1982 amendm
ing regulations purs
other than building s
requirements other
dards"; inserted, fol

1. In general
The Hazardous
(§ 25100 et seq.) whi
July 1, 1973, preem

§ 25152. Pub
Before adopti
standards and r
recycling, and d
the department s
a city within th
regulations. Ex
adopt the propos
are appropriate i
public hearing o
(Added by Stats.19
Stats.1977, c. 1039,
c. 89, § 10, eff. M

this section during the 1981 portion of the 1981–1982 Regular Session of the Legislature, on or before January 1, 1983.

(Added by Stats.1982, c. 89, § 8.5, eff. March 2, 1982.)

§ 25151. Variances; factors considered

The department may adopt varying regulations pursuant to Section 25150, other than building standards for different areas of the state depending on population density, climate, geology, types and volumes of hazardous waste generated in the area, types of waste treatment technology available in the area, and other factors relevant to hazardous waste handling, processing, storing, recycling, and disposal.

(Added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973. Amended by Stats.1979, c. 1152, p. 4311, § 191; Stats.1982, c. 89, § 9, eff. March 2, 1982.)

Historical Note

The 1979 amendment substituted "varying requirements other than building standards" for "varying standards".

The 1982 amendment substituted "varying regulations pursuant to Section 25150, other than building standards" for "varying requirements other than building standards"; inserted, following the word "geology", "types and volumes of hazardous waste generated in the area, types of waste treatment technology available in the area,"; and substituted at the end of the section "hazardous waste handling, processing, storing, recycling, and disposal." for "hazardous waste processing and disposal.".

Notes of Decisions

1. In general

The Hazardous Waste Control Law (§ 25100 et seq.) which became operative on July 1, 1973, preempts existing local ordinances and regulations pertaining to the processing, handling and disposal of hazardous and extremely hazardous waste materials. 57 Ops.Atty.Gen. 159, 4-4-74.

§ 25152. Public hearings

Before adopting building standards or adopting or revising other standards and regulations for the handling, processing, storing, use, recycling, and disposal of hazardous and extremely hazardous wastes, the department shall hold at least one public hearing in Sacramento, or in a city within the area of the state to be affected by the proposed regulations. Except as provided in Section 18930, the department shall adopt the proposed regulations after making changes or additions that are appropriate in view of the evidence and testimony presented at the public hearing or hearings.

(Added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973. Amended by Stats.1977, c. 1039, p. 3146, § 16; Stats.1979, c. 1152, p. 4311, § 192; Stats.1982, c. 89, § 10, eff. March 2, 1982.)

Historical Note

The 1977 amendment, preceding the words "the department", substituted "Before adopting or revising minimum standards and regulations for the handling, processing, storing, uses, and the disposal of, and the recovery of resources from, hazardous and extremely hazardous waste" for "Before adopting or revising minimum standards and regulations for the handling, processing, and disposal of hazardous and extremely hazardous wastes,".

The 1979 amendment inserted in the introduction the words "building standards or adopting"; and added the exception at the beginning of the second sentence.

The 1982 amendment substituted the introductory provisions preceding the words "the department" for the provisions as last amended in 1979 which had read:

"Before adopting building standards or adopting or revising other minimum standards and regulations for the handling, processing, storing, uses, and disposal of and the recovery of resources from, hazardous and extremely hazardous wastes,".

Notes of Decisions

1. In general

The Hazardous Waste Control Law (§ 25100 et seq.) which became operative on July 1, 1973, preempts existing local ordinances and regulations pertaining to the processing, handling and disposal of hazardous and extremely hazardous waste materials. 57 Ops.Atty.Gen. 159, 4-4-74.

§ 25153. Disposal of extremely hazardous waste; notice to department

Any person who is producing a material which he or she knows, or should know, or may reasonably consider, to be an extremely hazardous waste, and which he or she does not intend to recycle for reuse and intends to dispose of, shall notify the department of his or her intent to dispose of that material. The notification shall be sworn to or submitted under penalty of perjury.

(Added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973. Amended by Stats.1977, c. 1039, p. 3146, § 17; Stats.1982, c. 496, § 4, eff. July 12, 1982.)

Historical Note

The 1977 amendment rewrote the section which, as added, had read:

"Any person who is producing a waste material which he may reasonably consider to be an extremely hazardous waste, and which he does not intend to recycle for reuse and intends to dispose of as waste, shall notify the department of his intent to dispose of such waste material.".

The 1982 amendment substituted "producing a material which he or she knows, or should know, or may reasonably consider," for "producing a material which he may reasonably consider"; neutralized gender throughout the rest of the first sentence; substituted at the end of the first sentence "that material" for "material"; and added the second sentence.

§ 25154. Unlawful handling, storage, use, processing or disposal of hazardous waste

It shall be unlawful for any person to handle, store, use, process, or dispose of any hazardous waste or extremely hazardous waste except as

provided for in thi
pursuant to this ch

(Added by Stats.1972,
Stats.1977, c. 1039, p.

The 1977 amendment
which, as added, had re
"After the effective
tions adopted by the de
to this article, it shall b
person to dispose of an
tremely hazardous waste
for in such regulations."

§ 25155. Dispos
ful p

No extremely ha
processing to remo
regulations of the
particular extremely

(Added by Stats.1972,
Stats.1974, c. 545, p. 1

The 1974 amendment
beginning of the section
January 1, 1974".

The 1977 amendment
the first use of the

§ 25156. Hazardo
dards;

The department s
implement the provis
The department sha
technical advisory co

(Added by Stats.1980,

Costs incurred, payment f

Health and Environment

provided for in this chapter or regulations adopted by the department pursuant to this chapter.

(Added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973. Amended by Stats.1977, c. 1039, p. 3146, § 18; Stats.1982, c. 89, § 10.5, eff. March 2, 1982.)

Historical Note

The 1977 amendment rewrote the section which, as added, had read:

"After the effective date of the regulations adopted by the department pursuant to this article, it shall be unlawful for any person to dispose of any hazardous or extremely hazardous waste except as provided for in such regulations.".

The 1982 amendment substituted "hazardous waste or extremely hazardous waste" for "hazardous or extremely hazardous waste"; and substituted "this chapter or regulations" for "regulations".

§ 25155. Disposal of extremely hazardous waste: removal of harmful properties or as specified by regulations

No extremely hazardous waste may be disposed of without prior processing to remove its harmful properties or as specified by the regulations of the department for the handling and disposal of the particular extremely hazardous waste.

(Added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973. Amended by Stats.1974, c. 545, p. 1292, § 80; Stats.1977, c. 1039, p. 3146, § 19.)

Historical Note

The 1974 amendment deleted from the beginning of the section the words "After January 1, 1974".

The 1977 amendment deleted following the first use of the words "hazardous waste", the words "as listed by the department pursuant to Section 25140".

§ 25156. Hazardous waste disposal land use; regulations and standards; recommendations

The department shall develop and adopt regulations and standards to implement the provisions of Article 11 (commencing with Section 25220). The department shall seek recommendations of the hazardous waste technical advisory committee on wording of proposed regulations.

(Added by Stats.1980, c. 1161, p. 3900, § 3.)

Cross References

Costs incurred, payment from Hazardous Waste Control Account, see § 25239.

Library References

Health and Environment ⟹20.

C.J.S. Health and Environment §§ 2 to 6, 44 to 47, 62 to 64, 106, 125, 128, 130, 132, 137.

§ 25157. Treatment of extremely hazardous waste at site of production prior to transportation; disposal of hazardous waste at site of production

Regulations adopted pursuant to this chapter may require the treatment of extremely hazardous waste at the site of production prior to any transportation, if the director determines that treatment is necessary to provide safe transportation of the extremely hazardous waste. No provision of this chapter shall be construed to require disposal of hazardous waste at the site of production, provided, that the transportation of the extremely hazardous waste conforms to all applicable regulations.

(Added by Stats.1982, c. 89, § 11, eff. March 2, 1982.)

Historical Note

Derivation: Former § 25171, added by Stats.1972, c. 1236, p. 2388, § 1.

Administrative Code References

Disposal on land, see 22 Cal.Adm. Code 60237.

§ 25157.3. Emergency regulations for management of infectious waste as hazardous waste

The state department shall adopt and develop emergency regulations for the management of infectious waste as hazardous waste within 90 days after the effective date of this section. The regulations shall be deemed to be necessary for the immediate preservation of the public peace, health, safety, or general welfare.

(Added by Stats.1982, c. 1060, § 3, eff. Sept. 15, 1982.)

Library References

Health and Environment ⟹23.
C.J.S. Health and Environment §§ 18 to 21.

Article 5.5
COORDINATION WITH FEDERAL ACTS

Section

25159. Administration of state program in lieu of federal program; regulations.
25159.5. Adoption or revision of standards and regulations; conformance with corresponding federal regulations.
25159.6. Standards and regulations applicable until adoption of others by the department.
25159.7. Implementation of management responsibilities and regulations from federal law.

Section

25159.8. Trade secr
25159.9. Sharing of protectio

Article 5.5 v 2, 1982.

§ 25159. Admin gran

To the extent au and revise when receive and mainta program in lieu o Public Law 94-580

(Added by Stats.1982

[1] 42 U.S.C.A. § 6926.

Health and Environm
C.J.S. Health and Er seq., 106 et seq., 1

§ 25159.5. Adop fo

In adopting or chapter, the depar dards and regulati by the United St Public Law 94-580 ery Act of 1976, 4 preclude the depar are more stringent

(Added by Stats.1982

[1] 42 U.S.C.A. § 6901

§ 25159.6. Stan ot

Until such time corresponding to a regulations adopte Agency pursuant t Law 94-580, as an

(a) Any person v defined by Section adopted thereunde

Section
25159.8. Trade secret information.
25159.9. Sharing of information between department and federal environmental protection agency.

Article 5.5 was added by Stats.1982, c. 89, § 12.5, eff. March 2, 1982.

§ 25159. Administration of state program in lieu of federal program; regulations

To the extent authorized by Section 25145, the department shall adopt and revise when necessary regulations which will allow the state to receive and maintain authorization to administer a state hazardous waste program in lieu of the federal program pursuant to Section 3006 of Public Law 94–580, as amended (42 U.S.C. 6926)[1].

(Added by Stats.1982, c. 89, § 12.5, eff. March 2, 1982.)

[1] 42 U.S.C.A. § 6926.

Library References

Health and Environment ⟹25.5(5).
C.J.S. Health and Environment §§ 91 et seq., 106 et seq., 131.

§ 25159.5. Adoption or revision of standards and regulations; conformance with corresponding federal regulations

In adopting or revising standards and regulations pursuant to this chapter, the department shall, insofar as practicable, make such standards and regulations conform with corresponding regulations adopted by the United States Environmental Protection Agency pursuant to Public Law 94–580, as amended (the Resource Conservation and Recovery Act of 1976, 42 U.S.C. 6901 et seq.)[1]. Nothing in this section shall preclude the department from adopting standards and regulations which are more stringent or more extensive than federal regulations.

(Added by Stats.1982, c. 89, § 12.5, eff. March 2, 1982.)

[1] 42 U.S.C.A. § 6901 et seq.

§ 25159.6. Standards and regulations applicable until adoption of others by the department

Until such time as the department adopts standards and regulations corresponding to and equivalent to, or more stringent or extensive than, regulations adopted by the United States Environmental Protection Agency pursuant to Sections 3002, 3003, 3004, 3005 and 3006 of Public Law 94–580, as amended,[1] the following shall apply:

(a) Any person who produces a waste which is a hazardous waste as defined by Section 25117 shall comply with this chapter and regulations adopted thereunder and, in addition, to the extent that the waste is both

hazardous as defined by regulations adopted pursuant to Section 3001 of the Resource Conservation and Recovery Act, as amended (P.L. 94–580)[2] and has not been excluded from regulation pursuant to that section, the person shall also comply with federal regulations adopted pursuant to Section 3002 of that federal act.

(b) Any person who transports a waste which is a hazardous waste as defined by Section 25117 shall comply with this chapter and regulations adopted thereunder and, in addition, to the extent that such waste is both hazardous as defined by regulations adopted pursuant to Section 3001 of the Resource Conservation and Recovery Act, as amended (P.L. 94–580), and has not been excluded from regulation pursuant to that section, the person shall also comply with federal regulations adopted pursuant to Section 3003 of that act.

(c) Any person who owns or operates a hazardous waste facility shall comply with this chapter and regulations adopted thereunder and, in addition, to the extent that the facility is defined as a hazardous waste facility in regulations adopted under the Resource Conservation and Recovery Act, as amended (P.L. 94–580), and to the extent that the waste is both hazardous as defined by regulations adopted pursuant to Section 3001 of that act and has not been excluded from regulation pursuant to that section, such person shall also comply with federal regulations adopted pursuant to Sections 3004 and 3005 of that act.

(Added by Stats.1982, c. 89, § 12.5, eff. March 2, 1982.)

[1] 42 U.S.C.A. §§ 6922, 6923, 6924, 6925, 6926.

[2] 42 U.S.C.A. § 6921.

§ 25159.7. Implementation of management responsibilities and regulations from federal law

Except as otherwise authorized, the Department of Health Services is authorized to carry out all hazardous waste management responsibilities imposed or authorized by Public Law 94–580, as amended,[1] Public Law 96–510 (the Comprehensive Environmental Response, Compensation, and Liability Act of 1980), and subsequent amendments, and any regulations promulgated pursuant to these federal acts.

(Added by Stats.1982, c. 89, § 12.5, eff. March 2, 1982.)

[1] 42 U.S.C.A. § 6901 et seq.

§ 25159.8. Trade secret information

Nothing in this chapter shall be construed as prohibiting the furnishing of trade secret information to the federal Environmental Protection Agency to the extent required by law to obtain and maintain interim and final authorization to implement the state hazardous waste program in lieu of the federal program under the Resource Conservation and Recovery Act of 1976, P.L. 94–580, as amended (42 USC 6901 et seq.)[1]. If the department has received a written claim that particular information

furnished to the E
inform the EPA.

(Added by Stats.198

[1] 42 U.S.C.A. § 6901

§ 25159.9. Sha e

Notwithstandin
available to the f
information requi
the Resource Co
amended (42 USC
and final authoriz
in lieu of the fede
department and t
waiver by the de
confidentiality of

(Added by Stats.198

[1] 42 U.S.C.A. § 6901

Section
25160. List furni
25161. Rules and
25162. Document
25163. Registrati
25163.1. Registrati not inci
25165. Applicatio
25166. Fees.
25167. Payment

Article 6 operative Jul

§ 25160. List f ren

The person pro
any truck, a crev
carrying such haz
ous wastes carrie
and mineral comp
minimum percent
carried. The list,

furnished to the EPA is trade secret information, the department shall so inform the EPA.

(Added by Stats.1982, c. 89, § 12.5, eff. March 2, 1982.)

[1] 42 U.S.C.A. § 6901 et seq.

§ 25159.9. Sharing of information between department and federal environmental protection agency

Notwithstanding any other provision of law, the department may make available to the federal Environmental Protection Agency any and all information required by law to be furnished to such agency pursuant to the Resource Conservation and Recovery Act of 1976, P.L. 94-580, as amended (42 USC 6901 et seq.)[1] in order to obtain and maintain interim and final authorization to administer the state hazardous waste program in lieu of the federal program. The sharing of information between the department and the EPA pursuant to this section shall not constitute a waiver by the department or any affected person of any privilege or confidentiality of such information provided by law.

(Added by Stats.1982, c. 89, § 12.5, eff. March 2, 1982.)

[1] 42 U.S.C.A. § 6901 et seq.

Article 6

TRANSPORTATION

Section

25160. List furnished carrier or handler; required contents; surrender.
25161. Rules and regulations.
25162. Documents satisfying requirements.
25163. Registration; exemptions; inspection.
25163.1. Registration; persons not in business of hauling hazardous wastes or not incidental to any business.
25165. Application for registration; form; fees; filing; contents; signature.
25166. Fees.
25167. Payment of fees.

Article 6 was added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973.

§ 25160. List furnished carrier or handler; required contents; surrender

The person producing a hazardous waste shall provide the driver of any truck, a crew member of any train, or the captain of any vessel carrying such hazardous wastes with a list setting forth: (a) the hazardous wastes carried, (b) the amount of the waste, (c) the general chemical and mineral composition of the waste listed by probable maximum and minimum percentages, and (d) the origin and destination of the waste carried. The list, when appropriate, shall include information on anti-

dotes, first aid, or safety measures to be taken in case of accidental contact with the particular hazardous waste being carried. The person carrying, or handling the hazardous waste shall have the list in his possession while carrying or handling the hazardous waste and shall release the list to a person responsible for disposal of the hazardous waste at the time of delivery. The list shall be shown upon demand to any department official, officer of the California Highway Patrol, any local health officer, or any local public officer as designated by the director.

(Added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973. Amended by Stats.1977, c. 1039, p. 3146, § 20; Stats.1982, c. 496, § 5, eff. July 12, 1982.)

Historical Note

The 1977 amendment substituted, at the beginning of the section, "The person producing a hazardous waste shall provide the driver" for "After January 1, 1974, the person producing a hazardous waste listed by the department pursuant to Section 25140 shall provide the driver"; and added in the last sentence the words "any local health officer".

The 1982 amendment substituted, as the ending for the first sentence, "(a) the hazardous waste carried, (b) the amount of the waste, (c) the general chemical and mineral composition of the waste listed by probable maximum and minimum percentages, and (d) the origin and destination of the waste carried." for "the hazardous wastes carried, the amount of such waste, the general chemical and mineral composition of such waste listed by probable maximum and minimum percentages, and the origin and destination of any such waste carried."; substituted, at the beginning of the second sentence, "The list, when appropriate, shall include information on antidotes" for "Such list, when appropriate may include information on antidotes,"; and substituted, at the beginning of the last sentence, "The list" for "Such list".

Cross References

Department and officers authorized to enforce this section, see § 25180.
Possession of list, exemption, see § 25163.
Punishment for carrying or handling hazardous waste without driver's possession of list specified in this section, see § 25191.

Library References

Health and Environment ⇐25.5.
C.J.S. Health and Environment §§ 61 to 66, 69, 71 to 73, 78 to 80, 82 to 86, 88 to 90, 94, 104, 110, 115 to 126, 128, 129, 132, 133, 135, 137 to 140, 142, 144 to 153.

§ 25161. Rules and regulations

The department shall adopt and enforce all rules and regulations, including the form and content of the list, necessary and appropriate to accomplish the purposes of Section 25160.

(Added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973.)

§ 25162. Doc

Documents r
government wh
wastes being c
(Added by Stats.1

§ 25163. Reg

(a) Except as
unlawful for a
hazardous waste
the department,
custody of a ha
registration issu
department to a
person to whom

(b) Persons ha
toilet waste tha
other than the b
registration issu
ative pursuant t
exempt from the

(c) Persons ha
facility for trans
not exceed a tota
of 50 pounds, sh
and (e) and from
sion of the list
meeting all of th

(1) The conter
gallon or 10 pou

(2) The hazard
in a manner th
breaking during

(3) Different h
tainer during the

(4) The hazard
ous waste in Sec
Code.

(5) The person
hazardous waste.

(d) Any persor
subdivision (a) sh
Chapter 6 (comm
Code, but shall c
as the health off

§ 25162. Documents satisfying requirements

Documents required by other agencies of the state or the federal government which describe the character and amount of hazardous wastes being carried shall satisfy the requirement of Section 25160.

(Added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973.)

§ 25163. Registration; exemptions; inspection

(a) Except as otherwise provided in subdivisions (b) and (c), it is unlawful for any person to carry on, or engage in the hauling of hazardous wastes, unless such person holds a valid registration issued by the department, and it shall be unlawful for any person to transfer custody of a hazardous waste to a hauler who does not hold a valid registration issued by the department. Any registration issued by the department to a hauler of hazardous waste is not transferable from the person to whom it was issued to any other person.

(b) Persons hauling only septic tank, cesspool, seepage pit, or chemical toilet waste that does not contain a hazardous waste originating from other than the body of a human or animal and who hold an unrevoked registration issued by the health officer or his duly authorized representative pursuant to Chapter 6 (commencing with Section 25000) shall be exempt from the requirements of subdivision (a).

(c) Persons hauling hazardous wastes to a permitted hazardous waste facility for transfer, treatment, recycling, or disposal, which wastes do not exceed a total volume of five gallons or do not exceed a total weight of 50 pounds, shall be exempt from the requirements of subdivisions (a) and (e) and from the requirements of Section 25160 concerning possession of the list while carrying or handling hazardous waste, upon meeting all of the following conditions:

(1) The contents of any single container hauled do not exceed one gallon or 10 pounds.

(2) The hazardous wastes are hauled in closed containers and packed in a manner that prevents the containers from tipping, spilling, or breaking during the hauling.

(3) Different hazardous waste materials are not mixed within a container during the hauling.

(4) The hazardous waste hauled is not listed as an extremely hazardous waste in Section 66685 of Title 22 of the California Administrative Code.

(5) The person hauling the hazardous waste is the generator of that hazardous waste.

(d) Any person registered as a hazardous waste hauler pursuant to subdivision (a) shall not be subject to the registration requirements of Chapter 6 (commencing with Section 25000) of the Health and Safety Code, but shall comply with the terms, conditions, orders, and directions as the health officer or his or her duly authorized representative may

deem necessary for the protection of human health and comfort, and shall otherwise comply with the requirements for statements as provided in Section 25007. Violations of those requirements of Section 25007 shall be punished as provided in Section 25010. Proof of registration pursuant to subdivision (a) shall be submitted by mail or in person to the local health officer in the city, county, or city and county in which the registered hazardous waste hauler will be conducting the activities described in Section 25001.

(e) It is unlawful for any person to transport hazardous waste in any truck, trailer, semitrailer, vacuum tank, or cargo tank not inspected by the California Highway Patrol or to transport hazardous waste in any container, other than a container packaged pursuant to Federal Department of Transportation regulations, which has not been inspected by the California Highway Patrol.

(Added by Stats.1977, c. 1039, p. 3147, § 21. Amended by Stats.1979, c. 1097, p. 3963, § 1; Stats.1980, c. 848, p. 2642, § 1; Stats.1980, c. 1112, p. 3575, § 1.6; Stats.1983, c. 1037, § 2, eff. Sept. 22, 1983.)

Historical Note

The 1979 amendment substituted, following the exception in subd. (a), "it is unlawful for any person" for "after January 1, 1979, it shall be unlawful for any person"; and added subd. (c) [now subd. (b)].

The 1980 amendment by c. 1112 added the second sentence in subd. (a); inserted subd. (c); and relettered former subd. (c) as subd. (d).

Amendment of this section by § 2 of Stats.1980, c. 848, p. 2642, failed to take effect under the terms of § 4 of that Act.

Amendment of this section by § 1.5 of Stats.1980, c. 1112, p. 3574, failed to take effect under the terms of § 12 of that Act.

The 1983 amendment, in subd. (a), in the first sentence, pluralized "subdivision", inserted "and (c)", deleted ", the business of hauling hazardous waste, or" following "engage in" and pluralized "waste"; inserted a new subd. (c) and relettered the subsequent subdivisions accordingly.

Section 1 of Stats.1983, c. 1037, provides:

"The Legislature hereby finds and declares the following:

"(a) Existing law encourages private citizens and small business to violate the state's hazardous waste control laws by making proper disposal of minimal amounts of hazardous waste unreasonably costly.

"(b) In some instances, the misinterpretation of state law governing the transportation of hazardous waste has prohibited private citizens from properly disposing of hazardous waste byproducts without registering as a hazardous waste hauler or employing the use of one.

"(c) The costs involved in utilizing a hazardous waste hauler for these purposes is an undue financial burden on small hazardous waste generators, thereby encouraging individuals to illegally dump hazardous byproducts at solid waste disposal sites or to engage in illegal dumping by other means as these are the most cost-effective alternative methods.

"(d) Since the illegal disposal of hazardous wastes constitutes a clear and present danger to the public and the environment, it is the intent of the Legislature to encourage and promote the proper disposal of minimal amounts of hazardous wastes, thereby promoting public responsibility for that activity."

Cross References

Department and officers authorized to enforce subds. (a) and (d) of this section, see § 25180.

Punishment for engaging in transportation of hazardous waste in violation of subds. (a) or (d) of this section, see § 25191.

§ 25163.1. Reg
o

The department
hauling hazardous
ous wastes or wh
to, any business,
Section 25163 if t
(c) of Section 251
(Added by Stats.198

Legislative intent, see

§ 25165. Appli
sig

(a) A hazardou
registration shall
accompanied by t

(b) Any applica
with the departm
partnership, the
applicant to the f
residence of the a
the business, if a
shall require, and
and locations wh
application shall b
corporation, or by
(Added by Stats.19
3964, § 2.)

The 1979 amendme
(a) and (b), the forme
which had read:

"An application fo
this section shall be
ment. The applicatio
provided by the depa
the name in full, if a

§ 25166. Fees

(a) A registrat
department by ea
hauling hazardou
or incidental to, a

§ 25163.1. Registration; persons not in business of hauling hazardous wastes or not incidental to any business

The department shall not adopt any regulations requiring a person hauling hazardous wastes, who is not in the business of hauling hazardous wastes or who is not hauling these wastes as a part of, or incidental to, any business, to obtain the registration specified in subdivision (a) of Section 25163 if that person meets the conditions specified in subdivision (c) of Section 25163.

(Added by Stats.1983, c. 1037, § 3, eff. Sept. 22, 1983.)

Cross References

Legislative intent, see § 25163.

§ 25165. Application for registration; form; fees; filing; contents; signature

(a) A hazardous waste hauler's application for original and renewal registration shall be on a form provided by the department and shall be accompanied by the appropriate fees.

(b) Any application for registration under this section shall be filed with the department. The application shall state the name in full, if a partnership, the names of each of the partners, the relation of the applicant to the firm or partnership, the place of business and place of residence of the applicant for registration and of each of the partners in the business, if a partnership, such other information as the department shall require, and shall designate, as specifically as practical, the areas and locations where it is proposed to dispose of hazardous waste. The application shall be signed by the authorized officer of a corporation, if a corporation, or by the managing partner, if a partnership.

(Added by Stats.1977, c. 1039, p. 3147, § 22. Amended by Stats.1979, c. 1097, p. 3964, § 2.)

Historical Note

The 1979 amendment, rewrote, as subds. (a) and (b), the former first two sentences which had read:

"An application for registration under this section shall be filed with the department. The application shall be on a form provided by the department and shall state the name in full, if a partnership, the names of each of the partners, the relation of the applicant to the firm or partnership, the place of business and place of residence of the applicant for registration and of each of the partners in the business, if a partnership, and shall designate, as specifically as practical, the areas and locations where it is proposed to dispose of hazardous waste.".

§ 25166. Fees

(a) A registration fee of fifty dollars ($50) shall be paid to the department by each person who carries on, or engages in, the business of hauling hazardous waste or who handles hazardous waste as a part of, or incidental to, any business, for a calendar year or any portion thereof.

(b) A person who transports hazardous waste as a substantial part of any business or who transports hazardous wastes in vehicles designed for such transport shall also pay to the department fifteen dollars ($15) for the first vehicle used for the transportation of hazardous waste, ten dollars ($10) per vehicle for the second through sixth vehicle, and five dollars ($5) per vehicle for the seventh and any other vehicle, for a calendar year, or a prorated amount thereof for the unexpired portion of a calendar year.

(c) For the purposes of this section, "substantial part of any business" shall mean the generation of more than thirty-five thousand dollars ($35,000) in annual gross revenue from the hauling of hazardous waste within California during a calendar year. The fees imposed by this section are for the privilege of engaging in a business.

(Added by Stats.1977, c. 1039, p. 3147, § 23. Amended by Stats.1978, c. 664, p. 2134, § 1.)

Historical Note

The 1978 amendment inserted subdivision designations; and rewrote the former third sentence [now subd. (c)] which had read:

"For the purposes of this section, 'substantial part of any business' shall mean 8 percent or more of the total cargo transported during a calendar year.".

Cross References

Inspection of containers, fee to be collected at the same time as registration and vehicle fees prescribed by this section, see § 25168.5.

§ 25167. Payment of fees

The fees prescribed in Section 25166 shall be payable each year not later than the first day of February or within 30 days after commencing the use of any vehicle to haul hazardous waste, whichever occurs later, and deposited in the Hazardous Waste Control Account in the General Fund for administering the provisions of this chapter.

(Added by Stats.1977, c. 1039, p. 3148, § 24. Amended by Stats.1980, c. 804, p. 2532, § 1.)

Historical Note

The 1980 amendment inserted, following "whichever occurs later,", the words "and deposited in the Hazardous Waste Control Account in the General Fund".

Article 6.5

HAZARDOUS WASTE HAULERS

Section
25167.1. Citation of article; legislative intent.
25167.2. Legislative finding and declaration.

Section
25167.3. Legislative
25168. Inspection;
25168.1. Regulation
25168.2. Suspension registrat
25168.3. Certificate
25168.4. Fee for an
25168.5. Fee for an
25168.6. Deposit of
25169. Ability of
25169.1. Annual ins tainer d
25169.3. Transporta tions; e

Article 6.5

§ 25167.1. Cita

This article may
Haulers Act. It i
provisions to preer
specifically relatin
materials or nucle
(Added by Stats.197

Health and Environm

§ 25167.2. Leg

The Legislature
ardous waste are
reasonable safegu
transporting hazar
the public health a
(Added by Stats.197

§ 25167.3. Leg

It is the intent
regulations and al
tation of hazardou
tration of trucks,
containers used t
agency, city, city a
state, including, b

Section
25167.3. Legislative intent; preemption.
25168. Inspection; certificate of compliance; training of personnel.
25168.1. Regulations for containers; inspection by highway patrol.
25168.2. Suspension or revocation of certification or registration; denial of registration application; grounds.
25168.3. Certificate of compliance with inspection.
25168.4. Fee for annual inspection.
25168.5. Fee for annual inspection; time of collection.
25168.6. Deposit of inspection fees; appropriation for expenses of inspection.
25169. Ability of transporter to respond in damages.
25169.1. Annual inspection by highway patrol; certificate of compliance; container defined.
25169.3. Transportation from abandoned site to another disposal site; conditions; exceptions.

Article 6.5 was added by Stats.1979, c. 1097, p. 3964, § 3.

§ 25167.1. Citation of article; legislative intent

This article may be cited and shall be known as the Hazardous Waste Haulers Act. It is not the intent of the Legislature in enacting these provisions to preempt or weaken any state or federal law or regulation specifically relating to the handling or transportation of radioactive materials or nuclear waste.

(Added by Stats.1979, c. 1097, p. 3964, § 3.)

Library References

Health and Environment ⇐20.

C.J.S. Health and Environment §§ 2 to 6, 44 to 47, 62 to 64, 106, 125, 128, 130, 132, 137.

§ 25167.2. Legislative finding and declaration

The Legislature finds and declares that increasing quantities of hazardous waste are being produced in this state and that adequate and reasonable safeguards in handling hazardous wastes, particularly in transporting hazardous wastes to disposal sites, are necessary to protect the public health and environment.

(Added by Stats.1979, c. 1097, p. 3964, § 3.)

§ 25167.3. Legislative intent; preemption

It is the intent of the Legislature that this article preempt all local regulations and all conflicting state regulations concerning the transportation of hazardous waste, including all inspection, licensing, and registration of trucks, trailers, semitrailers, vacuum tanks, cargo tanks, and containers used to transport all types of hazardous wastes. No state agency, city, city and county, county, or other political subdivision of this state, including, but not limited to, a chartered city, city and county, or

county, shall adopt or enforce any ordinance or regulation which is inconsistent with the rules and regulations adopted by the State Department of Health Services, the Department of the California Highway Patrol, or the State Fire Marshal pursuant to this article.

(Added by Stats.1979, c. 1097, p. 3964, § 3. Amended by Stats.1980, c. 1112, p. 3576, § 2.)

Historical Note

The 1980 amendment substituted "this article" for "this act" in two places and added the word "semitrailers".

§ 25168. Inspection; certificate of compliance; training of personnel

No registration shall be granted under this article unless:

(a) The truck, trailer, semitrailer, vacuum tank, cargo tank, or container, excluding containers holding hazardous waste packages pursuant to Federal Department of Transportation requirements, used to transport all types of hazardous wastes, has been inspected and received a certificate of compliance under this article, and

(b) The owner or operator provides documentation indicating that all persons who will operate the truck, trailer, semitrailer, vacuum tank, cargo tank, or container have received training adequate to ensure the safe handling of the hazardous waste to be transported.

(Added by Stats.1979, c. 1097, p. 3964, § 3. Amended by Stats.1980, c. 1112, p. 3576, § 3.)

Historical Note

The 1980 amendment inserted the word "semitrailer" in two places.

§ 25168.1. Regulations for containers; inspection by highway patrol

The department shall adopt regulations for containers used to transport hazardous wastes not covered or packaged as required by federal regulations contained in Title 49 of the Code of Federal Regulations. The Department of the California Highway Patrol shall conduct an annual inspection of every truck, trailer, semitrailer, vacuum tank, cargo tank, or container used by registered waste haulers to transport hazardous waste on the highways. The inspection shall be designed to determine if each vehicle complies with the Vehicle Code and with regulations adopted by the State Fire Marshal under Section 34020 of the Vehicle Code, by the Highway Patrol under subdivisions (a) and (b) of Section 34501 of the Vehicle Code, and by the State Department of Health Services for containers used to haul hazardous waste. The Department of the California Highway Patrol shall determine whether the construc-

tion, design, equ
semitrailer, vacu
the standards w
safe transportat

(Added by Stats.1
3576, § 4; Stats.1

The 1980 amendm
throughout the secti
The 1981 amendm
the second senten

§ 25168.2. Su

The departme
11500) of Part 1
or revoke the ce
cargo tank, or co
or revoke the re
hazardous waste

(a) Failure of
upon application

(b) Failure of
container owned
adopted under S
the Vehicle Code
for containers us

(c) Failure or
trailer, semitrail
truck, trailer, se
ble for inspectio
reasonable notic

(d) Failure to
25169.

(e) Violation o

(Added by Stats.1
3577, § 5; Stats.1

The 1980 amendm
throughout the secti
The 1982 amendm
suspend or revoke t

tion, design, equipment, and safety features of every such truck, trailer, semitrailer, vacuum tank, cargo tank, or container are in compliance with the standards which the department determines are necessary for the safe transportation of hazardous waste.

(Added by Stats.1979, c. 1097, p. 3964, § 3. Amended by Stats.1980, c. 1112, p. 3576, § 4; Stats.1981, c. 912, p. 3450, § 1, eff. Sept. 28, 1981.)

Historical Note

The 1980 amendment added "semitrailer" throughout the section.

The 1981 amendment at the beginning of the second sentence, before "California Highway Patrol", inserted "Department of the"; and, in the third sentence, following "complies with" inserted "the Vehicle Code and with".

§ 25168.2. Suspension or revocation of certification or registration; denial of registration application; grounds

The department may, pursuant to Chapter 5 (commencing with Section 11500) of Part 1 of Division 3 of Title 2 of the Government Code, suspend or revoke the certification of a truck, trailer, semitrailer, vacuum tank, cargo tank, or container used to haul hazardous waste and may suspend or revoke the registration or deny the application for registration of a hazardous waste hauler for any of the following reasons:

(a) Failure of the registrant to pay required fees or misrepresentation upon application for original or renewal registration.

(b) Failure of a truck, trailer, semitrailer, vacuum tank, cargo tank, or container owned or operated by a registrant to comply with regulations adopted under Section 34020, subdivisions (a) and (b) of Section 34501 of the Vehicle Code, and those regulations promulgated by the department for containers used to haul hazardous waste.

(c) Failure or refusal of the registrant to permit inspection of a truck, trailer, semitrailer, vacuum tank, cargo tank, or container or make a truck, trailer, semitrailer, vacuum tank, cargo tank, or container available for inspection by a member of the California Highway Patrol upon reasonable notice.

(d) Failure to possess the minimum insurance, as prescribed in Section 25169.

(e) Violation of any provisions of this division.

(Added by Stats.1979, c. 1097, p. 3964, § 3. Amended by Stats.1980, c. 1112, p. 3577, § 5; Stats.1982, c. 1230, § 1.)

Historical Note

The 1980 amendment added "semitrailer" throughout the section.

The 1982 amendment substituted "may suspend or revoke the registration or deny the application for registration of a hazardous waste hauler" for "may revoke the registration of a hazardous waste hauler" in the introductory provision.

Cross References

Temporary suspension of certification of container used to transport hazardous waste and suspension of registration of hazardous waste hauler prior to hearing, remedies additional to those provided in this section, see § 25186.

§ 25168.3. Certificate of compliance with inspection

(a) Once a truck, trailer, semitrailer, vacuum tank, cargo tank, or container has been inspected and found to be in compliance with all design, construction, and safety requirements, the department shall issue a sticker, label, or other suitable device constituting a certificate of compliance to identify waste hauling vehicles which have passed inspection. The certificate of compliance shall be plainly affixed to the truck, trailer, semitrailer, vacuum tank, cargo tank, or container. The size, shape, color, and design of the certificate of compliance and the positioning of the certificate shall be determined by the department.

(b) The indicia required by this section shall be incorporated with, or take the place of, any indicia issued pursuant to the provisions of this article.

(Added by Stats.1979, c. 1097, p. 3964, § 3. Amended by Stats.1980, c. 1112, p. 3577, § 6.)

Historical Note

The 1980 amendment added "semitrailer" to subd. (a).

Cross References

Failure to display certificate of compliance as provided in this section, duty of person accepting hazardous waste to report such incident, see § 25201.2.
Punishment for transportation of hazardous waste without certificate of compliance as specified in this section, see § 25191.

§ 25168.4. Fee for annual inspection

The fee for the annual inspection of a truck, trailer, semitrailer, vacuum tank, cargo tank, or container used to transport hazardous wastes shall be determined by the commissioner of the Department of the California Highway Patrol as provided by Article 6 (commencing with Section 2560) of Chapter 2 of Division 2 of the Vehicle Code.

(Added by Stats.1979, c. 1097, p. 3964, § 3. Amended by Stats.1980, c. 1112, p. 3578, § 7.)

Historical Note

The 1980 amendment added "semitrailer".

§ 25168.5. I

The departm
registration an

(Added by Stats.

Derivation: Vel
by Stats.1979, c. 1

§ 25168.6.

All inspectic
Account in the
collected is he
Account to th
burse the depa

(Added by Stats

§ 25169. Al

Every trans
shall maintain
of his business

(a) The liab
Public Utilities

(b) A higher
and so establi

(Added by Stats

§ 25169.1.

(a) The Cal
semitrailer, v
hazardous wa
tion, design, e
promulgated
Section 25168.

(b) No pers
ways within t
vacuum tank,
being transpo
State Departr
inspected wit

§ 25168.5. Fee for annual inspection; time of collection

The department shall collect the inspection fee at the same time as the registration and vehicle fees prescribed by Section 25166.

(Added by Stats.1981, c. 912, p. 3450, § 2, eff. Sept. 28, 1981.)

Historical Note

Derivation: Veh.C. former § 2561, added by Stats.1979, c. 1097, p. 3967, § 6.

§ 25168.6. Deposit of inspection fees; appropriation for expenses of inspection

All inspection fees received shall be deposited in the Motor Vehicle Account in the State Transportation Fund. An amount equal to the fees collected is hereby continuously appropriated from the Motor Vehicle Account to the Department of the California Highway Patrol to reimburse the department for the inspections conducted.

(Added by Stats.1979, c. 1097, p. 3964, § 3.)

§ 25169. Ability of transporter to respond in damages

Every transporter of hazardous waste, as defined in Section 25117, shall maintain ability to respond in damages resulting from the operation of his business consistent with:

(a) The liability limits prescribed pursuant to Section 3631 of the Public Utilities Code.

(b) A higher limit than that prescribed in (a), when deemed necessary and so established by the State Department of Health Services.

(Added by Stats.1979, c. 1097, p. 3964, § 3.)

§ 25169.1. Annual inspection by highway patrol; certificate of compliance; container defined

(a) The California Highway Patrol shall inspect every truck, trailer, semitrailer, vacuum tank, cargo tank, or container used to transport hazardous waste at least once a year to ascertain whether its construction, design, equipment and safety features comply with the regulations promulgated by the State Department of Health Services pursuant to Section 25168.1.

(b) No person shall transport hazardous waste on streets and highways within the State of California, unless the truck, trailer, semitrailer, vacuum tank, cargo tank, or container in which the hazardous waste is being transported displays a certificate of compliance, issued by the State Department of Health Services, showing that the vehicle has been inspected within the last 12 months.

(c) For the purposes of this section, "container" means any portable tank or bin having a capacity greater than 110 U.S. gallons.

(Added by Stats.1979, c. 1097, p. 3964, § 3. Amended by Stats.1980, c. 1112, p. 3578, § 8; Stats.1981, c. 912, p. 3450, § 3, eff. Sept. 28, 1981.)

Historical Note

The 1980 amendment added "semitrailer" throughout the section.

The 1981 amendment added subd. (c).

Cross References

Department and officers authorized to enforce subd. (b) of this section, see § 25180.

§ 25169.3. Transportation from abandoned site to another disposal site; conditions; exceptions

Before hazardous waste is transported from an abandoned site to another disposal site, all of the following conditions shall be met:

(a) The department shall conduct such tests, or cause such tests to be completed by the responsible party, as are necessary to determine the general chemical and mineral composition of hazardous waste that is being transported.

(b) The hazardous waste hauler shall prepare a transportation and safety plan outlining safety features and procedures to be used by the hauler to protect the public during the transportation process.

(c) The department shall review and approve the transportation and safety plan.

(d) The hazardous waste hauler shall, under penalty of perjury, certify that he or she will follow the provisions of the transportation and safety plan.

(e) The department shall issue a certificate to the hazardous waste hauler certifying that the transportation and safety plan has been approved by the department. The person transporting the waste shall have the certificate in his or her possession while transporting the waste. Such certificate shall be shown upon demand to any department official, officer of the California Highway Patrol, or any local health officer.

The term "abandoned site", as used in this section, means an inactive waste disposal, treatment, or storage facility which cannot, with reasonable effort, be traced to a specific owner; a site whose owner has been determined bankrupt or who has not taken corrective action on or before the date specified in an order issued pursuant to Section 25187; or a location where hazardous waste has been illegally disposed.

(f) The requirements of this section shall not apply when the hazardous waste disposal is the direct result of an accidental spill or the

department dete
environment or t

(Added by Stats.19

TREAT

Section
25170. Duties c
25171. Report regula
25172. Renumb
25173. Trade se
25174. Disposal
25174.1. Environ subst
25174.2. Toxic re
25174.2. Fee sch
25174.3. Fees; a
25174.4. Water r
25174.5. Fees; c
25174.6. Operato
25174.7. Fees; d
25174.8. Operato
25174.9. Operato
25175. List of
25176. Recomm cling.
25177. Investig tion.
25178. Report

Article 7 operative J

Heading Stats.1982, appears.

§ 25170. Du

The departm

(a) Coordinat ardous waste h conduct approp

(b) Maintain recycling pract

(c) Provide s fication and ass agencies in the

department determines that emergency action is needed to protect the environment or the public health.

(Added by Stats.1982, c. 294, p. 1420, § 1, eff. June 22, 1982.)

Article 7

TREATMENT, RECYCLING, AND DISPOSAL TECHNOLOGY

Section

25170. Duties of department.
25171. Report on assessment of best available technologies; revisions to regulations.
25172. Renumbered.
25173. Trade secrets; confidential nature; definition.
25174. Disposal site operator's fees; amount; sufficiency; reserve; purpose.
25174.1. Environmental epidemiology and health effects studies related to toxic substances; use of funds to cover costs.
25174.2. Toxic research and information programs; use of funds.
25174.2. Fee schedule; changes; effective date; operative date of section.
25174.3. Fees; amount to cover certain costs; appropriation.
25174.4. Water monitoring; funds.
25174.5. Fees; criteria for increase or decrease.
25174.6. Operators; fees; maximum amount.
25174.7. Fees; duration of fees provided in § 25174.6.
25174.8. Operator's fees; effective date; duration.
25174.9. Operator's fees; increase in amount; emergency regulation; duration.
25175. List of hazardous wastes; recycling; statement; fees.
25176. Recommendations to legislature; listing of wastes feasible for recycling.
25177. Investigations; report and distribution of findings and results; publication.
25178. Report to legislature.

Article 7 was added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973.

Heading of Article 7, "Other Provisions", was amended by Stats.1982, c. 89, § 13, eff. March 2, 1982, to read as it now appears.

§ 25170. Duties of department

The department in performing its duties under this chapter shall:

(a) Coordinate research and development regarding methods of hazardous waste handling, storage, use, processing, and disposal and may conduct appropriate studies relating to hazardous wastes.

(b) Maintain a technical reference center on hazardous waste disposal, recycling practices, and related information for public and private use.

(c) Provide statewide planning for hazardous waste facility site identification and assessment and render technical assistance to state and local agencies in the planning and operation of hazardous waste programs.

(d) Provide for appropriate surveillance of hazardous waste processing, use, handling, storage, and disposal practices in the state.

(e) Coordinate research and study in the technical and managerial aspects of management and use of hazardous wastes, and recycling and recovery of resources from hazardous wastes.

(f) Determine existing and expected rates of production of hazardous waste.

(g) Investigate market potential and feasibility of use of hazardous wastes and recovery of resources from hazardous wastes.

(h) Promote recycling and recovery of resources from hazardous wastes.

(i) Conduct studies for the purpose of improving departmental operations.

(j) Encourage the reduction or exchange, or both, of hazardous waste.

(k) Establish and maintain an information clearinghouse, which shall consist of a record of wastes which may be recyclable. Every producer of hazardous waste shall supply the department with information for the clearinghouse. Each producer shall not be required to supply any more information than is required by the manifests provided for in Section 25160. The department shall make this information available to persons who desire to recycle the wastes. The information shall be made available in such a way that the trade secrets of the producer are protected.

(*l*) Conduct pilot projects, as appropriate, to document the technical performance of emerging technologies which offer potential for ameliorating California's hazardous waste disposal problems.

(Added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973. Amended by Stats.1977, c. 1039, p. 3148, § 26; Stats.1978, c. 1397, p. 4622, § 12; Stats.1982, c. 89, § 13.5, eff. March 2, 1982.)

Historical Note

The 1977 amendment rewrote subd. (a) which had read:

"Establish procedures for evaluation and coordination of research and development regarding methods of hazardous waste handling and disposal and may conduct appropriate studies relating to hazardous waste."; rewrote subd. (d) which, as added, had read:

"Provide for appropriate surveillance of hazardous waste processing and disposal practices in the state."; and added subds. (e) to (k).

The 1978 amendment rewrote subd. (c) which had read:

"Render technical assistance to state and local agencies in the planning and operation of hazardous waste program.".

The 1982 amendment added subd. (*l*).

Library References

Health and Environment ⟹25.5.
C.J.S. Health and Environment §§ 61 to 66, 69, 71 to 73, 78 to 80, 82 to 86, 88 to 90, 94, 104, 110, 115 to 126, 128, 129, 132, 133, 135, 137 to 140, 142, 144 to 153.

§ 25171. Report on assessment of best available technologies; revisions to regulations

Commencing July 1, 1982, and every other year thereafter, the department shall prepare and issue to the public a report that contains an assessment of the best available technologies for the treatment, storage, recycling, source reduction, and disposal of hazardous waste in preparation for revisions to regulations adopted pursuant to Section 25150. The assessment shall include, but not be limited to, those technologies considered by the department to be the best currently available and an estimate of the unit costs associated with each technology.

(Added by Stats.1982, c. 89, § 15, eff. March 2, 1982.)

Historical Note

Former § 25171, added by Stats.1972, c. 1236, p. 2388, § 1, relating to disposal of hazardous waste at the site of production, was repealed by Stats.1982, c. 89, § 14, eff. March 2, 1982. See, now, § 25157.

Library References

Health and Environment ⇐25.5(5)
C.J.S. Health and Environment §§ 91 et seq., 106 et seq., 131.

§ 25172. Renumbered § 25105 and amended by Stats.1982, c. 89, § 16

§ 25173. Trade secrets; confidential nature; definition

The department shall establish procedures to insure that trade secrets used by a person regarding methods of hazardous waste handling and disposal are utilized by the director, the department, or any authorized representative of the department only in connection with the responsibilities of the department pursuant to this chapter and that such trade secrets are not otherwise disseminated by the director, the department, or any authorized representative of the department without the consent of the person. "Trade secrets," as used in this section, may include, but are not limited to, any formula, plan, pattern, process, tool, mechanism, compound, procedure, production data, or compilation of information which is not patented, which is known only to certain individuals within a commercial concern who are using it to fabricate, produce, or compound an article of trade or a service having commercial value, and which gives its user an opportunity to obtain a business advantage over competitors who do not know or use it.

(Added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973.)

Cross References

Hazardous waste testing laboratories inspections, procedures to protect trade secrets pursuant to this section, see § 25198.5.

Photographs taken during inspection of place containing hazardous wastes, compliance with procedures established pursuant to this section, see § 25185.

§ 25174. Disposal site operator's fees; amount; sufficiency; reserve; purpose

Each operator of any site at which hazardous wastes or extremely hazardous wastes are disposed, including every person who disposes of those wastes on site, shall pay a fee to the State Board of Equalization for disposal of those wastes. The director shall establish a schedule of the fees to be paid to the State Board of Equalization by the operator for disposal of hazardous or extremely hazardous waste, which shall provide revenues which shall not exceed the amount necessary, but shall be sufficient, to cover all costs incurred in the administration of this chapter and to provide a 5 percent operating reserve. The fees shall be deposited by the State Board of Equalization in the Hazardous Waste Control Account in the General Fund. The funds deposited in that account are continuously appropriated for expenditure without regard to fiscal years for the following purposes:

(a) To the State Board of Equalization to pay refunds of fees collected pursuant to Section 43051 of the Revenue and Taxation Code.

(b) To the department to carry out the provisions of this chapter.

(Added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973. Amended by Stats.1973, c. 815, p. 1460, § 1; Stats.1974, c. 545, p. 1292, § 81; Stats.1977, c. 1252, p. 4422, § 313, operative July 1, 1978; Stats.1980, c. 806, p. 2535, § 1; Stats.1982, c. 496, § 6, eff. July 12, 1982; Stats.1982, c. 1244, § 1, eff. Sept. 22, 1982; Stats.1983, c. 323, § 60.7, eff. July 21, 1983.)

Historical Note

The 1973 amendment added the fourth sentence relating to continuous appropriation.

The 1974 amendment deleted from the beginning of the section the words "Beginning January 1, 1974,".

The 1977 amendment substituted "State Department of Health Services" for "Department of Health" [see the 1982 note].

The 1980 amendment, substituted in the second sentence "disposal of hazardous waste" for "each disposal of hazardous waste listed in such list or document,".

Section 2 of Stats.1980, c. 806, provided:

"The amendment to Section 25174 of the Health and Safety Code made by this act does not constitute a change in, but is declaratory of, the preexisting law."

The 1982 amendment by c. 496 rewrote the section which as amended in 1980 had read:

"Each operator of any site at which hazardous wastes are disposed shall pay a fee to the director for disposal of such wastes. The director shall establish a schedule of fees to be paid to the director by such operator for disposal of hazardous waste, which shall provide revenues which shall not exceed the amount necessary, but shall be sufficient, to cover all costs incurred in the administration of this chapter. Such fees shall be deposited each month in the Hazardous Waste Control Account in the General Fund. The funds deposited in such account are continuously appropriated for expenditure without regard to fiscal years to the State Department of Health Services to carry out the provisions of this chapter.".

Section 45 of Stats.1982, c. 496, provides:

"If Assembly Bill 3696 of the 1981–82 Regular Session of the Legislature [Stats. 1982, c. 1252] is chaptered and takes effect on or before January 1, 1983, and it amends Section 25174 of the Health and Safety

Code [Section 251
that section, as a
3696, shall becom
25174 and 25174.2
by Section 6 of t
Section 7 of this a
become operative,
3696 is chaptered
this act."

The 1982 amend
ing c. 496, subst
collected pursuan
"taxes authorized
with Section 4300

Section 11 of St

"The Legislatu
tention that the t
chapter shall be

Authorization to
§ 43051.
Liability of opera
director of heal

§ 25174.1.

Funds depos
Section 25174
ogy and healt
extremely haz
waste, as defi

(Added by Stats

§ 25174.2.

Funds depos
Section 25174
programs.

(Added by Stats

For an
1982, c. 4

§ 25174.2.

Any change
25174 shall b
month, or any

Code [Section 25174 was not so amended], that section, as amended by Assembly Bill 3696, shall become operative, and Sections 25174 and 25174.2 of that code, as amended by Section 6 of this act and as added by Section 7 of this act, respectively, shall not become operative, whether Assembly Bill 3696 is chaptered prior to or subsequent to this act."

The 1982 amendment by c. 1244, amending c. 496, substituted in subd. (a) "fees collected pursuant to Section 43051" for "taxes authorized by Part 22 (commencing with Section 43001) of Division 2".

Section 11 of Stats.1982, c. 1244, provides:

"The Legislature hereby declares its intention that the tax rates set forth in this chapter shall be revised by statute during the 1983 legislative session to ensure an equitable distribution of the tax burden by taking into account the relative environmental risk posed by all forms of hazardous waste disposal, including disposal into injection wells, and that these revised tax rates shall be applicable to disposal beginning January 1, 1982."

Effect of amendment of section by two or more acts at the same session of the legislature, see Government Code § 9605.

The 1983 amendment inserted, at the end of the second sentence, the words "and to provide a 5 percent operating reserve".

Stats.1983, c. 323 operative on July 21, 1983 and deemed to have become effective on July 1, 1983, unless otherwise provided, see Historical Note under C.C.P. § 1531.

Cross References

Authorization to collect fee pursuant to this section, see Revenue and Taxation Code § 43051.

Liability of operators of hazardous waste disposal sites for fees or charges payable to director of health, see Government Code § 6103.10.

§ 25174.1. Environmental epidemiology and health effects studies related to toxic substances; use of funds to cover costs

Funds deposited in the Hazardous Waste Control Account pursuant to Section 25174 may also be use to cover costs of environmental epidemiology and health effects studies related to toxic substances, including extremely hazardous waste, as defined in Section 25115, and hazardous waste, as defined in Section 25117.

(Added by Stats.1982, c. 327, § 114, eff. June 30, 1982.)

§ 25174.2. Toxic research and information programs; use of funds

Funds deposited in the Hazardous Waste Control Account pursuant to Section 25174 may also be used to support toxic research and information programs.

(Added by Stats.1982, c. 327, § 115, eff. June 30, 1982.)

For another section of the same number, added by Stats. 1982, c. 496, § 7, see § 25174.2, post.

§ 25174.2. Fee schedule; changes; effective date; operative date of section

Any change in the schedule of fees established pursuant to Section 25174 shall become effective as of the first day of the first calendar month, or any calendar month designated by the director, which begins

at least 60 days after the director has advised the State Board of Equalization in writing of the change.

This section shall become operative on January 1, 1983.

(Added by Stats.1982, c. 496, § 7, eff. July 12, 1982, operative Jan. 1, 1983.)

For another section of the same number, added by Stats. 1982, c. 327, § 115, see § 25174.2, ante.

Historical Note

Section 45 of Stats.1982, c. 496, provides:

"If Assembly Bill 3696 of the 1981-82 Regular Session of the Legislature [Stats. 1982, c. 1252] is chaptered and takes effect on or before January 1, 1983, and it amends Section 25174 of the Health and Safety Code [Section 25174 was not so amended], that section, as amended by Assembly Bill 3696, shall become operative, and Sections 25174 and 25174.2 of that code, as amended by Section 6 of this act and as added by Section 7 of this act, respectively, shall not become operative, whether Assembly Bill 3696 is chaptered prior to or subsequent to this act."

§ 25174.3. Fees; amount to cover certain costs; appropriation

The fee authorized by Section 25174 shall be calculated to produce revenues in an amount necessary also to cover all costs incurred in the administration of Section 13227 of the Water Code and costs incurred as a result of inspection of underground storage tanks and related enforcement costs pursuant to Section 13301 of the Water Code. It is the intent of the Legislature that funds be annually appropriated in the Budget Act from the Hazardous Waste Control Account to the State Water Resources Control Board for all costs incurred by the board in administering Sections 13227 and 13301 of the Water Code.

(Added by Stats.1982, c. 90, § 1, eff. March 2, 1982. Amended by Stats.1982, c. 496, § 7.3, eff. July 12, 1982; Stats.1983, c. 323, § 60.8, eff. July 21, 1983.)

Historical Note

The 1982 amendment rewrote the second sentence which had read:

"The department shall reimburse the State Water Resources Control Board for all expenses incurred by the board in administering Section 13227 of the Water Code."

The 1983 amendment added to the end of the first sentence the words "and costs incurred as a result of inspection of the underground storage tanks and related enforcement costs pursuant to Section 13301 of the Water Code."; and substituted, at the end of the section, "Sections 13227 and 13301" for "Section 13227".

Stats.1983, c. 323 operative on July 21, 1983 and deemed to have become effective on July 1, 1983, unless otherwise provided, see Historical Note under C.C.P. § 1531.

§ 25174.4. Water monitoring; funds

Funds deposited in the Hazardous Waste Control Account pursuant to Section 25174 shall be used to support water monitoring pursuant to Section 4026.1.

(Added by Stats.1982, c. 496, § 7.5, eff. July 12, 1982. Amended by Stats.1983, c. 323, § 60.9, eff. July 21, 1983.)

The 1983 amer
which had read:
"Funds depo
Waste Control A
25174 may also
research and inf

§ 25174.5.

The schedu
provide that t
as determine
the fee appli
according to t
hazardous wa
ment, when c
of in Californ
(Added by Stat

Health and En
C.J.S. Health
seq., 106 et

§ 25174.6.

(a) Notwith
otherwise pr
1983, the fee
operators of
dollars and f
hazardous wa
by Section 66
eighteen doll
hazardous w
California Ad
applies to lan
of Part 22 (co
and Taxation

(b) The ope
only for the f
hazardous wa
producer of h

(c) The ope
only for the f
hazardous wa
(Added by Stat
c. 1589, § 1.5;

Historical Note

The 1983 amendment rewrote the section which had read:

"Funds deposited in the Hazardous Waste Control Account pursuant to Section 25174 may also be used to support toxic research and information programs.".

Stats.1983, c. 323 operative on July 21, 1983 and deemed to have become effective on July 1, 1983, unless otherwise provided, see Historical Note under C.C.P. § 1531.

§ 25174.5. Fees; criteria for increase or decrease

The schedule of fees established pursuant to Section 25174 shall provide that the fee paid for the disposal of a class of hazardous waste, as determined by the department, be increased or decreased relative to the fee applied to the disposal of other classes of hazardous wastes according to the relative short-term and long-term hazards posed by the hazardous waste at the point of disposal, as determined by the department, when compared to the other classes of hazardous wastes disposed of in California.

(Added by Stats.1982, c. 89, § 18, eff. March 2, 1982.)

Library References

Health and Environment ⇐25.5(5).
C.J.S. Health and Environment §§ 91 et seq., 106 et seq., 131.

§ 25174.6. Operators; fees; maximum amount

(a) Notwithstanding the provisions of Section 25174.2 and except as otherwise provided in Sections 25174.8 and 25174.9, effective July 1, 1983, the fee provided pursuant to Section 25174 to be paid by the operators of onsite and offsite hazardous waste facilities shall be six dollars and forty cents ($6.40) for each ton, or fraction thereof, of hazardous wastes which are not restricted hazardous wastes as provided by Section 66900 of Title 22 of the California Administrative Code and eighteen dollars ($18) for each ton, or fraction thereof, of restricted hazardous wastes as provided by Section 66900 of Title 22 of the California Administrative Code which the operator disposes of on land or applies to land. The fees shall be paid in accordance with the provisions of Part 22 (commencing with Section 43001) of Division 2 of the Revenue and Taxation Code.

(b) The operator of an offsite hazardous waste facility shall pay fees only for the first 2,500 tons of hazardous waste, which are not restricted hazardous wastes, received in any one month from each site of each producer of hazardous waste.

(c) The operator of an onsite hazardous waste facility shall pay fees only for the first 2,500 tons of hazardous waste, which are not restricted hazardous wastes, which the operator disposes of in any one month.

(Added by Stats.1982, c. 327, § 116, eff. June 30, 1982. Amended by Stats.1982, c. 1589, § 1.5; Stats.1983, c. 323, § 60.10, eff. July 21, 1983.)

Historical Note

The 1982 amendment deleted the second and third sentences from subd. (a) which had read:

"The fees shall be paid within sixty days following the month of disposal. Thereafter a penalty shall be applied at the rate of 10 percent of the amount otherwise due for each month, or fraction thereof, during which fees remain unpaid.".

The 1983 amendment rewrote subd. (a) which had read:

"Effective July 1, 1982, the fee provided pursuant to Section 25174 to be paid by the operators of onsite and offsite hazardous waste facilities shall be four dollars ($4) for every ton, or fraction thereof of hazardous waste which the operator disposes of onland or applies to land."; inserted in subd. (b) following "hazardous waste" the words "which are not restricted hazardous wastes"; and rewrote subd. (c) which had read:

"The operator of an onsite hazardous waste facility shall pay fees only for the first 2,500 tons of hazardous waste which the operator disposes of on land or applies to land in any one month."

Stats.1983, c. 323 operative on July 21, 1983 and deemed to have become effective on July 1, 1983, unless otherwise provided, see Historical Note under C.C.P. § 1531.

Library References

Health and Environment ⇐25.5(5).
C.J.S. Health and Environment §§ 91 et seq., 106 et seq., 131.

§ 25174.7. Fees; duration of fees provided in § 25174.6

The fees provided in Section 25174.6 shall remain in effect until June 30, 1983.

(Added by Stats.1982, c. 327, § 117, eff. June 30, 1982.)

§ 25174.8. Operator's fees; effective date; duration

The fees provided in Section 25174.6 shall be effective commencing on July 1, 1983, and shall remain in effect until June 30, 1984.

(Added by Stats.1983, c. 323, § 60.14, eff. July 21, 1983.)

Historical Note

Stats.1983, c. 323 operative on July 21, 1983 and deemed to have become effective on July 1, 1983, unless otherwise provided, see Historical Note under C.C.P. § 1531.

§ 25174.9. Operator's fees; increase in amount; emergency regulation; duration

Notwithstanding any other provision of law, the department may, by emergency regulation, increase the amount of the fee established pursuant to Section 25174 or 25174.6 if it determines that the fees established are insufficient to fund the appropriations from the Hazardous Waste Control Account in the 1983–84 fiscal year.

For the purposes of the Administrative Procedure Act, the adoption of these regulations shall be deemed to be an emergency and necessary for the immediate preservation of the public peace, health and safety, and

general welfare. Notwithstanding the provisions of Chapter 3.5 (commencing with Section 11340) of Part 1 of Division 3 of Title 2 of the Government Code, these regulations shall not be subject to review, approval, or repeal by the Office of Administrative Law, and shall remain in effect until June 30, 1984.

(Added by Stats.1983, c. 323, § 60.15, eff. July 21, 1983.)

Historical Note

Stats.1983, c. 323 operative on July 21, 1983 and deemed to have become effective *on July 1, 1983, unless otherwise provided,* see Historical Note under C.C.P. § 1531.

§ 25175. List of hazardous wastes; recycling; statement; fees

(a) The department shall prepare and adopt and may revise when appropriate, a list of hazardous wastes which the department finds are economically and technologically feasible to recycle. Each substance shall be categorized according to the degree of difficulty and the kind of difficulty encountered in recycling that substance. Whenever any waste on the list is disposed of by a person, the department may request, and the producer or disposer of that waste shall supply the department with, a formal, complete, and detailed statement justifying why the waste was not recycled. If the request is made of any entity listed in Section 25118 other than an individual, the statement shall be issued by the responsible management of that entity. The department shall keep confidential any trade secrets contained in any such statement.

(b) If, after receipt of the statement described in subdivision (a), the department finds the recycling of a hazardous waste to be economically and technologically feasible at the site of production, as determined by the site operator, or, if the department provides the name of a ready, willing, and able purchaser of the recyclable waste, the disposer of the hazardous waste shall recycle the hazardous waste by either of the above described methods. Failure to comply with an order to recycle by either of these methods shall result in the assessment of fees for disposal pursuant to Section 25174. The director may establish fees for the disposal of hazardous wastes determined to be recyclable in amounts which may be up to two times the base fee paid under the annual fee schedule established by the director.

(Added by Stats.1977, c. 1039, p. 3149, § 27. Amended by Stats.1982, c. 89, § 21, eff. March 2, 1982.)

Historical Note

The 1982 amendment designated the original provisions as subd. (a) and added subd. (b).

Library References

Health and Environment ⇐25.5.
C.J.S. Health and Environment §§ 61 to 66, 77 to 80, 115 to 126, 137 to 140.

§ 25176. Recommendations to legislature; listing of wastes feasible for recycling

The listing of wastes feasible to recycle developed pursuant to Section 25175 shall be presented annually, commencing January, 1979, to the Legislature with specific recommendations to promote recycling.

(Added by Stats.1977, c. 1039, p. 3149, § 28.)

§ 25177. Investigations; report and distribution of findings and results; publication

The department may report findings and results of an investigation which the department undertakes pertaining to subject matter governed by this chapter, except for trade secrets as provided in Section 25173. The department may distribute such information as it considers necessary for the protection of the public or for the protection of human health, domestic livestock, wildlife, and the environment and to ensure the best use of natural resources. The department may publish reports summarizing or containing any order of the director or any judgment or court order which has been rendered pursuant to this chapter, including the nature of the charge and its disposition.

(Added by Stats.1980, c. 1161, p. 3900, § 4. Amended by Stats.1982, c. 89, § 22, eff. March 2, 1982.)

Historical Note

The 1982 amendment added to the end of the second sentence the words "and to insure the best use of natural resources".

§ 25178. Report to legislature

On or before January 1, 1983, and on or before January 1st of each odd-numbered year thereafter, the department shall prepare and submit to the Legislature a report containing, but not limited to, the following:

(a) The status of the regulatory and program developments required pursuant to legislative mandates.

(b) The status of the hazardous waste facilities permit program.

(c) The status of the hazardous waste facilities siting program.

(d) The status of the hazardous waste abandoned sites program.

(e) A summary of enforcement actions taken pursuant to this chapter and any other actions relating to hazardous waste management.

(f) Summary data on annual quantities and types of hazardous waste generated, transported, treated, stored, and disposed.

(g) Summary d
ous waste.

(h) Research a

(i) Regulatory
management.

(j) Any other c
ous waste manag

(Added by Stats.19

Section
25180. Departm
tions.
25181. Violatio
25182. Civil act
25183. Venue.
25184. Injuncti
25185. Inspecti
sure;
25185.5. Hazard
25186. Ground
25187. Violatio
25187.5. Correct
25188. Failure
25189. Intentio
25189.5. Disposa
ishme
25190. Repeale
25191. Acts su
25191.7. Informe
penal
25192. Penalti
25193. Cumula
25194. Abaten
25194.5. Withdr
ture
25195. Acts co
25196. Hazard

Article
operative

Easement upon h
problems, enforc
Restrictive covena
upon adjacent la

(g) Summary data regarding onsite and offsite disposition of hazardous waste.

(h) Research activity initiated by the department.

(i) Regulatory action by other agencies relating to hazardous waste management.

(j) Any other data considered pertinent by the department to hazardous waste management.

(Added by Stats.1982, c. 89, § 22.5, eff. March 2, 1982.)

Article 8

ENFORCEMENT

Section
25180. Department or officers authorized to enforce standards and regulations.
25181. Violations; injunctive relief.
25182. Civil actions; joinder.
25183. Venue.
25184. Injunctions; pleadings.
25185. Inspections; samples; photographs; report of violations; public disclosure; local health officer.
25185.5. Hazardous waste disposal land use; inspection of real property.
25186. Grounds for suspension or revocation of permit; public hearing.
25187. Violations; order specifying schedule for compliance or correction.
25187.5. Corrective action by department; contracts; costs; immunity.
25188. Failure to comply with schedule for compliance; civil penalty.
25189. Intentional or negligent acts; civil penalties.
25189.5. Disposal at facilities without permits or at unauthorized points; punishment.
25190. Repealed.
25191. Acts subject to fine or imprisonment.
25191.7. Information materially contributing to imposition of civil and criminal penalties; rewards to informants; amount; regulations.
25192. Penalties; deposit; appropriation.
25193. Cumulative remedies.
25194. Abatement of action.
25194.5. Withdrawal of application for permit; suspension, expiration or forfeiture of permit; effect.
25195. Acts constituting misdemeanors.
25196. Hazardous waste disposal land use; civil penalty.

Article 8 was added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973.

Cross References

Easement upon hazardous waste or border zone property to enter land to monitor problems, enforcement pursuant to this article, see § 25230.

Restrictive covenant upon use of land on which hazardous waste facility is located and upon adjacent land, enforcement pursuant to this article, see § 25202.5.

§ 25180. Department or officers authorized to enforce standards and regulations

(a) The standards and regulations adopted by the department pursuant to Section 25150 shall be enforced by the department or any local health officer or any local public officer as designated by the director.

(b) Any traffic officer, as defined by Section 625 of the Vehicle Code, or by a peace officer, as defined by Section 830.1 of the Penal Code, in addition to the department and local health officers, as specified in subdivision (a) may enforce Section 25160, subdivisions (a) and (d) of Section 25163, and subdivision (b) of Section 25169.1.

(Added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973. Amended by Stats.1982, c. 89, § 23, eff. March 2, 1982; Stats.1983, c. 798, § 1.)

Historical Note

The 1982 amendment deleted the word "minimum" preceding "standards and regulations" near the beginning of what is now subd. (a).

The 1983 amendment designated the original provisions as subd. (a) and added subd. (b).

Notes of Decisions

1. In general

The Hazardous Waste Control Law (§ 25100 et seq.) which became operative on July 1, 1973, preempts existing local ordinances and regulations pertaining to the processing, handling and disposal of hazardous and extremely hazardous waste materials. 57 Ops.Atty.Gen. 159, 4-4-74.

§ 25181. Violations; injunctive relief

When the department determines that any person has engaged in, is engaged in, or is about to engage in any acts or practices which constitute or will constitute a violation of any provision of this chapter, or any rule, regulation, permit, covenant, standard, requirement, or order issued, promulgated, or executed thereunder, and when requested by the department, the city attorney of the city in which such acts or practices occur, occurred, or will occur, the district attorney of the county in which such acts or practices occur, occurred, or will occur, or the Attorney General may make application to the superior court for an order enjoining such acts or practices, or for an order directing compliance, and upon a showing by the department that such person has engaged in or is about to engage in any such acts or practices, a permanent or temporary injunction, restraining order, or other order may be granted.

(Added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973. Amended by Stats.1980, c. 804, p. 2532, § 2.)

Historical Note

The 1980 amendment rewrote that part of the section preceding "or the Attorney General" which part previously read:

"Whenever, in the judgment of the department, any person has engaged in or is about to engage in any acts or practices

which constitute or
tion of any provision
rule, regulation, or o

Injunction, generally

Health and Enviro
C.J.S. Health and
66, 69, 71 to 73,

§ 25182. Civi

Every civil act
request of the
district attorney
the State of C
processing or di
ed.

(Added by Stats.1
Stats.1980, c. 804,

The 1980 amendn
attorney"; inserted

Coordination of Civi
Procedure § 404 e

§ 25183. Ven

Any civil actic
the county in w
made or propose
the defendant is
an office neare
defendants, or a

(Added by Stats.1
Stats.1982, c. 496,

The 1982 amendn
der of the section
proposed to be mad

which constitute or will constitute a violation of any provision of this chapter, or any rule, regulation, or order issued thereunder, and at the request of the department, the district attorney of the county in which such acts or practices occur or will occur."

Cross References

Injunction, generally, see Civil Code § 3420 et seq.; Code of Civil Procedure § 525 et seq.

Library References

Health and Environment ⇐25.5.
C.J.S. Health and Environment §§ 61 to 66, 69, 71 to 73, 78 to 80, 82 to 86, 88 to 90, 94, 104, 110, 115 to 126, 128, 129, 132, 133, 135, 137 to 140, 142, 144 to 153.

§ 25182. Civil actions; joinder

Every civil action brought under the provisions of this chapter at the request of the department shall be brought by the city attorney, the district attorney, or the Attorney General in the name of the people of the State of California, and any such actions relating to the same processing or disposal of hazardous wastes may be joined or consolidated.

(Added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973. Amended by Stats.1980, c. 804, p. 2533, § 3.)

Historical Note

The 1980 amendment inserted "the city attorney"; inserted "the" preceding "Attorney General"; and inserted commas following "district attorney" and "California."

Cross References

Coordination of Civil actions sharing a common question of fact or law, see Code of Civil Procedure § 404 et seq.

§ 25183. Venue

Any civil action brought pursuant to this chapter shall be brought in the county in which the processing or disposal of hazardous waste is made or proposed to be made, the county in which the principal office of the defendant is located, or the county in which the Attorney General has an office nearest to the county in which the principal office of the defendants, or any of them, is located in this state.

(Added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973. Amended by Stats.1982, c. 496, § 8, eff. July 12, 1982.)

Historical Note

The 1982 amendment added the remainder of the section following "is made or proposed to be made".

Cross References

Venue, generally, see Code of Civil Procedure § 392 et seq.

§ 25184. Injunctions; pleadings

In any civil action brought pursuant to this chapter in which a temporary restraining order, preliminary injunction, or permanent injunction is sought, it shall not be necessary to allege or prove at any stage of the proceeding that irreparable damage will occur should the temporary restraining order, preliminary injunction, or permanent injunction not be issued; or that the remedy at law is inadequate, and the temporary restraining order, preliminary injunction, or permanent injunction shall issue without such allegations and without such proof.

(Added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973.)

Cross References

Injunction, generally, see Civil Code § 3420 et seq.; Code of Civil Procedure § 525 et seq.

§ 25185. Inspections; samples; photographs; report of violations; public disclosure; local health officer

(a) In order to carry out the purposes of this chapter, any duly authorized representative of the department or of the local health officer may, at any reasonable hour of the day, do any of the following:

(1) Enter and inspect a factory, plant, construction site, waste disposal site, transfer station, establishment or any other place or environment where hazardous wastes are stored, handled, processed, disposed of, or being treated to recover resources.

(2) Obtain from any individual authorized by the operator, or from the property of any person, as defined in Section 25118, samples of waste, including samples from any vehicle in which wastes are being transported. However, upon request, split samples shall be given to the person from whom, or from whose property, such samples were obtained.

(3) Stop and inspect any vehicle reasonably suspected of transporting hazardous wastes when accompanied by a uniformed police officer in a clearly marked vehicle.

(4) Inspect and copy any records, reports, test results, or other information required to carry out the provisions of this chapter.

(5) Photograph any waste, waste container, waste container label, vehicle, waste treatment process, waste disposal site, or violation found during an inspection.

(b) During the inspection, the inspector shall comply with all reasonable security, safety, and sanitation measures. In addition, the inspector shall comply with reasonable precautionary measures specified by the operator.

(c) A report
prepared by th
copy of the re

(d) Wheneve
of subdivision
established pu
facility was ph
and, upon requ
to such perso
information, a
revealed by th
shall not inclu
jurisdiction or
ducted in cam

(e) "Local he
officers, city h
this code.

(Added by Stats
Stats.1980, c. 87

The 1980 amend
which formerly re
duly authorized r
partment may at a
day, enter a fac

§ 25185.5.

In order to
Section 25220)
may at any r
property which
hazardous was

(a) Obtain sa
land.

(b) Set up a
assessing or m
wastes on or t

(c) Survey a

(d) Photogra
dition describe
photographs sh
Section 25185.

(e) This secti
is required to b
to inspection p

(c) A report listing any violations found during the inspection shall be prepared by the inspector and shall be kept on file in the department. A copy of the report shall be provided to the operator.

(d) Whenever photographs have been taken pursuant to paragraph (5) of subdivision (a), the department shall comply with all procedures established pursuant to Section 25173 and shall notify the person whose facility was photographed prior to public disclosure of such photographs, and, upon request of that person, shall submit a copy of any photograph to such person for the purpose of determining whether trade secret information, as defined in Section 25173, or facility security would be revealed by the photograph. "Public disclosure," as used in this section, shall not include review of the photographs by a court of competent jurisdiction or an administrative law judge. Such review may be conducted in camera at the discretion of the court or judge.

(e) "Local health officer," as used in this section, means county health officers, city health officers, and district health officers, as defined in this code.

(Added by Stats.1972, c. 1236, p. 2388, § 1, operative July 1, 1973. Amended by Stats.1980, c. 878, p. 2758, § 10.)

Historical Note

The 1980 amendment rewrote the section which formerly read: "The director or any duly authorized representative of the department may at any reasonable hour of the day, enter a factory, plant, construction site, waste disposal site, establishment or any environment where hazardous wastes are stored, handled, processed or disposed of, in order to carry out the purposes of this chapter."

§ 25185.5. *Hazardous waste disposal land use; inspection of real property*

In order to carry out the purposes of Article 11 (commencing with Section 25220), any duly authorized representative of the department may at any reasonable hour of the day, enter and inspect any real property which is within 2,000 feet of a deposit of hazardous waste or a hazardous waste property and do any of the following:

(a) Obtain samples of the soil, vegetation, air, water, and biota on such land.

(b) Set up and maintain monitoring equipment for the purpose of assessing or measuring the actual or potential migration of hazardous wastes on or toward the land.

(c) Survey and determine the topography and geology of the land.

(d) Photograph any equipment, sample, activity, or environmental condition described in subdivision (a), (b), or (c) of this section. Such photographs shall be subject to the requirements of subdivision (d) of Section 25185.

(e) This section shall not apply to any hazardous waste facility which is required to be permitted pursuant to this chapter and which is subject to inspection pursuant to Section 25185.

(f) An inspector who inspects pursuant to this section shall make a reasonable effort to inform the owner or his authorized representative of such inspection and shall provide split samples to the owner or representative upon request and shall comply with the provisions of subdivision (b) of Section 25185.

(Added by Stats.1980, c. 1161, p. 3900, § 5.)

Cross References

Hazardous waste or border zone property, easement to enter land, subject to this section, to monitor problems, see § 25230.

§ 25186. Grounds for suspension or revocation of permit; public hearing

(a) The director, after a public hearing, may suspend or revoke any registration or permit issued pursuant to the provisions of this chapter based on any of the following:

(1) A violation of any provision of this chapter or any applicable requirement promulgated by the department pursuant to this chapter.

(2) The aiding or abetting the violation of any provision of this chapter or any requirement promulgated by the department pursuant to this chapter.

(3) An act or omission associated with the transportation of hazardous wastes that could cause or allow hazard to public health or safety, domestic livestock, or wildlife.

(4) The misrepresentation or omission of a significant fact either in the application for the registration or in information subsequently reported to the department.

(5) Noncompliance with an order issued by the director.

(b) In addition to the remedies provided in Section 25168.2, the director may temporarily suspend any certification of a truck, trailer, vacuum tank, cargo tank, or other container used to transport hazardous waste and may suspend the registration of a hazardous waste hauler issued pursuant to the provisions of this chapter prior to any hearing when, in the director's opinion, that action is necessary to prevent an imminent and substantial danger to health or the environment. The director shall notify the holder of the certification or registration of the temporary suspension and the effective date thereof and, at the same time, shall serve the holder with an accusation. Upon receipt of a notice of defense to the accusation, the director shall set the matter for a hearing which shall be held as soon as possible, but not later than 10 days after receipt of the notice of defense. The temporary suspension shall remain in effect until the hearing is completed and the director has made a final determination on the merits, which in any event shall be made within 10 days after the completion of the hearing. If the determination is not

transmitted with
suspension shall

(Added by Stats.1
2643, § 3; Stats.1
§ 9, eff. July 12,

The 1980 amendm
inal text as subd.
subds. (a) to (e) to b
of subd. (a); substit
of subd. (a) "revok
permit" for "revoke
in subd. (a)(2) "any p
or"; and added subd
The 1981 amendn
[see 1982 amendmer

§ 25187. Viol
co

Whenever the
person has viola
any permit, rule
gated pursuant
ing a schedule fo
the provisions of
take corrective
cleanup of such
any other neces
order pursuant
not limited to p
property where
ers, or disposers

(Added by Stats.1
2537, § 1.)

The 1980 amendm
which previously rea
"Whenever the di
public hearing, that

§ 25187.5. Co

(a) If correcti
an order issued
department imm
vent an immine

transmitted within 10 days after the hearing is completed, the temporary suspension shall be of no further effect.

(Added by Stats.1977, c. 1039, p. 3149, § 29. Amended by Stats.1980, c. 848, p. 2643, § 3; Stats.1981, c. 756, p. 2934, § 1, eff. Sept. 25, 1981; Stats.1982, c. 496, § 9, eff. July 12, 1982.)

Historical Note

The 1980 amendment designated the original text as subd. (a); changed former subds. (a) to (e) to be numbered paragraphs of subd. (a); substituted in the introduction of subd. (a) "revoke any registration or permit" for "revoke any permit"; inserted in subd. (a)(2) "any provision of this chapter or"; and added subd. (b).

The 1981 amendment added subd. (a)(6) [see 1982 amendment note].

The 1982 amendment substituted "that" or "the" for "such" where appropriate; substituted "the holder" for "such person" preceding "with an application" in the second sentence of subd. (b); and deleted former subd. (a)(6), which previously read: "A violation of any provision contained in Part 22 (commencing with Section 43001) of Division 2 of the Revenue and Taxation Code."

§ 25187. Violations; order specifying schedule for compliance or correction

Whenever the director determines, after public hearing, that any person has violated or is in violation of any provision of this chapter, or any permit, rule, regulation, standard, or requirement issued or promulgated pursuant to this chapter, the director may issue an order specifying a schedule for compliance or correction. An order issued pursuant to the provisions of this section may include a requirement that such person take corrective action with respect to hazardous waste, including the cleanup of such hazardous waste, abatement of the effects thereof, and any other necessary remedial action. Persons who are subject to an order pursuant to this section, upon proof of violation, include, but are not limited to present or prior owners, lessees, or operators of the property where the hazardous waste is located and producers, transporters, or disposers of the hazardous waste.

(Added by Stats.1977, c. 1039, p. 3149, § 30. Amended by Stats.1980, c. 808, p. 2537, § 1.)

Historical Note

The 1980 amendment rewrote the section which previously read:

"Whenever the director determines, after public hearing, that any person is in violation of any requirement of this chapter, the director may issue an order specifying a schedule for compliance."

§ 25187.5. Corrective action by department; contracts; costs; immunity

(a) If corrective action is not taken on or before the date specified in an order issued pursuant to Section 25187, or if in the judgment of the department immediate corrective action is necessary to remedy or prevent an imminent substantial danger to the public health, domestic

livestock, wildlife, or the environment, the department may take, or contract for the taking of, such corrective action and recover the cost thereof as provided in subdivision (c).

(b) The department may expend up to one hundred thousand dollars ($100,000) in a 12-month period of available moneys in the Hazardous Waste Control Account in the General Fund to take corrective action pursuant to subdivision (a). Notwithstanding any other provision of law, the department may enter into written contracts for corrective action taken or to be taken pursuant to subdivision (a), and may enter into oral contracts, not to exceed two thousand dollars ($2,000) in obligation, when in the judgment of the department immediate corrective action is necessary to remedy or prevent an imminent substantial danger to the public health, domestic livestock, wildlife, or the environment. Such contracts, whether written or oral, may include provisions for the rental of tools or equipment, either with or without operators furnished, and for the furnishing of labor and materials necessary to accomplish the work. Any such contract by the department shall be exempt from approval by the Department of General Services pursuant to the provisions of Section 14780 of the Government Code.

(c) If corrective action is taken pursuant to subdivision (a), the person or persons who were subject to the order of the department issued pursuant to Section 25187, or any person or persons whose violation resulted in the imminent and substantial danger to health or the environment shall be liable to the department for the reasonable cost actually incurred in taking corrective action. In addition, such person or persons shall be liable to the department for administrative costs in an amount equal to 10 percent of the reasonable cost actually incurred or five hundred dollars ($500), whichever is greater. The amount of cost determined pursuant to this subdivision shall be recoverable in a civil action by the department, in addition to any other fees or penalties. Persons who may be liable pursuant to this subdivision shall include, but not be limited to, present or prior owners, lessees, or operators of the property where the hazardous waste is located and producers, transporters or disposers of the hazardous waste.

(d) Neither the department, nor any person authorized by the department to enter upon any lands for the purpose of taking corrective action pursuant to subdivision (a) is liable to civil or criminal action for trespass for any acts which are necessary to carry out such corrective action.

(e) This section does not impose any new liability associated with acts that occurred before January 1, 1981, if the acts were not in violation of existing law or regulations at the time they occurred.

(Added by Stats.1980, c. 808, p. 2537, § 2.)

Library References

Health and Environment ⟹25.5(3).
C.J.S. Health and Environment §§ 91 et seq., 106 et seq., 129 et seq.

§ 25188. Failu
per

Any person su
Section 25187 wh
a civil penalty of
for each day of n

(Added by Stats.19
2748, § 1, eff. Sept

The 1980 amendme
"civil penalty".

§ 25189. Inter

(a) Any persor
statement or rep
report, permit, or
of compliance wit
exceed twenty-fiv
or, for continuin
continues.

(b) Except as
intentionally or n
permit, rule, regu
pursuant to this
twenty-five thous
provision or, for
ues.

(c) Any person
hazardous or extr
ed according to t
penalty of not l
twenty-five thous
ordered to disclos
persons as the co
and the person h
unless the perso
department and
issued by the d
cleanup.

(d) Any person
hazardous or extr
ed according to t
penalty of not m
violation and may
violations to thos

§ 25188. Failure to comply with schedule for compliance; civil penalty

Any person subject to a schedule for compliance issued pursuant to Section 25187 who does not comply with that schedule shall be subject to a civil penalty of not more than twenty-five thousand dollars ($25,000) for each day of noncompliance.

(Added by Stats.1977, c. 1039, p. 3149, § 31. Amended by Stats.1980, c. 876, p. 2748, § 1, eff. Sept. 10, 1980.)

Historical Note

The 1980 amendment changed "fine" to "civil penalty".

§ 25189. Intentional or negligent acts; civil penalties

(a) Any person who intentionally or negligently makes any false statement or representation in any application, label, manifest, record, report, permit, or other document filed, maintained, or used for purposes of compliance with this chapter, shall be liable for a civil penalty not to exceed twenty-five thousand dollars ($25,000) for each separate violation or, for continuing intentional violations, for each day that violation continues.

(b) Except as provided in subdivision (c) or (d), any person who intentionally or negligently violates any provision of this chapter or any permit, rule, regulation, standard, or requirement issued or promulgated pursuant to this chapter, shall be liable for a civil penalty not to exceed twenty-five thousand dollars ($25,000) for each violation of a separate provision or, for continuing violations, for each day that violation continues.

(c) Any person who intentionally disposes or causes the disposal of any hazardous or extremely hazardous waste at a point which is not authorized according to the provisions of this chapter shall be subject to a civil penalty of not less than one thousand dollars ($1,000) or more than twenty-five thousand dollars ($25,000) for each violation and may be ordered to disclose the fact of this violation or these violations to those persons as the court may direct. Each day on which the deposit remains and the person has knowledge thereof is a separate additional violation, unless the person immediately files a report of the deposit with the department and is complying with any order concerning the deposit issued by the director or a court of competent jurisdiction for the cleanup.

(d) Any person who negligently disposes or causes the disposal of any hazardous or extremely hazardous waste at a point which is not authorized according to the provisions of this chapter shall be subject to a civil penalty of not more than twenty-five thousand dollars ($25,000) for each violation and may be ordered to disclose the fact of this violation or these violations to those persons as the court may direct. Each day on which

the deposit remains and the person had knowledge thereof is a separate additional violation, unless the person immediately files a report of the deposit with the department and is complying with any order concerning the deposit issued by the director or a court of competent jurisdiction for the cleanup.

(e) Each civil penalty imposed for any separate violation pursuant to this section shall be separate and in addition to any other civil penalty imposed pursuant to this section or any other provision of law.

(Added by Stats.1977, c. 1039, p. 3149, § 31.1. Amended by Stats.1980, c. 876, p. 2748, § 2, eff. Sept. 10, 1980; Stats.1982. c. 496, § 10, eff. July 12, 1982.)

Historical Note

The 1980 amendment rewrote the section which formerly read:

"Any person who intentionally or negligently does any of the following shall be liable for a civil penalty not to exceed five thousand dollars ($5,000):

"(a) Disposes of any extremely hazardous waste listed pursuant to this chapter without having obtained a permit therefor from the department.

"(b) Makes any false statement or representation in any application, label, manifest, record, report, permit, or other document filed, maintained, or used for purposes of compliance with this chapter.

"(c) Violates any permit, rule, regulation, standard, or requirement issued or promulgated pursuant to this chapter."

The 1982 amendment increased the maximum penalty from $5,000 to $25,000 in subds. (a) and (b); added "or (d)" following "subdivision (c)" in subd. (b); deleted "or negligently" following "intentionally" in the first sentence of subd. (c); added "or causes the disposal" following "disposes" and "or extremely hazardous" following "hazardous" in subd. (c); inserted "less than one thousand dollars ($1,000) or" following "civil penalty of not" in subd. (c); substituted "those" or "the" for "such" where appropriate; inserted the current subd. (d); and designated former subd. (d) as subd. (e).

Amendment of this section by § 24 of Stats.1982, c. 89, failed to become operative under the provisions of § 29 of that Act.

§ 25189.5. Disposal at facilities without permits or at unauthorized points; punishment

(a) The disposal of any hazardous or extremely hazardous waste, or the causing thereof, is prohibited when the disposal is at a facility which does not have a permit from the department issued pursuant to the provisions of this chapter, or at any point which is not authorized according to the provisions of this chapter.

(b) Any person who is convicted of knowingly disposing of any hazardous or extremely hazardous waste or who causes any such waste to be disposed of at a facility which does not have a permit from the department issued pursuant to the provisions of this chapter, or at any point which is not authorized according to the provisions of this chapter shall, upon conviction, be punished by a fine of not less than five thousand dollars ($5,000) or more than fifty thousand dollars ($50,000) for each day of violation, or by imprisonment in the county jail for not to exceed one year, or by both that fine and imprisonment. If the conviction is for a violation committed after the first conviction of the person under this section, the person shall be punished by imprisonment in the state prison for 16, 20, or 24 months, or by imprisonment in the county jail for not to

exceed one year,
($5,000) or more
tion, or by both
(Added by Stats.19

Health and Enviro
C.J.S. Health and
seq., 106 et seq.,

§ 25190. Repe 19

The repealed sect
1977, c. 1039, p. 31

§ 25191. Acts

(a) Any person
upon conviction,
thousand dollars
in the county ja
imprisonment. I
conviction of the
by imprisonment
county jail for n
thousand dollars
per day of violat

(1) Makes any
label, manifest,
tained, or used f

(2) Has in his
storage, treatme
waste required t
altered or conce
1982.

(3) Destroys, a
storage, treatme
waste required t

(4) Withholds
the public health
the department i
responsibilities
substantial dang

(5) Engages in
subdivisions (a) c

exceed one year, or by a fine of not less than five thousand dollars ($5,000) or more than fifty thousand dollars ($50,000) per day of violation, or by both that fine and imprisonment.

(Added by Stats.1982, c. 496, § 11, eff. July 12, 1982.)

Library References

Health and Environment ⟹25.5(5).
C.J.S. Health and Environment §§ 91 et seq., 106 et seq., 131.

§ 25190. Repealed by Stats.1980, c. 876, p. 2749, § 3, eff. Sept. 10, 1980

Historical Note

The repealed section, added by Stats. 1977, c. 1039, p. 3150, § 31.2, provided a civil penalty for a knowing disposal of hazardous waste at an unauthorized point.

§ 25191. *Acts subject to fine or imprisonment*

(a) Any person who knowingly does any of the following acts shall, upon conviction, be punished by a fine of not more than twenty-five thousand dollars ($25,000) for each day of violation, or by imprisonment in the county jail not to exceed one year, or by both the fine and imprisonment. If the conviction is for a violation committed after a first conviction of the person under this section, the person shall be punished by imprisonment in the state prison for 16, 20, or 24 months, or in the county jail for not to exceed one year, or by a fine of not less than two thousand dollars ($2,000) or more than fifty thousand dollars ($50,000) per day of violation, or by both the fine and imprisonment:

(1) Makes any false statement or representation in any application, label, manifest, record, report, permit, or other document filed, maintained, or used for the purposes of compliance with this chapter.

(2) Has in his or her possession any record relating to the generation, storage, treatment, transportation, disposal, or handling of hazardous waste required to be maintained pursuant to this chapter, that has been altered or concealed, whether altered or concealed prior to January 1, 1982.

(3) Destroys, alters, or conceals any record relating to the generation, storage, treatment, transportation, disposal, or handling of hazardous waste required to be maintained pursuant to this chapter.

(4) Withholds information regarding a real and substantial danger to the public health or safety when such information has been requested by the department in writing and is required to carry out the department's responsibilities pursuant to this chapter in response to a real and substantial danger.

(5) Engages in the transportation of hazardous waste in violation of subdivisions (a) or (d) of Section 25163.

(b) The penalties imposed by subdivision (a) on any person who commits any of the acts specified in paragraph (5) of that subdivision shall be imposed only on the owner of the vehicle in which the hazardous wastes are unlawfully transported, carried, or handled or on the person who authorizes the transporting, carrying, or handling, and shall not be imposed on the driver of the vehicle, unless the driver is also the owner of the vehicle or authorized the transporting, carrying, or handling.

(c) Any person who knowingly does any of the following acts shall, upon conviction, be punished by a fine of not more than five hundred dollars ($500) for each day of violation, or by imprisonment in the county jail for not to exceed six months, or both the fine and imprisonment:

(1) Transports, or authorizes the transportation of, hazardous waste in a truck, trailer, semitrailer, vacuum tank, cargo tank, or container which does not contain a current certificate of compliance, as specified in Section 25168.3.

(2) Carries or handles, or authorizes the carrying or handling of, hazardous waste without having in the driver's possession the list specified in Section 25160.

Whenever any person is prosecuted for a violation pursuant to this subdivision the court may, on the request of the person, take appropriate steps to make the owner or lessee of the vehicle in which the hazardous wastes are unlawfully transported, carried, or handled, the driver of the vehicle, or any other person who authorized or directed the loading, maintenance, or operation of the vehicle, a codefendant or codefendants. If the codefendant or codefendants are held solely responsible and found guilty, the court may dismiss the charge against the person who was initially so charged.

(d) Any person who knowingly does any of the following acts shall, upon conviction, be punished by a fine of not less than two thousand dollars ($2,000) or more than fifty thousand dollars ($50,000) for each day of violation, or by imprisonment in the county jail not to exceed one year, or by both the fine and imprisonment. If the conviction is for a violation committed after a first conviction of the person under this section, the person shall be punished by imprisonment in the state prison for 16, 20, or 24 months, or in the county jail for not to exceed one year, or by a fine of not less than five thousand dollars ($5,000) or more than fifty thousand dollars ($50,000) per day of violation, or by both the fine and imprisonment.

(1) Transports any hazardous waste to a facility which does not have a permit from the department issued pursuant to this chapter, or to any point which is not authorized according to this chapter.

(2) Treats or stores any hazardous waste at a facility which does not have a permit from the department issued pursuant to this chapter, or at any point which is not authorized according to this chapter.

(Added by Stats.1977, c. 1039, p. 3150, § 31.3. Amended by Stats.1980, c. 873, p. 2734, § 1; Stats.1980, c. 876, p. 2749, § 4, eff. Sept. 10, 1980; Stats.1982, c. 496, § 12, eff. July 12, 1982; Stats.1983, c. 798, § 2.)

The 1980 amendr
wrote the section w

"Any person wh
any hazardous wast
authorized accordir
this chapter shall b
more than twenty
($25,000) for each v
ment not to exceed
may be required to
violation to such pe
direct."

Effect of amendn
more acts at the sar
ture, see Governme

The 1982 amendn
which prior to the a

"Any person who
the following acts s
punished by a fine o
five thousand dollar
of violation, or by in
ty jail not to exceed
fine and imprisonme
for a violation comr
viction of such per
such person shall b
ment in the state p
months, or in the
exceed one year, or
than fifty thousan
day of violation, or
imprisonment.

"(a) Transports ar
facility which does

§ 25191.7. Ir

(a) Any perso
to the imposition
provisions of su
reward by the
department und
the civil penalty
(b), or (c) of Sect
Account pursua
subdivision shall

(b) Any perso
to the conviction
(a), (b), or (c) o

Historical Note

The 1980 amendment, by c. 876, § 4, rewrote the section which formerly read:

"Any person who knowingly disposes of any hazardous waste at a point which is not authorized according to the provisions of this chapter shall be subject to a fine of not more than twenty-five thousand dollars ($25,000) for each violation, or to imprisonment not to exceed one year, or both, and may be required to disclose the fact of this violation to such persons as the court may direct."

Effect of amendment of section by two or more acts at the same session of the legislature, see Government Code § 9605.

The 1982 amendment rewrote the section, which prior to the amendment, read:

"Any person who knowingly does any of the following acts shall, upon conviction, be punished by a fine of not more than twenty-five thousand dollars ($25,000) for each day of violation, or by imprisonment in the county jail not to exceed one year, or both such fine and imprisonment. If the conviction is for a violation committed after a first conviction of such person under this section, such person shall be punished by imprisonment in the state prison for 16, 20, or 24 months, or in the county jail for not to exceed one year, or by a fine of not more than fifty thousand dollars ($50,000) per day of violation, or by both such fine and imprisonment.

"(a) Transports any hazardous waste to a facility which does not have a permit from the department issued pursuant to this chapter, or to any point which is not authorized according to the provisions of this chapter.

"(b) Treats, stores, or disposes of any hazardous waste at a facility which does not have a permit from the department issued pursuant to the provisions of this chapter, or at any point which is not authorized according to the provisions of this chapter.

"(c) Makes any false statement or representation in any application, label, manifest, record, report, permit, or other document filed, maintained, or used for the purposes of compliance with this chapter.

"(d) Withholds information regarding a real and substantial danger to the public health or safety when such information has been requested by the department in writing and is required to carry out the department's responsibilities pursuant to the provisions of this chapter in response to a real and substantial danger."

Amendment of this section by § 25 of Stats.1982, c. 89, failed to become operative under the provisions of § 30 of that Act.

The 1983 amendment substituted "the" for "such" throughout the section; substituted in subd. (a)(4) "pursuant to this chapter" for "pursuant to the provisions of this chapter"; added subd. (a)(5); added subds. (b) and (c); relettered subd. (b) to be subd. (d); and in subd. (d)(1) and (2) substituted "to this chapter" for "to the provisions of this chapter".

§ 25191.7. Information materially contributing to imposition of civil and criminal penalties; rewards to informants; amount; regulations

(a) Any person who provides information which materially contributes to the imposition of a civil penalty against any person for violating the provisions of subdivision (a), (b), or (c) of Section 25189, shall be paid a reward by the department pursuant to regulations adopted by the department under subdivision (f), equal to 10 percent of the amount of the civil penalty collected by the department pursuant to subdivision (a), (b), or (c) of Section 25189 and deposited in the Hazardous Waste Control Account pursuant to Section 25192. No reward paid pursuant to this subdivision shall exceed five thousand dollars ($5,000).

(b) Any person who provides information which materially contributes to the conviction of a person for violating the provisions of subdivision (a), (b), or (c) of Section 25191 shall be paid a reward by the county

pursuant to regulations adopted by the department under subdivision (f), equal to 10 percent of the amount of the fine collected pursuant to subdivision (a), (b), or (c) of Section 25191 and deposited in the county treasury pursuant to Section 1463 of the Penal Code. No reward paid pursuant to this subdivision shall exceed five thousand dollars ($5,000).

(c) No informant shall be eligible for a reward for a violation known to the department, unless the information materially contributes to the imposition of criminal or civil penalties for a violation specified in this section.

(d) If there is more than one informant for a single violation, the first notification received by the department shall be eligible for the reward. If the notifications are postmarked on the same day or telephoned notifications are received on the same day, the reward shall be divided equally among those informants.

(e) Public officers and employees of the United States, the State of California, or counties and cities in California, shall not be eligible for the reward pursuant to subdivision (a) or (b), unless reporting those violations does not relate in any manner to their responsibilities as public officers or employees.

(f) On or before July 1, 1982, the department shall adopt regulations which establish procedures for the receipt and review of claims for payment of rewards and for the determination of the material contribution by the information furnished to the imposition of civil or criminal penalties for a violation specified in this section. In each case brought under subdivision (a) the department shall determine whether the information materially contributes to the imposition of civil or criminal penalties for violations specified in this section. In each case brought under subdivision (b) the county shall determine whether the information materially contributes to the imposition of civil or criminal penalties for violations specified in this section.

(g) On or before April 1, 1982, and continuing thereafter, the department shall publicize the availability of the rewards pursuant to this section for persons who provide information pursuant to subdivision (a) or (b).

(h) Claims may be submitted only for those referrals made on or after January 1, 1982.

(Added by Stats.1982, c. 93, § 1.)

Library References

Rewards ⇐½.
C.J.S. Rewards §§ 1 to 3.

§ 25192. Penalties; deposit; appropriation

Penalties collected pursuant to this chapter shall be paid to the Hazardous Waste Control Account in the General Fund. Funds deposited in such account are continuously appropriated for expenditure without

regard to fisca
carry out the p
and the action
department, upo
amount which s
the city attorne
the penalty was
the amount of a
the amount paid
is less. If no pe
obligation to ma
incurred by th
prosecuting the
than one-half of
the amount paid
is greater, the
monetary differ
to partially fund
of this chapter

(Added by Stats.1
2533, § 4; Stats.1

The 1980 amendr
which, as added, re

"Fees and penalt
this chapter shall b
ardous Waste Contr
al Fund. Fees colle
25174, shall not ex
sary to cover all c
ministration of this
with fiscal year 197
this account shall b
submitted to the L

The 1982 amend
third sentence f

§ 25193. Cu

The remedies
construed as re
by law for the
shall preclude a
same facts.

(Added by Stats.

regard to fiscal years to the State Department of Health Services to carry out the provisions of this chapter. If civil penalties are awarded and the action is brought by a city attorney or district attorney, the department, upon payment of the penalty, shall pay the city or county an amount which shall be equal to the actual cost incurred by the office of the city attorney or district attorney for prosecuting the case for which the penalty was awarded, one-half of the penalty awarded, or one-half the amount of any civil penalty awarded and remaining after deducting the amount paid pursuant to subdivision (a) of Section 25191.7, whichever is less. If no penalty is awarded or paid, or both, the state shall have no obligation to make any payment to the city or county. If the actual cost incurred by the office of the city attorney or district attorney for prosecuting the case was less than one-half the penalty awarded or less than one-half of any civil penalty awarded and remaining after deducting the amount paid pursuant to subdivision (a) of Section 25191.7, whichever is greater, the department shall use funds in an amount equal to the monetary difference between such actual cost and one-half such penalty to partially fund activity of local health officers to enforce the provisions of this chapter pursuant to Section 25180.

(Added by Stats.1977, c. 1039, p. 3150, § 32. Amended by Stats.1980, c. 804, p. 2533, § 4; Stats.1982, c. 93, § 2.)

Historical Note

The 1980 amendment rewrote the section which, as added, read:

"Fees and penalties collected pursuant to this chapter shall be deposited in the Hazardous Waste Control Account in the General Fund. Fees collected pursuant to Section 25174, shall not exceed the amount necessary to cover all costs incurred in the administration of this chapter. Commencing with fiscal year 1978–79, expenditures from this account shall be included in the budget submitted to the Legislature."

The 1982 amendment substituted, in the third sentence following "penalty was awarded", "one-half of the penalty awarded or one-half the amount of any civil penalty awarded and remaining after deducting the amount paid pursuant to subd. (a) of Section 25191.7, whichever is less" for "or one-half the penalty awarded, whichever is less"; and, in the fifth sentence, following the words "case was less than", substituted "one-half the penalty awarded or less than one-half of any civil penalty awarded and remaining after deducting the amount paid pursuant to subdivision (a) of Section 25191.7, whichever is greater" for "half the penalty awarded".

§ 25193. *Cumulative remedies*

The remedies provided by this chapter are cumulative, and shall not be construed as restricting any remedy, provisional or otherwise, provided by law for the benefit of any party, and no judgment under this chapter shall preclude any party from obtaining additional relief based upon the same facts.

(Added by Stats.1980, c. 876, p. 2749, § 5, eff. Sept. 10, 1980.)

Library References

Health and Environment ⇐20.

C.J.S. Health and Environment §§ 2 to 6, 40, 44 to 47, 62 to 64, 106, 125, 128, 130, 132, 137.

§ 25194. Abatement of action

Any action brought by or for the director pursuant to this chapter against a person shall not abate by reason of a sale or other transfer of ownership, except with the express written consent of the director.

(Added by Stats.1980, c. 876, p. 2749, § 6, eff. Sept. 10, 1980.)

§ 25194.5. Withdrawal of application for permit; suspension, expiration or forfeiture of permit; effect

(a) The withdrawal of an application for a permit for a facility that has treated, stored, or disposed of hazardous waste after it has been filed with the department shall not, unless the department consents in writing to such withdrawal, deprive the department of its authority to institute or continue a proceeding against the applicant for the denial of the permit upon any ground provided by law or to enter an order denying the permit upon any such ground, and such a withdrawal shall not affect the authority of the department to institute or continue a proceeding against the applicant pertaining to any violation of this chapter or any rule, regulation, standard, or requirement issued or promulgated pursuant to this chapter.

(b) The suspension, expiration, or forfeiture by operation of law of a permit issued by the department, or its suspension, forfeiture, or cancellation by order of the department or by order of a court, or its surrender or attempted or actual transfer without the written consent of the department shall not deprive the department of its authority to institute or continue a disciplinary proceeding against the holder of a permit upon any ground, or of its authority to enter an order suspending or revoking the permit, or otherwise taking an action against the holder or a permit on any such ground.

(Added by Stats.1980, c. 876, p. 2749, § 7, eff. Sept. 10, 1980.)

Library References

Health and Environment ⇐25.5(5).
C.J.S. Health and Environment §§ 91 et seq., 106 et seq., 131.

§ 25195. Acts constituting misdemeanors

It is a misdemeanor for any person to do any of the following:

(a) Willfully prevent, interfere with, or attempt to impede in any way the work of any duly authorized representative of the department in the lawful enforcement of any provision of this chapter.

(b) Willfully pr
from examining a
her official duties

(c) Willfully pr
preserving of evi
chapter or of the
chapter.

(Added by Stats.19

Misdemeanor, genera

Health and Enviro
C.J.S. Health and
113, 114, 141, 14

§ 25196. Haz

Any person w
Section 25221 or
a civil penalty n
land and improv
improvements, c
established and

(Added by Stats.1

HAZARD

Section
25198. Analysi
anoth
25198.2. Regulat
identi
25198.3. Form o
recer
25198.4. Suspen
25198.5. Inspect
25198.6. Publica
25198.7. Fees.

Arti

(b) Willfully prevent or attempt to prevent any such representative from examining any relevant books or records in the conduct of his or her official duties under this chapter.

(c) Willfully prevent or interfere with any such representative in the preserving of evidence of any violation of any of the provisions of this chapter or of the rules and regulations promulgated pursuant to this chapter.

(Added by Stats.1980, c. 878, p. 2759, § 11.)

Cross References

Misdemeanor, generally, see Penal Code §§ 17, 19, 19a.

Library References

Health and Environment ⟹37.
C.J.S. Health and Environment §§ 48, 113, 114, 141, 143, 148, 149, 155.

§ 25196. Hazardous waste disposal land use; civil penalty

Any person who knowingly violates a provision of subdivision (a) of Section 25221 or subdivision (a) or (b) of Section 25232 shall be subject to a civil penalty not to exceed 25 percent of the fair market value of the land and improvements, 25 percent of the sale price of the land and improvements, or fifty thousand dollars ($50,000), whichever has been established and is greatest.

(Added by Stats.1980, c. 1161, p. 3901, § 6.)

Article 8.5

HAZARDOUS WASTE TESTING LABORATORIES

Section

25198. Analysis of material; certified laboratory; laboratory certification by another state or a federal agency; operative date of section.
25198.2. Regulations for certification, certification process, and analysis and identity of waste samples.
25198.3. Form of application for certification; issuance and term of certificate; recertification.
25198.4. Suspension, revocation, or denial of certificate.
25198.5. Inspections; proficiency test samples.
25198.6. Publication of list of certified laboratories.
25198.7. Fees.

Article 8.5 was added by Stats.1982, c. 1209, § 2.

§ 25198. Analysis of material; certified laboratory; laboratory certification by another state or a federal agency; operative date of section

(a) The analysis of any material required by this chapter shall be performed by a laboratory certified by the department to be competent and equipped to conduct the specific type of analysis to be performed.

(b) The department may accept a laboratory certification for a hazardous waste or hazardous materials analysis issued by an agency of another state or the federal government in lieu of its own if the requirements of that certification program are no less stringent than the requirements of the certification program established by this article. With prior written approval of the department, this section may be waived when no laboratory is certified to perform the type of analysis required under this chapter or the regulations adopted pursuant to this chapter or when the department determines that a certified laboratory is unavailable to perform the analysis within a reasonable time.

(c) This section shall become operative one year after the effective date of the regulations adopted pursuant to Section 25198.2.

(Added by Stats.1982, c. 1209, § 2.)

Operative one year after effective date of regulations adopted pursuant to § 25198.2.

Library References

Health and Environment ⇐25.5(5).
C.J.S. Health and Environment §§ 91 et seq., 106 et seq., 131.

§ 25198.2. Regulations for certification, certification process, and analysis and identity of waste samples

(a) The department shall adopt regulations governing the criteria for certification, the certification process, and the procedures to be used by hazardous waste laboratories to analyze and identify waste samples.

(b) The regulations shall include minimum standards for the following:

(1) Types of tests to be performed.

(2) Quality assurance programs.

(3) Equipment.

(4) Methods.

(5) Personnel qualifications.

(6) Any additional requirements, not inconsistent with this chapter, as may be necessary to carry out the provisions of this chapter.

(c) Whenever feasible, the tests and laboratory procedures adopted by the department pursuant to subdivision (b) shall either be tests and procedures recognized and endorsed by professional, standard-setting or

regulatory orgar
dures developed
(Added by Stats.1

§ 25198.3. F

Application fo
department. Th
from the date o
that the laborat
analysis and ide
ry shall apply f
the department.
denied accordin
(Added by Stats.1

§ 25198.4. S

The departme
determination c
(a) The labor
waste analysis
(b) The labo
regulation adop
(Added by Stats.

§ 25198.5. I

(a) In order
ed representat
hours of the la
(1) Enter an
or which has a
(2) Inspect a
mation require
(3) Photogra
equipment, wa
inspection.
(b) All reco
ered by the de
same procedur
protect trade s
(c) The depa
ry which is c
The sample s

regulatory organizations, or shall be specific tests and laboratory procedures developed by the department.

(Added by Stats.1982, c. 1209, § 2.)

§ 25198.3. Form of application for certification; issuance and term of certificate; recertification

Application for certification shall be made on forms approved by the department. The department shall issue a certificate valid for two years from the date of issue to a laboratory when the department determines that the laboratory is competent and equipped to conduct the type of analysis and identification for which certification is sought. A laboratory shall apply for recertification every two years on forms approved by the department. An application for recertification shall be granted or denied according to the criteria established for original certification.

(Added by Stats.1982, c. 1209, § 2.)

§ 25198.4. Suspension, revocation, or denial of certificate

The department may suspend, revoke, or deny a certificate upon its determination of either of the following:

(a) The laboratory is not competent or equipped to conduct hazardous waste analysis and identification.

(b) The laboratory has violated provisions of this chapter or any regulation adopted pursuant to this chapter.

(Added by Stats.1982, c. 1209, § 2.)

§ 25198.5. Inspections; proficiency test samples

(a) In order to carry out the purpose of this article, any duly authorized representative of the department may, during the regular business hours of the laboratory, do any of the following:

(1) Enter and inspect a laboratory which is certified under this article or which has applied for certification.

(2) Inspect and copy any records, reports, test results, or other information required to carry out the provisions of this article.

(3) Photograph any waste, waste container, waste container label, equipment, waste identification process, or violation found during an inspection.

(b) All records, test results, photographs, or other information gathered by the department pursuant to subdivision (a) shall be subject to the same procedures the department establishes pursuant to Section 25173 to protect trade secrets.

(c) The department may submit proficiency test samples to a laboratory which is certified or has applied for certification under this article. The sample shall be tested in the manner specified by regulations

adopted pursuant to this chapter. The results of the tests shall be sent to the department in writing within 60 days after receiving the sample. The department shall not be charged any fee for testing under this section.

(Added by Stats.1982, c. 1209, § 2.)

§ 25198.6. Publication of list of certified laboratories

The department may publish a list of laboratories certified under this article, including the specific tests or procedures for which the laboratory is certified.

(Added by Stats.1982, c. 1209, § 2.)

§ 25198.7. Fees

(a) Each laboratory initially applying for certification pursuant to this article shall pay to the department an application fee of six hundred dollars ($600).

(b) Each laboratory certified pursuant to this article shall pay an annual certification fee of five hundred dollars ($500), commencing one year after the date of the laboratory's initial application for certification.

(c) Fees collected under this section shall be adjusted annually, as specified in Section 113.

(d) If a laboratory fails to pay the annual certification fee, the certificate of the laboratory shall expire.

(e) No certification fee shall be required for any laboratory operated by the state or any state agency, or by a district, city, county, or city and county or any agency of a district, city, county, or city and county.

(f) Fees collected pursuant to this section shall be paid to the Hazardous Waste Control Account in the General Fund.

(Added by Stats.1982, c. 1209, § 2.)

Article 9
PERMITTING OF FACILITIES

Section
25200. Authority; standards and requirements.
25200.5. Interim status.
25201. Hazardous waste facilities permit; prerequisite to extended treatment or storage of hazardous wastes.
25201.2. Failure to display certificate of compliance with inspection; duty to report.
25202. Validity of permit; conditions.
25202.5. Restrictive covenants; land use; execution and recording; enforcement.
25202.6. Modification or removal of restrictive covenants, provisions or statements; requests; execution and recording of agreement.

Section
25202.7. Review of departmental decision concerning restrictive covenants.
25203. Unlawful disposition of hazardous waste.
25204. Refusal to issue permit or license.
25205. Financial assurances by operators; limitations, requirements and water quality determinations of state and regional boards.

Article 9 was added by Stats.1977, c. 1039, p. 3150, § 33.

§ 25200. Authority; standards and requirements

The department shall issue hazardous waste facilities permits to use and operate facilities which in the judgment of the department meet the building standards published in the State Building Standards Code relating to hazardous waste facilities and the other standards and requirements adopted pursuant to this chapter. The department may impose, as a condition of the permit, the requirement that the operator of a hazardous waste facility which receives hazardous waste from more than one producer shall comply with any order of the director which prohibits the facility operator from refusing to accept a hazardous waste based on geographical origin which is authorized to be accepted and may be accepted by the facility without extraordinary hazard.

(Added by Stats.1977, c. 1039, p. 3150, § 33. Amended by Stats.1978, c. 1397, p. 4623, § 13; Stats.1979, c. 1152, p. 4311, § 193; Stats.1980, c. 259, p. 532, § 1.)

Historical Note

The 1978 amendment inserted in the first sentence preceding the word "permits" the words "hazardous waste facilities".

The 1979 amendment inserted in the first sentence, following "department meet the", the words "building standards published in the State Building Standards Code relating to hazardous waste facilities and the other".

The 1980 amendment substituted, at the end of the first sentence, the words "this chapter" for "Section 25150" and added the second sentence.

§ 25200.5. Interim status

(a) Any person who desires to continue use or operation of a hazardous waste facility pending the review and decision of the department on the permit application, may be granted interim status by the department provided that the person has made application for a permit pursuant to Section 25200.

(b) The person operating under an interim status pursuant to this section shall not do any of the following acts:

(1) Treat, store, or dispose of hazardous wastes which are not identified.

(2) Employ processes not described in the permit application.

(3) Make substantial modifications or additions to the facility.

(c) A facility operating under interim status is not subject to civil or criminal penalties for operating without a permit, but is otherwise subject to the provisions of this chapter and the rules, regulations,

standards, and requirements issued or promulgated pursuant to the provisions of this chapter. Interim status may be granted subject to any conditions which the department deems necessary to protect public health or the environment. Interim status shall not be valid beyond the date of the decision of the department on the permit application.

(d) The department shall not grant interim status to any person who has been denied a hazardous waste facility permit or who has had a hazardous waste facility permit suspended or revoked.

(Added by Stats.1980, c. 876, p. 2750, § 8, eff. Sept. 10, 1980.)

Library References

Health and Environment ⟹25.5(5).
C.J.S. Health and Environment §§ 91 et seq., 106 et seq., 131.

§ 25201. Hazardous waste facilities permit; prerequisite to extended treatment or storage of hazardous wastes

No operator of a treatment facility, waste transfer station, waste storage area, resource recovery facility, or waste disposal site shall accept, treat, store for more than 90 days at an onsite facility or 96 hours at an offsite facility, or dispose of a hazardous waste at the facility, station, area, or site, unless the operator holds a hazardous waste facilities permit from the department to use and operate the facility, station, area, or site.

(Added by Stats.1977, c. 1039, p. 3150, § 33. Amended by Stats.1978, c. 1397, p. 4623, § 14; Stats.1980, c. 878, p. 2759, § 12; Stats.1982, c. 1121, § 7.)

Historical Note

The 1978 amendment substituted "valid hazardous waste facilities permit" for "valid permit" [see 1982 amendment note].

The 1980 amendment substituted "accept, treat, store for more than sixty days, or dispose of a hazardous waste at such facility, station, area, or site unless the operator holds a hazardous waste facilities permit" for "accept or dispose of hazardous waste unless the operator holds a valid hazardous waste facilities permit" [see 1982 amendment note].

The 1982 amendment rewrote the section, which as last amended in 1980, read:

"Three months after the department adopts standards and requirements pursuant to Section 25150, no operator of a treatment facility, waste transfer station, waste storage area, resource recovery facility, or waste disposal site shall accept, treat, store for more than sixty days, or dispose of a hazardous waste at such facility, station, area, or site unless the operator holds a hazardous waste facilities permit from the department to use and operate such facility, station, area, or site."

Legislative findings, declarations, and intent concerning Stats. 1982, c. 1121, see Historical Note under § 25117.11.

§ 25201.2. Failure to display certificate of compliance with inspection; duty to report

Any operator of a treatment facility, waste transfer station, waste storage area, resource recovery facility or waste disposal site or any

other person
semitrailer, o
ance as provi
Department o

(Added by Stat
3578, § 9.)

The 1980 ame
er".

§ 25202. V

Compliance
and with regu
shall be requi
shall impose c
wastes which
ing conditions
liabilities whic
of bond or oth
and closing th
operation of t
tions promulg
pose other con
of this chapte

(Added by Stats
4623, § 15; Stat
1982.)

The 1978 amend
sentence preceding
"permit", "hazard
serted "such" for
in the first and s
the second sente
ment" for "require
ment note).

The 1980 amend
end of the second
cility necessary to
tions promulgated
for "permittee nec

§ 25202.5.

In addition
permit imposed

other person who accepts hazardous waste from a vacuum truck, trailer, semitrailer, or container failing to display a valid certificate of compliance as provided in Section 25168.3, shall report the incident to the State Department of Health Services, as required by the department.

(Added by Stats.1979, c. 1097, p. 3966, § 4. Amended by Stats.1980, c. 1112, p. 3578, § 9.)

Historical Note

The 1980 amendment added "semitrailer".

§ 25202. Validity of permit; conditions

Compliance with conditions on the hazardous waste facilities permit and with regulations adopted by the department pursuant to this chapter shall be required to sustain the validity of such permit. The department shall impose conditions on such permit, specifying the types of hazardous wastes which may be accepted for treatment or disposal, special operating conditions, requirements for evidence of financial responsibility for liabilities which may be incurred in the operation of the facility, provision of bond or other sureties to cover the costs of monitoring, maintaining, and closing the facility, and of postclosure security, and changes in the operation of the permitted facility necessary to comply with the regulations promulgated pursuant to this chapter. The department may impose other conditions on such permit which are consistent with the intent of this chapter.

(Added by Stats.1977, c. 1039, p. 3151, § 33. Amended by Stats.1978, c. 1397, p. 4623, § 15; Stats.1980, c. 259, p. 532, § 2; Stats.1982, c. 89, § 26, eff. March 2, 1982.)

Historical Note

The 1978 amendment inserted in the first sentence preceding the first use of the word "permit", "hazardous waste facilities"; inserted "such" for "the" preceding "permit" in the first and second sentences; and in the second sentence substituted "requirement" for "requirements" (see 1980 amendment note).

The 1980 amendment substituted, at the end of the second sentence, "permitted facility necessary to comply with the regulations promulgated pursuant to this chapter" for "permittee necessary to comply with the requirement promulgated pursuant to this chapter".

The 1982 amendment rewrote the second sentence, which as last amended in 1980, read:

"The department may impose conditions on such permit, including, but not limited to, the types of hazardous wastes which may be accepted or disposed of, special operating conditions, and changes in the operation of the permitted facility necessary to comply with the regulations promulgated pursuant to this chapter."; and added the third sentence.

§ 25202.5. Restrictive covenants; land use; execution and recording; enforcement

In addition to any other condition of a hazardous waste facilities permit imposed by the department pursuant to this chapter, the depart-

ment may impose a requirement for the execution and recording of a written instrument which imposes a restrictive covenant upon the present and future uses of all or part of the land on which the hazardous waste facility subject to the permit is located and on all or part of any adjacent land held by, or for the beneficial use of, the owners of the land on which the hazardous waste facility subject to the permit is located. Such restrictive covenant shall be no more restrictive than needed, as determined by the department, to protect the present or future public health and safety and shall not place any restriction on any such land that limits the use, modification, or expansion of an existing industrial or manufacturing facility or complex. Such an instrument shall be executed by all of the owners of such land and by the director, shall particularly describe the real property affected by the instrument, and shall be recorded by the owner in the county in which the land is located within 10 days of the date of execution. The covenant shall state that the land described in the instrument has been, or will be, the site of a hazardous waste facility or is adjacent to the site of such a facility, and may impose such use restrictions as the department deems necessary to protect the present or future public health. Such restrictions may include restrictions upon activities on, over, or under the land, including, but not limited to, a prohibition against building, filling, grading, excavating, or mining without the written permission of the director. A certified copy of the recorded covenant shall be sent to the department upon recordation. Notwithstanding any other provision of law, except as provided in Section 25202.6, a covenant executed pursuant to this section shall run with the land from the date of recordation and shall be binding upon all of the owners of the land, their heirs, successors, and assignees, and the agents, employees, and lessees of such owners, heirs, successors, and assignees. The covenant shall be enforceable by the department pursuant to Article 8 (commencing with Section 25180).

(Added by Stats.1980, c. 655, p. 1832, § 1.)

Cross References

Covenants adopted as enforceable restrictions subject to Revenue and Taxation Code § 402.1, see § 25240.
Technical requirements for recording, see § 25235.

Library References

Health and Environment ⇐25.5(3).
C.J.S. Health and Environment §§ 91 et seq., 106 et seq., 129 et seq.

§ 25202.6. Modification or removal of restrictive covenants, provisions or statements; requests; execution and recording of agreement

The owner of land subject to a restrictive covenant, or other provision or statement in a written instrument, required by the department pursu-

ant to Section
remove such
request and s
the need for s
ate, and afte
covenant, pro
no more rest
safety. Whe
covenant, pro
such land sha
particularly d
the owner sha
located withir

(Added by Stat

§ 25202.7.

Any decisic
Section 2520
jurisdiction a
and shall be
substantial e

(Added by Sta

§ 25203. U

Three mon
pursuant to
of a hazardo
who holds a
to use and o

(Added by Sta
4624, § 16.)

The 1978 am
hazardous wast
id permit".

Unlawful dispo
standards an

§ 25204.

Notwithst
refuse to iss

ant to Section 25202.5, may make a written request of the department to remove such covenant, provision, or statement. Upon receipt of such a request and supporting material, the department shall promptly review the need for such covenant, provision, or statement and, when appropriate, and after a public hearing, shall agree to modify or remove such covenant, provision, or statement to make certain that it continues to be no more restrictive than necessary to protect the public health and safety. When the department agrees to modify or remove such a covenant, provision, or statement, the director and all of the owners of such land shall execute an instrument that reflects such agreement, shall particularly describe the real property affected by the instrument, and the owner shall record the instrument in the county in which such land is located within 10 days of the date of execution.

(Added by Stats.1980, c. 655, p. 1833, § 2.)

§ 25202.7. Review of departmental decisions concerning restrictive covenants

Any decision of the department pursuant to either Section 25202.5 or Section 25202.6 shall be subject to review by a court of competent jurisdiction as provided in Section 1094.5 of the Code of Civil Procedure and shall be upheld if the court finds the decision is supported by substantial evidence.

(Added by Stats.1980, c. 655, p. 1833, § 3.)

§ 25203. Unlawful disposition of hazardous waste

Three months after the department adopts standards and requirements pursuant to Section 25150, it shall be unlawful for any person to dispose of a hazardous waste except at a disposal site or facility of an operator who holds a valid hazardous waste facilities permit from the department to use and operate such site or facility.

(Added by Stats.1977, c. 1039, p. 3151, § 33. Amended by Stats.1978, c. 1397, p. 4624, § 16.)

Historical Note

The 1978 amendment substituted "valid hazardous waste facilities permit" for "valid permit".

Cross References

Unlawful disposition of hazardous waste, time period commencing after adoption of standards and requirements pursuant to this section, see § 25203.

§ 25204. Refusal to issue permit or license

Notwithstanding any other provision of law, no state agency may refuse to issue a permit or license for a hazardous waste facility on the

grounds that the applicant has not been granted a local land use permit; provided, however, that in issuing the permit or license the state agency may provide that the permit or license shall not become effective until the applicant is granted a local land use permit.

(Added by Stats.1980, c. 877, p. 2756, § 4.)

Historical Note

Former § 25204, added by Stats.1977, c. 1039, p. 3151, § 33, which allowed permits issued by the department or county health entity, which contained requirements that the department specified, to satisfy requirements for permit under this article, was repealed by Stats.1978, c. 1397, p. 4624, § 17.

Library References

Health and Environment ⟹25.5(5).
C.J.S. Health and Environment §§ 91 et seq., 106 et seq., 131.

§ 25205. Financial assurances by operators; limitations, requirements and water quality determinations of state and regional boards

(a) The department shall not issue, renew, or continue a permit to operate a hazardous waste facility unless the operator of the facility establishes and maintains the financial assurance prescribed pursuant to Section 25245. With respect to the continuation of an existing permit, the department shall allow a period of at least six months from the effective date of regulations relating to financial assurances adopted pursuant to Section 25245 for the operator to obtain the prescribed financial assurances.

(b) The department shall not issue a permit for, or take any other approval action regarding, a hazardous waste facility in conflict with any determination relating to water quality made by the State Water Resources Control Board or any regional water quality control board. Any limitations and requirements imposed upon a facility by a regional water quality control board pursuant to Section 13227 of the Water Code shall also be a condition of any permit issued for the facility by the department.

(Added by Stats.1982, c. 90, § 2, eff. March 2, 1982.)

Library References

Health and Environment ⟹25.5(5).
C.J.S. Health and Environment §§ 91 et seq., 106 et seq., 131.

Article 9.5

HAZARDOUS WASTE MANAGEMENT COUNCIL [REPEALED]

Article 9.5, added by Stats.1982, c. 89, § 28, eff. March 2, 1982, consisting of §§ 25206 to 25209.5, was repealed under the provisions of § 25209.5 on Jan. 1, 1984.

§§ 25206 to 25209.5. Repealed by Stats.1982, c. 89, § 28, operative Jan. 1, 1984

Historical Note

The repealed sections, added by Stats. 1982, c. 89, § 28, providing for the hazardous waste management council, were repealed on Jan. 1, 1984, under the provisions of § 25209.5.

Prior to repeal, § 25207 was amended by Stats.1983, c. 323, § 60.16, eff. July 21, 1983, and §§ 25208, 25208.5 were amended by Stats.1982, c. 1244, §§ 2, 3; Stats.1983, c. 323, §§ 60.18, 60.20, eff. July 21, 1983. See Historical Note under C.C.P. § 1531.

Article 10

PROHIBITED CHEMICALS

Article 10 was added by Stats.1977, c. 1039, p. 3151, § 34.

§ 25210. Nonbiodegradable toxic chemicals; unlawful use or sale; regulations

It shall be unlawful, on or after January 1, 1979, to use a nonbiodegradable toxic chemical in a chemical toilet, recreational vehicle, or waste facility of a vessel as the term vessel is defined in the Harbors and Navigation Code, and it shall be unlawful on or after January 1, 1979, to sell a nonbiodegradable toxic chemical in a container which indicates that the chemical could be used in a chemical toilet, a waste facility of a recreational vehicle, or a waste facility of a vessel as the term vessel is defined in the Harbors and Navigation Code. The department shall develop and adopt regulations to define nonbiodegradable toxic chemicals and limitations on the sale thereof by June 1, 1978.

(Added by Stats.1977, c. 1039, p. 3151, § 34.)

Cross References

Vessel, defined, see Harbors and Navigation Code § 21.

Administrative Code References

Chemical toilet additive defined, see 22 Cal.Adm.Code 60093.

Chemical toilet defined, see 22 Cal.Adm.Code 60091.
Chemical toilet waste, defined, see 22 Cal.Adm.Code 60095.
Criteria for identification of nonbiodegradable and toxic substances, see 22 Cal.Adm.Code 60289, 60291.
Prohibited chemical toilet additives, see 22 Cal.Adm.Code 60285 et seq.

Library References

Health and Environment ⟹25.5.
C.J.S. Health and Environment §§ 61 to 66 et seq., 78 to 80 et seq., 88 to 90 et seq., 104 et seq., 115 to 126 et seq., 137 to 140 et seq., 153.

Article 11

HAZARDOUS WASTE DISPOSAL LAND USE

Section

25220. Request for information.
25221. Application for designation as hazardous waste property or border zone property; prior determinations.
25222. Notice of hearing; issuance; service; contents.
25223. Public notice of hearing; publication; posting.
25224. Time of hearing.
25225. Consolidation of hearings; notice.
25226. Response to notice; appearance and testimony; intervention; procedure.
25227. Discovery for hearings.
25228. Burden of proof.
25229. Decision and findings of fact; issuance and service.
25230. Orders; issuance; service; notice; easement; instrument to accompany lease or rental agreements.
25231. Review of decisions.
25232. Prohibited actions on land without specific variance.
25233. Variance; application; notice of hearing; burden of proof; decision and findings of fact; recording of final determination; review.
25234. Removal of designation as hazardous waste property or border zone property; application; grounds; appeal; review; termination of easement.
25235. Recordation of final determination.
25236. Civil and criminal actions; land use restriction; law governing.
25237. Severability of article provisions.
25238. Disposal of hazardous waste onto specified lands; minimum buffer zone.
25239. Costs.
25240. Reassessment of restricted land.
25241. Exception to application of article.

Article 11 was added by Stats.1980, c. 1161, p. 3901, § 7.

§ 25220. *Request for information*

(a) Whenever there is reasonable cause for the department to believe that any land is a hazardous waste property, the department may, be certified mail, request any person who owns, leases, or occupies such land or any other person who has information relating to such land, to provide any or all of the following information:

(1) A descrip
(2) The type
waste containe
(3) The date
waste was dep
(4) A map o
or overlies ha
scale of not n
areas where
contained or
subdivision sh
in writing tha
existence or l
(b) Any per
subdivision (a
department w
(Added by Stat

Costs incurred, p
Inspection of pro
§ 25185.5.

Health and En
C.J.S. Health
seq., 106 et

§ 25221. A

(a) Any pe
probable cau
has occurred
or that the la
waste; and
land of a b
described in
year; shall
determinatio
waste prope
The addit
dwelling or
which do no
density does
purposes of

(1) A description of the present use of the land.

(2) The types and volumes of hazardous waste or extremely hazardous waste contained therein or thereon.

(3) The date or dates such hazardous waste or extremely hazardous waste was deposited into or onto the land.

(4) A map or maps of the property which they own and which contains or overlies hazardous waste or extremely hazardous waste, drawn to a scale of not more than 200 feet to the inch, which shows the area or areas where such hazardous waste or extremely hazardous waste is contained or was deposited. The provision of a map pursuant to this subdivision shall not be required if the respondent to the request asserts in writing that he has no knowledge or insufficient knowledge of the existence or location of such wastes to comply with this subdivision.

(b) Any person who is requested to provide information pursuant to subdivision (a) of this section shall submit such information to the department within 90 calendar days of receipt of the request.

(Added by Stats.1980, c. 1161, p. 3901, § 7.)

Cross References

Costs incurred, payment from Hazardous Waste Control Account, see § 25239.
Inspection of property relating to hazardous waste disposal for purposes of this article, see § 25185.5.

Library References

Health and Environment ⇐25.5(5).
C.J.S. Health and Environment §§ 91 et seq., 106 et seq., 131.

§ 25221. Application for designation as hazardous waste property or border zone property; prior determinations

(a) Any person as owner, lessor, or lessee who (1) knows or has probable cause to believe that a significant disposal of hazardous waste has occurred on, under, or into the land which he or she owns or leases or that the land is within 2,000 feet of a significant disposal of hazardous waste; and (2) intends to construct or allow the construction on such land of a building or structure to be used for a purpose which is described in subdivision (b) of Section 25232 within the next calendar year; shall apply to the department prior to such construction for a determination as to whether the land should be designated a hazardous waste property or a border zone property pursuant to Section 25229.

The addition of rooms or living space to an existing single-family dwelling or other minor repairs or improvements to residential property which do not change the use of the property or increase the population density does not constitute the construction of a building or structure for purposes of this subdivision.

(b) Any person who, as owner, lessor, or lessee, knows or has probable cause to believe that land which he or she owns or leases is a hazardous waste property or a border zone property, may apply to the department for a determination whether the land should be designated a hazardous waste property or a border zone property pursuant to Section 25229.

(c) If a city or county knows or has probable cause to believe that any land within its jurisdiction is a hazardous waste property or a border zone property, the city or county may apply to the department for a determination whether that land should be designated a hazardous waste property or a border zone property pursuant to Section 25229.

(d) Subdivisions (a), (b), and (c) shall not be applicable to any land on which a determination has previously been made pursuant to Section 25229 unless either of the following has occurred since such determination:

(1) A significant new disposal of hazardous waste has occurred on, under, or into the land.

(2) Significant new information about past disposal of hazardous waste on, or within 2,000 feet of, the land becomes known to the owner, lessor, or lessee of such land.

(Added by Stats.1980, c. 1161, p. 3901, § 7. Amended by Stats.1982, c. 165, § 1, eff. April 26, 1982; Stats.1982, c. 417, § 1, eff. July 8, 1982.)

Historical Note

The 1982 amendment by c. 165 neutralized gender in subds. (a) and (b); and deleted, in subd. (d) following "Section 25229", the words "or which is a hazardous waste property as defined in paragraph (1) of subdivision (a) of Section 25117.3,".

The 1982 amendment by c. 417, amending c. 165, added the second paragraph to subd. (a).

Effect of amendment of section by two or more acts at the same session of the legislature, see Government Code § 9605.

Cross References

Civil penalty for person who knowingly violates subd. (a) of this section, see § 25196.

§ 25222. *Notice of hearing; issuance; service; contents*

Whenever the department considers designating land as a hazardous waste property or a border zone property, it shall issue and cause to be served upon the owner of the land and the legislative body of the city or county in whose jurisdiction the land is located a notice of a hearing. The notice shall contain (1) a statement that the land is under consideration for designation as a hazardous waste property or a border zone property; (2) a summary of the reasons for such designation and what significant existing or potential health hazards are believed to exist; and (3) notice of the time, date, and place of the hearing, and any policy regarding continuance of the hearing.

(Added by Stats.1980, c. 1161, p. 3902, § 7. Amended by Stats.1982, c. 165, § 2, eff. April 26, 1982.)

The 1982 amendm
designation at the
and deleted subd. (
"The departmen
thority under Sectic
hazardous waste

Health and Envi
C.J.S. Health anc
103, 107, 140 e

§ 25223. Pu

Public notice
at least 15 da
publication onc
circulated in th
least three pub
(Added by Stats.

§ 25224. Ti

The hearing
designated by
the serving of
days of the s
hearing upon r
(Added by Stats

§ 25225. Co

The departm
which affect a
property. Not
but not less th
(Added by Stats

§ 25226. R

The persons
and to appear
time fixed in
agency conduc
intervene in th
ing shall, so f
of Chapter 5 (

Historical Note

The 1982 amendment deleted the subd. (a) designation at the beginning of the section and deleted subd. (b) which had read:

"The department shall exercise its authority under Section 25202.5 with regard to hazardous waste property as defined in paragraph (1) of subdivision (a) of Section 25117.3 to protect the present and future public health and safety from hazardous waste instead of utilizing the provisions of this article."

Library References

Health and Environment ⟹25.5(9).
C.J.S. Health and Environment §§ 65, 66, 103, 107, 140 et seq.

§ 25223. Public notice of hearing; publication; posting

Public notice of the hearing shall also be provided by the department at least 15 days before the hearing. Such notice shall be given by publication once in a newspaper of general circulation published and circulated in the locale, or if there is none, by posting the notice in at least three public places in the locale.

(Added by Stats.1980, c. 1161, p. 3902, § 7.)

§ 25224. Time of hearing

The hearing shall be held before the director, or any agent or agency designated by the director for such purpose, not less than 30 days after the serving of the notice. The hearing shall be commenced within 90 days of the serving of the notice. The department may delay the hearing upon request of any interested person.

(Added by Stats.1980, c. 1161, p. 3902, § 7.)

§ 25225. Consolidation of hearings; notice

The department may consolidate into a single hearing those hearings which affect a hazardous waste property and any associated border zone property. Notice of such consolidation shall occur as soon as practicable, but not less than 15 days before the hearing.

(Added by Stats.1980, c. 1161, p. 3903, § 7.)

§ 25226. Response to notice; appearance and testimony; intervention; procedure

The persons served shall have the right to file a response to the notice and to appear in person or otherwise and give testimony at the place and time fixed in the notice. At the discretion of the director, agent, or agency conducting the hearing, any interested person may be allowed to intervene in the proceeding and to present testimony. Any such proceeding shall, so far as practicable, be conducted pursuant to the provisions of Chapter 5 (commencing with Section 11500) of Part 1 of Division 3 of

Title 2 of the Government Code. All proceedings shall be appropriately reported, and the testimony taken shall be reduced to writing and filed with the director. Thereafter, at his or her discretion, the director, upon notice, may take further testimony or hear argument.

(Added by Stats.1980, c. 1161, p. 3903, § 7.)

Library References

Health and Environment ⇐25.5(9).
C.J.S. Health and Environment §§ 65, 66, 103, 107, 140 et seq.

§ 25227. Discovery for hearings

Discovery for a hearing held pursuant to this article shall be conducted as provided in Sections 11507.6, 11507.7, 11510, and 11511 of the Government Code.

(Added by Stats.1980, c. 1161, p. 3903, § 7.)

§ 25228. Burden of proof

(a) With regard to designating land as a hazardous waste property, the department shall have the burden of proving the hazardous waste has been deposited on, under, or in the land and that the hazardous waste creates a significant existing or potential hazard to present or future public health or safety on the hazardous waste property.

(b) With regard to designating land as a border zone property, the department shall have the burden of proving that hazardous waste has been deposited within 2,000 feet of the land and that the hazardous waste creates a significant existing or potential hazard to present or future public health or safety on the border zone property.

(Added by Stats.1980, c. 1161, p. 3903, § 7.)

§ 25229. Decision and findings of fact; issuance and service

(a) If, upon the preponderance of the testimony taken, including any evidence developed at any time prior to the hearing, the director is of the opinion that the land should be designated a hazardous waste property or a border zone property, the director shall issue and cause to be served on the owner of the land, the legislative body of the city or county in whose jurisdiction the land is located, and upon any other persons who were permitted to intervene in the proceedings, his or her decision and findings of fact. The findings of fact shall include reasons for such designation, including what substances are on, under, or in the land, and the significant existing or potential hazards to present or future public health and safety.

(b) If the director is of the opinion that the land should not be designated a hazardous waste property or border zone property, the

director shall is
subdivision (a)
(Added by Stats.

Recordation of fina
Restrictions subjec

§ 25230. Or

Upon designa
property pursu
be served on
legislative body
located and an
proceeding, orc
(a) The exec
imposes an eas
the land which
border zone pr
representatives
problems rega
by all the owi
describe the re
the location of
recorded with
within 10 day
county record
owner of the
department.
instrument is
any other prc
section shall r
binding upon
assignees, and
successors, an
department p
Notwithstandi
department sh
(b) The exec
lease or rental
ed a hazardou
ment shall be
contain the fo
"The land d
feet of land t
land and the

director shall issue and cause to be served on the parties mentioned in subdivision (a) his or her decision and findings of fact.

(Added by Stats.1980, c. 1161, p. 3903, § 7.)

Cross References

Recordation of final order, see § 25235.
Restrictions subject to Revenue and Taxation Code § 402.1, see § 25240.

§ 25230. Orders; issuance; service; notice; easement; instrument to accompany lease or rental agreements

Upon designation of land as hazardous waste property or border zone property pursuant to Section 25229, the director shall issue and cause to be served on the owner of the property and shall give notice to the legislative body of the city or county in whose jurisdiction the land is located and any other persons who were permitted to intervene in the proceeding, orders requiring all of the following:

(a) The execution and recordation of a written instrument which imposes an easement upon the present and future uses of all or part of the land which has been designated a hazardous waste property or a border zone property. Such easement shall permit the department or its representatives to enter the land, subject to Section 25185.5, to monitor problems regarding hazardous wastes. The easement shall be executed by all the owners of such land and by the director, shall particularly describe the real property affected by the instrument, and, if applicable, the location of the easement on the real property. The easement shall be recorded with the recorder of the county in which the land is located within 10 days of the date of execution and shall be indexed by the county recorder in the grantor index in the name of the record title owner of the real property and in the grantee index in the name of the department. The easement shall state that the land described in the instrument is subject to a hazardous waste easement. Notwithstanding any other provision of law, an easement executed pursuant to this section shall run with the land from the date of recordation and shall be binding upon all of the owners of the land, their heirs, successors, and assignees, and the agents, employees, or lessees of such owners, heirs, successors, and assignees. The easement shall be enforceable by the department pursuant to Article 8 (commencing with Section 25180). Notwithstanding any other provision of law, any easement held by the department shall not be sold or otherwise transferred to another person.

(b) The execution and service of a written instrument to accompany all lease or rental agreements relating to the land which has been designated a hazardous waste property or a border zone property. The instrument shall be prepared by the owner or lessor of the land and shall contain the following statement:

"The land described herein contains hazardous waste or is within 2,000 feet of land that contains hazardous waste. Such condition renders the land and the owner, lessee, or other possessor of the land subject to

requirements, restrictions, provisions, and liabilities contained in Chapter 6.5 (commencing with Section 25100) of Division 20 of the Health and Safety Code. This statement is not a declaration that a hazard exists."

(Added by Stats.1980, c. 1161, p. 3904, § 7. Amended by Stats.1982, c. 165, § 3, eff. April 26, 1982.)

Historical Note

The 1982 amendment, in the second sentence of subd. (a), substituted "subject to Section 25185.5" for "subject to Section 25185 or 25185.5".

§ 25231. Review of decisions

A decision of the director made after a hearing pursuant to Section 25229 shall be reviewable pursuant to Section 1094.5 of the Code of Civil Procedure.

(Added by Stats.1980, c. 1161, p. 3904, § 7.)

§ 25232. Prohibited actions on land without specific variance

(a) Except as provided in subdivision (c) of this section, after the director has provided notice in compliance with Section 25222 and a hearing or decision regarding specific land is pending, or after a hearing has been conducted and a decision has been made pursuant to Section 25229 that land is a hazardous waste property, then none of the following shall occur on the land without a specific variance approved in writing by the department for the land use and land in question:

(1) Any new use of the land, other than the use, modification, or expansion of an existing industrial or manufacturing facility or complex on land which is owned by, or held for the beneficial use of, such facility or complex as of January 1, 1981, and which is a hazardous waste property as defined in Section 25117.3.

(2) Subdivision of such land, as that term is used in Division 2 (commencing with Section 66410) of Title 7 of the Government Code, except that this paragraph shall not prevent the division of a parcel of land so as to divide that portion of the parcel which is designated a hazardous waste property from other portions of such parcel not so designated.

(b) Except as provided in subdivision (c) of this section, after the director has provided notice in compliance with Section 25222 and a hearing or decision regarding specific land is pending, or after a hearing has been conducted and a decision has been made pursuant to Section 25229 that land is a border zone property, then none of the following shall occur on the land without a specific variance approved in writing by the department for the land use and land in question:

(1) Construction or placement of a building or structure on the land which is intended for use as any of the following, or the new use of an existing structure for the purpose of serving as any of the following:

(A) A residence, including any mobilehome or factory built housing constructed or installed for use as permanently occupied human habitation, except that the addition of rooms or living space to an existing single-family dwelling or other minor repairs or improvements to residential property which do not change the use of the property or increase the population density does not constitute construction or placement of a building or structure for the purposes of this paragraph.

(B) A hospital for humans.

(C) A school for persons under 21 years of age.

(D) A day care center for children.

(E) Any permanently occupied human habitation other than those used for industrial purposes.

(2) Subdivision of such land, as that term is used in Division 2 (commencing with Section 66410) of Title 7 of the Government Code, except that this paragraph shall not prevent the division of a parcel of land so as to divide that portion of the parcel which is designated a border zone property from other portions of such parcel not so designated.

(c) This section shall not apply to a portion of a parcel of land which is determined by the director to meet all of the following requirements:

(1) The parcel has been previously classified as a class II-1 disposal site as defined in Section 2510 or 2511 of Title 23 of the California Administrative Code.

(2) The portion of the parcel is physically isolated from the remainder of the classified parcel by the construction of a freeway, as defined in Section 332 of the Vehicle Code, which divides the classified parcel.

(3) The portion of the parcel has not been used as a hazardous waste disposal site.

(4) The portion of the parcel does not contain or overlie hazardous waste.

(Added by Stats.1980, c. 1161, p. 3904, § 7. Amended by Stats.1982, c. 417, § 2, eff. July 8, 1982.)

Historical Note

The 1982 amendment added the exception at the end of subd. (b)(1)(A).

Cross References

Civil penalty for person who knowingly violates subd. (a) or (b) of this section, see § 25196.
Proximity of property to waste facility as health or safety hazard, see § 25149.3.

Library References

Health and Environment ⇐25.5(9).
C.J.S. Health and Environment §§ 65, 66, 103, 107, 140 et seq.

§ 25233. Variance; application; notice of hearing; burden of proof; decision and findings of fact; recording of final determination; review

(a) Any aggrieved person may apply to the department for a written variance from the requirements set forth in subdivision (a) or (b) of Section 25232. Any application shall contain sufficient evidence for the department to issue a notice for a hearing. The notice shall contain (1) a statement that a hearing is pending on the land or that the land has been designated a hazardous waste property or a border zone property and (2) a statement of who is applying for a variance, the proposed variance, and a statement of the reasons in support of the granting of a variance. The procedures for the conducting of this hearing shall be those set forth in this article. No person shall make a subsequent application pursuant to this section within 18 months of a final decision on an application by the department.

(b) The applicant shall have the burden of proving at the hearing that such variance will not cause or allow any of the following effects associated with hazardous waste or extremely hazardous waste:

(1) The creation or increase of significant present or future hazards to public health.

(2) Any significant diminution of the ability to mitigate any significant potential or actual hazard to public health.

(3) Any long-term increase in the number of humans or animals exposed to significant hazards which affect the health, well-being, or safety of the public.

(c) If, upon the preponderance of the testimony taken, the director is of the opinion that the variance should be granted, the director shall issue and cause to be served his or her decision and findings of fact on the owner of the land, the legislative body of the city or county in whose jurisdiction the land is located, and upon any other persons who were permitted to intervene in the proceedings. The findings of fact shall include the exact nature of the proposed variance and the reasons in support of the granting of the variance.

(d) If the director is of the opinion that the variance should not be granted, the director shall issue and cause to be served his or her findings of fact in support of the denial on the parties mentioned in subdivision (c).

(e) The department shall record within 10 days any final determination made pursuant to this section as provided in Section 25235.

(f) A decision of the director made after a hearing held pursuant to this section shall be reviewable pursuant to Section 1094.5 of the Code of Civil Procedure and shall be upheld if the court finds that it is supported by substantial evidence.

(Added by Stats.1980, c. 1161, p. 3906, § 7.)

§ 25234. Re

(a) Any agg
designation th
property on th
existing or pot
No person sha
within 12 moni
Any applicatio
make a findin

(1) The haz
since been rer
cant existing

(2) New sci
land or the m
concerning eit

(A) The nat
designated.

(B) The gec
designated la

(b) Any ag
made pursuar
to the directo
than 30 days
on the applica

(c) Upon re
hearing pursu

(d) The de
determination

(e) A decisi
to this sectio
of Civil Proc
supported by

(f) Whenev
ing the desi
property, the
automatically
recorded wit
particularly
shall be inde
department
owner of the

(Added by Sta

§ 25234. Removal of designation as hazardous waste property or border zone property; application; grounds; appeal; review; termination of easement

(a) Any aggrieved person may apply to the department to remove a designation that land is a hazardous waste property or a border zone property on the grounds that the waste no longer creates a significant existing or potential hazard to present or future public health or safety. No person shall make a subsequent application pursuant to this section within 12 months of a final decision on an application by the department. Any application shall contain sufficient evidence for the department to make a finding upon any or all of the following grounds:

(1) The hazardous waste which caused the land to be designated has since been removed or altered in a manner which precludes any significant existing or potential hazard to present or future public health.

(2) New scientific evidence is available since the designation of the land or the making of any previous application pursuant to this section, concerning either of the following:

(A) The nature of the hazardous waste which caused the land to be designated.

(B) The geology or other physical environmental characteristics of the designated land.

(b) Any aggrieved person may appeal a decision of the department made pursuant to subdivision (a) by submitting a request for a hearing to the director. The request shall be mailed by certified mail not later than 30 days after the date of the mailing of the department's decision on the application.

(c) Upon receipt of a timely appeal, the director shall give notice of a hearing pursuant to the procedures set forth in this article.

(d) The department shall record within 10 days any new and final determination made pursuant to this section as provided in Section 25235.

(e) A decision made by the department after a hearing held pursuant to this section shall be reviewable pursuant to Section 1094.5 of the Code of Civil Procedure and shall be upheld if the court finds that it is supported by substantial evidence.

(f) Whenever there is a final decision pursuant to this section removing the designation of a hazardous waste property or a border zone property, the easement on such land created by Section 25230 shall automatically terminate. The department shall record or cause to be recorded within 10 days a termination of the easement which shall particularly describe the real property subject to the easement and which shall be indexed by the recorder in the grantor index in the name of the department and in the grantee index in the name of the record title owner of the real property subject to the easement.

(Added by Stats.1980, c. 1161, p. 3907, § 7.)

§ 25235. Recordation of final determination

The department shall record within 10 days any final determination made pursuant to Section 25229 with the county recorder of the county in which the property is located. Any recordation made pursuant to this article or Section 25202.5 shall include the street address, assessor's parcel number, or legal description of each parcel affected and the name of the owner thereof, and the recordation shall be recorded by the recorder in the grantor index in the name of the record title owner of the real property and in the grantee index in the name of the department.

(Added by Stats.1980, c. 1161, p. 3907, § 7.)

§ 25236. Civil and criminal actions; land use restriction; law governing

(a) Prior to, or simultaneously with, utilizing the provisions of this article, the department shall diligently pursue feasible civil and criminal actions against any operator or other responsible party who violates the provisions of this chapter and the regulations promulgated thereunder. However, nothing in this chapter shall be construed as restricting or diminishing any remedy provided by law to the owner or possessor of any land which is affected by hazardous waste on or near such land against any person who produced such waste or against any other person who was responsible for the condition affecting the property.

(b) A determination by the department pursuant to Section 25229 shall constitute a land use restriction. Except as specifically provided in this chapter, nothing in this chapter shall diminish or limit the authority of any city or county to approve or disapprove proposed land uses. Nothing in this chapter shall be construed to require a local government to permit a particular land use, including but not limited to, commercial, industrial, agricultural, or other nonresidential use, on land which has been designated hazardous waste property or border zone property pursuant to Section 25229.

(Added by Stats.1980, c. 1161, p. 3908, § 7.)

§ 25237. Severability of article provisions

If any provision of this article or the application thereof to any person or circumstance is held invalid, such holding shall not affect other provisions or applications of this article which can be given effect without the invalid provision or application, and to this end, the provisions of the article are severable.

(Added by Stats.1980, c. 1161, p. 3908, § 7.)

§ 25238. Disposal of hazardous waste onto specified lands; minimum buffer zone

(a) Except as provided in subdivision (b) of this section, no person shall dispose of any hazardous waste or extremely hazardous waste into or

onto any land
existing land us
25232 as of Au

(b) This secti
defined in para
actually and la
unless such di
other provision

(c) It is the i
that any hazar
August 6, 1980
the actual loca
ing uses as of
subdivision (b)

(Added by Stats.

§ 25239. Co

All costs as
department, in
Section 25156
Control Accou

(Added by Stats

§ 25240. R

An assessor
to Section 252
as an enforcea
the Revenue
land, the use
the adoption c

(Added by Stat

§ 25241. E

The provisi
property as d
Such property
25202.5 in or
safety from h

(Added by Stat

onto any land or any portion of land which is within 2,000 feet of an existing land use described in paragraph (1) of subdivision (b) of Section 25232 as of August 6, 1980.

(b) This section shall not apply to any hazardous waste property as defined in paragraph (1) subdivision (a) of Section 25117.3 which was actually and lawfully disposing of hazardous waste on August 6, 1980, unless such disposal is prohibited pursuant to Section 25202.5 or any other provision of law.

(c) It is the intent of the Legislature in enacting this section to require that any hazardous waste disposal site which opens or reopens after August 6, 1980, shall have a minimum buffer zone of 2,000 feet between the actual location where hazardous wastes are disposed and any existing uses as of August 6, 1980, which are described in paragraph (1) of subdivision (b) of Section 25232.

(Added by Stats.1980, c. 1161, p. 3908, § 7.)

§ 25239. Costs

All costs associated with the administration of this article by the department, including, but not limited to, costs incurred to implement Section 25156 and 25220, shall be paid from the Hazardous Waste Control Account in the General Fund.

(Added by Stats.1980, c. 1161, p. 3908, § 7.)

§ 25240. Reassessment of restricted land

An assessor shall consider any restrictive covenant adopted pursuant to Section 25202.5 or any restriction imposed pursuant to Section 25229 as an enforceable restriction subject to the provisions of Section 402.1 of the Revenue and Taxation Code and shall appropriately reassess any land, the use of which has been so restricted, at the lien date following the adoption or imposition of the covenant or restriction.

(Added by Stats.1980, c. 1161, p. 3909, § 7.)

§ 25241. Exception to application of article

The provisions of this article shall not apply to hazardous waste property as defined in paragraph (1) of subdivision (a) of Section 25117.3. Such property shall be regulated by the department pursuant to Section 25202.5 in order to protect the present and future public health and safety from hazardous waste.

(Added by Stats.1982, c. 165, § 4, eff. April 26, 1982.)

Article 12

FINANCIAL RESPONSIBILITY AND CLOSURE AND MAINTENANCE OF FACILITIES

Section

25245. Standards and regulations.
25246. Hazardous waste facility closure and maintenance report; submission by operator to department.
25247. Reports; review and approval.
25248. Implementation of report during closure and maintenance period.
25249. Operators subject to this article.

Article 12 was added by Stats.1982, c. 90, § 3, eff. March 2, 1982.

§ 25245. Standards and regulations

The department shall adopt, within 90 days of the effective date of this article, and revise when appropriate, standards and regulations which shall do both of the following:

(a) Specify the financial assurances to be provided by the operator of a hazardous waste facility that are necessary to respond adequately to damage claims arising out of the operation of that type of facility and to provide for the cost of closure and subsequent maintenance of the facility, including, but not limited to, the monitoring of ground water and other aspects of the environment after closure. The financial assurance shall be a trust fund, surety bond, letter of credit, insurance, or other equivalent financial arrangement acceptable to the department.

(b) Provide that every hazardous waste facility can be closed and maintained for 30 years subsequent to its closure in a manner that protects human health and the environment and minimizes or eliminates the escape of hazardous waste constituents, leachate, contaminated rainfall, and waste decomposition products to ground and surface waters and to the atmosphere.

(Added by Stats.1982, c. 90, § 3, eff. March 2, 1982.)

Cross References

Permit to operate hazardous waste facility contingent upon establishing and maintaining financial assurance prescribed pursuant to this section, see § 25205.

Library References

Health and Environment ⟹25.5(5).
C.J.S. Health and Environment §§ 91 et seq., 106 et seq., 131.

§ 25246. Haz
su

(a) Each opera
ous waste facili
The report shall
and subsequent
prescribed pursu
the Water Code.

(b) The report
tion for a haz
submitted a req
prior to the ac
Section 25245 sl
ment issues a w
the facility, the
However, no op
actual closure o
standards and r

(c) An operat
nance report sh
hazardous wast

(Added by Stats.

§ 25247. Re

The departme
25246 and shal
with the standa
complies with
been approved

(Added by Stats.

§ 25248. Im

The operator
has been appr
maintenance pe

(Added by Stats.

§ 25249. Op

On the effec
Division 7.5 (co
subject to this

(Added by Stats

§ 25246. Hazardous waste facility closure and maintenance report; submission by operator to department

(a) Each operator of a hazardous waste facility shall submit a hazardous waste facility closure and maintenance report to the department. The report shall contain the operator's estimate of the cost of closure and subsequent maintenance and shall conform to the requirements prescribed pursuant to Section 25245 of this code and Section 13227 of the Water Code.

(b) The report shall be submitted to the department with the application for a hazardous waste facility permit. An operator who has submitted a request for or received a hazardous waste facility permit prior to the adoption of the standards and regulations pursuant to Section 25245 shall submit the report within 180 days after the department issues a written request for the report. Prior to actual closure of the facility, the report shall be updated if requested by the department. However, no operator shall be required to revise or amend a report after actual closure of the facility in order to reflect subsequent changes in the standards and regulations adopted pursuant to Section 25245.

(c) An operator who has not submitted a facility closure and maintenance report shall submit that report 180 days prior to closure of the hazardous waste facility.

(Added by Stats.1982, c. 90, § 3, eff. March 2, 1982.)

§ 25247. Reports; review and approval

The department shall review each report submitted pursuant to Section 25246 and shall approve the report if it finds that the report complies with the standards and regulations adopted pursuant to Section 25245, complies with other applicable state and federal regulations, and has been approved pursuant to Section 13227 of the Water Code.

(Added by Stats.1982, c. 90, § 3, eff. March 2, 1982.)

§ 25248. Implementation of report during closure and maintenance period

The operator of a facility for which a closure and maintenance report has been approved shall carry out the report during the closure and maintenance period required by law.

(Added by Stats.1982, c. 90, § 3, eff. March 2, 1982.)

§ 25249. Operators subject to this article

On the effective date of this article, any operator subject to former Division 7.5 (commencing with Section 14000) of the Water Code shall be subject to this article.

(Added by Stats.1982, c. 90, § 3, eff. March 2, 1982.)

22. Carpenter-Presley-Tanner Hazardous Substance Account. Chapter 6.8 of Division 20 of California Health and Safety Code, commencing with Section 25300

Chapter 6.8

HAZARDOUS SUBSTANCE ACCOUNT

Article		Section
1.	Short Title and Legislative Intent	25300
2.	Definitions	25310
3.	Hazardous Substance Account	25330
4.	Tax	25340
5.	Uses of the State Account	25350
6.	Recovery Actions	25360
7.	Compensation	25370
8.	Miscellaneous	25395

Chapter 6.8 was added by Stats.1981, c. 756, p. 2935, § 2, eff. Sept. 25, 1981.

Repeal

Chapter 6.8, added by Stats.1981, c. 756, p. 2935, § 2, is repealed July 1, 1991, under the terms of § 25395.

Article 1

SHORT TITLE AND LEGISLATIVE INTENT

Section
25300. Short title.
25301. Legislative intent.

Article 1 was added by Stats.1981, c. 756, p. 2935, § 2, eff. Sept. 25, 1981.

Cross References

Hazardous substance tax, governed by definitions contained in this chapter, see Revenue and Taxation Code § 43002.

Law Review Commentaries

Hazardous substance account, Hazardous Substance Tax Law. (1982) 13 Pacific L.J. 699.

Superfund and California's implementation: Potential conflict. (1983) 19 C.W.L.R. 373.

§ 25300. Short title

This chapter shall be known and may be cited as the Carpenter-Presley-Tanner Hazardous Substance Account Act.

(Added by Stats.1981, c. 756, p. 2935, § 2, eff. Sept. 25, 1981.)

§ 25301. Legi

It is the intent

(a) Establish a
of hazardous sul
sites that pose a

(b) Compensat
et medical exper
injuries proxima
stances.

(c) Make avai
California to as
mandated pursu
9604(c)(3) [1]).

(Added by Stats.1
[1] 42 U.S.C.A. § 96

Health and Envir

Section
25310. Applicati
25312. Departm
25313. Director.
25315. Federal
25316. Hazardo
25317. Hazardo
25319. Person.
25320. Release;
25321. Release;
25322. Remedy
25323. Remove
25324. State ac
25325. Federall
25326. Release

Article
Sept. 25,

Hazardous substa
and Taxation C

§ 25301. Legislative intent

It is the intent of the Legislature to:

(a) Establish a program to provide for response authority for releases of hazardous substances, including spills and hazardous waste disposal sites that pose a threat to the public health or the environment.

(b) Compensate persons, under certain circumstances, for out-of-pocket medical expenses and lost wages or business income resulting from injuries proximately caused by exposure to releases of hazardous substances.

(c) Make available adequate funds in order to permit the State of California to assure payment of its 10 percent share of the costs mandated pursuant to Section 104(c)(3) of the federal act (42 U.S.C. 9604(c)(3) [1]).

(Added by Stats.1981, c. 756, p. 2935, § 2, eff. Sept. 25, 1981.)

[1] 42 U.S.C.A. § 9604(c)(3).

Library References

Health and Environment ⟹25.5(2).

C.J.S. Health and Environment §§ 61 et seq., 91 et seq., 106 et seq., 115 et seq., 125 et seq., 133 et seq.

Article 2

DEFINITIONS

Section

25310. Application; definitions in federal act.
25312. Department.
25313. Director.
25315. Federal act.
25316. Hazardous substance; inclusions.
25317. Hazardous substance; exclusions.
25319. Person.
25320. Release; inclusions.
25321. Release; exclusions.
25322. Remedy or remedial action.
25323. Remove or removal.
25324. State account.
25325. Federally permitted release.
25326. Release authorized or permitted pursuant to state law.

Article 2 was added by Stats.1981, c. 756, p. 2935, § 2, eff. Sept. 25, 1981.

Cross References

Hazardous substance tax, governed by definitions contained in this chapter, see Revenue and Taxation Code § 43002.

Library References

Words and Phrases (Perm. Ed.)

§ 25310. Application; definitions in federal act

The definitions set forth in this article shall govern the interpretation of this chapter. Unless the context requires otherwise and except as provided in this article, the definitions contained in Section 101 of the federal act (42 U.S.C. 9601) [1] shall apply to the terms used in this chapter.

(Added by Stats.1981, c. 756, p. 2935, § 2, eff. Sept. 25, 1981.)

[1] 42 U.S.C.A. § 9601.

§ 25312. Department

"Department" means the State Department of Health Services.

(Added by Stats.1981, c. 756, p. 2935, § 2, eff. Sept. 25, 1981.)

§ 25313. Director

"Director" means the Director of Health Services.

(Added by Stats.1981, c. 756, p. 2935, § 2, eff. Sept. 25, 1981.)

§ 25315. Federal act

"Federal act" means the Comprehensive Environmental Response, Compensation, and Liability Act of 1980, P.L. 96–510 (42 U.S.C. 9601, et seq.) [1].

(Added by Stats.1981, c. 756, p. 2935, § 2, eff. Sept. 25, 1981.)

[1] 42 U.S.C.A. § 9601 et seq.

§ 25316. Hazardous substance; inclusions

"Hazardous substance" means:

(a) Any substance designated pursuant to Section 1321(b)(2)(A) of Title 33 of the United States Code [1].

(b) Any element, compound, mixture, solution, or substance designated pursuant to Section 102 of the federal act (42 U.S.C. 9602) [2].

(c) Any hazardous waste having the characteristics identified under or listed pursuant to Section 6921 of Title 42 of the United States Code [3], but not including any waste the regulation of which under the Solid Waste Disposal Act has been suspended by act of Congress.

(d) Any toxic pollutant listed under Section 1317(a) of Title 33 of the United States Code [4].

(e) Any hazardous air pollutant listed under Section 7412 of Title 42 of the United States Code [5].

(f) Any immine
respect to which
Protection Agency
of the United Stat

(g) Any hazardc
Sections 25117 an

(Added by Stats.198

[1] 33 U.S.C.A. § 1321
[2] 42 U.S.C.A. § 9602
[3] 42 U.S.C.A. § 6921
[4] 33 U.S.C.A. § 1317
[5] 42 U.S.C.A. § 7412
[6] 15 U.S.C.A. § 2606

§ 25317. Haza

"Hazardous sul

(a) Petroleum, i
otherwise specific
subdivisions (a)
natural gas liquid
(or mixtures of n
by a resource rec

(b) Nontoxic, n
from undergroun
sewers.

(Added by Stats.19

§ 25319. Pers

"Person" mean
ration, including,
ship, and associa
and the state or
government or ar
by law.

(Added by Stats.19

§ 25320. Rele

"Release" mea
emptying, discha
ing into the envi

(Added by Stats.19

(f) Any imminently hazardous chemical substance or mixture with respect to which the Administrator of the United States Environment Protection Agency has taken action pursuant to Section 2606 of Title 15 of the United States Code [6].

(g) Any hazardous waste or extremely hazardous waste as defined by Sections 25117 and 25115, respectively, unless expressly excluded.

(Added by Stats.1981, c. 756, p. 2935, § 2, eff. Sept. 25, 1981.)

[1] 33 U.S.C.A. § 1321(b)(2)(A).
[2] 42 U.S.C.A. § 9602.
[3] 42 U.S.C.A. § 6921.
[4] 33 U.S.C.A. § 1317(a).
[5] 42 U.S.C.A. § 7412.
[6] 15 U.S.C.A. § 2606.

§ 25317. Hazardous substance; exclusions

"Hazardous substance" does not include:

(a) Petroleum, including crude oil or any fraction thereof which is not otherwise specifically listed or designated as a hazardous substance in subdivisions (a) to (f), inclusive, of Section 25316, and natural gas, natural gas liquids, liquefied natural gas, or synthetic gas usable for fuel (or mixtures of natural gas and such synthetic gas), or the ash produced by a resource recovery facility utilizing a municipal solid waste stream.

(b) Nontoxic, nonflammable, noncorrosive stormwater run-off drained from underground vaults, chambers, or manholes into gutters or storm-sewers.

(Added by Stats.1981, c. 756, p. 2935, § 2, eff. Sept. 25, 1981.)

§ 25319. Person

"Person" means an individual, trust, firm, joint stock company, corporation, including, but not limited to, a government corporation, partnership, and association. "Person" also includes any city, county, district, and the state or any department or agency thereof, and the federal government or any department or agency thereof to the extent permitted by law.

(Added by Stats.1983, c. 1044, § 1, eff. Sept. 23, 1983.)

§ 25320. Release; inclusions

"Release" means any spilling, leaking, pumping, pouring, emitting, emptying, discharging, injecting, escaping, leaching, dumping, or disposing into the environment.

(Added by Stats.1981, c. 756, p. 2935, § 2, eff. Sept. 25, 1981.)

Cross References

Request by local agency responsible for underground hazardous substance storage to remedy release of substance, see § 25285.

§ 25321. Release; exclusions

"Release" does not include any of the following:

(a) Any release which results in exposure to persons solely within a workplace, with respect to a claim such exposed persons may assert against their employer.

(b) Emissions from the engine exhaust of a motor vehicle, rolling stock, aircraft, vessel, or pipeline pumping station engine.

(c) Release of source, byproduct, or special nuclear material from a nuclear incident, as those terms are defined in the Atomic Energy Act of 1954 (42 U.S.C. 2011, et seq.[1]), if such release is subject to requirements with respect to financial protection established by the Nuclear Regulatory Commission under Section 2210 of Title 42 of the United States Code[2] or, for the purposes of Section 104 of the federal act (42 U.S.C. 9604)[3] or any other response action, any release of source byproduct, or special nuclear material from any processing site designated under Section 7912(a)(1) or 7942(a) of Title 42 of the United States Code[4], which sections are a part of the Uranium Mill Tailings Radiation Control Act of 1978.

(d) The normal application of fertilizer, plant growth regulants, and pesticides.

(Added by Stats.1981, c. 756, p. 2935, § 2, eff. Sept. 25, 1981.)

[1] 42 U.S.C.A. § 2011, et seq.
[2] 42 U.S.C.A. § 2210.
[3] 42 U.S.C.A. § 9604.
[4] 42 U.S.C.A. §§ 7912(a)(1), 7942(a).

§ 25322. Remedy or remedial action

"Remedy" or "remedial action" includes all of the following:

(a) Those actions which are consistent with a permanent remedy, that are taken instead of, or in addition to, removal actions in the event of a release or threatened release of a hazardous substance into the environment, as further defined by Section 101(24) of the federal act (42 U.S.C. Sec. 9601(24)[1]), except that any reference in Section 101(24) of the federal act (42 U.S.C. Sec. 9601(24)) to the President, relating to determinations regarding the relocation of residents, businesses, and community facilities shall, for the purposes of this chapter, be deemed to be a reference to the Governor and any other reference in that section to the President shall, for the purposes of this chapter, be deemed a reference to the Governor, or the director, if designated by the Governor.

(b) Those actions which are necessary to monitor, assess, and evaluate a release or a threatened release of a hazardous substance.

(c) Site operati

(Added by Stats.19
Stats.1983, c. 1044,

[1] 42 U.S.C.A. § 960

The 1983 amendme
troductory phrase, "
inserted subdivision

§ 25323. Rem

"Remove" or '
hazardous substa
actions as may b
which may othe
further defined
9601(23))[1].

(Added by Stats.19

[1] 42 U.S.C.A. § 96

§ 25324. Stat

"State account
pursuant to Sect

(Added by Stats.19

§ 25325. Fed

"Federally pe
term is defined i

(Added by Stats.19

[1] 42 U.S.C.A. § 96

§ 25326. Rele

"A release au
release into the
regulation, or ru
or by any specifi
agency, includin
industry practic
which allow op
releases from s
ordinances, regu
ted release, as
accordance with

(Added by Stats.1

(c) Site operation and maintenance.

(Added by Stats.1981, c. 756, p. 2935, § 2, eff. Sept. 25, 1981. Amended by Stats.1983, c. 1044, § 2, eff. Sept. 23, 1983.)

[1] 42 U.S.C.A. § 9601(24).

Historical Note

The 1983 amendment inserted, in the introductory phrase, "all of the following:"; inserted subdivision designation (a); made nonsubstantive grammatical changes; and added subds. (b) and (c).

§ 25323. Remove or removal

"Remove" or "removal" includes the cleanup or removal of released hazardous substances from the environment or the taking of such other actions as may be necessary to prevent, minimize, or mitigate damage which may otherwise result from a release or threatened release, as further defined by Section 101(23) of the federal act (42 U.S.C. 9601(23)) [1].

(Added by Stats.1981, c. 756, p. 2935, § 2, eff. Sept. 25, 1981.)

[1] 42 U.S.C.A. § 9601(23).

§ 25324. State account

"State account" means the Hazardous Substance Account established pursuant to Section 25330.

(Added by Stats.1981, c. 756, p. 2935, § 2, eff. Sept. 25, 1981.)

§ 25325. Federally permitted release

"Federally permitted release" shall have the same meaning as that term is defined in Section 101(10) of the federal act (42 U.S.C. 9601(10)).[1].

(Added by Stats.1981, c. 756, p. 2935, § 2, eff. Sept. 25, 1981.)

[1] 42 U.S.C.A. § 9601(10).

§ 25326. Release authorized or permitted pursuant to state law

"A release authorized or permitted pursuant to state law" means any release into the environment which is authorized by statute, ordinance, regulation, or rule of any state, regional, or local agency or government or by any specific permit, license, or similar authorization from any such agency, including one of the foregoing which recognizes a standard industry practice, including variances obtained from any such agency which allow operations for facilities during a period of time when releases from such facilities do not conform with relevant statutes, ordinances, regulations, or rules. The term includes a federally permitted release, as defined by Section 25325, and releases which are in accordance with any court order or consent decree.

(Added by Stats.1981, c. 756, p. 2935, § 2, eff. Sept. 25, 1981.)

23. Comprehensive Environmental Response, Compensation, and Liability Act. (CERCLA) HR4761, 98th Cong. 2d Sess., (Proposed Amendments), February 6, 1984

98TH CONGRESS
2D SESSION

H. R. 4761

To amend the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (Superfund) to provide for removal, remedial action, and liability with respect to gasoline and other liquid hydrocarbons which leak from certain underground storage tanks and to establish standards to prevent releases from such tanks into the environment, and for other purposes

---

IN THE HOUSE OF REPRESENTATIVES

FEBRUARY 6, 1984

Mr. RITTER introduced the following bill; which was referred jointly to the Committees on Energy and Commerce and Public Works and Transportation

---

A BILL

To amend the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (Superfund) to provide for removal, remedial action, and liability with respect to gasoline and other liquid hydrocarbons which leak from certain underground storage tanks and to establish standards to prevent releases from such tanks into the environment, and for other purposes.

1 *Be it enacted by the Senate and House of Representa-*
2 *tives of the United States of America in Congress assembled,*

1 SHORT TITLE

2 SECTION 1. This Act may be cited as the "Leaking Un-
3 derground Storage Tank Liability and Standards Act of
4 1984".

5 AMENDMENT OF CERCLA

6 SEC. 2. (a) DEFINITION OF UNDERGROUND STORAGE
7 TANK.—Section 101 of the Comprehensive Environmental
8 Response, Compensation, and Liability Act of 1980 is
9 amended by striking out "and" at the end of paragraph (31),
10 by striking out the period at the end of paragraph (32) and
11 substituting "; and" and by adding the following new para-
12 graph at the end thereof:

13 "(33) 'underground storage tank' means a tank
14 which is located partially or wholly underground.".

15 (b) DEFINITION OF HAZARDOUS SUBSTANCE.—Sec-
16 tion 101(14) of the Comprehensive Environmental Response,
17 Compensation, and Liability Act of 1980 is amended by—

18 (1) striking out "and (F)" and substituting ", (F)",

19 (2) striking out "Control Act." and substituting
20 "Control Act, and (G) gasoline and other liquid hydro-
21 carbons which are stored in an underground storage
22 tank from which there is a release or threatened re-
23 lease."; and

1 (3) by striking out "The term does not include pe-
2 troleum" and substituting "Except as provided in sub-
3 paragraph (G), the term does not include".

4 STANDARDS FOR UNDERGROUND STORAGE TANKS USED
5 FOR STORAGE OF HAZARDOUS SUBSTANCES, INCLUD-
6 ING GASOLINE OR OTHER LIQUID HYDROCARBONS

7 SEC. 3. (a) STANDARDS.—Not later than twelve months
8 after the enactment of this Act, the Administrator of the En-
9 vironmental Protection Agency (hereinafter in this section re-
10 ferred to as the "Administrator") shall promulgate regula-
11 tions establishing performance standards, applicable to
12 owners and operators of underground storage tanks used for
13 the storage of hazardous substances, including gasoline or
14 other liquid hydrocarbons, in order to prevent releases into
15 the environment for the operational life of the tank. Such
16 regulations shall apply only to underground storage tanks
17 which are located on property used primarily for commercial
18 or governmental purposes. The Administrator shall, where
19 appropriate, distinguish in such standards between require-
20 ments appropriate for new tanks and for tanks in existence on
21 the date of promulgation of the standards. Such standards
22 shall include, but shall not be limited to, requirements re-
23 specting—

24 (1) the location, design, and construction of such
25 tanks;

1 (2) contingency plans for effective action to mini-
2 mize releases of hazardous substances, including gaso-
3 line or other liquid hydrocarbons, from such tanks;
4 (3) the maintenance and operation of such tanks;
5 (4) financial responsibility;
6 (5) monitoring or testing of such tanks and the
7 surrounding environment;
8 (6) corrective action in the event of a release of
9 any hazardous substance, including gasoline or other
10 liquid hydrocarbons, from such a tank;
11 (7) recordkeeping and reporting; and
12 (8) closure or removal of the tank at the end of its
13 operational life.
14 (b) IMPLEMENTATION AND ENFORCEMENT.—The Ad-
15 ministrator may promulgate, and make effective in accord-
16 ance with section 3010 of the Solid Waste Disposal Act, reg-
17 ulations to implement the standards of subsection (a) or the
18 Administrator may establish a permit program to implement
19 such standards where he finds that such a permit program is
20 necessary for such purposes. If the Administrator makes such
21 a determination, any person or category of persons who
22 stores any hazardous substance, including gasoline or any
23 other liquid hydrocarbon, in an underground storage tank lo-
24 cated on property used primarily for commercial or govern-

1 mental purposes may be required to have a permit for such
2 storage in order to assure compliance with such standards.
3 (c) APPLICATION OF SOLID WASTE DISPOSAL ACT
4 PROVISIONS.—The provisions of section 3006 and 3007 of
5 subtitle C of the Solid Waste Disposal Act, the provisions of
6 subsections (a) through (c) of section 3008 of such subtitle,
7 the provisions of section 3009 of such subtitle, the provisions
8 of section 3010(b) of such subtitle, the provisions of section
9 6001 of such Act, and the provisions of subtitle G of such
10 Act, shall apply to the program and requirements established
11 under this section in the same manner as such provisions
12 apply to the hazardous waste regulatory program established
13 under subtitle C of such Act. For purposes of applying such
14 provisions to the program and requirements established under
15 this Act, the term "hazardous substance, including gasoline
16 or other liquid hydrocarbons" shall be substituted for the
17 term "hazardous waste" when used in such provisions.
18 (d) DEFENSE TO OTHER SUPPLY REQUIREMENTS.—
19 If, upon the request of any person supplying any hazardous
20 substance, including gasoline or other liquid hydrocarbons, to
21 any underground storage tank, the owner or operator of any
22 underground storage tank fails or refuses to provide to such
23 supplier appropriate evidence of compliance with the stand-
24 ards established under this section, such failure or refusal
25 shall constitute a defense to any enforcement action brought

1 under any other authority of law to require such supplier to
2 deliver any hazardous substance, including gasoline or other
3 liquid hydrocarbons, to such tank. For purposes of this sub-
4 section, any permit issued for a tank under this section or any
5 other certification of compliance under this section, as deter-
6 mined by the Administrator, shall constitute appropriate evi-
7 dence of compliance with such standards.

8 (e) CRIMINAL PENALTY.—Any person who knowingly
9 commits a material violation or omission with respect to any
10 requirement established by the Administrator under this sec-
11 tion shall, if such violation or omission results in a release or
12 threatened release of any hazardous substance, including gas-
13 oline or other liquid hydrocarbon, from an underground stor-
14 age tank, be subject to a fine of not more than $50,000 for
15 each day of violation, or to imprisonment for not to exceed
16 two years, or both.

17 (f) DEFINITIONS.—As used in this section:

18 (1) The term "underground storage tank" means
19 a tank which is located wholly or partially under-
20 ground.

21 (2) The term "hazardous substance" has the
22 meaning provided by section 101(14) of the Compre-
23 hensive Environmental Response, Compensation, and
24 Liability Act of 1980, as amended by section 2 of this
25 Act.

1 (g) AUTHORIZATION.—There is authorized to be appro-
2 priated not more than $60,000,000 for the fiscal year period
3 1985 through 1987 to carry out this section. Not more than
4 50 per centum of the amount appropriated in any such fiscal
5 year may be used to make grants to the States for purposes
6 of assisting the States in the development and implementa-
7 tion of programs to carry out this section. Such State pro-
8 grams shall be carried out in the same manner as required
9 with respect to State programs under section 3006 of the
10 Solid Waste Disposal Act, and funds shall be allocated
11 among the States in the same manner as provided in subsec-
12 tion (b) of section 3011 of that Act.

13 (h) RESIDENTIAL UNDERGROUND STORAGE TANKS—
14 Not later than one year after the date of the enactment of
15 this Act, the Administrator of the Environmental Protection
16 Agency shall conduct a study regarding underground storage
17 tanks which are located on residential property and which are
18 used for the storage of hazardous substances (including gaso-
19 line or other liquid hydrocarbons). Such study shall include
20 estimates of the number and location of such tanks and an
21 analysis of the extent to which there may be releases or
22 threatened releases from such tanks into the environment.
23 Upon completion of the study, the Administrator shall submit
24 a report to the President and to the Congress containing the
25 results of the study and recommendations respecting whether

1 or not such tanks which are located on residential property
2 should be subject to the preceding provisions of this section.

O

CHIEF COUNSEL
OFFICE OF THE
FEB 1 0 1984
SECRETARY

24. Curran, G.M., et al. "Leaching of Trace Organics into Water From Five Common Plastics", Ground Water Monitoring Review, Summer 1983, pp. 68-71

2648

LEACHING OF TRACE ORGANICS INTO WATER FROM FIVE COMMON PLASTICS

Five plastics were tested to quantify their release of trace organics.

by Carol M. Curran and Mason B. Tomson

Many types of plastics are available for laboratory and field use. In recent years Teflon has been accepted as the least contaminating and most inert plastic for environmental work. Unfortunately, Teflon can be 10 to 20 times more expensive than other plastics such as PVC or polypropylene. Often plastics are used to case small wells used to monitor trace level organics at $\mu g/L^{-1}$ levels and below. Little is known about the extent of either leaching or sorption of trace organics from plastics. If materials other than Teflon could be used with confidence, considerable time and expense could be saved in monitoring and laboratory workup.

Scalf et al. (1981) discuss the economic vs. analytical certainty trade-offs often necessary in field investigations. They discuss the particular problems associated with glued PVC casing, but they present no data nor do they discuss options.

Junk et al. (1974a) reported on the contamination of water as it flows through various plastics. They reported organic contamination levels up to 5 mg/L^{-1} with typically a few tens of $\mu g/L^{-1}$ of contamination from various PVC tubes. They also suggested that high levels of contamination might bleed out of PVC for long periods of time. If this were to happen with PVC or other plastic well casing materials, it would preclude their use in ground-water monitoring programs. This report by Junk et al. is often cited as justification for far more expensive well materials such as Teflon or stainless steel. Based upon the laboratory and field evidence reported herein, it will be suggested that the types of rigid PVC often used for well casing, do not produce significant contamination and may thus be safely used as an economic alternative in ground-water monitoring programs.

A systematic study of the adsorption and desorption of volatile organics, such as trichloroethylene, 1,1,1-trichloroethane and bromoform, and the metals lead and chromium, onto polyethylene, polypropylene and schedule 40 PVC was conducted recently by G.D. Miller (1982). All of his experiments were 40mL batch studies. He reported adsorption of typically 25 to 75 percent of the trace organics after four to six weeks of exposing plastic sections to contaminated water. When contaminated sections were placed in clean water, generally only 25 to 75 percent of the adsorbed trace organic could be desorbed. Unfortunately, the leaching of less volatile trace organics, such as plasticizers, from the plastic tubing sections was not determined. He concluded that schedule 40 PVC causes fewer monitoring interferences with volatile organics than polyethylene or polypropylene under the conditions of his experiments.

Previous field work at Rice University suggested that PVC-cased wells might be satisfactorily employed for sampling ground water for trace organics, at least under some circumstances (Tomson et al. 1979). Single-piece PVC-cased monitoring wells (2-inch I.D. x ~20 feet) at a Ft. Devens, Massachusetts, rapid infiltration site were sampled for trace organics in 1979. These PVC wells had been in place for nine years. Numerous trace organics were found at the sub-ppb level in the ground water directly downgradient (~400 feet) from the applied sewage. Almost no trace organics were found in a similarly cased control well nearby, which was not in the influence of the applied sewage. Similarly, in a recent Rice University field study of ground-water contaminant movement from a pit associated with a creosote treatment plant, eight 4-inch schedule 40 PVC monitoring wells were installed to a depth of about 30 feet (Bedient et al. 1982). Again, water from those wells near the pit was found to contain high levels (1 to 10^3 $\mu g/L^{-1}$) of organics typical of creosote operations; water from a well 300 feet downgradient was found to have a similar suite of organics at 95(+) percent lower concentration (as might be expected); and water from a control well cased in the same manner was found to be free of contamination. These field observations indicate that the PVC well

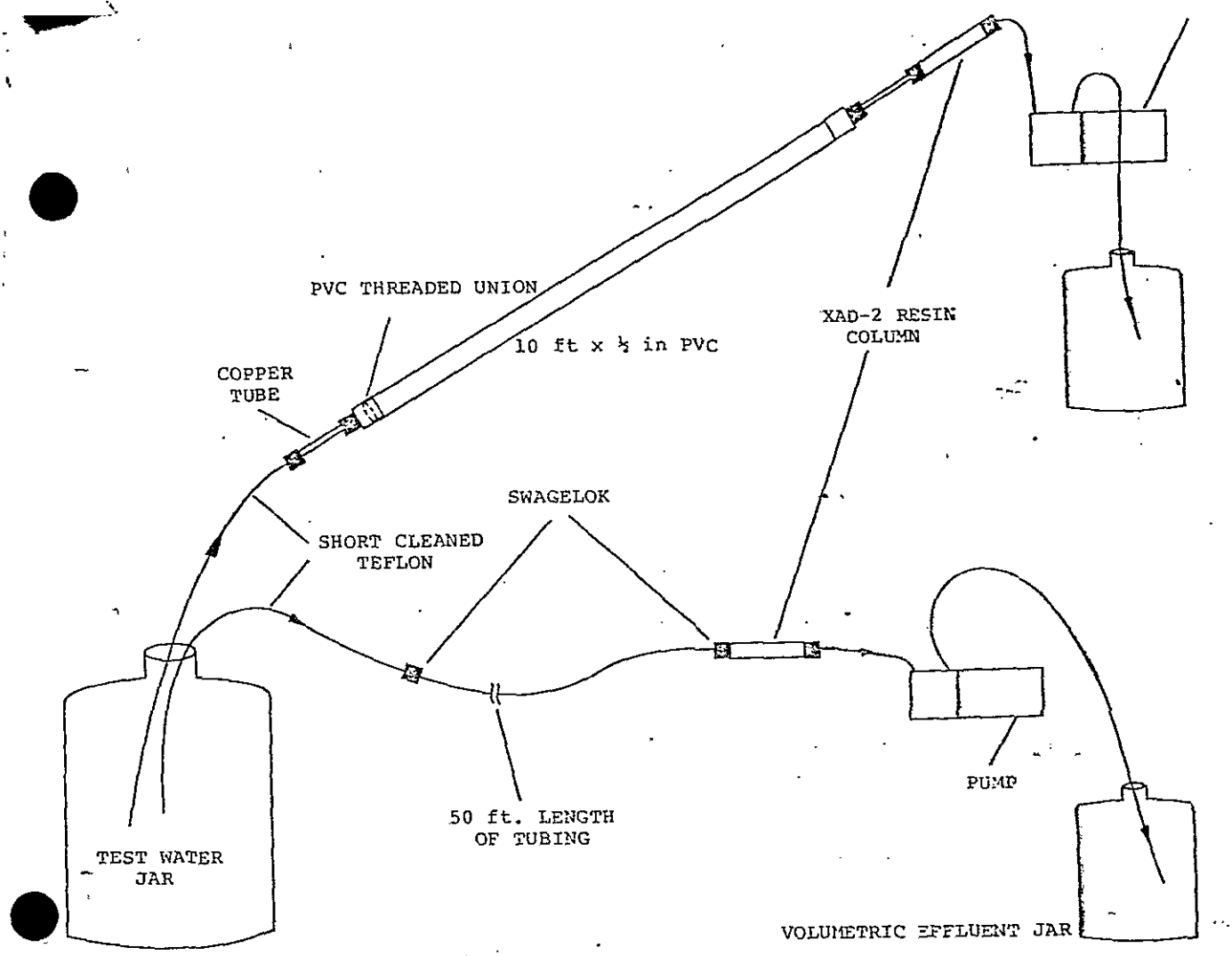


Figure 1. Tubing Test Setup

casings did not leach significant amounts of trace organics into, or sorb inordinate quantities of pollutants from, the sampled ground water.

The present research was initiated to better quantify the interaction of trace organics such as dichlorobenzene or naphthalene, with various plastics which may be usable either in the field or in the laboratory. The aqueous leaching and sorption of five plastics—Teflon, polyethylene, polypropylene, polyvinylchloride (PVC) glued and nonglued, and Tygon—were compared, with primary emphasis on rigid PVC because of its widespread use in monitoring wells.

Experimental

Tubing

Five plastics were used: polypropylene, polyethylene, Teflon, Tygon and PVC. Fifty-foot lengths of Teflon (TFE, Polypenco, Reading, Pennsylvania), Tygon (R-3603, Norton Co., Akron, Ohio), polypropylene (Resinol Type O®, Norton Co.), and polyethylene (Resinol Type A®, Norton Co.) tubing (1/8-inch I.D.) and three 10-foot lengths of PVC pipe (Grade 1, Type 1 from both R&G Sloane Mfg. Co. Inc., Sun Valley, California, and United Plastics, Houston, Texas,) (1/2-inch I.D.) were used. The internal surface areas of the lengths of tubing and pipe were equivalent. All tubings and pipe were purchased from the same distributor (A-1 Plastics, Houston, Texas).

PVC pipes were fitted into a PVC threaded union and reduced to 1/8 inch with a short (4-inch) piece of copper tubing. One length of PVC designated as "glued PVC" was glued at the threaded union with PVC pipe glue (Rector-Seal, Rector Corp.). The other pieces of PVC were connected to fittings with Teflon tape at the threaded union; no glue was used. All other fittings used were brass and stainless steel Swagelok®. PVC pipes were elevated at one end to a height of 3 feet so that the entire surface area would be contacted by the test water for the duration of each experiment (Figure 1).

In each experiment a short (3- to 5-foot) piece of cleaned Teflon tubing (3/16-inch I.D. x 1/8-inch O.D.) was used to convey test water from a glass reservoir to the influent end of the tubing or pipe. The exit was fitted to an 8mL Amberlite XAD-2 resin column and joined to a Masterflex pump to control flow at 30mL/min. A final length of tubing sent the effluent to a volumetric collection jar (Figure 1).

Sample Workup

The XAD-2 macroreticular resin columns were solvent-stripped and the extract processed and concentrated for Gas Chromatograph (GC) analysis according to the procedures of Junk et al. (1974b) with minor modifications (Tomson et al. 1979). One to 3 μL of the final concentrate was injected onto a Tracor 560 GC equipped with either a 50m fused silica Hewlett-Packard SP2100 capillary column or a 6-foot SP1240DA (Supelco) packed column and an FID detector.

taken through the same overall procedure, except the tubing or pipe was deleted (Figure 1).

Procedures

The first experiment involved pumping 20 l of organic-free water (at room temperature) with a 0.5 ppb naphthalene spike through each of the new tubings and the PVC pipe at 30mL min^{-1}. Water blanks were obtained by passing equivalent volumes of organic-free water directly through clean resin columns. During the second experiment 20 l of organic-free water spiked with 0.5 ppb para-dichlorobenzene was pumped through each of the five plastics at room temperature. The third experiment involved passing hot 80 C pure water (as might be used in a cleaning process) through each of the tubings, the glued PVC pipe and the PVC pipe with Teflon-taped unions. Ten liter volumes of organic-free water were heated to 80 C in glass jars and pumped quickly (400mL/min) through each of the tubings and pipes. After the hot-water flush, 20 l of 30 C water was pumped through each tubing at 30mL/min. Throughout each experiment, tubing leachates were collected on individual XAD-2 resin columns.

The first and second experiments were repeated using identical conditions except that a 0.05 $\mu g/L^{-1}$ naphthalene spike was used in the repetition of the second experiment.

Finally, a wax layer can develop on the inner wall of some PVC during manufacturing. To help remove this layer, one threaded PVC pipe, as before, was washed and swabbed (using a glass wool plug) three times rinsed with water before use in the previous procedure.

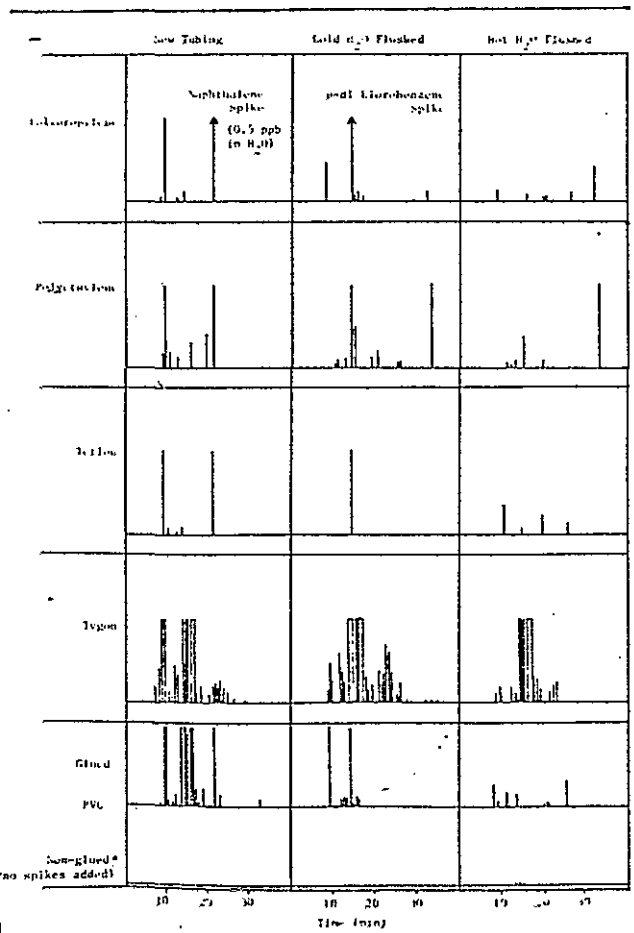


Figure 2. Graphic summary of capillary GC peak positions and heights from first set of experiments

Results and Discussion

A graphic summary of results from the first set of experiments is shown in Figure 2. Results of the second set of experiments were similar except a hot-water flush was not used. In most cases the resin blank showed little contamination and was subtracted from the sample chromatograms. The first set of experiments showed a decrease in the numbers of leachates after the second cool-water flush. However, the hot-water flush stimulated the release of additional contaminants (Figure 2). After cleaning one PVC pipe with detergents and swab, no leachates were found.

A semi-quantitative estimate of the total concentration of leachates in each case was made by using the peak area to calculate concentration of the internal spike (compared to a standard), then total concentration was calculated for each sample from the summed area of all the other peaks. The naphthalene and para-dichlorobenzene spikes were recovered at 80 to 100 percent in all tubing except those with Tygon which had a 50 percent or less recovery. After the first 20 l flush, total leachates from polyethylene, polypropylene, Teflon and Teflon-taped PVC were less than 2.0 ppb.

The recommended order with least contamination of the five plastics tested (after 40 l cool-water rinse) is the following:

Plastics	Upper Limit of Total Leachate Concentration
Teflon	None
PVC (nonglued)	0 to 0.1 ppb
Polyethylene	0.1 ppb
Polypropylene	0.5 ppb
PVC-glued	0.5 ppb
Tygon	1.0 ppb

As expected, Teflon showed the least contaminant leaching of the plastics studied. The results from PVC are consistent with our field observations, discussed earlier, but are much lower than the leachate values found by Junk et al. (1974a). The difference is probably because most of the PVC they used was "flexible." The flexibility is a result of adding large amounts of various plasticizers (up to 40 percent by weight). The PVC used in our work and generally used in monitoring wells is rigid and assembled with threaded joints. We also found lower total contaminant leaching for polyethylene and polypropylene than Junk et al., but this difference may have been a result of flow rate, tubing conditioning or specific manufacturing differences, because we have found similar overall recovery efficiencies using XAD-2 resin as reported by Junk et al. (1974a). It would be useful to study the relative leaching from plastics made by several manufacturers, but to date, no such information is available for comparison.

In summary, it can be inferred from data and reports presented herein that rigid PVC is an acceptable alternative to Teflon for monitoring wells if it is washed and rinsed with room temperature water before installation. Furthermore, depending upon desired detection limits, the plastics, polyethylene and then polypropylene, may be usable as well casing materials.

Biographical Sketches

Carol M. Curran is currently a research assistant in the Department of Environmental Science and Engineering at Rice University, Houston, Texas. She has a B.A.A.S. in biology from the University of Delaware. Curran has had a role in numerous publications in the fields of ground-water and surface-water monitoring and toxicology in the past five years at Rice University.

Mason B. Tomson received his B.S. in chemistry and mathematics from Southwestern State University, Weatherford, Oklahoma, in 1967. He received his Ph.D. in chemistry in 1972 from Oklahoma State University. From 1972 to 1977 Tomson studied at the State University of New York at Buffalo and was assistant to the provost, G.H. Nancollas, for four years. Tomson has been at Rice University, where he is an associate professor, since 1977. He has published more than 45 papers on water chemistry.

Acknowledgments

The authors gratefully acknowledge the cooperation and assistance of Dr. William J. Dunlap (Robert S. Kerr Environmental Research Laboratory, Ada, Oklahoma,) and Katherine M. Sloan for helpful discussion and suggestions, and Maurine Lee and Suzette Pruit for typing. Support for this work was provided by U.S. Environmental Protection Agency grants R-805292-02, CR806931-01 and CR806931-03.

References

Bedient, P.B. et al. 1982. Ground-water quality at a hazardous waste site. ASCE. J. Env. Eng. Div., submitted.

Junk, G.A. et al. 1974a. Contamination of water by synthetic polymer tubes. Envi. Sci. and Tech., v. 8, pp. 1100-1106.

Junk, G.A. et al. 1974b. Use of macroreticular resins in the analysis of water for trace organic contaminants. Journal of Chromatography, v. 7598, pp. 745-762.

Miller, G.D. 1982. Uptake and release of lead, chromium and trace-level volatile organics exposed to synthetic well casings. Proceedings of the Second National Symposium on Aquifer Restoration and Ground-Water Monitoring. National Water Well Association. Worthington, Ohio, pp. 236-245.

Scalf, M.R. et al. 1981. Manual of ground-water sampling procedures. National Water Well Association. Worthington, Ohio.

Tomson, M.B., S.R. Hutchins, J.M. King and C.H. Ward. 1979. Trace organic contamination of ground water: methods for study and preliminary results. III World Congress on Water Resources. Mexico City, Mexico. Papers, v. 8, pp. 3701-3709.

25. Danning vs. Daylin, Inc., 48SF. 2d 185 (9th Cir. 1973).

[illegible] range is armed and presently dangerous to the officer or to others, it would appear to be clearly unreasonable to deny the officer the power to take necessary measures to determine whether the person is in fact carrying a weapon and to neutralize the threat of physical harm. [392 U.S. at 23–24, 88 S.Ct. at 1881.]

Upon examination of the whole record in this case, we find that Glick's petition for relief is utterly without merit.[2] The trial court properly quashed the writ. Affirmed.

Curtis B. DANNING, Trustee in Bankruptcy, *Plaintiff-Appellant,*

v.

DAYLIN, INC., Defendant-Appellee.

No. 71-2782.

United States Court of Appeals, Ninth Circuit.

Nov. 1, 1973.

Rehearing Denied Dec. 7, 1973.

The trustee in bankruptcy of a corporation sought to set aside as void as a bulk transfer an exchange by the corporation of approximately 25% of its merchandise inventory and fixtures for inventory and fixtures owned by another company, the exchange being intended to implement the company's decision to divest itself of its retail department store business and to operate instead as the lessor of a chain of discount stores. The United States District Court for the Central District of California, Peirson M. Hall, J., refused to set the transaction aside, and the trustee appealed. The Court of Appeals, Eugene A. Wright, Circuit Judge, held that the bankrupt's "principal business" did not cease to be that of retail merchant merely because of its decision to enter into discount sales, that the fact that its inventory and fixtures were exchanged for inventory and fixtures of another company did not prevent the exchange from constituting a "transfer" within the meaning of the California Commercial Code, that the transfer was of a "substantial part" of its assets, and that the transfer was not in the ordinary course of its business.

Reversed and remanded.

1. Bankruptcy ⚷178(1)

Fact that bankrupt had determined to cease business as retail merchant and become lessor and operator of discount stores did not mean that retail merchandising did not remain bankrupt's "principal business" for purposes of judging legality, under law governing bulk transfers, of exchange of portion of its inventory and fixtures for those of another company while implementing its decision to leave retailing business. West's Ann.Cal.Com.Code, §§ 6101 et seq., 6102.

See publication Words and Phrases for other judicial constructions and definitions.

2. Fraudulent Conveyances ⚷47

Mere fact that merchant terminates business or engages in other lines of employment does not free him from requirement of bulk sales statute as applied to sale of stock of his former busi-

[2] We note that appellant's counsel, perhaps inadvertently, misled this court in his brief by citing only the evidence in the trial transcript and claiming that it "constituted all of the material *evidentiary facts*" on this appeal. This was not true. Important facts were contained in both the transcript of the trial and the transcript of the preliminary hearing. We recognize that appointed counsel may not have realized that federal courts are entitled to examine the entire record in cases of this kind to determine whether a constitutional violation exists and are not limited solely to a review of the record on trial, as was the South Dakota Supreme Court.

488 F.2d 185

ness. West's Ann.Cal.Com.Code, §§ 6105, 6107.

3. Fraudulent Conveyances ⟹47

Exchange by corporation of inventory and fixtures located at sundries department of one of its department stores in exchange for housewares and hardware inventory and fixtures owned by another company, accomplished in implementation of corporation's decision to abandon retailing business and operate instead as lessor of chain of discount stores, was "transfer" of its assets within meaning of California Commercial Code provisions on bulk transfers. West's Ann.Cal.Civ.Code, § 1039; West's Ann.Cal.Com.Code, §§ 6101 et seq., 6102; Bankr.Act, § 1(30), 11 U.S.C.A. § 1(30).

See publication Words and Phrases for other judicial constructions and definitions.

4. Fraudulent Conveyances ⟹47

Transfer of approximately 25% of bankrupt's merchandise inventory was transfer of "substantial part" of inventory within meaning of California Commercial Code provisions on bulk transfers. West's Ann.Cal.Com.Code, § 6102(1).

See publication Words and Phrases for other judicial constructions and definitions.

5. Fraudulent Conveyances ⟹47

Transfer by corporation of approximately 25% of its merchandise inventory to another company in exchange for inventory and fixtures of second company, accomplished to implement decision to withdraw from business of retail merchandising and to operate instead as lessor of chain of discount stores, was not transfer "in the ordinary course of the transferor's business" within meaning of California Commercial Code provisions concerning bulk transfers. West's Ann.Cal.Com.Code, § 6102(1).

See publication Words and Phrases for other judicial constructions and definitions.

6. Bankruptcy ⟹173(1)

Where bankrupt, in implementation of decision to abandon business of retail merchandising and to operate instead as lessor and operator of discount stores, transferred approximately 25% of its merchandise inventory to another company in exchange for inventory and fixtures of the second company, transaction was voidable by trustee in bankruptcy as fraudulent bulk transfer in absence of notification to creditors of transferor. West's Ann.Cal.Com.Code, § 6101 et seq.; Bankr.Act, § 70, sub. e(3), 11 U.S.C.A. § 110(e)(3).

On Denial of Rehearing

7. Fraudulent Conveyances ⟹47

Good faith and absence of fraudulent intent are not defenses in action to set aside bulk transfer for lack of proper statutory notice. West's Ann. Cal.Com.Code, §§ 6101–6111.

Stephen P. Feldman (argued), Jeffrey Chanin of Quittner, Stutman, Treiste & Glatt, Los Angeles, Cal., for plaintiff-appellant.

Leon Savitch (argued), of Buchalter, Nemer, Fields & Savitch, Los Angeles, Cal., for defendant-appellee.

Before HUFSTEDLER and WRIGHT, Circuit Judges, and RENFREW, District Judge.*

OPINION

EUGENE A. WRIGHT, Circuit Judge:

Plaintiff Danning, trustee in bankruptcy of First Gibson Stores, appeals from a judgment of the district court which denied the trustee's attempt to set aside as "fraudulent and void" under California law [Cal.Commercial Code § 6101, et seq. (West 1964)] an alleged bulk transfer of the bankrupt's inventory to Daylin. The court had jurisdiction under Section 70(e)(3) of the

*Of the Northern District of California.

Bankruptcy Act
(3)]. We reverse

The bankrupt, F
California, was i
1966 for the purpos
operating departme
two stores late in
goods" (drugs, su
etc.) and leased a p
to concessionaires
(clothing, etc.). The
with an inventory o
goods that First G
from 1,500 suppliers
was closed for lack o
ary 1967, and all
moved to the second
Heights. In Februar
son decided to divest
business and operate
sor of a chain of di
took over two new st
liquidate its retail inve

As part of its ch
methods, First Gib
agreed to exchange cer
Gibson agreed to deli
and fixtures located a
partment of its Rowla
in exchange for the
hardware inventory an
by Daylin at the co
leased at the two new s
an inventory by an i
First Gibson and Da
Daylin would pay appro
in cash to cover the di
between the two invent
about April 20 or 21, 19
no notice of the transac
tors of First Gibson, w
cated a bankrupt on Aug

California's law on bu
codification, with modifi
cle 6 of the Uniform C
which is designed to
chant's unsecured credito
position of inventory o
nary course of business
Introductory Comment,
Cal.Commercial Code 73
While Article 6 is aime
preventing fraud on th

Bankruptcy Act [11 U.S.C. § 110(e)(3)]. We reverse and remand.

The bankrupt, First Gibson Stores of California, was incorporated in July 1966 for the purpose of establishing and operating department stores. It opened two stores late in 1966. It sold "hard goods" (drugs, sundries, housewares, etc.) and leased a portion of each store to concessionaires of "soft goods" (clothing, etc.). The stores were opened with an inventory of some $300,000 in goods that First Gibson had ordered from 1,500 suppliers. The first store was closed for lack of business in January 1967, and all merchandise was moved to the second store at Rowland Heights. In February 1967, First Gibson decided to divest itself of its retail business and operate instead as the lessor of a chain of discount stores. It took over two new stores and began to liquidate its retail inventory.

As part of its change in business methods, First Gibson and Daylin agreed to exchange certain assets. First Gibson agreed to deliver all inventory and fixtures located at the sundry department of its Rowland Heights store in exchange for the housewares and hardware inventory and fixtures owned by Daylin at the concessions Daylin leased at the two new stores. Following an inventory by an independent firm, First Gibson and Daylin agreed that Daylin would pay approximately $15,000 in cash to cover the difference in value between the two inventories. This was about April 20 or 21, 1967. Daylin gave no notice of the transaction to the creditors of First Gibson, which was adjudicated a bankrupt on August 1, 1967.

California's law on bulk transfers is a codification, with modifications, of Article 6 of the Uniform Commercial Code, which is designed to protect a merchant's unsecured creditors from his disposition of inventory outside the ordinary course of business. C. Williams, Introductory Comment, Division 6, 23B Cal.Commercial Code 734 (West 1964). While Article 6 is aimed primarily at preventing fraud on the part of the transferor and transferee (*e. g.*, selling the inventory and absconding with the proceeds), it is also intended to protect against inadequacy of consideration, even where the transferor and transferee are innocent of any wrongdoing. J. White & R. Summers, Uniform Commercial Code 644 (1972).

Section 6102 of the California Commercial Code provides in pertinent part:

> "§ 6102 (1) A "bulk transfer" is any *transfer in bulk* and *not in the ordinary course of the transferor's business of a substantial part of the materials*, supplies, merchandise, or other inventory (Section 9109) of an enterprise subject to this division.
>
> . . .
>
> (3) The enterprises subject to this division are all those whose *principal business* is that of a baker, cafe or restaurant owner, garage owner, cleaner and dyer, or *retail or wholesale merchant*." Cal.Commercial Code (West 1964). (Emphasis added.)

When a transaction falls within the scope of Section 6102, the transferee must give notice of the transaction to the transferor's creditors, giving them time to investigate the proposed transfer and to protest if necessary. §§ 6105 and 6107. Failure to give notice renders the bulk transfer "fraudulent and void" against the transferor's creditors. § 6105.

The issue that confronts us, therefore, is whether the court below was correct in finding that the transaction complained of did not fall within the purview of these provisions. We conclude that the district court was in error.

I.

THE "PRINCIPAL BUSINESS" OF FIRST GIBSON

[1] The district court found that the principal business of First Gibson was that of a retail merchant until February 1967, at which time it became a lessor and operator of discount stores. The transaction in question was on April 20, 1967. The court concluded that "at the

times material to this action," First Gibson was not principally a retail merchant.

We find this conclusion to be incorrect as a matter of law. The district court's conclusion emasculates the policies underlying the bulk transfer statute by allowing First Gibson to acquire inventory as a merchant, change its principal business to that of lessor, and then dispose of its "merchant's inventory" in bulk without notice.

"While some bulk sales risk exists in [those businesses excluded from the scope of Article 6], they have in common the fact that unsecured credit is not commonly extended on the faith of a stock of merchandise." Official Comment 2, § 6102, Uniform Commercial Code (1962). In the present case, credit was presumably extended on the faith of First Gibson's stock. Since protection of creditors is the main concern of Article 6, First Gibson's subsequent change of business to that of a lessor should not affect its duty to notify creditors who extended credit while it was a retail merchant.

[2] We have found only two cases that have considered situations analogous to this, and both support our analysis. They held that the mere fact that a merchant terminates his business or engages in other lines of employment does not free him from the requirements of a bulk sales statute as applied to the sale of stock of his former business. Davidson v. Heyman, 243 App.Div. 546, 275 N.Y.S. 870 (1934); Teich v. McAuley, 212 S.W. 979 (Tex.Civ.App.1919).

II.

WAS THERE A "TRANSFER" ?

[3] Daylin contends that an *exchange* of assets, as occurred here, is not a "transfer" under Article 6. The purpose of a bulk transfer statute is to keep merchandise and inventory as a cushion available to satisfy the claims of creditors. Therefore, defendant argues, where there is merely a replacement of inventory and fixtures with another type of inventory and fixtures having equivalent value, there is no depletion of inventory, and existing creditors may not complain.

Article 6 requires, however, that creditors be allowed to police bulk sales, to make certain that the consideration paid in return is indeed equal in value to the inventory transferred. Daylin would have the transferor act as the "policeman" of his own sale.

The dangers of a bulk transfer—either fraud or mere inadequacy of consideration—can as easily occur with an exchange of assets as with a cash sale. When creditors have advance notice of a bulk sale, either for cash or assets, they can investigate before it is completed and then determine whether they should intervene. That the trustee in bankruptcy subsequently receives the exchanged assets, as he did here, is of small consolation to creditors if the assets are of less value or salability than those looked to by the creditors when they extended credit.

Additionally, while the term "transfer" is not expressly defined in the California Commercial Code, it is defined elsewhere in California law and the Bankruptcy Act to include an exchange. Cal.Civil Code § 1039 (West 1954); Bankruptcy Act § 1(30), 11 U.S.C. § 1(30) (1970). *See also* 42 Words and Phrases, p. 408 (1952, and 1973 Supp. at 68).

Defendant argues by analogy to a case excepting a purchase money mortgage from the scope of the bulk sales act. In re Mercury Engineering Co., 68 F.Supp. 376 (S.D.Cal.1946). The analogy is weak. A bulk sales act clearly should not apply to a purchase money mortgage, since in that situation the merchant is acquiring new assets that could not have been the basis for extending earlier credit. The California legislature recognized this by specifically excepting purchase money security interests from the scope of the act. Cal.Commercial Code § 6103(1)(a) (West 1964). In the present case, however, the assets

exchanged by First Gib
upon which creditors mi
ed credit.

III.

WAS A "SUBSTANT
TRANSFERR

[4] A very significar
tween California's bulk
and the official version
Commercial Code is that
fines a bulk transfer as
a "substantial part" of th
posed to a "major part."
Commercial Code § 6102(
with Uniform Comme
6102(1) (1962 Official T
nificance is that a "ma
generally been interprete
transfer of approximate
the transferor's inventory
and C. Williams, Califor
ment, 23B Cal.Commercia
(West 1964). Courts hav
"substantial part," on the
be as little as 5 percent
[Reed v. Anglo Scandinav
F.Supp. 310 (E.D.Cal.1969
[Markwell & Co. v. Lynch
(9th Cir. 1940)], 15 perc
Sampsell, 185 F.2d 333 (9
and 16 percent [Schainma
F.2d 475 (9th Cir. 1928)].

The merchandise inven
Gibson at the time of the
approximately $500,000,
$122,000 worth was trans
lin. This amount, rough
was clearly a "substantial
Gibson's inventory.

IV.

WAS THE TRANSFER "
ORDINARY COURSE
TRANSFEROR'S BUS

[5] Having produced
"swapping inventories" i
practice in the retail bus
contends that the transfe
"ordinary course of busin

exchanged by First Gibson were assets upon which creditors might have extended credit.

III.

WAS A "SUBSTANTIAL PART" TRANSFERRED?

[4] A very significant difference between California's bulk transfers law and the official version of the Uniform Commercial Code is that California defines a bulk transfer as the transfer of a "substantial part" of the assets, as opposed to a "major part." *Compare* Cal. Commercial Code § 6102(1) (West 1964) with Uniform Commercial Code § 6102(1) (1962 Official Text). The significance is that a "major part" has generally been interpreted to require a transfer of approximately one-half of the transferor's inventory. *See* J. Bohn and C. Williams, California Code Comment, 23B Cal.Commercial Code 739–40 (West 1964). Courts have interpreted a "substantial part," on the other hand to be as little as 5 percent of the value [Reed v. Anglo Scandinavian Corp., 298 F.Supp. 310 (E.D.Cal.1969)], 6.3 percent [Markwell & Co. v. Lynch, 114 F.2d 373 (9th Cir. 1940)], 15 percent [Jubas v. Sampsell, 185 F.2d 333 (9th Cir. 1950)], and 16 percent [Schainman v. Dean, 24 F.2d 475 (9th Cir. 1928)].

The merchandise inventory of First Gibson at the time of the transfer was approximately $500,000, of which $122,000 worth was transferred to Daylin. This amount, roughly 25 percent, was clearly a "substantial part" of First Gibson's inventory.

IV.

WAS THE TRANSFER "NOT IN THE ORDINARY COURSE OF THE TRANSFEROR'S BUSINESS"?

[5] Having produced evidence that "swapping inventories" is a common practice in the retail business, Daylin contends that the transfer was in the "ordinary course of business," and beyond the purview of the bulk transfer law.

This contention has been soundly rejected. In Jubas v. Sampsell, 185 F.2d 333 (9th Cir. 1950), a shoe store sold a quantity of shoes at one dollar per pair to another dealer, then declared bankruptcy. The trustee successfully moved to set aside the transfer as fraudulent under California's bulk sales act, despite the transferee's claim that "unloading" unmarketable shoes in that manner was a normal business practice. We held that "the ordinary course of business" contemplated only the day to day operation of a store, and not transfers of a significant portion of the inventory, no matter how usual a practice the transfer may have been.

> "The plain meaning of the statute is that when a storekeeper disposes of a substantial part of his stock in trade in bulk, and selling in bulk sales is not the usual and ordinary way in which he conducts his business from day to day, the sale falls within the statute." *Id.* at 334; Reed v. Anglo Scandinavian Corp., 298 F.Supp. 310 (E.D.Cal. 1969).

V.

[6] In summary, we find that the principal business of First Gibson was that of a retail merchant at times relevant to the transaction, that there was a transfer within the meaning of Section 6102, that First Gibson transferred a substantial part of its merchandise or inventory, and that this transfer was not in the ordinary course of the transferor's business.

The transaction therefore came within the statutory notice requirements of Section 6107 of the California Commercial Code. Daylin's failure to adhere to these requirements renders the transaction "fraudulent and void" against any creditor of First Gibson. § 6105.

Daylin now offers a subrogation defense. Since the district court neither reached nor decided this question, we remand on this issue alone. We refer

the district court to § 70(e) of the Bankruptcy Act [11 U.S.C. § 110(e)] and to Moore v. Bay, 284 U.S. 4, 52 S.Ct. 3, 76 L.Ed. 133 (1931).

Reversed and remanded.

[7] Appellee's petition for rehearing is denied. Appellee contends that evidence of good faith and the absence of fraudulent intent should be a defense in an action to set aside a bulk transfer for lack of notice in violation of § 6101–6111 of the California Commercial Code.

We disagree. Extending appellee's argument to its logical conclusion, the only ones who are bound to give statutory notice of a bulk transfer are those who are engaging in fraud. Others need not because they are acting in good faith and therefore have nothing to lose by failing to give notice. Such a result hardly promotes the policy underlying a bulk sales law that seeks to protect creditors by requiring that they be allowed to police bulk sales. Appellee would have us establish the transferor and transferee as the "policemen" of their own transaction. This would emasculate the very purpose of a bulk sales law.

UNITED STATES of America, Plaintiff-Appellee,

v.

Steven Paul NEWCOMB anod Wayne E. Lucas, Jr., Defendants-Appellants.

No. 73-1659.

United States Court of Appeals, Fifth Circuit.

Jan. 17, 1974.

Defendants were convicted in United States District Court for the Southern District of Florida at Miami, Charles B. Fulton, Chief Judge, of conspiracy to possess marijuana with intent to distribute, and they appealed. The Court of Appeals held that where both defendants vigorously denied the conspiracy and overt acts charged and admitted only purely innocuous acts such as renting cars, being innocent bystanders in the vicinity of the crime charged and associating with undercover agents who were interested in purchasing marijuana, and the government's case gave little or no cause for inference that either defendant had been entrapped, there was no occasion for invoking any exception to the general rule that the defense of entrapment is unavailable to one who denies commission of the acts constituting the offense charged; it further held that where the government agent in charge of the case testified before the grand jury and there was no reason to suspect that the indictment was ill-founded, the trial court did not abuse its discretion in refusing to order minutes of the grand jury testimony produced for defendants.

Affirmed.

1. Criminal Law ⟹772(6)

Where both defendants vigorously denied participation in alleged conspiracy to possess marijuana with intent to distribute, only overt acts admitted by defendants were purely innocuous ones of renting cars, being innocent bystanders in vicinity of crime charged and associating with undercover agents who were interested in purchasing marijuana, and government's case gave little or no cause for inference that either defendant had been entrapped, defendants were not entitled to instruction on defense of entrapment. Comprehensive Drug Abuse Prevention and Control Act of 1970, § 406, 21 U.S.C.A. § 846.

2. Indictment and Information ⟹10.1(2, 7)

Indictment based exclusively on hearsay evidence is not constitutionally invalid, and defendant is not entitled to litigate sufficiency of evidence presented to grand jury.

26. Department of Industrial Relations. Directors List of Hazardous Substances, State of California, October 1982

CONTENTS

INTRODUCTION.....3

LIST OF HAZARDOUS SUBSTANCES.....5

APPENDIX A - SYNONYMS.....27

RESOURCES.....39

REFERENCES.....41

ATTACHMENT 1

THE DIRECTOR'S LIST OF HAZARDOUS SUBSTANCES

October 1982

which sells substances on this List must also provide purchasers with MSDS.

If you are an employer who uses substances on the List to which workers might be exposed under either normal work conditions or reasonably foreseeable emergency conditions resulting from workplace operations, you must give those workers information based on MSDS and a copy of the MSDS upon request, and train them to work safely with these hazardous substances. Refer to General Industry Safety Orders 5194 and 3204 for requirements regarding MSDS. Refer to General Industry Safety Orders 5194 and 3203 for requirements regarding employee training.

If you are a worker, ask your employer whether you work with any substances on the List. If you do, your employer must provide you with information, including Material Safety Data Sheets, and training for working safely with these hazardous substances. See General Industry Safety Orders 5194, 3204, and 3203 for specific information about your rights.

INTRODUCTION

The List of Hazardous Substances was developed by the Director of the Department of Industrial Relations pursuant to the provision of the Hazardous Substances Information and Training Act (SB 1874). The substances on this List are subject to the requirements of General Industry Safety Order 5194 of Title 8 of the California Administrative Code and Division 5, Chapter 2.5 of the California Labor Code. The Hazardous Substances Information and Training Act, implemented by GISO 5194 became effective and enforceable on February 21, 1983.

Substances included on this List are those for which Material Safety Data Sheets are required. "Hazardous" is a relative term, and the degree of hazard to human health of these substances varies widely. Substances on the List are identified by their CAS number. The CAS number is a number assigned by the Chemical Abstrac Service to give a specific chemical substance a unique identity. Substances are included on the List because they appear in one or more of the sources listed below. The source(s) of each hazardous substance on the List is designated by a number in the middle column of the List. The numbers represent the following sources:

(1) International Agency for Research on Cancer (IARC) (human or animal carcinogens)

(2) Environmental Protection Agency - Federal Clean Water and Clean Air Acts

(3) CAL/OSHA list of airborne chemical contaminants (GISO 5155)

(4) California Food and Agriculture Code list of restricted materia

(5) Hazard Evaluation System and Information Service hazard alerts.

The List of Hazardous Substances will be reviewed and revised, as appropriate, annually. Title 8 Section 337 describes how substances will be added to or deleted from the List.

The resources listed on pages 39 and 40 will assist you with a further questions you may have about your rights and responsibiliti under the Hazardous Substances Information and Training Act and General Industry Safety Order 5194 or about substances included on the List.

If you manufacture a substance (or a mixture containing a substance at a certain percentage) listed on the List of Hazardous Substances, you must prepare and provide a Material Safety Data She (MSDS) to anyone who purchases the material or within 15 working days to anyone who requests the MSDS. Any other person or company

CAS NO.	SOURCE	SUBSTANCE	FOOTNOTES
628637, 123922, 626380, 625161	2,3	Amyl acetate, all isomers	
62533	2,3	Aniline	
90040	3	o-Anisidine	
104949	3	p-Anisidine	
7440360	2,3	Antimony	3
	2,3	Antimony compounds	4
	1,2,3,4	Arsenic and arsenic compounds	32
7784421	3	Arsine	
1332214	1,2,3	Asbestos	5
MX8052424	3	Asphalt (petroleum) fumes	6
1912249	3	Atrazine	
492808	1	Auramine	
115026	1	Azaserine	
	2,3	Barium, soluble compounds	2
17804352	3	Benomyl	
56553	1	Benz[a]anthracene	
71432	1,2,3	Benzene	
531851, 531862, 92875	1,2,3	Benzidine (and its salts)	31
205992	1	Benzo[b]fluoranthene	
65850	2	Benzoic acid	7
100470	2	Benzonitrile	
50328	1	Benzo[a]pyrene	
98884	2	Benzoyl chloride	
94360	3	Benzoyl peroxide	
100447	2,3	Benzyl chloride	
1694093	1	Benzyl violet 4B	
	1,2,3	Beryllium and beryllium compounds	
92524	3	Biphenyl	
542881	1,3	Bis(chloromethyl) ether	31
	3	Bis(dimethylthiocarbamoyl)-disulfide	
494031	1	N,N-Bis(2-chloroethyl)-2-naphthylamine	
115322	3,4	1,1-Bis-(p-chlorophenyl)-2,2,2-trichloroethanol(dicofol)	
	3	Borates, tetra, sodium salts	8
1303862	3	Boron oxide	8
10294334	3	Boron tribromide	
314409	3	Bromacil	
7726956	3	Bromine	
74975	3	Bromochloromethane	
75274	2	Bromodichloromethane	
75252	3	Bromoform	
75638	3	Bromotrifluoromethane	
106990	3	1,3-Butadiene	
78933	3	2-Butanone	
123864, 105464, 540885	2,3	Butyl acetate	
141322	3	Butyl acrylate	

CAS NO.	SOURCE	SUBSTANCE	FOOTNOTES
83329	2	Acenaphthene	
75070	2,3	Acetaldehyde	1
64197	2,3	Acetic acid	
108247	2,3	Acetic anhydride	
67641	3	Acetone	
75865	2	Acetone cyanohydrin	
75058	3	Acetonitrile	
53963	3	2-Acetylaminofluorene	
506967	2	Acetyl bromide	
79367	2	Acetyl chloride	
74862	3	Acetylene	
540590	2,3	Acetylene dichloride	
79276	3	Acetylene tetrabromide	
79345	3	Acetylene tetrachloride	
107028	2,3,4	Acrolein	
79061	3	Acrylamide	
107131	1,2,3,4	Acrylonitrile	
1402386, 1397780, 8052162, 50760, 1402546, 12623788	1	Actinomycins	
	1	Aflatoxins	
116063	4	Aldicarb	
309002	2,3,4	Aldrin	
107186	2,3,4	Allyl alcohol	
107051	2,3	Allyl chloride	
106923	3	Allyl glycidyl ether	12
2179591	3	Allyl propyl disulfide	
	3	Aluminum	3
	3	Aluminum, alkyls	
20859738	4	Aluminum phosphide	
	3	Aluminum pyro powders	
	3	Aluminum, soluble salts	2
92671	1,3	4-Aminodiphenyl	31
712685	1	2-Amino-5-(5-nitro-2-furyl)-1,3,4-thiadiazole	
504290	3	2-Aminopyridine	
504245	4	4-Aminopyridine	
97563	1	o-Aminoazotoluene	
61825	1	Amitrole	
7664417	3	Ammonia	
10192300	2	Ammonium bisulfite	
1111780	2	Ammonium carbamate	
13826830	2	Ammonium fluoborate	
1336216	2	Ammonium hydroxide	29
6009707	2	Ammonium oxalate	
16919190	2	Ammonium silicofluoride	
7773060	2,3	Ammonium sulfamate	
12135761	2	Ammonium sulfide	
10196040	2	Ammonium sulfite	
1762954	2	Ammonium thiocyanate	
7783188	2	Ammonium thiosulfate	

CAS NO.	SOURCE	SUBSTANCE	FOOTNOTES
	2,3	Chloroalkyl ethers	
510156	4	Chlorobenzilate	
2698411	3	o-Chlorobenzylidene-malononitrile	
75456	3	Chlorodifluoromethane (FC-22)	
67663	1,2,3	Chloroform	
600259	3	1-Chloro-1-nitropropane	
76062	3,4	Chloropicrin	
95578	2	2-Chlorophenol	
590216	3	Chloroprene	
1331288	3	o-Chlorostyrene	
7790945	2	Chlorosulfonic acid	
95498	3	Chlorotoluene	
7745893	4	3-Chloro-p-toluidine hydrochloride	
1929824	3	2-Chloro-6-(trichloromethyl)pyridine	
2921882	2,3	Chlorpyrifos	
	1,2,3	Chromic, chromous and chromate salts	
7440473	1,2,3	Chromium	3
6358538	1	Citrus Red no. 2	
1420048	4	Clonitralid	
2971906	3	Clopidol	
8007452	3	Coal tar pitch volatiles	11
7440484	3	Cobalt	3
7789437	2	Cobaltous bromide	
544183	2	Cobaltous formate	
14017415	2	Cobaltous sulfamate	
7440508	2,3	Copper	3
	2,3	Copper compounds	
	3	Cotton dust	27
56724	2	Coumaphos	
MX8026946	2,3	Cresol	
123739	2,3	Crotonaldehyde	
98828	3	Cumene	
420042	3	Cyanamide	
	2,3,4	Cyanides, inorganic salts	
460195	3	Cyanogen	
506774	2	Cyanogen chloride	
14901087	1	Cycasin	
110827	2,3	Cyclohexane	
108930	3	Cyclohexanol	
108941	3	Cyclohexanone	
110838	3	Cyclohexene	
66819	4	Cycloheximide	
108918	3	Cyclohexylamine	
542927	3	Cyclopentadiene	
50180	1	Cyclophosphamide	
121824	3	Cyclotrimethylene-trinitramine	
94757	2,3,4	2,4-D (2,4-dichlorophenoxyacetic acid)	

CAS NO.	SOURCE	SUBSTANCE	FOOTNOTES
71363, 78922, 75650	3	Butyl alcohol	
109739; 78819, 513495, 13952846, 75649	2,3	Butylamine, all isomers	
299865	3	4-tert-Butyl-2-chlorophenylmethyl methylphosphoramidate	
2426086	3	n-Butyl glycidyl ether	12
138227	3	n-Butyl lactate	
109795	3	n-Butyl mercaptan	
140578	1	2-(p-tert)-Butylphenoxy)isopropyl-2-chloroethyl sulfite	
98511	3	p-tert-Butyltoluene	
107926	2	Butyric acid	
3068880	1	beta-Butyrolactone	
	1,2,3,4	Cadmium and cadmium oxide	3
	2,3,4	Cadmium compounds	
75207	2	Calcium carbide	
156627	3	Calcium cyanamide	
26264062	2	Calcium dodecylbenzene-sulphonate	9
1305620	3	Calcium hydroxide	
7778543	2	Calcium hypochlorite	
1305788	3	Calcium oxide	
76222	3	Camphor	
105602	3	Caprolactam	
2425061	3	Captafol	
133062	2,3	Captan	
63252	2,3,4	Carbaryl	
7786347	2,3,4	alpha-2-Carbomethoxy-1-methylvinyl dimethyl phosphate (mevinphos)	
	3	Carbon black	10
75150	2,3,4	Carbon disulfide	
630080	3	Carbon monoxide	
558134	3	Carbon tetrabromide	
56235	1,2,3,4	Carbon tetrachloride	
786196	4	Carbophenothion	
120809	3	Catechol	
21351791	3	Cesium hydroxide	
305033	1	Chlorambucil	
57749	2,3,4	Chlordane	
6164983	4	Chlordimeform	
470906	4	Chlorfenvinphos	
	2	Chlorinated benzenes	
	2	Chlorinated cresols	
	3	Chlorinated diphenyl oxide	
	2	Chlorinated naphthalenes, (other than those listed elsewhere)	
7782505	2,3	Chlorine	
10049044	3	Chlorine dioxide	
107200	3	Chloroacetaldehyde	
532274	3	alpha-Chloroacetophenone	

CAS NO.	SOURCE	SUBSTANCE	FOOTNOTES
76142	3	1,2-Dichloro-1,1,2,2-tetrafluoroethane (FC-114)	
62737	2,3	Dichlorvos	
5124301	3	Dicyclohexylmethane-4,4'-diisocyanate	
77736	3	Dicyclopentadiene	
102545	3	Dicyclopentadienyl iron	
60571	2,3,4	Dieldrin	
1464535	1	Diepoxybutane	12
109897	2,3	Diethylamine	
100378	3	2-(Diethylamino)ethanol	
111400	3	Diethylenetriamine	
1615801	1	1,2-Diethylhydrazine	
56531	1	Diethylstilboestrol	
64675	1	Diethyl sulphate	
2238075	3	Diglycidyl ether	
94586	1	Dihydrosafrole	
1563662	2,3,4	2,3-Dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate (carbofuran)	
108838	3	Diisobutyl ketone	
108189	3	Diisopropylamine	
119904	1	3,3'-Dimethoxybenzidine	
6923224	3,4	3-(Dimethoxy phosphinyloxy)-N-methyl-cis-crotonamide (monocrotophos)	
127195	3	N,N-Dimethylacetamide	
124403	2,3	Dimethylamine	
60117	1,3	4-Dimethylaminoazobenzene	
55738540	1	trans-2[(Dimethylamino) methylimino]-5-[2-(5-nitro-2-furyl)vinyl]-1,3,4-oxadiazole	
121697	3	N,N-Dimethylaniline	
119937	1	3,3'-Dimethylbenzidine	
79447	1	Dimethylcarbamoyl chloride	
300765	2,3	0,0-Dimethyl 0-(1,2-dibromo-2,2-dichloroethyl) phosphate	
68122	3	N,N-Dimethylformamide	
57147, 540738	1,3	Dimethylhydrazine (all isomers)	
115902, 115913	3,4	0,0-Dimethyl 0-[p-(methylsulfinyl) phenyl] phosphorothioate (fensulfothion)	
86500	2,3,4	0,0-Dimethyl S-[(4-oxo-benzotriazino-3) methyl] phosphorodithioate	
10265926	4	0,S-Dimethyl phosphoramidothioate	
950378	4	0,0-Dimethyl phosphorodithioate, S-ester with 4-(mercaptomethyl)-2-methoxy-Δ^2-1,3,4-thiadiazolin-5-one	

CAS NO.	SOURCE	SUBSTANCE	FOOTNOTES
94111, 94791, 94804, 1320189, 1928387, 1928616, 1929733, 2971382, 25168267, 53467111	2	2,4-D ester (2,4-dichlorophenoxyacetic acid ester)	
94826	4	2,4-DB (2,4-dichlorophenoxybutyric acid)	
50293	2,3,4	DDT (1,1,1-trichloro-2,2-bis (p-chlorophenyl)ethane)	
120365	4	2,4-DP (2,4-dichlorophenoxypropionic acid)	
20830813	1	Daunomycin	
1304025	3	Decaborane	
8065483	3,4	Demeton	
613354	1	N,N'-Diacetylbenzidine	
10311849	4	Dialifor	
101814	1	4,4-Diaminodiphenyl ether	
95807	1	2,4-Diaminotoluene	
333415	2,3	Diazinon	
334883	3	Diazomethane	
226368	1	Dibenz[a,h]acridine	
224420	1	Dibenz[a,j]acridine	
53703	1	Dibenz[a,h]anthracene	
194592	1	7H-Dibenzo[c,g]carbazole	
192654	1	Dibenzo[a,e]pyrene	
189640	1	Dibenzo[a,h]pyrene	
189559	1	Dibenzo[a,i]pyrene	
94360	3	Dibenzoyl peroxide	
1304003	3	Diborane	
96128	1,3	1,2-Dibromo-3-chloropropane	
75616	3	Dibromodifluoromethane	
102818	3	2-(Dibutylamino) ethanol	
128370	3	2,6-Di-tert-butyl-p-cresol	7
107664	3	Dibutyl phosphate	
1918009	2,4	Dicamba	
1194656	2	Dichlobenil	
117806	2	Dichlone	
7572294	3	Dichloroacetylene	
	1,2,3	Dichlorobenzidine (and its salts)	
72559	2,4	1,1-Dichloro-2,2-bis (p-chlorophenyl)ethylene	
28434868	1	3,3'-Dichloro-4,4'-diaminodiphenyl ether	
75718	3	Dichlorodifluoromethane (FC-12)	
118525	3	1,3-Dichloro-5,5-dimethylhydantoin	
75434	3	Dichloromonofluoromethane (FC-21)	
594729	3	1,1-Dichloro-1-nitroethane	
120832	2	2,4-Dichlorophenol	
1836755	4	2,4-Dichlorophenyl p-nitrophenyl ether	
26638197, 78875, 142289, 78999	2,3	Dichloropropanes	
26952238, 542756, 78886	2,4	Dichloropropenes	
75990	2	2,2-Dichloropropionic acid	

CAS NO.	SOURCE	SUBSTANCE	FOOTNOTES
107211	3	Ethylene glycol	14
628966	3	Ethylene glycol dinitrate	
111762	2,3	Ethylene glycol monobutyl ether	
110805	3,5	Ethylene glycol monoethyl ether	
111159	3	Ethylene glycol monoethyl ether acetate	
109864	3,5	Ethylene glycol monomethyl ether	
110496	3	Ethylene glycol monomethyl ether acetate	
151564	3	Ethyleneimine	
75218	1,3	Ethylene oxide	12
96457	1	Ethylenethiourea	
60297	3	Ethyl ether	
109944	3	Ethyl formate	
75343	3	Ethylidene chloride	
16219753	3	Ethylidene norbornene	
75081	3	Ethyl mercaptan	
62500	1	Ethyl methanesulphonate	
22224926	4	Ethyl 3-methyl-4-(methylthio)-phenyl (1-methylethyl)phosphoramidate	
100743	3	N-Ethylmorpholine	
56382	4	Ethyl parathion	
78104	3	Ethyl silicate	
301053	3	Ferbam	
1336169	2,3	Ferrovanadium dust	3
206440	2	Fluoranthene	
	2,3	Fluoride, and inorganic fluoride compounds	
7782414	3	Fluorine	
640197	4	Fluoroacetamide/1081	
75694	3	Fluorotrichloromethane	
944229	3,4	Fonofos	
50000	2,3	Formaldehyde	
75127	3	Formamide	
64186	2,3	Formic acid	
3570750	1	2-(2-Formylhydrazino)-4-(5-nitro-2-furyl)thiazole	

CAS NO.	SOURCE	SUBSTANCE	FOOTNOTES
77781	1,3	Dimethyl sulfate	
25154545, 99650, 100254, 528290	2,3	Dinitrobenzenes, all isomers	
534521	2,3,4	4,6-Dinitro-o-cresol	
51285, 329715, 573568	2,4	Dinitrophenols	
148016	3	3,5-Dinitro-o-toluamide	
25321146, 121142, 121142, 606202, 610399, 602017, 619518	2,3	Dinitrotoluenes, all isomers	
88857	4	Dinoseb	
123911	1,3	p-Dioxane	
78342	3,4	2,3-p-Dioxanedithiol S,S-bis (0,0-diethyl phosphorodithioate) (dioxathion)	
122394	3	Diphenylamine	
38622183	2	Diphenylhydrazine	
1321217	3	Dipropylene glycol monomethyl ether	
2764729	2,3	Diquat	
97778	3	Disulfiram	
298044	2,3,4	Disulfoton	
330541	2,3	Diuron	
27176870	2	Dodecylbenzenesulfonic acid	9
60004	2	EDTA	
115297	2,3,4	Endosulfan	
72208	2,3,4	Endrin	
106898	2,3	Epichlorohydrin	12
2104645	3,4	EPN	
50282	1	Estradiol-17B	
53167	1	Estrone	
141435	3	Ethanolamine	
57636	1	Ethinyloestradiol	
563122	2,3,4	Ethion	
141786	3	Ethyl acetate	
140885	3	Ethyl acrylate	
64175	3	Ethyl alcohol	13
75047	2,3	Ethylamine	
541855	3	Ethyl sec-amyl ketone	
100414	2,3	Ethylbenzene	
74964	3	Ethyl bromide	
106354	3	Ethyl butyl ketone	
75003	3	Ethyl chloride	
13194484	4	0-Ethyl S,S-dipropyl phosphorodithioate (ethoprop)	
107073	3	Ethylene chlorohydrin	
107153	2,3	Ethylenediamine	
106934	1,2,3,4,5	Ethylene dibromide	33
107062	1,2,3,4	Ethylene dichloride	

CAS NO.	SOURCE	SUBSTANCE	FOOTNOTES
7647010	2,3	Hydrogen chloride	
74908	2,3,4	Hydrogen cyanide	
7664393	2,3	Hydrogen fluoride	
7722841	3	Hydrogen peroxide	
7783064	2,3	Hydrogen sulfide	
123319	3	Hydroquinone	
141662	3,4	3-Hydroxy N,N-dimethyl-cis-crotonamide dimethyl phosphate (*dicrotophos*)	
123422	3	4-Hydroxy-4-methyl-2-pentanone	
95316	3	Indene	
	3	Indium and indium compounds	
7553562	3	Iodine	
75478	3	Iodoform	
9004664	1	Iron dextran	
1309371	3	Iron oxide	3
13463406	3	Iron pentacarbonyl	
	2,3	Iron salts, soluble	18
123513	3	Isoamyl alcohol	
78831	3	*Isobutyl alcohol*	
78591	2,3	Isophorone	
4098719	3	Isophorone diisocyanate	
78795	2	Isoprene	
42504461	2	Isopropanolamine dodecylbenzesulfonate	9
114261	3	2-Isopropoxyphenyl N-methylcarbamate (propoxur)	
108214	3	Isopropyl acetate	
67630	1,3	Isopropyl alcohol	
75310	3	Isopropylamine	
108203	3	Isopropyl ether	
4016142	3	Isopropyl glycidyl ether	12
120581	1	Isosafrole	
463514	3	Ketene	
143500	1,2	Kepone	
303344	1	Lasiocarpine	
7439921	1,2,3	Lead	3
	1,2,3	Lead compounds	
58899	2,3,4	Lindane	
7580678	3	Lithium hydride	
1309484	3	*Magnesium oxide*	3
121755	2,3	Malathion	

CAS NO.	SOURCE	SUBSTANCE	FOOTNOTES
110178	2	Fumaric acid	15
98011	2,3	Furfural	
98000	3	Furfuryl alcohol	
MX8006619	3	Gasoline	16
7782652	3	Germanium tetrahydride	
	3	Glass, fibrous or dust	
111308	3	Glutaraldehyde	
765344	1	Glycidaldehyde	
556525	3	Glycidol	12
7782425	3	Graphite	17
7440586	3	Hafnium	
	2	Haloethers (other than those listed elsewhere, includes chlorophenylphenyl ethers, bromophenylphenyl ether, bis(dichloroisopropyl) ether, bis(chloroethoxy)methane and polychlorinated diphenyl ethers)	
7440597	3	Helium	
76448	2,3,4	Heptachlor	
142845	3	n-Heptane	
87683	2,3	Hexachlorobutadiene	
608731	2	Hexachlorocyclohexane	
77474	2,3	Hexachlorocyclopentadiene	
67721	3	Hexachloroethane	
684162	3	Hexafluoroacetone	
1335871	2,3	Hexachloronaphthalene	
684162	3	Hexafluoroacetone	
822060	3	Hexamethylene diisocyanate	
680319	1	Hexamethylphosphoramide	
110543	3	n-Hexane	
108849	3	sec-Hexyl acetate	
107415	3	Hexylene glycol	
302012	1,3	Hydrazine	
10035106	3	Hydrobromic acid	
7647010	2,3	Hydrochloric acid	
74908	2,3,4	Hydrocyanic acid	
7664393	2,3	Hydrofluoric acid	
1333740	3	Hydrogen	
	3	Hydrogenated terphenyls	
10035106	3	Hydrogen bromide	

CAS NO.	SOURCE	SUBSTANCE	FOOTNOTES
101144	1,3	4,4'-Methylene bis(2-chloroaniline)	
5124301	3	Methylene bis (4-cyclohexylisocyanate)	
838880	1	4,4-Methylene bis(2-methylaniline)	
101688	3	Methylene bis(4-phenyl isocyanate)	
1338234	3	Methyl ethyl ketone peroxide	
107313	3	Methyl formate	
60344	3	Methyl hydrazine	
74884	1,3	Methyl iodide	
110123	3	Methyl isoamyl ketone	
108112	3	Methyl isobutyl carbinol	
108101	3	Methyl isobutyl ketone	
624839	3	Methyl isocyanate	
74931	2,3	Methyl mercaptan	
80626	2,3	Methyl methacrylate	
66273	1	Methyl methanesulphonate	
16752775	3,4	S-Methyl N-[(methylcarbamoyl)oxy] thioacetamidate (methomyl)	
70257	1	N-Methyl-N'-nitro-N-nitrosoguanidine	
298000	2,3,4	Methyl parathion	
681845	3	Methyl silicate	
98839	3	alpha-Methylstyrene	
56042	1	Methylthiouracil	
315184	2	Mexacarbate	
12001262	3	Mica	19
	3	Mineral wool fiber	
2385855	1	Mirex	
50077	1	Mitomycin C	
7439987	3	Molybdenum	3
	3	Molybdenum compounds	20
315220	1	Monocrotaline	
110918	3	Morpholine	
139913	1	5-(Morpholinomethyl)-3-[(5-nitrofurfurylidene)-amino]-2-oxazolidinone	
505602	1	Mustard Gas	
MX8030317	3	Naphtha, coal tar	
91203	2,3	Naphthalene	
25551284	3	Naphthalene diisocyanate	
134327	3	alpha-Naphthylamine	
91598	1,3	beta-Naphthylamine	31
86884	3	1-(1-Naphthyl)-2-thiourea	
1338245	2	Naphthenic acid	
7440020	1,2,3	Nickel	3
	1,2,3	*Nickel compounds*	
54115	3,4	Nicotine	
61574	1	Niridazole	
7697372	2,3	Nitric acid	
10102439	3	Nitric oxide	
602879	1	5-Nitroacenaphthene	
100016	3	p-Nitroaniline	

CAS NO.	SOURCE	SUBSTANCE	FOOTNOTE
110167	2	Maleic acid	
108316	2,3	Maleic anhydride	
7439965	3	Manganese	3
	3	Manganese compounds	
12079651	3	Manganese, cyclopentadienyl-tricarbonyl	
94746	4	MCPA (2-methyl-4-chlorophenoxyacetic acid)	
148823	1	Melphalan	
2032657	2	Mercaptodimethur	
	2,3,4	*Mercury and mercury compounds*	
531760	1	Merphalan	
141797	3	Mesityl oxide	
72333	1	Mestranol	
72435	2,3	Methoxychlor	
79209	3	Methyl acetate	
74997	3	Methyl acetylene	
	3	Methyl acetylene-propadiene mixture	
96333	3	Methyl acrylate	
126987	3	alpha-Methylacrylonitrile	
109875	3	Methylal	
67561	3	Methyl alcohol	30
74895	2,3	Methylamine	
110430	3	Methyl n-amyl ketone	
100618	3	N-Methylaniline	
95534	3	o-Methylaniline	
75558	1,3	2-Methylaziridine	
592621	1	Methylazoxymethyl acetate	
74839	2,3,4	Methyl bromide	
591786	3	Methyl n-butyl ketone	
74873	2,3	Methyl chloride	
71556	3	Methyl chloroform	
107302	3	Methyl chloromethyl ether	31
137053	3	Methyl 2-cyanoacrylate	
108872	3	Methylcyclohexane	
1331233, 591231, 583595, 25639423	3	Methylcyclohexanol, all isomers	
583608	3	o-Methylcyclohexanone	
12108133	3	2-Methylcyclopentadienyl manganese tricarbonyl	
MX8022002	3	Methyl demeton	
75092	2,3	Methylene chloride	

CAS NO.	SOURCE	SUBSTANCE	FOOTNOTES
434071	1	Oxymetholone	
10028156	3	Ozone	22
30525894	2	Paraformaldehyde	
2074502, 1910425	3,4	Paraquat	
56382	2,3,4	Parathion	
1303975	3	Pentaborane	
1321648	2,3	Pentachloronaphthalene	
87865	2,3	Pentachlorophenol	
109660	3	Pentane	
107879	3	2-Pentanone	
127184	2,3	Perchloroethylene	
75707	3	Perchloromethyl mercaptan	
62442	1	Phenacetin	
108952	2,3	Phenol	
92842	3	Phenothiazine	
106503	3	p-Phenylenediamine	
101848	3	Phenyl ether, vapor	14
	3	Phenyl ether-diphenyl (eutectic mixture),vapor	14
122601	3	Phenyl glycidyl ether	12
100630	3	Phenylhydrazine	
108985	3	Phenyl mercaptan	
638211	3	Phenylphosphine	
298022	3,4	Phorate	
4104147	4	Phosacetim	
75445	2,3	Phosgene	
13171216	4	Phosphamidon	
7803512	3	Phosphine	
7664382	2,3	Phosphoric acid	
7723140	2,3	Phosphorus	
10025873	2	Phosphorus oxychloride	
10026138	3	Phosphorus pentachloride	
1314803	2,3	Phosphorus pentasulfide	
7719122	2,3	Phosphorus trichloride	
	2	Phthalate esters	
85449	3	Phthalic anhydride	
626175	3	m-Phthalodinitrile	
1918021	3,4	Picloram	
88891	3	Picric acid	
83261	3	2-Pivalyl-1,3-indandione (pindone)	
	3	Platinum, soluble salts	

CAS NO.	SOURCE	SUBSTANCE	FOOTNOTES
98953	2,3	Nitrobenzene	
100005	3	p-Nitrochlorobenzene	
92933	3	4-Nitrodiphenyl	31
79243	3	Nitroethane	
555840	1	1-{(5-Nitrofurfurylidene)-amino}-2-imidazolidinone	
531828	1	N-{4-(5-Nitro-2-furyl)-2-thiazolyl}acetamide	
10102440	2,3	Nitrogen dioxide	
51752, 55867	1	Nitrogen mustard and its hydrochloride	
302705, 126852	1	Nitrogen mustard N-oxide and its hydrochloride	
7783542	3	Nitrogen trifluoride	
55630	3	Nitroglycerin	
75525	3	Nitromethane	
25154556, 554847, 88755, 100027	2	Nitrophenols, all isomers	
108032,79469	3	Nitropropanes	
924163	1	N-Nitroso-di-n-butylamine	
1116547	1	N-Nitrosodiethanolamine	
55185	1	N-Nitrosodiethylamine	
62759	1,3	N-Nitrosodimethylamine	
621647	1	N-Nitroso-di-n-propylamine	
759739	1	N-Nitroso-N-ethylurea	
10595956	1	N-Nitrosomethylethylamine	
684935	1	N-Nitroso-N-methylurea	
615532	1	N-Nitroso-N-methylurethane	
4549400	1	N-Nitrosomethylvinylamine	
59892	1	N-Nitrosomorpholine	
16543558	1	N-Nitrosonornicotine	
100754	1	N-Nitrosopiperidine	
930552	1	N-Nitrosopyrrolidine	
13256229	1	N-Nitrososarcosine	
1321126, 88722, 99081, 99990	2,3	Nitrotoluenes	
10024972	3	Nitrous oxide	
111842	3	Nonane	
2234131	2,3	Octachloronaphthalene	
111659	3	Octane	
	3	Oil mist,particulate	21
2646175	1	Oil orange SS	
20816120	3	Osmium tetroxide	
144627	3	Oxalic acid	
7783417	3	Oxygen difluoride	

CAS NO.	SOURCE	SUBSTANCE	FOOTNOTES
26628228	3	Sodium azide	
7631905	2	Sodium bisulfite	
136787	3	Sodium 2-(2,4-dichlorophenoxy)-ethyl sulfate	
25155300	2	Sodium dodecylbenzenesulfonate	9
62748	3,4	Sodium fluoroacetate	
16721805	2	Sodium hydrosulfide	
1310732	2,3	Sodium hydroxide	
7681529	2	Sodium hypochlorite	
124414	2	Sodium methylate	
7632000	2	Sodium nitrite	
10048132	1	Sterigmatocystin	
MX8052413	3	Stoddard solvent	
18883664	1	Streptozotocin	
57249	2,3,4	Strychnine	
100425	2,3	Styrene, monomer	
	3	Subtilisins (proteolytic enzymes)	
3689245	4	Sulfotepp	
7446095	3	Sulfur dioxide	
2551624	3	Sulfur hexafluoride	
10025679	2,3	Sulfur monochloride	
5714227	3	Sulfur pentafluoride	
7783600	3	Sulfur tetrafluoride	
7664939	2,3	Sulfuric acid	
2699798	3	Sulfuryl fluoride	
14807966	3	Talc	19
	3	Tantalum and tantalum oxide	3
72548	2,4	TDE	
10028167	3	Tellurium	3
	3	Tellurium compounds	
1323042	3	Terphenyls	
58220	1	Testosterone	
1746016	2	2,3,7,8-Tetrachlorodibenzo-p-dioxin	
76119	3	1,1,1,2-Tetrachloro-2,2-difluoroethane	
76120	3	1,1,2,2-Tetrachloro-1,2-difluoroethane (FC-112)	
1335882	2,3	Tetrachloronaphthalene	
3689245	3	Tetraethyl dithionopyrophosphate	
107493	2,3,4	Tetraethyl pyrophosphate	
109999	3	Tetrahydrofuran	
3383968	3	Tetramethyl O,O'-thio-di-p-phenylene phosphorothioate (temephos)	
3333526	3	Tetramethyl succinonitrile (decomposition product of 2,2'-azobisisobutyronitrile)	

CAS NO.	SOURCE	SUBSTANCE	FOOTNOT
1336363	1,2,3	Polychlorobiphenyls	
	2	Polynuclear aromatic hydrocarbons	23
	3	Polytetrafluoroethylene, decomposition products	
3761533	1	Ponceau MX	
3564098	1	Ponceau 3R	
1310583	2,3	Potassium hydroxide	
7722647	2	Potassium permanganate	
1120714	1	1,3-Propane sultone	
709988	4	Propanil	
2312358	2	Propargite	
107197	3	Propargyl alcohol	
57578	1,3	beta-Propiolactone	
79094	2	Propionic acid	
123626	2	Propionic anhydride	
109604	3	n-Propyl acetate	
71238	3	n-Propyl alcohol	
115071	3	Propylene	
6423434	3	Propylene glycol dinitrate	
1320678	3	Propylene glycol monomethyl ether	
75569	2,3	Propylene oxide	12
627134	3	n-Propyl nitrate	
51525	1	Propylthiouracil	
121299, 121211	2	Pyrethrins	
MX8003347	3	Pyrethrum	
110861	3	Pyridine	
91225	2	Quinoline	
106514	3	Quinone	
108463	2,3	Resorcinol	
7440166	3	Rhodium	3
	3	Rhodium, soluble salts	2
299843	3	Ronnel	
	3	Rosin core solder, pyrolysis products	24
83794	3	Rotenone, commercial	
	3	Rubber solvent (naphtha)	
94597	1	Safrole	
152169	4	Schradan	
	2,3	Selenium and selenium compounds	
7803625	3	Silane	
7631869	3	Silica	25
7429905	2,3	Silver	3
	2,3	Silver compounds	26
	3	Soapstone	19
7440235	2	Sodium	

CAS NO.	SOURCE	SUBSTANCE	FOOTNOTES
115866	3	Triphenyl phosphate	
52244	1	Tris(1-aziridinyl)phosphine sulphide	
126727	1	Tris(2,3-dibromopropyl) phosphate	
72571	1	Trypan blue (commercial grade)	
7440337	3	Tungsten	3
		Tungsten compounds	
MX8006642	3	Turpentine	
66751	1	Uracil mustard	
7440611	2,3	Uranium	3
	2,3	Uranium compounds	
51796	1	Urethane	
8030306	3	VM & P (Varnish Makers & Painters) naphtha	
110623	3	Valeraldehyde	
1314621	2,3	Vanadium pentoxide	3
27774136	2	Vanadyl sulfate	
108054	2,3	Vinyl acetate	
593602	3	Vinyl bromide	
75014	1,2,3	Vinyl chloride	
106876	3	Vinyl cyclohexene dioxide	
75354	2,3	Vinylidene chloride	
25013154	3	Vinyltoluene	
81812	3	Warfarin	
1330207, 95476, 106423, 108383	2,3	Xylene, all isomers	
1477550	3	m-Xylene-$\alpha\alpha'$-diamine	
1300716	2	Xylenol	
1300738	3	Xylidine	
	3	Yttrium compounds	
7440666	2,3,4	Zinc	3
	2,3,4	Zinc compounds	28
10026116	2,3	Zirconium tetrachloride	

NOTE: Authority: Labor Code sections 54, 55 and 6380 and 8 CAC 337

Reference: Labor Code Sections 6380, 6380.5, 6382 and 6383

CAS NO.	SOURCE	SUBSTANCE	FOOTNOTES
509148	3	Tetranitromethane	
479458	3	Tetryl	
7440280	2,3	Thallium	3
	2,3	Thallium compounds	
62555	1	Thioacetamide	
96662	3	4,4'-Thiobis(6-tert-butyl-m-cresol)	
68111	3	Thioglycolic acid	
62566	1	Thiourea	
	3	Tin compounds	
108883	2,3	Toluene	
584849	3	Toluene-2,4-diisocyanate	
MX8001352	1,2,3,4	Toxaphene	
14567738	3	Tremolite	
126738	3	Tributyl phosphate	
78488	4	S,S,S-Tributyl phosphorotrithioate	
150505	4	S,S,S-Tributyl phosphorotrithioite	
52686	2	Trichlorfon	
79005	3	1,1,2-Trichloroethane	
79016	2,3	Trichloroethylene	
1321659	2,3	Trichloronaphthalene	
25167822	2	Trichlorophenols	
15950660, 933788, 933755, 95954, 609198, 88062, 93765	2,3,4	2,4,5-T (2,4,5-trichlorophenoxyacetic acid)	
6369966, 6369977, 1319728, 3813147	2	2,4,5-T amines	
2545597, 93798, 61792072, 1928478, 25168154	2,4	2,4,5-T esters (2,4,5-trichlorophenoxyacetic esters)	
13560991	2	2,4,5-T salts (acetic acid, 2,4,5-trichlorophenoxy sodium salt)	
93721	2,4	2,4,5-TP acid (propanoic acid, 2-(2,4,5-trichlorophenoxy))	
32534955	2	2,4,5-TP ester (propanoic acid, 2-(2,4,5-trichlorophenoxy)-isooctyl ester)	
96184	3	1,2,3-Trichloropropane	
76131	3	1,1,2-Trichloro-1,2,2-trifluoroethane (FC-113)	
78308	3	Tri-o-cresyl phosphate	
27323417	2	Triethanolamine dodecylbenzenesulfonate	9
121448	2,3	Triethylamine	
75503	2	Trimethylamine	
	3	Trimethylbenzene (all isomers)	
118967	3	2,4,6-Trinitrotoluene	

14. Exempt except when vapors or particulates are or can be formed due to work practices or procedures.

15. Exempt except when present as a dust.

16. Exempt when used as fuel.

17. Exempt except when inhalable dust and/or particulates are present or are generated through use of the product.

18. Refers to the water soluble salts only; exempt when mixed in food or animal feed.

19. Exempt except when inhalable dust is present or can be generated through use.

20. Exempt when in mixture, suspension, or where inhalable dust or particles are not present or cannot be formed.

21. Exempt except where mists can be generated in the ordinary use of the products, e.g. cutting oils.

22. Occupational sources of ozone include, but are not limited to:

    a. during oxidizing process of fine organic chemicals production (primarily ozoalic acid)

    b. during operations involving high-intensity UV light (plasma torch operations, glass blowing, hot metal operations, photoengraving operations, use of mercury vapor lamps, direct copying machines, projecting equipment)

    c. during operations involving high voltage electrical equipment (spectrographic and fluorometric apparatus, electroplating operations, high-volt linear accelerators, and electrostatic precipitators)

    d. during operations involving ozonizing process in treatment of water, industrial waste, and sewage; during air purification

    e. during drilling, cutting, and welding operations utilizing laser radiation

    f. during bleaching operations (textiles, pulp, paper, waxes, starch, sugar, teflon, and synthetic fibers), refining of mineral oils and their derivatives, processing of perfumes, vanilin, and camphor, aging and drying operations (wood, wines, whiskies, varnishes, and printing inks)

    g. during food preserving operations for mold and bacteria control

FOOTNOTES FOR HAZARDOUS SUBSTANCE LIST

1. Refers to solutions greater than or equal to 10%. Exempt when present in food or beverages, such as vinegar, apple cider, and wine, regardless of concentration.

2. Refers to water soluble salts only; all other salts are exempt.

3. An MSDS must be provided under the following circumstances:

    a) The metal is supplied as a fine powder.

    b) The metal is in welding or brazing rods.

    c) The metal may be melted with the generation of toxic fume.

    d) Under normal use, toxic dust or fume is likely to be generated by any manufacturing process.

4. Exempt when in bonded form or when antimony compounds cannot be released due to cutting, grinding, heating, etc.

5. Except:

    a) Exterior and interior coatings and laminating resins containing encapsulated asbestos fibers with such products.

    b) Cold process asphalt roof coatings.

    c) Non-friable encapsulated products such as floor tiles.

6. Any liquids; and products that could give rise to asphalt fume under normal conditions are included. Mechanical breakup of hardened asphalt surfaces is exempt.

7. Exempt when used in foods and feeds as a preservative.

8. Exempt except when present as free crystal/powder.

9. Exempt when in solution.

10. Exempt when in form where exposure to dust cannot occur.

11. Products that could give rise to coal tar pitch volatiles during normal use are included.

12. Exempt when part of a cured epoxy or rubber.

13. Refers to solutions greater than or equal to 25%. Beverage alcohol (as defined by Sections 23004 and 23005 of the California Alcoholic Beverage Control Act) in any concentration is exempt.

h. during welding operations using inert gas shielded arc welding devices, bare wire arc welding

i. during manufacturing production of ozone

23. Includes benzanthracenes, benzopyrenes, benzofluoranthrene, chrysenes, dibenzanthracenes, and indenopyrenes.

24. Refers to smoke and fume products given off during soldering.

25. Exempt except when inhalable particulates are present or can be generated.

26. Silver compounds existing in stable emulsions or suspensions, as in photographic film, are exempt.

27. Applicable to cotton fiber for use in industries or operations covered by General Industry Safety Order 5219, Cotton Dust.

28. Zinc oxide is exempt except when present as dust or when generated as a fume. Zinc stearate is exempt except when present as dust.

29. Refers to solutions greater than or equal to 4%.

30. Refers to solutions greater than or equal to 3%.

31. Refers to any mixture containing 0.1% or greater of this substance.

32. Refers to any mixture containing 0.02% or greater inorganic arsenic.

33. Refers to any mixture containing 0.1% or greater EDB.

APPENDIX A

LIST OF SYNONYMS

SOURCE	SUBSTANCE
3	Abate; tetramethyl 0,0'-thiodi-p-phenylene phosphorothioate
3	3-(Alpha-acetonylbenzyl)-4-hydroxycoumarin; warfarin
2,4	Aldifen; dinitrophenols
2	Aluminum sulfate; aluminum, soluble salts
3	Aminodimethylbenzene; xylidine
2,3	Aminoethane; ethylamine
3	2-Aminoethanol; ethanolamine
1,3	2-Aminonaphthalene; beta-Naphthylamine
3,4	4-Amino-3,5,6-trichloropicolini acid; picloram
2,3	Ammate; ammonium sulfamate
2	Ammonium bichromate; chromic, chromous and chromate salts
2	Ammonium bifluoride; fluoride and inorganic flouride compounds
2	Ammonium chromate; chromic, chromous and chromate salts
2	Ammonium fluoride; fluoride, and inorganic fluoride compounds
2,3	Antimony tribromide; antimony compounds
2,3	Antimony trichloride; antimony compounds
2,3	Antimony trifluoride; antimony compounds
2,3	Antimony trioxide; antimony compounds
3	Aqualin; acrolein
1	Aramite; 2-(p-tert-Buty(phenoxy)isopropyl 2-chloroethyl sulfite
3	Arasan; bis(dimethylthiocarbamoyl) disulfide
2,3	Arsenic disulfide; arsenic and arsenic compounds
2,3	Arsenic pentoxide; arsenic and arsenic compounds
2,3	Arsenic trichloride; arsenic and arsenic compounds
2,3	Arsenic trioxide; arsenic and arsenic compounds
2,3	Arsenic trisulfide; arsenic and arsenic compounds
2,3,4	Azinphos methyl; 0,0-dimethyl S-[(4-oxobenzotriazino-3-methyl)] phosphorodithioate
3,4	Azodrin; 3-(dimethyoxyphosphinyloxy)-N-methyl-cis crotonamide
2,3	Barium cyanide; cyanides, inorganic salts
3	Bantu; 1-(1-naphthyl)-2-thiourea
3	Baygon; 2-isopropoxyphenyl N-methylcarbamate
2,3	Benzene chloride; chlorinated benzenes
2,3	1,2-Benzenedicarboxylic acid; phthalate esters
3	1,4-Benzenediol; hydroquinone
2,3	1,3-Benzenediol; resorcinol
2,3,4	Benzene hexachloride; hexachlorocyclohexane
3	Benzin; benzene

LIST OF SYNONYMS

SOURCE	SUBSTANCE
3	Benzol; benzene
2	Benzo(b)pyridine; quinoline
3	p-Benzoquinone; quinone
2,3	Beryllium chloride; beryllium and beryllium compounds
2,3	Beryllium fluoride; beryllium and beryllium compounds
2,3	Beryllium nitrate; beryllium and beryllium compounds
3	BGE; n-butyl glycidyl ether
2,3,4	BHC; hexachlorocyclohexane
3,4	Bidrin; 3-hydroxy N,N-dimethyl-cis-crotonamide dimethyl phosphate
3	Bismuth telluride; tellurium compounds
3	Bromoethane; ethyl bromide
3	Bromoethylene; vinyl bromide
3	Bromomethane; methyl bromide
3	Butanol; butyl alcohol
2,3	2-Butenal propylene aldehyde; crotonaldehyde
2,3	cis-Butenedioic anhydride; maleic anhydride
3	1-Butoxy-2,3-epoxypropane; n-butyl glycidyl ether
3	2-Butoxyethanol; ethylene glycol monobutyl ether
3	Butyl cellosolve; ethylene glycol monobutyl ether
3	di-tert-Butyl chromate; chromic, chromous, and chromate salts
3	tert-Butyl chromate; chromic, chromous, and chromate salts
2,3	n-Butyl phthalate; phthalate esters
2	Cadmium acetate; cadmium and cadmium compounds
2	Cadmium bromide; cadmium and cadmium compounds
1,2	Cadmium chloride; cadmium and cadmium compounds
2,3	Calcium arsenate; arsenic and arsenic compounds
2	Calcium arsenite; arsenic and arsenic compounds
1,2	Calcium chromate; chromic, chromous, and chromate salts
3	Calcium cyanamide; cyanamide
2,4	Calcium cyanide; cyanides, inorganic salts
2,3,4	Carbomethoxy-1-propen-2-yl dimethyl phosphate; alpha-2-carbomethoxy-1-methylvinyl dimethyl phosphate
2,3,4	Carbon bisulfide; carbon disulfide
2,3	Carbonyl chloride; phosgene
3	Carbonyl fluoride; fluoride and inorganic fluoride compounds
3	Caustic soda; sodium hydroxide
3	Cellosolve; ethylene glycol monoethyl ether
3	Cellosolve acetate; ethyene glycol monoethyl ether acetate
1	Chlordecone; kepone
1,2,3,4	Chlorinated camphene; toxaphene
1	Chlornaphazine; N,N-bis(2-chloroethyl)-2-naphthylamine
2,3	Chlorobenzene; chlorinated benzenes
3	Chlorobromomethane; bromochloromethane

LIST OF SYNONYMS

SOURCE	SUBSTANCE
2,3	1,2-Diaminoethane; ethylenediamine
1	ortho-Dianisidine; 3,3'-dimethoxybenzidine
2,3	Dibenzanthracenes; polynuclear aromatic hydrocarbons
3	Dibenzothiazine; phenothiazine
2,3	Dibrom; 0,0-dimethyl 0-(1,2-dibromo-2,2-dichloroethyl) phosphate
1,2,3,4	1,2-Dibromoethane; ethylene dibromide
2,3	Dibutyl phthalate; phthalate esters
2,3	Dichlorobenzenes; chlorinated benzenes
1,3	3,3'-Dichlorobenzidine; dichlorobenzidene (and its salts)
2,4	1,1-Dichloro-2,2-bis(p-chlorophenyl) ethane; TDE
3	1,1-Dichloroethane; ethylidene chloride
1,2,3,4	1,2-Dichloroethane; ethylene dichloride
2,3	1,2-Dichloroethylene; acetylene dichloride
2,3	1,1 Dichloroethylene; vinylidene choride
3	Dichloroethyl ether; chloroalkyl ethers
1	β,β'-Dichloroethyl sulfide; mustard gas
3	Dichloromethane; methylene chloride
2	Dichloronaphthoquinone; dichlone
2,3,4	2,4-Dichlorophenoxyacetic acid; 2,4-D
4	3,4-Dichloropropionanilide; propanil
2,3	2,2-Dichlorovinyl dimethyl phosphate; dichlorvos
1,3	1,4-Diethylene dioxide; p-dioxane
3	Diethyl ether; ethyl ether
2,3,4	0,0-Diethyl S-2-(ethylthio)ethyl phosphorodithioate; disulfoton
3,4	0,0-S-Diethyl S-(ethylthio)methyl phosphorodithioate; phorate
3	Di-(2-ethylhexyl)phthalate; phthalate esters
2,3	0,0-Diethyl 0-(2-isopropyl-6-methyl-4-pyrimidinyl) phosphorothioate; diazinon
2,3,4	0,0-Diethyl 0-(p-nitrophenyl)phosphorothioate; parathion
3	Diethyl phthalate; phthalate esters
3	Difolatan; captafol
2,3	meta-Dihydroxybenzene; resorcinol
3	p-Dihydroxybenzene; hydroquinone
3	Diisopropyl ether; isopropyl ether
3	Dimethoxymethane; methylal
3	Dimethylaminobenzene; xylidine
2,3	Dimethylbenzene; xylene, all isomers
3	1,3-Dimethylbutyl acetate; sec-hexyl acetate
2,3	0,0-Dimethyl S-(1,2-dicarboethoxyethyl) phosphorodithioate; malathion
3	Dimethylenimine; ethyleneimine
3	0,0-Dimethyl 0-(2-(ethylthio)-ethyl) phosphorothioate and 0,0-Dimethyl S-(2-(ethylthio)-ethyl) phosphoro thioate mixture; methyl demeton
3	2,6-Dimethyl-4-heptanone; diisobutyl ketone
3	Dimethyl ketone; acetone
2,3,4	0,0-Dimethyl 0-(p-nitrophenyl) phosphorothioate; methyl parathion

LIST OF SYNONYMS

SOURCE	SUBSTANCE
3	2-Chloro-1,3-butadiene; chloroprene
1,2,3	Chlorodiphenyl; polychlorobiphenyls
2,3	1-Chloro-2,3,-epoxypropane; epichlorohydrin
3	Chloroethane; ethyl chloride
3	2-Chloroethanol; ethylene chlorohydrin
1,2,3	Chloroethylene; vinyl chloride
2,3	bis(2-Chloroethyl)ether; chloroalkyl ethers
2,3	Chloroformyl chloride; phosgene
3	Chloromethane; methyl chloride
3	di-Chloromethyl ether; chloroalkyl ethers
3	1-Chloro-4-nitrobenzene; p-nitrochlorobenzene
2,3	alpha-Chlorotoluene; benzyl chloride
2	Chromic acetate; chromic, chromous, and chromate salts
2,3	Chromic acid; chromic, chromous, and chromate salts
2	Chromic sulfate; chromic, chromous, and chromate salts
3	Chromium metal; chromium
2	Chromous chloride; chromic, chromous, and chromate salts
2,3	Chrysenes; polynuclear aromatic hydrocarbons
3,4	Compound 1080; sodium fluoroacetate
3	Coyden; clopidol
3	Crag herbicide; sodium 2-(2,4-dichlorophenoxy)ethyl sulfate
3	Crufomate; 4-tert-butyl(-2-chlorophenylmethyl methylphosphoramidate
2,3	Cupric acetate; copper compounds
2,3	Cupric acetoarsenite; copper compounds
2,3	Cupric chloride; copper compounds
2,3	Cupric nitrate; copper compounds
2,3	Cupric oxalate; copper compounds
2,3	Cupric sulfate; copper compounds
2,3	Cupric sulfate, ammoniated; copper compounds
2,3	Cupric tartrate; copper compounds
2	Cyanobenzene; benzonitrile
2,3	Cythion; malathion
3,4	Dasanit; 0,0-dimethyl 0-[4-(methylsulfinyl) phenyl] phosphorothioate
2,4	DDD; TDE
2	DDE; 1,1-dichloro-2,2-bis(p-chlorophenyl)-ethylene
2,3	DDVP; dichlorvos
4	DEF; S,S,S tributyl phosphorotrithioate
3,4	Delnav; 2,3-p-dioxanedithiol S,S-bis (0,0-diethyl-phosphorodithioate
3	DGE; diglycidyl ether
3	Diacetone alcohol; 4-hydroxy-4-methyl-2-pentanone
1,2,3	4,4'-Diaminobiphenyl; benzidine (and its salts)
3	4,4'-Diamino-3,3'-dichlorobiphenyl; dichlorobenzidine and its salts

SOURCE	SUBSTANCE
3	n-Fluoren-2-yl-acetamide; 2-acetylamino-fluorene
3	Fluorocarbon 11; fluorotrichloromethane
3	Fluorocarbon 12; dichlorodifluoromethane
3	Fluorocarbon 21; dichloromonofluoromethane
3	Fluorocarbon 22; chlorodifluoromethane
3	Fluorocarbon 112; 1,1,2,2-tetrachloro-1,2-difluoroethane
3	Fluorocarbon 113; 1,1,2-Trichloro-1,2,2-trifluoroethane
3	Fluorocarbon 114; 1,2-dichloro-1,1,2,2,-tetrafluoroethane
4	Folex; S,S,S-tributyl phosphorotrithioite
	Freons; [see specific fluorocarbons]
4	Fundal; chlordimeform
2,3	2-Furaldehyde; furfural
4	Galecron; chlordimeform
1,2,3,4	Glycol dibromide; ethylene dibromide
2,3,4	Guthion; 0,0-Dimethyl S-[(4-oxobenzotriazino-3) methyl] phosphorodithioate
3	Halon 1301; bromotrifluoromethane
3	HDI; hexamethylene diisocyanate
2,3,4	1,4,5,6,7,8,8-heptachloro-3a,4,7,7a-tetrahydro-4,7-methanoindene and methabolites; heptachlor
3	2-Heptanone; methyl n-amyl ketone
3	3-Heptanone; ethyl butyl ketone
1	Hexachlorobenzene; chlorinated benzene
2,3,4	1,2,3,4,10,10-Hexachloro-6,7-epoxy-,1,4,4a,5,6,7,8,8a-octahydro-1,4-endo-endo-5,8-dimethanonaphthalene and methabolites; Endrin
2,3,4	1,2,3,4,10,10-Hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-1,4-endo-exo-5,8-dimethanonaphthalene; Dieldrin
2,3,4	1,2,3,4,10,10-Hexachloro-1,4,4a,5,8,8a-hexahydro-endo-1,2-exo-5,8-dimethanonaphthalene; aldrin
3	1,1,1,3,3,3-Hexafluoro-2-propanone; hexafluoroacetone
2,3,4	6,7,8,9,10,10-Hexahydro-1,5,5a,6,9,9a-hexahydro-6,9-methano-2,4,3-benzodioxathiepin-3-oxide; endosulfan
3	2-Hexanone; methyl n-butyl ketone
3	Hexone; methyl isobutyl ketone
3	Hydrogen selenide; selenium and selenium compounds
3	Hydrogenated MDI; dicyclohexylmethane-4,4'-diisocyanate
3,4	3-hydroxy-N-methyl-cis-crotonamide dimethyl phosphate; 3-(Dimethyoxy phosphinyloxy)-N-methyl-cis crotonamide

SOURCE	SUBSTANCE
1,3	N,N-Dimethylnitrosamine; N-nitrosodimethylamine
2	2,4-Dimethyl phenol; xylenol
3	Dimethylphenylamine; N,N-dimethylaniline
3	Dimethyl phthalate; phthalate esters
3	0,0-Dimethyl 0-(2,4,5-trichlorophenyl) phosphorothioate; ronnel
2,3	Dinitrobenzol; dinitrobenzenes, all isomers
2	Dinitrocresol; nitrophenols, all isomers
2	2,4-Dinitrophenol; dinitrophenols
3	Di-sec-octyl phthalate; phthalate esters
3	1,4-Dioxacyclohexane; p-dioxane
3	Diphenyl; biphenyl
1,3	Diphenylmethane diisocyanate; methylene bis (4-phenyl isocyanate)
2,3,4	Disyston; disulfoton
3	DMF; N,N-dimethylformamide
3	DMH; dimethylhydrazine (all isomers)
3	Dowtherm A; phenyl ether diphenyl (eutectic mixture), vapor
2,3	Dursban; chlorpyrifos
3	1,2-Epoxy-3-isopropoxypropane; isopropyl glycidyl ether
3	1,2-Epoxy-3-phenoxypropane; phenyl glycidyl ether
2,3	1,2-Epoxypropane; propylene oxide
3	2,3-Epoxypropanol; glycidol
3	bis(2,3-Epoxypropyl)ether; diglycidyl ether
2,3	1,2-Ethane diamine; ethylenediamine
3	Ethanenitrile; acetonitrile
3	Ethanethiol; ethyl mercaptan
3	Ethanol; ethyl alcohol
3	Ethenone; ketene
3	2-Ethoxyethanol; ethylene glycol monoethyl ether
3	2-Ethoxyethyl acetate; ethylene glycol monoethyl ether
2,3	1,1'-Ethylene-2,2'-bipyridinium ion; diquat
2,3	Ethylene trichloride; trichloroethylene
3	Ethylenimine; ethyleneimine
2,3,4	Ethyl methylene; ethion
3	Ethyl methyl ketone; 2-butanone
3,4	0-Ethyl 0-(p-nitrophenyl) phenylphosphonothioate; EPN
3	4-Ethyl-1,4-tetrahydrooxazine; N-ethylmorpholine
4	Fenamiphos; ethyl-3-methyl-4-(methylthio) phenyl(1-methylethyl)phosphoramidate
3	Fermate; ferbam
2	Ferric ammonium citrate; iron salts, soluble
2	Ferric amonium oxalate; iron salts, soluble
2	Ferric chloride; iron salts, soluble
3	Ferric N,N-dimethylthiocarbamate; ferbam
2	Ferric fluoride; iron salts, soluble
2	Ferric nitrate; iron salts, soluble
2	Ferric sulfate; iron salts, soluble
2	Ferrous ammonium sulfate; iron salts, soluble
2	Ferrous chloride; iron salts, soluble
2	Ferrous sulfate; iron salts, soluble

LIST OF SYNONYMS

SOURCE	SUBSTANCE
3	2-Methoxyethyl acetate; ethylene glycol monomethyl ether acetate
2,3	beta-Methylacrolein; crotonaldehyde
3	Methyl amyl alcohol; methyl isobutyl carbinol
2	2-Methyl-1,3-butadiene; isoprene
3	3-Methylbutanol; isoamyl alcohol
3	3-Methylbutyl acetate; amyl acetate, all isomers
3	Methyl Cellosolve; ethylene glycol monomethyl ether
3	Methyl Cellosolve acetate; ethylene glycol monomethyl ether acetate
3	Methyl cyanide; acetonitrile
3,4	2-Methyl-4,6-dinitrophenol; 4,6-dinitro-o-cresol
3	Methylene chlorobromide; bromochloromethane
3	Methyl ethyl ketone; 2-butanone
3	5-Methyl-3-heptanone; ethyl sec-amyl ketone
2,3	Methyl 2-methyl-2-propenoate; methyl methacrylate
3	4-Methyl-3-pentene-2-one; mesityl oxide
3	4-Methyl-2-pentanol; methyl isobutyl carbinol
3	4-Methyl-2-pentyl acetate; sec-hexyl acetate
3	1-Methyl-1-phenylethene; alpha- methylstyrene
3	2-Methylpropanol; isobutyl alcohol
3	2-Methypropyl acetate; butyl acetate
3	Methyl propyl ketone; 2-pentanone
3,4	1-Methyl-2-(3-pyridyl) pyrrolidine; nicotine
1,3	Methyl sulfate; dimethyl sulfate
2,3	MLT; malathion
4	Mocap; 0-ethyl S,S-dipropyl phosphorodithioate
4	Monitor; 0,S-dimethyl phosphoramidothioate
2,3	Monochlorobenzene; chlorinated benzenes
2,3	Monoethylamine; ethylamine
2,3	Monomethylamine; methylamine
3	Monomethylaniline; N-methylaniline
3	Monomethyl hydrazine; methyl hydrazine
2,3	Moxie; methoxychlor
2,3	Muriatic acid; hydrochloric acid
2,3	Naled; 0,0-dimethyl 0-(1,2-dibromo-2,2 dichloroethyl) phosphate
3	Nankor; ronnel
3	1-Naphthylamine; alpha-naphthylamine
2,3,4	1-Naphthyl N-methylcarbamate; carbaryl
3	NDI; naphthalene diisocyanate
4	Nemacur; ethyl 3-methyl-4-(methylthio)phenyl (1-methyl ethyl)phosphoramidate
2,3,4	Nialate; ethion
2	Nickel ammonium sulfate; nickel compounds
2,3	Nickel carbonyl; nickel compounds
2	Nickel chloride; nickel compounds
2	Nickel hydroxide; nickel compounds
2	Nickel nitrate; nickel compounds
1	Nickel subsulphide; nickel compounds
2	Nickel sulfate; nickel compounds
3	Nickel sulfide roasting; nickel compounds

LIST OF SYNONYMS

SOURCE	SUBSTANCE
3	IGE; isopropyl glycidyl ether
2,3	Indenopyrenes; polynuclear aromatic hydrocarbons
3	IPDI; isophorone diisocyanate
3	Isoamyl acetate; amyl acetate
3	Isobutyl acetate; butyl acetate
2	Isobutylamine; butylamine, all isomers
3	Isopropylbenzene; cumene
2,3,4	Kelthane; 1,1-bis(p-chlorophenyl)2,2,2-trichloroethanol
2,3,4	Kilmite 40; tetraethyl pyrophosphate
3	Korlan; ronnel
3,4	Lannate; S-Methyl N-[(methyl carbamoyl)-oxy] thioacetamidate
1,2	Lead acetate; lead compounds
2,3	Lead arsenate; lead componds
2	Lead chloride; lead compounds
2,3	Lead chromate; lead compounds
2	Lead fluoborate; lead compounds
2	Lead fluoride; lead compounds
2	Lead iodide; lead compounds
2	Lead nitrate; lead compounds
1	Lead phosphate; lead compounds
2	Lead stearate; lead compounds
1	Lead subacetate; lead compounds
2	Lead sulfate; lead compounds
2	Lead sulfide; lead compounds
2,3	Lead tetraethyl; lead compounds
3	Lead tetramethyl; lead compounds
2	Lead thiocyanate; lead compounds
3	Lime; calcium oxide
2,3,4	Lindane; hexachlorocyclohexane
2	Lithium chromate; chromic, chromous, and chromate salts
2,3	Mariate; methoxychlor
3	MAPP; methyl acetylene-propadiene mixture
1,3	MDI, methylene bis (4-phenyl isocyanate)
3	MEK; 2-butanone
2	Mecuric nitrate; mercury and mercury compounds
2	Mecuric sulfate; mercury and mercury compounds
2	Mercuric thiocyanate; mercury and mercury compounds
2	Mecurous nitrate; mercury and mercury compounds
3	Mesitylene; trimethylbenzene (all isomers)
2	Mesurol; mecaptodimethur
4	Methamidophos; 0,S-dimethyl phosphoramidothioate
2,3	Methanethiol; methyl mercaptan
3	Methanol; methyl alcohol
4	Methidathion; 0,0-dimethyl phosphorodithioate, S-ester with 4-(mercaptomethyl)-2-methoxy-Δ^2 1,3,4 - thiadiazolin-5-one
3	2-Methoxyethanol; ethylene glycol monomethyl ether

LIST OF SYNONYMS

SOURCE	SUBSTANCE
3	N-Serve; 2-chloro-6-(trichloromethyl) pyridine
2,3,4	Sevin; carbaryl
3	Silicon tetrahydride; silane
2	Silver nitrate; silver compounds
3,4	Silvex; 2,4,5 TP acid
2	Sodium arsenate; arsenic and arsenic compounds
2,4	Sodium arsenite; arsenic and arsenic compounds
2	Sodium bichromate; chromic, chromous, and chromate salts
2	Sodium bifluoride; fluoride and fluoride compounds
2	Sodium chromate; chromic, chromous, and chromate salts
2,4	Sodium cyanide; cyanides, inorganic salts
2	Sodium fluoride; fluoride and fluoride compounds
2	Sodium selenite; selenium and selenium compounds
4	Starlicide; 3-chloro-p-toluidine hydrochloride
3	Stibine; antimony compounds
2	Strontium chromate; chromic, chromous, and chromate salts
2,3	Sulfur chloride; sulfur monochloride
2	Sulfuric chlorohydrin; chlorosulfonic acid
4	Surpracide; 0,0-dimethyl phosphorodithioate, S-ether with 4-(mercaptomethyl)-2-methoxy-Δ2-1,3,4-thiadiazolin-5-one
3,4	Systox; demeton
4	Tamaron; 0,S-dimethyl phosphoramidothioate
2	TCDD; 2,3,7,8-tetrachlorodibenzo-p-dioxin
3	TCP; tri-o-cresyl phosphate
3	TDI; toluene-2,4-diisocyanate
3	TEDP; tetraethyl dithionopyrophosphate
3	Teflon, decomposition products; polytetrafluoroethylene, decomposition products
3	Tellurium hexafluoride; tellurium compounds
2,3,4	TEPP; tetraethyl pyrophosphate
3	1,1,2,2-Tetrabromomethane; acetylene tetrabromide
3	Tetrabromoethane; carbon tetrabromide
3	1,1,2,2-Tetrachloroethane; acetylene tetrachoride
2,3	Tetrachloroethylene; perchloroethylene
1,2,3,4	Tetrachloromethane; carbon tetrachloride
2,3	Tetraethyl lead; lead compounds
3	Tetraethyl silicate; ethyl silicate
3	Tetrahydro-4H-1-4-oxazine; morpholine
3	Tetramethyl lead; lead compounds
3	Tetramethyl silicate; methyl silicate
3	Tetramethyl thiuran disulfide; bis(dimethylthiocarbamoyl)disulfide
2	Thallium sulfate; thallium compounds
3	THF; tetrahydrofuran
3,4	Thimet, phorate
2,3,4	Thiodan; endosulfan
1	Thiotepa; Tris(1-aziridinyl)phosphine sulphide
3	Thiram; bis(dimethylthiocarbamyl)disulfide

LIST OF SYNONYMS

SOURCE	SUBSTANCE
2,3,4	Niran; parathion
3	Nitrogen tetroxide; nitrogen dioxide
3,4	Nitrotrichloromethane; chloropicrin
1,2,3,4	Octachlorocamphene; toxaphene
2,3,4	1,2,4,5,6,7,8,8-Octachloro 3a,4,7,7a-tetrahydro-4,7-methanoindane; chlordane
4	OMPA; schradan
3,4	Paraquat(dichloride); paraquat
3,4	Paraquat bis(methyl sulfate); paraquat
3	PCB; polychlorobiphenyls
2,3	PCP; pentachlorophenol
2,3	Perchlorocyclopentadiene; hexachlorocyclopentadiene
3	Perchloroethane; hexachloroethane
3	Perchloryl fluoride; fluoride and inorganic fluoride compounds
3	PGE; phenyl glycidyl ether
3	Phenacyl chloride; alpha-chloroacetophenone
3	n-Phenylaniline; diphenylamine
3	Phenylbenzene; biphenyl
2	Phenyl cyanide; benzonitrile
2,3	Phenylethane; ethylbenzene
2,3	Phenylethylene; styrene, monomer
2,3,4	Phosdrin; alpha-2-carbomethoxy-1-methylvinyl dimethyl phosphate
2,3,4	Phosphorodithioate; ethion
2,3	Phospothion; malathion
3	Pival; 2-Pivalyl-1,3-indandione
3	Plictram; tin compounds
2	Potassium arsenate; arsenic and arsenic compounds
2	Potassium arsenite; arsenic and arsenic compounds
2	Potassium bichromate; chromic, chromous, and chromate salts
2	Potassium chromate; chromic, chromous, and chromate salts
2	Potassium cyanide; cyanides, inorganic salts
2,3	Propylene dichloride; dichloropropanes
1,3	Propyleneimine; 2-methylaziridine
3	Propyne; methylacetylene
3	Propyn-1-ol; propargyl alcohol
3	Pyrocatechol; catechol
2,3	Pyromucic aldehyde; furfural
3	Rattack; 1-(1-naphthyl)-2-thiourea
3	RDX; cyclotrimethylenetrinitramine
3	Rouge; iron oxide
2,3	Santobrite; pentachlorophenol
3	Selenium hexafluoride; selenium compounds and selenium compounds
2	Selenium oxide; selenium compounds and selenium compounds

SOURCE	SUBSTANCE
3	TNT; 2,4,6-trinitrotoluene
4	Tok; 2,4-dichlorophenyl-p-nitrophenyl ether
3	o-Toluidine; o-methylaniline
2,3	Toluol; toluene
4	Torak; dialifor
3,4	Tordon; picloram
3	TPP; triphenyl phosphate
3	Tribromomethane; bromoform
3	1,2,4-Trichlorobenzene; chlorinated benzene
2,3	1,1,1-Trichloro-2,2-bis(p-chlorophenyl)ethane; DDT
3	1,1,1-Trichloroethane; methyl chloroform
2,3	Trichloroethene; trichloroethylene
3	Trichlorofluoromethane; fluorotrichloromethane
1,2,3	Trichloromethane; chloroform
3	Trichloromethanethiol; perchloromethyl mercaptan
2,3	1,1,1-Trichloro-2,2-bis(p-methoxyphenyl) ethane; methoxychlor
3,4	Trichloronitromethane; chloropicrin
2,3,4	2,4,5-Trichlorophenoxypropionic acid; 2,4,5 TP esters
3	Tricyclohexylhydroxystanne; tin compounds
3	Trifluoromonobromomethane; bromotrifluoromethane
2,3	3,5,5-Trimethyl-2-cyclohexene-1-one; isophorone
3	2,4,6-Trinitrophenol; picric acid
3	2,4,6-Trinitrophenylmethylnitramine; tetryl
4	Trithion; carbophenothion
3	Trolene; ronnel
2	Uranyl acetate; uranium compounds
2	Uranyl nitrate; uranium compounds
2,3	Vapona; dichlorvos
2,3,4	Vapotone; tetraethyl pyrophosphate
2,3	Vinylbenzene; styrene, monomer
1,2,3,4	Vinyl cyanide; acrylonitrile
2,3,4	Weedon 638; 2,4-D
2,3	Xylol; xylene, all isomers
2	Zinc acetate; zinc compounds
2	Zinc ammonium chloride; zinc compounds
2	Zinc borate; zinc compounds
2	Zinc bromide; zinc compounds
2	Zinc carbonate; zinc compounds
2,3	Zinc chloride; zinc compounds
3	Zinc chromate; zinc compounds
2	Zinc cyanide; cyanides, inorganic salts
2	Zinc fluoride; zinc compounds
2	Zinc formate; zinc compounds

SOURCE	SUBSTANCE
2	Zinc hydrosulfite; zinc compounds
2	Zinc nitrate; zinc compounds
3	Zinc oxide fume; zinc compounds
2	Zinc phenolsulfonate; zinc compounds
2,4	Zinc phosphide; zinc compounds
2	Zinc silicofluoride; zinc compounds
3	Zinc stearate; zinc compounds
2	Zinc sulfate; zinc compounds
2	Zirconium nitrate; zirconium compounds
2	Zirconium potassium fluoride; zirconium compounds
2	Zirconium sulfate; zirconium compounds
3	Zoalene; 3,5-dinitro-o-toluamide

HAZARD EVALUATION SYSTEM AND INFORMATION SERVICE (HESIS)
(call collect) (415) 540-3014

HESIS provides workers, unions, employers, and health professionals with information about the health effects of toxic substances in the workplace and how to use such substances safely.

POISON CONTROL CENTER (415) 666-2845

The Poison Control Center offers emergency medical advice to both doctors and victims for the treatment of exposure to toxic substances.

Fire, police, and rescue personnel who are faced with emergencies involving potentially toxic substances can call the Center at (415) 666-5222 for referral to appropriate agencies for information about testing, containment, decontamination, and disposal.

RESOURCES

CAL/OSHA CONSULTATION SERVICE

The CAL/OSHA Consultation Service can assist employers who have questions about their responsibilities under the Hazardous Substances Information and Training Act and related CAL/OSHA standards.

Information.....Toll-free (800) 652-1476

HEADQUARTERS

San Francisco....525 Golden Gate Ave. 94102 (415) 557-2870

FIELD OFFICES

Downey.....8535 E. Florence Ave. 90240 (213) 861-9993
Fresno.....3374 E. Shields Ave. 93726 (209) 445-5072
Panorama City.....14547 Titus St. 91402 (213) 786-3870
Sacramento.....2424 Arden Way 95825 (916) 920-6131
San Bernardino.....303 W. Third St. 92401 (714) 383-4567
San Diego.....6151 Fairmount Ext. 92120 (619) 280-5304
San Francisco....455 Golden Gate Ave. 94102 (415) 557-1034

DIVISION OF OCCUPATIONAL SAFETY AND HEALTH

Workers who have questions about their rights under the Hazardous Substances Information and Training Act and related CAL/OSHA standards, including their right to see and copy Material Safety Data Sheets, can contact CAL/OSHA's EMPLOYEE EDUCATION unit at (415) 557-2037.

Workers who want to make a complaint alleging failure of an employer to abide by the provisions of this law, can contact any office of the Division of Occupational Safety and Health.

DISTRICT OFFICES

Bakersfield.....4800 Stockdale Hwy. 93309 (805) 395-2718
Berkeley.....1625 Shattuck Ave. 94709 (415) 540-3030
El Monte.....3415 Fletcher Ave. 91731 (213) 575-6960
Fresno.....2550 Mariposa St. 93721 (209) 445-5302
Long Beach.....245 West Broadway 90802 (213) 595-8477
Los Angeles.....3460 Wilshire Blvd. 90010 (213) 736-3041
Modesto.....1800 Coffee Rd. 95355 (209) 576-6260
Oakland.....1111 Jackson St. 94607 (415) 464-1300
Panorama City.....8155 Van Nuys Blvd. 91402 (213) 782-1800
Redding.....1421 Court St. 96001 (916) 246-6571
Sacramento.....2422 Arden Way 95825 (916) 920-6123
San Bernardino.....303 W. Third St. 92401 (714) 383-4321
San Diego.....7807 Convoy Court 92111 (619) 237-7325
San Francisco....455 Golden Gate Ave. 94102 (415) 557-1677
San Jose...100 Paseo de San Antonio 95113 (408) 277-1260
Santa Ana.....28 Civic Center Plaza 92701 (714) 558-4141
Santa Barbara.....3704 State St. 93105 (805) 682-2578
Santa Fe Springs 14111 E. Freeway Dr. 90670 (213) 802-1711
Santa Rosa.....50 D St. 95404 (707) 576-2388
Vernon.....2833 Leonis Blvd. 90058 (213) 589-5848

Occupational Medicine: Principles and Practical Applications
by C. Zenz
Yearbook Medical Publishers, Inc., Chicago, IL

Chemical Hazards of the Workplace, by N. Proctor and J. Hughes
J.B. Lippincott Company, Philadelphia, PA

Hazardous and Toxic Effects of Industrial Chemicals, by M. Sittig
Noyes Data Corp., Park Ridge, NJ

Fire Protection Guide on Hazardous Materials
National Fire Protection Association, 470 Atlantic Avenue, Boston, MA 02210

NIOSH/OSHA Occupational Health Guidelines for Chemical Hazards
January 1981. DHHS (NIOSH) Publication No. 81-123 for sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402

REFERENCES

For detailed chemical, physical, and toxicological information which can be used to prepare Material Safety Data Sheets (MSDS) or supplement the information contained in MSDS, the following are some useful resources which can be found in most large medical or public health libraries:

Condensed Chemical Dictionary, by A. and E. Rose
Reinhold Publishing Corporation. 450 West 33rd Street, New York, NY 10001

The Merck Index: An Encyclopedia of Chemicals and Drugs
Merck and Company, Inc., 126 E. Lincoln Avenue, Rahway, NJ 07065

IARC Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man
Geneva: World Health Organization
International Agency for Research on Cancer, 1972-1977
(Multivolume work)

American Industrial Hygiene Association Hygienic Guides
American Industrial Hygiene Association
475 Wolf Ledges Parkway, Akron, OH 44311-1087

Industrial Hygiene and Toxicology, by F.A. Patty
John Wiley & Sons, Inc., New York, NY (Five volumes)

Toxicology: The Basic Science of Poisons, by Louis J. Casarett and John Doull
Macmillan Publishing Co., Inc., New York, NY

Industrial Toxicology, by Alice Hamilton and Harriet L. Hardy
Publishing Sciences Group, Inc., Acton, MA

Toxicology of the Eye, by W. Morton Grant, Charles C. Thomas, Springfield, MO

Handbook of Chemistry and Physics
Chemical Rubber Company, 18901 Cranwood Parkway, Cleveland, OH 44128

Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes
American Conference of Governmental Industrial Hygienists, 1014 Broadway, Cincinnati, OH 45202

Dangerous Properties of Industrial Materials, by N. Irving Sax
Reinhold Publishing Corporation, 450 West 33rd Street, New York, NY 10001

(5) Tributaries of waters identified in paragraphs (i)(1)-(4) of this section, including adjacent wetlands; and

(6) Wetlands adjacent to waters identified in paragraphs (i)(1)-(5) of this section ("Wetlands" means those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally included playa lakes, swamps, marshes, bogs, and similar areas such as sloughs, prairie potholes, wet meadows, prairie river overflows, mudflats, and natural ponds): *Provided*, That waste treatment systems (other than cooling ponds meeting the criteria of this paragraph) are not waters of the United States.

(j) "Process waste water" means any water which, during manufacturing or processing, comes into direct contact with or results from the production or use of any raw material, intermediate product, finished product, byproduct, or waste product.

§ 117.2 Abbreviations.

NPDES equals National Pollutant Discharge Elimination System. RQ equals reportable quantity.

§ 117.3 Determination of reportable quantities.

The quantity listed with each substance in Table 117.3 is determined to be the reportable quantity for that substance.

TABLE 117.3—REPORTABLE QUANTITIES OF HAZARDOUS SUBSTANCES

NOTE: The first number under the column headed "RQ" is the reportable quantity in pounds. The number in parentheses is the metric equivalent in kilograms. For convenience, the table contains a column headed "Category" which lists the code letters "X", "A", "B", "C" and "D" associated with reportable quantities of 1, 10, 100, 1000 and 5000 pounds respectively.

Material	Category	RQ in pounds (kilograms)
Acetaldehyde	C	1,000 (454)
Acetic acid	C	1,000 (454)
Acetic anhydride	C	1,000 (454)
Acetone cyanohydrin	A	10 (4.54)
Acetyl bromide	D	5,000 (2,270)
Acetyl chloride	D	5,000 (2,270)
Acrolein	X	1 (0.454)
Acrylonitrile	B	100 (45.4)
Adipic acid	D	5,000 (2,270)
Aldrin	X	1 (0.454)
Allyl alcohol	B	100 (45.4)
Allyl chloride	C	1,000 (454)
Aluminum sulfate	D	5,000 (2,270)
Ammonia	B	100 (45.4)
Ammonium acetate	D	5,000 (2,270)
Ammonium benzoate	D	5,000 (2,270)
Ammonium bicarbonate	D	5,000 (2,270)
Ammonium bichromate	C	1,000 (454)
Ammonium bifluoride	D	5,000 (2,270)
Ammonium bisulfite	D	5,000 (2,270)
Ammonium carbamate	D	5,000 (2,270)
Ammonium carbonate	D	5,000 (2,270)
Ammonium chloride	D	5,000 (2,270)
Ammonium chromate	C	1,000 (454)
Ammonium citrate	D	5,000 (2,270)
Ammonium fluoborate	D	5,000 (2,270)
Ammonium fluoride	D	5,000 (2,270)
Ammonium hydroxide	C	1,000 (454)
Ammonium oxalate	D	5,000 (2,270)
Ammonium silicofluoride	C	1,000 (454)
Ammonium sulfamate	D	5,000 (2,270)
Ammonium sulfide	D	5,000 (2,270)
Ammonium sulfite	D	5,000 (2,270)
Ammonium tartrate	D	5,000 (2,270)
Ammonium thiocyanate	D	5,000 (2,270)
Ammonium thiosulfate	D	5,000 (2,270)
Amyl acetate	C	1,000 (454)
Aniline	C	1,000 (454)
Antimony pentachloride	C	1,000 (454)
Antimony potassium tartrate	C	1,000 (454)
Antimony tribromide	C	1,000 (454)
Antimony trichloride	C	1,000 (454)
Antimony trifluoride	C	1,000 (454)
Antimony trioxide	D	5,000 (2,270)
Arsenic disulfide	D	5,000 (2,270)
Arsenic pentoxide	D	5,000 (2,270)
Arsenic trichloride	D	5,000 (2,270)
Arsenic trioxide	D	5,000 (2,270)
Arsenic trisulfide	D	5,000 (2,270)
Barium cyanide	A	10 (4.54)
Benzene	C	1,000 (454)
Benzoic acid	D	5,000 (2,270)
Benzonitrile	C	1,000 (454)
Benzoyl chloride	C	1,000 (454)
Benzyl chloride	B	100 (45.4)
Beryllium chloride	D	5,000 (2,270)
Beryllium fluoride	D	5,000 (2,270)
Beryllium nitrate	D	5,000 (2,270)
Butyl acetate	D	5,000 (2,270)
n-Butyl phthalate	B	100 (45.4)
Butylamine	C	1,000 (454)
Butyric acid	D	5,000 (2,270)
Cadmium acetate	B	100 (45.4)
Cadmium bromide	B	100 (45.4)
Cadmium chloride	B	100 (45.4)
Calcium arsenate	C	1,000 (454)
Calcium arsenite	C	1,000 (454)
Calcium carbide	D	5,000 (2,270)
Calcium chromate	C	1,000 (454)
Calcium cyanide	A	10 (4.54)
Calcium dodecylbenzenesulfonate	C	1,000 (454)
Calcium hypochlorite	B	100 (45.4)
Captan	A	10 (4.54)
Carbaryl	B	100 (45.4)

ATTACHMENT 2

CODE OF FEDERAL REGULATIONS

Protection of Environment

40

PARTS 100 to 149

Revised as of July 1, 1983

CONTAINING
A CODIFICATION OF DOCUMENTS
OF GENERAL APPLICABILITY
AND FUTURE EFFECT

AS OF JULY 1, 1983

With Ancillaries

Published by
the Office of the Federal Register
National Archives and Records Service
General Services Administration

as a Special Edition of
the Federal Register

Material	Category	RQ in pounds (kilograms)
Carbofuran	A	10 (4.54)
Carbon disulfide	D	5,000 (2,270)
Carbon tetrachloride	D	5,000 (2,270)
Chlordane	X	1 (0.454)
Chlorine	A	10 (4.54)
Chlorobenzene	B	100 (45.4)
Chloroform	D	5,000 (2,270)
Chlorpyrifos	X	1 (0.454)
Chlorosulfonic acid	C	1,000 (454)
Chromic acetate	C	1,000 (454)
Chromic acid	C	1,000 (454)
Chromic sulfate	C	1,000 (454)
Chromous chloride	C	1,000 (454)
Cobaltous bromide	C	1,000 (454)
Cobaltous formate	C	1,000 (454)
Cobaltous sulfamate	C	1,000 (454)
Coumaphos	A	10 (4.54)
Cresol	C	1,000 (454)
Crotonal dehyde	B	100 (45.4)
Cupric acetate	B	100 (45.4)
Cupric acetoarsenite	B	100 (45.4)
Cupric chloride	A	10 (4.54)
Cupric nitrate	B	100 (45.4)
Cupric oxalate	B	100 (45.4)
Cupric sulfate	A	10 (4.54)
Cupric sulfate ammoniated	B	100 (45.4)
Cupric tartrate	B	100 (45.4)
Cyanogen chloride	A	10 (4.54)
Cyclohexane	C	1,000 (454)
2,4-D Acid	B	100 (45.4)
2,4-D Esters	B	100 (45.4)
DDT	X	1 (0.454)
Diazinon	X	1 (0.454)
Dicamba	C	1,000 (454)
Dichlobenil	C	1,000 (454)
Dichlone	X	1 (0.454)
Dichlorobenzene	B	100 (45.4)
Dichloropropane	D	5,000 (2,270)
Dichloropropene	D	5,000 (2,270)
Dichloropropene-Dichloropropane Mixture.	D	5,000 (2,270)
2,2-Dichloropropionic acid	D	5,000 (2,270)
Dichlorvos	A	10 (4.54)
Dieldrin	X	1 (0.454)
Diethylamine	C	1,000 (454)
Dimethylamine	C	1,000 (454)
Dinitrobenzene	C	1,000 (454)
Dinitrophenol	C	1,000 (454)
Dinitrotoluene	C	1,000 (454)
Diquat	C	1,000 (454)
Disulfoton	X	1 (0.454)
Diuron	B	100 (45.4)
Dodecylbenzenesulfonic acid	C	1,000 (454)
Endosulfan	X	1 (0.454)
Endrin	X	1 (0.454)
Epichlorohydrin	C	1,000 (454)
Ethion	A	10 (4.54)
Ethylbenzene	C	1,000 (454)
Ethylenediamine	C	1,000 (454)
Ethylene dibromide	C	1,000 (454)
Ethylene dichloride	D	5,000 (2,270)
EDTA	D	5,000 (2,270)
Ferric ammonium citrate	C	1,000 (454)
Ferric ammonium oxalate	C	1,000 (454)
Ferric chloride	C	1,000 (454)
Ferric fluoride	B	100 (45.4)
Ferric nitrate	C	1,000 (454)
Ferric sulfate	C	1,000 (454)
Ferrous ammonium sulfate	C	1,000 (454)
Ferrous chloride	B	100 (45.4)
Ferrous sulfate	C	1,000 (454)
Formaldehyde	C	1,000 (454)
Formic acid	D	5,000 (2,270)
Fumaric acid	D	5,000 (2,270)
Furfural	C	1,000 (454)
Guthion	X	1 (0.454)
Heptachlor	X	1 (0.454)
Hexachlorocyclopentadiene	X	1 (0.454)
Hydrochloric acid	D	5,000 (2,270)
Hydrofluoric acid	D	5,000 (2,270)
Hydrogen cyanide	A	10 (4.54)
Hydrogen sulfide	B	100 (45.4)
Isoprene	C	1,000 (454)
Isopropanolamine dodecylbenzenesulfonate.	C	1,000 (454)
Kelthane	D	5,000 (2,270)
Kepone	X	1 (0.454)
Lead acetate	D	5,000 (2,270)
Lead arsenate	D	5,000 (2,270)
Lead chloride	D	5,000 (2,270)
Lead fluoborate	D	5,000 (2,270)
Lead fluoride	C	1,000 (454)
Lead iodide	D	5,000 (2,270)
Lead nitrate	D	5,000 (2,270)
Lead stearate	D	5,000 (2,270)
Lead sulfate	D	5,000 (2,270)
Lead sulfide	D	5,000 (2,270)
Lead thiocyanate	D	5,000 (2,270)
Lindane	X	1 (0.454)
Lithium chromate	C	1,000 (454)
Malathion	A	10 (4.54)
Maleic acid	D	5,000 (2,270)
Maleic anhydride	D	5,000 (2,270)
Mercaptodimethur	B	100 (45.4)
Mercuric cyanide	X	1 (0.454)
Mercuric nitrate	A	10 (4.54)
Mercuric sulfate	A	10 (4.54)
Mercuric thiocyanate	A	10 (4.54)
Mercurous nitrate	A	10 (4.54)
Methoxychlor	X	1 (0.454)
Methyl mercaptan	B	100 (45.4)
Methyl methacrylate	D	5,000 (2,270)
Methyl parathion	B	100 (45.4)
Mevinphos	X	1 (0.454)
Mexacarbate	C	1,000 (454)
Monoethylamine	C	1,000 (454)
Monomethylamine	C	1,000 (454)
Naled	A	10 (4.54)
Naphthalene	D	5,000 (2,270)
Naphthenic acid	B	100 (45.4)
Nickel ammonium sulfate	D	5,000 (2,270)
Nickel chloride	D	5,000 (2,270)
Nickel hydroxide	C	1,000 (454)
Nickel nitrate	D	5,000 (2,270)
Nickel sulfate	D	5,000 (2,270)
Nitric acid	C	1,000 (454)
Nitrobenzene	C	1,000 (454)
Nitrogen dioxide	C	1,000 (454)
Nitrophenol	C	1,000 (454)
Nitrotoluene	C	1,000 (454)
Paraformaldehyde	C	1,000 (454)
Parathion	X	1 (0.454)
Pentachlorophenol	A	10 (4.54)
Phenol	C	1,000 (454)
Phosgene	D	5,000 (2,270)
Phosphoric acid	D	5,000 (2,270)
Phosphorus	X	1 (0.454)
Phosphorus oxychloride	D	5,000 (2,270)
Phosphorus pentasulfide	B	100 (45.4)
Phosphorus trichloride	D	5,000 (2,270)
Polychlorinated biphenyls	A	10 (4.54)
Potassium arsenate	C	1,000 (454)
Potassium arsenite	C	1,000 (454)
Potassium bichromate	C	1,000 (454)

Material	Category	RQ in pounds (kilograms)
Potassium chromate	C	1,000 (454)
Potassium cyanide	A	10 (4.54)
Potassium hydroxide	C	1000 (454)
Potassium permanganate	B	100 (45.4)
Propargite	A	10 (4.54)
Propionic acid	D	5,000 (2,270)
Propionic anhydride	D	5,000 (2,270)
Propylene oxide	D	5,000 (2,270)
Pyrethrins	C	1,000 (454)
Quinoline	C	1,000 (454)
Resorcinol	C	1,000 (454)
Selenium oxide	C	1,000 (454)
Silver nitrate	X	1 (0.454)
Sodium	C	1,000 (454)
Sodium arsenate	C	1,000 (454)
Sodium arsenite	C	1,000 (454)
Sodium bichromate	C	1,000 (454)
Sodium bifluoride	D	5,000 (2,270)
Sodium bisulfite	D	5,000 (2,270)
Sodium chromate	C	1,000 (454)
Sodium cyanide	A	10 (4.54)
Sodium dodecylbenzenesulfonate.	C	1,000 (454)
Sodium fluoride	D	5,000 (2,270)
Sodium hydrosulfide	D	5,000 (2,270)
Sodium hydroxide	C	1,000 (454)
Sodium hypochlorite	B	100 (45.4)
Sodium methylate	C	1,000 (454)
Sodium nitrite	B	100 (45.4)
Sodium phosphate, dibasic	D	5,000 (2,270)
Sodium phosphate, tribasic	D	5,000 (2,270)
Sodium selenite	C	1,000 (454)
Strontium chromate	C	1,000 (454)
Strychnine	A	10 (4.54)
Styrene	C	1,000 (454)
Sulfuric acid	C	1,000 (454)
Sulfur monochloride	C	1,000 (454)
2,4,5-T acid	B	100 (45.4)
2,4,5-T amines	B	100 (45.4)
2,4,5-T esters	B	100 (45.4)
2,4,5-T salts	B	100 (45.4)
2,4,5-TP acid	B	100 (45.4)
2,4,5-TP acid esters	B	100 (45.4)
TDE	X	1 (0.454)
Tetraethyl lead	B	100 (45.4)
Tetraethyl pyrophosphate	B	100 (45.4)
Thallium sulfate	C	1,000 (454)
Toluene	C	1,000 (454)
Toxaphene	X	1 (0.454)
Trichlorfon	C	1,000 (454)
Trichloroethylene	C	1,000 (454)
Trichlorophenol	A	10 (4.54)
Triethanolamine dodecylbenzenesulfonate.	C	1,000 (454)
Triethylamine	D	5,000 (2,270)
Trimethylamine	C	1,000 (454)
Uranyl acetate	D	5,000 (2,270)
Uranyl nitrate	D	5,000 (2,270)
Vanadium pentoxide	C	1,000 (454)
Vanadyl sulfate	C	1,000 (454)
Vinyl acetate	C	1,000 (454)
Vinylidene chloride	D	5,000 (2,270)
Xylene	C	1,000 (454)
Xylenol	C	1,000 (454)
Zinc acetate	C	1,000 (454)
Zinc ammonium chloride	D	5,000 (2,270)
Zinc borate	C	1,000 (454)
Zinc bromide	D	5,000 (2,270)
Zinc carbonate	C	1,000 (454)
Zinc chloride	D	5,000 (2,270)
Zinc cyanide	A	10 (4.54)
Zinc fluoride	C	1,000 (454)
Zinc formate	C	1,000 (454)
Zinc hydrosulfite	C	1,000 (454)
Zinc nitrate	D	5,000 (2,270)
Zinc phenolsulfonate	D	5,000 (2,270)
Zinc phosphide	C	1,000 (454)
Zinc silicofluoride	D	5,000 (2,270)
Zinc sulfate	C	1,000 (454)
Zirconium nitrate	D	5,000 (2,270)
Zirconium potassium fluoride	D	5,000 (2,270)
Zirconium sulfate	D	5,000 (2,270)
Zirconium tetrachloride	D	5,000 (2,270)

[44 FR 50776, Aug. 29, 1979, as amended at 44 FR 58712, Oct. 11, 1979; 44 FR 65400, Nov. 13, 1979]

Subpart B—Applicability

§ 117.11 General applicability.

This regulation sets forth a determination of the reportable quantity for each substance designated as hazardous in 40 CFR Part 116. The regulation applies to quantities of designated substances equal to or greater than the reportable quantities, when discharged into or upon the navigable waters of the United States, adjoining shorelines, into or upon the contiguous zone, or beyond the contiguous zone as provided in section 311(b)(3) of the Act, except to the extent that the owner or operator can show such that discharges are made:

(a) In compliance with a permit issued under the Marine Protection, Research and Sanctuaries Act of 1972 (33 U.S.C. 1401 et seq.);

(b) In compliance with approved water treatment plant operations as specified by local or State regulations pertaining to safe drinking water;

(c) Pursuant to the label directions for application of a pesticide product registered under section 3 or section 24 of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), as amended (7 U.S.C. 136 et seq.), or pursuant to the terms and conditions of an experimental use permit issued under section 5 of FIFRA, or pursuant to an exemption granted under section 18 of FIFRA;

(d) In compliance with the regulations issued under section 3004 or with permit conditions issued pursuant to section 3005 of the Resource Conserva-

Industry and EPA hazardous waste No.	Hazardous waste	Hazard code
Inorganic pigments:		
K002	Wastewater treatment sludge from the production of chrome yellow and orange pigments.	(T)
K003	Wastewater treatment sludge from the production of molybdate orange pigments	(T)
K004	Wastewater treatment sludge from the production of zinc yellow pigments	(T)
K005	Wastewater treatment sludge from the production of chrome green pigments	(T)
K006	Wastewater treatment sludge from the production of chrome oxide green pigments (anhydrous and hydrated).	(T)
K007	Wastewater treatment sludge from the production of iron blue pigments	(T)
K008	Oven residue from the production of chrome oxide green pigments	(T)
Organic chemicals:		
K009	Distillation bottoms from the production of acetaldehyde from ethylene	(T)
K010	Distillation side cuts from the production of acetaldehyde from ethylene	(T)
K011	Bottom stream from the wastewater stripper in the production of acrylonitrile	(R, T)
K013	Bottom stream from the acetonitrile column in the production of acrylonitrile	(R, T)
K014	Bottoms from the acetonitrile purification column in the production of acrylonitrile	(T)
K015	Still bottoms from the distillation of benzyl chloride	(T)
K016	Heavy ends or distillation residues from the production of carbon tetrachloride	(T)
K017	Heavy ends (still bottoms) from the purification column in the production of epichlorohydrin	(T)
K018	Heavy ends from the fractionation column in ethyl chloride production	(T)
K019	Heavy ends from the distillation of ethylene dichloride in ethylene dichloride production.	(T)
K020	Heavy ends from the distillation of vinyl chloride in vinyl chloride monomer production.	(T)
K021	Aqueous spent antimony catalyst waste from fluoromethanes production	(T)
K022	Distillation bottom tars from the production of phenol/acetone from cumene	(T)
K023	Distillation light ends from the production of phthalic anhydride from naphthalene	(T)
K024	Distillation bottoms from the production of phthalic anhydride from naphthalene	(T)
K093	Distillation light ends from the production of phthalic anhydride from ortho-xylene	(T)
K094	Distillation bottoms from the production of phthalic anhydride from ortho-xylene	(T)
K025	Distillation bottoms from the production of nitrobenzene by the nitration of benzene	(T)
K026	Stripping still tails from the production of methy ethyl pyridines	(T)
K027	Centrifuge and distillation residues from toluene diisocyanate production	(R, T)
K028	Spent catalyst from the hydrochlorinator reactor in the production of 1,1,1-trichloroethane.	(T)
K029	Waste from the product steam stripper in the production of 1,1,1-trichloroethane	(T)
K095	Distillation bottoms from the production of 1,1,1-trichloroethane	(T)
K096	Heavy ends from the heavy ends column from the production of 1,1,1-trichloroethane.	(T)
K030	Column bottoms or heavy ends from the combined production of trichloroethylene and perchloroethylene.	(T)
K083	Distillation bottoms from aniline production	(T)
K103	Process residues from aniline extraction from the production of aniline	(T)
K104	Combined wastewater streams generated from nitrobenzene/aniline production	(T)
K085	Distillation or fractionation column bottoms from the production of chlorobenzenes	(T)
K105	Separated aqueous stream from the reactor product washing step in the production of chlorobenzenes.	(T)
Inorganic chemicals:		
K071	Brine purification muds from the mercury cell process in chlorine production, where separately prepurified brine is not used.	(T)
K073	Chlorinated hydrocarbon waste from the purification step of the diaphragm cell process using graphite anodes in chlorine production.	(T)
K106	Wastewater treatment sludge from the mercury cell process in chlorine production	(T)
Pesticides:		
K031	By-product salts generated in the production of MSMA and cacodylic acid	(T)
K032	Wastewater treatment sludge from the production of chlordane	(T)
K033	Wastewater and scrub water from the chlorination of cyclopentadiene in the production of chlordane.	(T)
K034	Filter solids from the filtration of hexachlorocyclopentadiene in the production of chlordane	(T)
K097	Vacuum stripper discharge from the chlordane chlorinator in the production of chlordane.	(T)
K035	Wastewater treatment sludges generated in the production of creosote	(T)
K036	Still bottoms from toluene reclamation distillation in the production of disulfoton	(T)
K037	Wastewater treatment sludges from the production of disulfoton	(T)
K038	Wastewater from the washing and stripping of phorate production	(T)
K039	Filter cake from the filtration of diethylphosphorodithioic acid in the production of phorate	(T)
K040	Wastewater treatment sludge from the production of phorate	(T)
K041	Wastewater treatment sludge from the production of toxaphene	(T)
K098	Untreated process wastewater from the production of toxaphene	(T)

ardous Waste Number which precedes the name of the waste. This number must be used in complying with the notification requirements of Section 3010 of the Act and certain recordkeeping and reporting requirements under Parts 262 through 265 and Part 270 of this chapter.

(d) The following hazardous wastes listed in § 261.31 or § 261.32 are subject to the exclusion limits for acutely hazardous wastes established in § 261.5: [Reserved]

[45 FR 33119, May 19, 1980, as amended at 45 FR 74892, Nov. 12, 1980; 48 FR 14294, Apr. 1, 1983]

§ 261.31 Hazardous wastes from non-specific sources.

Industry and EPA hazardous waste No.	Hazardous waste	Hazard code
Generic:		
F001	The following spent halogenated solvents used in degreasing: tetrachloroethylene, trichloroethylene, methylene chloride, 1,1,1-trichloroethane, carbon tetrachloride, and chlorinated fluorocarbons; and sludges from the recovery of these solvents in degreasing operations.	(T)
F002	The following spent halogenated solvents: tetrachloroethylene, methylene chloride, trichloroethylene, 1,1,1-trichloroethane, chlorobenzene, 1,1,2-trichloro-1,2,2-trifluoroethane, ortho-dichlorobenzene, and trichlorofluoromethane; and the still bottoms from the recovery of these solvents.	(T)
F003	The following spent non-halogenated solvents: xylene, acetone, ethyl acetate, ethyl benzene, ethyl ether, methyl isobutyl ketone, n-butyl alcohol, cyclohexanone, and methanol; and the still bottoms from the recovery of these solvents.	(I)
F004	The following spent non-halogenated solvents: cresols and cresylic acid, and nitrobenzene; and the still bottoms from the recovery of these solvents.	(T)
F005	The following spent non-halogenated solvents: toluene, methyl ethyl ketone, carbon disulfide, isobutanol, and pyridine; and the still bottoms from the recovery of these solvents.	(I, T)
F006	Wastewater treatment sludges from electroplating operations except from the following processes: (1) sulfuric acid anodizing of aluminum; (2) tin plating on carbon steel; (3) zinc plating (segregated basis) on carbon steel; (4) aluminum or zinc-aluminum plating on carbon steel; (5) cleaning/stripping associated with tin, zinc and aluminum plating on carbon steel; and (6) chemical etching and milling of aluminum.	(T)
F019	Wastewater treatment sludges from the chemical conversion coating of aluminum	(T)
F007	Spent cyanide plating bath solutions from electroplating operations (except for precious metals electroplating spent cyanide plating bath solutions).	(R, T)
F008	Plating bath sludges from the bottom of plating baths from electroplating operations where cyanides are used in the process (except for precious metals electroplating plating bath sludges).	(R, T)
F009	Spent stripping and cleaning bath solutions from electroplating operations where cyanides are used in the process (except for precious metals electroplating spent stripping and cleaning bath solutions).	(R, T)
F010	Quenching bath sludge from oil baths from metal heat treating operations where cyanides are used in the process (except for precious metals heat-treating quenching bath sludges).	(R, T)
F011	Spent cyanide solutions from salt bath pot cleaning from metal heat treating operations (except for precious metals heat treating spent cyanide solutions from salt bath pot cleaning).	(R, T)
F012	Quenching wastewater treatment sludges from metal heat treating operations where cyanides are used in the process (except for precious metals heat treating quenching wastewater treatment sludges).	(T)

[46 FR 4617, Jan. 16, 1981, as amended at 46 FR 27477, May 20, 1981]

§ 261.32 Hazardous wastes from specific sources.

Industry and EPA hazardous waste No.	Hazardous waste	Hazard code
Wood preservation: K001	Bottom sediment sludge from the treatment of wastewaters from wood preserving processes that use creosote and/or pentachlorophenol.	(T)

ATTACHMENT 3

(d) Any residue or contaminated soil, water or other debris resulting from the cleanup of a spill into or on any land or water of any commercial chemical product or manufacturing chemical intermediate having the generic name listed in paragraph (e) or (f) of this section, or any residue or contaminated soil, water or other debris resulting from the cleanup of a spill, into or on any land or water, of any off-specification chemical product and manufacturing chemical intermediate which, if it met specifications, would have the generic name listed in paragraph (e) or (f) of this section.

[*Comment:* The phrase "commercial chemical product or manufacturing chemical intermediate having the generic name listed in . . ." refers to a chemical substance which is manufactured or formulated for commercial or manufacturing use which consists of the commercially pure grade of the chemical, any technical grades of the chemical that are produced or marketed, and all formulations in which the chemical is the sole active ingredient. It does not refer to a material, such as a manufacturing process waste, that contains any of the substances listed in paragraphs (e) or (f). Where a manufacturing process waste is deemed to be a hazardous waste because it contains a substance listed in paragraphs (e) or (f), such waste will be listed in either §§ 261.31 or 261.32 or will be identified as a hazardous waste by the characteristics set forth in Subpart C of this part.]

(e) The commercial chemical products, manufacturing chemical intermediates or off-specification commercial chemical products or manufacturing chemical intermediates referred to in paragraphs (a) through (d) of this section, are identified as acute hazardous wastes (H) and are subject to be the small quantity exclusion defined in § 261.5(e).

[*Comment:* For the convenience of the regulated community the primary hazardous properties of these materials have been indicated by the letters T (Toxicity), and R (Reactivity). Absence of a letter indicates that the compound only is listed for acute toxicity.]

These wastes and their corresponding EPA Hazardous Waste Numbers are:

Hazardous waste No.	Substance
P023	Acetaldehyde, chloro-
P002	Acetamide, N-(aminothioxomethyl)-
P057	Acetamide, 2-fluoro-
P058	Acetic acid, fluoro-, sodium salt
P066	Acetimidic acid, N-[(methylcarbamoyl)oxy]thio-, methyl ester
P001	3-(alpha-acetonylbenzyl)-4-hydroxycoumarin and salts
P002	1-Acetyl-2-thiourea
P003	Acrolein
P070	Aldicarb
P004	Aldrin
P005	Allyl alcohol
P006	Aluminum phosphide
P007	5-(Aminomethyl)-3-isoxazolol
P008	4-aAminopyridine
P009	Ammonium picrate (R)
P119	Ammonium vanadate
P010	Arsenic acid
P012	Arsenic (III) oxide
P011	Arsenic (V) oxide
P011	Arsenic pentoxide
P012	Arsenic trioxide
P038	Arsine, diethyl-
P054	Aziridine
P013	Barium cyanide
P024	Benzenamine, 4-chloro-
P077	Benzenamine, 4-nitro-
P028	Benzene, (chloromethyl)-
P042	1,2-Benzenediol, 4-[1-hydroxy-2-(methylamino)ethyl]-
P014	Benzenethiol
P028	Benzyl chloride
P015	Beryllium dust
P016	*Bis(chloromethyl) ether*
P017	Bromoacetone
P018	Brucine
P021	Calcium cyanide
P123	Camphene, octachloro-
P103	Carbamimidoselenoic acid
P022	Carbon bisulfide
P022	Carbon disulfide
P095	Carbonyl chloride
P033	Chlorine cyanide
P023	Chloroacetaldehyde
P024	p-Chloroaniline
P026	1-(o-Chlorophenyl)thiourea
P027	3-Chloropropionitrile
P029	Copper cyanides
P030	Cyanides (soluble cyanide salts), not elsewhere specified
P031	Cyanogen
P033	Cyanogen chloride
P036	Dichlorophenylarsine
P037	Dieldrin
P038	Diethylarsine
P039	O,O-Diethyl S [2-(ethylthio)ethyl] phosphorodithioate
P041	Diethyl-p-nitrophenyl phosphate
P040	O,O-Diethyl O-pyrazinyl phosphorothioate
P043	Diisopropyl fluorophosphate
P044	Dimethoate
P045	3,3-Dimethyl-1-(methylthio)-2-butanone, O-[(methylamino)carbonyl] oxime
P071	O,O-Dimethyl O-p-nitrophenyl phosphorothioate
P082	Dimethylnitrosamine
P046	alpha, alpha-Dimethylphenethylamine
P047	4,6-Dinitro-o-cresol and salts
P034	4,6-Dinitro-o-cyclohexylphenol
P048	2,4-Dinitrophenol
P020	Dinoseb

Industry and EPA hazardous waste No.	Hazardous waste	Haz cod
K042	Heavy ends or distillation residues from the distillation of tetrachlorobenzene in the production of 2,4,5-T.	(T)
K043	2,6-Dichlorophenol waste from the production of 2,4-D	(T)
K099	Untreated wastewater from the production of 2,4-D	(T)
Explosives:		
K044	Wastewater treatment sludges from the manufacturing and processing of explosives	(R)
K045	Spent carbon from the treatment of wastewater containing explosives	(R)
K046	Wastewater treatment sludges from the manufacturing, formulation and loading of lead-based initiating compounds.	(T)
K047	Pink/red water from TNT operations	(R)
Petroleum refining:		
K048	Dissolved air flotation (DAF) float from the petroleum refining industry	(T)
K049	Slop oil emulsion solids from the petroleum refining industry	(T)
K050	Heat exchanger bundle cleaning sludge from the petroleum refining industry	(T)
K051	API separator sludge from the petroleum refining industry	(T)
K052	Tank bottoms (leaded) from the petroleum refining industry	(T)
Iron and steel:		
K061	Emission control dust/sludge from the primary production of steel in electric furnaces.	(T)
K062	Spent pickle liquor from steel finishing operations	(C, T)
Secondary lead:		
K069	Emission control dust/sludge from secondary lead smelting.	(T)
K100	Waste leaching solution from acid leaching of emission control dust/sludge from secondary lead smelting.	(T)
Veterinary pharmaceuticals.		
K084	Wastewater treatment sludges generated during the production of veterinary pharmaceuticals from arsenic or organo-arsenic compounds.	(T)
K101	Distillation tar residues from the distillation of aniline-based compounds in the production of veterinary pharmaceuticals from arsenic or organo-arsenic compounds.	(T)
K102	Residue from the use of activated carbon for decolorization in the production of veterinary pharmaceuticals from arsenic or organo-arsenic compounds.	(T)
Ink formulation: K086	Solvent washes and sludges, caustic washes and sludges, or water washes and sludges from cleaning tubs and equipment used in the formulation of ink from pigments, driers, soaps, and stabilizers containing chromium and lead.	(T)
Coking:		
K060	Ammonia still lime sludge from coking operations	(T)
K087	Decanter tank tar sludge from coking operations	(T)

[46 FR 4618, Jan. 16, 1981, as amended at 46 FR 27476-27477, May 20, 1981]

§ 261.33 Discarded commercial chemical products, off-specification species, container residues, and spill residues thereof.

The following materials or items are hazardous wastes if and when they are discarded or intended to be discarded:

(a) Any commercial chemical product, or manufacturing chemical intermediate having the generic name listed in paragraph (e) or (f) of this section.

(b) Any off-specification commercial chemical product or manufacturing chemical intermediate which, if it met specifications, would have the generic name listed in paragraph (e) or (f) of this section.

(c) Any residue remaining in a container or an inner liner removed from a container that has held any commercial chemical product or manufacturing chemical intermediate having tl generic name listed in paragraph (e) this section, unless the container *empty as defined in § 261.7(b)(3)* this chapter.

[*Comment:* Unless the residue is being bei ficially used or reused, or legitimately re cled or reclaimed; or being accumulat stored, transported or treated prior to su use, re-use, recycling or reclamation, El considers the residue to be intended for d card, and thus a hazardous waste. An exa ple of a legitimate re-use of the resid would be where the residue remains in t container and the container is used to hc the same commerical chemical product manufacturing chemical product or mar facturing chemical intermediate it previo ly held. An example of the discard of t residue would be where the drum is sent a drum reconditioner who reconditions t drum but discards the residue.]

Hazardous waste No.	Substance
P118	Trichloromethanethiol
P119	Vanadic acid, ammonium salt
P120	Vanadium pentoxide
P120	Vanadium(V) oxide
P001	Warfarin
P121	Zinc cyanide
P122	Zinc phosphide (R,T)

(f) The commercial chemical products, manufacturing chemical intermediates, or off-specification commercial chemical products referred to in paragraphs (a) through (d) of this section, are identified as toxic wastes (T) unless otherwise designated and are subject to the small quantity exclusion defined in § 261.5 (a) and (f).

[*Comment:* For the convenience of the regulated community, the primary hazardous properties of these materials have been indicated by the letters T (Toxicity), R (Reactivity), I (Ignitability) and C (Corrosivity). Absence of a letter indicates that the compound is only listed for toxicity.]

These wastes and their corresponding EPA Hazardous Waste Numbers are:

Hazardous Waste No.	Substance
U001	Acetaldehyde (I)
U034	Acetaldehyde, trichloro-
U197	*Acetamide, N-(4-ethoxyphenyl)-*
U005	Acetamide, N-9H-fluoren-2-yl-
U112	Acetic acid, ethyl ester (I)
U144	Acetic acid, lead salt
U214	Acetic acid, thallium(I) salt
U002	Acetone (I)
U003	Acetonitrile (I,T)
U004	Acetophenone
U005	2-Acetylaminofluorene
U006	Acetyl chloride (C,R,T)
U007	Acrylamide
U008	Acrylic acid (I)
U009	Acrylonitrile
U150	Alanine, 3-[p-bis(2-chloroethyl)amino] phenyl-, L-
U011	Amitrole
U012	Aniline (I,T)
U014	Auramine
U015	Azaserine
U010	Azirino(2',3':3,4)pyrrolo(1,2-a)indole-4,7-dione, 6-amino-8-[((aminocarbonyl) oxy)methyl]-1,1a,2,8,8a,8b-hexahydro-8a-methoxy-5-methyl-,
U157	Benz[j]aceanthrylene, 1,2-dihydro-3-methyl-
U016	Benz[c]acridine
U016	*3,4-Benzacridine*
U017	Benzal chloride
U018	Benz[a]anthracene
U018	1,2-Benzanthracene
U094	1,2-Benzanthracene, 7,12-dimethyl-
U012	Benzenamine (I,T)

Hazardous Waste No.	Substance
U014	Benzenamine, 4,4'-carbonimidoylbis(N,N-dimethyl-
U049	Benzenamine, 4-chloro-2-methyl-
U093	Benzenamine, N,N-dimethyl-4-phenylazo-
U158	Benzenamine, 4,4'-methylenebis(2-chloro-
U222	Benzenamine, 2-methyl-, hydrochloride
U181	Benzenamine, 2-methyl-5-nitro
U019	Benzene (I,T)
U038	Benzeneacetic acid, 4-chloro-alpha-(4-chlorophenyl)-alpha-hydroxy, ethyl ester
U030	Benzene, 1-bromo-4-phenoxy-
U037	Benzene, chloro-
U190	1,2-Benzenedicarboxylic acid anhydride
U028	1,2-Benzenedicarboxylic acid, [bis(2-ethylhexyl)] ester
U069	1,2-Benzenedicarboxylic acid, dibutyl ester
U088	1,2-Benzenedicarboxylic acid, diethyl ester
U102	1,2-Benzenedicarboxylic acid, dimethyl ester
U107	1,2-Benzenedicarboxylic acid, di-n-octyl ester
U070	Benzene, 1,2-dichloro-
U071	Benzene, 1,3-dichloro-
U072	Benzene, 1,4-dichloro-
U017	Benzene, (dichloromethyl)-
U223	Benzene, 1,3-diisocyanatomethyl- (R,T)
U239	Benzene, dimethyl- (I,T)
U201	1,3-Benzenediol
U127	Benzene, hexachloro-
U056	Benzene, hexahydro- (I)
U188	Benzene, hydroxy-
U220	*Benzene, methyl-*
U105	Benzene, 1-methyl-1-2,4-dinitro-
U106	Benzene, 1-methyl-2,6-dinitro-
U203	Benzene, 1,2-methylenedioxy-4-allyl-
U141	Benzene, 1,2-methylenedioxy-4-propenyl-
U090	Benzene, 1,2-methylenedioxy-4-propyl-
U055	Benzene, (1-methylethyl)- (I)
U169	Benzene, nitro- (I,T)
U183	Benzene, pentachloro-
U185	Benzene, pentachloro-nitro-
U020	Benzenesulfonic acid chloride (C,R)
U020	Benzenesulfonyl chloride (C,R)
U207	Benzene, 1,2,4,5-tetrachloro-
U023	Benzene, (trichloromethyl)-(C,R,T)
0234	Benzene, 1,3,5-trinitro- (R,T)
U021	Benzidine
U202	1,2-Benzisothiazolin-3-one, 1,1-dioxide
U120	Benzo[j,k]fluorene
U022	Benzo[a]pyrene
U022	3,4-Benzopyrene
U197	p-Benzoquinone
U023	Benzotrichloride (C,R,T)
U050	1,2-Benzphenanthrene
U085	2,2'-Bioxirane (I,T)
U021	(1,1'-Biphenyl)-4,4'-diamine
U073	(1,1'-Biphenyl)-4,4'-diamine, 3,3'-dichloro-
U091	(1,1'-Biphenyl)-4,4'-diamine, 3,3'-dimethoxy-
U095	(1,1'-Biphenyl)-4,4'-diamine, 3,3'-dimethyl-
U024	Bis(2-chloroethoxy) methane
U027	Bis(2-chloroisopropyl) ether
U244	Bis(dimethylthiocarbamoyl) disulfide
U028	Bis(2-ethylhexyl) phthalate
U246	Bromine cyanide
U225	Bromoform
U030	4-Bromophenyl phenyl ether
U128	1,3-Butadiene, 1,1,2,3,4,4-hexachloro-
U172	1-Butanamine, N-butyl-N-nitroso-
U035	*Butanoic acid, 4-[Bis(2-chloroethyl)amino] benzene-*
U031	1-Butanol (I)
U159	2-Butanone (I,T)
U160	2-Butanone peroxide (R,T)
U053	2-Butenal

Hazardous waste No.	Substance
P085	Diphosphoramide, octamethyl-
P039	Disulfoton
P049	2,4-Dithiobiuret
P109	Dithiopyrophosphoric acid, tetraethyl ester
P050	Endosulfan
P088	Endothall
P051	Endrin
P042	Epinephrine
P046	Ethanamine, 1,1-dimethyl-2-phenyl-
P084	Ethenamine, N-methyl-N-nitroso-
P101	Ethyl cyanide
P054	Ethylenimine
P097	Famphur
P056	Fluorine
P057	Fluoroacetamide
P058	Fluoroacetic acid, sodium salt
P065	Fulminic acid, mercury(II) salt (R,T)
P059	Heptachlor
P051	1,2,3,4,10,10-Hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-endo,endo-1,4:5,8-dimethanonaphthalene
P037	1,2,3,4,10,10-Hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-endo,exo-1,4:5,8-dimethanonaphthalene
P060	1,2,3,4,10,10-Hexachloro-1,4,4a,5,8,8a-hexahydro-1,4:5,8-endo, endo-dimethanonaphthalene
P004	1,2,3,4,10,10-Hexachloro-1,4,4a,5,8,8a-*hexahydro-1,4:5,8-endo,exo-*dimethanonaphthalene
P060	Hexachlorohexahydro-exo,exo-dimethanonaphthalene
P062	Hexaethyl tetraphosphate
P116	Hydrazinecarbothioamide
P068	Hydrazine, methyl-
P063	Hydrocyanic acid
P063	Hydrogen cyanide
P096	Hydrogen phosphide
P064	Isocyanic acid, methyl ester
P007	3(2H)-Isoxazolone, 5-(aminomethyl)-
P092	Mercury, (acetato-O)phenyl-
P065	Mercury fulminate (R,T)
P016	Methane, oxybis(chloro-
P112	Methane, tetranitro- (R)
P118	Methanethiol, trichloro-
P059	4,7-Methano-1H-indene, 1,4,5,6,7,8,8-heptachloro-3a,4,7,7a-tetrahydro-
P066	Methomyl
P067	2-Methylaziridine
P068	Methyl hydrazine
P064	Methyl isocyanate
P069	2-Methyllactonitrile
P071	Methyl parathion
P072	alpha-Naphthylthiourea
P073	Nickel carbonyl
P074	Nickel cyanide
P074	Nickel(II) cyanide
P073	Nickel tetracarbonyl
P075	Nicotine and salts
P076	Nitric oxide
P077	p-Nitroaniline
P078	Nitrogen dioxide
P076	Nitrogen(II) oxide
P078	Nitrogen(IV) oxide
P081	Nitroglycerine (R)
P082	N-Nitrosodimethylamine
P084	N-Nitrosomethylvinylamine
P050	5-Norbornene-2,3-dimethanol, 1,4,5,6,7,7-hexachloro, cyclic sulfite
P085	Octamethylpyrophosphoramide
P087	Osmium oxide
P087	Osmium tetroxide

Hazardous waste No.	Substance
P088	7-Oxabicyclo[2.2.1]heptane-2,3-dicarboxylic acid
P089	Parathion
P034	Phenol, 2-cyclohexyl-4,6-dinitro-
P048	Phenol, 2,4-dinitro-
P047	Phenol, 2,4-dinitro-6-methyl-
P020	Phenol, 2,4-dinitro-6-(1-methylpropyl)-
P009	Phenol, 2,4,6-trinitro-, ammonium salt (R)
P036	Phenyl dichloroarsine
P092	Phenylmercuric acetate
P093	N-Phenylthiourea
P094	Phorate
P095	Phosgene
P096	Phosphine
P041	Phosphoric acid, diethyl p-nitrophenyl ester
P044	Phosphorodithioic acid, O,O-dimethyl S-[2-*(methylamino)-2-oxoethyl]ester*
P043	Phosphorofluoric acid, bis(1-methylethyl)-ester
P094	Phosphorothioic acid, O,O-diethyl S-(ethylthio)methyl ester
P089	Phosphorothioic acid, O,O-diethyl O-(p-nitrophenyl) ester
P040	Phosphorothioic acid, O,O-diethyl O- pyrazinyl ester
P097	Phosphorothioic acid, O,O-dimethyl O-[p-((dimethylamino)-sulfonyl)phenyl]ester
P110	Plumbane, tetraethyl-
P098	*Potassium cyanide*
P099	Potassium silver cyanide
P070	Propanal, 2-methyl-2-(methylthio)-, O-[(methylamino)carbonyl]oxime
P101	Propanenitrile
P027	Propanenitrile, 3-chloro-
P069	Propanenitrile, 2-hydroxy-2-methyl-
P081	1,2,3-Propanetriol, trinitrate- (R)
P017	2-Propanone, 1-bromo-
P102	Propargyl alcohol
P003	2-Propenal
P005	2-Propen-1-ol
P067	1,2-Propylenimine
P102	2-Propyn-1-ol
P008	4-Pyridinamine
P075	Pyridine, (S)-3-(1-methyl-2-pyrrolidinyl)-, and salts
P111	Pyrophosphoric acid, tetraethyl ester
P103	Selenourea
P104	Silver cyanide
P105	Sodium azide
P106	Sodium cyanide
P107	Strontium sulfide
P108	Strychnidin-10-one, and salts
P018	Strychnidin-10-one, 2,3-dimethoxy-
P108	*Strychnine and salts*
P115	Sulfuric acid, thallium(I) salt
P109	Tetraethyldithiopyrophosphate
P110	Tetraethyl lead
P111	Tetraethylpyrophosphate
P112	Tetranitromethane (R)
P062	Tetraphosphoric acid, hexaethyl ester
P113	Thallic oxide
P113	Thallium(III) oxide
P114	Thallium(I) selenite
P115	Thallium(I) sulfate
P045	Thiofanox
P049	Thioimidodicarbonic diamide
P014	Thiophenol
P116	Thiosemicarbazide
P026	Thiourea, (2-chlorophenyl)-
P072	Thiourea, 1-naphthalenyl-
P093	Thiourea, phenyl-
P123	Toxaphene

13-128 O—83——25

Hazardous Waste No.	Substance
U122	Formaldehyde
U123	Formic acid (C,T)
U124	Furan (I)
U125	2-Furancarboxaldehyde (I)
U147	2,5-Furandione
U213	Furan, tetrahydro- (I)
U125	Furfural (I)
U124	Furfuran (I)
U206	D-Glucopyranose, 2-deoxy-2(3-methyl-3-nitrosoureido)-
U126	Glycidylaldehyde
U163	Guanidine, N-nitroso-N-methyl-N'nitro-
U127	Hexachlorobenzene
U128	Hexachlorobutadiene
U129	Hexachlorocyclohexane (gamma isomer)
U130	Hexachlorocyclopentadiene
U131	Hexachloroethane
U132	Hexachlorophene
U243	Hexachloropropene
U133	Hydrazine (R,T)
U086	Hydrazine, 1,2-diethyl-
U098	Hydrazine, 1,1-dimethyl-
U099	Hydrazine, 1,2-dimethyl-
U109	Hydrazine, 1,2-diphenyl-
U134	Hydrofluoric acid (C,T)
U134	Hydrogen fluoride (C,T)
U135	Hydrogen sulfide
U096	Hydroperoxide, 1-methyl-1-phenylethyl- (R)
U136	Hydroxydimethylarsine oxide
U116	2-Imidazolidinethione
U137	Indeno[1,2,3-cd]pyrene
U139	Iron dextran
U140	Isobutyl alcohol (I,T)
U141	Isosafrole
U142	Kepone
U143	Lasiocarpine
U144	Lead acetate
U145	Lead phosphate
U146	Lead subacetate
U129	Lindane
U147	Maleic anhydride
U148	Maleic hydrazide
U149	Malononitrile
U150	Melphalan
U151	Mercury
U152	Methacrylonitrile (I,T)
U092	Methanamine, N-methyl- (I)
U029	Methane, bromo-
U045	Methane, chloro- (I,T)
U046	Methane, chloromethoxy-
U068	Methane, dibromo-
U080	Methane, dichloro-
U075	Methane, dichlorodifluoro-
U138	Methane, iodo-
U119	Methanesulfonic acid, ethyl ester
U211	Methane, tetrachloro-
U121	Methane, trichlorofluoro-
U153	Methanethiol (I,T)
U225	Methane, tribromo-
U044	Methane, trichloro-
U121	Methane, trichlorofluoro-
U123	Methanoic acid (C,T)
U036	4,7-Methanoindan, 1,2,4,5,6,7,8,8-octachloro-3a,4,7,7a-tetrahydro-
U154	Methanol (I)
U155	Methapyrilene
U247	Methoxychlor
U154	Methyl alcohol (I)
U029	Methyl bromide
U186	1-Methylbutadiene (I)
U045	Methyl chloride (I,T)
U156	Methyl chlorocarbonate (I,T)

Hazardous Waste No.	Substance
U226	Methylchloroform
U157	3-Methylcholanthrene
U158	4,4'-Methylenebis(2-chloroaniline)
U132	2,2'-Methylenebis(3,4,6-trichlorophenol)
U068	Methylene bromide
U080	Methylene chloride
U122	Methylene oxide
U159	Methyl ethyl ketone (I,T)
U160	Methyl ethyl ketone peroxide (R,T)
U138	Methyl iodide
U161	Methyl isobutyl ketone (I)
U162	Methyl methacrylate (I,T)
U163	N-Methyl-N'-nitro-N-nitrosoguanidine
U161	4-Methyl-2-pentanone (I)
U164	Methylthiouracil
U010	Mitomycin C
U059	5,12-Naphthacenedione, (8S-cis)-8-acetyl-10-[(3-amino-2,3,6-trideoxy-alpha-L-lyxohexopyranosyl)oxy]-7,8,9,10-tetrahydro-6,8,11-trihydroxy-1-methoxy-
U165	Naphthalene
U047	Naphthalene, 2-chloro-
U166	1,4-Naphthalenedione
U236	2,7-Naphthalenedisulfonic acid, 3,3'-[(3,3'-dimethyl-[1,1'-biphenyl]-4,4'diyl)]-bis(azo)bis(5-amino-4-hydroxy)-,tetrasodium salt
U166	1,4,Naphthaquinone
U167	1-Naphthylamine
U168	2-Naphthylamine
U167	alpha-Naphthylamine
U168	beta-Naphthylamine
U026	2-Naphthylamine, N,N'-bis(2-chloromethyl)-
U169	Nitrobenzene (I,T)
U170	p-Nitrophenol
U171	2-Nitropropane (I)
U172	N-Nitrosodi-n-butylamine
U173	N-Nitrosodiethanolamine
U174	N-Nitrosodiethylamine
U111	N-Nitroso-N-propylamine
U176	N-Nitroso-N-ethylurea
U177	N-Nitroso-N-methylurea
U178	N-Nitroso-N-methylurethane
U179	N-Nitrosopiperidine
U180	N-Nitrosopyrrolidine
U181	5-Nitro-o-toluidine
U193	1,2-Oxathiolane, 2,2-dioxide
U058	2H-1,3,2-Oxazaphosphorine, 2-[bis(2-chloroethyl)amino]tetrahydro-, oxide 2-
U115	Oxirane (I,T)
U041	Oxirane, 2-(chloromethyl)-
U182	Paraldehyde
U183	Pentachlorobenzene
U184	Pentachloroethane
U185	Pentachloronitrobenzene
U242	Pentachlorophenol
U186	1,3-Pentadiene (I)
U187	Phenacetin
U188	Phenol
U048	Phenol, 2-chloro-
U039	Phenol, 4-chloro-3-methyl-
U081	Phenol, 2,4-dichloro-
U082	Phenol, 2,6-dichloro-
U101	Phenol, 2,4-dimethyl-
U170	Phenol, 4-nitro-
U242	Phenol, pentachloro-
U212	Phenol, 2,3,4,6-tetrachloro-
U230	Phenol, 2,4,5-trichloro-
U231	Phenol, 2,4,6-trichloro-
U137	1,10-(1,2-phenylene)pyrene
U145	Phosphoric acid, lead salt

Hazardous Waste No.	Substance
U074	2-Butene, 1,4-dichloro- (I,T)
U031	n-Butyl alchohol (I)
U136	Cacodylic acid
U032	Calcium chromate
U238	Carbamic acid, ethyl ester
U178	Carbamic acid, methylnitroso-, ethyl ester
U176	Carbamide, N-ethyl-N-nitroso-
U177	Carbamide, N-methyl-N-nitroso-
U219	Carbamide, thio-
U097	Carbamoyl chloride, dimethyl-
U215	Carbonic acid, dithallium(I) salt
U156	Carbonochloridic acid, methyl ester (I,T)
U033	Carbon oxyfluoride (R,T)
U211	Carbon tetrachloride
U033	Carbonyl fluoride (R,T)
U034	Chloral
U035	Chlorambucil
U036	Chlordane, technical
U026	Chlornaphazine
U037	Chlorobenzene
U039	4-Chloro-m-cresol
U041	1-Chloro-2,3-epoxypropane
U042	2-Chloroethyl vinyl ether
U044	Chloroform
U046	Chloromethyl methyl ether
U047	beta-Chloronaphthalene
U048	o-Chlorophenol
U049	4-Chloro-o-toluidine, hydrochloride
U032	Chromic acid, calcium salt
U050	Chrysene
U051	Creosote
U052	Cresols
U052	Cresylic acid
U053	Crotonaldehyde
U055	Cumene (I)
U246	Cyanogen bromide
U197	1,4-Cyclohexadienedione
U056	Cyclohexane (I)
U057	Cyclohexanone (I)
U130	1,3-Cyclopentadiene, 1,2,3,4,5,5-hexa- chloro-
U058	Cyclophosphamide
U240	2,4-D, salts and esters
U059	Daunomycin
U060	DDD
U061	DDT
U142	Decachlorooctahydro-1,3,4-metheno-2H-cyclobuta[c,d]-pentalen-2-one
U062	Diallate
U133	Diamine (R,T)
U221	Diaminotoluene
U063	Dibenz[a,h]anthracene
U063	1,2:5,6-Dibenzanthracene
U064	1,2:7,8-Dibenzopyrene
U064	Dibenz[a,i]pyrene
U066	1,2-Dibromo-3-chloropropane
U069	Dibutyl phthalate
U062	S-(2,3-Dichloroallyl) diisopropylthiocarbamate
U070	o-Dichlorobenzene
U071	m-Dichlorobenzene
U072	p-Dichlorobenzene
U073	3,3'-Dichlorobenzidine
U074	1,4-Dichloro-2-butene (I,T)
U075	Dichlorodifluoromethane
U192	3,5-Dichloro-N-(1,1-dimethyl-2-propynyl) benzamide
U060	Dichloro diphenyl dichloroethane
U061	Dichloro diphenyl trichloroethane
U078	1,1-Dichloroethylene
U079	1,2-Dichloroethylene
U025	Dichloroethyl ether
U081	2,4-Dichlorophenol
U082	2,6-Dichlorophenol

Hazardous Waste No.	Substance
U240	2,4-Dichlorophenoxyacetic acid, salts and esters
U083	1,2-Dichloropropane
U084	1,3-Dichloropropene
U085	1,2:3,4-Diepoxybutane (I,T)
U108	1,4-Diethylene dioxide
U086	N,N-Diethylhydrazine
U087	O,O-Diethyl-S-methyl-dithiophosphate
U088	Diethyl phthalate
U089	Diethylstilbestrol
U148	1,2-Dihydro-3,6-pyradizinedione
U090	Dihydrosafrole
U091	3,3'-Dimethoxybenzidine
U092	Dimethylamine (I)
U093	Dimethylaminoazobenzene
U094	7,12-Dimethylbenz[a]anthracene
U095	3,3'-Dimethylbenzidine
U096	alpha,alpha-Dimethylbenzylhydroperoxide (R)
U097	Dimethylcarbamoyl chloride
U098	1,1-Dimethylhydrazine
U099	1,2-Dimethylhydrazine
U101	2,4-Dimethylphenol
U102	Dimethyl phthalate
U103	Dimethyl sulfate
U105	2,4-Dinitrotoluene
U106	2,6-Dinitrotoluene
U107	Di-n-octyl phthalate
U108	1,4-Dioxane
U109	1,2- Diphenylhydrazine
U110	Dipropylamine (I)
U111	Di-N-propylnitrosamine
U001	Ethanal (I)
U174	Ethanamine, N-ethyl-N-nitroso-
U067	Ethane, 1,2-dibromo-
U076	Ethane, 1,1-dichloro-
U077	Ethane, 1,2-dichloro-
U114	1,2-Ethanediylbiscarbamodithioic acid
U131	Ethane, 1,1,1,2,2,2-hexachloro-
U024	Ethane, 1,1'-[methylenebis(oxy)]bis[2-chloro-
U003	Ethanenitrile (I, T)
U117	Ethane,1,1'-oxybis- (I)
U025	Ethane, 1,1'-oxybis[2-chloro-
U184	Ethane, pentachloro-
U208	Ethane, 1,1,1,2-tetrachloro-
U209	Ethane, 1,1,2,2-tetrachloro-
U218	Ethanethioamide
U247	Ethane, 1,1,1,-trichloro-2,2-bis(p-methoxyphenyl).
U227	Ethane, 1,1,2-trichloro-
U043	Ethene, chloro-
U042	Ethene, 2-chloroethoxy-
U078	Ethene, 1,1-dichloro-
U079	Ethene, trans-1,2-dichloro-
U210	Ethene, 1,1,2,2-tetrachloro-
U173	Ethanol, 2,2'-(nitrosoimino)bis-
U004	Ethanone, 1-phenyl-
U006	Ethanoyl chloride (C,R,T)
U112	Ethyl acetate (I)
U113	Ethyl acrylate (I)
U238	Ethyl carbamate (urethan)
U038	Ethyl 4,4'-dichlorobenzilate
U114	Ethylenebis(dithiocarbamic acid)
U067	Ethylene dibromide
U077	Ethylene dichloride
U115	Ethlene oxide (I,T)
U116	Ethylene thiourea
U117	Ethyl ether (I)
U076	Ethylidene dichloride
U118	Ethylmethacrylate
U119	Ethyl methanesulfonate
U139	Ferric dextran
U120	Fluoranthene

Hazardous Waste No.	Substance
U087	Phosphorodithioic acid, 0,0-diethyl-, S-methyl-ester
U189	Phosphorous sulfide (R)
U190	Phthalic anhydride
U191	2-Picoline
U192	Pronamide
U194	1-Propanamine (I,T)
U110	1-Propanamine, N-propyl- (I)
U066	Propane, 1,2-dibromo-3-chloro-
U149	Propanedinitrile
U171	Propane, 2-nitro- (I)
U027	Propane, 2,2'oxybis[2-chloro-
U193	1,3-Propane sultone
U235	1-Propanol, 2,3-dibromo-, phosphate (3:1)
U126	1-Propanol, 2,3-epoxy-
U140	1-Propanol, 2-methyl- (I,T)
U002	2-Propanone (I)
U007	2-Propenamide
U084	Propene, 1,3-dichloro-
U243	1-Propene, 1,1,2,3,3,3-hexachloro-
U009	2-Propenenitrile
U152	2-Propenenitrile, 2-methyl- (I,T)
U008	2-Propenoic acid (I)
U113	2-Propenoic acid, ethyl ester (I)
U118	2-Propenoic acid, 2-methyl-, ethyl ester
U162	2-Propenoic acid, 2-methyl-, methyl ester (I,T)
U233	Propionic acid, 2-(2,4,5-trichlorophenoxy)-
U194	n-Propylamine (I,T)
U083	Propylene dichloride
U196	Pyridine
U155	Pyridine, 2-[(2-(dimethylamino)-2-thenylamino]-
U179	Pyridine, hexahydro-N-nitroso-
U191	Pyridine, 2-methyl-
U164	4(1H)-Pyrimidinone, 2,3-dihydro-6-methyl-2-thioxo-
U180	Pyrrole, tetrahydro-N-nitroso-
U200	Reserpine
U201	Resorcinol
U202	Saccharin and salts
U203	Safrole
U204	Selenious acid
U204	Selenium dioxide
U205	Selenium disulfide (R,T)
U015	L-Serine, diazoacetate (ester)
U233	Silvex
U089	4,4'-Stilbenediol, alpha,alpha'-diethyl-
U206	Streptozotocin
U135	Sulfur hydride
U103	Sulfuric acid, dimethyl ester
U189	Sulfur phosphide (R)
U205	Sulfur selenide (R,T)
U232	2,4,5-T
U207	1,2,4,5-Tetrachlorobenzene
U208	1,1,1,2-Tetrachloroethane
U209	1,1,2,2-Tetrachloroethane
U210	Tetrachloroethylene
U212	2,3,4,6-Tetrachlorophenol
U213	Tetrahydrofuran (I)
U214	Thallium(I) acetate
U215	Thallium(I) carbonate
U216	Thallium(I) chloride
U217	Thallium(I) nitrate
U218	Thioacetamide
U153	Thiomethanol (I,T)
U219	Thiourea
U244	Thiram
U220	Toluene
U221	Toluenediamine
U223	Toluene diisocyanate (R,T)
U222	O-Toluidine hydrochloride
U011	1H-1,2,4-Triazol-3-amine
U226	1,1,1-Trichloroethane
U227	1,1,2-Trichloroethane
U228	Trichloroethene
U228	Trichloroethylene
U121	Trichloromonofluoromethane
U230	2,4,5-Trichlorophenol
U231	2,4,6-Trichlorophenol
U232	2,4,5-Trichlorophenoxyacetic acid
U234	sym-Trinitrobenzene (R,T)
U182	1,3,5-Trioxane, 2,4,5-trimethyl-
U235	Tris(2,3-dibromopropyl) phosphate
U236	Trypan blue
U237	Uracil, 5[bis(2-chloromethyl)amino]-
U237	Uracil mustard
U043	Vinyl chloride
U239	Xylene (I)
U200	Yohimban-16-carboxylic acid, 11,17-dimethoxy-18-[(3,4,5-trimethoxy-benzoyl)oxy]-, methyl ester.

[45 FR 78529, 78541, Nov. 25, 1980, as amended at 46 FR 27477, May 20, 1981]

APPENDIX I—REPRESENTATIVE SAMPLING METHODS

The methods and equipment used for sampling waste materials will vary with the form and consistency of the waste materials to be sampled. Samples collected using the sampling protocols listed below, for sampling waste with properties similar to the indicated materials, will be considered by the Agency to be representative of the waste.

Extremely viscous liquid—ASTM Standard D140-70 Crushed or powdered material—ASTM Standard D346-75 Soil or rock-like material—ASTM Standard D420-69 Soil-like material—ASTM Standard D1452-65

Fly Ash-like material—ASTM Standard D2234-76 [ASTM Standards are available from ASTM, 1916 Race St., Philadelphia, PA 19103]

Containerized liquid wastes—"COLIWASA" described in "Test Methods for the Evaluation of Solid Waste, Physical/Chemical Methods," * U.S. Environmental Protection Agency, Office of Solid Waste, Washington, D.C. 20460. [Copies may be obtained from Solid Waste Information, U.S. Environmental Protection Agency, 26 W. St. Clair St., Cincinnati, Ohio 45268]

Liquid waste in pits, ponds, lagoons, and similar reservoirs.—"Pond Sampler" described in "Test Methods for the Evaluation of Solid Waste, Physical/Chemical Methods." *

* These methods are also described in "Samplers and Sampling Procedures for Hazardous Waste Streams," EPA 600/2-80-018, January 1980.

66620. Removal of Spilled or Improperly Deposited Waste.

The Department may require the operator to remove from the disposal site and properly dispose of any extremely hazardous waste disposed of or applied on land, and any soil contacted by the waste, if the disposal or application of the waste was not consistent with the requirements of this Chapter and the conditions of the Extremely Hazardous Waste Disposal Permit issued by the Department.

66645. Recurring Disposal of Extremely Hazardous Waste.

The Department may grant a producer of an extremely hazardous waste an Extremely Hazardous Waste Disposal Permit, valid up to 12 months, that specifies approved methods for the handling and disposal of a specific extremely hazardous waste that is routinely produced.

Article 8. Fees

66670. Fees for Off-site Disposal.

(a) The operator of an off-site hazardous waste facility shall pay fees to the Department for hazardous waste which he disposes of on or into land or applies to land, based on:

(1) Manifests received at the site for hazardous wastes delivered to him other than by pipeline.

(2) Other waste disposal records maintained in accordance with Section 66550 (a) (3) for hazardous wastes delivered to him by pipeline.

(b) The operator of an off-site hazardous waste facility shall pay fees to the Department for the first 2,500 tons per month received from one specific site of one specific producer of hazardous waste. The fees, which shall be increased at a rate of 10 percent per month if not paid within 60 days of the month of disposal, shall be:

(1) One dollar for each load of hazardous waste, delivered to him other than by pipeline, which weighs one ton or less and which he disposes of on land or applies to land.

(2) One dollar for each load or one dollar per ton, whichever is greater, for each load of hazardous waste, delivered other than by pipeline, which weighs more than one ton and which is disposed of on land or is applied to land.

(3) One dollar per ton for all hazardous waste delivered to him by pipeline, based on the weight disposed of on land or applied to land.

(c) No more than $2,500 need be paid the Department for any amount of hazardous waste received from one specific site owned by a specific producer of hazardous waste during one month.

(d) If scales are not available at a hazardous waste facility, the operator shall calculate the weight of all hazardous waste disposed of based on the known or estimated volume and density of the waste or based on other measurements or estimates approved by the Department.

(e) Hazardous wastes transported on public roads and subsequently disposed of legally to sanitary sewers shall not be exempted from the disposal fees nor from the requirements of this Chapter. The sewerage agency shall send legible copies of all completed hazardous waste manifests to the Department on a monthly basis along with one dollar per ton for the wastes so disposed.

NOTE: Authority and reference cited: Section 208, Health and Safety Code.

HISTORY.

1. Amendment of subsection (a) (2) filed 5-10-79; effective thirtieth day thereafter (Register 79, No 19).

66672. Fees for On-site Disposal.

(a) The operator of an on-site hazardous waste facility shall pay a fee of one dollar per ton to the Department for the first 2,500 tons of hazardous waste which he disposes of on or into land or applies to land in any one month.

(b) No more than $2,500 need be paid the Department for any amount of hazardous waste disposed of at one specific on-site hazardous waste facility in one month.

(c) The fees shall be increased at a rate of 10 percent per month if not paid within 60 days of the month of disposal.

66674. Payment of Fees.

Fees due the Department shall be mailed to the following address:

State Department of Health
Accounting Section
Hazardous Waste Control Account
744 P Street
Sacramento, CA 95814

66676. Waiver of Fee.

(a) The operator of a hazardous waste facility shall pay the appropriate fee as required by this Article unless the Department has given the operator a written waiver of fees for disposal of that waste. The fee may be waived if it is shown to the satisfaction of the Department that the waste has been rendered nonhazardous.

(b) Requests for waiver shall be made in writing and shall include:

(1) A description of the processing method used.

(2) A chemical analysis of the waste before and after treatment.

(3) The volume of the waste before and after treatment.

(4) The volumes and compositions of any hazardous residues which are removed from the waste or which are generated as result of treatment of the waste.

(5) The method to be used for disposal of the treated waste and of any residues.

(c) The Department may obtain and analyze samples of the waste collected before and after treatment.

(d) The Department shall continue, grant or deny each request within 30 days.

(e) The Department may waive the fee for disposal of a waste for a period up to 12 months, provided the treatment and disposal method and the chemical composition of the waste do not change during that period.

Article 9. Hazardous Wastes and Hazardous Materials

66680. Lists of Chemical Names and Common Names.

(a) A waste that consists of or contains a material cited in the List of Chemical Names or the List of Common Names presented in this Article shall be considered a hazardous waste and shall be handled and disposed of according to the requirements set forth in this Chapter, unless it is shown to the satisfaction of the Department that the waste does not meet the definition of hazardous waste presented in Article 1 of this Chapter.

ATTACHMENT 4

(b) The potential hazardous property of a material cited in the List of Chemical Names or the List of Common Names is indicated in the list as follows: (T) toxic, (C) corrosive, (I) irritant, (F) flammable, (S) strong sensitizer and (P) pressure generating. An asterisk (*) in Subsection (d) denotes an extremely hazardous waste (see Article 10 of this Chapter). All letters in trademark names are capitalized.

(c) A waste that meets the definition of hazardous waste presented in Article 1 of this Chapter shall be considered a hazardous waste whether or not the waste is cited in this Article. Such a waste shall be handled and disposed of according to the requirements of this Chapter.

(d) List of Chemical Names:

1. Acetaldehyde (T,F)
2. Acetic acid (T,C)
3. Acetone, Propanone (T,F)
4. *Acetone cyanohydrin (T)
5. Acetonitrile (T,F)
6. *2-Acetylaminofluorene, 2-AAf (T)
7. Acetyl benzoyl peroxide (T,F,P)
8. Acetyl chloride (T,C,F)
9. Acetyl peroxide (T,F,P)
10. Acridine (T,C)
11. *Acrolein, Aqualin (T,I,F)
12. *Acrylonitrile (T,F)
13. *Adiponitrile (T)
14. *Aldrin; 1,2,3,4,10,10-Hexachloro-1,4,4a,5,8,8a-hexahydro-1,4,5,8-endo-exodimethanonaphthalene (T)
15. Alkyl aluminum chloride (C,F,P)
16. Alkyl aluminum compounds (C,F,P)
17. Allyl alcohol, 2-Propen-1-ol (T,F)
18. Allyl bromide, 3-Bromopropene (T,I,F)
19. Allyl chloride, 3-Chloropropene (T,I,F)
20. Allyl chlorocarbonate, Allyl Chloroformate (T,I,F)
21. Allytrichlorosilane (T,C,F)
22. Aluminum (powder) (F)
23. Aluminum chloride (T,C)
24. Aluminum fluoride (T,C)
25. Aluminum nitrate (F)
26. *Aluminum phosphide, PHOSTOXIN (T,F)
27. *4-Aminodiphenyl, 4-ADP (T)
28. *2-Aminopyridine (T)
29. *Ammonium arsenate (T)
30. *Ammonium bifluoride (T,C)
31. Ammonium chromate (T,S,F)
32. Ammonium dichromate, Ammonium bichromate (T,C,S,F)
33. Ammonium fluoride (T,C)
34. Ammonium hydroxide (T,C)
35. Ammonium molybdate (T)
36. Ammonium nitrate (F,P)

37. Ammonium perchlorate (I,F,P)
38. Ammonium permanganate (T,F,P)
39. Ammonium persulfate (F,P)
40. Ammonium picrate (T,S,P)
41. Ammonium sulfide (T,C)
42. n-Amyl acetate, 1-Acetoxypentane (and isomers) (T,F)
43. n-Amylamine, 1-Aminopentane (and isomers) (T,I,F)
44. n-Amyl chloride, 1-Chloropentane (and isomers) (T,F)
45. n-Amyl mercaptan, 1-Pentanethiol (and isomers) (T,F)
46. n-Amylene, 1-Pentene (and isomers) (T,F)
47. n-Amyl nitrate, n-Pentyl nitrite (and isomers) (T,F)
48. Amyl trichlorosilane (and isomers) (T,C)
49. Aniline, Aminobenzene (T,S)
50. Anisoyl chloride (T,C)
51. Anthracene (T,I)
52. Antimony (T)
53. Antimony compounds (T)
54. Antimony pentachloride (T,C)
55. Antimony pentafluoride (T,C)
56. Antimony pentasulfide (T,F)
57. Antimony potassium tartrate (T)
58. Antimony sulfate, Antimony trisulfate (T,F)
59. Antimony trichloride, Antimony chloride (T,C)
60. Antimony trifluoride, Antimony fluoride (T,C)
61. Antimony trioxide, Antimony oxide (T)
62. Antimony trisulfide, Antimony sulfide (T,F,P)
63. *Arsenic (T)
64. *Arsenic acid and salts (T)
65. *Arsenic compounds (T)
66. *Arsenic pentaselenide (T)
67. *Arsenic pentoxide, Arsenic oxide (T)
68. *Arsenic sulfide, Arsenic disulfide (T)
69. *Arsenic tribromide, Arsenic bromide (T,I)
70. *Arsenic trichloride, Arsenic chloride (T,I)
71. *Arsenic triiodide, Arsenic iodide (T)
72. *Arsenic trioxide, Arsenious oxide (T)
73. *Arsenious acid and salts (T)
74. *Arsines (T)
75. Asbestos (including chrysotile, amosite, crocidolite, tremolite, anthophyllite, and actinolite) (T)
76. *AZODRIN, 3-Hydroxy-N-cis-crotonamide (T)
77. Barium (T,F)
78. Barium azide (T,P)
79. Barium bromide (T)
80. Barium carbonate (T)
81. Barium chlorate (T,C,F,P)
82. Barium chloride (T)
83. Barium chromate (T)
84. Barium citrate (T)

85. Barium compounds (soluble) (T)
86. *Barium cyanide (T)
87. Barium fluoride (T)
88. Barium fluosilicate (T)
89. Barium hydroxide (T)
90. Barium iodide (T)
91. Barium manganate (T)
92. Barium nitrate (T,F)
93. Barium oxide, Barium monoxide (T,I)
94. Barium perchlorate (T,F,P)
95. Barium permanganate (T,F,P)
96. Barium peroxide (T,F,P)
97. Barium phosphate (T)
98. Barium stearate (T)
99. Barium sulfide (T)
100. Barium sulfite (T)
101. Benzene (T,F)
102. Benzene hexachloride, BHC; 1,2,3,4,5,6-Hexachlorocyclohexane (T,I)
103. Benzenephosphorous dichloride (T,I)
104. Benzenesulfonic acid (T,C)
105. *Benzidine and salts (T)
106. *Benzotrifluoride, Trifluoromethylbenzene (T,F)
107. Benzoyl chloride (T,C)
108. Benzoyl peroxide, Dibenzoyl peroxide (T,F,P)
109. Benzyl bromide, alpha-Bromotoluene (T,C)
110. Benzyl chloride, alpha-Chlorotoluene (T,I)
111. Benzyl chlorocarbonate, Benzyl chloroformate (T,C)
112. *Beryllium (T,F)
113. *Beryllium chloride (T)
114. *Beryllium compounds (T)
115. *Beryllium copper (T)
116. *Beryllium fluoride (T)
117. *Beryllium hydride (T,C,F)
118. *Beryllium hydroxide (T)
119. *Beryllium oxide (T)
120. *BIDRIN, Dicrotophos, 3-(Dimethylamino)-1-methyl-3-oxo-1-propenyl dimethyl phosphate (T)
121. *bis (Chloromethyl) ether, Dichoromethylether, BCME(T)
122. Bismuth (T,F)
123. *bis (Methylmercuric) sulfate, CEREWET, Ceresan liquid (T)
124. Bismuth chromate (T,S)
125. *BOMYL, Dimethyl 3-hydroxyglutaconate dimethyl phosphate (T)
126. *Boranes (T,F)
127. *Bordeaux arsenites (T)
128. Boron trichloride (T,C)
129. Boron trifluoride (T,C)
130. Bromic acid (T,C)
131. *Bromine (T,C,F)

132. *Bomine pentafluoride (T,C,F)
133. *Bromine trifluoride (T,C,F)
134. *Brucine, Dimethoxystrychnine (T)
135. 1,2,4-Butanetriol trinitrate (P)
136. n-Butyl acetate, 1-Acetoxybutane (and isomers) (T,I,F)
137. n-Butyl alcohol, 1-Butanol (and isomers) (T,I,F)
138. n-Butyl amine, 1-Aminobutane (and isomers) (T,I,F)
139. n-Butyl formate (and isomers) (T,I,F)
140. tert-Butyl hydroperoxide, (and isomers) (T,F)
141. n-Butyllithium (and isomers) (T,C,F)
142. n-Butyl mercaptan, 1-Butanethiol (and isomers) (T,F)
143. tert-Butyl peroxyacetate, tert-Butyl peracetate (F)
144. tert-Butyl peroxybenzoate, tert-Butyl perbenzoate (F)
145. tert-Butyl peroxypivalate (F,P)
146. n-Butyltrichlorosilane (C,F)
147. para-tert-Butyl toluene (T)
148. n-Butyraldehyde, n-Butanal (and isomers) (T,F)
149. *Cacodylic acid, Dimethylarsinic acid (T)
150. Cadmium (powder) (T,F)
151. Cadmium chloride (T)
152. Cadmium compounds (T)
153. *Cadmium cyanide (T)
154. Cadmium fluoride (T)
155. Cadmium nitrate (T,F,P)
156. Cadmium oxide (T)
157. Cadmium phosphate (T)
158. Cadmium sulfate (T)
159. Calcium (F)
160. *Calcium arsenate, PENSAL (T)
161. *Calcium arsenite (T)
162. Calcium carbide (C,F)
163. Calcium chlorate (F)
164. Calcium chlorite (F)
165. Calcium fluoride (T,I)
166. Calcium hydride (C,F)
167. Calcium hydroxide, Hydrated lime (C)
168. Calcium hypochlorite, Calcium oxychloride (T,C,F)
169. Calcium molybdate (T)
170. Calcium nitrate, Lime nitrate, Nitrocalcite (F,P)
171. Calcium oxide, Lime, Slaked Lime (C)
172. Calcium permanganate (T,I,F)
173. Calcium peroxide, Calcium dioxide (C,F)
174. Calcium phosphide (T,F)
175. Calcium resinate (F)
176. Caprylyl peroxide, Octyl peroxide (F)
177. *Carbanolate, BANOL, 2-Chloro-4,5-dimethylphenyl methylcarbamate (T)
178. Carbon disulfide, Carbon bisulfide (T,F)
179. Carbon tetrachloride, Tetrachloromethane (T)

180. *Carbophenothion, TRITHION, S[(4-Chlorophenyl) thio]methyl] O, O-diethyl phosphorodithioate (T)
181. Choral hydrate, Trichloroacetaldehyde (hydrated) (T)
182. Chlordan; 1,2,4,5,6,7,8,8-Octachloro-4,7-methoano-3a,4,7,7a-tetrahydroindane (T)
183. *Chlorfenvinphos, Compound 4072, 2-Chloro-1-(2,4-dichlorophenyl) vinyl diethyl phosphate (T)
184. *Chlorine (T,C,F)
185. *Chlorine dioxide (T,C,F,P)
186. *Chlorine pentafluoride (T,C,F,P)
187. *Chlorine trifluoride (T,C,F,P)
188. *Chloroacetaldehyde (T,F)
189. *alpha-Chloroacetophenone, Phenyl chloromethyl ketone (T,I)
190. *Chloroacetyl chloride (T,C)
191. Chlorobenzene (T,F)
192. Para-Chlorobenzoyl peroxide (F,P)
193. *ortho-Chlorobenzylidene malonitrile, OCMB (T)
194. Chloroform, Trichloromethane (T)
195. *Chloropicrin, Chlorpicrin, Trichloronitromethane (T,I)
196. Chlorosulfonic acid (T,C,F)
197. Chloro-ortho-toluidine, 2-Amino-4-chlorotoluene (T,I)
198. Chromic acid, Chromium trioxide, Chromic anhydride (T,C,F,S)
199. Chromic chloride, Chromium trichloride (T,I,S)
200. Chromic fluoride, Chromium trifluoride (T,I,S)
201. Chromic hydroxide, Chromium hydroxide (T,I,S)
202. Chromic oxide, Chromium oxide (T,I,S)
203. Chromic sulfate, Chromium sulfate (T,I,S)
204. Chromium (1V) compounds, Hexavalent chromium compounds (T,C,F,S)
205. Chromyl chloride, Chlorochromic anhydride (T,C,F,S)
206. Cobalt (powder) (T,F)
207. Cobalt compounds (T)
208. Cobaltous bromide, Cobalt bromide (T)
209. Cobaltous chloride, Cobalt chloride (T)
210. Cobaltous nitrate, Cobalt nitrate (T,F)
211. Cobaltous resinate, Cobalt resinate (T,F)
212. Cobaltous sulfate, Cobalt sulfate (T)
213. Cocculus, Fishberry (T)
214. Collodion, Pyroxylin (nitrocellulose) in ether and alcohol (F)
215. *Copper acetoarsenite, Paris green (T)
216. Copper acetylide (T,P)
217. *Copper arsenate, Cupric arsenate (T)
218. *Copper arsenite, Cupric arsenite (T)
219. Copper chloride, Cupric chloride (T)
220. Copper chlorotetrazole (T,P)
221. Copper compounds (T)
222. *Copper cyanide, Cupric cyanide (T)
223. Copper nitrate, Cupric nitrate (T,F,P)
224. Copper sulfate, Cupric sulfate, Blue vitriol (T)

225. *Coroxon; ortho,ortho-Diethyl-ortho-(3-chloro-4-methylcoumarin-7-yl) phosphate (T)
226. *Coumafuryl, FUMARIN, 3-[1-(2-Furanyl)-3-oxobutyl]1-4-hydroxy-2H-1-benzopyran-2-one (T)
227. *Coumatetralyl, BAYER 25634, RACUMIN 57, 4-Hydroxy-3-(1,2,3,4-tetrahydro-1-naphthalenyl)-2H-1-benzopyran-2-one (T)
228. *Crimidine, CASTRIX, 2-Chloro-4-dimethylamino-6-methylpyrimidine (T)
229. *Crotonaldehyde, 2-Butenal (T,I,F)
230. Cumene, Isopropyl benzene (T)
231. Cumene hydroperoxide; alpha,alpha-Dimethylbenzyl hydroperoxide (T,F)
232. Cupriethylene diamine (T,I)
233. *Cyanide salts (T)
234. Cyanoacetic acid, Malonic nitrile (T,C)
235. *Cyanogen (T,F)
236. Cyanogen bromide, Bromine cyanide (T,I)
237. Cyanuric triazide (T,P)
238. Cycloheptane (T,F)
239. Cyclohexane (T,F)
240. Cyclohexanone peroxide (T,F)
241. Cyclohexenyltrichlorosilane (T,C)
242. *Cycloheximide, ACTIDIONE (T,I)
243. Cyclohexyltrichlorosilane (T,C)
244. Cyclopentane (T,F)
245. Cyclopentanol (F)
246. Cyclopentene (T,F)
247. DDT; 1,1,1-Trichloro-2,2-bis(chlorophenyl) ethane (T)
248. *DDVP, Dichlorvos, VAPONA, Dimethyl dichlorovinyl phosphate (T)
249. *Decaborane (T,F,P)
250. DECALIN, Decahydronaphthalene (T,I)
251. *Demeton, SYSTOX (T)
252. *Demeton-S-methyl sulfone, METAISOSYSTOX-SULFON, S-[2-(ethylsulfonyl) ethyl] O,O-dimethyl phosphorothinoate (T)
253. Diazodinitrophenol, DDNP, 2-Diazo-4,6-dinitrobenzene-1-oxide (T,P)
254. *Diborane, Diboron hexahydride (T,I,F)
255. 2,3-Dibromo-1-chloropropane, DBCP, FUMAZONE, NEMAGON (T,I)
256. n-Dibutyl ether, Butyl ether (and isomers) (T,F)
257. Dichlorobenzene (ortho, meta, para) (T,I)
258. *3,3-Dichlorobenzidine and salts, DCB (T)
259. 1,2-Dichloroethylene; 1,2-Dichloroethene (T,I,F)
260. Dichloroethyl ether, Dichloroether (T,I)
261. Dichloroisocyanuric acid, Dichloro-S-triazine-2,4,6-trione (T,F)
262. Dichloromethane, Methylene chloride (T,I)
263. 2,4-Dichlorophenoxyacetic acid; 2,4-D (T,I)
264. 1,2-Dichloropropane, Propylene dichloride (T,F)

265. 1,3-Dichloropropylene; 1,3-Dichloropropene (T,I,F)
266. Dicumyl peroxide (F)
267. Dieldrin; 1,2,3,4,10,10-Hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-1,4-endo, exo-5,8-dimethanonaphthalene (T)
268. Diethylaluminum chloride, Aluminum diethyl monochloride, DEAC (F)
269. Diethylamine (T,I,F)
270. *Diethyl chlorovinyl phosphate, Compound 1836 (T)
271. Diethyldichlorosilane (T,C,F)
272. Diethylene glycol dinitrate (T,P)
273. Diethylene triamine (T,I,S)
274. *O,O-Diethyl-S-(isopropylthiomethyl) phosphorodithioate (T)
275. Diethylzinc, Zinc ethyl (C,F)
276. Difluorophosphoric acid (T,C)
277. *Diglycidyl ether, bis(2,3-Epoxypropyl) ether (T,S)
278. Diisopropylbenzene hydroperoxide (T,F)
279. Diisopropyl peroxydicarbonate (T,C,F,P)
280. *Dimefox, HANANE, PEXTOX 14, Tetramethylphosphorodiamidic fluoride (T)
281. Dimethylamine, DMA (T,I,F)
282. *Dimethylaminoazobenzene, Methyl yellow (T)
283. Dimethyldichlorosilane, Dichlorodimethylsilane (T,C,F)
284. 2,5-Dimethylhexane;2,5-Dihydroperoxide (I,F)
285. *1,1-Dimethylhydrazine, UDMH (T,F)
286. *Dimethyl sulfate, Methyl sulfate (T)
287. *Dimethyl sulfide, Methyl sulfide (T,F)
288. 2,4-Dinitroaniline (T,I)
289. *Dinitrobenzene (ortho, meta, para) (T,I,P)
290. Dinitrochlorobenzene, 1-Chloro-2,4-dinitrobenzene (T,I,P)
291. *2,6-Dinitro-ortho-cresol, DNPC, SINOX, EGETOL 30 (T)
292. *Dinitrophenol (2,3-;2,4-;2,6-isomers) (T,P)
293. 2,4-Dinitrophenylhydrazine (T,F,P)
294. Dinitrotoluene (2,4-;3,4-;3,5-isomers) (T,F,P)
295. *DINOSEB; 2,4-Dinitro-6-sec-butylphenol (T)
296. 1,4-Dioxane; 1,4-Diethylene dioxide (T,F)
297. *Dioxathion, DELNAV;S,S-1,4-dioxane-2,3-diyl bis(O,O-diethyl phosphorodithioate) (T)
298. Dipentaerythritol hexanitrate (P)
299. *Diphenyl, Biphenyl, Phenylbenzene (T)
300. Diphenylamine, DPA, N-Phenylaniline (T)
301. *Diphenylamine chloroarsine, Phenarazine chloride (T,I)
302. Diphenyldichlorosilane (T,C)
303. Dipicrylamine, Hexanitrodiphenyl amine (T,P)
304. Dipropyl ether (T,F)
305. *Disulfoton, DI-SYSTON;O,O-Diethyl S-[2-(ethylthio) ethyl] phosphorodithioate (T)
306. Dodecyltrichlorosilane (T,C)
307. *DOWCO-139, ZECTRAN, Mexacarbate, 4-(Dimethylamino -3,5-dimethylphenyl methylcarbarnate (T)

308. *DOWICIDE 7, Pentachlorophenol,PCP (T)
309. *DYFONATE, Fonofos, O-Ethyl-S-phenylethyl phosphonodithioate (T)
310. *Endosulfan, THIODAN; 6,7,8,9,10,10-Hexachloro- 1,5,5a,6,9, 9a-hexahydro-6,9-methano-2,4,3-benzo-dioxathiepin-3-oxide (T)
311. *Endothal, 7-Oxabicyclo [2.2.1]heptane-2,3-dicarboxylic acid (T)
312. *Endothion, EXOTHION, S-[(5-Methoxy-4-oxo-4H-pyran-2-yl)-methyl] O,O-dimethyl phosphorothioate (T)
313. *Endrin; 1,2,3,4,10,10-Hexachloro-6,7-epoxy-1,4,4,4a,5,6,7,8,8a-octahydro-1,4-endo-endo-5,8-dimethanonaphthalene (T)
314. Epichlorohydrin, Chloropropylene oxide (T,I,F)
315. *EPN; O-Ethyl O-para-nitrophenyl phenyphosphonothioate (T)
316. *Ethion, NIALATE;O,O,O′,O′-Tetraethyl-S,S-methylenediphosphorodithioate (T)
317. Ethyl acetate (T,I,F)
318. Ethyl alcohol, Ethanol (T,F)
319. Ethylamine, Aminoethane (T,I,F)
320. Ethylbenzene, Phenylethane (T,I,F)
321. Ethyl butyrate, Ethyl butanoate (I,F)
322. Ethyl chloride, Chloroethane (T,I,F)
323. Ethyl chloroformate, Ethyl chlorocarbonate (T,C,F)
324. *Ethyldichloroarsine, Dichloroethylarsine (T,I)
325. Ethyldichlorosilane (T,C,F)
326. Ethylene cyanohydrin, beta-Hydroxypropionitrile (T)
327. Ethylene diamine (T,I,S)
328. Ethylene dibromide, 1,2-Dibromoethane (T,I)
329. Ethylene dichloride, 1,2-Dichloroethane (T,I,F)
330. *Ethyleneimine, Aziridine, EI (T,F)
331. Ethylene oxide, Epoxyethane (T,I,F,P)
332. Ethyl ether, Diethyl ether (F,P)
333. Ethyl formate (T,I,F)
334. Ethyl mercaptan, Ethanethiol (T,F)
335. Ethyl nitrate (F,P)
336. Ethyl nitrite (F,P)
337. Ethylphenyldichlorosilane (T,C)
338. Ethyl propionate (I,F)
339. Ethyltrichlorosilane (T,I,F)
340. *Fensulfothion, BAYER 25141, DASANIT, O,O-Diethyl-O-[4-(methylsulfinyl)phenyl] phosphorothioate (T)
341. *Ferric arsenate (T,I)
342. Ferric chloride, Iron (111) chloride (T,C)
343. *Ferrous arsenate, Iron arsenate (T)
344. *Fluoboric acid, Fluoroboric acid (T,C)
345. Fluoride salts (T)
346. *Fluorine (T,C,F)
347. *Fluoroacetanilide, AFL 1082 (T)
348. *Fluoroacetic acid and salts, Compound 1080 (T)
349. *Fluorosulfonic acid, Fluosulfonic acid (T,C)

350. Formaldehyde, Methanal (T,F,S)
351. Formic acid, Methanoic acid (T,C)
352. Fulminate of mercury, Mercuric cyanate (T,P)
353. *FURADAN, NIA 10,242, Carbofuran; 2,3-Dihydro-2,2-dimethyl-7-benzofuranylmethylcarbamate (T)
354. Furan, Furfuran (T,F,P)
355. Gasoline (F)
356. *GB, O-Isopropyl methyl phosphoryl fluoride (T)
357. Glutaraldehyde (T,I,S)
358. Glycerolmonolactate trinitrate (P)
359. Glycol dinitrate, Ethylene glycol dinitrate (P)
360. Gold fulminate, Gold cyanate (P)
361. Guanidine nitrate (F,P)
362. Guanyl nitrosaminoguanylidene hydrazine (P)
363. Guthion; O,O-Dimethyl-S-4-oxo-1,2,3-benzotriazin-3(4H)-ylmethyl phosphorodithioate (T)
364. Hafnium (F)
365. Heptachlor; 1,4,5,6,7,8,8-Heptachloro-3a,4,7,7a-tetrahydro-4,7-methanoindene (T)
366. n-Heptane (and isomers) (T,F)
367. 1-Heptene (and isomers) (T,F)
368. Hexadecyltrichlorosilane (T,C)
369. Hexaethyl tetraphosphate, HETP (T)
370. Hexafluorophosphoric acid (T,C)
371. Hexamethylenediamine; 1,6-Diaminohexane (T,I)
372. n-Hexane (and isomers) (T,F)
373. 1-Hexene (and isomers) (T,I,F)
374. n-Hexylamine, 1-Aminohexane (and isomers) (T,I,F)
375. Hexyltrichlorosilane (T,C)
376. *Hydrazine, Diamine (T,I,F)
377. Hydrazine azide (T,P)
378. Hydrazoic acid, Hydrogen azide (T,I,P)
379. Hydriodic acid, Hydrogen iodide (T,C)
380. Hydrobromic acid, Hydrogen bromide (T,C)
381. Hydrochloric acid, Hydrogen chloride, Muriatic Acid (T,C)
382. *Hydrocyanic acid, Hydrogen cyanide (T,F)
383. *Hydrofluoric acid, Hydrogen fluoride (T,C)
384. Hydrofluosilicic acid, Fluosilicic acid (T,C)
385. Hydrogen peroxide (T,C,F,P)
386. *Hydrogen selenide (T,I,F)
387. *Hydrogen sulfide (T,I,F)
388. Hypochlorite compounds (T,C,F)
389. Indium (T)
390. Indium compounds (T)
391. Iodine monochloride (T,C)
392. Isooctane; 2,2,4-Trimethylpentane (T,F)
393. Isooctene (mixture of isomers) (T,F)
394. Isopentane, 2-Methylbutane (T,F)
395. Isoprene, 2-Methyl-1,3-butadiene (T,I,F,P)

396. Isopropanol, Isopropyl alcohol, 2-Propanol (T,F)
397. Isopropyl acetate (T,F)
398. Isopropyl acetylene, 3-Methylbutyne (T,F)
399. Isopropylamine, 2-Aminopropane (T,I,F)
400. Isopropyl chloride, 2-Chloropropane (F)
401. Isopropyl ether, Diisopropyl ether (T,I,F)
402. Isopropyl mercaptan, 2-Propanethiol (T,I,F)
403. Isopropyl percarbonate, Diisopropyl peroxydicarborate (C,F)
404. *meta-Isopropylphenyl-N-methylcarbamate, Ac 5,727 (T)
405. Lauroyl peroxide, Di-n-dodecyl peroxide (T,C,F,P)
406. Lead compounds (T)
407. Lead acetate (T)
408. *Lead arsenate, Lead orthoarsenate (T)
409. *Lead arsenite (T)
410. Lead azide (T,P)
411. Lead carbonate (T)
412. Lead chlorite (T,P)
413. *Lead cyanide (T)
414. Lead 2,4-dinitroresorcinate (T,P)
415. Lead mononitroresorcinate (T,P)
416. Lead nitrate (T,F)
417. Lead oxide (T)
418. Lead styphnate, Lead trinitroresorcinate (T,P)
419. *Lewisite, beta-Chlorovinyldichloroarsine (T)
420. Lithium (C,F)
421. Lithium aluminum hydride, LAH (C,F,P)
422. Lithium amide (C,F,P)
423. Lithium ferrosilicon (F)
424. Lithium hydride (C,F,P)
425. Lithium hypochlorite (T,C,F)
426. Lithium peroxide (C,F,P)
427. Lithium silicon (F,P)
428. *London purple, Mixture of arsenic trioxide, aniline, lime, and ferus oxide (T)
429. Magnesium (F)
430. *Magnesium arsenate (T)
431. *Magnesium arsenite (T)
432. Magnesium chlorate (T,F)
433. Magnesium nitrate (F,P)
434. Magnesium perchlorate (T,F,P)
435. Magnesium peroxide, Magnesium dioxide (F)
436. *Maleic anhydride (T,I)
437. Manganese (powder) (F)
438. Manganese acetate (T)
439. *Manganese arsenate, Manganous arsenate (T)
440. Manganese bromide, Manganous bromide (T,I)
441. Manganese chloride, Manganous chloride (T,I)
442. Manganese methylcyclopentadienyl tricarbonyl (T)
443. Managanese nitrate, Manganous nitrate (T,F)

444. Mannitol hexanitrate, Nitromannite (P)
445. *MECARBAM;O,O-Diethyl S-(N-ethoxycarbonyl N-methylcarbamoylmethyl) phosphorodithioate (T)
446. *Medinoterb acetate, 2-tert-Butyl-5-methyl-4,6-dinitrophenyl acetate (T)
447. Memtetrahydrophthalic anhydride (T,C)
448. Mercuric acetate, Mercury acetate (T,I)
449. Mercuric ammonium chloride, Mercury ammonium chloride (T,I)
450. Mercuric benzoate, Mercury benzoate (T,I)
451. Mercuric bromide, Mercury bromide (T,I)
452. *Mercuric chloride, Mercury chloride (T,I)
453. *Mercuric cyanide, Mercury cyanide (T,I)
454. Mercuric iodide, Mercury iodide (T,I)
455. Mercuric nitrate, Mercury nitrate (T,F)
456. Mercuric oleate, Mercury oleate (T)
457. Mercuric oxide (red and yellow) (T,F)
458. Mercuric oxycyanide (T,P)
459. Mercuric-potassium iodide, Mayer's reagent (T)
460. Mercuric salicylate, Salicylated mercury (T)
461. Mercuric subsulfate, Mercuric dioxysulfate (T)
462. Mercuric sulfate, Mercury sulfate (T)
463. Mercuric thiocyanide, Mercury thiocyanate (T)
464. Mercurol, Mercury nucleate (T)
465. Mercurous bromide (T)
466. Mercurous gluconate (T)
467. Mercurous iodide (T)
468. Mercurous nitrate (T,P)
469. Mercurous oxide (T)
470. Mercurous sulfate, Mercury bisulfate (T)
471. para-Menthane hydroperoxide, Paramenthane hydroperoxide (I,F)
472. *Mercury (T)
473. Mercury compounds (T)
474. Metal carbonyls (T)
475. Metal hydrides (F,P)
476. Metal powders (T,F)
477. *Methomyl; LANNATE, S-Methyl-N-((methyl-carbamonyl) oxy) thioacetamidate (T)
478. *Methoxyethylmercuric chloride, AGALLOL, ARETAN (T)
479. Methyl acetate (T,F)
480. Methyl acetone (Mixture of acetone, methyl acetate, and methyl alcohol) (T,F)
481. Methyl alcohol, Methanol (T,F)
482. Methylaluminum Sesquibromide (F)
483. Methylaluminum sesquichloride (F)
484. Methylamine, Aminomethane (T,I,F)
485. N-Methylaniline (T)
486. *Methyl bromide, Bromomethane (T,I)
487. 2-Methyl-1-butene (F)
488. 3-Methyl-1-butene (F)

489. Methyl butyl ether (and isomers) (T,F)
490. Methyl butyrate (and isomers) (T,F)
491. Methyl chloride, Chloromethane (T,F)
492. Methyl chloroformate, Methyl chlorocarbonate (T,I,F)
493. *Methyl chloromethyl ether, CMME (T)
494. Methylcyclohexane (T,F)
495. *Methyldichloroarsine (T,I)
496. Methyldichlorosilane (T,I)
497. *4,4-Methylene bis(2-chloroaniline), MOCA (T)
498. Methyl ethyl ether (T,F)
499. Methyl ethyl ketone, 2-Butanone (T,F)
500. Methyl ethyl ketone peroxide (T,I,F)
501. Methyl formate (T,I,F)
502. *Methyl hydrazine, Monomethyl hydrazine, MMH (T,F)
503. *Methyl isocyanate (T,F)
504. Methyl isopropenyl ketone, 2-Methyl-4-butene-3-one (T,F)
505. Methylmagnesium bromide (C,F,P)
506. Methylmagnesium chloride (C,F,P)
507. Methylmagnesium iodide (C,F,P)
508. Methyl mercaptan, Methanethiol (T,I,F)
509. Methyl methacrylate (monomer) (T,F)
510. *Methyl parathion;O,O-Dimethyl-O-para-nitrophenylphosphorothioate (T)
511. Methyl propionate (F)
512. Methyltrichlorosilane (T,C,F)
513. Methyl valerate, Methyl pentanoate (and isomers) (F)
514. Methyl vinyl ketone, 3-Butene-2-one (T,I,F)
515. *Mevinphos, PHOSDRIN, 2-Carbomethoxy-1-methylvinyl dimethyl phosphate (T)
516. *MOCAP, O-Ethyl-S,S-dipropyl phosphorodithioate (T)
517. Molybdenum (powder) (F)
518. Molybdenum trioxide, Molybdenum anhydride (T,I)
519. Molybdic acid and salts (T)
520. Monochloroacetic acid, Chloracetic acid, MCA (T,C)
521. Monochloroacetone, Chloroacetone, 1-Chloro-2-propanone (T,I)
522. Monofluorophosphoric acid (T,C)
523. Naphtha (of petroleum or coal tar origin) (T,F)
524. Naphthalene (T,I,S)
525. *alpha-Naphthylamine, 1-NA (T)
526. *beta-Naphthylamine, 2-NA (T)
527. Neohexane; 2,2-Dimethylbutane (T,F)
528. Nickel (powder) (T,F)
529. Nickel acetate (T)
530. Nickel antimonide (T)
531. *Nickel arsenate, Nickelous arsenate (T)
532. *Nickel carbonyl, Nickel tetracarbonyl (T)
533. Nickel chloride, Nickelous chloride (T)
534. *Nickel cyanide (T)
535. Nickel nitrate, Nickelous nitrate (T,F,P)

536. Nickel selenide (T)
537. Nickel sulfate (T)
538. Nicotine, beta-pyridyl-alpha-N-methyl pyrrolidine (T)
539. Nicotine salts (T)
540. Nitric acid (T,C,F)
541. Nitroaniline, Nitraniline (ortho, meta, para) (T,P)
542. *Nitrobenzol, Nitrobenzene (T)
543. *4-Nitrobiphenyl, 4-NBP (T)
544. Nitro carbo nitrate (F,P)
545. Nitrocellulose, Cellulose nitrate, Guncotton, Pyroxylin (F,P)
546. Nitrochlorobenzene, Chloronitrobenzene (ortho,meta,para) (T)
547. Nitrogen mustard (T,C,I)
548. Nitrogen tetroxide, Nitrogen dioxide (T,F)
549. Nitroglycerin, Trinitroglycerin (T,F,P)
550. Nitrohydrochloric acid, Aqua regia (T,C,F)
551. *Nitrophenol (ortho, meta, para) (T)
552. *N-Nitrosodimethylamine, Dimethyl nitrosoamine (T)
553. Nitrosoguanidine (P)
554. Nitrostarch, Starch nitrate (F,P)
555. Nitroxylol, Nitroxylene, Dimethylnitrobenzene (2,4-;3,4-;2,5-isomers) (T)
556. 1-Nonene, 1-Nonylene (and isomers) (T,F)
557. Nonyltrichlorosilane (T,I)
558. Octadecyltrichlorosilane (T,I)
559. n-Octane (and isomers) (T,F)
560. 1-Octene, 1-Caprylene (T,F)
561. Octyltrichlorosilane (T,I)
562. Oil of bergamot (S)
563. Oleum, Fuming sulfuric acid (T,C)
564. Orris root (S)
565. Osmium compounds (T)
566. Oxalic acid (T,I)
567. *Oxygen difluoride (T,C,P)
568. *Para-oxon, MINTACOL;O,O-Diethyl-O-para-nitrophenyl phosphate (T)
569. *Parathion; O,O-Diethyl-O-para-nitrophenyl phosphorothioate (T)
570. Pentaborane (T,I,F)
571. Pentaerythrite tetranitrate, Pentaerythritol tetranitrate (P)
572. n-Pentane (and isomers) (T,F)
573. 2-Pentanone, Methyl propyl ketone (and isomers) (T,F)
574. Peracetic acid, Peroxyacetic acid (T,C,F,P)
575. Perchloric acid (T,C,F,P)
576. Perchloroethylene, Tetrachloroethylene (T,I)
577. *Perchloromethyl mercaptan, Trichloromethylsulfenyl chloride (T,I)
578. Perchloryl fluoride (T,C,F)
579. Petroleum ether, Petroleum naphtha (T,F)
580. Phenol, Carbolic acid (T,C)
581. *Phenyldichloroarsine (T,I)
582. Phenylenediamine, Diaminobenzene (ortho,meta,para) (T,I,S)

583. Phenylhydrazine hydrochloride (T)
584. *Phenylphenol, Orthozenol, DOWICIDE 1 (T)
585. Phenyltrichorosilane (T,C)
586. *Phorate, THIMET; O,O-Diethyl-S-[(Ethylthio) methyl] phosphorodithioate (T)
587. *Phosfolan, CYOLAN, 2-(Diethoxyphosphinylimino)-1,3-dithiolane (T)
588. *Phosgene, Carbonyl chloride (T,I)
589. *Phosphamidon, DIMECRON, 2-Chloro-2-diethylcarbamoyl-1-methylvinyl dimethyl phosphate (T)
590. *Phosphine, Hydrogen phosphide (T,I)
591. Phosphoric acid (C)
592. Phosphoric anhydride, Phosphorus pentoxide (C,F)
593. Phosphorus (amorphous, red) (T,F,P)
594. *Phosphorus (white or yellow) (T,F,P)
595. Phosphorus oxygromide, Phosphoryl bromide (T,C)
596. *Phosphorus oxychloride, Phosphoryl chloride (T,C)
597. *Phosphorus pentachloride, Phosphoric chloride (T,C,F,P)
598. Phosphorus pentasulfide, Phosphoric sulfide (T,C,F,P)
599. Phosphorus sesquisulfide, Tetraphosphorus trisulfide (T,C,F)
600. Phosphorus tribromide (T,C,P)
601. *Phosphorus trichloride (T,C,P)
602. Picramide, Trinitroaniline (T,P)
603. Picric acid, Trinitrophenol (T,P)
604. Picryl chloride, 2-Chloro-1,3,5-trinitrobenzene (T,P)
605. *Platinum compounds (T)
606. *Polychlorinated biphenyls, PCB, Askarel, AROCLOR, CHLOREXTOL, INERTEEN, PYRANOL (T,I)
607. Polyvinyl nitrate (F,P)
608. POTASAN; O,O-Diethyl-O-(4-methylumbelliferone) phosphorothioate (T)
609. Potassium (C,F,P)
610. *Potassium arsenate (T,I)
611. *Potassium arsenite (T,I)
612. *Potassium bifluoride, Potassium acid fluoride (T,C)
613. Potassium binoxalate, Potassium acid oxalate (T,I)
614. Potassium bromate (T,I,F)
615. *Potassium cyanide (T)
616. Potassium dichloroisocyanurate (T,I,F)
617. Potassium dichromate, Potassium bichromate (T,C,S,F)
618. Potassium dinitrobenzfuroxan (T,P)
619. Potassium fluoride (T,I)
620. Potassium hydride (C,F,P)
621. Potassium hydroxide, Caustic potash (T,C)
622. Potassium nitrate, Saltpeter (F,P)
623. Potassium nitrite (F,P)
624. Potassium oxalate (T,I)
625. Potassium perchlorate (T,I,F,P)

626. Potassium permanganate (T,C,F)
627. Potassium peroxide (C,F,P)
628. Potassium sulfide (T,F)
629. *Propargyl bromide, 3-Bromo-1-propyne (T,I,F)
630. *beta-Propiolactone, BPL (T,I)
631. Propionaldehyde, Propanal (T,I,F)
632. Propionic acid, Propanoic acid (T,C)
633. n-Propyl acetate (T,F)
634. n-Propyl alcohol, 1-Propanol (T,F)
635. n-Propylamine (and isomers) (T,I,F)
636. Propyleneimine, 2-Methylaziridine (T,F)
637. Propylene oxide (T,I,F)
638. n-Propyl formate (T,F)
639. n-Propyl mercaptan, 1-Propanethiol (T,F)
640. n-Propyltrichlorosilane (T,C,F)
641. *Prothoate, FOSTION, FAC; O,O-Diethyl-S-carboethoxyethyl phosphorodithioate (T)
642. Pyridine (T,F)
643. Pyrosulfuryl chloride, Disulfuryl chloride (T,C,P)
644. *Quinone; 1,4-Benzoquinone (T,I)
645. Raney nickel (F)
646. *Schradan, Actamethyl pyrophosphoramide, OMPA (T)
647. Selenium (T)
648. *Selenium fluoride (T)
649. *Selenous acid, Selenious acid and salts (T)
650. Silicon tetrachloride, Silicon chloride (T,C)
651 Silver acetylide (T,P)
652. Silver azide (T,P)
653. Silver compounds (T)
654. Silver nitrate (T,I)
655. Silver styphnate, Silver trinitroresorcinate (T,P)
656. Silver tetrazene (T,P)
657. Sodium (C,F,P)
658. Sodium aluminate (C)
659. Sodium aluminum hydride (C,F,P)
660. Sodium amide, Sodamide (C,F)
661. *Sodium arsenate (T)
662. *Sodium arsenite (T)
663. Sodium azide (T,P)
664. *Sodium bifluoride, Sodium acid fluoride (T,C)
665. Sodium bromate (T,I,F)
666. *Sodium cacodylate, Sodium dimethylarsenate (T)
667. Sodium carbonate peroxide (I,F)
668. Sodium chlorate (T,I,F)
669. Sodium chlorite (T,I,F)
670. Sodium chromate (T,C,S)
671. *Sodium cyanide (T)
672. Sodium dichloroisocyanurate (I,F)
673. Sodium dichromate, Sodium bichromate (T,C,S,F)

674. Sodium fluoride (T,I)
675. Sodium hydride (T,C,F,P)
676. Sodium hydrosulfite, Sodium hyposulfite (F)
677. Sodium hydroxide, Caustic soda, Lye (T,C)
678. Sodium hypochlorite (T,I,F)
679. Sodium methylate, Sodium methoxide (C,F)
680. Sodium molybdate (T,I)
681. Sodium nitrate, Soda niter (T,F,P)
682. Sodium nitrite (T,F,P)
683. Sodium oxide, Sodium monoxide (T,C)
684. Sodium perchlorate (T,I,F,P)
685. Sodium permanganate (T,I,F)
686. Sodium peroxide (T,I,F,P)
687. Sodium picramate (T,I,F,P)
688. Sodium potassium alloy, Nak,Nack (C,F,P)
689. *Sodium selenate (T)
690. Sodium sulfide (and Sodium hydrosulfide) (T,I,F)
691. Sodium thiocyanate, Sodium sulfocyanate (T)
692. Stannic chloride, Tin tetrachloride (T,C)
693. *Strontium arsenate (T)
694. Strontium nitrate (T,F,P)
695. Strontium peroxide, Strontium dioxide (I,F,P)
696. *Strychnine and salts (T)
697. Styrene, Vinylbenzene (T,F)
698. Succinic acid peroxide (T,I,F)
699. Sulfide salts (soluble) (T)
700. *Sulfotepp, DITHIONE, BALDAFUM, Tetraethyl dithiopyrophosphate (T)
701. Sulfur chloride, Sulfur monochloride (T,C,P)
702. Sulfur mustard (T,C)
703. *Sulfur pentafluoride (T,C)
704. Sulfur trioxide, Sulfuric anhydride (T,C,F)
705. Sulfuric acid, Oil of vitriol, Battery acid (T,C)
706. Sulfurous acid (T,C)
707. Sulfuryl chloride, Sulfonyl chloride (T,C)
708. Sulfuryl fluoride, Sulfonyl fluoride (T,C)
709. *SUPRACIDE, ULTRACIDE, S-[(5-Methoxy-2-oxo-1,3,4-thiadiazol-3(2H)-yl) methyl] -O,O-dimethyl phosphorodithioate (T)
710. *SURECIDE, Cyanophenphos, O-para-Cyanophenyl-O-ethyl phenyl phosphonothioate (T)
711. *Tellurium hexafluoride (T,C)
712. *TELODRIN, Isobenzan; 1,3,4,5,6,7,8,8-Octachloro-1,3,3a,4,7,7a-hexahydro-4,7-methanoisobenzofuran (T)
713. *TEMIK, Aldicarb, 2-Methyl-2(methylthio) propionaldehyde-O-(methylcarbamoyl) oxime (T)
714. *2,3,7,8-Tetrachlorodibenzo-para-dioxin, TCDD, Dioxin (T)
715. sym-Tetrachloroethane (T)
716. *Tetraethyl dithionopyrophosphate, TEDP (T)
717. *Tetraethyl lead, TEL (and other organic lead) (T,F)

718. *Tetraethyl pyrophosphate, TEPP (T)
719. Tetrahydrofuran, THF (T,I,F)
720. TETRALIN, Tetrahydronaphthalene (T,I)
721. Tetramethyl lead, TML (T,F)
722. *Tetramethyl succinonitrile (T)
723. *Tetranitromethane (T,F,P)
724. *Tetrasul, ANIMERT V-101, S-para-Chlorophenyl-2,4,5-trichlorophenyl sulfide (T)
725. Tetrazene, 4-Amidino-1-(nitrosamino-amidino)-1-tetrazene (T,P)
726. Thallium (T)
727. *Thallium compounds (T)
728. *Thallous sulfate, Thallium sulfate, RATOX (T)
729. Thiocarbonychloride, Thiophosgene (T,C)
730. *Thionazin, ZINOPHOS; O,O-Tetramethylthiuram monosulfide (T)
731. Thionyl chloride, Sulfur oxychloride (T,C)
732. Thiophosphoryl chloride (T,C)
733. Thorium (powder) (F)
734. Tin compounds (organic) (T)
735. Titanium (powder) (F)
736. Titanium sulfate (T,I)
737. Titanium tetrachloride, Titanic chloride (T,C)
738. Toluene, Methylbenzene (T,F)
739. *Toluene-2,4-diisocyanate, TDI (T,I,S,P)
740. Toluidine, Aminotoluene (ortho,meta,para) (T)
741. *TRANID, exo-3-Chloro-endo-6-cyano-2-norbornanone-O-(methylcarbamoyl) oxime (T)
742. Trichloroborane (T,F)
743. 1,1,2-Trichloroethane (T,I)
744. Trichloroethylene; 1,1,2-Trichlorethene (T,F)
745. Trichloroisocyanuric acid (T,I,F)
746. 2,4,5-Trichlorophenoxyacetic acid; 2,4,5-T (T)
747. Trichlorosilane, Silicochloroform (T,C,F)
748. Trimethylamine, TMA (T,I,F)
749. Trinitroanisole; 2,4,6-Trinitrophenyl methyl ether (T,P)
750. 1,3,5-Trinitrobenzene, TNB (T,P)
751. 2,4,6-Trinitrobenzoic acid (T,P)
752. Trinitronaphthalene, Naphtite (T,P)
753. 2,4,6-Trinitroresorcinol, Styphnic acid (T,P)
754. 2,4,6-Trinitrotoluene, TNT (T,F,P)
755. *tris(1-Aziridinyl) phosphine oxide, Triethylenephosphoramide, TEPA (T,I)
756. Tungstic acid and salts (T)
757. Turpentine (T,F)
758. Uranyl nitrate, Uranium nitrate (T,F,P)
759. Urea nitrate (T,F,P)
760. n-Valeraldehyde, n-Pentanal (and isomers) (T,F)
761. Vanadic acid salts (T)
762. Vanadium oxytrichloride (T,C)
763. Vanadium pentoxide, Vanadic acid anhydride (T,I)

764. Vanadium tetrachloride (T,C)
765. Vanadium tetraoxide (T,I)
766. Vanadium trioxide, Vanadium sesquioxide (T,I)
767. Vanadyl sulfate, Vanadium sulfate (T,I)
768. Vinyl acetate (F)
769. *Vinyl chloride (T,I,F)
770. Vinyl ethyl ether (F)
771. Vinyl isopropyl ether (F)
772. Vinylidene chloride, VC (T,F)
773. Vinyltrichlorosilane (T,C,F)
774. VX, O-Ethyl methyl phosphoryl N,N-diisopropyl thiocholine (T)
775. *WEPSYN 155, WP 155, Triamiphos, para-(5-Amino-3-phenyl-1H-1,2,4-triazol-1-yl)-N,N,N',N'-tetramethyl phosphonic diamide (T)
776. Xylene, Dimethylbenzene (ortho,meta,para) (T,F)
777. Zinc (powder) (F)
778. Zinc ammonium nitrate (T,F)
779. *Zinc arsenate (T)
780. *Zinc arsenite (T)
781. Zinc chloride (T,C)
782. Zinc compounds (T)
783. *Zinc cyanide (T)
784. Zinc nitrate (T,F,P)
785. Zinc permanganate (T,I,F)
786. Zinc peroxide, Zinc dioxide (T,F,P)
787. *Zinc phosphide (T,F)
788. Zinc sulfate (T,I)
789. Zirconium (powder) (F)
790. Zirconium chloride, Zirconium tetrachloride (T,C)
791. Zirconium picramate (F)

(e) List of Common Names. Any of the following waste shall be handled and disposed of according to the regulations set forth in this Chapter. The hazardous property of each waste is identified as follows: (T) toxic, (C) corrosive, (I) irritant, (F) flammable, (S) strong sensitizer and (P) pressure generating. In this subsection an asterisk denotes the common name of an item which comes under the requirements of this Chapter if it contains a hazardous material.

Acetylene sludge (C,I)
Acid and water (C,I)
Acid sludge (C,I)
AFU Floc (T)
Alkaline caustic liquids (C,I)
Alkaline cleaner (C,I)
Alkaline corrosive battery fluid (C,I)
Alkaline corrosive liquids (C,I)
Asbestos waste (T)
Ashes (T,C,I)
Bag house wastes*
Battery acid (C,I)
Beryllium waste (T)

Bilge water (T)
Boiler cleaning waste (T,C,I)
Bunker Oil (T,F)
Catalyst*
Caustic sludge (C,I)
Caustic wastewater (C,I)
Chemical cleaners*
Chemical toilet waste*
Cleaning solvents (F)
Corrosion inhibitor (T,C,I)
Data processing fluid (F,I)
Drilling fluids*
Drilling mud*
Dyes*
Etching acid liquid or solvent (C,I,F)
Fly ash (T,C,I)
Fuel waste (T,F)
Insecticides (T)
Laboratory waste*
Lime and sulfur sludge (C,I)
Lime and water (C,I)
Lime sludge (C,I)
Lime wastewater (C,I)
Liquid cement*
*Liquid cleaning compounds**
Mine tailings*
Obsolete explosives (P)
Oil and water (T)
Oil Ash (T,C,I)
Oil of bergamot (S)
Paint (or varnish) remover or stripper (I,F)
Paint thinner (T,I,F)
Paint waste (or slops) (T,F)
Pickling liquor (C,I)
Pigments*
Plating waste (T,C,I)
Powdered orris root and products containing it (S)
Printing Ink*
Retrograde explosives (P)
Sludge acid (C,I)
Soda ash (C,I)
Solvents (I,F)
Spent acid (C,I)
Spent caustic (C,I)
Spent (or waste) cyanide solutions (T,C,I)
Spent mixed acid (C,I)
Spent plating solution (T,C,I)
Spent sulfuric acid (C,I)
Stripping solution (T,I,F)
Sulfonation oil (I,F)

Tank bottom sediment*
Tank cleaning sludges*
Tanning sludges (T,I,S)
Toxic chemical toilet wastes (T)
Unrinsed pesticide containers (T)
Unwanted or waste pesticides—an unusable portion of active ingredient or undiluted formulation (T)
Waste chemicals*
Waste epoxy*
Waste (or slop) oil (F)
Weed Killer (T)

Article 10. Extremely Hazardous Wastes and Extremely Hazardous Materials

66685. List of Extremely Hazardous Wastes.

(a) A waste containing any of the materials cited in the List of Extremely Hazardous Wastes presented in this Article shall be considered an extremely hazardous waste and shall be handled and disposed of according to requirements of this Chapter. The potential hazardous property of each material is identified as follows: (T) toxic, (C) corrosive, (I) irritant, (F) flammable, (S) *strong sensitizer or (P) pressure generating.* All letters in trademark names are capitalized.

(b) A waste that meets the definition of extremely hazardous waste presented in Article 1 of this Chapter shall be considered an extremely hazardous waste whether or not the waste is cited in this Article. Such a waste shall be handled and disposed of according to the requirements of this Chapter that pertain to hazardous wastes and extremely hazardous wastes.

(c) List of extremely hazardous chemicals:
Acetone cyanohydrin (T)
2-Acetylaminofluorene, 2-AAF (T)
Acrolein, Aqualin (T,I,F)
Acrylonitrile (T,F)
Adiponitrile (T)
Aldrin; 1,2,3,4,10,10-Hexachloro-1,4,4a,5,8,8a-hexahydro-1,4,5,8-endo-exodimethanonaphthalene (T)
Aluminum phosphide, PHOSTOXIN (T,F)
4-Aminodiphenyl, 4-ADP (T)
2-Aminopyridine (T)
Ammonium arsenate (T)
Ammonium bifluoride (T,C)
Arsenic (T)
Arsenic acid and salts (T)
Arsenic compounds (T)
Arsenic pentaselenide (T)
Arsenic pentoxide, Arsenic oxide (T)
Arsenic sulfide, Arsenic disulfide (T)
Arsenic tribromide, Arsenic bromide (T)
Arsenic trichloride, Arsenic chloride (T)
Arsenic triiodide, Arsenic iodide (T)
Arsenic trioxide, Arsenic oxide (T)

Arsenious acid and salts (T)
Arsines (T)
AZODRIN, 3-Hydroxy-N-cis-crotonamide (T)
Barium cyanide (T)
Benzidine and salts (T)
Benzotrifluoride, Trifluoromethylbenzene (T,F)
Beryllium (T,F)
Beryllium chloride (T)
Beryllium compounds (T)
Beryllium copper (T)
Beryllium fluoride (T)
Beryllium hydride (T,C,F)
Beryllium hydroxide (T)
Beryllium oxide (T)
BIDRIN, Dicrotophos, 3-(Dimethylamino)-1-methyl-3-oxo-1-propenyl dimethyl phosphate (T)
bis(Chloromethyl) ether, Dichloromethyl ether, BCME (T)
bis(Methylmercuric) sulfate, CEREWET, Ceresan liquid (T)
BOMYL, Dimethyl-3-hydroxyglutaconate dimethyl phosphate (T)
Boranes (T,F)
Bordeaux arsenites (T)
Bromine (T,C,F)
Bromine pentafluoride (T,C,F)
Bromine trifluoride (T,C,F)
Brucine, Dimethoxystrychnine (T)
Cacodylic acid, Dimethylarsinic acid (T)
Cadmium cyanide (T)
Calcium arsenate, PENSAL (T)
Calcium arsenite (T)
Carbanolate, BANOL, 2-Chloro-4,5-dimethylphenyl methylcarbamate (T)
Carbophenothion, TRITHION, S-{[4-(Chlorophenyl)thio]methyl}O,O-diethyl phosphorodithioate (T)
Chlorfenvinphos, Compound 4072, 2-Chloro-1-(2,4-dichlorophenyl) vinyl diethyl phosphate (T)
Chlorine (T,C,F)
Chlorine dioxide (T,C,F,P)
Chlorine pentafluoride (T,C,F,P)
Chlorine trifluoride (T,C,F,P)
Chloroacetaldehyde (T,F)
alpha-Chloroacetophenone, Phenyl Chloromethyl ketone (T,I)
Chloroacetyl chloride (T,C)
ortho-Chlorobenzylidene malonitrile, OCMB (T)
Chloropicrin, Chlorpicrin, Trichloronitromethane (T,I)
Copper acetoarsenite, Paris green (T)
Copper arsenate, Cupric arsenate (T)
Copper arsenite, Cupric arsenite (T)
Copper cyanide, Cupric cyanide (T)
Coroxon; ortho,ortho-Diethyl-ortho-(3-chloro-4-methylcoumarin-7-yl) phosphate (T)
Coumafuryl, FUMARIN, 3-[1-(2-Furanyl)-3-oxobutyl]-4-hydroxy-2H-1-benzopyran-2-one (T)

Coumatetralyl, BAYER 25634, RACUMIN-57, 4-Hydroxy-3-(1,2,3,4-tetrahydro-1-naphthalenyl)-2H-1-benzopyran-2-one (T)
Crimidine, CASTRIX, 2-Chloro-4-dimethyl-amino-6-methylpyrimidine (T)
Crotonaldehyde, 2-Butenal (T,I,F)
Cyanide salts (T)
Cyanogen (T,F)
Cycloheximide, ACTIDIONE (T,I)
DDVP, Dichlorvos, VAPONA, Dimethyl dichlorovinyl phosphate (T)
Decaborane (T,F,P)
Demeton, SYSTOX (T)
Demeton-S-methyl sulfone, METAISOSYSTOX-SULFON, S-{2-(Ethylsulfonyl) ethyl}-O,O-dimethyl phosphorothioate (T)
Diborane, Diboron hexahydride (T,I,F)
3,3-Dichlorobenzidine and salts, DCB (T)
Diethyl chlorovinyl phosphate, Compound 1836 (T)
O,O-Diethyl-S-(isopropylthiomethyl) phosphorodithioate (T)
Digylcidyl ether, bis(2,3-Epoxypropyl)ether (T,S)
Dimefox, HANANE, PEXTOX 14, Tetramethylphosphorodiamidic fluoride (T)
Dimethylaminoazobenzene, Methyl yellow (T)
1,1-Dimethylhydrazene, UDMH (T,F)
Dimethyl sulfate, Methyl sulfate (T)
Dimethyl sulfide, Methyl sulfide (T,F)
Dinitrobenzene (ortho,meta,para) (T,I,P)
2,6-Dinitro-ortho-cresol, DNPC, SINOX, EGETOL 30 (T)
Dinitrophenol (2,3-;2,4-;2,6-isomers) (T,P)
DINOSEB; 2,4-Dinitro-6-sec-butylphenol (T)
Dioxathion, DELNAV; S,S-1,4-Dioxane-2,3-diyl bis(O,O-diethyl phosphorodithioate) (T)
Diphenyl, Biphenyl, Phenylbenzene (T)
Diphenylamine chloroarsine, Phenarazine chloride (T,I)
Disulfoton, DI-SYSTON; O,O-Diethyl-S-{2-(ethylthio)ethyl} phosphorodithioate (T)
DOWCO-139, ZECTRAN, Mexacarbate, 4-(Dimethylamino)-3,5-dimethylphenyl methylcarbamate (T)
DOWICIDE 7, Pentachlorophenol, PCP (T)
DYFONATE, Fonofos, O-Ethyl-S-phenyl ethyl phosphonodithioate (T)
Endosulfan, THIODAN; 6,7,8,9,10,10-Hexachloro-1,5,5a,6,9,9a-hexahydro-6,9-methano-2,4,3-benzodioxathiepin-3-oxide (T)
Endothal, 7-Oxabicyclo[2.2.1]heptane-2,3-dicarboxylic acid (T)
Endothion, EXOTHION, S-{(5-methoxy-4-oxo-4H-pyran-2-yl)-methyl} O,O-dimethyl phosphorothioate (T)
Endrin; 1,2,3,4,10,10-Hexachloro-6,7-epoxy-1,4,4,4a,5,6,7,8,8a-octahydro-1,4-endo-endo-5,8-dimethanonaphthalene (T)
EPN; O-Ethyl-O-para-nitrophenyl phenylphosphonothioate (T)
Ethion, NIALATE; O,O,O′,O′-Tetraethyl-S,S-methylenediphosphorodithioate (T)
Ethyldichloroarsine, Dichloroethylarsine (T,I)

Ethyleneimine, Aziridine, EI (T,F)
Fensulfothion, BAYER 25141, DASANIT, O,O-Diethyl-O- [4-(methyl-sulfinyl) phenyl] phosphorothioate (T)
Ferric arsenate (T,I)
Ferrous arsenate, Iron arsenate (T)
Fluoboric acid, Fluoroboric acid (T,C)
Fluorine (T,C,F)
Fluoroacetanilide, AFL 1082 (T)
Fluoroacetic acid and salts, Compound 1080 (T)
Fluorosulfonic acid, Fluosulfonic acid (T,C)
FURADAN, NIA 10,242, Carbofuran; 2,3-Dihydro-2,2-dimethyl-7-benzofuranylmethylcarbamate (T)
GB, O-Isopropyl methyl phosphoryl fluoride (T)
Hydrazine, Diamine (T,I,F)
Hydrocyanic acid, Hydrogen cyanide (T,F)
Hydrofluoric acid, Hydrogen fluoride (T,C)
Hydrogen selenide (T,I,F)
Hydrogen sulfide (T,I,F)
meta-Isopropylphenyl-N-methylcarbamate, Ac 5,727 (T)
Lead arsenate, Lead orthoarsenate (T)
Lead arsenite (T)
Lead cyanide (T)
Lewisite, beta-Chlorovinyldichloroarsine (T)
London purple, Mixture of arsenic trioxide, aniline, lime, and ferrous oxide (T)
Magnesium arsenate (T)
Magnesium arsenite (T)
Maleic anhydride (T,I)
Manganese arsenate, Manganous arsenate (T)
MECARBAM; O,O-Diethyl-S-(N-ethyoxycarbonyl-N-methylcarbamoyl methyl) phosphorodithioate (T)
Medinoterb acetate, 2-tert-Butyl-5-methyl-4,6-dinitrophenyl acetate (T)
Mercuric chloride, Mercury chloride (T,I)
Mercuric cyanide, Mercury cyanide (T,I)
Mercury (T)
Methomyl, LANNATE, S-Methyl-N-((methyl carbamoyl)oxy) thio-acetamidate (T)
Methoxyethylmercuric chloride, AGALLOL, ARETAN (T)
Methyl bromide, Bromomethane (T,I)
Methyl chloromethyl ether, CMME (T)
Methyldichloroarsine (T,I)
4,4'-Methylene bis(2-chloroaniline), MOCA (T)
Methyl hydrazine, Monomethyl hydrazine, MM (T,F)
Methyl isocyanate (T,F)
Methyl parathion; O,O-Dimethyl-O-para-nitrophenylphosphorothioate (T)
Mevinphos, PHOSDRIN, 2-Carbomethoxy-1-methylvinyl dimethyl phosphate (T)
MOCAP, O-Ethyl-S,S-dipropyl phosphorodithioate (T)
alpha-Naphthylamine, 1-NA (T)

beta-Naphthylamine, 2-NA (T)
Nickel arsenate, Nickelous arsenate (T)
Nickel carbonyl, Nickel tetracarbonyl (T)
Nickel cyanide (T)
4-Nitrobiphenyl, 4-NBP (T)
Nitrophenol (ortho,meta,para) (T)
N-Nitrosodimethylamine, Dimethyl nitrosoamine (T)
Oxygen difluoride (T,C,P)
Para-oxon, MINTACOL; O,O-Diethyl-O-para-nitrophenyl phosphate (T)
Parathion;O,O-Diethyl-O-para-nitrophenyl phosphorothioate (T)
Perchloromethyl mercaptan, Trichloromethylsulfenyl chloride (T,I)
Phenyldichloroarsine (T,I)
Phenylphenol, Orthozenol, DOWICIDE I (T)
Phorate, THIMET; O,O-Diethyl-S-[(ethylthio)methyl] phosphorodithioate (T)
Phosfolan, CYOLAN, 2-(Diethoxyphosphinylimino)-1,3-dithiolane (T)
Phosgene, Carbonyl chloride (T,I)
Phosphamidon, DIMECRON, 2-chloro-2-diethylcarbamoyl-1-methylvinyl dimethyl phosphate (T)
Phosphine, Hydrogen phosphide (T,I)
Phosphorus (white or yellow) (T,F,P)
Phosphorus oxychloride, Phosphoryl chloride (T,C)
Phosphorus pentachloride, Phosphoric chloride (T,C,F,P)
Phosphorus trichloride (T,C,P)
Polychlorinated biphenyls, PCB, Askarel, AROCLOR, CHLOREXTOL, INERTEEN, PYRANOL (T,I)
POTASAN; O,O-Diethyl-O-(4-methylumbelliferone) phosphorothioate (T)
Potassium arsenate (T,I)
Potassium arsenite (T,I)
Potassium bifluoride, Potassium acid fluoride (T,C)
Potassium cyanide (T)
Propargyl bromide, 3-Bromo-1-propyne (T,I,F)
beta-Propiolactone, BPL (T,I)
Prothoate, FOSTION, FAC; O,O-Diethyl-S-carboethyoxyethyl phosphorodithioate (T)
Quinone; 1,4-Benzoquinone (T,I)
Schradan, Actamethyl pyrophosphoramide, OMPA (T)
Selenium fluoride (T)
Selenous acid, Selenious acid and salts (T)
Sodium arsenate (T)
Sodium arsenite (T)
Sodium bifluoride, Sodium acid fluoride (T,C)
Sodium cacodylate, Sodium dimethylarsenate (T)
Sodium cyanide (T)
Sodium selenate (T)
Strontium arsenate (T)
Strychnine and salts (T)
Sulfotepp, DITHIONE, BLADAFUM, Tetraethyl dithiopyrophosphate (T)
Sulfur pentafluoride (T,C)

SUPRACIDE, ULTRACIDE, S-[(5-Methoxy-2-oxo-1,3,4-thiadiazol-3(2H)-yl)methyl]-O,O-dimethyl phosphorodithioate (T)
Tellurium hexafluoride (T,C)
TELODRIN, Isobenzan; 1,3,4,5,6,7,8,8-Octachloro-1,3,3a,4,7,7a,-hexahydro-4,7-methanoisobenzofuran (T)
TEMIK, Aldicarb, 2-Methyl-2-(methylthio) propionaldehyde-O-(methylcarbamoyl)oxime (T)
2,3,7,8-Tetrachlorodibenzo-para-dioxin, TCDD, Dioxin (T)
Tetraethyl dithionopyrophosphate, TEDP (T)
Tetraethyl lead, TEL, and other organic lead (T,F)
Tetraethyl pyrophosphate, TEPP (T)
Tetramethyl lead, TML (T,F)
Tetramethyl succinonitrile (T)
Tetranitromethane (T,F,P)
Tetrasul, ANIMERT V-101, S-para-Chlorophenyl-2,4,5-trichlorophenyl sulfide (T)
Thallium (T)
Thallium compounds (T)
Thallous sulfate, Thallium sulfate, RATOX (T)
Thionazin, ZINOPHOS; O,O-Tetramethylthiuram monosulfide (T)
Toluene-2,4-diisocyanate, TDI (T,I,S,P)
TRANID, exo-3-Chloro-endo-6-cyano-2-norbornanone-O-(methylcarbamoyl) oxime (T)
tris(1-Aziridinyl) phosphine oxide, Triethylenephosphosphoramide, TEPA (T,I)
Vinyl chloride (T,I,F)
WEPSYN 155,WP 155, Triamiphos, para-(5-Amino-3-phenyl-1H-1,2,4-triazol-1-yl)-N,N,N',N',-tetramethyl phosphonic diamide(T)
Zinc arsenate (T)
Zinc arsenite (T)
Zinc cyanide (T)
Zinc phosphide (T,F)

Article 12. Recyclable Hazardous Wastes

66763. Recyclable Hazardous Waste Disposal Statement

(a) Within 180 days of the disposal of a recyclable hazardous waste of a type listed in Section 66796, the Department may request the producer of such waste to provide the Department with a written statement justifying having not recycled the waste. A person requested to provide such a statement shall comply within 30 days of the Department's written request. If the request is made of an entity specified in Section 66160 other than an individual, the statement shall be issued by the responsible management of that entity.

(b) The Department's request for a statement from the waste producer pursuant to subsection (a) above shall cite a special property or component of the waste and a possible use or method of reclamation on the basis of which the Department considers that the waste might feasibly be recycled.

(c) The statement from the waste producer justifying having not recycled a hazardous waste pursuant to subsection (a) above shall include, but need not be limited to, the following:

(1) The general description, source, chemical composition, physical state, and amount of the waste.

(2) The amount of similar waste discarded or recycled during the 365-day period preceding the disposal in question.

(3) An estimate of the amount of similar waste to be generated by the producer in the 365-day period succeeding the disposal in question.

(4) A summary of efforts made to find a use for the waste such as the following:

(A) Use without processing.

(B) Use after processing to remove or modify undesired impurities.

(C) Use as a source of energy by the producer or by another person.

(5) Technologic, economic or other reason for not recycling the waste, taking into account relevant factors which may include any of the following:

(A) The available amount and the storability of the waste.

(B) Chemical, physical, toxicological or other properties of the waste which might affect its recyclability.

(C) The concentration or recoverability of the chemical component, chemical reactivity, fuel value or other attribute cited by the Department pursuant to subsection (b) above which may determine the feasibility of recycling the waste.

(D) The processing required in recycling the waste and the availability and cost of suitable processing technology and facilities.

(E) The marketability of the waste as such or as its reclaimed components in terms of the distance from the waste source to the point of use or reclamation, the costs of handling and transport, and the current market prices for the individual waste components as pure or technical grade materials.

(d) The statement shall indicate what information contained therein is considered to be a trade secret. The Department shall keep confidential trade secrets contained in any statement submitted to the Department pursuant to this section.

NOTE: Authority cited: Section 25175, Health and Safety Code. Reference: Section 25175, Health and Safety Code.

HISTORY:

1. New Article 12 (Sections 66763 and 66796) filed 5-16-79; effective thirtieth day thereafter (Register 79, No. 19).

66796. List of Recyclable Hazardous Waste Types.

(a) Wastes of the types cited on the list of Recyclable Hazardous Wastes in subsection (b) are waste types which the Department finds to be both economically and technologically feasible to recycle.

(b) List of Recyclable Hazardous Waste Types (including examples of potential recycling methods or uses);

(1) Commercial chemical products including unused laboratory grade products (return to manufacturer or supplier or turn over to chemical salvager for resale or resource recovery; sell or barter to another consumer).

(2) Solvents, used or contaminated (reclaim, in-plant or through custom solvent reclaimer, by purification processes of rectification, ion exchange, adsorption, or extraction; or if combustible, use in-plant or sell for use as energy resource for heating, cooling, or power generation), including:

(A) Halogenated solvents such as trichloroethane, perchloroethylene, methylene dichloride, chloroform, carbon tetrachloride, Freons(R);

(B) Oxygenated solvents, such as acetone, methyl ethyl ketone, methanol, ethanol, butanol, ethyl acetate;

(C) Hydrocarbon solvents, such as hexanes, Stoddard, benzene, toluene, xylenes, paint thinner.

(d) A waste that meets the definition of extremely hazardous waste presented in Section 25115 of the *Health and Safety Code* or satisfies any of the criteria of extremely hazardous waste presented in Article 11 of this Chapter shall be considered an extremely hazardous waste whether or not the waste *is cited in this* Article. Such a waste shall be handled and disposed of according to the provisions of this Chapter.

(e) List of Chemical Names:

(This list is condensed to show changes *only*)

2. Acetic acid (T,C~~)~~,F)
3. *Acetone, Propanone* (~~T,~~F)
6. *2-Acetylaminofluorene, 2-AA~~F~~F (T)
7. Acetyl benzoyl peroxide (T,F,~~P)~~ R)
8. *Acetyl chloride (T,C,F~~)~~,R)
9. Acetyl peroxide (T,F,P~~)~~ R)
10. Acridine (T~~,E~~)
11. *Acrolein, Aqualin (T,~~I,~~F)
15. *Alkyl aluminum chloride (C,F,P~~)~~ R)
16. *Alkyl aluminum compounds (C,F,P~~)~~ R)
18. Allyl bromide, 3-Bromopropene (T,~~I,~~F)
19. Allyl chloride, 3-Chloropropene (T~~,I,~~F)
20. Allyl chlorocarbonate, Allyl ~~C~~chloroformate (T,~~I,~~F)
21. *Allyl trichlorosilane (T,C,F~~)~~,R)

23A. Aluminum chloride (T,C)

23B. *Aluminum chloride (anhydrous) (T,C,R)

Article 9. Hazardous Wastes and Hazardous Materials

66680. Lists of Chemical Names and Common Names.

(a) A Except as provided in Section 66305 or 66310, a waste that consists of or contains a material cited in the *List of Chemical Names or* the List of Common Names presented in this Article shall be considered a hazardous waste and shall be handled and disposed of according to the ~~requirements~~ provisions *set forth in this Chapter*~~,~~. ~~unless it is shown to the satisfaction of the Department that the waste does not meet the definition of hazardous waste presented in Article 1 of this Chapter.~~

(b) The potential hazardous property of a material cited in the List of Chemical Names or the List of Common Names *is indicated in the list as* follows: (T) toxic, (C) corrosive, ~~(I) irritant,~~ (F) ~~flammable,~~ ignitable, ~~(S) strong sensitizer~~ and ~~(P) pressure generating~~ (R) reactive. An asterisk (*) in *Subsection* ~~(d)~~ (e) *denotes an extremely* hazardous waste. ~~(see Article 10 of this Chapter).~~ All letters in trademark names are capitalized.

(c) A waste that meets the definition of hazardous waste presented in Section 25117 of the Health and Safety Code ~~Article 1 of this Chapter~~ or satisfies any of the criteria of hazardous waste presented in Article 11 of this Chapter shall be considered a hazardous waste whether or not the waste is cited in this Article. Such a waste shall be handled and disposed of according to the ~~requirements~~ provisions *of this Chapter*.

ATTACHMENT 5

93. Barium oxide, Barium monoxide (T,I)
94. Barium perchlorate (T,F,P) R)
95. Barium permanganate (T,F,P) R)
96. Barium peroxide (T,F,P) R)
102. *Benzene hexachloride, BHC; 1,2,3,4,5,6-Hexachlorocyclohexane (T,I)
103. *Benzenephosphorous dichloride (T,I) R)
104. Benzenesulfonic acid (T,C)
107. *Benzoyl chloride (T,C),R)
108. Benzoyl peroxide, Dibenzoyl peroxide (T,F,P) R)
110. Benzyl chloride, alpha-Chlorotoluene (T,I)
111. *Benzyl chlorocarbonate, Benzyl chloroformate (T,C),R)
117. *Beryllium hydride (T,C,F),R)
124. Bismuth chromate (T,S)
126. *Boranes (T,F),R)
128. *Boron trichloride, Trichloroborane (T,C),R)
129. *Boron trifluoride (T,C),R)
130. Bromic acid (T,C)
132. *Bromine pentafluoride (T,C,F),R)
133. *Bromine trifluoride (T,C,F),R)
135. 1,2,4-Butanetriol trinitrate (P) (R)
136. n-Butyl acetate, 1-Acetoxybutane (and isomers) (T,I,F)
137. n-Butyl alcohol, 1-Butanol (and isomers) (T,I,F)
138. n-Butyl amine, 1-Aminobutane (and isomers) (T,I,F)
139. n-Butyl formate (and isomers) (T,I,F)

25. Aluminum nitrate (F) (T,F)
26. *Aluminum phosphide, PHOSTOXIN (T,F),R)
31. Ammonium chromate (T,S,F)
32. Ammonium dichromate, Ammonium bichromate (T,C,S,F)
36. Ammonium nitrate (F,P) R)
37. Ammonium perchlorate (I,F,P) R)
38. Ammonium permanganate (T,F,P) R)
39. Ammonium persulfate (F,P) R)
40. Ammonium picrate (T,S,P) R)
41. Ammonium sulfide (T,C),F,R)
43. n-Amylamine, 1-Aminopentane (and isomers) (T,I,F)
~~45. n-Amyl mercaptan, 1-Pentanethiol (and isomers) (T,F)~~
45. n-Amylene, 1-Pentene (and isomers) (T,F)
~~46. n-Amylene, 1-Pentene (and isomers) (T,F)~~
46. n-Amyl mercaptan, 1-Pentanethiol (and isomers) (T,F)
47. n-Amyl nitrate, n-Pentyl nitrite (and isomers) (T,F)
48. *Amyl trichlorosilane (and isomers) (T,C),R)
49. Aniline, Aminobenzene (T,S)
51. Anthracene (T,I)
54. *Antimony pentachloride (T,C),R)
55. *Antimony pentafluoride (T,C),R)
62. Antimony trisulfide, Antimony sulfide (T,F,P) R)
69. *Arsenic tribromide, Arsenic bromide (T,I)
70. *Arsenic trichloride, Arsenic chloride (T,I)
78. Barium azide (T,P) R)
81. Barium chlorate (T,C,F,P) R)

187. *Chlorine trifluoride (T,C,F,P) R)

188. *Chloroacetaldehyde (T,F)C)

189. *alpha-Chloroacetophenone, Phenyl chloromethyl ketone (T,I)

190. *Chloroacetyl chloride (T,C),R)

192. Ppara-Chlorobenzoyl peroxide (F,P) R)

195. *Chloropicrin, Chlorpicrin, Trichloronitromethane (T,I)

196. Chlorosulfonic acid (T,C,F),R)

197. Chloro-ortho-toluidine, 2-Amino-4-chlorotoluene (T,I)

198. Chromic acid, Chromium trioxide, Chromic anhydride (T,C,F,S)

199. Chromic chloride, Chromium trichloride (T,I,S)

200. Chromic fluoride, Chromium trifluoride (T,I,S)

201. Chromic hydroxide, Chromium hydroxide (T,I,S)

202. Chromic oxide, Chromium oxide (T,I,S)

203. Chromic sulfate, Chromium sulfate (T,I,S)

204. Chromium (VI) compounds, Hexavalent chromium compounds (T,C,F,S)

205. *Chromyl chloride, Chlorochromic anhydride (T,C,F,S) R)

213. Cocculus, Fishberry, Picrotoxin (T)

214. Collodion, Pyroxylin (nitrocellulose) in ether and alcohol (F)

216. Copper acetylide (T,P) R)

220. Copper chlorotetrazole (F,P)

223. Copper nitrate, Cupric nitrate (T,F,P) R)

229. *Crotonaldehyde, 2-Butenal (T,I,F)

230. Cumene, Isopropyl benzene (T),F)

232. Cupriethylene diamine (T,I)

234. Cyanoacetic acid, Malonic nitrile (T, C)

235. *Cyanogen (T, F),R)

236. Cyanogen bromide, Bromine cyanide (T,I)

140. tert-Butyl hydroperoxide, (and isomers) (T,F)

141. *n-Butyllithium (and isomers) (T,C,F),R)

143. tert-Butyl peroxyacetate, tert-Butyl peracetate (F),R)

144. tert-Butyl peroxybenzoate, tert-Butyl perbenzoate (F),R)

145. tert-Butyl peroxypivalate (F,P) R)

146. *n-Butyltrichlorosilane (C,F),R)

150. *Cadmium (powder) (T, F)

152. *Cadmium compounds (T)

155. Cadmium nitrate (T,F,P) R)

159. *Calcium (F),R)

162. *Calcium carbide (C,F),R)

163. Calcium chlorate (F),R)

165. Calcium fluoride (T,I)

166. *Calcium hydride (C,F),R)

168. *Calcium hypochlorite, Calcium oxychloride (dry) (T,C,F),R)

170. Calcium nitrate, Lime nitrate, Nitrocalcite (F,P) R)

171. Calcium oxide, Lime, Slaked lime (C)

172. Calcium permanganate (T,I,F)

174. Calcium phosphide (T,F),R)

181. Chloral hydrate, Trichloroacetaldehyde (hydrated) (T)

182. *Chlordan; 1,2,4,5,6,7,8,8-Octachloro-4,7-methoano-3a,4,7,7a-tetrahydroindane (T)

184. *Chlorine (T,C,F),R)

185. *Chlorine dioxide (T,C,F,P) R)

186. *Chlorine pentafluoride (T,C,F,P) R)

273. Diethylene triamine (T,I,S)

275. *Diethylzinc, Zinc ethyl (C,F),R)

276. *Difluorophosphoric acid (T,C),R)

277. *Diglycidyl ether, bis (2,3-Epoxypropyl) ether (T,S)

279. Diisopropyl peroxydicarbonate, (T,C,F,P) Isopropyl percarbonate (T,C,F,R)

281. Dimethylamine, DMA (T,I,F)

283. *Dimethyldichlorosilane, Dichlorodimethylsilane (T,C,F),R)

284. 2,5-Dimethylhexane,-2,5-Dihydroperoxide (I,F)

285. *1,1-Dimethylhydrazine, UDMH (T,F),C)

286. *Dimethyl sulfate, Methyl sulfate (T),R)

287. *Dimethyl sulfide, Methyl sulfide (T,F),R)

288. 2,4-Dinitroaniline (T,I)

289. *Dinitrobenzene (ortho, meta, para) (T,I,P) R)

290. Dinitrochlorobenzene, 1-Chloro-2,4-dinitrobenzene (T,I,P) R)

291. *2 4,6-Dinitro-ortho-cresol, DNPC, SINOX, EGETOL 30 (T)

292. *Dinitrophenol (2,3-;2,4-;2,6-isomers) (T,P) R)

293. 2,4-Dinitrophenylhydrazine (T,F,P) R)

294. Dinitrotoluene (2,4-;3,4-;3,5-isomers) (T,F,P) R)

296. 1,4-Dioxane; 1,4-Diethylene dioxide (T,F),R)

298. Dipentaerythritol hexanitrate (P) (R)

301. *Diphenylamine chloroarsine, Phenarsazine chloride (T,I)

302. *Diphenyldichlorosilane (T,C),R)

303. Dipicrylamine, Hexanitrodiphenyl amine (T,P) R)

306. *Dodecyltrichlorosilane (T,C),R)

237. Cyanuric triazide (T,P) R)

240. Cyclohexanone peroxide (T,F)

241. *Cyclohexenyltrichlorosilane (T,C)

242. *Cycloheximide, ACTIDIONE (T,I)

243. *Cyclohexyltrichlorosilane (T,C),R)

249. *Decaborane (T,F,P) R)

250. DECALIN, Decahydronaphthalene (T,I)

252. *Demeton-S-methyl sulfone, METAISOSYSTOX-SULFON, S-[2-(ethylsulfonyl) ethyl] 0,0-dimethyl phosphorothinoate (T)

253. Diazodinitrophenol, DDNP, 2-Diazo-4,6-dinitrobenzene-1-oxide (T,P) R)

254. *Diborane, Diboron hexahydride (T,I,F),R)

255. *2,3 1,2-Dibromo-3-chloropropane, DBCP, FUMAZONE, NEMAGON (T,I)

257. Dichlorobenzene (ortho, meta, para) (T,I)

259. 1,2-Dichloroethylene; 1,2-Dichloroethene (T,I,F)

260. Dichloroethyl ether, Dichloroether (T,I) F)

261. Dichloroisocyanuric acid, Dichloro-S-triazine-2, 4, 6-trione (T,F),R)

262. Dichloromethane, Methylene chloride (T,I)

263. *2,4-Dichlorophenoxyacetic acid; 2,4-D (T,I)

265. 1,3-Dichloropropylene; 1,3-Dichloropropene (T,I,F)

266. Dicumyl peroxide (F),T)

267. *Dieldrin; 1,2,3,4,10,10-Hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-Octahydro-1,4-endo, exo-5,8-dimethanonaphthalene (T)

268. *Diethylaluminum chloride, Aluminum diethyl monochloride, DEAC (F),R)

269. Diethylamine (T,I,F)

271. *Diethyldichlorosilane (T,C,F),R)

272. Diethylene glycol dinitrate (T,P) R)

338. Ethyl propionate (I,F)

339. *Ethyltrichlorosilane (T,I,F),R)

341. *Ferric arsenate (T,I)

342. Ferric chloride; Iron (III) chloride (T,C)

346. *Fluorine (T,C,F),R)

349. *Fluorosulfonic acid, fluosulfonic acid (T,C),R)

350. Formaldehyde, Methanal (T,F,S)

352. Fulminate of mercury, Mercuric cyanate (T,P) R)

354. Furan, Furfuran (T,F,P) R)

357. Glutaraldehyde (T,I,S)

358. Glycerolmonolactate trinitrate (P) (R)

359. Glycol dinitrate, Ethylene glycol dinitrate (P) (R)

360. Gold fulminate, Gold cyanate (P) (R)

361. Guanidine nitrate (F,P) R)

362. Guanyl nitrosaminoguanylidene hydrazine (P) (R)

363. *GUTHION, 0,0-Dimethyl-S-4-oxo-1, 2, 3-benzotriazin-3 (4H) -ylmethyl phosphorodithioate (T)

364. Hafnium (F),T,R)

365. *Heptachlor; 1,4,5,6,7,8,8-Heptachloro-3a,4,7,7a-tetrahydro-4,7-methanoindene (T)

368. *Hexadecyltrichlorosilane (T,C),R)

371. Hexamethylene diamine; 1,6-Diaminohexane (T,I)

373. 1-Hexene (and isomers) (T,I,F)

374. n-Hexylamine, 1-Aminohexane (and isomers) (T,I,F)

375. *Hexyltrichlorosilane (T,C),R)

376. *Hydrazine, Diamine (T,I,F)

307. *DOWCO-139, ZECTRAN, Mexacarbate, 4-(Dimethylamino)-3, 5-dimethylphenyl methylcarbamate (T)

308. *Bowicide 7, Pentachlorophenol, PCP (T)

314. Epichlorohydrin, Chloropropylene oxide (T,I,F)

315. *EPN; 0-Ethyl 0-para-nitrophenyl phenylphosphonothioate (T)

317. Ethyl acetate (T,I,F)

319. Ethylamine, Aminoethane (T,I,F)

320. Ethylbenzene, Phenylethane (T,I,F)

321. Ethyl butyrate, Ethyl butanoate (I,F)

322. Ethyl chloride, Chloroethane (T,I,F)

323. *Ethyl chloroformate, Ethyl chlorocarbonate (T,C,F),R)

324. *Ethyldichloroarsine, Dichloroethylarsine (T,I),R)

325. *Ethyldichlorosilane (T,C,F),R)

326. *Ethylene cyanohydrin, beta-Hydroxypropionitrile (T),R)

327. Ethylene diamine (T,I,S)

328. Ethylene dibromide; 1,2-Dibromoethane (T,I)

329. Ethylene dichloride; 1,2-Dichloroethane (T,I,F)

330. *Ethyleneimine, Aziridine, EI (T,F),R)

331. Ethylene oxide, Epoxyethane (T,I,F,P) R)

332. Ethyl ether, Diethyl ether (F,P) R)

333. Ethyl formate (T,I,F)

334. Ethyl mercaptan, Ethanethiol (T,F),R)

335. Ethyl nitrate (F,P) R)

336. Ethyl nitrite (F,P) R)

337. *Ethylphenyldichlorosilane (T,C),R)

414. Lead 2,4-dinitroresorcinate (T,P) R)

415. Lead mononitroresorcinate (T,P) R)

418. Lead styphnate, Lead trinitroresorcinate (T,P) R)

420. *Lithium (C,F),R)

421. *Lithium aluminum hydride, LAH (C,F,P) R)

422. *Lithium amide (C,F,P) R)

423. *Lithium ferrosilicon (F),R)

424. *Lithium hydride (C,F,P) R)

425. *Lithium hypochlorite (T,C,F),R)

426. Lithium peroxide (C,F,P) R)

427. Lithium silicon (F,P) R)

428. *London purple, Mixture of arsenic trioxide, aniline, lime, and ferrous oxide (T)

429. *Magnesium (F) ,R

432. Magnesium chlorate (T,F),R)

433. Magnesium nitrate (F,P) R)

434. Magnesium perchlorate (T,F,P) R)

436. *Maleic anhydride (T,I)

440. Manganese bromide, Manganous bromide (T,I)

441. Manganese chloride, Manganous chloride (T,I)

443. Managanese nitrate, Manganous nitrate (T,F)

444. Mannitol hexanitrate, Nitromannite (P) (R)

447. Memtetrahydrophthalic anhydride (T,C) para-Menthane hydroperoxide, Paramenthanehydroperoxide (F,R)

448. Mercuric acetate, Mercury acetate (T,I)

448. para-Menthane hydroperoxide, Paramenthane hydroperoxide (C)

377. Hydrazine azide (T,P) R)

378. Hydrazoic acid, Hydrogen azide (T,I,P) R)

379. *Hydriodic acid, Hydrogen iodide (T,C),R)

380. *Hydrobromic acid, Hydrogen bromide (T,C),R)

381. *Hydrochloric acid, Hydrogen chloride, Muriatic acid (T,C),R)

382. *Hydrocyanic acid, Hydrogen cyanide (T,F),R)

383. *Hydrofluoric acid, Hydrogen fluoride (T,C),R)

385. Hydrogen peroxide (T,C,F,P),R)

386. *Hydrogen selenide (T,I,F)

387. *Hydrogen sulfide (T,I,F)

388. *Hypochlorite compounds (T,C,F),R)

391. Iodine monochloride (T,C),R)

393. Isooctene (mixture of isomers) (T,F)

394. Isopentane, 2-Methylbutane (T,F)

395. Isoprene, 2-Methyl-1,3-butadiene (T,I,F,P) R)

398. Isopropyl acetylene, 3-Methylbutyne (T,F)

399. Isopropylamine, 2-Aminopropane (T,I,F)

401. Isopropyl ether, Diisopropyl ether (T,I,F),R)

402. Isopropyl mercaptan, 2-Propanethiol (T,I,F)

403. Isopropyl percarbonate, Diisopropyl peroxydicarbonate (C,F)

403. *Kepone; 1,1a,3,3a,4,5,5,5a,5b,6-Decachlorooctahydro-1,2,4-metheno-2H-cyclobuta (cd) pentalen-2-one, Chlordecone (T)

405. Lauroyl peroxide, Di-n-dodecyl peroxide (T,C,F,P) R)

410. Lead azide (T,P) R)

412. Lead chlorite (T,P) R)

600. *Phosphorus tribromide (T,C,P) R)

601. *Phosphorus trichloride (T,C,P) R)

602. Picramide, Trinitroaniline (T,P) R)

603. Picric acid, Trinitrophenol (T,P) R)

604. Picryl chloride, 2-Chloro-1,3,5-trinitrobenzene (T,P) R)

606. *Polychlorinated biphenyls, PCB, Askarel, AROCLOR, CHLOREXTOL, INERTEEN, PYRANOL (T,I)

607. Polyvinyl nitrate (F,P) R)

609. *Potassium (C,F,P) R)

610. *Potassium arsenate (T,I)

611. *Potassium arsenite (T,I)

613. Potassium binoxalate, Potassium acid oxalate (T,I)

614. Potassium bromate (T,I,F)

616. Potassium dichloroisocyanurate (T,I,F)

617. Potassium dichromate, Potassium bichromate (T,C,S,F)

~~618. Potassium dinitrobenzfuroxan (T,P)~~

619. Potassium fluoride (T,I)

620. *Potassium hydride (C,F,P) R)

622. Potassium nitrate, Saltpeter (F,P) R)

623. Potassium nitrite (F,P) R)

624. Potassium oxalate (T,I)

625. Potassium perchlorate (T,I,F,P) R)

627. Potassium peroxide (C,F,P) R)

629. *Propargyl bromide, 3-Bromo-1-propyne (T,I,F)

630. *beta-Propiolactone, BPL (T,I)

~~562. Oil of bergamot (S)~~

563. *Oleum, Fuming sulfuric acid (T,C) ,R)

~~564. Orris root (S)~~

566. Oxalic acid (T,I)

567. *Oxygen difluoride (T,C,P) R)

570A. *Pentaborane (T,I,F),R)

570B. Pentachlorophenol, PCP, DOWICIDE 7 (T)

571. Pentaerythrite tetranitrate, Pentaerythritol tetranitrate (P) (R)

574. Peracetic acid, Peroxyacetic acid (T,C,F,P) R)

575. Perchloric acid (T,C,F,P) R)

576. Perchloroethylene, Tetrachloroethylene (T,I)

577. *Perchloromethyl mercaptan, Trichloromethylsulfenyl chloride (T,I)

~~579. Petroleum ether, Petroleum naphtha (T,F)~~

581. *Phenyldichloroarsine (T,I)

582. Phenylenediamine, Diaminobenzene (ortho, meta, para) (T,I,S)

585. *Phenyltrichlorosilane (T,C),R)

588. *Phosgene, Carbonyl chloride (T,I),R)

590. *Phosphine, Hydrogen phosphide (T,I) F)

593. Phosphorus (amorphous, red) (T,F,P) R)

594. *Phosphorus (white or yellow) (T,F,P) R)

595. *Phosphorus oxybromide, Phosphoryl bromide (T,C),R)

596. *Phosphorus oxychloride, Phosphoryl chloride (T,C),R)

597. *Phosphorus pentachloride, Phosphoric chloride (T,C,F,P) R)

598. *Phosphorus pentasulfide, Phosphoric sulfide (T,C,F,P) R)

599. *Phosphorus sesquisulfide, Tetraphosphorus trisulfide (T,C,F),R)

504. Methyl isopropenyl ketone, 2 3-Methyl-43-buten-32-one (T,F)

505. *Methylmagnesium bromide (C,F,P) R)

506. *Methylmagnesium chloride (C,F,P) R)

507. *Methylmagnesium iodide (C,F,P) R)

508. Methyl mercaptan, Methanethiol (T,I,F)

512. *Methyltrichlorosilane (T,C,F),R)

514. Methyl vinyl ketone, 3-Buten-2-one (T,I,F)

515A. *Mevinphos, PHOSDRIN, 2-Carbomethoxy-1-methylvinyl dimethyl phosphate (T)

515B. *Mirex; 1,1a,2,2,3,3a,4,5,5,5a,5b,6-Dodecachlorooctahydro-1,3,4-metheno-1H-cyclobuta (cd) pentalene, Dechlorane (T)

518. Molybdenum trioxide, Molybdenum anhydride (T,I)

521. Monochloroacetone, Chloroacetone, 1-Chloro-2-propanone (T,I)

523. Naphtha (of petroleum or coal tar origin), (I,F) Petroleum ether, Petroleum naphtha (T,F)

524. Naphthalene (T,I,S)

535. Nickel nitrate, Nickelous nitrate (T,F,P) R)

541. Nitroaniline, Nitraniline (ortho, meta, para) (T,P) R)

544. Nitro carbo nitrate (F,P) R)

545. Nitrocellulose, Cellulose nitrate, Guncotton, Pyroxylin, (F,P) Collodion, Pyroxylin (nitrocellulose) in ether and alcohol (F,R)

547. Nitrogen mustard (T,C,I)

549. Nitroglycerin, Trinitroglycerin (T,F,P) R)

553. Nitrosoguanidine (P) (R)

554. Nitrostarch, Starch nitrate (F,P) R)

557. *Nonyltrichlorosilane (T,I) R)

558. *Octadecyltrichlorosilane (T,I) R)

561. *Octyltrichlorosilane (T,I) R)

449. Mercuric ammonium chloride, Mercury ammonium chloride (T,I)

450. Mercuric benzoate, Mercury benzoate (T,I)

451. Mercuric bromide, Mercury bromide (T,I)

452. *Mercuric chloride, Mercury chloride (T,I)

453. *Mercuric cyanide, Mercury cyanide (T,I)

454. Mercuric iodide, Mercury iodide (T,I)

458. Mercuric oxycyanide (T,P) R)

468. Mercurous nitrate (T,P) R)

471. para-Menthane hydroperoxide, Paramenthene hydroperoxide (I,F)

473. *Mercury compounds (T)

475. *Metal hydrides (F,P) R)

477A. *Methomyl, LANNATE, S-Methyl-N-((methyl-carbamonyl) oxy) thioacetaimidate (T)

477B. *Methoxychlor; 1,1,1-Trichloro-2,2-bis(p-methoxyphenyl)ethane, CHEMFORM, MARLATE (T)

482. *Methylaluminum Sesquibromide (F),R)

483. *Methylaluminum sesquichloride (F),R)

484. Methylamine, Aminomethane (T,I,F)

486. *Methyl bromide, Bromomethane (T,I)

492. *Methyl chloroformate, Methyl chlorocarbonate (T,I,F),R)

493. *Methyl chloromethyl ether, CMME (T),F)

495. *Methyldichloroarsine (T,I)

496. *Methyldichlorosilane (T,I) F,R)

500. Methyl ethyl ketone peroxide (T,I,F)

501. Methyl formate (T,I,F)

670. Sodium chromate (T,C,S)

672. Sodium dichloroisocyanurate (I,F)

673. Sodium dichromate, Sodium bichromate (T,C,S,F)

674. Sodium fluoride (T,I)

675. *Sodium hydride (T,C,F,P) R)

678. *Sodium hypochlorite (T,I,F),R)

679. *Sodium methylate, Sodium methoxide (C,F),R)

680. Sodium molybdate (T,I)

681. Sodium nitrate, Soda niter (T,F,P) R)

682. Sodium nitrite (T,F,P) R)

684. Sodium perchlorate (T,I,F,P) R)

685. Sodium permanganate (T,I,F)

686. *Sodium peroxide (T,I,F,P) R)

687. Sodium picramate (T,I,F,P) R)

688. *Sodium potassium alloy, NaK, Nack (C,F,P) R)

690. Sodium sulfide (and, Sodium hydrosulfide) (T,I,F)

694. Strontium nitrate (T,F,P) R)

695. Strontium peroxide, Strontium dioxide (I,F,P) R)

698. Succinic acid peroxide (T,I,F)

700. *Sulfotepp, DITHIONE, BALADAFUM, Tetraethyl dithiopyrophosphate, TEDP (T)

701. *Sulfur chloride, Sulfur monochloride (T,C,P) R)

702. *Sulfur mustard (T,C)

707. *Sulfuryl chloride, Sulfonyl chloride (T,C),R)

708. *Sulfuryl fluoride, Sulfonyl fluoride (T,C),R)

631. Propionaldehyde, Propanal (T,I,F)

632. Propionic acid, Propanoic acid (T,C),F)

635. n-Propylamine (and isomers) (T,I,F)

636. *Propyleneimine, 2-Methylaziridine (T,F)

637. Propylene oxide (T,I,F)

640. *n-Propyltrichlorosilane (T,C,F),R)

643. *Pyrosulfuryl chloride, Disulfuryl chloride (T,C,P) R)

644. *Quinone; 1,4-Benzoquinone (T,I)

646. *Schradan, AOctamethyl pyrophosphoramide, OMPA (T)

647A. *Selenium (T)

647B. *Selenium compounds (T)

650. *Silicon tetrachloride, Silicon chloride (T,C),R)

651. *Silver acetylide (T,P) R)

652. Silver azide (T,P) R)

654. Silver nitrate (T,I)

655. Silver styphnate, Silver trinitroresorcinate (T,P) R)

656. Silver tetrazene (T,P) R)

657. *Sodium (C,F,P) R)

659. *Sodium aluminum hydride (C,F,P) R)

660. *Sodium amide, Sodamide (C,F),R)

663. Sodium azide (T,P) R)

665. Sodium bromate (T,I,F)

667. Sodium carbonate peroxide (I,F)

668. Sodium chlorate (T,I,F)

669. Sodium chlorite (T,I,F)

753. 2,4,6-Trinitroresorcinol, Styphnic acid (T,P) R)

754. 2,4,6-Trinitrotoluene, TNT (T,F,P) R)

755. *tris (1-Aziridinyl) phosphine oxide, Triethylene phosphoramide, TEPA (T,I)

758. Uranyl nitrate, Uranium nitrate (T,F,P) R)

759. Urea nitrate (T,F,P) R)

763. *Vanadium pentoxide, Vanadic acid anhydride (T,I)

765. Vanadium tetraoxide (T,I)

766. Vanadium trioxide, Vanadium sesquioxide (T,I)

767. Vanadyl sulfate, Vanadium sulfate (T,I)

768. Vinyl acetate (F),T)

769. *Vinyl chloride (T,I,F)

~~771. Vinyl isopropyl ether (F)~~

771. Vinylidene chloride, VC (T,F)

~~772. Vinylidene chloride, VC (T,F)~~

772. Vinyl isopropyl ether (F)

773. *Vinyltrichlorosilane (T,C,F),R)

784. Zinc nitrate (T,F,P) R)

785. Zinc permanganate (T,I,F)

786. Zinc peroxide, Zinc dioxide (T,F,P) R)

787. *Zinc phosphide (T,F),R)

788. Zinc sulfate (T,I)

790. *Zirconium chloride, Zirconium tetrachloride (T,C),R)

~~(e)~~(f) List of Common Names. Any of the following waste shall be handled and disposed of according to the regulations set forth in this Chapter.

~~716. *Tetraethyl dithionopyrophosphate, TEDP (T)~~

719A. Tetrahydrofuran; THF (T,I,F)

719B. Tetrahydrophthalic anhydride, Memtetrahydrophthalic anhydride (T)

720. TETRALIN, Tetrahydronaphthalene (T,I)

723. *Tetranitromethane (T,F,P) R)

725. Tetrazene, 4-Amidino-1-(nitrosamino-amidino)-1-tetrazene (T,P) R)

726. *Thallium (T)

729. *Thiocarbonylchloride, Thiophosgene (T,C),R)

731. *Thionyl chloride, Sulfur oxychloride (T,C),R)

732. *Thiophosphoryl chloride (T,C),R)

736. Titanium sulfate (T,I)

737. *Titanium tetrachloride, Titanic chloride (T,C),R)

739. *Toluene-2,4-diisocyanate, TDI (T,I,G,P) R)

740A. Toluidine, Aminotoluene (ortho,meta,para) (T)

740B. *Toxaphene, Polychlorocamphene (T)

~~742. Trichloroborane (T,F)~~

743. 1,1,2-Trichloroethane (T,I)

744. Trichloroethylene; I; I; 2/Trichloroethene (T,F)

746. *2,4,5-Trichlorophenoxyacetic acid; 2,4,5-T (T)

747. *Trichlorosilane, Silicochloroform (T,C,F),R)

748. Trimethylamine, TMA (T,I,F)

749. Trinitroanisole; 2,4,6-Trinitrophenyl methyl ether (T,P) R)

750. 1,3,5-Trinitrobenzene, TNB (T,P) R)

751. 2,4,6-Trinitrobenzoic acid (T,P) R)

752. Trinitronaphthalene, Naphtite (T,P) R)

Drilling fluids*†

Drilling mud*†

Dyes*†

Etching acid liquid or solvent (C,~~I,~~F)

Fly ash (T,C~~,I~~)

Laboratory waste*†

Lime and sulfur sludge (C~~,I~~)

Lime and water (C~~,I~~)

Lime sludge (C~~,I~~)

Lime wastewater (C~~,I~~)

Liquid cement*†

Liquid cleaning compounds *†

Mine tailings *†

Obsolete explosives ~~(P)~~ (R)

Oil Ash (T,C~~,I~~)

~~Oil of bergamot (S)~~

Paint (or varnish) remover or stripper (~~I,~~F)

Paint thinner (T,~~I,~~F)

Pickling liquor (C~~,I~~)

Pigments*†

Plating waste (T,C~~,I~~)

~~Powdered orris root and products containing it (S)~~

Printing ink*†

Retrograde explosives ~~(P)~~ (R)

The hazardous property of each waste is identified as follows: (T) toxic, (C) corrosive, ~~(I) irritant,~~ (F) ~~flammable,~~ ignitable, ~~(S) strong sensitizer~~ and ~~(P) pressure generating~~ (R) reactive. In this subsection ~~an asterisk~~ dagger denotes the common name of ~~an item~~ a waste which comes under the ~~requirements~~ *provisions of this Chapter if it contains a hazardous material.*

(This list is condensed to show changes only)

Acetylene sludge (C~~,I~~)

Acid and water (C~~,I~~)

Acid sludge (C~~,I~~)

Alkaline caustic liquids (C~~,I~~)

Alkaline cleaner (C~~,I~~)

Alkaline corrosive battery fluid (C~~,I~~)

Alkaline corrosive liquids (C~~,I~~)

Ashes (T,C~~,I~~)

Bag house wastes*†

Battery acid (C~~,I~~)

Boiler cleaning waste (T,C~~,I~~)

Catalyst*†

Caustic sludge (C~~,I~~)

Caustic wastewater (C~~,I~~)

Chemical cleaners*†

Chemical toilet waste*†

Corrosion inhibitor (T,C~~,I~~)

Data processing fluid (F~~,I~~)

Sludge acid (C~~,I~~)

Soda ash (C~~,I~~)

Solvents (~~I,~~F)

Spent acid (C~~,I~~)

Spent caustic (C~~,I~~)

Spent (or waste) cyanide solutions (T,C~~,I~~)

Spent mixed acid (C~~,I~~)

Spent plating solution (T,C~~,I~~)

Spent sulfuric acid (C~~,I~~)

Stripping solution (T,~~I,~~F)

Sulfonation oil (~~I,~~F)

Tank bottom sediment*~~†~~

Tank cleaning sludges*~~-~~

Tanning sludges (T,~~I,~~S)

Waste chemicals*~~†~~

Waste epoxy~~i~~des*~~†~~

Waste (or slop) oil ~~(F)~~ (T)

NOTE: Authority cited: Sections 208, 25141 and 25150, Health and Safety Code.

Reference: Section 25141, Health and Safety Code.

REPEAL

Beryllium oxide (T)
BIDRIN, Dicrotophos, 3-(Dimethylamino)-1-methyl-3-oxo-1-propenyl dimethyl phosphate (T)
bis(Chloromethyl) ether, Dichloromethyl ether, BCME (T)
bis(Methylmercuric) sulfate, CEREWET, Ceresan liquid (T)
BOMYL, Dimethyl-3-hydroxyglutaconate dimethyl phosphate (T)
Boranes (T,F)
Bordeaux arsenites (T)
Bromine (T,C,F)
Bromine pentafluoride (T,C,F)
Bromine trifluoride (T,C,F)
Brucine, Dimethoxystrychnine (T)
Cacodylic acid, Dimethylarsinic acid (T)
Cadmium cyanide (T)
Calcium arsenate, PENSAL (T)
Calcium arsenite (T)
Carbanolate, BANOL, 2-Chloro-4,5-dimethylphenyl methylcarbamate (T)
Carbophenothion, TRITHION, S-[[4-(Chlorophenyl)thio] methyl]O,O-diethyl phosphorodithioate (T)
Chlorfenvinphos, Compound 4072, 2-Chloro-1-(2,4-dichlorophenyl) vinyl diethyl phosphate (T)
Chlorine (T,C,F)
Chlorine dioxide (T,C,F,P)
Chlorine pentafluoride (T,C,F,P)
Chlorine trifluoride (T,C,F,P)
Chloroacetaldehyde (T,F)
alpha-Chloroacetophenone, Phenyl Chloromethyl ketone (T,I)
Chloroacetyl chloride (T,C)
ortho-Chlorobenzylidene malonitrile, OCMB (T)
Chloropicrin, Chlorpicrin, Trichloronitromethane (T,I)
Copper acetoarsenite, Paris green (T)
Copper arsenate, Cupric arsenate (T)
Copper arsenite, Cupric arsenite (T)
Copper cyanide, Cupric cyanide (T)
Coroxon; ortho,ortho-Diethyl-ortho-(3-chloro-4-methylcoumarin-7-yl) phosphate (T)
Coumafuryl, FUMARIN, 3-[1-(2-Furanyl)-3-oxobutyl]-4-hydroxy-2H-1-benzopyran-2-one (T)
Coumatetralyl, BAYER 25634, RACUMIN-57, 4-Hydroxy-3-(1,2,3,4-tetrahydro-1-naphthalenyl)-2H-1-benzopyran-2-one (T)
Crimidine, CASTRIX, 2-Chloro-4-dimethyl-amino-6-methylpyrimidine (T)
Crotonaldehyde, 2-Butenal (T,I,F)
Cyanide salts (T)
Cyanogen (T,F)
Cycloheximide, ACTIDIONE (T,I)
DDVP, Dichlorvos, VAPONA, Dimethyl dichlorovinyl phosphate (T)
Decaborane (T,F,P)
Demeton, SYSTOX (T)

DRAFT – FOR DISCUSSION ONLY
Date JAN 11 1984

REPEAL

Article 10. Extremely Hazardous Wastes and Extremely Hazardous Materials

66685. List of Extremely Hazardous Wastes.

(a) A waste containing any of the materials cited in the List of Extremely Hazardous Wastes presented in this Article shall be considered an extremely hazardous waste and shall be handled and disposed of according to requirements of this Chapter. The potential hazardous property of each material is identified as follows: (T) toxic, (C) corrosive, (I) irritant, (F) flammable, (S) strong sensitizer or (P) pressure generating. All letters in trademark names are capitalized.

(b) A waste that meets the definition of extremely hazardous waste presented in Article 1 of this Chapter shall be considered an extremely hazardous waste whether or not the waste is cited in this Article. Such a waste shall be handled and disposed of according to the requirements of this Chapter that pertain to hazardous wastes and extremely hazardous wastes.

(c) List of extremely hazardous chemicals:

Acetone cyanohydrin (T)
2-Acetylaminofluorene, 2-AAF (T)
Acrolein, Aqualin (T,I,F)
Acrylonitrile (T,F)
Adiponitrile (T)
Aldrin; 1,2,3,4,10,10-Hexachloro-1,4,4a,5,8,8a-hexahydro-1,4,5,8-endo-exodimethanonaphthalene (T)
Aluminum phosphide, PHOSTOXIN (T,F)
4-Aminodiphenyl, 4-ADP (T)
2-Aminopyridine (T)
Ammonium arsenate (T)
Ammonium bifluoride (T,C)
Arsenic (T)
Arsenic acid and salts (T)
Arsenic compounds (T)
Arsenic pentaselenide (T)
Arsenic pentoxide, Arsenic oxide (T)
Arsenic sulfide, Arsenic disulfide (T)
Arsenic tribromide, Arsenic bromide (T)
Arsenic trichloride, Arsenic chloride (T)
Arsenic triiodide, Arsenic iodide (T)
Arsenic trioxide, Arsenic oxide (T)
Arsenious acid and salts (T)
Arsines (T)
AZODRIN, 3-Hydroxy-N-cis-crotonamide (T)
Barium cyanide (T)
Benzidine and salts (T)
Benzotrifluoride, Trifluoromethylbenzene (T,F)
Beryllium (T,F)
Beryllium chloride (T)
Beryllium compounds (T)
Beryllium copper (T)
Beryllium fluoride (T)
Beryllium hydride (T,C,F)
Beryllium hydroxide (T)

REPEAL

GB, O-Isopropyl methyl phosphoryl fluoride (T)
Hydrazine, Diamine (T,I,F)
Hydrocyanic acid, Hydrogen cyanide (T,F)
Hydrofluoric acid, Hydrogen fluoride (T,C)
Hydrogen selenide (T,I,F)
Hydrogen sulfide (T,I,F)
meta-Isopropylphenyl-N-methylcarbamate, Ac 5,727 (T)
Lead arsenate, Lead orthoarsenate (T)
Lead arsenite (T)
Lead cyanide (T)
Lewisite, beta-Chlorovinyldichloroarsine (T)
London purple, Mixture of arsenic trioxide, aniline, lime, and ferrous oxide (T)
Magnesium arsenate (T)
Magnesium arsenite (T)
Maleic anhydride (T,I)
Manganese arsenate, Manganous arsenate (T)
MECARBAM; O,O-Diethyl-S-(N-ethyoxycarbonyl-N-methylcarbamoyl methyl) phosphorodithioate (T)
Medinoterb acetate, 2-tert-Butyl-5-methyl-4,6-dinitrophenyl acetate (T)
Mercuric chloride, Mercury chloride (T,I)
Mercuric cyanide, Mercury cyanide (T,I)
Mercury (T)
Methomyl, LANNATE, S-Methyl-N-((methyl carbamoyl)oxy) thio-acetamidate (T)
Methoxyethylmercuric chloride, AGALLOL, ARETAN (T)
Methyl bromide, Bromomethane (T,I)
Methyl chloromethyl ether, CMME (T)
Methyldichloroarsine (T,I)
4,4'-Methylene bis(2-chloroaniline), MOCA (T)
Methyl hydrazine, Monomethyl hydrazine, MM (T,F)
Methyl isocyanate (T,F)
Methyl parathion; O,O-Dimethyl-O-para-nitrophenylphosphorothioate (T)
Mevinphos, *PHOSDRIN*, 2-Carbomethoxy-1-methylvinyl dimethyl phosphate (T)
MOCAP, O-Ethyl-S,S-dipropyl phosphorodithioate (T)
alpha-Naphthylamine, 1-NA (T)
beta-Naphthylamine, 2-NA (T)
Nickel arsenate, Nickelous arsenate (T)
Nickel carbonyl, Nickel tetracarbonyl (T)
Nickel cyanide (T)
4-Nitrobiphenyl, 4-NBP (T)
Nitrophenol (ortho,meta,para) (T)
N-Nitrosodimethylamine, Dimethyl nitrosoamine (T)
Oxygen difluoride (T,C,P)
Para-oxon, MINTACOL; O,O-Diethyl-O-para-nitrophenyl phosphate (T)
Parathion;O,O-Diethyl-O-para-nitrophenyl phosphorothioate (T)
Perchloromethyl mercaptan, *Trichloromethylsulfenyl chloride* (T,I)
Phenyldichloroarsine (T,I)

REPEAL

Demeton-S-methyl sulfone, METAISOSYSTOX-SULFON, S-[2-(Ethylsulfonyl) ethyl]-O,O-dimethyl phosphor*othioate* (T)
Diborane, Diboron hexahydride (T,I,F)
3,3-Dichlorobenzidine and salts, DCB (T)
Diethyl chlorovinyl phosphate, Compound 1836 (T)
O,O-Diethyl-S-(isopropylthiomethyl) phosphorodithioate (T)
Digylcidyl ether, bis(2,3-Epoxypropyl)ether (T,S)
Dimefox, HANANE, PEXTOX 14, Tetramethylphosphorodiamidic fluoride (T)
Dimethylaminoazobenzene, Methyl yellow (T)
1,1-Dimethylhydrazene, UDMH (T,F)
Dimethyl sulfate, Methyl sulfate (T)
Dimethyl sulfide, Methyl sulfide (T,F)
Dinitrobenzene (ortho,meta,para) (T,I,P)
2,6-Dinitro-ortho-cresol, DNPC, SINOX, EGETOL 30 (T)
Dinitrophenol (2,3-;2,4-;2,6-isomers)-(T,P)
DINOSEB; 2,4-Dinitro-6-sec-butylphenol (T)
Dioxathion, DELNAV; S,S-1,4-Dioxane-2,3-diyl bis(O,O-diethyl phosphorodithioate) (T)
Diphenyl, Biphenyl, Phenylbenzene (T)
Diphenylamine chloroarsine, Phenarazine chloride (T,I)
Disulfoton, DI-SYSTON; O,O-Diethyl-S-[2-(ethylthio)ethyl] phosphorodithioate (T)
DOWCO-139, ZECTRAN, Mexacarbate, 4-(Dimethylamino)-3,5-dimethylphenyl methylcarbamate (T)
DOWICIDE 7, Pentachlorophenol, PCP (T)
DYFONATE, Fonofos, O-Ethyl-S-phenyl ethyl phosphonodithioate (T)
Endosulfan, THIODAN; 6,7,8,9,10,10-Hexachloro-1,5,5a,6,9,9a-hexahydro-6,9-*methano*-2,4,3-benzodioxathiepin-3-oxide (T)
Endothal, 7-Oxabicyclo[2.2.1]heptane-2,3-dicarboxylic acid (T)
Endothion, EXOTHION, S-[(5-methoxy-4-oxo-4H-pyran-2-yl)-methyl] O,O-dimethyl phosphorothicate (T)
Endrin; 1,2,3,4,10,10-Hexachloro-6,7-epoxy-1,4,4,4a,5,6,7,8,8a-octahydro-1,4-endo-endo-5,8-dimethanonaphthalene (T)
EPN; O-Ethyl-O-para-nitrophenyl phenylphosphonothioate (T)
Ethion, NIALATE; O,O,O',O'-Tetraethyl-S,S-methylenediphosphorodithioate (T)
Ethyldichloroarsine, Dichloroethylarsine (T,I)
Ethyleneimine, Aziridine, EI (T,F)
Fensulfothion, BAYER 25141, DASANIT, O,O-Diethyl-O- [4-(methyl-sulfinyl) phenyl] phosphorothioate (T)
Ferric arsenate (T,I)
Ferrous arsenate, Iron arsenate (T)
Fluoboric acid, Fluoroboric acid (T,C)
Fluorine (T,C,F)
Fluoroacetanilide, AFL 1082 (T)
Fluoroacetic acid and salts, Compound 1080 (T)
Fluorosulfonic acid, Fluosulfonic acid (T,C)
FURADAN, NIA 10,242, Carbofuran; 2,3-Dihydro-2,2-dimethyl-7-benzofuranylmethylcarbamate (T)

REPEAL

Tetrasul, ANIMERT V-101, S-para-Chlorophenyl-2,4,5-trichlorophenyl sulfide (T)
Thallium (T)
Thallium compounds (T)
Thallous sulfate, Thallium sulfate, RATOX (T)
Thionazin, ZINOPHOS; O,O-Tetramethylthiuram monosulfide (T)
Toluene-2,4-diisocyanate, TDI (T,I,S,P)
TRANID, exo-3-Chloro-endo-6-cyano-2-norbornanone-O-(methylcarbamoyl) oxime (T)
tris(1-Aziridinyl) phosphine oxide, Triethylenephosphosphoramide, TEPA (T,I)
Vinyl chloride (T,I,F)
WEPSYN 155,WP 155, Triamiphos, para-(5-Amino-3-phenyl-1H-1,2,4-trizzol-1-yl)-N,N,N',N',-tetramethyl phosphonic diamide(T)
Zinc arsenate (T)
Zinc arsenite (T)
Zinc cyanide (T)
Zinc phosphide (T,F)

Note: Authority cited: Sections 208, 25141 and 25150, Health and Safety Code.

Reference: Section 25141, Health and Safety Code.

REPEAL

Phenylphenol, Orthozenol, DOWICIDE I (T)
Phorate, THIMET; O,O-Diethyl-S-[(ethylthio)methyl] phosphorodithioate (T)
Phosfolan, CYOLAN, 2-(Diethoxyphosphinylimino)-1,3-dithiolane (T)
Phosgene, Carbonyl chloride (T,I)
Phosphamidon, DIMECRON, 2-chloro-2-diethylcarbamoyl-1-methylvinyl dimethyl phosphate (T)
Phosphine, Hydrogen phosphide (T,I)
Phosphorus (white or yellow) (T,F,P)
Phosphorus oxychloride, Phosphoryl chloride (T,C)
Phosphorus pentachloride, Phosphoric chloride (T,C,F,P)
Phosphorus trichloride (T,C,P)
Polychlorinated biphenyls, PCB, Askarel, AROCLOR, CHLOREXTOL, INERTEEN, PYRANOL (T,I)
POTASAN; O,O-Diethyl-O-(4-methylumbelliferone) phosphorothioate (T)
Potassium arsenate (T,I)
Potassium arsenite (T,I)
Potassium bifluoride, Potassium acid fluoride (T,C)
Potassium cyanide (T)
Propargyl bromide, 3-Bromo-1-propyne (T,I,F)
beta-Propiolactone, BPL (T,I)
Prothoate, FOSTION, FAC; O,O-Diethyl-S-carboethyoxyethyl phosphorodithioate (T)
Quinone; 1,4-Benzoquinone (T,I)
Schradan, Octamethyl pyrophosphoramide, OMPA (T)
Selenium fluoride (T)
Selenous acid, Selenious acid and salts (T)
Sodium arsenate (T)
Sodium arsenite (T)
Sodium bifluoride, Sodium acid fluoride (T,C)
Sodium cacodylate, Sodium dimethylarsenate (T)
Sodium cyanide (T)
Sodium selenate (T)
Strontium arsenate (T)
Strychnine and salts (T)
Sulfotepp, DITHIONE, BLADAFUM, Tetraethyl dithiopyrophosphate (T)
Sulfur pentafluoride (T,C)
SUPRACIDE, ULTRACIDE, S-[(5-Methoxy-2-oxo-1,3,4-thiadiazol-3(2H)-yl)methyl]-O,O-dimethyl phosphorodithioate (T)
Tellurium hexafluoride (T,C)
TELODRIN, Isobenzan; 1,3,4,5,6,7,8,8-Octachloro-1,3,3a,4,7,7a,-hexahydro-4,7-methanoisobenzofuran (T)
TEMIK, Aldicarb, 2-Methyl-2-(methylthio) propionaldehyde-O-(methylcarbamoyl)oxime (T)
2,3,7,8-Tetrachlorodibenzo-para-dioxin, TCDD, Dioxin (T)
Tetraethyl dithionopyrophosphate, TEDP (T)
Tetraethyl lead, TEL, and other organic lead (T,F)
Tetraethyl pyrophosphate, TEPP (T)
Tetramethyl lead, TML (T,F)
Tetramethyl succinonitrile (T)
Tetranitromethane (T,F,P)

BULK PLANT shall mean that portion of a property where flammable or combustible liquids are received by tank vessel, pipe lines, tank car, or tank vehicle, and are stored or blended in bulk for the purpose of distributing such liquids by tank vessel, pipe line, tank car, tank vehicle, or container.

CHEMICAL PLANT shall mean a large integrated plant or that portion of such a plant other than a refinery or distillery where flammable or combustible liquids are produced by chemical reactions or used in chemical reactions.

CLOSED CONTAINER shall mean a container as herein defined, so sealed by means of a lid or other device that neither liquid nor vapor will escape from it at ordinary temperatures.

COMBUSTIBLE LIQUIDS — See LIQUIDS.

CONTAINER shall mean any vessel of 60 U.S. gallons or less capacity used for transporting or storing flammable or combustible liquids.

CRUDE PETROLEUM shall mean hydrocarbon mixtures that have a flash point below 150° F. and which have not been processed in a refinery.

DISTILLERY shall mean a plant or that portion of a plant where flammable or combustible liquids produced by fermentation are concentrated, and where the concentrated products may also be mixed, stored, or packaged.

DWELLING shall mean a building occupied exclusively for residence purposes and having not more than two dwelling units or as a boarding or rooming house serving not more than 15 persons with meals or sleeping accommodations or both.

DWELLING UNIT shall mean one or more rooms arranged for the use of one or more individuals living together as a single housekeeping unit, with cooking, living, sanitary and sleeping facilities.

EDUCATIONAL OCCUPANCY shall mean the occupancy or use of a building or structure or any portion thereof by persons assembled for the purpose of learning or of receiving educational instruction.

FIRE AREA shall mean an area of a building separated from the remainder of the building by construction having a fire resistance of at least one hour and having all communicating openings properly protected by an assembly having a fire resistance rating of at least one hour.

FLAMMABLE AEROSOL shall mean an aerosol which is required

to be labeled "Flammable" under the U.S. Federal Hazardous Substances Labeling Act. For the purposes of this Code (Chapter IV) such aerosols are considered Class IA liquids.

FLASH POINT of a liquid shall mean the minimum temperature at which it gives off vapor in sufficient concentration to form an ignitible mixture with air near the surface of the liquid within the vessel as specified by appropriate test procedure and apparatus as follows:

The flash point of a liquid having a viscosity less than 45 SUS at 100° F (37.8° C) and a flash point below 200° F (93.4° C), shall be determined in accordance with the Standard Method of Test for Flash Point by the Tag Closed Tester, ASTM D-56-70.*

The flash point of a liquid having a viscosity of 45 SUS or more at 100° F (37.8° C) or a flash point of 200° F (93.4° C) or higher shall be determined in accordance with the Standard Method of Test for Flash Point by the Pensky Martens Closed Tester, ASTM D-93-72.*

HOTEL shall mean buildings or groups of buildings under the same management in which there are sleeping accommodations for hire, primarily used by transients who are lodged with or without meals including but not limited to inns, clubs, motels and apartment hotels.

INSTITUTIONAL OCCUPANCY shall mean the occupancy or use of a building or structure or any portion thereof by persons harbored or detained to receive medical, charitable or other care or treatment, or by persons involuntarily detained.

LIQUID shall mean, for the purpose of this Code, any material which has a fluidity greater than that of 300 penetration asphalt when tested in accordance with ASTM Test for Penetration for Bituminous Materials, D-5-71.* When not otherwise identified, the term liquid shall include both flammable and combustible liquids.

COMBUSTIBLE LIQUID shall mean a liquid having a flash point at or above 100° F (37.8 degrees C).

COMBUSTIBLE LIQUIDS shall be subdivided as follows:

Class II liquids shall include those having flash points at or above 100° F (37.8° C) and below 140° F (60° C).

*Available from American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103.

ATTACHMENT 6

Class IIIA Liquids shall include those having flash points at or above 140° F. (60° C) and below 200° F (93.4° C).

Class IIIB Liquids shall include those having flash points at or above 200° F (93.4° C).

FLAMMABLE LIQUID shall mean a liquid having a flash point below 100° F (37.8° C) and having a vapor pressure not exceeding 40 pounds per square inch (absolute) at 100° F (37.8° C) and shall be known as a Class I liquid.

Class I liquids shall be subdivided as follows:

Class IA shall include those having flash points below 73° F (22.8° C) and having a boiling point below 100° F (37.8° C).

Class IB shall include those having flash points below 73° F (22.8° C) and having a boiling point at or above 100° F (37.8° C).

Class IC shall include those having flash points at or above 73° F (22.8° C) and below 100° F (37.8° C).

UNSTABLE (REACTIVE) LIQUID shall mean a liquid which in the pure state or as commercially produced or transported will vigorously polymerize, decompose, condense, or will become self-reactive under conditions of shock, pressure, or temperature.

LISTED shall mean equipment or materials included in a list published by a nationally recognized testing laboratory that maintains periodic inspection of production of listed equipment or materials, and whose listing states either that the equipment or material meets nationally recognized standards or has been tested and found suitable for use in a specified manner.

LOW PRESSURE TANK. Low pressure tank shall mean a storage tank designed to withstand an internal pressure above 0.5 psig but not more than 15 psig.

MERCANTILE OCCUPANCY shall mean the occupancy or use of a building or structure or any portion thereof for the displaying, selling or buying of goods, wares, or merchandise.

OFFICE OCCUPANCY shall mean the occupancy or use of a building or structure or any portion thereof for the transaction of business, or the rendering or receiving of professional services.

PORTABLE TANK shall mean any closed vessel having a liquid capacity over 60 U.S. gallons and not intended for fixed installation.

PRESSURE VESSEL. Pressure vessel shall mean any fired or unfired vessel within the scope of the applicable section of the ASME Boiler and Pressure Vessel code.

PROTECTION FOR EXPOSURES shall mean fire protection for structures on property adjacent to tanks. When acceptable to the authority having jurisdiction, such structures located (1) within the jurisdiction of any public fire department or (2) within or adjacent to plants having private fire brigades shall be considered as having adequate protection for exposures.

REFINERY shall mean a plant in which flammable or combustible liquids are produced on a commerical scale from crude petroleum, natural gasoline, or other hydrocarbon sources.

SAFETY CAN shall mean an approved container, of not more than five gallons capacity, having a spring-closing lid and spout cover and so designed that it will safely relieve internal pressure when subjected to fire exposure.

SERVICE STATIONS

AUTOMOTIVE SERVICE STATION shall mean that portion of property where liquids used as motor fuels are stored and dispensed from fixed equipment into the fuel tanks of motor vehicles and shall include any facilities available for the sale and service of tires, batteries and accessories, and for minor automotive maintenance work. Major automotive repairs, painting, body and fender work are excluded.

MARINE SERVICE STATION shall mean that portion of a property where flammable or combustible liquids used as fuels are stored and dispensed from fixed equipment on shore, piers, wharves, or floating docks into the fuel tanks of self-propelled craft, and shall include all facilities used in connection therewith.

VAPOR PRESSURE shall mean the pressure, measured in pounds per square inch (absolute) exerted by a volatile liquid as determined by the "Standard Method of Test for Vapor Pressure of Petroleum Products (Reid Method)," (ASTM D323-68).*

VENTILATION as specified in this Code is for the prevention of fire and explosion. It is considered adequate if it is sufficient to prevent accumulation of significant quantities of vapor-air mixtures in concentration over one-fourth of the lower flammable limit.

12. Storage. Flammable or combustible liquids shall be stored in a tank or in a container in accordance with Chapter II or Chapter IV.

*Available from American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103.

27. Elliott, R.A. "Pilot Pipe Study", ANLAB Analytical Laboratory Report No~ 144682, November 1982

2648

Anlab
ANALYTICAL LABORATORY
A DIVISION OF DEWANTE & STOWELL
1914 S STREET, SACRAMENTO, CALIFORNIA 95814 • 916-447-2946

November 29, 1982

Leonardini and Fathy
400 Capitol Mall
Suite 221
Sacramento, CA 95814

ATTN: Mr. Raymond J. Leonardini

RE: Results of Pipe Study

Dear Mr. Leonardini:

Enclosed is the report of the Pilot Pipe Study. Included are the Protocol, material data sheets, and analytical results. Concentrations for gasoline, GC/MS, are approximate.

If you have any questions, please contact us. Thank you for your continued business.

Sincerely,

ANLAB

Roger A. Elliott

Roger A. Elliott

RAE:lk
Encl.

Anlab
ANALYTICAL LABORATORY
A DIVISION OF DEWANTE & STOWELL
1914 S STREET, SACRAMENTO, CALIFORNIA 95814 • 916-447-2946

November 29, 1982

Leonardini and Fathy
400 Capitol Mall, Suite 221
Sacramento, CA 95814

ATTN: Mr. Raymond J. Leonardini

-- ABSTRACT --

PILOT PIPE STUDY

Three plastic water supply pipes: polyvinylchloride (PVC), polyethylene (PE), and polybutylene (PB), were exposed to selected compounds to determine permeability. Copper pipe was included as a quality control sample. The exposure chemicals were: 1,2,-Dichloropropane; 1,1,1-Trichloroethane; Chlordane (72% formulation diluted 1:100 v:v in water); Chevron Super-Unleaded Gasoline; and Tap Water as a quality control blank. Exposure time was one week.

Results indicate that PVC is permeated by 1,2-Dichloropropane and 1,1,1-Trichloroethane; PE and PB were permeated by 1,2-Dichloropropane, 1,1,1-Trichloroethane, and Gasoline. In addition, results of the control samples indicate that several compounds leach into the water from the pipe material; sealants, glues, joining compounds, flux, etc. The data indicates that as the compounds permeate the pipe they also extract and carry with them other soluble compounds in the pipe material. Comparison of small quantities of leachate compounds to exposed pipes was not always possible due to necessary dilutions of the samples because of the high concentrations of other compounds.

Roger A. Elliott

Roger A. Elliott

RAE:lk

This report is applicable only to the sample received by the laboratory. The liability of the laboratory is limited to the amount paid for this report. This report is for the exclusive use of the client to whom it is addressed and upon the condition that the client assumes all liability for the further distribution of the report or its contents.

Anlab
ANALYTICAL LABORATORY
A DIVISION OF DEWANTE & STOWELL

1914 S STREET, SACRAMENTO, CALIFORNIA 95814 • 916-447-2946

November 29, 1982

Report #: 144682
Page One

Leonardini and Fathy
400 Capitol Mall, Suite 221
Sacramento, CA 95814

ATTN: Raymond J. Leonardini

Pilot Pipe Study

I. Introduction

The purpose for the pilot study was to apply chemicals to different pipe materials, "mimicking soil conditions", and analyzing the water samples in each pipe for any possible migration of applied compounds through each type of pipe. Any further studies could be based on the results of the pilot program.

Protocol for the actual set-up of the study was established through cooperative agreement between Anlab staff, Mr. Leonardini, and Mr. Leonardini's representatives. (Appendix A)

II. Protocol Data

A. Photographs -- Photographs of the various phases of the experiment were taken and have already been supplied.

B. Quality Control

1. An "Initial Tap Water" was collected and analyzed to determine if any of the respective compounds were present in the test water before treatment.

2. A "water control box" was used as a blank to determine if any compounds of interest leached naturally from the pipe, sealants, sand, etc.

3. Copper pipe was used in each box as an exposure control.

4. Each box was checked and kept filled during the entire exposure period.

5. EPA analytical protocol was strictly adhered to for the collection, preservation, and analysis of the test samples.

6. Blind replicate samples were sent to Radian Corp. for GC/MS confirmation.

This report is applicable only to the sample received by the laboratory. The liability of the laboratory is limited to the amount paid for this report. This report is for the exclusive use of the client to whom it is addressed and upon the condition that the client assumes all liability for the further distribution of the report or its contents.

a. 1,1,1-Trichloroethane and 1,2-Dichloropropane were analyzed by EPA Method #624, "Organics by Purge and Trap," using Gas Chromatography-Coulson Detection.

b. Chlordane was analyzed by EPA Method #608, "Organochlorine Pesticides and PCB's," using Gas Chromatography-Electron Capture Detection.

c. Gasoline was analyzed using EPA Method #624, "Purge and Trap," and hydrocarbon analyses, Supelco, by Gas Chromatography-Flame Ionization Detection (fingerprinting).

C. Material Data Sheets -- (See Appendix B)

D. Project Termination

The rubber silicon sealant did not seal against the compounds being used. Excessive leaking caused us to terminate the study at one week.

III. Analytical Data

A. Chemical Data Sheets -- (See Appendix C)

B. Anlab I.D. Codes

1. Pipe codes: "PV-W" = Polyvinylchloride - White; "PE-K" = Polyethylene - Black; "PB-KE" = Polybutylene - Black and Blue; "CC-C" = Copper.

2. Box Codes: "A" = 1,2-Dichloropropane; "B" = 1,1,1-Trichloroethane; "C" = Chlordane 8E; "D" = Super Unleaded Gasoline; "E" = Water control.

3. Code Use: Pipe-Color-Box; example, "PV-W-B" is Polyvinylchloride-White-Box B.

C. Pipe Volumes

1. All pipes contained 1400 ml to 2100 ml of water sample. Individual volumes are in Appendix D.

D. Analytical Results

1. "Test-Chemical" Results - ONLY

This report is applicable only to the sample received by the laboratory. The liability of the laboratory is limited to the amount paid for this report. This report is for the exclusive use of the client to whom it is addressed and upon the condition that the client assumes all liability for the further distribution of the report or its contents.

Anlab
ANALYTICAL LABORATORY
A DIVISION OF DEWANTE & STOWELL
1914 S STREET, SACRAMENTO, CALIFORNIA 95814 • 916-447-2945

Pipe/Sample	1,2-Dichloro-Propane, ppb	1,1,1-Trichloro-ethane, ppb	Chlordane ppb	Gasoline, ppm (by total area)
Initial Control	None Detected	None Detected	None Detected	None Detected
PV-W	0.98	2.2[c]	None Detected	None Detected[c]
PV-W(E)	None Detected	None Detected[c]	None Detected	None Detected[c]
PE-K	1,800	46,000[c]	None Detected	120[c]
PE-K(E)	None Detected	None Detected[c]	None Detected	None Detected[c]
PB-KE	310	25,000[c]	None Detected	78[c]
PB-KE(E)	20*[c]	None Detected[c]	None Detected	None Detected[c]
CC-C	None Detected	4.6[1c]	None Detected	0.59[1c]
CC-C(E)	None Detected	None Detected[c]	None Detected	None Detected[c]
Detection Limit	0.30	0.25	0.1	0.05

*There is no explanation of this anomylous result in a control sample. There may have been contamination. This result was confirmed by GC/MS. We have rigorously looked at contamination possibilities and no explanation is available.

[c]Confirmed by GC/MS.

[1]This result is possibly due to a pinhole or crack in the copper pipe or soldered joints. Each exposure box contained ten (10) soldered joints.

This report is applicable only to the sample received by the laboratory. The liability of the laboratory is limited to the amount paid for this report. This report is for the exclusive use of the client to whom it is addressed and upon the condition that the client assumes all liability for the further distribution of the report or its contents.

Anlab
ANALYTICAL LABORATORY
A DIVISION OF DEWANTE & STOWELL
1914 S STREET, SACRAMENTO, CALIFORNIA 95814 • 916-447-2946

2. GC/MS results - By Pipe Type* (1)

a. Polyvinylchloride Pipe

Compound, ppb	1,1,1-Trichloroethane Exposure Box - B	Water Control Box - E
Chloroform	230	30
Tetrahydrofuran	11,000	4.9
2-Butanone	5	10
Methylpentanone	170	None Detected
Toluene	360	None Detected
Dichloromethane	None Detected	280
Acetone	None Detected	26

Gasoline, ppm	Exposure Box - D	Control Box - E
Butane	None Detected	None Detected
Heptane	None Detected	None Detected
Benzene	None Detected	None Detected
Toluene	1 - 5	1 - 5
Octane	None Detected	None Detected
Xylenes	None Detected	None Detected
Trimethyl Benzenes	None Detected	None Detected
Tetramethyl Benzenes	None Detected	None Detected
Ethylbenzene	None Detected	None Detected

*Exposure compounds confirmed. See Section D.1., Page 3.

(1) Some compounds may not have been detected in the exposure pipe samples that were found in the control samples, due to sample dilution.

This report is applicable only to the sample received by the laboratory. The liability of the laboratory is limited to the amount paid for this report. This report is for the exclusive use of the client to whom it is addressed and upon the condition that the client assumes all liability for the further distribution of the report or its contents.

Anlab
ANALYTICAL LABORATORY
A DIVISION OF DEWANTE & STOWELL
1914 S STREET, SACRAMENTO, CALIFORNIA 95814 • 916-447-2946

b. Polyethylene Pipe

Compound, ppb	Trichloroethane Exposure Box - B	Water Control Box - E
Ethyloxirane	5200	None Detected
1,2-Dichloroethane	4500	None Detected
Trichloroethylene	70	None Detected
Benzene	300	None Detected
Methylpyrole	280	None Detected
Dichloromethane	None Detected	100
Chloroform	None Detected	26
Acetone	None Detected	2.2
Tetrahydrofuran	None Detected	90
2-Butanone	None Detected	200

Gasoline, ppm	Exposure Box - D*	Control Box - E
Butane	100	None Detected
Heptane	None Detected	None Detected
Benzene	100	None Detected
Toluene	100	1 - 5
Octane	None Detected	None Detected
Xylenes	100	None Detected
Trimethylbenzenes	20 - 100	None Detected
Tetramethylbenzenes	20 - 100	None Detected
Ethylbenzene	100	None Detected

*In addition, the following compounds were found in the exposure pipe that was not in the gasoline: methylethylbenzene, cyclopentane, dihydroindene, and dimethylethylbenzene.

This report is applicable only to the sample received by the laboratory. The liability of the laboratory is limited to the amount paid for this report. This report is for the exclusive use of the client to whom it is addressed and upon the condition that the client assumes all liability for the further distribution of the report or its contents.

Anlab
ANALYTICAL LABORATORY
A DIVISION OF DEWANTE & STOWELL
1914 S STREET, SACRAMENTO, CALIFORNIA 95814 • 916-447-2946

2. GC/MS

c. Polybutylene Pipe

Compound, ppb	Trichloroethane Exposure Box - B	Water Control Box - E
Dichloromethane	None Detected	10
Chloroform	None Detected	47
Acetone	None Detected	130

Gasoline, ppm	Exposure Box - D*	Control Box - E[2]
Butane	100	
Heptane	None Detected	None Detected
Benzene	100	None Detected
Toluene	100	None Detected
Octane	None Detected	None Detected
Xylenes	100	None Detected
Trimethylbenzenes	100	None Detected
Tetramethylbenzenes	100	None Detected
Ethylbenzene	100	None Detected

[2]No gasoline components detected.

*In addition, the following compounds were found in the exposed pipe which were not in the gasoline: Methylethylbenzene, cyclopentane, Dihydroindene, and Dimethylethylbenzene.

This report is applicable only to the sample received by the laboratory. The liability of the laboratory is limited to the amount paid for this report. This report is for the exclusive use of the client to whom it is addressed and upon the condition that the client assumes all liability for the further distribution of the report or its contents.

Anlab
ANALYTICAL LABORATORY
A DIVISION OF DEWANTE & STOWELL
1914 S STREET, SACRAMENTO, CALIFORNIA 95814 • 916-447-2946

d. Copper Pipe

Compound, ppb	Trichloroethane Exposure Box - B	Water Control Box - E
2-Butanone	640	None Detected
1-Chloropentene	30	None Detected
Toluene	80	None Detected
Dichloromethane	None Detected	57
Chloroform	None Detected	26

Gasoline, ppm	Exposure Box - D*	Control Box - E[2]
Butane	None Detected	None Detected
Heptane	None Detected	None Detected
Benzene	None Detected	None Detected
Toluene	10	None Detected
Octane	None Detected	None Detected
Xylenes	10	None Detected
Trimethylbenzenes	None Detected	None Detected
Tetramethylbenzenes	None Detected	None Detected
Ethylbenzene	None Detected	None Detected

[2]No gasoline compounds detected; no others detected.

*In addition, methylethylbenzene was found which was not a part of the gasoline.

DATA CERTIFIED BY Roger Elliott

REPORT APPROVED BY Ken Nanlo

ANLAB/T. Ikesaki

1k

This report is applicable only to the sample received by the laboratory. The liability of the laboratory is limited to the amount paid for this report. This report is for the exclusive use of the client to whom it is addressed and upon the condition that the client assumes all liability for the further distribution of the report or its contents.

Anlab
ANALYTICAL LABORATORY
A DIVISION OF DEWANTE & STOWELL
1914 S STREET, SACRAMENTO, CALIFORNIA 95814 • 916-447-2946

October 5, 1982

PILOT PIPE STUDY

PHASE I

Assemble pipe chambers. Pressurize the pipes to approx. 40 psi (working conditions). Wait 48 hrs. and check for any signs of water leaks in the pipe structures. After the sealants are cured, fill each box with water to demonstrate a sealed chamber.

PHASE II

After the chambers are leak-free, they are then filled with fresh water, as are the pipes. Measure approximate flush volume through the pipes. The chambers are left overnight and checked for leaks, after which the chambers are emptied and dried.

PHASE III

Fill each chamber with "washed" sand. Label each box uniquely and label each type of pipe [1] uniquely. Collect an initial water sample and preserve as a control sample. Fill and pressurize the pipes to working conditions. Saturate each chamber with its prospective compound or formulation [2]. Each chamber to be sealed with silicon rubber and a wire security tag, to be attached at two places on the lid. Contact time shall be one week, after which the water from each pipe type will be collected, marked for identification, analyzed, and volume measured [3].

PHASE IV

The pipes will be flushed and refilled to operating conditions. The lids will be opened and chambers refilled (where required) with their respective compounds, to saturation. The procedure will be the same as in Phase III except a two-week exposure time will elapse.

PHASE V

All samples from the pipes will be analyzed for their respective compounds. In addition, they will be compared to: (a) the initial water control; (b) a standard of the original compound or formulation; (c) the control box "E" samples. From this data, it will be determined if any of these compounds are

present and if any other compounds (either from the formulations or the structural materials) have entered the water from or through the pipe.

PHASE VI - APPENDIX

A. All stages of work will be photographed.

B. Complete pipe descriptions will be recorded, including manufacturer if possible.

C. Sections of each pipe will be kept for material evidence.

D. Final disposition of all sand, compounds and samples to be done by Anlab.

E. Daily checks to be made of each chamber for its intactness and for any leaks.

F. Several checks to be made during each contact time that the chamber remains at saturation and appropriate solutions are added if needed.

1/

Pipe Material	Lab Identification
Polyvinyl chloride - white	PV-W
Polybutylene - Black	PB-K
Polybutylene - Blue	PB-E
Polyethylene - Black	PE-K

2/

Box Label	Compound	Conc.
A	1,2-Dichloropropane	100%
B	1,1,1-Trichloroethane	100%
C	Chlordane-8E	1% formulation
D	Super Unleaded Gasoline	100%
E	Tap Water	100%
F	Spare	

3/ Analyses of compounds will follow EPA protocol where applicable.

Compound	EPA Method No.
Chlordane	608
1,2-Dichloropropane	624
1,1,1-Trichloroethane	624
Gasoline	624

Thomas I. Ikesaki
Laboratory Director

TII:lk

MATERIAL DATA SHEETS

The written data found on the side of each pipe was carefully recorded and checked for accuracy.

Polyvinylchloride Pipe (Lab Code PVW) White, rigid.

Pipe Code: Extruded Plastic Co. NSF-pw 3/4" IPS SC-40-80PSI @ 73°F PVC 1120 ASTM D1785-75

Polyethylene Pipe (Lab Code PEK) Black, coiled.

Pipe Code: Westflex Series 80 3/4" Polyethylene 80 PSI 6-82 B-15

Polybutylene Pipe (Lab Code PBK) Black, coiled*.

Pipe Code: 3/4" Westflex 250 PSI Polybrute PB2110 SDR9 Water Service Tubing NSF-pw-SE-W-C-248-79

Polybutylene Pipe (Lab Code PBE) Blue, coiled*.

Pipe Code: 3/4" CTS Westflex Polybrute PB-2110 250 psi SDR-9 ASTM-D-2666 Water Service Tubing NSF-PW-S-B-27 10-81

Copper Pipe (Lab Code CCC) Copper, rigid.

Pipe Code: 3/4" - TYPE L - Made in U.S.A. - Phelps Dodge

* Both blue and black were used in each box.

CHEMICAL DATA SHEETS

1,1,1-Trichloroethane, (Stabilized), Technical Grade, $C_2H_3Cl_3$, F.W.133.4, Lot 217621, 20L, Cat. #W509-1, J.T. Baker Chemical Co., Phillipsburg, NJ 08865

1,2-Dichloropropane, 99%, Toxic!Irritant!Flammable!, F.W. 112.99, $CH_3CH(Cl)CH_2Cl$, b.p. 95-96°, N_D^{20} 1.4384, d 1.156, Lot No. EJ 0921DJ, Cat. #D7,218-2, 4kg, Aldrich Chemical Co., Inc., Milwaukee, WI 53233

Super Unleaded Gasoline, Chevron, Inc.

Chlordane 8E, Lilly Miller, Insecticide, Termites (Subterranean), Active Ingredients: *Chlordane, technical... 72.3%; Petroleum distilate... 21.5%; Inert Ingredients... 6.2%, *Equivalent to 43.38% Octachloro-4,7-Methanotetrahydroindane and 28.92% related compounds, Net Contents: 1/2 gallon, The Chas. H. Lilly Co., Portland, Oregon 97218, EPA Est 802-OR-1, EPA Reg. No. 802-71

Water, Sacramento City Public Water, from tap.

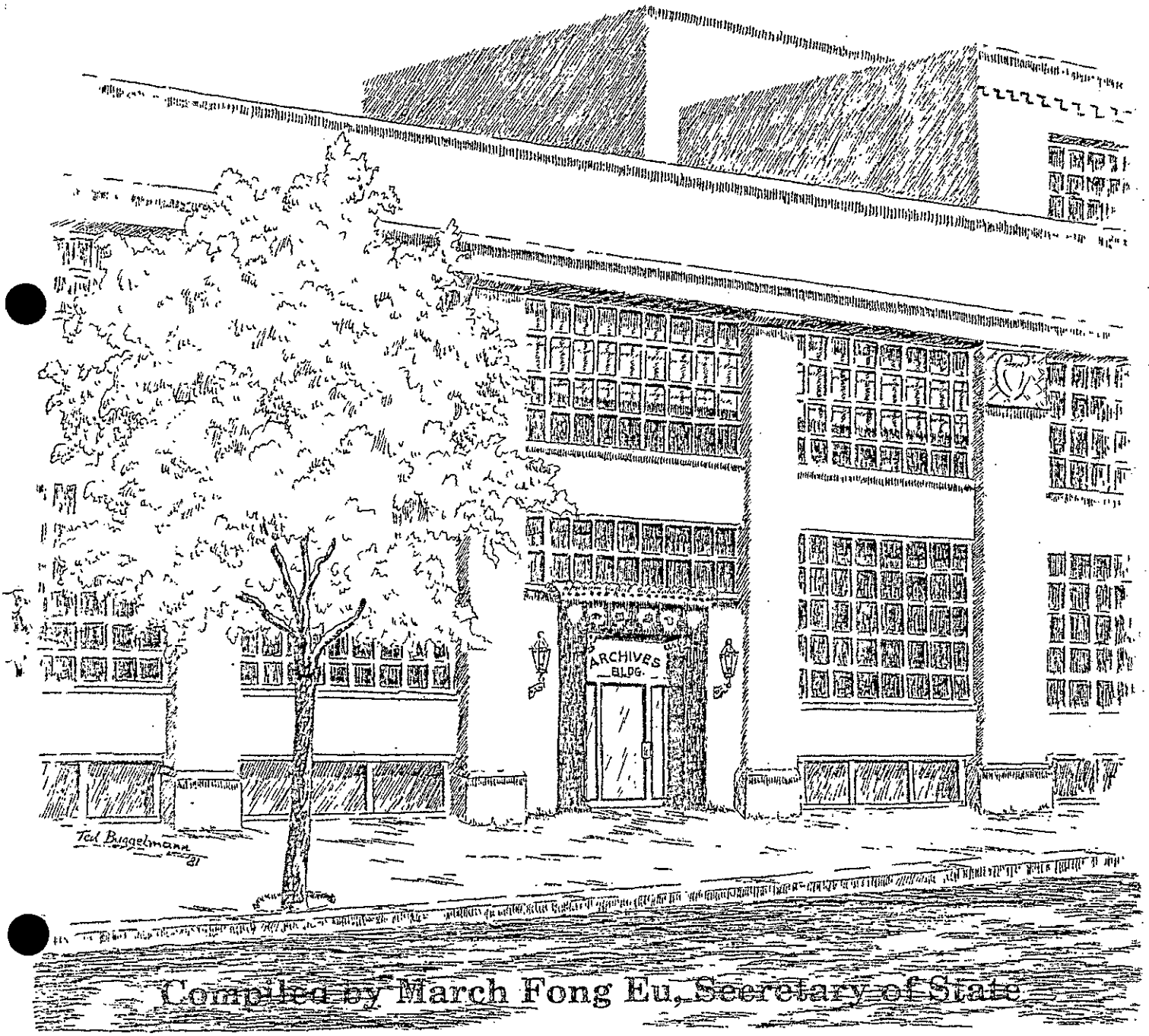
PIPE CAPACITY/VOLUME

PV-W-A	2000 ml
PE-K-A	1600
PE-KE-A	1600
CC-C-A	1600
PV-W-B	2000
PE-K-B	1600
PE-KE-B	1600
CC-C-B	1600
PV-W-C	2000
PE-K-C	2100
PB-KE-C	1600
CC-C-C	1800
PV-W-D	2000
PE-K-D	1600
PE-KE-D	1600
CC-C-D	1600
PV-W-E	2000
PE-K-E	2000
PB-KE-E	1400
CC-C-E	1600

28. Eu, March Fong (Secretary of State). 1981-82 California Roster, 1983

1981-1982

CALIFORNIA ROSTER



Compiled by March Fong Eu, Secretary of State

ROSTER

CALIFORNIA STATE, COUNTY, CITY AND TOWNSHIP OFFICIALS
STATE OFFICIALS OF THE UNITED STATES

DIRECTORY OF STATE SERVICES
OF THE
STATE OF CALIFORNIA

COMPILED BY

MARCH FONG EU
SECRETARY OF STATE

1981–1982

CONTENTS

	Page
Legislative Department	3
Legislative District Maps	9
Legislative Districts by Counties	15
History of California State Officeholders	17
Executive Branch California State Government	20
State Agencies	21
Agricultural Associations	77
Counties	82
California Marshals and Constables	105
Cities Election Dates	108
City and Town Officials for California	110
Unincorporated Areas of California	186
Legal Holidays in California	190
Consular Corps	191
State Officials for United States	194
Index	209

COUNTIES

(A) = Appointed Officials

ALAMEDA COUNTY

Incorporated March 25, 1853
(Charter Form of Government)

Legislative Districts: 8th, 9th and 10th Congressional; 8th, 9th and 11th Senatorial; 12th, 13th, 14th, 15th and 25th Assembly

Population: 1,108,300

COUNTY SEAT, OAKLAND

Central County Info: 1221 Oak Street, 94612; 415-874-5556

County Administrator: Mel Hing

Board of Supervisors

Meetings held every Tuesday.

Donald A. Excell, District 1, Pleasanton
Charles Santana, District 2, San Leandro
Fred F. Cooper, District 3, Alameda
Joseph P. Bort, District 4, Berkeley (Chairman)
John George, District 5, Oakland

Elected and Appointed Officials

Assessor, Donald J. Hutchinson
Auditor-Controller, Donald M. Parkin
County Clerk-Recorder, Rene C. Davidson
District Attorney, D. Lowell Jensen
Sheriff, Glenn E. Dyer
Superintendent of Schools, Robert C. Coney
Treasurer-Tax Collector, Robert G. Knox
Director, Public Works, H. A. Flertzheim (A)
Director, Planning, William H. Fraley (A)
Purchasing Agent, Patricia Henas (A)
Director, Social Services, Librado Perez (A)
Public Defender, James Jenner (A)
County Counsel, Richard J. Moore (A)
Parks and Recreation, N/A (A)

Superior Court Judges

Richard Hodge, Michael E. Ballachey, Robert K. Barber, Robert L. Bostick, Carl West Anderson, John S. Cooper, Ken M. Kawaichi, Stanley P. Golde, Winton McKibben, Henry Ramsey, Jr., Allen E. Broussard, Harold B. Hove, Robert H. Kroninger, J. P. Vukasin Jr., Alan A. Lindsay, Martin N. Pulich, Gorden Minder, Richard A. Bancroft, Richard Bartilini, Howard L. Schwartz, John J. Purchio, Myron A. Martin, M. O. Sabraw, Jr., Zook Sutton, Wilmont Sweeney, Richard A. Haugner, Jacqueline Taber, Raymond Marsh, Donald McCullum, Demetrios P. Agretelis

Municipal Court Judges

Alameda Judicial District: George E. McDonald

Berkeley-Albany Judicial District: Mario H. Barsotti, George Brunn, Dawn B. Girard, Carol S. Brosnahan

Fremont-Newark-Union City Judicial District: Roy G. Pucci, James F. Perley, Joseph W. Jay

Livermore-Pleasanton Judicial District: John A. Lewis, Mark L. Eaton

Oakland-Piedmont Judicial District: Courtland Arne, Clifford B. Bachand, Roderic Duncan, Carlos G. Ynostroza, Marie Collins, William F. Levins, James Stanford White, Lewis P. May, Benjamin Travis, J. Robert Friborg, Gordon S. Baranco, James C. Walsh, Jr., Vacant

San Leandro-Hayward Judicial District: Robert K. Byers, Dallas Edgar, Robert Fairwell, David E. Hunter, Alfred A. Delucchi, Joseph J. Carson, William Shannon Parrish

ALPINE COUNTY

Incorporated March 16, 1864

Legislative Districts: 14th Congressional; 13th Senatorial; 7th Assembly

COUNTY SEAT, MARKLEEVILLE

County Central Info: County Administrative Office Building 916-694-2281

Population: 1,200

Board of Supervisors

Meetings held first and third Tuesdays of each month.

Franklin F. Jerauld, District 1, Markleeville
William K. Freeman District 2, Bear Valley
Stuart P. Merrill, District 3, Markleeville
Harold Duarte, District 4, Woodfords
Wilton H. Neddenriep, District 5, Fredericksberg
Chairman not indicated

Elected and Appointed Officials

Assessor, Roger L. Olson
County Clerk, Joan G. Chacon
Auditor-Recorder, Barbara Ryan
Public Works Director, John Haug (A)
District Attorney-Public Adminstrator, Henry G. Murdock
Sheriff-Coroner, Archie P. Wood, Jr.
Superintendent of Schools, Richard Martin
Treasurer-Tax Collector, Clyde Brooker
Planner, Leonard Turnbeaugh (A)
Social Welfare, Robert Eakins (A)
County Counsel, Henry G. Murdock
Parks & Recreation, None
Purchasing Agent, None
Public Defender, None

Superior Court Judge

J. Hilary Cook

Justice Court Judge

Alpine Judicial District: Thomas M. Kelly

AMADOR COUNTY

Incorporated May 11, 1854

Legislative Districts: 14th Congressional; 13th Senatorial; 7th Assembly

Population: 19,261

COUNTY SEAT, JACKSON

County Central Info: 108 Court Street 209-223-0840

Board of Supervisors

Meetings held Tuesday of each week at 9 a.m. in

Supervisors' Room.
John C. Begovich, District 1, Jackson
Myron D. Questo, District 2, Ione
Fred C. Joyce, District 3, Pine Grove
Willard W. Summers, District 4, Sutter Creek (Chairman)
Jon D. Colburn, District 5, Plymouth

Elected and Appointed Officials *

Assessor, Raymond Olivarria
Coroner, Ronald G. Curran
County Clerk-Recorder, Sheldon D. Johnson
District Attorney, Gale Cuneo
Sheriff, Ronald G. Curran
Superintendent of Schools, Lawrence Ferdani
Treasurer-Tax Collector, Elmer G. Evans
Public Works Director, Gary Caldwell
Planning Director, Gary Clark
Purchasing Agent, Trevor Mottishaw
Welfare Director, Janet Lovett
Public Defender, None
County Counsel, John F. Hahn
Auditor-Controller, John Kirkpatrick
* Did not indicate appointed positions.

Superior Court Judge

Martin Ryan

Justice Court Judge

Amador Judicial District: Don F. Howard

BUTTE COUNTY

Incorporated February 18, 1850
(Charter Form of Government)
Legislative Districts: 1st Congressional; 1st Senatorial; 1st and 3rd Assembly
Population: NOT SUBMITTED
COUNTY SEAT, OROVILLE
County Central Info: 25 County Center Drive, 95965
(916) 534-4783
County Administrator: Clifton C. Mickelson (A)

Board of Supervisors

Meetings held Tuesday of each week in Butte County Administration Building

Alfred J. Saraceni, District 1, Oroville
Jane Dolan, District 2, Chico
Hilda Wheeler, District 3, Chico (Vice Chairman)
Bertha Moseley, District 4, Oroville (Chairman)
Robert Lemke, District 5, Paradise

Elected Officials

Assessor, Edwin Brown
Auditor, James Johansen
County Clerk-Recorder, Clark A. Nelson
District Attorney, Will Mattly
Sheriff-Coroner, Larry Gillick
Superintendent of Schools, Duane Powers
Treasurer-Tax Collector, Carl Morton

Superior Court Judges

Reginald Watt, Loyd H. Mulkey, Jr., Lucian B. Vandegrift

Municipal Court Judge

Ann H. Rutherford

Justice Court Judges

Biggs Judicial District, Norris Goodwin
Gridley Judicial District, Steven McNells
Oroville Judicial District, Brian Rix
Paradise Judicial District, Brian Rix

CALAVERAS COUNTY

Incorporated February 18, 1850
Legislative Districts: 14th Congressional; 13th Senatorial; 7th Assembly
Population: NOT SUBMITTED
COUNTY SEAT, SAN ANDREAS
No Central County Info number

Board of Supervisors

Meetings held every Monday morning of each month in Courts and Legal Building

John J. Lodato, District 1, San Andreas (Chairman)
Thomas A. Taylor, District 2
Suzanne Kuehl, District 3
Charles Wistos, District 4
J. W. "Wes" Hodgson, District 5, Valley Springs

Elected Officials*

Assessor, Charles Clark
Auditor-Controller, Joann Long
Coroner, Adolph A. Gualdoni
County Clerk-Recorder, Nadine Jackson
District Attorney, Douglas Mewhinney
Sheriff, Claud C. Ballard
Treasurer-Tax Collector, Marian Hewett
Public Works Director, Charles R. Leitzell
Planning Director, Brent Harrington
Purchasing Agent, John Crane
Social Welfare Director, Thomas Miller
Public Defender, William B. Wolfson
County Counsel, Jeffrey Tuttle
*Did not indicate appointed positions

Superior Court Judge

Joseph S. Huberty

Justice Court Judges

Calaveras Judicial District, Orrin K. Airola

COLUSA COUNTY

Incorporated February 18, 1850
Legislative Districts: 4th Congressional; 1st Senatorial; 3rd Assembly
Population: 13,000
COUNTY SEAT, COLUSA
County Central Info: 546 Jay Street, 95932
916-458-4516

Board of Supervisors

Meetings held Tuesdays of each week, 10 a.m., Hall of Records Bldg., 546 Jay St.

H. L. Peterson, District 1, Arbuckle
Howard Foster, District 2, Colusa
Floyd Myers Marsh, District 3, Williams
T. K. Marshall, District 4, Princeton (Chairman)
David G. Womble, District 5, Colusa

Elected and Appointed Officials

Assessor, E. Dan O'Connell, III
Auditor, Robert L. Kessinger
Coroner-Public Administrator, Eugene P. Moore
County Clerk-Recorder, Martha Nannen
District Attorney, William L. Fisher
Sheriff, Bobby D. McWatters (A)
Superintendent of Schools, Clinton B. Nielson
Treasurer-Tax Collector, Myles W. Spann
Public Works Director, Dan Klar (A)
Planning Director, Stanley Walker (A)
Purchasing Agent, Jack Lawrence (A)
Social Welfare Director, Lucy I. Lack (A)
Public Defenders, Jerre Box, Leo Steidlmayer (A)
County Counsel, Harold Wilsey, Jr. (A)
Parks & Recreation Director, None (A)

Superior Court Judge

Richard E. Patton

Justice Court Judge

Colusa-Williams Judicial District, Al J. Carrion

CONTRA COSTA COUNTY

Incorporated February 18, 1850
Legislative Districts: 7th, 8th (por.), and 9th (por.) Congressional; 7th and 9th (por.) Senatorial; 10th, 11th and 12th (por.) Assembly
Population: 645,300

COUNTY SEAT, MARTINEZ
County Central Info: Courthouse, 415-372-4121

County Administrator: Melvyrn G. Wingett

Board of Supervisors

Meetings held Tuesdays of each month, Administration Building.

Tom Powers, District 1, Richmond (Chairman)
Nancy C. Fahden, District 2, Martinez
Robert I. Schroder, District 3, Lafayette
Sunne Wright McPeak, District 4, Concord
Tom Torlakson, District 5, Antioch

Elected and Appointed Officials*

Assessor, Carl Rush
Auditor-Controller, Donald L. Bouchet
County Clerk-Recorder, James R. Olsson
District Attorney-Public Administrator, William A. O'Malley
Sheriff-Coroner, Richard K. Rainey
Superintendent of Schools, Richard LaPointe
Treasurer-Tax Collector, Alfred P. Lomeli
Purchasing Agent (County Auditor-Controller), Donald L. Bouchet
Public Works Director, J. Michael Walford
Planning Director, Anthony A. Dehaesus
Health Services, Arnold S. Leff, M.D.
Public Defender, Patrick R. Murphy
County Counsel, John B. Clausen
Social Services, Robert E. Jornlin
*Did not indicate appointed positions

Superior Court Judges

Richard E. Arnason, William R. Channell, Robert J. Cooney, David Dolgin, Sam Hall, Wayne A. Westover, Gary E. Strankman, Thomas F. McBride, Martin E. Rothenberg, Max Wilcox, Jr., Coleman F. Fannin, E. Patricia Herron, Richard L. Patsey, Norman Spellberg

Municipal Court Judges

Mt. Diablo Judicial District, John D. Hatzenbuhler, Louis L. Edmunds, Mark B. Simons, Ellen S. James
Bay Judicial District, Bessie P. Dreibelbis, David W. Calfee, George Carroll, Thomas F. Curtin
Delta Judicial District, Manual C. Rose, Jr., Gerald A. Belleci
Walnut Creek-Danville Judicial District, Joseph R. Longacre, Jr., Michael J. Phealn, John C. Minney

Juvenile Court Referees

Mark Thomas, Douglas T. Corbin

DEL NORTE COUNTY

Incorporated March 2, 1857
Legislative Districts: 2nd Congressional; 2nd Senatorial; 2nd Assembly
Population: 18,210

COUNTY SEAT, CRESCENT CITY
County Central Info: Courthouse, Crescent City 707-464-3101

Board of Supervisors

Meetings held first four Mondays of each month at 9:30 a.m.

Helga Burns, District 1, Crescent City
Richard Brown, District 2, Crescent City
Joyce Crockett, District 3, Gasquet
Dale Rupert, District 4, Crescent City
Peter Kaufman, District 5, Klamath
Chairman not indicated

Elected and Appointed Officials

Assessor, Gerald Cochran
County Clerk-Recorder, John D. Alexander
District Attorney, Robert W. Weir
Auditor-Controller, William Fullan
Sheriff-Coroner, G. Thomas Hooper
Superintendent of Schools, Arthur Timmer
Treasurer-Tax Collector, Nadine Finley
County Counsel, Thomas S. Owen (A)
Planning Director, Ross Cox (A)
Public Defender, Vacant (A)
Purchasing Director, Ellen Brown (A)
Parks and Recreation Director, Paul Taylor (A)

Superior Court Judge

Frank S. Petersen

Justice Court Judge

Del Norte County Judicial District, William W. Speer

EL DORADO COUNTY

Incorporated February 18, 1850
Legislative Districts: 14th Congressional; 13th Senatorial; 7th Assembly
Population: 56,603

COUNTY SEAT, PLACERVILLE
County Central Info: 330 Fair Lane, Placerville 95667
916-626-2238

County Administrative Officer: Kent Taylor

Board of Supervisors

Meetings held Tuesday of each week.

Robert Dorr, District 1, Placerville
Patricia Lowe, District 2, South Lake Tahoe
William P. Walker, Jr., District 3, Placerville ~~(Chairman)~~
Joseph V. Flynn, District 4, Camino
Thomas L. Stewart, District 5, South Lake Tahoe (Chairman)

Elected and Appointed Officials

Assessor, John H. Thorne
Auditor, Amelia McAnnally
County Clerk, Dolores Bredeson
District Attorney, Ronald Tepper
Recorder, Dorothy Carr
Sheriff-Coroner, Richard F. Pacileo
Superintendent of Schools, Hazel E. Hoak
Treasurer and Tax Collector, Elvis R. Ferguson
Public Works Director, G. Arthur Cort (A)
County Counsel, David Whittington (A)
Public Defender, Stephen A. Tapson (A)
Planning Director, Ken Milam (A)
Purchasing Agent, William Schultz (A)
Welfare Director, Paul Berman (A)

Superior Court Judges

Charles F. Fogerty, William E. Byrne, Terrence M. Finney

Justice Court Judges

El Dorado Judicial District, Jerrold L. Wenger
Georgetown Divide Judicial District, Thomas A. Smith
Lake Valley Judicial District, L. Eugene Rasmussen
Placerville Judicial District, Lloyd B. Hamilton

FRESNO COUNTY

Incorporated April 19, 1856
(Charter Form of Government)

Legislative Districts: 15th and 17th Congressional; 14th and 15th Senatorial; 30th and 31st Assembly
Population: 456,500

COUNTY SEAT, FRESNO
County Central Info: 2200 Fresno St., 93721, 409-488-3033

County Administrative Officer: Allan H. Colman

Board of Supervisors

Meetings held Tuesday of each week.

Harry Huey, District 1, Fresno
Sheron Levy, District 2, Fresno
Bruce Bronzan, District 3, Fresno (Chairman)
Willard H. Johnson, District 4, Fresno
Jeff Reich, District 5, Fresno

Elected and Appointed Officials *

Assessor, William C. Greenwood
Auditor-Controller, Lawrence D. Jernagan
County Clerk-Recorder, Galen Larson
District Attorney, Dale A. Blickenstaff
Coroner-Public Administrator, David M. Hadden, M.D.
Sheriff, Harold C. McKinney
Superintendent of Schools, Ernest A. Poore
Treasurer-Tax Collector, James B. Malmstrom
Public Works Director, Clinton Berry
Planning Director, Acting, Robert Bolt
Social Welfare Director, Ben J. Kelley
Public Defender, Melvin W. Nitz
County Counsel, Floyd R. B. Viau
* Did not indicate appointed positions

Superior Court Judges

A. Dennis Caeton, Hollis G. Best, Eugene W. Krum, Leonard I. Meyers, John Fitch, Blaine Pettitt, Stephen R. Henry, Frank J. Creede, Jr., Wilbur K. Kessler, Robert L. Martin, Charles F. Hamlin, Robert Mardikian, Vacant.

Municipal Court Judges

Annette LaRue, Gene M. Gomes, Carl P. Evans, James Ardaiz, Armando Rodriguez, Joan L. McIntosh, Vacant, Lemore Schreiber, John P. Zylka, William Kent Levis, Jr. (Court Commissioner), Everett H. Longstaff (Clerk)

Justice Court Judges

Caruthers-Fowler Judicial District, Mikio Uchiyama
Coalinga Judicial District, Aubrey H. Seed
Dunlap-Reedley Judicial District, Charles W. Edwards
Firebaugh-Kerman Judicial District, Dennis R. Scott
Kingsburg-Riverdale Judicial District, James Aaron
Parlier-Selma Judicial District, Mario G. Olmos
Sanger Judicial District, no name submitted

GLENN COUNTY

Incorporated March 11, 1891
Legislative Districts: 1st Congressional; 1st Senatorial; 1st Assembly
Population: 21,300

COUNTY SEAT, WILLOWS
County Central Info: 526 W. Sycamore St., Willows 95988, 916-934-3364

Board of Supervisors

Meetings held first four Tuesdays of each month in courthouse.

Stephen Blacet, District 1, Orland
George A. Edwards, District 2, Orland
George F. Pride, District 3, Willows
Jean Rumiano, District 4, Willows
Keith C. Hansen, District 5, Glenn

Elected and Appointed Officials

Assessor, R. McCulloch
Auditor-Controller, Joseph W. Sites
County Clerk-Recorder, Milton E. Walker
District Attorney, Robert Maloney
Public Administrator, Betty Hardcastle
Sheriff-Coroner, Roger Roberts
Superintendent of Schools, Ralph L. Herman
Treasurer-Tax Collector, R. Christina Nelson
Road Commissioner, Jack Gilmore (A)
Planning Director, Ed Howard (A)
Welfare Director, Don Louderback (A)
County Counsel, Leonard G. Krup (A)
Parks Director, Bill Quint (A)

Superior Court Judge

Roy G. MacFarland

Justice Court Judges

Orland Judicial District, Robert Trimble
Willows Judicial District, Bruce H. Thomas

HUMBOLDT COUNTY

Incorporated May 12, 1853
Legislative District: 2nd Congressional; 2nd Senatorial; 2nd Assembly
Population: 107,000

COUNTY SEAT, EUREKA
County Central Info: Humboldt County Courthouse, 1st Fl., Eureka
County Administrative Officer: Robert E. Hendrix

Board of Supervisors

Meetings held Tuesday of each month at 9:00 a.m.

Ervin C. Renner, District 1, Eureka
Harry Pritchard, District 2, Fortuna (Chairman)
Wesley Chesbro, District 3, Arcata
Danny Walsh, District 4, Eureka
Erick Hedlund, District 5, Trinidad

Elected and Appointed Officials *

Assessor, Raymond Flynn
Auditor-Controller, Neil Prince
Coroner-Public Administrator, Glenn H. Sipma
County Clerk, Donald Michael
District Attorney, Bernie DePaoli
Recorder, Grace Jackson
Sheriff, Gene W. Cox
Superintendent of Schools, Bill C. Rich
Treasurer and Tax Collector, Stephen A. Strawn
* Did not indicate appointed positions

Superior Court Judges

Thomas M. Montgomery, Lawrence A. Truitt, John E. Buffington

Municipal Court Judges

Harold Neville, John Morrison

Justice Court Judges

Arcata Judicial District, Ronald D. Rowland
Fortuna Judicial District, Leslie V. Suprey
Garberville Judicial District, John R. Morrison
Klamath-Trinity Judicial District, P. Timothy Murphy

IMPERIAL COUNTY

Incorporated August 15, 1907
Legislative Districts: 38th Congressional; 43rd Senatorial; 75th Assembly
Population: NOT SUBMITTED

COUNTY SEAT, EL CENTRO
County Central Info: Courthouse, El Centro 92243 714-352-3610
County Administrative Officer: John McClure, II

Board of Supervisors

Meetings held every Tuesday, 9:00 a.m.

Luis M. Legaspi, District 1, Calexico
John Kennerson, District 2, El Centro
James M. Bucher, District 3, Imperial
Abe Seabolt, District 4, Brawley
Louis Curiel, District 5, Holtville (Chairman)

Elected and Appointed Officials *

Assessor, Walter Lancaster
Auditor-Controller, David A. Titsworth
County Clerk, Harry M. Free
District Attorney, Roger Cognata
Public Administrator, Phyllis J. Roberts
Recorder, Dolores Provencio
Sheriff-Coroner, Oren R. Fox
Superintendent of Schools, Herbert S. Farrar, Jr.
Tax Collector, Leon F. Baker
Treasurer, Ronald Gene Lemon
* Did not indicate appointed positions

Superior Court Judges

L. Harold Chaille, Henry Wein, Vacant

Municipal Court Judges

Matias Contreras, Robert Fox, William Lehnhardt, Vacant

INYO COUNTY

Incorporated March 22, 1866
Legislative Districts: 18th Congressional; 16th Senatorial; 34th Assembly
Population: 17,200

COUNTY SEAT, INDEPENDENCE
County Central Info: 168 N. Edwards St. Independence 714-878-2411
County Administrator: John K. Smith

Board of Supervisors

Meetings held first four Tuesdays of each month.

H. B. Irwin, District 1, Bishop (Chairman)
P. D. Cook, District 2, Bishop
Wilma Muth, District 3, Bishop
Vernon E. "Johnny" Johnson, District 4, Independence
Robert Bremmer, District 5, Lone Pine

Elected and Appointed Officials *

Assessor, Jack Clay
Auditor, Richard Krejci
Coroner-Public Administrator, Leon Brune
County Clerk-Recorder, Margaret "Rita" Bromley
District Attorney, L. H. Gibbons
Sheriff, Floyd O. Barton
Superintendent of Schools, Janet Watkins
Treasurer-Tax Collector, John Treacy
Public Works Director, Harold Callahan
Planning Director, Edward J. Hilton
Purchasing Agent, John K. Smith
Social Welfare Director, Norman Paulson
Public Defender, Dean Stout
Parks and Recreation Director, James Angelo
Public Administrator, Fran Owen
* Did not indicate appointed positions

Superior Court Judge

Verne Summers

Justice Court Judge

Donald L. Chapman

KERN COUNTY

Incorporated April 2, 1866

Legislative Districts: 18th Congressional; 15th and 16th Senatorial;
32nd, 33rd, and 34th Assembly
Population: 400,506

COUNTY SEAT, BAKERSFIELD

County Central Info: Civic Center, 1415 Truxtun Avenue, Bakersfield 93301, 805-861-2111

County Administrative Officer: Ronald S. Holden

Board of Supervisors

Meetings held each Tuesday at 10:00 a.m.

Gene Tackett, District 1, Delano (Chairman)
David A. Head, District 2, Lamont
Gene Young, District 3, Bakersfield
Trice Harvey, District 4, Bakersfield
John C. Mitchell, District 5, Bakersfield

Elected and Appointed Officials *

Assessor, Herbert E. Roberts
Auditor-Controller, Bill J. Jackson
Coroner-Public Administrator, Richard P. Gervais
County Clerk, Gale S. Enstad
District Attorney, Albert M. Leddy
Recorder, Ray A. Vercammen
Sheriff, Al Loustalot
Superintendent of Schools, Dr. Claude W. Richardson
Tax Collector-Treasurer, John R. Doty
County Counsel, Ralph B. Jordan
General Services, Director, Charles H. Bell
Parks & Recreation, Frank L. Stramler, Director
Planning Commission, Director, Randall L. Abbott
Public Defender, Willard L. Weddell
Public Health Officer, Leon M. Hebertson
Public Works Director, L. Dale Mills
Purchasing Agent, Thomas W. Keever
Welfare Director, O. C. Sills

* Did not indicate appointed positions

Superior Court Judges

Robert T. Baca, William A. Stone, Marvin E. Ferguson, John D. Jelletich, John M. Nairn, Walter Osborn, Jr., Gerald K. Davis, Lewis E. King.

Municipal Court Judges

West Kern: Walter H. Condley, Henry E. Bianchi, Jack E. Lund, James G. Bowles, Milton A. Elconin.
East Kern: Charles E. Porter, John M. Stanton

KINGS COUNTY

Incorporated March 22, 1893

Legislative Districts: 17th Congressional, 15th Senatorial; 32nd Assembly
Population: 71,000

COUNTY SEAT, HANFORD

County Central Info: Kings County Government Center, 1400 W. Lacey Blvd., Hanford 209-582-3211

Administrative Officer: Milton D. McCoy

Board of Supervisors

Meetings held each Tuesday at 10:00 a.m.

Leslie K. Brown, District 1, Lemoore (Chairman)
Joe Hammond, District 2, Corcoran
Evon G. Cody, District 3, Hanford
Daniel "Doyle" Davis, District 4, Hanford
Abel J. Meirelles, District 5, Hanford

Elected and Appointed Officials *

Assessor, Donald B. Drew
Auditor-Controller, Darrell Warnock
Coroner-Public Administrator, David O. Moore
County Clerk-Recorder, Joan L. Bullock
District Attorney, Robert R. Maline
Sheriff, Donald L. Bengtson
Superintendent of Schools, Harold H. Gibson
Treasurer-Tax Collector, Marion Rose
Public Works Director, Raymond Nielsen
Planning Director, Charles Gardner
Purchasing Agent, Earl Ray
Welfare Director, John T. Neyerlin
County Counsel, Larry G. McKee
* Did not indicate appointed positions

Superior Court Judges

Larry G. McKee, Charles W. Jennings

Justice Court Judges

Avenal Judicial District, Martin C. Suits
Corcoran Judicial District, Carlos P. Baker, Jr.
Hanford Judicial District, Timothy S. Buckley
Lemoore Judicial District, Manuel N. Vierra

LAKE COUNTY

Incorporated May 20, 1861

Legislative Districts: 2nd Congressional; 2nd Senatorial; 2nd Assembly
Population: 35,000

COUNTY SEAT, LAKEPORT

County Central Info: 255 No. Forbes Street, Lakeport, 95453, 707-263-2367
County Administrative Officer: Position repealed

Board of Supervisors

Meetings held Mondays and Tuesdays of each month at 9 a.m. in Courthouse

Howard D. Day, District 1, Lower Lake
Vacant, District 2, Clearlake Oaks
Walter C. Wilcox, District 3, Nice (Chairman)
Ray Couch, District 4, Lakeport
Jesse Combs, District 5, Kelseyville

Elected and Appointed Officials*

Assessor, Verdon L. Strong
Auditor-Controller, Norma J. Barker
County Clerk-Recorder, Lois R. Hesterberg
District Attorney-Public Administrator, Robert L. Crone, Jr.
Sheriff-Coroner, Alvie G. Rochester
Superintendent of Schools, Judith E. Luchsinger
Tax Collector-Treasurer, Cora L. Taylor
Health Director, Vacant
Health Officer, Sidney W. Maurer, Jr. M.D.
Planning Director, George R. Volker
Parks & Recreation Director, Eugene P. Collins
Welfare Director, Dana Tryk
County Counsel, Charles D. Haughton
Purchasing Agent, Dale Barney
* Did not indicate appointed positions

Superior Court Judge

John J. Golden

Justice Court Judges

Clearlake Highlands Judicial District, Richard L. Freeborn
Kelseyville Judicial District, Arthur H. Mann
Lakeport Judicial District, Raymond E. Schaal
Middletown-Lower Lake Judicial District, Henry E. Morse, Jr.
Upper Lake Judicial District, Anthony P. Bellante

LASSEN COUNTY

Incorporated April 1, 1864
Legislative Districts: 1st Congressional; 1st Senatorial; 1st Assembly
Population: 18,600

COUNTY SEAT, SUSANVILLE
Central County Info: Courthouse, South Lassen St., Susanville, 96130
916-257-7191

Board of Supervisors

Meetings held first four Tuesdays of each month at 10:00 a.m.

Paul Drake, District 1, Westwood
James L. Chapman, District 2, Susanville
Harold A. Stoy, District 3, Doyle
Frank A. Kimberling, District 4, Little Valley
William Farris, District 5, Susanville

Did not indicate Chairman

Elected and Appointed Officials

Assessor, Kenneth M. Stedman
Auditor-Recorder, Peter J. Ithurburn
County Clerk, Jacquelyn Fuller
District Attorney-Public Administrator, Paul DePasquale
Sheriff-Coroner, Delford L. Gorbet
Superintendent of Schools, Donald F. Mullaney
Treasurer-Tax Collector, Beatrice Price
Public Works Director, William D. McIntosh (A)
Planning/Purchasing Director, Mark A. Totten (A)
Social Welfare Director, Elyzabeth Lawson (A)
County Counsel, Dawson Arnold (A)

Superior Court Judge

Joseph B. Harvey

Justice Court Judge

Lassen Judicial District, Donald S. MacIntyre

LOS ANGELES COUNTY

Incorporated February 18, 1850
(Charter Form of Government)

Legislative Districts:
18th, 20th through 35th, Congressional;
19th through 33rd, Senatorial;
34th, 37th through 65th, Assembly
Population: NOT SUBMITTED

COUNTY SEAT, LOS ANGELES
County Central Info: 500 W. Temple St., Rm. 358, Los Angeles 90012, 213-974-1363

Chief Administrative Officer: Harry L. Hufford

Board of Supervisors

Meetings held each Tuesday at 9 a.m. in Room 381, Hall of Administration, 500 W. Temple Street

Peter E. Schabarum, District 1, Covina
Kenneth Hahn, District 2, Los Angeles (Chairman)
Edmund D. Edelman, District 3, Los Angeles
Deane Dana, District 4, Los Angeles
Michael D. Antonovich, District 5, La Canada

Elected and Appointed Officials *

Assessor, Alexander H. Pope
County Clerk, John J. Corcoran
District Attorney, John K. Van De Kamp
Sheriff, Peter J. Pitchess
Superintendent of Schools, Dr. Stuart E. Gothold
Treasurer-Tax Collector, Howard B. Alvord
Planning Director, Norman Murdoch
Purchasing Agent, H. E. Davis
Social Services Director, Ed Tanaka
Public Defender, Wilbur Littlefield
County Counsel, John H. Larson
Parks & Recreation Director, Ralph S. Cryder
* Did not indicate appointed positions.

Superior Court Judges

Harold J. Ackerman, David J. Aisenson, Warren D. Allen,

Gilbert C. Alston, Robert T. Altman, Richard Amerian, Armand Arabian, John A. Arguelles, Frank Baffa, Arthur Baldonado, Victor T. Barrera, Alfonso M. Bazan, Elsworth M. Beam, Michael Berg, Florence Bernstein, M. Ross Bigelow, Ralph A. Biggerstaff, Paul G. Breckinridge, Jr., Richard P. Byrne, Raymond Cardenas, Eli Chernow, Raymond Choate, Sam Cianchetti, William R. Clay, Mario Clinco, John L. Cole, Barnet M. Cooperman, Jack A. Crickard, David F. Cunningham, Vincent S. Dalsimer, Warren H. Deering, George M. Dell, Max F. Deutz, Robert R. Devich, Alfred W. Dibb, Joseph J. DiGuiseppe, Burch Donahue, Roosevelt F. Dorn, Norman R. Dowds, William Drake, Rosemary Dunbar, Carroll M. Dunnum, David N. Eagleson, Alexander R. Early III, Paul Egly, Norman L. Epstein, D. Sterry Fagan, Robert Fainer, Robert Feinerman, Jerome K. Fields, Donald K. Fitzpatrick, David N. Fitts, Daniel L. Fletcher, Madeleine I. Flier, Vernon G. Foster, Thomas W. Fredricks, Charles E. Frisco, Hiroshi Fujisaki, Mario L. Fukuto, Richard A. Gadbois, Rafael H. Galceran, Jr., Kenneth Gale, Francis J. Garvey, Bruce R. Geernaert, Ronald M. George, Arthur Gilbert, August J. Goebel, Jack E. Goertzen, Samuel Greenfield, Gabriel A. Gutierrez, Richard F. C. Hayden, Robert J. Higa, Edward A. Hinz, Jr., Maurice R. Hogan, William P. Hogoboom, Charles M. Hughes, Harry L. Hupp, Hampton Hutton, Richard A. Ibanez, James M. Ideman, Thomas T. Johnson, Philip E. Jones, Charles E. Jones, Edward Y. Kakita, Burton Katz, Daniel Kaufmann, William B. Keene, Ernest L. Kelley, James Greeley Kolts, Richard G. Kolostian, Stephen M. Lachs, Richard Lavine, Gerald J. Levie, Julius A. Leetham, Thomas W. LeSage, Leslie W. Light, Charles S. Litwin, Robert B. Lopez, Robert H. London, John A. Loomis, Campbell M. Lucas, Elwood Lui, Stanley R. Malone, Jr., Robert Mallano, Alfred L. Margolis, Christian E. Markey, Jr., Francis X. Marnell, Arthur K. Marshall, Bonnie L. Martin, Albert D. Matthews, William E. McGinley, William J. McVittie, Billy G. Mills, Loren Miller, Jr., Richard Montes, H. Randolph Moore, Jr., Dion G. Morrow, Pat Mullendore, Aurelio Munoz, Thomas C. Murphy, Irwin J. Nebron, Henry P. Nelson, Jack M. Newman, Phillip M. Newman, Roy L. Norman, Robert C. Nye, Charles H. Older, Lester E. Olson, Robert M. Olson., Jr., Jerry Pacht, Harry V. Peetris, Glenn M. Pfau, George R. Perkovich, Jr., Sheila F. Pokras, Florence T. Pickard, Edward Rafeedie, Sara K. Radin, Roberta Ralph, William J. Rea, J. Wesley Reed, James N. Reese, Earl F. Riley, Everett E. Ricks, Fred Rimerman, Gordon Ringer, Laurence J. Rittenband, Robert L. Roberson, Mary Goode Rogan, William A. Ross, David M. Rothman, Frances Rothschild, Jack T. Ryburn, Philip M. Saeta, Leon Savitch, Charles R. Scarlett, Richard Schauer, Robert Schifferman, Thomas Schneider, S. S. Schwartz, Bernard S. Selber, Harry T. Shafer, Henry W. Shatford, Betty Jo Sheldon, Huey P. Shepard, John A. Shidler, Peter S. Smith, Lillian May Stevens, Peter H. Stevens, Robert S. Stevens, Stephen R. Stothers, Ronald E. Swearinger, Jack W. Swink, Jack Tenner, Dickran M. Tevrizian, Jr., Howard J. Thelin, David A. Thomas, Leon Thompson, Julius M. Title, Ricardo A. Torres, Jack B. Tso, W. James Turpit, Arch R. Tuthill, Carlos E. Velarde, Lawrence C. Waddington, J. Kimball Walker, Nancy B. Watson, Diane Wayne, Robert Weil, Richard L. Wells, Robert A. Wenke, Jacqueline L. Weiss, Jess Whitehill, Leonard S. Wolf, Delbert E. Wong, Charles H. Woodmansee, Eric Younger.

Municipal Court Judges

Alhambra Judicial District: Don R. Bercu, John R. Stanton, Jr., Carlos A. Uranga

Antelope Judicial District: Ian R. Grant, William H. Seelicke

Beverly Hills Judicial District: Andrew J. Weisz, Charles D. Boags, Jill Jakes

Burbank Judicial District: Marion E. Gubler, Bernard Kaufman

Citrus Judicial District: Fred A. Felix, Eugene Osko, Robert Young, John L. Nichols, William Robert Mayes, Michael B. Rutberg

Compton Judicial District: Homer L. Garrott, Hugo E. Hill, G. Tom Thompson, Cecil Mills, John H. Leahy, Dean E. Farrar

Culver City Judicial District: Frank W. Troost, Harold I. Cherness

Downey Judicial District: Reynaldo Chapparo, Leon Emerson, Richard C. Cumming, F. Lawrence Plotkin

East Los Angeles Judicial District: Mario P. Gonzales, Manuel Q. Sanz, Gilbert R. Ruiz, Benjamin U. Vega

Glendale Judicial District: Donald K. Fitzpatrick, Joseph R. Kalin

Inglewood Judicial District: Desmond J. Bourke, Wardell G. Moss, Roosevelt Robinson, Jr., John J. Lynch, Edward M. Ross, Kenneth E. Vassie

Long Beach Judicial District: Carl T. Zeiger, G. W. Dunn, Elvira S. Austin, Marcus O. Tucker, Jr., Eugene J. Long, W. H. Winston, William C. Beverly, Jr.

Los Angeles Judicial District: Richard A. Adler, Susan E. Andelson, Judith M. Ashmann, Ernest L. Aubry, Erich Auerbach, Glenette Blackwell, Aviva K. Bobb, Michael L. Burke, Nancy Brown, Isabel R. Cohen, Candace D. Cooper, Robert D. Fratianne, Leila Bulgrin, Martha Goldin, Carol Boas Goodson, Sidney Cherniss, James M. Coleman, Edward L. Davenport, Giles Jackson, Brian D. Crahan, Vincent M. Erickson, Edward I. Gorman, David A. Horowitz, David M. Horowitz, Patti Jo McKay, Barbara Jean Johnson, Harry Mock, Jr., Malcolm H. Mackey, Paul Metzler, L.C. Nunley, Ramona L. Godoy Perez, Maurice J. Hindin, Rand Schrader, Harold E. Shabo, David Perez, Ronald R. Schoenberg, David M. Kennick, Zenophon F. Lang, Abby Soven, Kathryn D. Todd, Rosemary Shumsky, Maxine F. Thomas, James P. Natoli, James F. Nelson, Marion L. Obera, Everette M. Porter, Morton Rochman, Juaneita M. Veron, James E. Satt, Michael T. Sauer, Harold J. Sinclair, Sherman W. Smith, Jr., Madge S. Watai, Clarence A. Stromwell, James S. Yip, George W. Trammell III, Mary E. Waters, Glenn A. Wymore, David A. Workman, Michael J. Yelovich.

Los Cerritos Judicial District: Joseph A. Farina, James E. Pearcie, Richard S. Hanki

Malibu Judicial District: John J. Merrick

Newhall Judicial District: Adrian W. Adams, Jack B. Clark

Pasadena Judicial District: Gary Klausner, Samuel L. Laidig, Mortimer G. Franciscus, John F. Hassler, Jr.

Pomona Judicial District: Robert Gustaveson, James H. Piatt, Thomas F. Nuss

Rio Hondo Judicial District: Jaime R. Corral, Milton Gelber, J. Gordon McNulty, Rudolph A. Diaz

Santa Anita Judicial District: John H. Saunders

Santa Monica Judicial District: Joseph W. Chandler, Rex H.

Minter, Robert W. Thomas
South Bay Judicial District: Thomas P. Foye, William R. Hollingsworth, Jr., William G. Willett, Benjamin Aranda III, Ernest M. Hiroshige, Mark Wood
Southeast Judicial District: John W. Bunnett, Porter deDubovay, Frank Gafkowski, Jr., John R. Hopson, Russell F. Schooling
Whittier Judicial District: Herber J. Adden, Jr., Alfonso D. Hermo, Patricia J. Hofstetter, James A. McKechnic

Justice Court Judge

Catalina Judicial District, Robert Lafont

MADERA COUNTY

Incorporated March 11, 1893
Legislative Districts: 15th Congressional; 14th Senatorial; 30th Assembly
Population: 63,078

COUNTY SEAT, MADERA
County Central Info: Government Center, 93637
209-674-4641

Administrative Officer: Donald M. Handly (A)

Board of Supervisors

Meetings held first four Tuesdays of each month. Administrative Practices Sessions first four Mondays of each month.

J. Gordon Kennedy, District 1, Madera
Alfred Ginsburg, District 2, Chowchilla
Elmo Del Bianco, District 3, Madera
Bill Hill, District 4, Ahwahnee
Wm. Donald Darnell, District 5, Bass Lake (Chairman)

Elected and Appointed Officials

Assessor, Richard E. Gordon
Auditor-Controller, Glenn R. Jessing
County Clerk-Recorder, Evelyn C. Branstetter
District Attorney, David D. Minier
Sheriff-Coroner, Ovonual Berkley
Superintendent of Schools, Norman M. Gould
Tax Collector-Treasurer, Willie A. Neufeld
County Counsel, Mark Wasser (A)
Planning Director, Leonard Garoupa (A)
Public Defender, Lester J. Gendron (A)
Health and Medical Director, James V. L. Bradley (A)
Welfare Director, Janice Edwards (A)

Superior Court Judge

Jack L. Hammerberg, Clifford H. Plumley

Justice Court Judges

Chowchilla Judicial District, Howard C. Green
Madera Judicial District, Victor C. Dahman
Sierra Judicial District, Kenneth R. Ballard

MARIN COUNTY

Incorporated February 18, 1850

Legislative Districts: 5th Congressional; 2nd Senatorial; 9th Assembly
Population: NOT SUBMITTED

COUNTY SEAT, SAN RAFAEL
County Central Info: Civic Center, San Rafael 94903
NO CENTRAL TELEPHONE NUMBER

County Administrator: John Barrows (A)

Board of Supervisors

Meetings held every Tuesday at 9:00 a.m.

Bob Roumiguiere, District 1, San Rafael
Barbara Boxer, District 2, Greenbrae
Al Aramburu, District 3, Tiburon
Gary Giacomini, District 4, West Marin
Gail Wilhelm, District 5, Novato

Elected Officials

Assessor, W. Bruce Shafer
Auditor-Controller, Michael Mitchell
Coroner, Ervin J. Jindrich
County Clerk, Peter Meyer
District Attorney, Jerry R. Herman
Recorder, W. Bruce Shafer
Sheriff, G. Albert Howenstein, Jr.
Superintendent of Schools, Virgil S. Hollis
Treasurer-Tax Collector-Public Administrator, Joseph A. Coffrini

Superior Court Judges

Henry J. Broderick, Peter Allen Smith, E. Warren McGuire, Joseph G. Wilson, David Menary, Jr., Richard H. Breiner

Municipal Court Judges

Gary W. Thomas, Robert A. Smallman, William H. Stephens, David R. Baty

MARIPOSA COUNTY

Incorporated February 18, 1850
Legislative Districts: 15th Congressional; 14th Senatorial; 30th Assembly
Population: 11,055

COUNTY SEAT, MARIPOSA
County Central Info: Courthouse, 95338
209-966-3222

Board of Supervisors

Meetings held first four Tuesdays of each month.

Carroll N. Clark, District 1, Midpines
Eugene Dalton, Jr., District 2, Coulterville
Eric Erickson, District 3, Hornitos
William H. Moffitt, District 4, Mariposa (Chairman)
Gertrude Taber, District 5, Mariposa

Elected and Appointed Officials *

Assessor, Steve Dunbar
Auditor-Recorder, Barbara P. Saye
County Clerk, Ellen Bronson
District Attorney-Public Administrator, J. Bruce Eckerson
Sheriff-Coroner, Paul E. Paige
Superintendent of Schools, George J. Barendse
Treasurer-Tax Collector, Don Z. Phillips
Social Welfare Director, Lois Lewis
County Counsel, Richard K. Denhalter
Parks & Recreation Director, Richard Begley
* Did not indicate appointed positions

Superior Court Judge

Dean C. Lauritzen

Justice Court Judge

Mariposa Judicial District, Egon W. Mueller

MENDOCINO COUNTY

Incorporated February 18, 1850
Legislative Districts: 2nd Congressional; 2nd Senatorial; 2nd Assembly
Population: NOT SUBMITTED

COUNTY SEAT, UKIAH
County Central Info: Courthouse, Ukiah

County Administrator: Albert Beltrami

Board of Supervisors

Meetings held every Tuesday at 9:00 a.m. in the Courthouse.

Thomas H. Crofoot, District 1, Ukiah
Dan Hamburg, District 2, Ukiah
James (Jim) C. Eddie, District 3, Potter Valley (Chairman)
John Cimolino, District 4, Fort Bragg
Norman de Vall, District 5, Mendocino

Elected Officials

Assessor, Duane K. Wells
Auditor-Controller, Merydel M. Peterson
County Clerk-Recorder, Viola N. Richardson
District Attorney-Public Administrator, Joseph D. Allen
Sheriff-Coroner, Thomas Jondahl
Superintendent of Schools, Louis G. Delsol
Treasurer-Tax Collector, Irene Lange

Superior Court Judges

Arthur B. Broaddus, Timothy W. O'Brien

Justice Court Judges

Anderson Judicial District, Richard Kossow
Arena Judicial District, Vincent Lechowick
Big River Judicial District, William Lamb
Little Lake Judicial District, Galen Hathaway
Long Valley Judicial District, Joseph Orr
Round Valley Judicial District, Kirk Gustafson
Sanel Judicial District, George Lee Nelson
Ten Mile Judicial District, Robert H. Heeb
Ukiah Judicial District, James Luther

MERCED COUNTY

Incorporated April 19, 1855

Legislative Districts: 15th Congressional; 14th Senatorial; 27th and 30th Assembly
Population: 118,783

COUNTY SEAT, MERCED
County Central Info: 2222 M Street 209-726-7434

County Administrator: Clark Channing

Board of Supervisors

Meetings held Tuesdays at 9:00 a.m.

Albert E. Bardini, District 1, Merced
Ann Klinger, District 2, Merced
Frederick J. Wack, District 3, Atwater
Albert E. Goman, District 4, Gustine (Chairman)
Pete Casinerio, District 5, Los Banos

Elected and Appointed Officials *

Assessor, David Cardella
Auditor-Controller-Recorder, LeRoy G. Gilsdorf
Coroner, Kenneth A. Riggs
Public Administrator, Pat Hallford
County Clerk, Kenneth L. Randol
District Attorney, Pat Hallford
Sheriff, Jess Bowling
Superintendent of Schools, William Stockard
Treasurer-Tax Collector, Norman Fullerton
Public Works Director, Vern L. Davis
Planning Director, Robert Petersen
Purchasing Agent, Sue Traves
Human Resources Director, Dean Richmond
Public Defender, John Ellery
County Counsel, Russell Koch
Parks & Recreation Director, George Rodrigues
* Did not indicate appointed positions

Superior Court Judges

George C. Barrett, III, Donald R. Fretz, George G. Murray

Municipal Court Judges

Robert M. Falasco, Robert Quall, Keith D. Sharrow

MODOC COUNTY

Incorporated February 17, 1874
Legislative Districts: 1st Congressional; 1st Senatorial; 1st Assembly
Population: 8,618

COUNTY SEAT, ALTURAS
County Central Info: Courthouse, Alturas 96101
916-233-2215

Board of Supervisors

Meetings held first and third Mondays of each month.

John B. Laxague, District 1, Cedarville
Melvin L. Anderson, District 2, Alturas
Neal Phillips, District 3, Alturas
M. W. Jones, District 4, Alturas, (Chairman)
Manuel P. Silva, District 5, Tulelake

Elected and Appointed Officials*

Assessor, Franklin R. Lew
Auditor and Recorder, M. F. "Peggy" Jones
County Clerk, Iris B. Turner
District Attorney-Public Administrator, John P. Baker
Sheriff-Coroner, Lynn E. Harris
Superintendent of Schools, Gordon L. House
Treasurer-Tax Collector, Maxine Gloster
*Did not indicate appointed positions

Superior Court Judge

Guy Martin Young

Justice Court Judge

Modoc Judicial District, Robert A. Barclay

MONO COUNTY

Incorporated April 24, 1861
Legislative Districts: 14th Congressional; 13th Senatorial; 7th Assembly
Population: 8,500

COUNTY SEAT, BRIDGEPORT
County Central Info: Courthouse, Bridgeport 93517
714-932-7911

Board of Supervisors

Meetings held first four Tuesdays of each month.

Bob Stanford, District 1 (Chairman)
Vacant, District 2
Paul Johnson, District 3
William M. Reid, District 4
E. L. Maner, District 5

Elected and Appointed Officials*

Assessor, Daniel L. Bryant
Auditor-Controller, Myron K. Schlaegel
County Clerk-Recorder, Renn Nolan
District Attorney, N. Edward Denton
Sheriff-Coroner, Martin Strelneck
Superintendent of Schools, Edward J. Inwood
Treasurer-Tax Collector, Alan C. Cohan
County Counsel, Neil B. Van Winkle
*Did not indicate appointed positions

Superior Court Judge

Harry R. Roberts

Justice Court Judge

Mono Judicial District, F. William Murano

MONTEREY COUNTY

Incorporated February 18, 1850
Legislative Districts: 16th Congressional; 17th Senatorial; 28th and 29th Assembly
Population: 275,000

COUNTY SEAT, SALINAS
County Central Info: Courthouse, 240 Church St., Salinas 93901, 408-424-8611

Administrative Officer: Richard Andrew

Board of Supervisors

Meetings held every Tuesday at 10 a.m. in Supervisors' Chambers, Courthouse.

Marc Del Piero, District 1, Watsonville
Barbara Shipnuck, District 2, Salinas (Chairman)
Dusan Petrovic, District 3, King City
Michal Moore, District 4, Monterey
William Peters, District 5, Monterey

Elected and Appointed Officials*

Assessor, Donald P. Stewart
Auditor, Stanley E. Davis
Coroner-Public Administrator, Harvey Hilbun
County Clerk-Recorder, Ernest A. Maggini
District Attorney, William Curtis
Sheriff, Bud Cook
Superintendent of Schools, James Stefan
Treasurer-Tax Collector, Thomas White
Public Works Director, Bruce McClain
County Counsel, Ralph Kuchler
Parks, Pete Soderberg
Planning Director, Edward W. DeMars
Social Services Director, Dardell McFarlin
Public Defender, Michael Lawrence
Purchasing, Chuck Thorson
*Did not indicate appointed positions

Superior Court Judges

Nat Agliano, Ralph Drummond, Edmund J. Leach, Jr., Harkjoon Paik, William Stewart, D. Richard Barelli, Richard Silver

Municipal Court Judges

Michael Fields, William Burleigh, Donald Thomas, John F. Novinger, William Moreno, Raymond Simmons, Robert O'Farrell

Justice Court Judges

Central Judicial District, Alan Hedegard
Southern Judicial District, Howard T. Hudson

NAPA COUNTY

Incorporated February 18, 1850

Legislative Districts: 2nd Congressional; 4th Senatorial; 8th Assembly
Population: 92,948

COUNTY SEAT, NAPA
County Central Info: Courthouse, 94558
707-253-4481

County Administrator: Albert J. Haberger (A)

Board of Supervisors

Meetings held second, third and fourth Tuesdays of each month at 1115 First St., Napa

Sam Chapman, District 1, Napa
William L. "Bill" Chew, District 2, Napa (Vice Chairman)
Dowell E. Martz, District 3, Angwin
Harold Moskowite, District 4 (Chairman)
John J. Mikolajcik, District 5, Napa

Elected and Appointed Officials

Assessor, George P. Abate
Auditor-Controller, James H. Marek, Jr.
County Clerk, Florence W. Cunny
District Attorney-Public Administrator, James D. Boitano
Recorder, Eleanor E. Kimbrough
Sheriff-Coroner, Phillip E. Stewart
Superintendent of Schools, Floyd E. Seifert
Treasurer-Tax Collector, Isabelle Burrell
Public Works Director, Harry D. Hamilton (A)
Planning Director, James H. Hickey (A)
Purchasing Agent, Albert J. Haberger (A)
Social Services Director, Virginia Giovanini (A)

County Counsel, Stephen W. Hackett (A)
Parks & Recreation Director, Daryl Nord (A)

Superior Court Judges

Philip A. Champlin, Thomas Kongsgaard

Municipal Court Judges

W. Scott Snowden, John J. Quigley

NEVADA COUNTY

Incorporated April 25, 1851
Legislative Districts: 1st Congressional; 1st Senatorial; 3rd Assembly
Population: 51,510

COUNTY SEAT, NEVADA CITY
County Central Info: County Courthouse, 95959, 916-265-2461

Board of Supervisors

Meetings held each Tuesday at 9:00 a.m.

Ilse Barnhart, District 1, Nevada City (Chairman)
Robert Wilder, District 2, Grass Valley
Karsten Hansen, District 3, Grass Valley
Eric Rood, District 4, Grass Valley
Pat Sutton, District 5, Truckee

Elected and Appointed Officials*

Assessor, Elton Tobiassen
Auditor-Controller, Yvonne M. Vonah
County Clerk-Recorder, Bruce C. Bolinger
District Attorney, John Darlington
Public Administrator, Wayne Brown
Sheriff-Coroner, Wayne Brown
Superintendent of Schools, Jerome Hund
Treasurer-Tax Collector, Marcella J. Carson
Planning Director, Jeff (Ben) Hulse
Public Works Director, Terrance Lowell
Purchasing Agent, Vacant
Social Welfare Director, Sandra Terrell
Public Defender, Richard Campbell
County Counsel, Brian A. Bishop
* Did not indicate appointed positions

Superior Court Judges

Harold F. Wolters, Frank D. Francis

Justice Court Judges

Nevada Judicial District, Karen J. Gunderson
Truckee Judicial District, George Pifer
Vera Butisbauch, Jury Commissioner

ORANGE COUNTY

Incorporated March 11, 1889

Legislative Districts: 34th, 38th, 39th and 40th Congressional; 35th, 36th, and 37th Senatorial; 69th through 74th Assembly
Population: 1,896,172

COUNTY SEAT, SANTA ANA
County Central Info: 10 Civic Center Plaza, 3rd Fl., Santa Ana, 92701

714-834-2000

County Administrative Officer: Robert E. Thomas

Board of Supervisors

Meetings held each Tuesday and Wednesday at 9:30 a.m. in the County Administration Building.

Roger R. Stanton, District 1, Santa Ana
Harriett Wieder, District 2, Garden Grove
Bruce Nestande, District 3, Fullerton
Ralph B. Clark, District 4, Orange (Chairman)
Thomas F. Riley, District 5, Laguna Beach

Elected and Appointed Officials

Assessor, Bradley L. Jacobs
Auditor-Controller, V. A. Heim
County Clerk-Recorder, Lee A. Branch
District Attorney, Cecil Hicks
Public Adminstrator-Public Guardian, James E. Heim
Sheriff-Coroner, Brad Gates
Tax Collector-Treasurer, Robert L. Citron
Superintendent of Schools, Dr. Robert D. Peterson (A)
General Services Agency Director, Thomas R. Egan (A)
Social Services Interim Director, Richard P. Ruiz (A)
Environmental Management Agency Director, Murray Storm (A)
Public Defender, Frank L. Williams (A)
County Counsel, Adrian Kuyper (A)

Superior Court Judges

Robert E. Rickles, Presiding, Walter W. Charamza, Robert A. Banyard, Lloyd E. Blanpied, Jr., Luis A. Cardenas, Richard J. Beacom, Francisco P. Briseno, Everett W. Dickey, Frank D. Domenichini, John L. Flynn, Jr., George Francis, Robert H. Green, James F. Judge, James W. Cook, Kenneth E. Lae, Betty Lou Lamoreaux, William S. Lee, Leonard H. McBride, Donald A. McCartin, Bryon K. McMillan, Theodore Millard, William L. Murray, Jerrold S. Oliver, Robert R. Fitzgerald, Leonard Goldstein, James A. Jackman, J. E. T. Rutter, Harman G. Scoville, Mark A. Soden, Alicemarie Stotler, Bruce W. Summer, Ronald H. Prenner, James L. Smith, William W. Thomson, Robert C. Todd, John K. Trotter, Jr., James K. Turner, Raymond F. Vincent, Edward J. Wallin, James O. Perez, Philip E. Schwab.

Municipal Court Judges

Central Orange County Judicial District: Karl C. Frank, Edward L. Laird, Eugene C. Langhauser, Bobby Youngblood, Gary P. Ryan, Barbara Tam Thompson, John H. Smith, Jr., John Ryan, Robert Thomas, Alan A. Plaia, Richard N. Parslow, Jr.

North Orange County Judicial District: James J. Alfano, Dave Bach, Myron S. Brown, Linda Hodge McLaughlin, Phillip R. McGraw, Logan Moore, Betty L. Elias, H. H. Clark, Comm., Phillip Petty, Robert L. Schatz.

Orange County Harbor Judicial District: Donald Dungan, Selim S. Franklin, Calvin P. Schmidt, Frances Munoz, Richard Luesebrink, Robert J. Polis, Richard Sullivan, Comm., Glenn Mahler, Comm.

South Orange County Judicial District: Blair T. Barnette, John A. Griffin, Richard Hamilton, Martin Heneghan, Comm.

West Orange County Judicial District: Phillip Cox, Ragner

R. Engebretsen, Alan N. McKone, William L. Mock, Kenneth M. Smith, John H. Wyatt, Jr., Robert A. Knox, Marvin G. Weeks, Joanne Harrold, Sam Collins, Comm., David Kerr, Comm.

PLACER COUNTY

Incorporated April 25, 1851

Legislative Districts: 1st Congressional; 1st Senatorial; 3rd Assembly

Population: 117,293

COUNTY SEAT, AUBURN
County Central Info: Administration Center, 175 Fulweiler Avenue, Rm. 401, 95603
916-823-4011

Executive Officer: Tom Schopflin (A)

Board of Supervisors

Meetings held each Tuesday at 10:00 a.m.

Robert P. Mahan, District 1, Roseville C
Alex Ferreira, District 2, Newcastle VC
Theresa "Terry" Cook, District 3, Auburn
Michael "Mike" Lee, District 4, Loomis (~~Chairman~~)
Larry Sevison, District 5, Tahoe (~~Vice-Chairman~~)

Elected and Appointed Officials

Assessor, Frank R. Chilton, Jr.
Auditor, Kimbuck Williams, Jr.
County Clerk-Recorder, Gay Trombley
District Attorney, Daniel J. Higgins
Sheriff-Coroner, Donald J. Nunes
Superintendent of Schools, Kenneth L. Lonergan
Treasurer-Tax Collector, F. Earl Corin
Planning Director, Thomas McMahan (A)
Purchasing Agent, Jim Hickman (A)
Social Welfare, Vacant (A)
Public Defender, Robert J. Trombley (A)
County Counsel, L. J. Dewald (A)

Superior Court Judges

J. Richard Couzens (Presiding), Keith F. Sparks, Wayne Wylie, Richard Sims

Justice Court Judges

Auburn Judicial District, George Yonehiro
Colfax-Alta-Dutch Flat Judicial District, George Yonehiro
Foresthill Judicial District, Richard J. Ryan
Lincoln Judicial District, Robert A. Young
Loomis Judicial District, Robert A. Young
Roseville Judicial District, Howard G. Gibson
Tahoe Judicial District, Robert A. Fugazi

PLUMAS COUNTY

Incorporated March 18, 1854

Legislative Districts: 1st Congressional; 1st Senatorial; 1st Assembly

Population: 17,365

COUNTY SEAT, QUINCY
County Central Info: P.O. Box 207, Quincy, 95971
916-283-1060

Board of Supervisors

Meetings held first, second and third Tuesdays of each month.

Leonard Ross, District 1, Portola
Russell H. Papenhausen, District 2, Greenville
Jessie Wellenbrock, District 3, Chester (Chairman)
B. A. (Sandy) Pricer, District 4, Meadow Valley
Bill Coates, District 5, Blairsden

Elected and Appointed Officials *

Assessor, Dow Bettis
Auditor, Ann Pattan
County Clerk-Recorder, Ila Diggs
District Attorney-Public Administrator, Gerald E. Flanagan
Sheriff-Coroner, S. Doug Thomas
Superintendent of Schools, John V. Malarkey
Tax Collector-Treasurer, Lois Alexander
Planning Director, John McMorrow
Social Welfare, Mona J. Green
Public Defenders, contracts expired 1/31/81
County Counsel, Baird McKnight
Parks and Recreation, John McMorrow
* Did not indicate appointed positions

Superior Court Judge

Stanley C. Young, Jr.

Justice Court Judges

Almanor Judicial District, Roger M. Settlemire
Plumas Judicial District, Alan H. Thieler

RIVERSIDE COUNTY

Incorporated March 11, 1893

Legislative Districts: 36th, 37th and 43rd Congressional; 34th and 38th Senatorial: 67th, 68th and 75th Assembly
Population: 594,055

COUNTY SEAT, RIVERSIDE
County Central Info: Administrative Center 4080 Lemon Street, 92501, 714-787-2544

Administrative Officer: Robert J. Fitch

Board of Supervisors

Meetings held each Tuesday at 9:00 a.m. in Administrative Center.

Walt P. Abraham, District 1, Riverside
Donald L. Schroeder, District 2, Riverside
Kay Ceniceros, District 3, Hemet (Vice Chairman)
A. A. McCandless, District 4, Palm Desert (Chairman)
A. Norton Younglove, District 5, Riverside

Elected and Appointed Officials

Assessor, Frank C. Seeley
Auditor-Controller, Howard D. Stephens
Coroner-Public Administrator, William J. Dykes
County Clerk, Donald D. Sullivan
District Attorney, Byron C. Morton
Recorder, Donald D. Sullivan
Sheriff, Bernard J. Clark
Superintendent of Schools, Don F. Kenny

Treasurer and Tax Collector, Donna B. Babcock
Planning Director, Patricia Nemeth (A)
Purchasing Agent, W. G. Henderson (A)
Public Social Services Director, Paul R. Wiley (A)
Public Defender, Malcolm MacMillan (A)
County Counsel, James H. Angell (A)
Parks and Recreation Director, Richard Simons (A)
Road Commissioner/Surveyor, A. E. "Jack" Newcomb

Superior Court Judges

Gerald F. Schulte, E. Scott Dales, John P. Carroll, Robert K. Garst, J. David Hennigan, John D. McFarland, Ernest M. Lopez, J. William Mortland, John H. Hews, Richard M. Marsh, Fred R. Metheny, Jr., Frank Moore, George G. Grover, Vacant, Warren E. Slaughter, Ronald T. Deissler, Robert J. Timlin

Municipal Court Judges

Corona Judicial District, Charles F. Pendleton, Michael F. Flynn.

Desert Judicial District, Phillip R. LaRocca, Richard H. Robinson, James H. Herrin, Noah N. Jamin, Eugene R. Bishop

Mt. San Jacinto Judicial District, Fred A. McCarthy, Robert L. Peterson

Riverside Judicial District, John H. Barnard, Vacant, George H. Miller, Howard M. Dabney, Robert D. Macomber

Three Lakes Judicial District, William R. Bailey, Jr.

SACRAMENTO COUNTY

Incorporated February 18, 1850
(Charter Form of Government)

Legislative Districts: 1st, 3rd, 4th and 14th Congressional; 3rd, 4th and 13th Senatorial; 4th, 5th, 6th and 8th Assembly
Population: NOT SUBMITTED

COUNTY SEAT, SACRAMENTO
County Central Info: 700 H Street, 95814
916-440-5522

County Executive: Brian Richter

Board of Supervisors

Meetings held each Tuesday and Thursday at 9 a.m., 1st floor of the County Administration Building, 700 H Street.

Joseph E. Sheedy, District 1, Sacramento
Illa Collins, District 2, Sacramento
Sandra R. Smoley, District 3, Sacramento
Bill Bryan, District 4, Sacramento (Chairman)
C. Tobias Johnson, District 5, Sacramento

Officials

Assessor, William C. Lynch
Auditor-Controller, Edgar A. Sayre
County Clerk/Recorder, James A. Simpson
District Attorney, E. Herbert Jackson
Sheriff, Duane Lowe
Superintendent of Schools, William L. Cunningham
Public Works Director, D. W. McKenzie
Planning Director, Lance Bailey
Purchasing Agent, Andrew P. Reshke
Social Welfare Director, Dennis B. Hart
Public Defender, Kenneth M. Wells
County Counsel, Lee Elam
Parks and Recreation Director, Don H. Nance

Superior Court Judges

Carol Miller, Joseph G. Babich, John J. Boskovich, Horace E. Cecchettini, Robert W. Cole, Joseph A. DeCristoforo, Robert N. Zarick, Eugene T. Gualco, Sheldon Grossfeld, William H. Lally, Irving H. Perluss, Lloyd A. Phillips, Jr., Mamoru Sakuma, William A. White, Michael J. Virga, Fred W. Marler, Jr., John M. Sapunor, William K. Morgan, Richard Tuttle, Rothwell Mason, Benjamin A. Diaz, A. Richard Backus, James T. Ford, Cecily B. Nyomarky.

Municipal Court Judges.

Darrel W. Lewis, Ronald Tochterman, Arthur Eissinger, Edward J. Garcia, Peter Mering, Lorenzo Patino, Roger K. Warren, Lawrence W. Marvin, Jr., John V. Stroud, Earl Warren, Jr., Cathryn Canlis, Allen P. Fields, Leighton Hatch, Rudolph Woncke.

Justice Court Judges

Elk Grove-Galt Judicial District, James P. Henke
Walnut Grove-Isleton Judicial District, James A. Gualco

SAN BENITO COUNTY

Incorporated February 12, 1874

Legislative Districts: 16th Congressional; 11th Senatorial; 24th Assembly
Population: 24,910

COUNTY SEAT, HOLLISTER
County Central Info: Courthouse, Room 206, Hollister 95023, 408-637-3786

Board of Supervisors

Meetings held first day and first and third Mondays of each month at 9:30 a.m. in Courthouse

Frank J. Sabbatini, District 1, Hollister
Enos N. Silva, District 2, San Juan Bautista
George B. Shore, District 3, Hollister
George F. Kincaid, District 4, Tres Pinos, (Chairman)
Harold Cerrato, District 5, Hollister

Elected and Appointed Officials

Assessor, Arnold R. Fontes
County Clerk-Auditor-Recorder, Ronald H. Jones
District Attorney, David Pipal
Sheriff-Coroner-Tax Collector, Julian Medina
Superintendent of Schools, Robert H. Bouchard
Treasurer-Public Administrator-Tax Collector, Margaret Orlaine Tavaras
Planning Director, Arnold Egger (A)
Public Works Director, Keith Carlen (A)
Social Welfare Director, Edward Anderson (A)

Superior Court Judge

Thomas P. Breen

Justice Court Judge

San Benito Judicial District, Bernard P. McCullough

SAN BERNARDINO COUNTY

Incorporated April 26, 1853
(Charter Form of Government)

Legislative Districts: 35th, 36th and 37th Congressional; 16th, 32nd and 34th Senatorial; 34th, 65th, 66th and 67th Assembly
Population: 756,000

COUNTY SEAT, SAN BERNARDINO
County Central Info: 175 W. 5th Street, 92415
714-383-2311

Administrative Officer: DID NOT SUBMIT NAME

Board of Supervisors

Board meets each Monday at 10:00 a.m. in Civic Center Building

Robert Older, District 1, Apple Valley
Cal McElwain, District 2, Upland
David McKenna, District 3, Redlands
Robert O. Townsend, District 4, Chino
Robert L. Hammock, District 5, San Bernardino (Chairman)

Elected and Appointed Officials*

Assessor, Gorden Young
Auditor, Errol J. Mackzum
Coroner-Public Administrator, Bill Hill
County Clerk, Vacant
District Attorney, A. Rex Victor (Acting)
Recorder, V. Dennis Wardle
Sheriff, Frank Bland
Superintendent of Schools, Roy C. Hill
Tax Collector-Treasurer, Joe Bell
*Did not indicate appointed positions

Superior Court Judges

Ben T. Kayashima, Clifton L. Allen, Joseph B. Campbell, John Ingro, William Pitt Hyde, Richard C. Garner, Roy Chapman, Rex W. Cranmer, Donald R. Egan, Thomas M. Haldorsen, Joseph A. Katz, Patrick J. Morris, Don A. Turner, J. Steve Williams, Kenneth G. Ziebarth, Jr., Bob N. Krug, Charles Bierschbach, Duke D. Rouse, Philip E. Schaefer

Municipal Court Judges

Carl E. Davis, Leroy Simmons, James A. Edwards, Martin Hildreth, John W. Kennedy, Jacob H. Jager, Theo G. Krumm, Dan L. Rankins, Ray L. Craig, David C. Merriam, Donald Van Leuven, Jr., Kenneth Kloepher, Dyson W. Cox, Ward O. Mathews, Wallace L. Taggart, Dana Henry, Carol Koppel, H. Trevor Hamilton, Holley Graham.

Justice Court Judges

Bear Valley Judicial District, Robert S. Drake
Needles-Calzona Judicial District, Jack I. Massey
Trona Judicial District, Edward L. Heap

SAN DIEGO COUNTY

Incorporated February 18, 1850

(Charter Form of Government)
Legislative Districts: 40th through 43rd Congressional; 36th, 38th through 40th Senatorial; 74th through 80th Assembly
Population: 1,819,292

COUNTY SEAT, SAN DIEGO
County Central Info: County Courthouse, 220 W. Broadway, 92101, 714-236-2121

Chief Administrative Officer: Clifford W. Graves

Board of Supervisors

Meetings held Tuesday and Wednesday of each week at Room 310, 335 County Administration Building

Thomas D. Hamilton, Jr., District 1
Paul W. Fordem, District 2
Roger E. Hedgecock, District 3
Jim Bates, District 4
Paul Eckert, District 5

Elected and Appointed Officials*

Assessor, E. C. Williams
County Clerk, Robert D. Zumwalt
District Attorney, Edwin Miller
Recorder, Vera L. Lyle
Sheriff, John Duffy
Superintendent of Schools, Gerald Rosander
Tax Collector-Treasurer, James E. Jones
*Did not indicate appointed positions

Superior Court Judges

Thomas G. Duffy, G. Dennis Adams, Edward T. Butler, Anthony C. Joseph, Wesley B. Buttermore, Jr., Carlos A. Cazares, Norbert Ehrenfreund, Hugo M. Fisher, James L. Focht, Charles W. Froehlich, Jr., Don Martinson, Judith McConnell, David M. Gill, Michael I. Greer, Ben W. Hamrick, Gilbert Harelson, Artemis G. Henderson, Joseph A. Kilgarif, J. Perry Langford, Daniel C. Leedy, Jack R. Levitt, Alpha L. Montgomery, Gerald J. Lewis, F. V. Lopardo, Alfred Lord, William T. Low, Earl H. Maas, Jr., James A. Malkus, Milton Milkes, Gilbert Nares, Franklin B. Orfield, Paul E. Overton, Raul Rosado, Robert J. O'Neill, Ross G. Tharp, William L. Todd, Jr., Louis M. Welsh, Donald W. Smith, Douglas R. Woodworth, Elizabeth N. Zumwalt

Municipal Court Judges

El Cajon Judicial District: Richard H. Bein, Larrie R. Brainard, Thomas R. Murphy, Elizabeth A. Riggs, William J. Howatt, Jr., Michael W. Brennan, J. William Beard

North County Judicial District: Michael L. Burley, Zalman J. Scherer, Suzanne W. Knauf, Raymond G. Hall, Luther L. Leeger, J. Morgan Lester, Victor E. Ramirez.

San Diego Judicial District: Earl K. Adams, Richard J. Hanscom, Earl J. Cantos, Robert J. Cooney, Patricia A. Y. Cowett, Janet Kintner, Richard J. Curran, Ronald A. Mayo, T. Bruce Iredale, Kenneth A. Johns, Manuel L. Kugler, Mack P. Lovett, Charles M. Snell, Robert J. Stahl, Jr., Napoleon A. Jones, Jr., Sheridan E. Reed, Lewis A. Wenzell, David B. Moon, Jr.

South Bay Judicial District: Vacant, Thomas J. Gilgorea, James M. Edmunds, Luftig Murray, Susan Finley. Traffic Referee: Terry Scott.

CITY AND COUNTY OF SAN FRANCISCO

Incorporated February 18, 1850
(Charter Form of Government)

Legislative Districts: 5th and 6th Congressional; 5th and 6th Senatorial; 16th, 17th and 18th Assembly

Population 667,700
County Central Info: 415-558-6161

MAYOR: DIANNE FEINSTEIN

Chief Administrative Officer: Roger Boas

Board of Supervisors

Meetings held every Monday at 2:00 p.m. in the Legislative Chambers

Willie B. Kennedy, District 1
Louise Renne, District 2
John L. Molinari, District 3, (President)
Nancy G. Walker, District 4
Harry Britt, District 5
Carol Ruth Silver, District 6
Doris Ward, District 7
Wendy Nelder, District 8
Lee Dolson, District 9
Quentin L. Kopp, District 10
Dick Honisto, District 11

Elected Officials

Assessor, Samuel Duca
City Attorney, George Agnost
County Clerk, Carl Olsen (non-elective)
District Attorney, Arlo Smith
Public Defender, Geoffrey Brown
Sheriff, Mike Hennessy
Treasurer, Mary Callihan
Superintendent of Schools, Robert Alioto (A)
Planning Director, Dean Macres (A)
Public Works Director, Jeffrey Lee (A)
Purchaser, Joseph C. Gavin (A)
Social Welfare, Edwin Sarsfield (A)

Superior Court Judges

Raymond J. Arata, Jr., John E. Benson, Ira A. Brown, Jr., Richard P. Figone, Walter F. Calcagno, Victor M. Campilongo, Edward L. Cragen, John E. Dearman, Robert L. Dossee, Morton R. Colvin, Donald B. Constine, Robert J. Drewes, John Ertola, Thomas Dandurand, Daniel M. Hanlon, Donald B. King, Harry Low, Eugene F. Lynch, Lawrence S. Mana, Francis W. Mayer, Ollie Marie-Victoire, Robert W. Merrill, William Mullins, Claude D. Perasso, Jay Pfotenhauer, Henry R. Rolph, Edward E. Stern, Frank W. Shaw, S. Lee Vavuris

Municipal Court Judges

Ira Gyemant, Charles E. Goff, Lucy Kelly McCabe, Frank E. Hart, Louis Garcia, Gerald J. O'Gara, Dorothy Von Beroldingen, Daniel H. Weinstein, Maxine Chesney, J. Dominique Olcomendy, Alex Saldamando, Raymond Williamson, Jr., Albert C. Wollenberg, Roy L. Wonder, Perker Meeks, Jr., Isabella Grant.

SAN JOAQUIN COUNTY

Incorporated February 18, 1850

Legislative Districts: 14th Congressional; 13th Senatorial; 7th and 26th Assembly
Population: 302,200

COUNTY SEAT, STOCKTON
County Central Info: 222 E. Weber Avenue, Rm. 703
Stockton 209-944-3131

County Administrator: C. E. Dixon

Board of Supervisors

Meetings held Tuesday of each week at 10 a.m.

Richard Yoshikawa, District 1, Stockton
Doug Wilhoit, District 2, Stockton
Jose L. Alva, District 3, Stockton
George Barber, District 4, Lodi
Evelyn L. Costa, District 5, Tracy

Elected and Appointed Officials

Assessor, Robert Shellenberger
Auditor, Paul Heurlin
County Clerk, Ralph W. Epperson
District Attorney, Joseph H. Baker
Public Administrator, Susan Patterson
Recorder, James Johnstone
Sheriff-Coroner, Frank W. Harty
Superintendent of Schools, Gaylord A. Nelson
Treasurer and Tax Collector, John A. Prowse
Public Works Director, William Ward (A)
Planning Director, Robert Hunter (A)
Purchasing Agent, Jack Delzell (A)
Social Welfare, Harry Brodie (A)
Public Defender, Robert Chargin (A)
County Counsel, Gerald Sherwin (A)
Parks & Recreation Director, Gene Andal (A)

Superior Court Judges

John F. Cruikshank, Jr., F. Duane Martin, James P. Darrah, William L. Dozier, Frank S. Kim, Chris Papas, Norman C. Sullivan, vacant

Municipal Court Judges

Lodi Judicial District: J. Thomas Seibly
Manteca-Ripon-Escalon-Tracy-Eastern Division Judicial District: Donald Asher
Western Division: Frank A. Grande
Stockton Judicial District: Thomas B. Teaford, K. Peter Saiers, Nels B. Fransen, Ann Marie Chargin, William R. Giffen

SAN LUIS OBISPO COUNTY

Incorporated February 18, 1850

Legislative Districts: 16th and 19th Congressional; 17th Senatorial; 29th Assembly
Population: 136,286

COUNTY SEAT, SAN LUIS OBISPO
County Central Info: Courthouse Annex, 93408
805-549-5000

County Administrative Officer: Donald D. Stilwell

Board of Supervisors

Meetings held first four Mondays of each month

Jerry Diefenderfer, District 1, Templeton
Steve Mac Elvaine, District 2, Morro Bay (Chairman)
Kurt P. Kupper, District 3, San Luis Obispo
Howard D. Mankins, District 4, Arroyo Grande
Jeff Jorgensen, District 5, San Luis Obispo

Elected and Appointed Officials

Assessor, Dick Frank
Auditor-Controller, Fred W. Cusick
County Clerk, F. M. Cooney
District Attorney, Christopher Money
Recorder, William E. Zimarik
Sheriff-Coroner, George S. Whiting
Superintendent of Schools, Earl D. Cornwell
Treasurer-Tax Collector-Public Administrator, Frank Freitas
Engineer-Surveyor, George Protopapas (A)
Planning Director, Paul Crawford (A)
Purchasing Agent, Don Ramsey (A)
Social Services Director, Thomas Ganoe (A)
General Services Director, Duane P. Leib (A)

Superior Court Judges

William R. Fredman, Harry E. Woolpert, Wickson R. Woolpert, Richard C. Kirkpatrick

Municipal Court Judges

Warren C. Conklin, Richard D. Wood, Harold Johnson, J. Barry Hammer

SAN MATEO COUNTY

Incorporated April 19, 1856
(Charter Form of Government)

Legislative Districts: 11th and 12th Congressional; 6th and 10th Senatorial; 18th, 19th, 20th and 21st Assembly
Population: 581,700

COUNTY SEAT, REDWOOD CITY
County Central Info: 401 Marshall Street, Redwood City 94063, 415-~~364-5600~~ 363-4571
County Manager: David L. Nichols

Board of Supervisors

Meetings held first four Tuesdays of month at 9:30 a.m., Hall of Justice and Records, 401 Marshall St.

K. Jacqueline Speier, District 1
John M. Ward, District 2 (Chairman)
Edward J. Bacciocco, Jr., District 3
Arlen Gregorio, District 4
William J. Schumacher, District 5

Elected and Appointed Officials

Assessor, Roland Giannini
Coroner, Paul B. Jensen
County Clerk-Recorder, Marvin Church
County Controller, W. J. Bergman, Jr.
District Attorney, Keith C. Sorenson
Sheriff, John R. McDonald, Jr.
Superintendent of Schools, William K. Jennings
Tax Collector-Treasurer, Ross Conti
Planning Director, Paul Koenig (A)
Purchasing Agent, Robert Sorensen (A)
Public Health & Welfare, Charles Windsor (A)
Parks & Recreation, Duane Mattison, Director (A)

Superior Court Judges

Alan W. Haverty, Thomas M. Jenkins, Allan J. Bollhoffer, Robert E. Carey, Melvin E. Cohn, Walter P. Capaccioli, Lyle R. Edson, John J. Bible, V. Gene McDonald, Francis William Lanam, Robert D. Miller, Frank Piombo, Gerald E. Ragan, Zerne Haning, III

Municipal Court Judges

Northern Judicial District: Margaret J. Kemp, James O. Miller, F. Jose DeLarios
Southern Judicial District: Wilbur R. Johnson, Gregory Jensen, Thomas McGinn Smith, Thomas B. Caldwell, Edward W. Pliska, Phrasel L. Shelton

SANTA BARBARA COUNTY

Incorporated February 18, 1850

Legislative Districts: 19th Congressional; 17th and 18th Senatorial; 29th and 35th Assembly
Population: 284,531

COUNTY SEAT, SANTA BARBARA
County Central Info: 105 E. Anapamu Street
805-966-1611

Administrative Officer: Larry Parrish

Board of Supervisors

Meetings held every Monday at 9:30 a.m. in County Administration Building

David M. Yager, District 1, Santa Barbara
Robert E. Kallman, District 2, Santa Barbara
William B. Wallace, District 3, Goleta (Chairman)
DeWayne Holmdahl, District 4, Lompoc
Harrell Fletcher, District 5, Santa Maria

Elected and Appointed Officials *

Assessor, William H. Cook
Auditor-Controller, Kristi M. Johnson
County Clerk-Recorder, Howard C. Menzel
District Attorney, Stanley M. Roden
Sheriff, John W. Carpenter
Superintendent of Schools, Lorenzo Dall'Armi
Tax Collector, J. Newton Blanchard
Treasurer-Public Administrator, Glen W. Neikirk
County Counsel, Kenneth L. Nelson
Planning Director, Britt A. Johnson
Public Works Director, Charles Wagner
Public Defender, Glen Mowrer, Jr.
Purchasing Agent, Ray Fann
Parks Director, Michael H. Pahos
* Did not indicate appointed positions

Superior Court Judges

Bruce W. Dodds, Arden T. Jensen, John T. Rickard, Royce R. Lewellen, Robert L. Trapp, Sr., Charles S. Stevens, Jr., L. Donald Boden

Municipal Court Judges

Lompoc Judicial District: Eugene L. Huseman
Santa Barbara-Goleta Judicial District: Arnold D. Gowans,

James M. Slater, Joseph Lodge
Santa Maria Judicial District: Robert G. Eckhoff, James B. Jennings

Justice Court Judges

Carpinteria-Montecito Judicial District, James L. Pattillo
Solvang Judicial District, Rick S. Brown

SANTA CLARA COUNTY

Incorporated February 18, 1850
(Charter Form of Government)

Legislative Districts: 10th, 12th and 13th Congressional; 10th, 11th, and 12th Senatorial; 21st through 25th Assembly
Population: 1,283,043

COUNTY SEAT, SAN JOSE
County Central Info: 70 W. Hedding St., San Jose 95110
408-~~299-1121~~ 299-2323

County Executive: William M. Siegel

Board of Supervisors

Meetings held every Monday and Tuesday, 9:30 a.m., 70 West Hedding St., San Jose 95110

Suzanne B. Wilson, District 1, San Jose
Zoe Lofgren, District 2, San Jose
Dan A. McCorquodale, District 3, San Jose
Rodney J. Diridon, District 4, San Jose (Chairman)
Rebecca Morgan, District 5, Palo Alto

Elected and Appointed Officials*

Assessor, Alfred Carlson
County Clerk-Court Executive Officer; John Kazubowski
District Attorney, Louis P. Bergna
Sheriff, Robert Winter
Superintendent of Schools, Glenn W. Hoffman
Planning Director, Roy S. Cameron
Environmental Management-General Services Director, Paul Yarborough
Social Services Director, Wesley Jones
County Counsel, Selby Brown, Jr.
Parks and Recreation Director, David Christy
*Did not indicate appointed positions

Superior Court Judges

George W. Bonney, James A. Wright, Bruce F. Allen, Peter Anello, George H. Barnett, John A. Flaherty, O. Vincent Bruno, David W. Leahy, Eugene M. Premo, Lawrence F. Terry, James Duvaras, Jr., Taketsugu Takei, Stanley R. Evans, William J. Fernandez, Daniel E. Creed, Peter G. Stone, Charles Gordon, John R. Kennedy, John E. Longinotti, John S. McInerny, Edward A. Panelli, J. Barton Phelps, Richard W. Rhodes, Marilyn Pestarino Zecher, Homer B. Thompson, William J. Harris, Jr., Thomas C. Hastings, Reed Ambler, Paul R. Teilh, R. Donald Chapman, Frank Cliff, Conrad L. Rushing, John Schatz, Jr.

Municipal Court Judges

Nancy Hoffman, Fred S. Lucero, James W. Stewart, Joseph F. Biafore, Jr., Edwin Pearce, Leonard P. Edwards, Vacant, Edgar P. Taylor, James B. O'Grady, Edward C. Scoyen, Tomothy J. Hanifin, Robert P. Ahern, Louis C. Doll, Robert M. Foley, Wayne M. Kanemoto, Gerald J. Kettman, Edward J. Nelson, Arvin O. Robb, William F. Brown, Jr., Mark E. Thomas, Jr., Mariam E. Wolff

SANTA CRUZ COUNTY

Incorporated February 18, 1850

Legislative Districts: 16th Congressional; 17th Senatorial; 28th Assembly
Population: 186,873

COUNTY SEAT, SANTA CRUZ
County Central Info: 701 Ocean Street, Santa Cruz 95060
408-425-2175

Acting County Administrative Officer: George T. Newell

Board of Supervisors

Meetings every Tuesday at 9:00 a.m.

D. Dan Forbus, District 1, Santa Cruz
Robley Levy, District 2, Aptos
Gary A. Patton District 3, Santa Cruz (Chairman)
E. Wayne Moore, Jr., District 4, Watsonville
Joseph F. Cucchiara, District 5, Santa Cruz

Elected Officials

Assessor, Robert C. Petersen
Auditor-Controller, Arthur Merrill
County Clerk-Recorder, Richard C. Neal
District Attorney-Public Administrator, Arthur Danner III
Sheriff-Coroner, Alfred F. Noren
Superintendent of Schools, Richard H. Van Deren
Treasurer-Tax Collector, William P. Murphy

Superior Court Judges

Harry F. Brauer, Christopher C. Cottle, Roland K. Hall, Donald O. May

Municipal Court Judges

Santa Cruz Judicial District: William M. Kelsay, Richard W. Kessell, John A. Marlo, Richard J. McAdams

SHASTA COUNTY

Incorporated February 18, 1850

Legislative Districts: 1st Congressional; 1st Senatorial; 1st Assembly
Population: 94,429

COUNTY SEAT, REDDING
County Central Info: 916-246-5631

County Executive: Bill G. Minton (A)

Board of Supervisors

Meetings held on each Tuesday in the Board of Supervisors Room, Courthouse.

Stephen C. Swendiman, District 1, Redding
John Strange, District 2, Redding
John R. Caton, District 3, Montgomery Creek (Chairman)
Don C. Maddox, District 4, Redding
R. D. "Dan" Gover, District 5, Cottonwood

Elected and Appointed Officials

Assessor, Virginia A. Loftus

Auditor-Controller, Edward B. Davis
County Clerk, Richard C. Brennan
District Attorney, Skip Teacher, Acting
Public Administrator and Coroner, Joseph W. Kohn
Recorder, Marjorie A. Kivley
Sheriff, John Balma
Superintendent of Schools, Dean Dennett
Treasurer-Tax Collector, Jacque C. Williams
Public Works Director, Richard Curry (A)
Planning Director, Joe Hunter (A)
Purchasing Agent, Bill G. Minton (A)
Welfare Director, Marian Babiarz (A)
County Counsel, John S. Kenny (A)
Recreation Commission, Larry Preston, Secretary (A)

Superior Court Judges

Richard W. Abbe, William H. Phelps, Joseph H. Redmon

Municipal Court Judge

Donald R. Kennedy

Justice Court Judges

Anderson Judicial District, Richard A. McEachen
Burney Judicial District, Larry J. Frumes
Central Valley Judicial District, William R. Lund, Jr.

SIERRA COUNTY

Incorporated April 16, 1852

Legislative Districts: 1st Congressional; 1st Senatorial; 3rd Assembly
Population: NOT SUBMITTED

COUNTY SEAT, DOWNIEVILLE
County Central Info: 916-289-3271

Board of Supervisors

Meetings held in courthouse on first and third Tuesdays of each month

Harold L. Pratt, District 1, Downieville
Earl Withyeombe, II, District 2, Sierra City
George Filippini, District 3, Loyalton
Bison S. Robinson, District 4, Loyalton (Chairman)
Charles E. Wilmoth, District 5, Loyalton

Elected and Appointed Officials*

Assessor, William G. Copren
County Clerk-Auditor-Recorder, Georgie M. Peterman
District Attorney-Public Administrator, James Dreman
Sheriff-Coroner, Albert E. Johnson
Superintendent of Schools, Charles Best
Treasurer-Tax Collector, Marian R. Lavezzola
Public Works Director, Johnny Conaway
Planning Director, Tim H. Beals
Welfare Director, Connie J. Bennett
Public Defender, David VanNote
County Counsel, Vacant
*Did not indicate appointed positions

Superior Court Judge

John F. Keane

Justice Court Judge

Sierra Judicial District: William G. Brigance

SISKIYOU COUNTY

Incorporated March 22, 1852

Legislative Districts: 1st Congressional; 1st Senatorial; 1st Assembly
Population: 39,500

COUNTY SEAT, YREKA
County Central Info: 311 4th St., Yreka 96097
916-842-3531

County Administrator: Richard Sierck

Board of Supervisors

Meetings held second and fourth Tuesdays of each month

Norma Frey, District 1, Tulelake
Philip Mattos, District 2, Mt. Shasta
Mike Belcastro, District 3, Weed
James Steinhaus, District 4, Yreka
Vernon Zink, District 5, Etna (Chairman)

Elected and Appointed Officials*

Assessor, Donald Carey
Auditor-Controller-Recorder, P. K. Bley
County Clerk, Norma Price
District Attorney-Public Administrator, Steven B. Plumer
Sheriff-Coroner, Laurence E. Taylor
Superintendent of Schools, Robert A. Dais
Tax Collector-Treasurer, Lillian Durkee
Public Works Director, David Gravenkamp
Planning Director, David Hedberg
Purchasing Agent, Richard Sierck
Social Welfare, W. M. VanOver
Public Defender, Lillian Durkee
County Counsel, Frank DeMarco
*Did not indicate appointed positions

Superior Court Judge

James E. Kleaver

Justice Court Judges

Dorris-Tulelake Judicial District, David Otis
Dunsmuir-Mt. Shasta Judicial District, Howard E. Jones
McCloud Judicial District, Chris Stromsness
Shasta Valley Judicial District, Ross Bigler
Western Judicial District, George G. Tyler

SOLANO COUNTY

Incorporated February 18, 1850

Legislative Districts: 4th Congressional; 2nd and 4th Senatorial; 4th and 8th Assembly
Population: 208,300

COUNTY SEAT, FAIRFIELD
County Central Info: Hall of Justice, Fairfield 94533
707-429-6412

Administrative Officer: David Balmer

Board of Supervisors

Meetings held every Tuesday at 9:00 a.m. in Courthouse

Osby Davis, District 1, Vallejo
John Cunningham, District 2, Vallejo

Joan R. Hewitt, District 3, Fairfield
Wallace W. Brazelton, District 4, Vacaville
Richard Brann, District 5, Rio Vista (Chairman)

Elected and Appointed Officials*

Assessor, Gordon Gojkovich
Auditor-Controller, Anthony A. Kalamaras
Coroner and Public Administrator, James E. O'Brien
County Clerk, Neil Crawford
District Attorney, Neal P. McCaslin
Recorder, Ronald J. Azevedo
Sheriff, Albert M. Cardoza
Superintendent of Schools, James Chadbourne
Acting Tax Collector, Virginia Ryan
Treasurer, Bobby D. Stow
*Did not indicate appointed positions

Superior Court Judges

Thomas N. Healy, William E. Jensen, Michael L. McInnis, Ellis R. Randall, Dwight C. Ely

Municipal Court Judges

Northern Solano Judicial District: John A. DeRonde, Curtis G. Singleton, Richard M. Harris

Vallejo-Benicia Judicial District: Richard J. Swan, Paul Dacey

Justice Court Judges

Rio Vista Judicial District, Donald L. Balding

SONOMA COUNTY

Incorporated February 18, 1850

Legislative Districts: 2nd and 5th Congressional; 2nd and 4th Senatorial; 2nd, 8th and 9th Assembly
Population: NOT SUBMITTED

COUNTY SEAT, SANTA ROSA
County Central Info: 575 Administration Drive, Santa Rosa 95401
707-527-2941

County Administrator: Leonard Whorton

Board of Supervisors

Meetings held every Tuesday, Administration Building, 2555 Mendocino Ave.

Robert "Bob" Adams, District 1, Santa Rosa
Helen Putnam, District 2, Petaluma
Helen Rudee, District 3, Santa Rosa
Nick Esposti, District 4, Santa Rosa
Ernest "Ernie" Carpenter, District 5, Sebastopol

Elected and Appointed Officials

Assessor, Ernest Comalli
Auditor-Controller, S. Robert "Bob" Conner
County Clerk, Eeve T. Lewis
District Attorney-Public Administrator, Gene Tunney
Recorder, Bernice A. Peterson
Sheriff-Coroner, Roger McDermott
Superintendent of Schools, Dr. Walter A. Eagan
Treasurer-Tax Collector, Donald W. Merz
County Counsel, James Botz (A)
Public Defender, Marteen Miller (A)
Purchasing Agent, Alfred P. Wood (A)
Parks Director, Joseph D. Rodota (A)
Welfare Director, Paul M. Allen, Jr. (A)

Superior Court Judges

Kenneth M. Eymann, John J. Gallagher, R. Brian Jamar, Rex H. Sater, Joseph P. Murphy, Jr., William B. Boone

Municipal Court Judges

Sonoma County Judicial District: Lawrence "Gary" Antolini, Raymond Giordano, Frank J. Passalacqua, Raymond Byrne, William Bettinelli

STANISLAUS COUNTY

Incorporated April 1, 1854

Legislative Districts: 14th and 15th Congressional; 13th and 14th Senatorial; 26th and 27th Assembly
Population: 265,671

COUNTY SEAT, MODESTO
County Central Info: 209-526-6011

Chief Administrative Officer: Gardner L. Hutchins

Board of Supervisors

Meetings held every Tuesday, Board Chambers, County Administration Bldg., 1100 "H" Street

Dan Terry, District 1, Waterford
Rolland C. Starn, District 2, Hughson
William C. Ulm, District 3, Modesto
Raymond Clark Simon, District 4, Modesto
Gary Condit, District 5, Ceres

Elected and Appointed Officials

Assessor, David W. Triplett
Auditor, Robert E. Hubbard
County Clerk-Recorder, Dwayne E. Lilly
District Attorney, Donald N. Stahl
Sheriff-Coroner, Lynn S. Wood
Superintendent of Schools, John B. Allard
Treasurer-Tax Collector, F. L. de Camp
County Counsel, Gilbert Boyne (A)
Public Defender, Dallas J. Cole (A)
Public Works Director, Richard G. Barhite (A)
Planning Director, Harter R. Bruch (A)
Purchasing Agent, Richard T. Lang (A)
Parks and Recreation, William L. Tiernan (A)

Superior Court Judges

Jeremy C. Cook, Francis W. Halley, Frank S. Pierson, Gerald V. Underwood, Hugh Rose, III, Norman S. Reid

Municipal Court Judges

Stanislaus Judicial District: Edward M. Lacey, Jr., Carson N. Taylor, Charles V. Stone, Donald B. Cantwell, Eugene M. Azevedo, J. Augustus Accurso, Charles E. Aguilar

SUTTER COUNTY

Incorporated February 18, 1850
Legislative Districts: 4th Congressional; 1st Senatorial; 3rd Assembly
Population: 52,000

COUNTY SEAT, YUBA CITY

County Central Info: 463 2nd Street
Yuba City 95991
916-673-5140

County Administrative Officer: Ronald H. Piorek

Board of Supervisors

Meetings held Tuesday of each week at 9:30 a.m.

Allen A. Eager, District 1, Live Oak
Joseph A. Benatar, District 2, Yuba City (Chairman)
Mary Knapp, District 3, Yuba City
Roger C. Chandler, District 4, Yuba City
Richard Withrow, District 5, Pleasant Grove

Elected and Appointed Officials*

Assessor, Gerald F. Allen
Auditor-Controller, Clifford Wetherbee
County Clerk-Recorder, Lonna B. Smith
District Attorney and Public Administrator, H. Ted Hansen
Sheriff-Coroner, Roy D. Whiteaker
Superintendent of Schools, William E. Robinson
Treasurer-Tax Collector, Louvena Emery
Planning Director, Richard King
County Counsel, Darrell Larsen
Public Defender, Roy J. Van den Heuvel
Parks and Recreation, Milton B. Skaggs
Welfare Director, David Biggers
*Did not indicate appointed positions

Superior Court Judges

Robert W. Steel, Terence J. Keely

Municipal Court Judge

Sutter Judicial District: Timothy J. Evans

TEHAMA COUNTY

Incorporated April 9, 1856

(Charter Form of Government)

Legislative Districts: 1st Congressional; 1st Senatorial; 1st Assembly
Population: 38,876 527 4655

COUNTY SEAT, RED BLUFF
County Central Info: P. O. Box 250, Red Bluff

Board of Supervisors

Meetings held each Tuesday

Judi H. Johnson, District 1, Red Bluff
Russ Frey, District 2, Red Bluff
Barbara V. Crowley, District 3, Red Bluff
Bill Flournoy, District 4, Corning
Burton Bundy, District 5, Gerber

Elected and Appointed Officials*

Assessor-Tax Collector, Robert L. Risberg
Auditor, Jimmie L. Hinkle
Coroner-Public Administrator, Andrew D. Ward
County Clerk-Recorder, Floyd A. Hicks
District Attorney, William O. Scott, Jr.
Sheriff, Ron Koenig
Superintendent of Schools, Louis J. Bosetti
Treasurer, Doris J. Forward
Purchasing Agent, Floyd A. Hicks
Welfare Director, Del Skillman
Planning Director, Robert McCullough
Health Officer, A. H. Meuser, M.D.
*Did not indicate appointed positions

Superior Court Judge

Noel Watkins

Justice Court Judges

Corning Judicial District, Richard E. Hultgren
Red Bluff Judicial District, Dennis Murray

TRINITY COUNTY

Incorporated February 18, 1850

Legislative Districts: 1st Congressional; 1st Senatorial; 1st Assembly
Population: 10,001

COUNTY SEAT, WEAVERVILLE
County Central Info: NOT SUBMITTED

Board of Supervisors

Meetings held every Monday of each month.

Richard J. Austin, District 1, Lewiston
Roger W. Adian, District 2, Weaverville
Ralph R. Modine, District 3, Hayfork
Irvin "Jim" Smith, District 4, Junction City (Chairman)
Donald A. Straw, District 5, Zenia

Elected and Appointed Officials*

Assessor, M. L. "Red" Wells
Auditor-Controller, John D. Larkin
Coroner-Public Administrator, George Files
County Clerk-Recorder, Barbara M. Rhodes
District Attorney, Ronald Barbatoe
Sheriff, Tom L. Kelly
Superintendent of Schools, Robert C. Gravette
Treasurer-Tax Collector, Magdalene K. Stone
Planning Director, Jeff Shields
Social Welfare Director, Ruby Gimlin
Public Defender, James J. White, William R. Neill
County Counsel, Ronald Barbatoe
*Did not indicate appointed positions

Superior Court Judge

Harold Underwood

Justice Court Judge

Trinity Judicial District, John L. Loomis

TULARE COUNTY

Incorporated April 20, 1852

Legislative Districts: 17th and 18th Congressional; 15th Senatorial; 31st and 32nd Assembly
Population: 224,700

COUNTY SEAT, VISALIA
County Central Info: Civic Center, Visalia 93277
Executive Officer: James E. Williams (A)

Board of Supervisors

Meetings held each Tuesday

Clyde Gould, District 1, Porterville (Chairman)
John Conway, District 2, Tulare
Delores E. (Lorie) Mangine, District 3, Visalia
LeRoy Swiney, District 4, Dinuba
Raymond J. Muller, District 5, Terra Bella

Elected Officials

Assessor, Lawrence M. Nichols
Auditor, Thomas C. Logan
County Clerk-Recorder, Jay C. Bayless
District Attorney-Public Administrator, William A. Richmond
Sheriff-Coroner, Bob Wiley
Superintendent of Schools, W. Dean Hall
Treasurer-Tax Collector, C. Ralph Howard

Superior Court Judges

David L. Allen, Jay R. Ballantyne, Nathaniel O. Bradley, Kenneth Conn, Edward Kim, William Silveira, Jr.

Municipal Court Judges

Visalia Judicial District: Robert C. Van Auken, Robert E. Bradstreet
Porterville Judicial District: Richard Thompson
Tulare-Pixley Judicial District: Walter L. Gorelick

Justice Court Judges

Dinuba Judicial District, Stephen Drew
Exeter-Farmersville Judicial District, Freddie McKenzie
Lindsay Judicial District, J. Patrick Sullivan
Woodlake Judicial District, Chris J. White

TUOLUMNE COUNTY

Incorporated February 18, 1850
Legislative Districts: 14th Congressional; 13th Senatorial; 7th Assembly
Population: NOT SUBMITTED

COUNTY SEAT, SONORA
County Central Info: 2 So. Green St., Sonora 95370
209-533-5511
Administrative Officer: Steven C. Szalay (A)

Board of Supervisors

Meetings held on Tuesday of each week in courthouse

Mildred Filiberti, District 1 (Vice Chairman)
Sidney Hatler, District 2
Billy H. Marr, District 3 (Chairman)
Clyde W. May, District 4
William C. Davidson, District 5

Elected and Appointed Officials

Assessor, David Wynne
County Clerk-Auditor-Controller, Robert W. André
District Attorney, Eric L. DuTemple
Recorder, Jeanette Ghiorso (Acting)
Sheriff-Coroner, Wallace Berry
Superintendent of Schools, Orville Millhollin
Treasurer-Tax Collector, John A. Nicolini (A)
Planning Director, James Nuzum (A)
Social Welfare, Clifton T. White (A)
County Counsel, Stephen Dietrich, Jr. (A)
Recreation Director, Leon Casas, Jr. (A)

Superior Court Judge

Theodore R. Vilas

Justice Court Judges

First Judicial District, Alan Ellis
Second Judicial District, Vivian Quinn
Third Judicial District, Thomas Parrington
Fourth Judicial District, Alan E. Ellis
Fifth Judicial District, Kent Grunewald

VENTURA COUNTY

Incorporated March 22, 1872

Legislative Districts: 19th and 20th Congressional; 18th and 19th Senatorial; 36th, 37th and 38th Assembly
Population: 488,900

COUNTY SEAT, VENTURA
County Central Info: County Government Center
800 South Victoria Avenue, Ventura 93009

County Executive: Richard Wittenberg (A)

Board of Supervisors

Meetings held each Tuesday at 8:30 a.m. in Courthouse

Susan K. Lacey, District 1
Edwin A. Jones, District 2
Maggie Erickson, District 3
James Dougherty, District 4
John K. Flynn, District 5

Elected Officials

Assessor, Jack M. Waterman
Auditor-Controller, Norman Hawkes
County Clerk and Recorder, Robert L. Hamm
District Attorney, Michael D. Bradbury
Sheriff, Al Jalaty
Superintendent of Schools, Dr. James F. Cowan
Tax Collector-Treasurer-Public Administrator, Robert G. Branch

Superior Court Judges

Lawrence Storch, Jerome H. Berenson, Bruce A. Thompson, Marvin H. Lewis, Ben F. Ruffner, Robert L. Shaw, Kenneth Cleaver, Steven J. Stone, Charles R. McGrath, William L. Peck

Court Commissioner, Roland N. Purnell, Juvenile Court Referee, Henry F. Flitt, Sr., Referee, John Sullivan

Municipal Court Judges

Albert T. Blanford, Lee E. Cooper, Burt M. Henson, John J. Hunter, Richard D. Love, Edwin M. Osborne, Frederick A. Jones, Bruce A. Clark, Joe D. Hadden, Robert J. Soares

YOLO COUNTY

Incorporated February 18, 1850
Legislative Districts: 4th Congressional; 4th Senatorial; 4th Assembly

Population: 106,000

COUNTY SEAT, WOODLAND
County Central Info: 725 Court Street, Woodland 95695
916-666-8011

County Executive: David D. Rowlands, Jr. (A)

Board of Supervisors

Meetings held every Tuesday at 9:00 a.m.

Clark H. Cameron, District 1, West Sacramento
Robert N. Black, District 2, Davis (Chairman)
George P. DeMars, District 3, Bryte
Mrs. Betsy A. Marchand, District 4, Davis
Twyla S. Thompson, District 5, Yolo

Elected and Appointed Officials

Assessor, Malcolm A. Nicolson
Auditor-Controller, Arthur M. Heasley
County Clerk-Recorder, Peter C. McNamee
District Attorney, Richard L. Gilbert
Public Administrator-Guardian, Elmo E. Novelli, Jr.
Sheriff-Coroner, Ronald E. Whitehead
Superintendent of Schools, Jack L. Potter
Treasurer-Tax Collector, John L. Dahler
County Counsel, Charles R. Mack (A)
Health Director, Dr. Otis B. Cobb, M.D. (A)
Public Defender, Rudolf H. Binsch (A)
Public Works Director, Lloyd Roberts (A)
Welfare Director, John R. Vera (A)
Purchasing Officer, George R. Jacob (A)

Superior Court Judges

Harry Albright Ackley, James F. Roach, Warren K. Taylor

Municipal Court Judges

Charles A. McGahan, Jr., Joseph A. Martin, Clarence Walden

YUBA COUNTY

Incorporated February 18, 1850
Legislative Districts: 1st Congressional; 1st Senatorial; 3rd Assembly
Population: 45,872

COUNTY SEAT, MARYSVILLE
County Central Info: Courthouse, 215 5th Street, Marysville 95901
916-743-1511

Board of Supervisors

Meetings held every Tuesday at 9:30 a.m.

George Deveraux, District 1, Marysville
John Dower, District 2, Marysville (Chairman)
Charles Center, District 3, Olivehurst
Douglas Waltz, District 4, Wheatland
Charlie Parker, District 5, Brownsville

Elected and Appointed Officials*

Assessor, Pat Bluett
Auditor, Dean E. Sellers
County Clerk-Recorder, Frances J. Fairey
District Attorney, Thomas Mathews
Sheriff-Coroner, Bob Day
Superintendent of Schools, Victor T. Pulsifer
Treasurer-Tax Collector, James Kennedy
* Did not indicate appointed positions

Superior Court Judges

Charles C. Dawson, Jr., Richard A. Schoenig

Municipal Court Judges

Marysville Judicial District, Donald K. Wahlberg
Wheatland Judicial District, James Dawson

CALIFORNIA MARSHALS AND CONSTABLES *

(as listed by county)

Alameda County
Frank Madigan, Marshal and Constable of all Alameda County Municipal and Justice Courts
Joseph Shelton, Constable, Pleasanton

Alpine County
Edwin Schalbert, Woodfords

Amador County
Angelo J. Casazza, Constable, Jackson

Butte County
James Bachand, Marshal, Chico
Ray Valverde, Constable, Biggs
W. H. Tamagni, Constable, Gridley
F. Sickels, Constable, Oroville
Leslie M. Thomas, Constable, Paradise

Calaveras County
Elaine Baratono, Deputy Constable, Angels Camp
Floyd Seagale, Deputy Constable, Angels Camp
L. R. Garrett, Constable, Murphys
James Carson, Constable, West Point
Arvil Whited, Constable, San Andreas
Phillip Woodworth, Deputy Constable, Valley Springs
Larry Turner, Deputy Constable, San Andreas
James L. Gurney, Deputy, Mokelumne Hill

Colusa County
Delton M. Nannen, Constable, Colusa
Harold J. Irvin, Constable, Williams

Contra Costa County
Charles Iverson, Marshal, Richmond
Donald Terrell, Marshal, Pittsburg
William H. Davis, Marshal, Walnut Creek
Carl Groshell, Marshal, Concord

Del Norte County
Herbert C. Tidd, Constable, Crescent City

El Dorado County
Stanley D. Rolfe, Constable, Placerville
Robert D. Rolfe, Constable, Garden Valley
George L. Bergman, Sr., Constable, South Lake Tahoe
M. P. Juarez, Constable, Placerville

Fresno County
Melvin A. Wilmirth, ex-officio Marshal and Constable

Glenn County
Lawrence London, Constable, Orland
George D. Ellis, Constable, Willows

Humboldt County
H. Wayne Nelson, Marshal, Eureka
William A. Nickols, Constable, Arcata
John Pelletier, Constable, Fortuna
Edward E. Prince, Jr., Constable, Garberville
Kenneth C. Anderson, Constable, Hoopa

Imperial County
C. E. Ritzenthaler, Constable, Brawley
Arthur J. Armenta, Jr., Constable, Calexico
Floyd H. Pitts, Constable, Calipatria
Dale A. Nice, Constable, El Centro
Coy Taylor, Constable, Holtville
Ben B. Mullins, Constable, Imperial
Sidney Guy Mealer, Constable, Westmorland
A. Paul Skinner, Sr., Constable, Winterhaven

Inyo County
Gerald Kane, Constable, Bishop
Jesse R. Covington, Constable, Lone Pine

Kern County
Charles H. Dodge, Marshal, Bakersfield
Frank R. Loustalot, Jr., Constable, Bakersfield
Henry M. Alvidres, Constable, Buttonwillow
B. C. McNutt, Constable, Delano-McFarland
Lee M. Wengler, Constable, Ridgecrest
Kenneth D. Hed, Constable, Kernville
Edward F. Coffee, Constable, Taft
William H. Deaver, Constable, Mojave
Ray Rose, Constable, Shafter
Lee R. Waddell, Constable, Tehachapi
Herbert J. Huffman, Constable, Wasco

Kings County
Roy M. Young, Constable, Avenal
Harry Martin, Constable, Corcoran
Leonard Simas, Constable, Hanford
Frank L. Silva, Jr., Constable, Lemoore

Lake County
E. L. Anderson, Ex-officio Constable, Lakeport

Lassen County
Eugene O. Duarte, Constable, Bieber
Vern E. Healey, Constable, Susanville

Los Angeles County
John Mahon, Marshal, Los Angeles
Guy Barnick, Constable, Malibu

Madera County
Elwin Newsom, Constable, Chowchilla
Virginia Camy, Constable, Madera
John M. Ades, Constable, Oakhurst

Marin County
Louis P. Mountanos, Marshal, San Rafael

Mariposa County
Wayne N. Abbot, Constable, Coulterville
Edward L. Mancins, Constable, Mariposa

Mendocino County
Paul E. Titus, Constable, Boonville
Leonard Craig, Constable, Point Arena
Edward B. Finley, Constable, Albion
Leandro Persico, Constable, Willits

Vaughn F. Hudman, Constable, Laytonville
Henry C. Bahnsen, Constable, Dos Rios
Claude H. Foster, Constable, Fort Bragg
Bob Byrnes, Constable, Ukiah

Merced County

L. M. Cardoza, Jr., Marshal, Merced
A. R. Williams, Constable, Dos Palos
Norman J. Silva, Constable, Gustine
William Slate, Constable, LeGrand
Norman R. Bertalotto, Constable, Livingston
Pete A. Cassinerio, Constable, Los Banos
C. A. (Chuck) Levy, Constable, Merced
Arden P. Wollstenhulme, Constable, Snelling

Modoc County

Bruce Mix, Constable, Adin
Perry Tilson, Constable, Adin
Charles M. Thompson, Constable, Tulelake
L. F. Sweeney, Constable, Cedarville

Mono County

Vacant, Constable

Monterey County

Lester Barker, Constable, Castroville
Robert Cheatwood, Constable, Gonzales
Carl Thomas Roberts, Constable, Greenfield
Phil Crocker, Constable, King City
Gene Getz, Constable, Pacific Grove
Thomas W. Brown, Constable, San Ardo

Napa County

Lamar L. Tallman, Constable, Napa

Nevada County

Elton F. Williams, Constable, Grass Valley
Wayne Brown, Constable, Nevada City
N. F. Dolley, Constable, Truckee

Orange County

Don Rhea, Marshal, Santa Ana

Placer County

Russ Davis, Constable, Auburn
William E. Fonseca, Constable, Colfax
Glenn Lowery, Jr., Constable, Foresthill
Hike M. Yego, Constable, Loomis
San J. Zien, Constable, Roseville
Adam Sabat, Constable, Tahoe City

Plumas County

James Youngman, Constable, Greenville
Max Knadler, Constable, Blairsden
Andy Nelson, Constable, Quincy

Riverside County

Donald W. Foster, Marshal, Palm Springs
William Schmidt, Marshal, Riverside
John T. Waugh, Constable, Beaumont
Doyle D. McLaughlin, Constable, Coachella
Owen C. Northup, Constable, Elsinore
John H. Dykes, Constable, Hemet
Robert L. Thompson, Constable, Riverside
S. A. Hicks, Constable, Temecula
Lemuel B. Todd, Constable, Blythe
Michael Buchko, Constable, Perris
Ed. L. Palmer, Jr., Constable, Banning
Albert L. Napeleton, Constable, San Jacinto

Sacramento County

Lee Jay Ghilarducci, Marshal, Sacramento
Delbert Stuck, Constable, Elk Grove
Glenn Pfaal, Constable, Fair Oaks
Ben Cox, Constable, Walnut Grove

San Benito County

Cliff Gawatt, Constable, Hollister
Frank Luchelli, Constable, San Juan Bautista
George J. Madeiros, Jr., Constable, Tres Piños

San Bernardino County

R. C. Randolph, Marshal, San Bernardino
Paul R. Simon, Constable, Barstow
Edgar Jay Reed, Constable, Big Bear Lake
Dewey G. Beaton, Constable, Bloomington
Bill Carlisle, Constable, Earp
S. J. Coppess, Constable, Chino
P. S. Oliva, Constable, Colton
H. A. Morris, Constable, Crestline
R. J. Plamondon, Constable, Cucamonga
Alfred W. McGuire, Constable, Etiwanda
Eugene Debs Wilson, Constable, Highland
Gordon Beer, Constable, Loma Linda
R. D. Weant, Constable, Needles
Fidel G. Ruiz, Constable, Trona
L. O. Dugas, Constable, Twentynine Palms
Joe Holland, Constable, Yermo
James Martines, Constable, Yucaipa

San Diego County

Mike Sgobba, Marshal, San Diego

San Francisco County

Richard Hongisto, Marshal, San Francisco

San Joaquin County

Charles E. Chapman, Marshal, Lodi
Monte D. McFall, Marshal, Manteca
Nick Crocci, Marshal, Stockton
John J. Dubitsky, Constable, Tracy

San Luis Obispo County

Robert E. Summers, Constable, Paso Robles
Joe King, Constable, Morro Bay
Delmo E. Bassetti, Constable, San Luis Obispo
Tony Galaviz, Constable, Grover City
John Norman, Constable, Atascadero

San Mateo County

Earl B. Whitmore, Marshal, Redwood City

Santa Barbara County

Walt T. Livingston, Marshal, Lompoc
Bruce Kieper, Marshal, Santa Barbara
Ronald J. Rodenberger, Marshal, Santa Maria
Stephen C. Romero, Constable, Carpinteria
Leonard Chapman, Constable, Guadalupe
L. R. Crews, Constable, Solvang

Santa Clara County
James Geary, Marshal and Constable, San Jose

Santa Cruz County
Douglas James, Marshal, Santa Cruz

Shasta County
John McFarland, Constable, Anderson
Jim Barrington, Constable, Burney
Sam P. Spatafora, Constable, Castella
Fred C. Gardner, Constable, Central Valley
Paul Walthers, Constable, Cottonwood
James C. Nolan, Constable, Fall River Mills
Byron E. Johnston, Constable, Montgomery Creek
George Alveras, Constable, Redding.

Sierra County
No constables

Siskiyou County
Ralph Honey, Constable, Dorris
Perry C. Shelton, Constable, Mt. Shasta
Alan March, Constable, Happy Camp
Jack F. Fairchild, Constable, McCloud
Paul I. Garrison, Constable, Fort Jones
Felice Groppi, Constable, Edgewood
H. E. Opdenhoff, Constable, Tulelake
Louis A. Price, Constable, Yreka

Solano County
Robert Grate, Marshal, Vallejo

Sonoma County
Donald Striepeke, Marshal, Santa Rosa

Stanislaus County
Robert Earl, Marshal, Modesto
Clifford R. Ridley, Constable, Ceres
John M. Silveira, Jr., Constable, Newman
Mrs. Rae Coslet, Constable, Oakdale
Ed Lisota, Constable, Patterson
Robert Hutcheon, Constable, Riverbank
Charles V. Naff, Constable, Turlock

Sutter County
M. J. Freeman, Constable, Live Oak

Tehama County
Lloyd King, Constable, Corning
Lyle Williams, Ex-officio Constable, Red Bluff

Trinity County
George Whitcomb, Constable, Hayfork
Howard Smith, Constable, Junction City
George A. Short, Constable, Mad River
Adolph C. Schwarz, Constable, Lewiston
Edward W. Baxter, Constable, Weaverville

Tulare County
Olen R. Lane, Marshal, Visalia
Duard D. Sprague, Marshal, Tulare
Vincent Arcure, Marshal, Porterville
James E. Franks, Constable, Dinuba
Nyle Edwards, Constable, Exeter
Keith L. Wells, Constable, Lindsay
Carl E. Barber, Constable, Pixley
William H. Thompson, Constable, Porterville
Coy Dodd, Constable, Woodlake

Tuolumne County
Joseph Pease, Constable, Sonora
J. M. Robertson, Constable, Columbia
LeRoy A. Clark, Constable, Twain Harte
James N. Crawford, Jr., Constable, Groveland
Herbert L. Chafin, Constable, Jamestown

Ventura County
John MacIntyre, Marshal, Ventura

Yolo County
James W. Brady, Constable, Davis
Barrick D. Archer, Constable, Knights Landing
Theodore J. Prickett, Constable, Broderick
Yolo Briggs, Constable, Winters
J. R. Morris, Constable, Zamora

Yuba County
William E. Groves, Constable, Camptonville
Partick Collins, Constable, Marysville

* Because of difficulties in obtaining updated information for this section, it is only partially updated.

CALIFORNIA CITIES ELECTION DAYS

GENERAL LAW CITIES

General election; elective officers; term

Unless otherwise required by Section 34329.1 . . ., a general municipal election shall be held on the second Tuesday in April in each even-numbered year. Except as otherwise provided in this title, city councilmen, the city clerk, and the city treasurer shall be elected by the city electors at a general municipal election. City councilmen, the city clerk, and the city treasurer shall hold office for four years from the Tuesday succeeding their election, and until their successors are elected and qualified. **Gov. C.** § 36503, am Stats. 1978, c. 1376.

City council members; terms of office

If the first general municipal election following an incorporation election will occur less than one year after the incorporation election, all of the city council members elected at the incorporation election shall hold office until the second general municipal election following the incorporation election and until their successors are elected and qualified. Of the five council members elected at such second general municipal election, the three receiving the lowest number of votes shall hold office for two years and until their successors are elected and qualified, and the two receiving the highest number of votes shall hold office for four years and until their successors are elected and qualified. Subsequent council members shall hold office for four years from the Tuesday succeeding their election, and until their successors are elected and qualified.

This section shall apply only to council members elected at an incorporation election held after the effective date of this section. If this section applies, the first general municipal election following the incorporation election shall not be held unless either a proposition is to be voted upon or offices other than council member offices are to be filled. **Gov. C.** § 35443, ad Stats. 1977, c. 1253.

CHARTER CITIES—MUNICIPAL ELECTIONS *

Alameda—1st Tuesday, March, odd years
Albany—2nd Tuesday, April, even years
Alhambra—1st Tuesday, after 1st Monday, Nov., even years
Anaheim—2nd Tuesday, April, even years
Arcadia—2nd Tuesday, April, even years
Bakersfield—1st Tuesday after 1st Monday, March, odd years
Berkeley—3rd Tuesday, April, odd years
Burbank—Nom: Last Tuesday, February, odd years
Gen: 1st Tuesday, April, odd years
Cerritos—2nd Tuesday, April, even years
Chico—1st Tuesday after 1st Monday, April, odd years
Chula Vista—Council—Nom: 2nd Tuesday, April, even years
Run-off consolidated with Statewide June election
Mayor—1st Tuesday after 1st Monday, November, odd years
Compton—Pri: 3rd Tuesday, April, odd years
Gen: 1st Tuesday, June, odd years
Culver City—2nd Tuesday, April, even years
Cypress—Same as General Law
Del Mar—Same as General Law
Dorris—1st Tuesday, March, even years
Downey—2nd Tuesday, April, even years
Eureka—Consolidated with Statewide Primary and General election, even years
Fresno—1st Tuesday after 1st Monday, March, odd years
Gilroy—1st Tuesday, November, odd years
Glendale—1st Tuesday, April, odd years
Grass Valley—1st Tuesday, May, odd years
Hayward—2nd Tuesday, April, even years
Hughson—1st Tuesday, even years
Huntington Beach—2nd Tuesday, April, even years
Industry—Same as General Law
Inglewood—1st Tuesday, April, odd years. If a candidate fails to receive a majority vote, run-off election is held within 70 days after nominating election
Irvine—1st Tuesday after 1st Monday, June, even years
Kerman—1st Tuesday, March, even years
Long Beach—Nom: 3rd Tuesday, March, even years
Gen: 2nd Tuesday, May, even years
Los Alamitos—2nd Tuesday, April, even years
Los Angeles—Nom: 1st Tuesday, April, odd years
Gen: Last Tuesday, May, odd years
Marina—1st Tuesday, March, even years
Marysville—November general election, even years
Merced—3rd Tuesday, April, odd years
Modesto—1st Tuesday after 1st Monday, March, odd years
Monterey—2nd Tuesday, May, odd years
Mountain View—2nd Tuesday, April, even years
Napa—2nd Tuesday, April, even years
Needles—2nd Tuesday, April, even years
Newport Beach—2nd Tuesday, April, even years
Oakland—Nom: 3rd Tuesday, April, odd years
Gen: 4th Tuesday after Nom election
Ontario—1st Tuesday, even years
Oroville—2nd Tuesday, April, odd years
Pacific Grove—2nd Tuesday, April, odd years
Palo Alto—2nd Tuesday, May, odd years
Pasadena—Nom: 6th Tuesday preceding General election, odd years
Gen: 3rd Tuesday, April, odd years
Petaluma—2nd Tuesday, June, odd years
Piedmont—Last Tuesday, February, even years
Placentia—2nd Tuesday, April, even years
Pomona—Nom: 1st Tuesday after 1st Monday, March, odd years
Gen: 3rd Tuesday, April, odd years
Porterville—1st Tuesday, March, odd years
Redondo Beach—1st Tuesday after 1st Monday, March, odd years
Redwood City—2nd Tuesday, April, even years
Richmond—Nom: 5 weeks prior to General
Gen: 2nd Tuesday, May, odd years
Riverside—1st Tuesday after 1st Monday, November, odd years. If a candidate fails to receive a majority vote, run-off election is held not less than 45 days and not more than 70 days after nominating election.
Roseville—Same as General Law
Sacramento—Pri: 6th Tuesday before date of General
Gen: 1st Tuesday after 1st Monday, November, odd years
Salinas—1st Tuesday, June, odd years
San Bernardino—1st Tuesday, May, odd years

San Buenaventura—1st Tuesday after 1st Monday, November, odd years
San Diego—Nom: 3rd Tuesday, September, odd years
Gen: 1st Tuesday after 1st Monday, November, odd years
San Francisco—Nom: 1st Tuesday after 1st Monday, November, odd years.
Gen: 2nd Tuesday, December, odd years
San Jose—Gen: 1st Tuesday after 1st Monday, June, even years
Run: 1st Tuesday after 1st Monday, November, even years
San Leandro—2nd Tuesday, April, even years
San Luis Obispo—1st Tuesday after 1st Monday, March, odd years
San Marino—April, even years
San Mateo—1st Tuesday, April, odd years, unless there is a Special Election in February, March, or April in which case the Municipal Election is consolidated with the Special Election
San Rafael—1st Tuesday, after 1st Monday, November, odd years
Santa Ana—1st Tuesday, April, odd years
Santa Barbara—1st Tuesday following 1st Monday, March, odd years
Santa Clara—1st Tuesday after 1st Monday, March, odd years
Santa Cruz—1st Tuesday after 1st Monday, November, odd years
Santa Monica—2nd Tuesday, April, odd years
Santa Rosa—2nd Tuesday, April, even years
Seal Beach—Pri: Last Tuesday, March, even years
Run: 2nd Tuesday, May, even years
Stockton—2nd Tuesday, October, odd years
Sunnyvale—2nd Tuesday, March, odd years
Temple City—2nd Tuesday, April, even years
Torrance—1st Tuesday after 1st Monday, March, even years
Tulare—1st Tuesday after 1st Monday, November, odd years
Vallejo—1st Tuesday, March, odd years
Ventura—see city of San Buenaventura
Visalia—1st Tuesday after 1st Monday, November, odd years
Watsonville—2nd Tuesday, May, odd years
Whittier—2nd Tuesday, April, even years

CITY AND TOWN OFFICIALS FOR CALIFORNIA

CITY OF ADELANTO

(County of San Bernardino)

Incorporated December 22, 1970
Legislative Districts: 37th Congressional; 16th Senatorial; 34th Assembly
General law city. Population 2,773. Council meets second and fourth Tuesday of each month at 11740 Bartlett Ave., 92301.
Central Telephone: 714-246-8606
Mayor: Charlotte Y. Foster
City Administrator: Patricia A. Chamberlaine
Mayor pro Tem, Edward J. Dondelinger
Councilman, Edward A. Dunagan
Councilman, George R. Sutton
Councilman, Gus Ronnebeck
City Clerk, Elizabeth E. McClure
Police Chief, John E. Morrissey
Fire Chief, Tom Fogerson
School Superintendent, Theodore Vick
City Treasurer, Sandra R. Ouellette
City Attorney, Ivan Hopkins

CITY OF ALAMEDA

(County of Alameda)

Incorporated April 19, 1854
Legislative Districts: 9th Congressional; 9th Senatorial; 13th Assembly
Chartered city. Population 63,700. Council meets first and third Tuesday of month at 7:30 p.m. in Council Chamber, City Hall, Santa Clara Ave. and Oak St., 94501.
Central Telephone: 415-522-4100
Mayor: Carmelo J. Corica
City Manager: J. Bruce Rupp
Councilman, Amey Stone
*Councilman, Anne Diament
Councilman, Michael Gorman
Councilman, Richard Sherratt
City Attorney, Carter Stroud
City Clerk, Deen Speegle
Police Chief, Robert Shiells
Fire Chief, Richard Quarante
Treasurer, Lawrence Stickney
Auditor-Assessor, Robert Lofstrand
School Superintendent, Clarence R. Kline
*Prefers title "Councilman".

CITY OF ALBANY

(County of Alameda)

Incorporated September 22, 1908
Legislative Districts: 8th Congressional; 11th Senatorial; 12th Assembly
Chartered city. Population 15,561. Council meets each Monday at 8:00 p.m. in Council Chambers, 1000 San Pablo Ave., 94706.
Central Telephone: 415-644-8523
Mayor: William A. Lewis
Administrative Officer: William E. Haden
Councilman, Louis L. George
Councilwoman, Anne Rotramel
Councilman, William Johns
Councilwoman, Ruth Ganong
City Clerk, Jacqueline Bucholz
Attorney, Robert Zweben
Police Chief, James Simmons
Fire Chief, Horace Koepke
Treasurer, Jo Ann Honer
School Superintendent, Stephen Goldstone

CITY OF ALHAMBRA

(County of Los Angeles)

Incorporated July 11, 1903
Legislative Districts: 26th Congressional; 26th Senatoria; 59th Assembly
Chartered city. Population 64,764. Council meets second and fourth Mondays of month at 7:30 p.m. in Council Chambers, City Hall, 111 S. First St., 91801.
Central Telephone: 213-570-5111
Mayor: Peter J. Letourneau
City Manager: Andrew C. Lazzaretto, Jr.
Vice-Mayor, Michael Messina
Councilman, W. Sherman Hall, Jr.
Councilman, Talmage V. Burke
Councilman, J. Parker Williams
City Clerk, Dorothy Outwater, CMC
City Attorney, Leland C. Dolley
Police Chief, Joseph T. Molloy
Fire Chief, Robert G. Tolladay
School Superintendent, Dr. Bruce H. Peppin

CITY OF ALTURAS

(County of Modoc)

Incorporated September 16, 1901
Legislative Districts: 1st Congressional; 1st Senatorial; 1st Assembly
General law city. Population 2,980. Council meets 1st Thursday of each month at 7:00 p.m. in City Hall, 218 North St., 96101.
Central Telephone: 916-233-2512
Mayor: Joe S. Phillips
Councilman, Roger Dorris
Councilwoman, Beth Swift
Councilman, John Dederick
Councilman, Tony Lelli
City Attorney, Paul Baker
City Clerk, Bette P. Fountain
Police Chief, Ernest O. Hawes
Fire Chief, James W. Porter
Treasurer, Kathie Utt

CITY OF AMADOR

(County of Amador)

Incorporated June 2, 1915

Legislative Districts: 14th Congressional; 13th Senatorial; 7th Assembly

General law city. Population 156. Council meets second Thursday of month in Fire Hall, Main St., 95601.
Central Telephone: 209-267-0321

Mayor: Lloyd L. Smith

Councilman, Alfred M. Fagundes
Councilman, William H. Hart
Councilman, Alan W. Robello
Councilman Peter Daubenspeck III
City Attorney, James Deasey
City Clerk, Harold K. Buus
Treasurer, Ruth J. Tippett

CITY OF ANAHEIM

(County of Orange)

Incorporated March 18, 1876

Legislative Districts: 38th and 39th Congressional; 35th and 37th Senatorial; 69th, 70th, 71st and 72nd Assembly

Chartered city. Population 214,688. Council meets every Tuesday of each month at 1:30 p.m. in Civic Center, 200 S. Anaheim Blvd., 92805.
Central Telephone: 714-999-5166

Mayor: John Seymour
City Manager: William O. Talley

Mayor pro Tem. E. Llewellyn Overholt, Jr.
Councilwoman, Miriam Kaywood
Councilman, Don R. Roth
Councilman, Ben Bay
City Clerk, Linda D. Roberts
Police Chief, George P. Tielsch
Fire Chief, Bob Simpson
City Attorney, William P. Hopkins

CITY OF ANDERSON

(County of Shasta)

Incorporated January 16, 1956

Legislative Districts: 1st Congressional; 1st Senatorial; 1st Assembly

General law city. Population 7,316. Council meets first and third Tuesdays of each month in City Hall, 1887 Howard Street, 96007.
Central Telephone: 916-365-2521

Mayor: Jim Logan
City Manager: William R. Garr

Mayor pro Tem. Thomas E. Pepper
Councilman, Marvin P. Bennett
Councilman, J. Robert Di Lullo
Councilman, Jerry Vorrhees
City Attorney, Michael C. Fitzpatrick
City Clerk, Jacqueline J. Padilla
Police Chief, Phil Raner
Fire Chief, Ross Phipps, Jr.

CITY OF ANGELS

(County of Calaveras)

Incorporated January 24, 1912

Legislative Districts: 14th Congressional; 13th Senatorial; 7th Assembly

Post Office: Angels Camp

General law city. Population 2,859. Council meets on the first and third Tuesday of month at 8 p.m. in City Hall, 95222.

Mayor: Oliver W. Garcia

Vice Mayor, Elizabeth Alford
Councilman Gary L. Hinman
Councilman, Paul D. Raggio
Councilman, Tad Folendorf
City Clerk, Jacqueline L. Heintz
Police Chief, Ronald Adams
Fire Chief, Joe Carley
Treasurer, Sam Urruty
City Attorney, George Huberty

CITY OF ANTIOCH

(County of Contra Costa)

Incorporated February 6, 1872

Legislative Districts: 7th Congressional; 7th Senatorial; 10th Assembly

General law city. Population 42,251. Council meets second and fourth Tuesday of each month at 4:30 p.m. in City Hall, 212 H Street, 94509.
Central Telephone: 415-757-3333

Mayor: Verne L. Roberts
City Manager: George F. Anast

Mayor pro Tem, Victor Catanzaro
Councilmember, Walter K. Pierce
Councilmember, John Hall
Councilmember, Wilhelmina Andrade
City Clerk, Dorothy P. Marks
Police Chief, Leonard Herendeen
Fire Chief, Vincent Aiello
Treasurer, Ethel Lampley
School Superintendent, Gerald Pangburn

CITY OF ARCADIA

(County of Los Angeles)

Incorporated August 5, 1903

Legislative Districts: 26th Congressional; 25th Senatorial; 61st Assembly

Chartered city. Population 45,678. Council meets first and third Tuesdays at 7:30 p.m. in Council Chambers, City Hall, 240 W. Huntington Drive 91006.
Central Telephone: 213-446-4471

Mayor: Donald D. Pellegrino
City Manager: Lyle W. Alberg

Councilman, Jeffrey A. Dring
Councilman, Richard A. Haltom
Councilman, Charles E. Gilb
Councilman, Jack Saelid
City Clerk, Christine Van Maanen
Police Chief, Charles Mitchell
Fire Chief, Gerald Gardner

School Superintendent, Edward V. Ryan
City Attorney, Charles Liberto

CITY OF ARCATA

(County of Humboldt)

Incorporated February 2, 1858
Legislative Districts: 2nd Congressional; 2nd Senatorial; 2nd Assembly
General law city. Population 13,000. Council meets first and third Tuesday of each month at 8:00 p.m. in City Hall, 736 F Street, 95521.
Central Telephone: 707-822-5951
Mayor: Daniel Hauser
City Manager: Roger A. Storey

Mayor pro Tem, Sam Pennisi
Councilmember, Julie Fulkerson
Councilmember, Victor Green
Councilmember, Stephen Leiker
City Attorney, David Tranberg
City Clerk, Kenneth W. Frazier
Police Chief, Michael Manick

CITY OF ARROYO GRANDE

(County of San Luis Obispo)

Incorporated July 10, 1911
Legislative Districts: 19th Congressional; 17th Senatorial; 29th Assembly
General law city. Population 9,350. Council meets *second and fourth Tuesday of each month* at 214 E. Branch St., 93420.
Central Telephone: 805-489-1303
Mayor: Hugh O. Pope, Jr.
City Administrator: Thomas M. Butch

Mayor pro Tem, Lawrence E. Vandeveer
Councilmember, Mark M. Mills
Councilmember, Karl A. Hogan
Councilmember, B'Ann Smith
City Clerk, Ines A. del Campo
Police Chief, James C. Clark
Fire Chief-Fire Marshal, Tony Marsalek
Treasurer, Jo Ann Wizemann
Finance Director, David E. Bacon

CITY OF ARTESIA

(County of Los Angeles)

Incorporated May 29, 1959
Legislative Districts: 34th Congressional; 33rd Senatorial; 63rd Assembly
General law city. Population 15,200. Council meets second Monday of each month at City Hall, 18747 Clarkdale Ave., 90701.
Central Telephone: 213-865-6262
Mayor: Dennis R. Fellows
City Manager: M. D. McKeown

Mayor pro Tem, Gretchen A. Whitney
Councilman, James A. Van Horn
Councilman, Ronald H. Oliver
Councilman, Robert J. Jamison
City Clerk,-Treasurer, Margaret M. Rittel
City Attorney, Glenn Watson
*City Council will reorganize 4/81

CITY OF ARVIN

(County of Kern)

Incorporated December 21, 1960
Legislative Districts: 18th Congressional; 16th Senatorial; 33rd Assembly
General law city. Population 6,787. Council meets second and fourth Monday each month in Courtroom/Council Chamber, 200 Campus Drive, 93203.
Mayor: John Sams

Councilman, Walker Christian
Councilman, Jess G. Ortiz
Councilman, Steve Franetovich
Councilman, Donald Burkett
City Administrator, O. L. Wooner
City Clerk, Olga Leonard
Police Chief, Robert McIntosh
Treasurer, Jess Woods
City Attorney, Ray A. Yinger

CITY OF ATASCADERO

(County of San Luis Obispo)

Incorporated July 2, 1979
Legislative Districts:-16th Congressional; 17th Senatorial; 29th Assembly
General law city. Population 16,796. Council meets 2nd and 4th Mondays, 7:30 p.m, Rotunda Room, Administration Building, 6500 Palma, 93423.
Central Telephone: 805-466-8000
Mayor: Robert J. Wilkins, Jr.
City Manager: Murray L. Warden

Mayor pro Tem, William H. Stover
Councilman, George P. Highland
Councilwoman, Marjorie R. Mackey
Councilman, Rolfe D. Nelson
City Clerk, Murray L. Warden
Police Chief, Richard H. (Bud) McHale
Fire Chief, Donald Sylvia
School Superintendent, Anthony Avina
City Attorney, Allen Grimes

TOWN OF ATHERTON

(County of San Mateo)

Incorporated September 12, 1923
Legislative Districts: 12th Congressional; 10th Senatorial; 20th Assembly
General law city. Population 8,175. Council meets 2nd Tuesday of month at 7:30 p.m. in Town Hall, 94 Ashfield Rd., 94025.
Central Telephone: 415-325-4457
Mayor: Malcolm H. Dudley
City Manager: Ross G. Hubbard

Vice-Mayor, John W. Dinkelspiel
Councilman, John Fisher

Councilman, Harry Hagey
Councilwoman, Nanette F. Chapman
City Clerk, Ross G. Hubbard
Police Chief, Richard L. Moore
Fire Chief, Vincent DelPozzo
City Attorney, Bradford Jeffries

CITY OF ATWATER

(County of Merced)

Incorporated August 16, 1922
Legislative Districts: 15th Congressional; 14th Senatorial; 27th Assembly
General law city. Population 17,500. Council meets second and fourth Mondays of month at 7:30 p.m. in Council Chambers, City Hall, 750 Bellevue Road, 95301.
Central Telephone: 209-358-5606
Mayor: Gregory R. Olzack
City Manager: Thomas I. Smith

Councilman, John Cupples
Councilman, Robert Mitchell
Councilwoman, Leona Zimmerman
Councilwoman, Linda Dash
City Clerk, Donna E. Legg
Police Chief, Ray Blake
Treasurer, James Heller, Jr.
Fire Chief, Vern Willhoite
School Superintendent, Frank English

CITY OF AUBURN

(County of Placer)

Incorporated May 2, 1888
Legislative Districts: 1st Congressional; 1st Senatorial; 3rd Assembly
General law city. Population 7,513. Council meets second and fourth Mondays of month in City Hall, 1103 High St., 95603.
Central Telephone: 916-885-5661
Mayor: Jack Veal
City Manager: Jack H. Sausser

Councilman, Al Albertazzi
Councilman, George Beland
Councilman, Richard T. Gailbreath
Councilman, Ronald Lichau
City Attorney, Richard Prather
City Clerk, Florence Ladeck
Police Chief, Nicholas S. Willick
Fire Chief, Henry Gietzen
Treasurer, Edna M. Casebeer

CITY OF AVALON

(County of Los Angeles)

Incorporated June 26, 1913
Legislative Districts: 32nd Congressional; 27th Senatorial; 52nd Assembly
General law city. Population 2,029. Council meets first and third Mondays of month at 7:00 p.m. in Council Chambers, 209 Metropole, 90704.
Mayor: George Scott
City Manager: John Longley

Mayor pro Tem, Gilbert Saldana
Councilman, Carol Fagot
Councilman, Norman Perluss
Councilman, Hugh T. "Bud" Smith
City Clerk, Shirley Davy
Police Chief, Charles Wood
Fire Chief: Jack Goslin
Treasurer, Margaret Perry

CITY OF AVENAL

(County of Kings)

Incorporated September 11, 1979
Legislative Districts: 17th Congressional; 15th Senatorial; 32nd Assembly
General law city. Population 4,130. Council meets 7:00 p.m. every second and fourth Thursday of the month at 919 Skyline Blvd., City Hall, 93204.
Central Telephone: 209-386-5766
Mayor: T. A. Funk
City Manager: Homer L. Bludau

Councilman, James Castleman
Councilman, Harlin Casida
Councilman, Samuel Glover
Councilman, Norman Messer
City Clerk, E. Jane Strong
City Treasurer, Susan E. Henderson
City Attorney, Henry Leckman
Police Chief, contracted
Fire Chief, fire district
School Superintendent, George Davis

CITY OF AZUSA

(County of Los Angeles)

Incorporated December 29, 1898
Legislative Districts: 26th Congressional; 25th Senatorial; 61st Assembly
General law city. Population 29,232. Council meets first and third Mondays of month in Civic Auditorium, 213 E. Foothill Blvd., 91702.
Mayor: Jens J. Solem
City Administrator: John R. Dangleis

Mayor pro Tem, Willard R. Decker
Councilman, Robert G. Fry
Councilman, Lucio D. Cruz
Councilman, Eugene F. Moses
City Clerk, Adolph A. Solis
Police Chief, Carl W. Elkins
Fire Chief, John B. Littlefield
Treasurer, Robert E. Talley
School Superintendent, Dr. Lewis L. Beall
City Attorney, Carl Newton

CITY OF BAKERSFIELD

(County of Kern)

Incorporated January 11, 1898
Legislative Districts: 18th Congressional; 16th Senatorial;

33rd Assembly
Charter city. Population 106,173. Council meets every Wednesday evening in City Hall, 1501 Truxtun Ave., 93301.
Central Telephone: 805-861-2711
Mayor: Mary K. Shell
City Manager: Philip Kelmar

Councilman, Vernon D. Strong
Councilman, Thomas A. Payne
Councilman, James J. Barton
Councilman, Arthur Rockoff
Councilman, John M. Means
Councilman, Donald K. Ratty
Councilman, J. M. "Chris" Christensen
City Clerk, Philip Kelmar
Police Chief, Bob Price
Fire Chief, Dennis Needham
School Superintendent, Dr. Herbert M. Cole, Jr.
Assistant City Manager-Finance, Philip Kelmar
City Attorney, Richard J. Oberholzer

CITY OF BALDWIN PARK

(County of Los Angeles)

Incorporated January 25, 1956
Legislative Districts: 26th Congressional; 26th Senatorial; 60th Assembly
General law city. Population 50,538. Council meets first and third Wednesday of month at 7:30 p.m. in Council Chambers, City Hall, 14403 E. Pacific Avenue, 91706.
Central Telephone: 213-960-4011
Mayor: Jack B. White
City Manager: Vacant

Mayor pro Tem, Robert N. McNeill
Councilman, Felipe Aguilar, Jr.
Councilman, Blair Holman
Councilman, Leo W. King
City Clerk, Linda L. Gair
Police Chief, David Snowden
Fire Chief, Robert Sarno
Treasurer, Ana Montenegro
School Superintendent, Jerry D. Holland
City Attorney, Robert Flandrick

CITY OF BANNING

(County of Riverside)

Incorporated February 6, 1913
Legislative Districts: 37th Congressional; 34th Senatorial; 67th Assembly
General law city. Population 13,200. Council meets second and fourth Mondays of each month at County Administration Bldg., 155 E. Hays St., City Hall: 161 W. Ramsey St. 92220.
Central Telephone: 714-849-4511
Mayor: Carl V. Wolfram
City Manager: Stephen B. Julian

Councilwoman, E. Brigitte Page
Councilman, Frank Burgess
Councilman, Robert Kohagen
Councilman, Leonard Perkins
City Clerk, Lucille M. Elizondo
Police Chief, A. L. Aldrich
Fire Chief, Frank Sexton
Treasurer, Alf J. Danielsen
School Superintendent, Fred Pasquale

CITY OF BARSTOW

(County of San Bernardino)

Incorporated September 30, 1947
Legislative Districts: 37th Congressional; 16th Senatorial; 34th Assembly
General law city. Population 17,590. Council meets at 7:30 p.m. first and third Mondays and third Monday at 4:30 p.m. (Hospital business), Council Chambers 220 E. Mt. View Ave., 92311.
Mayor: Paul R. Simon
City Manager: E. Wayne Lamoreaux

Mayor pro Tem, Richard Padilla
Councilman, James A. Bellomy
Councilman, A. J. Pontecorvo
Councilman, Al Vigil
City Clerk, Mrs. Betty Rowe
Police Chief, H. O. Davis
Fire Chief, David Mathews
Treasurer, Evelyn L. Radel
School Superintendent, Eugene Ferrick

CITY OF BEAUMONT

(County of Riverside)

Incorporated November 18, 1912
Legislative Districts: 37th Congressional; 34th Senatorial; 67th Assembly
General law city. Population 6,572. Council meets second and fourth Mondays of each month in City Hall, 550 6th Ave., 92223.
Central Telephone: 714-845-1171
Mayor: Aubrey Allen
City Manager: Glenn Sparks

Councilman, Fred Shaw
Councilman, Richard Hammel
Councilman, Carl Peterson
Councilman, William Lowry
Councilman, Jack Blankenship
City Clerk, LaVerne Jones
Police Chief, Robert Bridges
Fire Chief, Contract with CDF
Treasurer, Don Houston
School Superintendent, James L. Lucas

CITY OF BELL

(County of Los Angeles)

Incorporated November 7, 1927
Legislative Districts: 29th Congressional; 29th Senatorial; 47th Assembly
General law city. Population 25,454. Council meets first and third Mondays of month at 7:30 p.m. in City Hall, 6330 Pine Ave., 90201.

Central Telephone: 213-588-6211
Mayor: Clarence H. Knechtel
City Administrator: John D. Pitts
Mayor pro Tem, George K. Simmons
Councilmember, Donna L. Caddy
Councilmember, Lou Ida Caster
Councilmember, Jay B. Price
City Clerk, George A. Brennan
Police Chief, Edward L. Ballinger
Treasurer, Hazel F. Collett
City Attorney, Robert Flandrick

CITY OF BELLFLOWER

(County of Los Angeles)

Incorporated September 3, 1957
Legislative Districts: 34th Congressional; 28th Senatorial; 54th Assembly
General law city. Population 53,079. Council meets second and fourth Mondays at 7:30 p.m. in City Hall, 9838 E. Belmont St., 90706.
Central Telephone: 213-866-9003
Mayor: Henry Kruid
City Administrator: Jack A. Simpson
Mayor pro Tem, Lee Walker
Councilman, Edward H. Drayer
Councilman, George Marsh
Councilwoman, Shirley B. Feenstra
City Clerk, Pamela S. Swift
School Superintendent, Dr. Leonard Burns
City Attorney, Maurice O'Shea

CITY OF BELL GARDENS

(County of Los Angeles)

Incorporated August 1, 1961
Legislative Districts: 30th Congressional; 24th Senatorial; 56th Assembly
General law city. Population 29,308. Council meets second and fourth Mondays of month in City Hall, 7100 S. Garfield Ave., 90201.
Central Telephone: 213-927-8301
Mayor: Helen West
City Manager: Larry Kosmont
Mayor pro Tem, Marvin Graves
Councilman, Frank C. Dana
Councilman, Roger McComas
Councilman, Roy Paul
City Clerk, Leanna Keltner
Police Chief, Philipp Henson
City Attorney, Peter Wallin

CITY OF BELMONT

(County of San Mateo)

Incorporated October 29, 1926
Legislative Districts: 11th Congressional; 10th Senatorial; 20th Assembly
General law city. Population 24,421. Council meets second and fourth Tuesdays of month at 8:00 p.m., Council Chambers, City Hall, 1365 Fifth Ave., 94002.
Central Telephone: 415-573-2790
Mayor: Margaret A. Buckley
City Manager: James P. DeChaine
Vice-Mayor, Joseph W. Green
Councilman, Robert H. Hoffman
Councilman, William H. Hardwick
Councilman, William E. Moore
City Clerk, James W. McLaughlin
Police Chief, William R. Singer
Fire Chief, Gary Schmitz (South County fire)
Treasurer, Jean Zucca
School Superintendent, Claude C. Turner
City Attorney, Kenneth Dickerson

CITY OF BELVEDERE

(County of Marin)

Incorporated December 24, 1896
Legislative Districts: 5th Congressional; 2nd Senatorial; 9th Assembly
General law city. Population 2,600. Council meets first Monday of month at 8:00 p.m. in Community Center, 450 San Rafael Ave., 94920.
Central Telephone: 415-435-3838
Mayor: Charles E. Auerbach
City Manager: Sandra Y. Marker
Councilman, Don Davis
Councilman, Erwin Farley
Councilwoman, Sherry C. Levit
Councilman, Bill Smith
City Clerk, Sandra Y. Marker
Police Chief, Frank W. Barner
Fire Chief, Frank Buscher
City Treasurer, Margaret Gill

CITY OF BENICIA

(County of Solano)

Incorporated March 27, 1850
Legislative Districts: 4th Congressional; 4th Senatorial; 4th Assembly
General law city. Population 10,850. Council meetings held on first and third Tuesdays of each month in the Council Chambers of City Hall, 250 E. "L" St., 94510.
Mayor: Warren R. O'Blennis
City Manager: John F. Silva
Councilman, Jack Cody
Councilman, C. Carsten Johansen
Councilman, Gary Winston, M.D.
Councilman, Roger E. Lipman
City Clerk, Betty M. Pellinen
Police Chief, Pierre T. Bidou

CITY OF BERKELEY

(County of Alameda)

Incorporated April 4, 1878
Legislative Districts: 8th Congressional; 9th Senatorial; 12th and 13th Assembly
Chartered city. Population 108,756. Council meets first four Tuesdays of each month in Council Chambers,

City Hall, 2134 Grove St., 94704.
Central Telephone: 415-644-6480
Mayor: Eugene Newport
City Manager: Wise E. Allen

*Councilmember, James Sweeney
*Councilmember, Veronika Fukson
*Councilmember, Andrea Washburn
*Councilmember, Shirley Dean
*Councilmember, Gilda H. Feller
*Councilmember, Florence McDonald
*Councilmember, John Denton
City Clerk, Edythe Campbell
Police Chief, T.W. Johnson (Acting)
Fire Chief, Victor Porter
School Superintendent, Dr. David P. Tansey

*Prefers title Councilmember

CITY OF BEVERLY HILLS

(County of Los Angeles)

Incorporated January 28, 1914
Legislative Districts: 23rd Congressional; 22nd Senatorial; 43rd Assembly
General law city. Population 33,416. Council meets first and third Tuesdays, 7:30 p.m., in Council Chambers, City Hall, 450 N. Crescent Dr., 90210.
Central Telephone: 213-550-4700
Mayor: Edward I. Brown
City Manager: Edward S. Kreins

Vice-Mayor, Donna Ellman
Councilmember, Charles Aronberg, M.D.
Councilmember, Benjamin Stansbury, Jr.
Councilmember, Benjamin Norton
City Clerk, Jean M. Ushijima
Police Chief, Lee Tracy
Fire Chief, William Daley
Treasurer, Ramon I. Gerson
School Superintendent, Kenneth L. Peters
City Attorney, Jack Allen (Acting)

CITY OF BIG BEAR LAKE

(County of San Bernardino)

Incorporated November 24, 1980
Legislative Districts: 37th Congressional; 34th Senatorial; 67th Assembly
General Law city. Population 10,000. Council meets second and fourth Wednesdays of each month at 7:00 p.m. in Council Chambers; Courtroom, County Building, 477 Summit Blvd., 92315.
Central Telephone: 714-866-5831
Mayor: John C. Eminger
City Manager: Robert L. Van Nort

Councilman, Alvin W. Beardsley
Councilman, Richard W. Burton
Councilman, John Joyner
Councilman, Norman Reinik, Jr.
City Clerk, Robert Van Nort
City Attorney, William E. Coombs
Police Chief, Frank Bland
Fire Chief, John K. Linder

CITY OF BIGGS

(County of Butte)

Incorporated June 26, 1903
Legislative Districts: 1st Congressional; 1st Senatorial; 1st Assembly
General law city. Population 1,490. Council meets second Monday of month at 7:00 p.m. in City Hall, 464-B "B" St., 95917.
Central Telephone: 916-868-5436
Mayor: William H. Callaway

Vice-Mayor, Charles E. Hicks
Councilman, Arturo A. Marquez
Councilman, William H. Thebach
Councilman, Harold W. McDonald
City Clerk, Luella A. Tamagni
Police Chief, Scott E. Nelson
Fire Chief, Raymon Valverde
Finance Director, Luella A. Tamagni
Treasurer, Luella A. Tamagni
Deputy City Clerk, Joyce A. Howard
City Attorney, Robert Millington
Public Works Director, William T. West (Assistant)

CITY OF BISHOP

(County of Inyo)

Incorporated May 6, 1903
Legislative Districts: 18th Congressional; 16th Senatorial; 34th Assembly
General law city. Population 3,790. Council meets second and fourth Monday of month at 7:30 p.m. in Council Chambers, City Hall, 301 W. Line St., 93514.
Central Telephone: 714-873-5863
Mayor: M.J. Fisher

Mayor pro Tem, Don R. Swenson
Councilman, Randy Davis
Councilman, Ron Kister
Councilman, Peter Pearson
City Administrator/Clerk, Richard F. Pucci
Police Chief, Fred G. Coburn
Fire Chief, Philip E. Moxley
Treasurer, George C. Patten
City Attorney, Rodney K. Smith

CITY OF BLUE LAKE

(County of Humboldt)

Incorporated April 23, 1910
Legislative Districts: 2nd Congressional; 2nd Senatorial; 2nd Assembly
General law city. Population 1,210. Council meets second and fourth Tuesdays of month at 111 Greenwood Ave., 95525.
Central Telephone: 707-668-5655
Mayor: Steven Wright

Mayor pro Tem, Glen Ray

Councilman, Elmer Retchless
Councilman, Fred A. Jacobson
Councilperson, Mark Bryant
City Clerk, Mary Taylor
Treasurer, Karen Nessler
City Attorney, Richard Platz

CITY OF BLYTHE

(County of Riverside)

Incorporated July 21, 1916
Legislative Districts: 37th Congressional; 38th Senatorial; 75th Assembly
General law city. Population 7,289. Council meets second and fourth Tuesday evenings in Council Chambers, City Hall, 220 North Spring Street, 92225.
Central Telephone: 714-922-6161
Mayor: Ernest E. Weeks
City Manager: Dick Milkovich

Vice-Mayor, Lyle M. Ellison
Councilman, Cyle Johnson
Councilman, Doris Morgan
Councilwoman, Frances Duggins
Police Chief, Glen R. Mackey
City Clerk, Jeanene Manly
Fire Chief, Robert Barrozo
Treasurer, Leora Hollingshead
School Superintendent, Clifford Hillis
City Attorney, J. Scott Zundel

CITY OF BRADBURY

(County of Los Angeles)

Incorporated July 26, 1957
Legislative Districts: 26th Congressional; 25th Senatorial; 61st Assembly
General law city. Population 873. Council meets third Tuesday of month at 7:30 p.m. in City Hall, 600 Winston Ave., 91010.
Central Telephone: 213-358-3218
Mayor: Ronald G. Westmyer
City Manager: Mrs. Dolly Vollaire

Mayor pro Tem, Jeffrey Alkana
Councilwoman, Kim Dillard
Councilman, George McRoberts
Councilman, Vacant due to recall
City Clerk, Mrs. Dolly Vollaire
City Attorney, Leland C. Dolley
City Engineer, Dwight French

CITY OF BRAWLEY

(County of Imperial)

Incorporated April 16, 1908
Legislative Districts: 43rd Congressional; 38th Senatorial; 75th Assembly
General law city. Population 14,753. Council meets first and third Mondays of month at 7:30 p.m. in Council Chambers, City Hall, 400 Main St., 92227.
Central Telephone: 714-344-1550
Mayor: Pat Williams
City Manager: Walker J. Ritter

Councilmember, Grace E. Hull
Councilmember, Ike Adams
Councilmember, R. C. Valenzuela
Councilmember, Wayne T. Zills
City Clerk, Adyne C. Benedict
Police Chief, W. J. Santos
Fire Chief, Amos K. Jones
Treasurer, Marjorie B. Panosh
City Attorney, Joseph Schmitt

CITY OF BREA

(County of Orange)

Incorporated February 23, 1917
Legislative Districts: 39th Congressional; 35th Senatorial; 69th and 70th Assembly
General law city. Population 28,650. Council meets first and third Tuesdays of month in Civic/Cultural Center, Number One Civic Center Circle, 92621.
Central Telephone: 714-990-7600
Mayor: Donald L. Fox
City Manager: Wayne D. Wedin

Mayor pro Tem, Melvin J. LeBaron
Councilman, Sal F. Gambina
Councilwoman, Norma Hicks
Councilman, Ron Isles
City Clerk, Dorothy D. Storm
Police Chief, Donald L. Forkus
Fire Chief, Jerry McDowell and Richard Francesconi
Treasurer, John M. Stark, Jr.
School Superintendent, C. Gordon Bishop

CITY OF BRENTWOOD

(County of Contra Costa)

Incorporated January 21, 1948
Legislative Districts: 7th Congressional; 7th Senatorial; 10th Assembly
General law city. Population 4,000. Council meets second and fourth Tuesdays of each month in City Hall, 708 Third St., 94513.
Central Telephone: 415-634-3505
Mayor: Barbara J. Guise
City Administrator: Harry E. Gill

Councilman, Bruce C. Ghiselli
Councilman, Douglass W. Hanner
Councilman, George G. Gambel
Councilman, Roger P. Moore
City Clerk, Harry E. Gill
Police Chief, James A. Frank
City Attorney, Dale Adams

CITY OF BRISBANE

(County of San Mateo)

Incorporated November 27, 1961
Legislative Districts: 11th Congressional; 6th Senatorial; 19th Assembly
General law city. Population 3,500. Council meets second and fourth Mondays of month at 7 p.m. in

City Hall, 44 Visitacion Ave., 94005.
Central Telephone: 415-467-1515
Mayor: Fred Smith
City Manager: Brad Kerwin

Mayor pro Tem, Art Montenegro, Jr.
Councilmember, Jeannine Hodge
Councilman, William E. Lawrence
Councilman, Don Bradshaw
City Clerk, Brad Kerwin
Director of Public Safety, E. A. "Bud" Martini
Fire Chief, C. R. Moritz
School Superintendent, Robert J. Lloyd
City Attorney, George J. Silvestri

CITY OF BUENA PARK

(County of Orange)

Incorporated January 27, 1953
Legislative Districts: 38th and 39th Congressional; 35th and 37th Senatorial; 69th and 71st Assembly
General law city. Population 63,900. Council meets first and third Mondays of each month in Council Chambers, City Hall, 6650 Beach Blvd., 90620.
Central Telephone: 714-521-9900
Mayor: Jesse M. Davis
City Manager: Samuel J. Winner (Acting)

Mayor pro Tem, James T. Jarrell
Councilman, Kenneth B. Jones
Councilman, Lester J. Reese
Councilman, Don R. Griffin
City Clerk, Marguerite G. Courson
Police Chief, Robert T. Reber
Fire Chief, Sam J. Winner
City Attorney, Ronald H. Bevins

CITY OF BURBANK

(County of Los Angeles)

Incorporated July 8, 1911
Legislative Districts: 22nd Congressional; 21st Senatorial; 41st Assembly
Chartered city. Population 88,659. Council meets Tuesdays at 7 p.m. in City Hall, 275 E. Olive Avenue, 91502.
Central Telephone: 213-847-8600
Mayor: Robert E. Olney
City Manager: James A. Algie

Vice-Mayor, Mary Lou Howard
Councilman, Leland C. Ayers
Councilman, E. Daniel Remy
Councilman, Larry Stamper
City Clerk, Evelyn L. Haley
Police Chief, James L. Shafer
Fire Chief, Curtis V. Reynolds
School Superintendent, Thomas D. Barkelew
City Treasurer, John B. Whitney

CITY OF BURLINGAME

(County of San Mateo)

Incorporated June 6, 1908
Legislative Districts: 11th Congressional; 6th Senatorial; 19th Assembly
General law city. Population 26,209. Council meets first and third Mondays of month at 8:00 p.m. in City Hall, 501 Primrose Road, 94010.
Central Telephone: 415-342-8931
Mayor: R. D. Martin
City Manager: Charles F. Schwalm

Vice-Mayor, Victor A. Mangini
Councilman, Irving S. Amstrup
Councilman, Gloria H. Barton
Councilman, William J. Crosby
City Clerk, Evelyn H. Hill
Police Chief, Alfred J. Palmer
Fire Chief, O. Fred Fricke
School Superintendent, James E. Black
Director of Finance, Dennis J. Argyres
City Attorney, Jerome F. Coleman

CITY OF CALEXICO

(County of Imperial)

Incorporated April 16, 1908
Legislative Districts: 43rd Congressional; 38th Senatorial; 75th Assembly
General law city. Population 14,545. Council meets first and third Tuesday of month in City Hall, 408 Heber Ave., 92231.
Central Telephone: 714-357-1176
Mayor: Fernando L. Arguelles
City Manager: M. Chris Burt

Mayor pro Tempore, Fred M. Knechel
Councilman, Fernando R. Torres, Jr.
Councilman, William L. Moreno
Councilman, Antonio P. Tirado
City Clerk, James H. Black, Jr.
Police Chief, Humberto C. Hernandez
Fire Chief, Froilan S. Pedroza
Treasurer, Oscar G. Rodriguez
School Superintendent, R. F. Valdez
City Attorney, Eduardo A. Rivera

CITY OF CALIFORNIA CITY

(County of Kern)

Incorporated December 10, 1965
Legislative Districts: 18th Congressional; 16th Senatorial; 34th Assembly
General law city. Population 2,740. Council meets first and third Tuesdays at 7:30 p.m. in Council Chambers, City Hall, 21000 Hacienda Blvd., 93505.
714-373-8661
Mayor: Nancy B. Crews
City Manager: Joseph L. Cloonan

Vice-Mayor, W. C. (Bill) Rasmussen
Councilmember, William G. Cooper
Councilmember, Patrick G. Hamilton
Councilmember, Lottie M. Walker
City Clerk, Rosemary Harrison
Treasurer, Michael Goss
Police Chief, Guy L. Floyd

City Attorney, Wayne K. Lemieux
Fire Chief, Thomas D. Hodgson

CITY OF CALIPATRIA

(County of Imperial)

Incorporated February 28, 1919
Legislative Districts: 43rd Congressional; 38th Senatorial; 75th Assembly
General law city. Population 2,360. Council meets second and fourth Tuesdays of month at 7:30 p.m. in City Hall, 101 North Lake Avenue, 92233.
Central Telephone: 714-348-2293
Mayor: Dr. Norman K. Caldwell

Vice-Mayor, Sharron Walker
Councilman, L. Romualdo Medina
Councilman, Lloyd (Gene) Sones
Councilman, Gary Smith
City Clerk, Margaret Hatfield
Police Chief, Frank M. Emanuel
Fire Chief, John Woelke
Treasurer, Grace B. Erickson
City Attorney, Jack Boggust

CITY OF CALISTOGA

(County of Napa)

Incorporated January 6, 1886
Legislative Districts: 2nd Congressional; 4th Senatorial; 8th Assembly
General law city. Population 3,550. Council meets first and third Tuesdays of each month in Community Center Building, 1307 Washington Street, 94515.
Central Telephone: 707-942-5188
Mayor: Willem Berkhout
City Administrator: Vacant

Councilman, Nick Rulli
Councilman, Gayle Keller
Councilman, Melvin Avila
Councilperson, Eda M. Wilkinson
City Clerk, Mary M. Duffy
Police Chief, Tom Johnson
Fire Chief, Donald Meyer
Treasurer, Louise Schmidt
School Superintendent, Billy Watts
City Attorney, Homer W. Jones, Jr.

CITY OF CAMARILLO

(County of Ventura)

Incorporated October 22, 1964
Legislative Districts: 20th Congressional; 18th Senatorial; 36th Assembly
General law city. Population 38,996. Council meets second and fourth Wednesday of each month at 4:00 p.m. at 601 Carmen Drive, 93010.
Mayor: Mary R. Gayle
City Manager: Thomas W. Oglesby

Vice Mayor, Ronald V. McConville
Councilman, Roderick B. Moore
Councilman, F. Burrows Esty
Councilman, Michael D. Morgan
City Clerk, Kay Kelly
Police Chief, Alfred Jalaty
Fire Chief, Stanley E. Masson

CITY OF CAMPBELL

(County of Santa Clara)

Incorporated March 28, 1952
Legislative Districts: 13th Congressional; 12th Senatorial; 22nd Assembly
General law city. Population 29,500. Council meets second and fourth Mondays of month at 8:00 p.m. in Council Chambers, City Hall, 75 N. Central Ave., 95008.
Central Telephone: 408-378-8141
Mayor: Ralph Doetsch, Sr.

Vice Mayor, William R. Podgorsek
Councilman, Dean Chamberlin
Councilman, Russell J. Hammer
Councilman, Norman Paul
City Clerk, Phyllis O. Acker
Treasurer, M. Nadine Sargent
Fire Chief, James F. McMullen
Police Chief, Donald R. Burr
Attorney, J. Robert Dempster
City Manager, Robert C. Stephens
Finance Director, G. H. Whittaker
Planning Director, Arthur A. Kee
Director of Public Works, Joseph Elliott
• Council reorganization 4/81

CITY OF CAPITOLA

(County of Santa Cruz)

Incorporated January 11, 1949
Legislative Districts: 16th Congressional; 17th Senatorial; 28th Assembly
General law city. Population 9,300. Council meets second and fourth Thursdays of each month at 7:00 p.m. in City Hall, 420 Capitola Ave., 95010.
Central Telephone: 408-475-7300
Mayor: Jerry E. Clarke
City Manager: Stephen R. Burrell

Councilmember, Robert Garcia
Councilmember, Carin Mudgett
Councilmember, Michael Routh
Councilmember, Ronald E. Graves
City Clerk, Cathleen Athenour
Police Chief, Robert L. Allen
Treasurer, John I. Andersen
City Attorney, Richard Manning

CITY OF CARLSBAD

(County of San Diego)

Incorporated July 16, 1952
Legislative Districts: 43rd Congressional; 38th Senatorial; 76th Assembly
General law city. Population 34,000. Council meets first and third Tuesdays at 6:00 p.m. in Council Chambers, City Hall, 1200 Elm Ave. 92008.

Central Telephone: 714-438-5621
Mayor: Ronald C. Packard
City Manager: Frank D. Aleshire
Vice Mayor, Mary H. Casler
Councilman, Claude A. Lewis
Councilman, Girard W. Anear
Councilwoman, Ann J. Kulchin
City Clerk, Aletha L. Rautenkranz
Police Chief, Vincent Jimno
Fire Chief, James K. Thompson
Treasurer, Frank C. Rice
School Superintendent, Robert A. Crawford
City Attorney, Vincent F. Biondo

CITY OF CARMEL-BY-THE-SEA

(County of Monterey)

Incorporated October 31, 1916
Legislative Districts: 16th Congressional; 17th Senatorial; 28th Assembly
General law city. Population 4,780. Council meets the first and second Monday of each month, at 7:30 p.m. in Council Chambers, City Hall, Monte Verde St., 93921.
Central Telephone: 408-624-2781
Mayor: Bernard Laiolo
City Administrator: Douglas D. Peterson
Councilman, Michael Brown
Councilman, Frank Lloyd
Councilman, Helen B. Arnold
Councilman, Howard Brunn
City Clerk, Jeanne Kettelkamp
Police Chief, William Ellis
Fire Chief, Robert A. Updike
Treasurer, Jack Skillicorn

CITY OF CARPINTERIA

(County of Santa Barbara)

Incorporated September 28, 1965
Legislative Districts: 19th Congressional; 18th Senatorial; 35th Assembly
General law city. Population 10,769. Council meets second and fourth Mondays at 7:30 p.m. in Council Chambers, City Hall, 5775 Carpinteria Avenue, 93013.
Central Telephone: 805-684-5405
Mayor: John K. Fukasawa
City Manager: Allan R. Coates, Jr.
Mayor pro Tem, Thomas N. Lewis
Councilman, David G. Lawrence
Councilman, Ruben Organista
Councilman, Ernest C. Wullbrandt
City Clerk, Allan R. Coates, Jr.
Police Chief, John R. Frontado
Fire Chief, Claude Welch
School Superintendent, William T. Carty
City Engineer, Raymond Spencer
City Attorney, James R. Christiansen
City Treasurer, Delphin Kent
Community Development Director, Phillip G. Berry

CITY OF CARSON

(County of Los Angeles)

Incorporated February 20, 1968
Legislative Districts: 32nd Congressional; 28th and 31st Senatorial; 53rd and 57th Assembly
General law city. Population 84,963. Council meets first and third Mondays of the month in Council Chambers, City Hall, 701 East Carson Street, 90745.
Central Telephone: 213-830-7600
Mayor: Clarence A. Bridgers
City Administrator: E. F. Bien
Mayor pro Tem, Thomas G. Mills
Councilwoman, Kay A. Calas
Councilman, Walter J. Egan
Councilman, Vacant (Election 6/81)
City Clerk, Helen S. Kawagoe
Treasurer, Dorothy Carter
City Attorney, Glenn R. Watson

CITY OF CERES

(County of Stanislaus)

Incorporated February 25, 1918
Legislative Districts: 14th and 15th Congressional; 14th Senatorial; 27th Assembly
General law city. Population 13,000. Council meets second and fourth Mondays of month at 7:30 p.m. in City Hall, 2720 Second Street, 95307.
Central Telephone: 209-537-8911
Mayor: Sal Cannella
City Manager: James G. Marshall
Vice Mayor, Brian Carlin
Councilman, Ted Humphries
Councilman, James Delhart
Councilman, Gary Sorlien
City Clerk, Janet Billings
Police Chief, Leroy Cunningham
Fire Chief, Truman L. Showen
Treasurer, Beth Hillard
School Superintendent, M. Robert Adkison
City Attorney, C. Ernest Rushing
Public Works Director, Joe Hollstein
Planning Director, James G. Marshall

CITY OF CERRITOS

(County of Los Angeles)

Incorporated April 24, 1956
Legislative Districts: 33rd and 34th Congressional; 33rd Senatorial; 63rd Assembly
Chartered city. Population 52,591. Council meets first Wednesday of each month and first Thursday after third Wednesday at Bloomfield and 183rd Street, 90701.
Central Telephone: 213-860-0311
Mayor: Diana S. Needham
City Manager: Gaylord F. Knapp
Mayor pro Tem, Alex H. Beanum
Councilman, Don Knabe
Councilman, Barry A. Rabbitt
Councilman, Daniel K. Wong, M.D.
City Clerk-Treasurer, Agnes Hickey
City Attorney, J. Kenneth Brown

CITY OF CHICO

(County of Butte)

Incorporated January 8, 1872
Legislative Districts: 1st Congressional; 1st Senatorial; 1st Assembly
Chartered city. Population 26,950. Council meets first Tuesday of month in Chico Municipal Center, 421 Main Street, 95926.
Central Telephone: 916-895-4800

Mayor: Margaret R. Worley
City Manager: Fred Davis

Councilman, Shelton Enochs
Councilman, Tod Hackman
Councilman, Karl E. Ory
Councilman, William Brashears
Councilman, David Guzzetti
Councilman, Dan Hays
City Clerk, Barbara A. Evans
Police Chief, Ulrich F. Bullerjahn
Fire Chief, Phillip Johnston
Finance Officer, Robert E. Shepherd
Director, Public Works, Allan Savitz
Planning Director, Thomas Lando
Park Superintendent, Dan Neff
City Attorney, Robert G. Boehm

CITY OF CHINO

(County of San Bernardino)

Incorporated February 28, 1910
Legislative Districts: 35th Congressional; 32nd Senatorial; 65th Assembly
General law city. Population 37,200. Council meets first and third Tuesdays of month in Council Chambers, 13220 Central Avenue, 91710.
Central Telephone: 714-627-7577

Mayor: Larry Walker
City Manager: John Gerardi

Mayor pro Tem, Fred Aguiar
Councilman, Rafael Kenealy
Councilman, Ben Burrell
Councilman, Vacant
Councilwoman, Eileen Carter
City Clerk, Patricia A. Biery
Police Chief, James Anthony
Fire Chief, O. M. Short
School Superintendent, Duane E. Stiff
Treasurer, James S. Diaz

CITY OF CHOWCHILLA

(County of Madera)

Incorporated February 7, 1923
Legislative Districts: 15th Congressional; 14th Senatorial; 30th Assembly
General law city. Population 5,115. Council meets second and fourth Mondays of month at 7:00 p.m. in City Hall, 145 Robertson Blvd., 93610.
Central Telephone: 209-665-4816

Mayor: Reginald O. Upton
City Administrator: James W. Peel

Councilmember, Roy Price
Councilmember, Curtis Bennett
Councilmember, Ed Roberts
Councilmember, E. L. "Andy" Anderson
City Clerk, James W. Peel
Police Chief, James Curutchet (Acting)
Fire Chief, Frank Borba
Treasurer, James W. Peel
Public Works Director, William Searcy
City Attorney, Richard Hargrove

CITY OF CHULA VISTA

(County of San Diego)

Incorporated October 26, 1911
Legislative Districts: 42nd Congressional; 40th Senatorial; 80th Assembly
Chartered city. Population 85,000. Council meets first four Tuesdays of month at 7:00 p.m. in Council Chamber, Public Services/City Council Chamber Building, 276 Fourth Ave., 92010.

* Mayor: Will T. Hyde
City Manager: Lane F. Cole

Mayor pro Tem, Frank A. Scott
Councilman, George B. Gillow
Councilwoman, Gayle L. McCandliss
Councilman, Gregory R. Cox
City Clerk, Jennie M. Fulasz
Public Services (Fire & Police) Director, William J. Winters
School Superintendent, Leonard Servetter

* Term expires 11/81 (4 yr. term)

CITY OF CLAREMONT

(County of Los Angeles)

Incorporated October 3, 1907
Legislative Districts: 35th Congressional; 25th Senatorial; 62nd Assembly
General law city. Population 30,600. Council meets second and fourth Tuesday of month at 7:30 p.m. at 207 Harvard Ave., 91711.
Central Telephone: 714-624-4531

Mayor: Eleanor M. Cohen
City Manager: Leonard G. Wood

Vice-Mayor, Enid H. Douglass
Councilmember, Sheldon G. Wellins
Councilmember, Claire K. McDonald
Councilmember, Stuart M. Wahrenbrock
City Clerk, Barbara A. Hallamore
Police Chief, Charles Lines
School Superintendent, Richard S. Kirkendall
Treasurer, Martha Gratz

CITY OF CLAYTON

(County of Contra Costa)

Incorporated March 18, 1964
Legislative Districts: 7th Congressional; 7th Senatorial; 10th Assembly
General law city. Population 4,300. Council meets first

and third Wednesdays of month at 7:30 p.m. in Community Hall, Center and Oak Sts., 94517.
Central Telephone: 415-689-3622
Mayor: Helen M. Allen
City Administrator: Joseph E. Comstock

Vice-Mayor, Leo Saunders
Councilman, Serafino Bianchi
Councilman, James McCormick
Councilman, Charles A. Levine
City Clerk, Joseph E. Comstock
City Treasurer, Ottomar H. Groschwitz
City Attorney, M. E. Huguet, Jr.

CITY OF CLEARLAKE

(County of Lake)

Incorporated November 14, 1980
Legislative Districts: 2nd Congressional; 2nd Senatorial; 2nd Assembly
General law city. Population 13,275. Council meets 1st and 3rd Monday at 7:30 p.m. at South Shore Seniors Clubhouse, Golf Avenue, 95422.
Central Telephone: 707-994-8201
Mayor: Thomas M. Hewlett
City Manager: Vacant

Councilmember, Doris C. Logoteta
Councilmember, Ed Robey, Jr.
Councilmember, Eugene Achter
Councilmember, John J. Lucich, Jr.
City Clerk, Teresa G. Rifesi
Police Chief, Vacant
Fire Chief, Vacant
School Superintendent, Vacant
Interim City Treasurer, Roy L. Mead
Interim City Attorney, Ronald V. Thunen

CITY OF CLOVERDALE

(County of Sonoma)

Incorporated February 28, 1872
Legislative Districts: 2nd Congressional; 2nd Senatorial; 2nd Assembly
General law city. Population 3,950. Council meets second and fourth Tuesday of month at City Hall, 124 Cloverdale Blvd. No., 95425.
Central Telephone: 707-894-2521
Mayor: Jack Domenichelli

Councilman, Jerry E. Moore
Councilman, Stephen J. Congdon
Councilwoman, Marie O. Vandagriff
Councilman, Angelo Scalese, Sr.
City Clerk, Barbara Peugh
Police Chief, Rodney H. Persons
Fire Chief, Milton C. Holt
City Attorney, John A. Klein

CITY OF CLOVIS

(County of Fresno)

Incorporated February 27, 1912
Legislative Districts: 17th Congressional; 15th Senatorial; 31st Assembly
General law city. Population 32,050. Council meets first, second and third Mondays of month, 7:30 p.m. in City Hall, 1033 Fifth St., 93612.
Central Telephone: 209-298-8061
Mayor: Dennis G. Prindiville
City Manager: Allen L. Goodman

Mayor pro Tem, Peggy M. Bos
Councilman, William H. Armstrong
Councilman, Stanley E. King
Councilman, Gene Papenhausen
City Clerk, Michael Prandini
Police Chief, Gerald T. Galvin
Fire Chief, James Rankin
Treasurer, Lois Shriner
City Attorney, Marvin Helon

CITY OF COACHELLA

(County of Riverside)

Incorporated December 13, 1946
Legislative Districts: 38th Congressional; 36th Senatorial; 75th Assembly
General law city. Population 9,900. Council meets first and third Tuesdays of month in City Hall, 1515 Sixth St., 92236.
Central Telephone: 714-398-6131
Mayor: Roger H. Perez, Sr.
City Manager: Gregory T. Meyer

Councilman, Frank V. Duran
Councilman, Manuel Arredondo
Councilman, Manuel M. Rios
Councilwoman, Yolanda R. Coba
City Clerk, Fern L. Hinkle
Treasurer, Alice H. Lowery
Police Chief, Arnold Jimenez
Fire Chief, John M. Rios
School Superintendent, Bobby G. Duke
City Attorney, Chandler Brown

CITY OF COALINGA

(County of Fresno)

Incorporated April 3, 1906
Legislative Districts: 15th Congressional; 14th Senatorial; 30th Assembly
General law city. Population 6,400. Council meets first and third Mondays of month in the City Hall, Sixth and Elm Streets, 93210.
Central Telephone: 209-935-1533
Mayor: Edward T. O'Neill
City Manager: Glenn H. Marcussen

Councilman, Walker G. Armstrong
Councilman, Vincent D. Papagni
Councilman, Keith M. Scrivner
Councilman, James E. Lam
City Clerk, Johnnie D. Quinney
Police Chief, James A. Henry
Fire Chief, Fred R. Frederickson
Treasurer, Connie A. Bell

City Attorney, Henry T. Leckman
Director of Public Works, Vacant

CITY OF COLFAX

(County of Placer)

Incorporated February 23, 1910
Legislative Districts: 1st Congressional; 1st Senatorial; 3rd Assembly
General law city. Population 798. Council meets second and fourth Tuesdays of month in City Hall, Main St., 95713.
Central Telephone: 916-346-2313
Mayor: C.E. "Buster" Noxon

Mayor pro Tem, Norman Ruestow
Councilman, John Kauffman
Councilman, Robert Findley
Councilman, Bill Mintline
City Clerk, Betty Delgado
Police Chief, Kenneth H. Westphalen
Fire Chief, Doran Wilson
Treasurer, Edna Daniels
City Attorney, Smith and Ash

TOWN OF COLMA

(County of San Mateo)

Incorporated August 5, 1924
Legislative Districts: 11th Congressional; 6th Senatorial; 19th Assembly
General law city. Population 537. Council meets second Wednesday of month at 7:30 p.m. in Council Chambers, City Hall, El Camino Real at Serramonte Blvd., 94014.
Central Telephone: 415-755-6141
Mayor: Eugene E. Daneluz

Councilman, Charles Gerrans
Councilman, Raymond D. Ottoboni
Councilman, Raymond J. Ottoboni
Councilman, Richard R. Vallerga
Town Administrator/Town Clerk, Frances Liston
Police Chief, Arthur D. Dollosso
Fire Chief, George Riccomi
Treasurer, Julia B. Taylor
Town Attorney, Robert H. Cornell

CITY OF COLTON

(County of San Bernardino)

Incorporated July 20, 1887
Legislative Districts: 36th and 37th Congressional; 32nd and 34th Senatorial; 66th and 67th Assembly
General law city. Population 22,500. Council meets first and third Tuesday of month at Civic Center, 650 N. LaCadena Dr., 92324.
Central Telephone: 714-825-3110
Mayor: Frank A. Gonzales
City Manager: Robert Trevino

Mayor Pro Tem, James D. Hayes
Councilman, Leroy Rehrer
Councilwoman, Pauline Garcia
Councilwoman, Connie (Paddy) Cisneros
City Clerk, Helen A. Ramos
Police Chief, Phillip Elliott
Fire Chief, Allan A. Teague
Treasurer, Margaret Berkebile
City Attorney, Stephen W. Edwards

CITY OF COLUSA

(County of Colusa)

Incorporated June 16, 1868
Legislative Districts: 4th Congressional; 1st Senatorial; 3rd Assembly
General law city. Population 4,034. Council meets second and fourth Tuesdays at 7:30 p.m. in City Hall, 425 Webster Street, 95932.
Central Telephone: 916-458-4941
Mayor: Frank W. Hubbell

Councilman, Larry Hicks
Councilman, Oliver O. Vaughn
Councilwoman, Kathleen Beduhn
Councilman, Frank Jaconetti, Sr.
City Clerk, Joyce McCullough
Police Chief, Raegene C. Cation
Fire Chief, John T. Kiely
Treasurer, Charles E. Riley
School Superintendent, Jim Mark

CITY OF COMMERCE

(County of Los Angeles)

Incorporated January 28, 1960
Legislative Districts: 30th Congressional; 24th Senatorial; 56th Assembly
General law city. Population 10,662. Council meets first and third Mondays of month in Council Chambers, 5655 Jilson Street, 90040.
Mayor: Arthur A. Loya
City Administrator: Robert Hinderliter

Mayor pro Tempore, Ricardo Vasquez
Councilman, Robert Eula
Councilman, James B. Dimas, Sr.
Councilman, Dr. Michael V. Guerra
City Clerk, John A. Bramhall

CITY OF COMPTON

(County of Los Angeles)

Incorporated May 11, 1888
Legislative Districts: 31st Congressional; 28th Senatorial; 54th Assembly
Chartered City. Population 79,261. Council meets first and third Tuesdays at 7:00 p.m., second and fourth Tuesdays at 3 p.m., City Hall, 205 S. Willowbrook Ave., 90220.
Central Telephone: 213-537-8000
Mayor: Lionel B. Cade
City Manager: Joseph T. Rouzan

Councilman, Floyd James
Councilman, Robert L. Adams

Councilwoman, Jane D. Robbins
Councilman, Maxcy D. Filer
City Clerk, Charles Davis
Police Chief, James Carrington
Fire Chief, Monroe Smith
School Superintendent, Aaron Wade
City Attorney, Wesley Fenderson

CITY OF CONCORD

(County of Contra Costa)

Incorporated February 9, 1905
Legislative Districts: 7th Congressional; 7th Senatorial; 10th Assembly
General law city. Population 103,809. Council meets first, second and fourth Mondays of month in Council Chamber, Civic Center, 1950 Parkside, 94519.
Central Telephone: 415-671-3000
Mayor: June V. Bulman
City Manager: Farrel A. Stewart

Vice-Mayor, William H. Dixon
Councilwoman, Diane Longshore
Councilman, Richard T. La Pointe
Councilman, Stephen L. Weir
City Clerk, Bernadette Carroll
Police Chief, G. "Bud" Savage
Fire Chief, William F. Maxfield
Treasurer, Harold O. Ostling
City Attorney, David J. Levy

CITY OF CORCORAN

(County of Kings)

Incorporated August 11, 1914
Legislative District: 17th Congressional; 15th Senatorial; 32nd Assembly
General law city. Population 6,416. Council meets first and third Mondays of month at 7:00 p.m. in City Hall, 1033 Chittenden Ave., 93212.
Central Telephone: 209-992-2151
Mayor: Albert F. Kessler
City Manager: George T. Lambert

Vice Mayor, Harold A. James
Councilman, Gary LeMay
Councilman, Bruce George
Councilman, Sonny Oxford
City Clerk, Connie Harris
Police Chief, Joel Patton
Finance Director, Joyce Denzinger
Fire Chief, Contracted
Community Development Director, Barbara A. Kaiser

CITY OF CORNING

(County of Tehama)

Incorporated August 6, 1907
Legislative Districts: 1st Congressional; 1st Senatorial; 1st Assembly
General law city. Population 4,980. Council meets second and fourth Monday of month at 7:30 p.m. in Council Chambers, City Hall, 3rd and Solano Sts., 96021.
Central Telephone: 916-824-5558
Mayor: Gary R. Strack
City Manager: Ben B. Anderson

Councilman, George "Bud" Williams
Councilman, A. R. Kirkpatrick
Councilman, Morris Thompson
Councilman, Alan Honore
City Clerk, Darlene Dickison
Police Chief, John B. Fulks, Jr.
Fire Chief, James Calbreath
Treasurer, Sally Martin
City Attorney, C. A. Stromsness

CITY OF CORONA

(County of Riverside)

Incorporated July 13, 1896
Legislative Districts: 36th Congressional; 34th Senatorial; 68th Assembly
General law city. Population 37,867. Council meets first and third Wednesdays at 6:30 p.m. in Council Chambers, 815 Sixth St., 91720.
Central Telephone: 714-736-2201
Mayor: Tom Gunderson
City Manager: James D. Wheaton

Mayor pro Tem, Lewis W. Hull
Councilman, Bill F. Bass
Councilman, Richard Deininger, Jr.
Councilman, David A. Felix
City Clerk, Diedre' D. Lingenfelter
Police Chief, Bob J. Talbert
Fire Chief, Vacant.
Treasurer, Mrs. Ina R. Smith
School Superintendent, Dr. Augustine Ramirez

CITY OF CORONADO

(County of San Diego)

Incorporated December 11, 1890
Legislative Districts: 42nd Congressional; 40th Senatorial; 79th Assembly
General law city. Population 18,800. Council meets first and third Tuesday of the month at 3:00 p.m. in City Hall, 1825 Strand Way, 92118.
Central Telephone: 714-435-2211
Mayor: C. Patrick Callahan
City Manager: Ray Silver

Mayor pro Tem, Mary Herron
Councilman, William Adams
Councilman, Dick Bottomley
Councilman, Robert Odiorne
City Clerk, Thomas Patricola
Police Chief, Vacant
Fire Chief, Robert E. Shanahan
School Superintendent, Dr. William A. Kinzler

TOWN OF CORTE MADERA

(County of Marin)

Incorporated June 10, 1916
Legislative Districts: 5th Congressional;

2nd Senatorial; 9th Assembly
General law city. Population 7,982. Council meets first and third Mondays of month in Town Hall, 94925.
Central Telephone: 415-924-1700
Mayor: Michael J. Boland
Town Manager: Douglas Dawson

Councilwoman, Marta Sullivan
Councilman, Robert L. Dunn
Councilman, Robert J. Flahive
Councilwoman, Jana Haehl
Town Clerk, Betty S. Behel
Police Chief, Phillip Green
Fire Chief, Robert W. Shearer
Treasurer, George T. Warman, Jr.
Town Attorney, Albert Bianchi

CITY OF COSTA MESA

(County of Orange)

Incorporated June 29, 1953
Legislative Districts: 40th Congressional; 36th Senatorial; 73rd and 74th Assembly
General law city. Population 81,600. Council meetings held first and third Mondays in City Hall, 77 Fair Drive, 92626.
Central Telephone: 714-754-5223
Mayor: Arlene Schafer
City Manager: Fred Sorsabal

Vice Mayor, Donn Hall
Councilwoman, Norma Hertzog
Councilman, Eric Johnson
Councilman, Ed McFarland
City Clerk, Eileen P. Phinney
Police Chief, Roger E. Neth
Fire Chief, John Marshall
City Attorney, Tom Wood

CITY OF COTATI

(County of Sonoma)

Incorporated July 16, 1963
Legislative Districts: 2nd Congressional; 2nd Senatorial; 9th Assembly
General law city. Population 3,572. Council meets second and fourth Tuesdays of each month in City Hall, 201 Sierra Ave., 94928.
Central Telephone: 707-795-5478
Mayor: Eve O'Rourke
City Manager, Rory C. Robinson

Councilwoman, Linda Shorey
Councilwoman, Tamara Davis
Councilman, Allen Stansbury
Councilwoman, Katherine Roberts
City Clerk, Rory Robinson
Police Chief, Gerald Kohler
City Attorney, Jeffrey A. Walter

CITY OF COVINA

(County of Los Angeles)

Incorporated August 14, 1901
Legislative Districts: 35th Congressional; 25th Senatorial; 62nd Assembly
General law city. Population 39,000. Council meets first and third Mondays of month in City Hall, 125 E. College St., 91723.
Central Telephone: 213-331-0111
Mayor: Charles G. Colver
City Manager: Richard A. Miller

Councilman, Jerry Edgar
Councilman, Karl W. Jaeger
Councilman, Robert G. Low
Councilman, Henry M. Morgan
City Clerk, Frieda C. Richardson
Police Chief, Michael O'Day
Fire Chief, Carl Johnson
Treasurer, Alburt Braggins
School Superintendent, Erwin N. Jones

CITY OF CRESCENT CITY

(County of Del Norte)

Incorporated April 13, 1854
Legislative Districts: 2nd Congressional; 2nd Senatorial; 2nd Assembly
General law city. Population 3,105. Council meets Monday following third Friday in City Hall, 450 H St., 95531.
Central Telephone: 707-464-7483
Mayor: Robert Seligman
City Manager: William G. McGinnis

Mayor pro Tem, Roberta L. Littleton
Councilman, George R. Mayer
Councilman, Michael J. Scavuzzo
Councilman, C. Ray Smith
City Clerk, Marcia Standley
Police Chief, Clinton R. Standley
Fire Chief Arthur R. Wakefield
Treasurer/Finance Director, Rodney Jahn
Public Works Director, Nicholas G. Gargaetas

CITY OF CUDAHY

(County of Los Angeles)

Incorporated November 10, 1960
Legislative Districts: 29th Congressional; 29th Senatorial; 47th Assembly
General law city. Population 18,114. Council meets first Monday of each month at 7:30 p.m. in Council Chambers, 5240 Santa Ana St., 90201.
Central Telephone: 213-773-5143
Mayor: Leo P. Turner
City Manager: Frank M. Usher

Mayor pro Tem, Faye N. Dunlap
Councilman, Ernest B. Bristow
Councilman, Fred Guido
Councilman, John O. Robertson, Jr.
City Clerk, Frank M. Usher
City Attorney, Richard Laskin

CITY OF CULVER CITY

(County of Los Angeles)

Incorporated September 17, 1917

Legislative Districts: 28th Congressional; 30th Senatorial; 49th Assembly

Chartered city. Population 38,671. Council meets second and fourth Mondays at 7:30 p.m. in City Hall, 9770 Culver Blvd., 90230.
Central Telephone: 213-837-5211

Mayor: A. Ronald Perkins
Chief Administrative Officer: Harry D. Jones

Vice Mayor, Paul A. Netzel
Councilman, Paul A. Jacobs
Councilman, Richard Brundo
Councilman, Richard M. Alexander
City Clerk, Pauline C. Dolce
Fire Chief, George F. Sweeny
Police Chief, E. E. Cooke
City Treasurer, Lu Herrera
School Superintendent, Dr. Curtis I. Rathmeyer
City Attorney, Robert D. Ogle

CITY OF CUPERTINO

(County of Santa Clara)

Incorporated October 10, 1955

Legislative Districts: 13th Congressional; 12th Senatorial; 21st, 22nd and 23rd Assembly

General law city. Population 40,591. Council meets first and third Mondays of month at 6:45 p.m. in Council Chambers, City Hall, 10300 Torre Ave., 95014.
Central Telephone: 408-252-4505

Mayor: W. Reed Sparks
City Manager: Robert W. Quinlan

Mayor pro Tem: John Gatto
Councilwoman, Barbara A. Rogers
Councilman, Phil Johnson
Councilman, John Plungy
City Clerk, Dorothy Cornelius
Police Chief, Robert W. Quinlan
Fire Chief, Gordon Payne
Treasurer, Blaine Snyder
City Attorney, Charles Kilian

CITY OF CYPRESS

(County of Orange)

Incorporated July 24, 1956

Legislative Districts: 38th Congressional; 37th Senatorial; 71st Assembly

Charter city. Population 40,400. Council meets second and fourth Mondays of each month in Council Chambers, City Hall, 5275 Orange Avenue, 90630.
Central Telephone: 714-828-2200

Mayor: Gerald Mullen
City Manager: Darrell Essex

Mayor pro Tem., Cornelius M. Coronado, Jr.
Councilman, Otto J. Lacayo
Councilman, Howard Rowan
City Clerk, Darrell Essex
City Treasurer, Dennis Davenport
Police Chief, Orbrey L. Duke
School Superintendent, William B. Calton
City Attorney, John J. Murphy

CITY OF DALY CITY

(County of San Mateo)

Incorporated March 21, 1911

Legislative Districts: 11th Congressional; 6th Senatorial; 18th and 19th Assembly

General law city. Population 78,500. Council meets second and fourth Mondays of month in Council Chambers, City Hall, 333 90th Street, 94015.
Central Telephone: 415-992-4500

Mayor: Anthony A. Giammona
City Manager: David R. Rowe

Mayor pro Tem, Albert M. Teglia
Councilman, Victor G. Kyriakis
Councilwoman, Jane Powell
Councilman, James J. Tucker
City Clerk, Betty Mazza
Treasurer, Anthony Zidich
Police Chief, David A. Hansen
Fire Chief, H. Keith Schrock
City Attorney, Albert E. Polonsky

CITY OF DAVIS

(County of Yolo)

Incorporated March 28, 1917

Legislative Districts: 4th Congressional; 4th Senatorial; 4th Assembly

General law city. Population 37,800. Council meets first four Wednesdays in City Hall, 23 Russell Blvd., 95616.
Central Telephone: 916-756-3740

Mayor: Cecily J. Motley
City Manager: Howard L. Reese

Mayor pro Tem, William D. Kopper
Councilman, Gerald J. Adler
Councilman, Thomas J. Tomasi
Councilman, James L. Stevens, Jr.
City Clerk, Howard Reese
Police Chief, V. W. Mentink
Fire Chief, Michael L. Doneen
School Superintendent, Robert Trigg
City Attorney, P. Lawrence Klose

CITY OF DELANO

(County of Kern)

Incorporated April 13, 1915

Legislative Districts: 18th Congressional; 15th Senatorial; 32nd Assembly

General law city. Population 16,475. Council meets first and third Mondays of month at 7:30 p.m. in Council Chambers, 1015 11th Avenue, 93215.
Central Telephone: 805-725-0230

Mayor: Harry T. Hofman
City Manager: Richard Copeland

Mayor pro Tem, Leonard T. Velasco
Councilman, Earl W. Schauland
Councilman, Joe Hochschield
Councilman, Steven D. Kinsey
City Clerk, Dorothy Dowell
Police Chief, Mickey Chernekoff
Fire Chief, Willard Swarts
Treasurer, Larry Wendell

CITY OF DEL MAR

(County of San Diego)

Incorporated July 15, 1959

Legislative Districts: 43rd Congressional; 38th Senatorial; 76th Assembly

Chartered city. Population 5,168. Council meets first and third Mondays of month at 7:30 p.m. in Council Chambers, City Hall, 1050 Camino del Mar, 92014.
Central Telephone: 714-755-9313

Mayor: Louis M. Terrell
City Manager: Robert L. Nelson

Mayor pro Tem, Richard L. Roe
Councilmember, Nancy Hoover
Councilmember, Harvey Shapiro
Councilmember, Rosalind Feierabend
City Clerk, Mari Slater
Fire Chief, William H. Tripp
School Superintendent, Patricia Horkan
City Attorney, D. Dwight Worden

CITY OF DEL REY OAKS

(County of Monterey)

Incorporated September 3, 1953

Legislative Districts: 16th Congressional; 17th Senatorial; 28th Assembly

General law city. Population 1,830. Council meets fourth Tuesday of month at 8 p.m. in City Hall, 650 Canyon Del Rey Rd., 93940.
Central Telephone: 408-394-8511

Mayor: Robert B. Franco

Councilman, Joseph P. Russell
Councilwoman, Joan G. Moises
Councilman, Charles W. Benson
Councilwoman, Melva D. Bryant
City Clerk, Joyce A. Dettman
Police Chief, Herschel R. Amos
City Attorney, Robert Wellington

CITY OF DESERT HOT SPRINGS

(County of Riverside)

Incorporated September 25, 1963

Legislative Districts: 37th Congressional; 38th Senatorial; 75th Assembly

General law city. Population 6,000. Council meets first Tuesday of each month at 7:30 p.m. in the City Hall Council Chambers, 11711 West Drive, 92240.
Central Telephone: 714-329-6411

Mayor: Julius Corsini
City Manager: Leslie J. Crist

Vice-Mayor, Carl May
Councilman, Bill Minney
Councilman, Bea Wolf
Councilman, William Gibson
City Clerk, Leslie J. Crist
City Attorney, John Brown

CITY OF DINUBA

(County of Tulare)

Incorporated January 6, 1906

Legislative Districts: 17th Congressional; 15th Senatorial; 31st Assembly

General law city. Population 9,839. Council meets second and fourth Tuesdays of month at 7:30 p.m. in Council Chambers, Recreation Center, 1390 E. Elizabeth Way, 93618.
Central Telephone: 209-591-1203

Mayor: Jack Conway
City Manager: Vacant

Vice-Mayor, George Wayadande
Councilman, Dennis Tatum
Councilman, Gary Truitt
Councilman, Don Rager
City Clerk/Finance Director, Noble Shaw
Police Chief, Pat Buie
Fire Chief, Art Gillespie
School Superintendent, Dr. Mark Fabrizio
City Attorney, Ernest H. Tuttle

CITY OF DIXON

(County of Solano)

Incorporated March 30, 1878

Legislative Districts: 4th Congressional; 4th Senatorial; 4th Assembly

General law city. Population 7,491. Council meets second and fourth Tuesdays of month in Police-Courts Bldg., 155 N. 2nd St., 95620.
Central Telephone: 916-678-2326

Mayor: Marime Burton-Halloran
City Manager: David L. Harris

Mayor pro Tem, Joe Anderson
Councilwoman, Maureen Southwell
Councilman, Bob Reeb
Councilman, Ted Hickman
City Clerk, Bea Fairfield
Police Chief, James Van Cleaf
Fire Chief, W. H. Fairfield
City Treasurer, Bea Fairfield
School Superintendent, Gerry Laird
City Attorney, Ronald E. Moe

CITY OF DORRIS

(County of Siskiyou)

Incorporated December 23, 1908

Legislative District: 1st Congressional; 1st Senatorial; 1st Assembly

General law city. Population 840. Council meets first Monday of each month at 7:30 p.m. in Council Chambers, City Hall, 96023.
Central Telephone: 916-397-4281

Mayor: Danny Andreatta

Councilman, Fred O'Connor
Councilwoman, Martha Devitt
Councilman, Allen Barison
Councilman, John Kempke
City Clerk, Nancy N. Morrison
Police Chief, Denver Worthington

Fire Chief, Rickey Bay
Treasurer, Pam S. Roy
City Attorney, Robert Thomas Attorneys

CITY OF DOS PALOS

(County of Merced)

Incorporated May 4, 1935
Legislative Districts: 15th Congressional; 14th Senatorial; 27th Assembly
General law city. Population 3,213. Council meets first and third Tuesdays of month at 7:00 p.m. in City Hall, 1546 Golden Gate Ave., 93620
Central Telephone: 209-392-2174
Mayor: James F. Foster
City Administrator: Anthony J. Dias

Mayor pro Tem, Mario Giannoni
Councilman, Gerald Westlake
Councilman, Alleyne Antoine
Councilman, Jerald O'Banion
City Clerk, Joseph G. Lerner
Police Chief, Howard A. Sager
Fire Chief, "Chick" Ceccarelli
Treasurer, Betty J. Atkins
School Superintendent, Leamon Hansen & Van Sweet

CITY OF DOWNEY

(County of Los Angeles)

Incorporated December 17, 1956
Legislative Districts: 33rd Congressional; 63rd Assembly; 33rd Senatorial
Chartered city. Population 82,404. Council meets second and fourth Tuesday of month at 7:30 p.m. in Council Chambers, City Hall, 8425 E. 2nd St., 90241.
Mayor: Theodore H. Jackman
City Manager: Charles W. Thompson

Mayor pro Tem, Milton R. Mackaig
Councilman, Lyell W. Swearingen
Councilman, James T. Quinn
Councilman, Robert G. Cormack
City Clerk-Treasurer, Robert L. Shand
Police Chief, Wm. F. Martin
Fire Chief, Don Davis
School Superintendent, Manuel Gellegos

CITY OF DUARTE

(County of Los Angeles)

Incorporated August 22, 1957
Legislative Districts: 26th Congressional; 25th Senatorial; 61st Assembly
General law city. Population 15,100. Council meets second and fourth Tuesdays of month in City Hall, 1634 E. 3rd St., 91010.
Central Telephone: 213-357-7931
Mayor: James J. Coughlin
City Manager: J. Kenneth Caresio

Mayor pro Tem: Carl Falkenborg
Councilman, Mervin A. Money
Councilman, John C. Van Doren
Councilman, J. A. Montgomery
City Clerk-Treasurer, J. Kenneth Caresio
School Superintendent, Dr. Richard Key
City Attorney, William Camil

CITY OF DUNSMUIR

(County of Siskiyou)

Incorporated August 7, 1909
Legislative Districts: 1st Congressional; 1st Senatorial; 1st Assembly
General law city. Population 2,340. Council meets first and third Tuesdays of month at 7:30 p.m. in City Hall. Cedar St. and Dunsmuire Ave., 96025.
Mayor: V. L. "Buck" Osborne
City Manager: Casey Nesbit

Councilperson, Billiejean Blank
Councilperson, Harry Renoud
Councilperson, Emmett Hill
Councilperson, Margaret Thunborg
City Clerk, Ardith L. Wopschall
Police Chief, John Rowland
Fire Chief, Robert Kenoyer
Treasurer, P. W. Lindt
City Attorney, Chris Stromsness

CITY OF EL CAJON

(County of San Diego)

Incorporated November 20, 1912
Legislative Districts: 43rd Congressinal; 39th Senatorial; 77th Assembly
General law city. Population 72,100. Council meets every Tuesday of month at 4:00 p.m. & 7:30 p.m. in Council Chambers, 200 East Main Street, 92020.
Central Telephone: 714-440-1776
Mayor: John Reber
City Manager: Robert M. Applegate

Mayor pro Tem, Dona W. Foster
Councilwoman, Harriet M. Stockwell
Councilman, Jack L. Hanson
Councilman, C. Dan Conaway
City Clerk, Mildred R. Kennel
Police Chief, Wallace A. Dart
Fire Chief, Roger D. House
Treasurer, Harvey H. Henderson
City Attorney, Lynn R. McDougal

CITY OF EL CENTRO

(County of Imperial)

Incorporated April 16, 1908
Legislative Districts: 43rd Congressional; 38th Senatorial; 75th Assembly
General law city. Population 25,600. Council meets first and third Wednesdays of month at 7:30 p.m. in Council Chambers, City Hall, 1275 Main Street, 92243.
Central Telephone: 714-352-4011
Mayor: Dale Gares
City Manager: Abdel L. Salem (Acting)

Mayor pro Tem, James House

Councilman, Henry P. Alarcorn
Councilwoman, Iris R. DeZarn
Councilman, Tony Beltran
City Clerk, Rita Noden
Police Chief, Hugh Keating
Fire Chief, Tom Garner
Treasurer, Randall Horton
School Superintendent, Dr. Richard H. Brautigam
Director of Finance, Abdel L. Salem
Planning Director, Oliver M. Alvarado
City Engineer, Dan Brammer
Director of Public Works, Darryl M. Avrit
City Attorney, James L. Darrow

CITY OF EL CERRITO

(County of Contra Costa)

Incorporated August 23, 1917

Legislative Districts: 8th Congressional; 7th Senatorial; 11th Assembly

General law city. Population 22,689. Council meets first and third Mondays at 8 p.m. in Council Chambers, City Hall, 10890 San Pablo Ave., 94530.
Central Telephone: 415-234-2323

Mayor: James E. Allen, Jr.
City Manager: Richard V. Brown

Mayor pro Tem, Jean B. Siri
Councilman, Howard P. Abelson
Councilman, Margaret A. Collins
Councilman, Richard A. Spellmann
City Clerk, Lucille V. Irish
Police Chief, Patrick T. Reeve
Acting Fire Chief, Nye Butler
Community Development Director, Jean Travis Smith
City Attorney, William J. Kretzmer
City Treasurer, Patricia L. Calvert

CITY OF EL MONTE

(County of Los Angeles)

Incorporated November 18, 1912

Legislative Districts: 26th and 30th Congressional; 26th Senatorial; 60th Assembly

General law city. Population 79,005. Council meets second and fourth Tuesdays at 7:30 p.m. in Council Chambers, City Hall, 11333 Valley Blvd., 91734.
Central Telephone: 213-575-2252

Mayor: Jack T. Crippen
City Administrator: Doughlas Dunlap

Mayor pro Tem, Don McMillen
Councilman, Murray Cluff
Councilman, Henry Velasco
Councilman, Thomas Keiser
City Clerk, Louise Herbert
Police Chief, Wayne Clayton
Fire Chief, Charles Masten
Treasurer, Charles Roybal

CITY OF EL SEGUNDO

(County of Los Angeles)

Incorporated January 18, 1917

Legislative Districts: 27th Congressional; 27th Senatorial; 51st Assembly

General law city. Population 15,600. Council meets first and third Tuesdays at 7:00 p.m. in Council Chambers, City Hall, 350 Main St., 90245.
Central Telephone: 213-322-4670

Mayor: Richard K. Van Vranken
City Manager: Arthur E. Jones

Mayor pro Tem, William D. Bue
Councilman, Charles K. Armstrong
Councilman, Marvin R. Johnson
Councilman, Jack E. Siadek
City Clerk, Valerie A. Burrowes
Police Chief, James H. Johnson
Fire Chief, Thomas J. Baron
Treasurer, Louise Eckersley
School Superintendent, Dr. Chester R. Ingils
City Attorney, Mark C. Allen, Jr.

CITY OF EMERYVILLE

(County of Alameda)

Incorporated December 8, 1896

Legislative Districts: 8th Congressional; 9th Senatorial; 13th Assembly

General law city. Population 4,200. Council meets first and third Tuesdays at 8:00 p.m. in City Hall, 2449 Powell Street, 94608.
Central Telephone: 415-654-6161

Mayor: Wallace E. Fox

Vice-Mayor, Esther Spriggs
Councilmember, James Golden
Councilmember, Laura Davenport
Councilmember, Dorothy Heintz
City Clerk, Odessa T. Hall
Police Chief, John B. Lacoste
Fire Chief, Ramon Vittori
Treas[illegible]er, James S. Lindsay
School Superintendent, William Murray
City Attorney, H. Theodore Craig III

CITY OF ESCALON

(County of San Joaquin)

Incorporated March 12, 1957

Legislative Districts: 14th Congressional; 13th Senatorial; 26th Assembly

General law city. Population 3,117. Council meets first and third Monday evenings at 1855 Coley Ave., 95320.
Central Telephone: 209-838-3556

Mayor: Thomas F. Hagan
City Administrator: Earl Wilson

Vice Mayor, James Fulton
Councilman, Carl Vilen
Councilman, David C. Ennis
Councilman, Melvin R. Focha
City Clerk, Earl Wilson
Police Chief, Jack B. Storne
Fire Chief, Frank Silviera
School Superintendent, Jacob Klessens

Attorney, Leo Milich
City Treasurer, Patsy Haley

CITY OF ESCONDIDO

(County of San Diego)

Incorporated October 8, 1888
Legislative Districts: 43rd Congressional; 38th Senatorial; 76th Assembly
General law city. Population 62,500. Council meets first four Wednesdays of each month at 7:30 p.m. in Council Chamber, 100 Valley Blvd., 92025.
Central Telephone: 714-741-4703.
Mayor: Ron Bittner
City Manager: Ray Windsor

Mayor pro Tem, Art Danell
Councilman, Doug Best
Councilman, Jerry C. Harmon
Councilman, James M. Rady
City Clerk, Lina M. Hill
Police Chief, James Connole
Fire Chief, Louis Whyte
Treasurer, Ruth V. Thomas
City Attorney, David R. Chapman

CITY OF ETNA

(County of Siskiyou)

Incorporated March 13, 1878
Legislative Districts: 1st Congressional; 1st Senatorial; 1st Assembly
General law city. Population 751. Council meets first and third Mondays of month in Council Room. City Hall, 96027.
Central Telephone: 916-467-5256
Mayor: Wendell H. Seward

Mayor pro Tem, George A. White
Councilman, Dean Autry
Councilman, Leroy Bartel
Councilman, Gleason Balfrey
City Clerk, Lousie Thomas
Police Chief, David Bradford
Fire Chief, Ariel F. Facey
Treasurer, Delores Hottendorf

CITY OF EUREKA

(County of Humboldt)

Incorporated April 18, 1856
Legislative Districts: 2nd Congressional; 2nd Senatorial; 2nd Assembly
Chartered city. Population 24,337. Council meets first and third Tuesdays of month in Council Chamber, City Hall, 531 K Street, 95501.
Central Telephone: 707-443-7331
Mayor: Fred J. Moore, Jr.
City Manager: Robert Stockwell

Councilman, James A. Howard
Councilman, William P. Dimmick
Councilwoman, Bonnie B. Gool
Councilman, Clifford L. Stewart
Councilman, Thomas J. McMurray, Jr.
City Clerk, Patricia A. Banducci
Police Chief, O. R. Shipley
Fire Chief, Raymond R. Lay
City Attorney, John L. Cook

CITY OF EXETER

(County of Tulare)

Incorporated March 2, 1911
Legislative Districts: 17th Congressional; 15th Senatorial; 32nd Assembly
General law city. Population 5,488. Council meets second and fourth Tuesdays of month at 7:00 p.m. P.O. Box 237, Exeter 93221
Central Telephone: 209-592-3710
Mayor: Phyllis Turner
City Administrator: Stanleigh Megargee

Councilman, Henry Fry
Councilman, Alvin Miller
Councilman, Alvin Goularte
Councilwoman, Vicki Dungan
City Clerk, Leigh Megargee
Police Chief, Frank Jeffers
Treasurer, John Mangini

TOWN OF FAIRFAX

(County of Marin)

Incorporated March 2, 1931
Legislative Districts: 5th Congressional; 2nd Senatorial; 9th Assembly
General law city. Population 7,661. Council meets second Monday of each month in Council Chambers, Women's Club Bldg., 46 Park Road, 94930.
Central Telephone: 415-453-1584
Mayor: JoHanna Willmann
City Administrator: Rodney B. Brown

Mayor pro Tem, Frank J. Egger
Councilman, John S. Arnold
Councilwoman, Carol Sherman
Councilman, Francis J. O'Connell
City Clerk, Elizabeth L. Yafa
Police Chief, Charles A. Grasso
Fire Chief, George Hettema
School Superintendent, Carolyn Horan (Acting)
City Attorney, Wallace S. Myers

CITY OF FAIRFIELD

(County of Solano)

Incorporated December 12, 1903
Legislative Districts: 4th Congressional; 4th Senatorial; 4th Assembly
General law city. Population 58,100. Council meets first and third Tuesdays at 7:00 p.m. in Council Chambers, 1000 Webster Street, Civic Center, 94533.
Central Telephone: 707-425-1031
Mayor: Gary Falati
City Manager: B. Gale Wilson

Councilman, Carl Pullen

Councilman, G. Ben Huber
Councilman, Manuel Campos
Councilman, Carl V. Carlson
City Clerk, Bessie M. Day
Chief of Public Safety, Charles Huchel
Treasurer, Elsie Turri
School Superintendent, Justin Bardellini

CITY OF FARMERSVILLE

(County of Tulare)

Incorporated October 5, 1960

Legislative Districts: 17th Congressional; 15th Senatorial; 32nd Assembly

General law city. Population 4,220. Council meets second and fourth Wednesdays of month in City Hall, 147 E. Front St., 93223.

Mayor: Larry Miller

Vice-Mayor, Joe Alvarado
Councilmember, Charlie Joiner
Councilmember, Nancy Rye
Councilmember, Charles Felix
City Clerk, Lucille Scott
Police Chief, Garry Meek
Volunteer Fire Chief, Garry Meek

CITY OF FERNDALE

(County of Humboldt)

Incorporated August 28, 1893

Legislative Districts: 2nd Congressional; 2nd Senatorial; 2nd Assembly

General law city. Population 1,400. Council meets first Monday of month in City Hall, 834 Main St., 95536
Central Telephone: 707-786-4224

Mayor: Stanley L. Dixon

Councilman, William A. Etter
Councilman, Michael A. Ring
Councilman, Jack Altman
Councilman, Charles Goff
City Clerk, Mary C. Jorgensen
Police Chief, Jerry Meadors
Fire Chief, Lee Tomasini
City Attorney, Dominic Banducci

CITY OF FILLMORE

(County of Ventura)

Incorporated July 10, 1914

Legislative Districts: 20th Congressional; 19th Senatorial; 37th Assembly

General law city. Population 8,661. Council meets second and fourth Tuesdays of month in City Hall, 524 Sespe Ave., 93015.
Central Telephone: 805-524-3701

Mayor: Ernest J. Morales
City Manager: R. Wesley Nichols

Vice Mayor, Arthur B. Henry
Councilman, Kenneth C. Stewart
Councilman, William A. Dewey
Councilwoman, Delores I. Day
City Clerk, Mary E. Scoles
Police Chief, William A. Brewer
Fire Chief, George Campbell
Treasurer, Jim L. McGuire
City Attorney, Joseph P. D. Kern

CITY OF FIREBAUGH

(County of Fresno)

Incorporated September 17, 1914

Legislative Districts: 15th Congressional; 14th Senatorial; 30th Assembly

General law city. Population 4,126. Council meets second and fourth Mondays of month in City Hall, 1575 11th St., 93622.

Mayor: Ralph P. Tucci
City Administrator: Mark Duchon

Mayor pro Tem, Martin Sean Howard
Councilman, Ron Leyva
Councilman, Clyde Fannon
Councilman, Eugene Cline, Jr.
Councilman, R. E. Landucci
City Clerk, Flora Mae Shuemake
Police Chief, Howard C. Manes
Fire Chief, John G. Borboa
Treasurer, Barbara Hall Bolton
School Superintendent, Morris W. Kyle

CITY OF FOLSOM

(County of Sacramento)

Incorporated April 20, 1946

Legislative Districts: 1st and 3rd Congressional; 3rd and 13th Senatorial; 5th and 7th Assembly

General law city. Population 11,350.
Council meets first and third Mondays of each month at 7:30 p.m. in City Hall, 50 Natoma St., 95630.
Central Telephone: 916-985-2070

Mayor: P. Stanley Gisler
City Administrator: James R. Erickson

Vice-Mayor, Fred V. Scheidegger
Councilman, Rodney M. Carmody
Councilman, George E. Hannaford
Councilman, Dennis D. Inks
City Clerk, Ms. Arlene Soto
Police Chief, Clifford L. Smith
Fire Chief, Robert Welch
Treasurer, Mrs. Barbara Patrick
School Superintendent, James S. Laughridge
City Attorney, Philip C. Mering

CITY OF FONTANA

(County of San Bernardino)

Incorporated June 25, 1952

Legislative Districts: 36th Congressional; 32nd Senatorial; 66th Assembly

General law city. Population 25,275.
Council meets first and third Tuesdays of month in City Hall, 8353 Sierra Ave., 92335.

Central Telephone: 714-823-3411
Mayor: Frank Horzen
City Manager: Jean D. Ratelle II
Mayor pro Tem, William Kragness
Councilman, Charles Koehler
Councilman, Bill Freeman
Councilman, John G. Gilday, Jr.
City Clerk, Patricia M. Murray
Treasurer, John D. Piazza
Police Chief, Joseph L. Uhalley
Fire Chief, Duane Mellinger (Co. Dist.)
School Superintendent, Rudolph Macioge (Acting)
City Attorney, Steven Dorsey

CITY OF FORT BRAGG

(County of Mendocino)

Incorporated August 5, 1889
Legislative Districts: 2nd Congressional; 2nd Senatorial; 2nd Assembly
General law city. Population 5,025. Council meets second and fourth Mondays of month in City Hall, 416 Franklin St., 95437.
Central Telephone: 707-964-5325
Mayor: Mathew V. Huber
Councilman, Robert Barney
Councilman, Dick Seale
Councilman, Matt Huber
Councilman, Andre Schade
City Clerk, Naida Andreis
Police Chief, Jodean Mayberry
Fire Chief, Fred Baroni
Treasurer, Gary D. Milliman
School Superintendent, Daniel F. Mulvihill

CITY OF FORT JONES

(County of Siskiyou)

Incorporated March 16, 1872
Legislative Districts: 1st Congressional; 1st Senatorial; 1st Assembly
General law city. Population 515. Council meets first Monday of each month at 7:30 p.m. in Community Center, 96032.
Central Telephone: 916-468-2281
Mayor: Mary Berry
Councilman, Janice Baker
Councilman, Daniel Hunt
Councilman, Warren F. Nelson
Councilman, David Meyer
City Clerk, Gerald Scouten
Police Chief, Paul Wagner
Fire Chief, David LaMarr
Treasurer, Earl Herzberg
City Attorney, Larry Bacon

CITY OF FORTUNA

(County of Humboldt)

Incorporated February 20, 1906
Legislative Districts: 1st Congressional; 1st Senatorial; 2nd Assembly
General law city. Population 8,950. Council meets first and third Mondays of month at 7:30 p.m. in the Council Chamber, City Hall, 621 11th St., 95540.
Central Telephone: 707-725-3308
Mayor: Ray E. Steward
City Manager, Robert M. Davis
Councilman, Neil P. Palmer
Councilman, Virgil S. Nesbitt
Councilman, Dudley N. Maxwell
Councilman, Beth Rundell
City Clerk, Jo Ann Boerger
Police Chief, William P. Terry
Fire Chief, "Bud" Wescott
City Attorney, Sam L. Stone
Superintendent of Public Works, Thomas J. McWhorter

CITY OF FOSTER CITY

(County of San Mateo)

Incorporated April 27, 1971
Legislative Districts: 11th Congressional; 10th Senatorial; 20th Assembly
General law city. Population 24,600. Council meets first and third Mondays at 7:30 p.m. in Council Chambers, 600 Foster City Boulevard, 94404.
Central Telephone: 415-349-1200
Mayor: David R. Kruss
Vice Mayor: Roger Chinn
City Manager: Richard D. Wykoff
Councilman, Clifton A. Chavez
Councilman, Peter S. Gilbert
Councilman, Clark A. Barrett
City Clerk, Andrea M. Pavone
Public Safety Director, John J. Norton
City Treasurer, Stanley F. Stephens, Jr.
City Attorney, Kenneth M. Dickerson

CITY OF FOUNTAIN VALLEY

(County of Orange)

Incorporated June 13, 1957
Legislative Districts: 38th and 40th Congressional; 36th and 37th Senatorial; 71st, 72nd and 73rd Assembly
General law city. Population 54,590. Council meets first and third Tuesdays of each month at 8 p.m. in City Hall, 10200 Slater Ave., 92708.
Central Telephone: 714-963-8321
Mayor: Al Hollinden
City Manager: Robert Vollmer
Mayor pro Tem, Ben Nielsen
Councilman, Marvin P. Adler
Councilman, Eugene Van Dask
Councilwoman, Barbara Brown
City Clerk, Evelyn McClendon
Police Chief, Marvin K. Fortin
Fire Chief, Tom Feierabend
City Attorney, Thomas L. Woodruff

CITY OF FOWLER

(County of Fresno)

Incorporated June 15, 1908

Legislative Districts: 17th Congressional; 15th Senatorial; 31st Assembly

General law city. Population 2,280. Council meets first and third Tuesdays in City Hall, 125 S. Sixth, 93625.

Mayor: Johnny Tikijian

Mayor pro Tem, Fred Davis
Councilman, Ken Karle
Councilman, Kirk Mirigian
Councilman, Roland Hill
City Clerk, Merle Kleinhammer
Police Chief, James Martin
Fire Chief, Clyde Baumback
Treasurer, Annette Feaver
School Superintendent, John Taylor
City Attorney, R. R. Campagna
Director of Public Works, James Grigsby

CITY OF FREMONT

(County of Alameda)

Incorporated January 23, 1956

Legislative Districts: 10th Congressional; 11th Senatorial; 25th Assembly

General law city. Population 131,486. Council meets first four Tuesdays of month at 7:30 p.m. in the Council Chambers, City Government Bldg. 39700 Civic Center Drive, 94538.
Central Telephone: 415-791-4500

Mayor: Leon J. Mezzetti
City Manager: Allen E. Sprague (Acting)

Vice-Mayor, Yoshio Fujiwara
Councilman, Angus Morrison
Councilman, Bob Reeder
Councilwoman, Jan Stillwell
City Clerk, Douglas Eads
Police Chief, Robert Wasserman
Fire Chief, Dean Holzgrafe
School Superintendent, Dr. Wayne Ferguson
City Attorney, Lyle Lopus (Acting)

CITY OF FRESNO

(County of Fresno)

Incorporated October 12, 1885

Legislative Districts: 15th and 17th Congressional; 14th and 15th Senatorial; 30th and 31st Assembly

Chartered city. Population 194,826. Council meets every Tuesday at 9:00 a.m., except 2nd and 4th Tuesdays at 2:00 p.m. in Council Chambers, City Hall, 2326 Fresno St., 93721.
Central Telephone: 209-488-3033

Mayor: Daniel K. Whitehurst
Chief Administrative Officer: Gerald E. Newfarmer

Councilman, Joe Reich
Councilman, Leonel Alvarado
Councilman, Joe Williams
Councilwoman, Linda Mack
Councilman, Dale Doig
Councilman, Ted C. Wills
City Clerk, Jacqueline L. Ryle
Police Chief, George Hansen
Fire Chief, Lee Hill
School Superintendent, Vacant
City Attorney, James A. McKelvey

CITY OF FULLERTON

(County of Orange)

Incorporated February 15, 1904

Legislative Districts: 39th Congressional; 35th Senatorial; 69th Assembly

General law city. Population 103,334. Council meets first, second and third Tuesday of month in Council Chambers, City Hall, 303 W. Commonwealth, 92632.
Central Telephone: 714-738-6300

Mayor: Wayne H. Bornhoft
City Manager: Leslie R. White

Mayor pro Tem, Richard C. Ackerman
Councilman, Linda LeQuire
Councilwoman, Sue Tsuda
Councilman, Duane Winters
City Clerk, Anne M. York
Police Chief, Martin Hairabedian
Fire Chief, William Houser
City Attorney, R. K. Fox

CITY OF GALT

(County of Sacramento)

Incorporated August 16, 1946

Legislative Districts: 14th Congressional; 13th Senatorial; 7th Assembly

General law city. Population 5,554. Council meets first and third Tuesdays of month in Council Chambers, City Hall, 380 Civic Drive, 95632.
Central Telephone: 209-745-1535

Mayor: Robert G. Dunnett
City Administrator: Joseph M. Tanner

Councilman, Ken L. Mattlin
Councilman, Ronald V. Jacobsen
Councilman, Don Prachar, Jr.
Councilman, Marian O. Lawrence
City Clerk, Berniece Shelley
Police Chief, Robert S. Fuller
City Engineer, Waldo Kolb
City Treasurer, Jacqueline A. Davy
City Attorney, Keith W. Lamb

CITY OF GARDEN GROVE

(County of Orange)

Incorporated June 18, 1956

Legislative Districts: 38th and 39th Congressional; 35th and 37th Senatorial; 69th, 70th, 71st, and 72nd Assembly

General law city. Population 121,789. Council meets first four Tuesdays of the month at 7:30 p.m. in Council Chambers, Community Center, 11300 Stanford Avenue, 92640.
Central Telephone: 714-638-6623

Mayor: Jonathan H. Cannon
City Manager: Delbert L. Powers
Mayor pro Tem, J. Tilman Williams
Councilman, Robert F. Dinsen
Councilman, Leonard Holland
Councilman, Milton Krieger
City Clerk, Jeri Louise Stately, CMC
Police Chief, Frank Kessler
Fire Chief, Douglas Spickard

CITY OF GARDENA

(County of Los Angeles)

Incorporated September 11, 1930
Legislative Districts: 31st Congressional; 28th Senatorial; 53rd Assembly
General law city. Population 44,551.
Council meets second and fourth Tuesdays of month at 1700 W. 162nd St., 90247.
Central Telephone: 213-327-0220
Mayor: Edmond J. Russ
Administrative Officer: John C. Sheehan
Mayor pro Tem, Donald L. Dear
Councilman, Charles A. Nader
Councilman, Paul Tsukahara
Councilman, Masani (Mas) Fukai
City Clerk, May Y. Doi
Police Chief, Richard K. Propster
Fire Chief, Andy Bero
Treasurer, George Kobayashi
City Attorney, Michael H. Miller

CITY OF GILROY

(County of Santa Clara)

Incorporated March 12, 1870
Legislative Districts: 13th Congressional; 11th Senatorial; 24th Assembly
Chartered city. Population 21,550.
Council meets first and third Mondays of month in Council Chambers, City Hall, 7351 Rosanna St., 95020.
Central Telephone: 408-842-3191
Mayor: Norman B. Goodrich
City Administrator: Fred O. Wood
Mayor pro Tem, John E. Pate
Councilman, Robert E. Taylor
Councilman, Brian D. Cunningham
Councilman, Marion T. Link
Councilwoman, Sharon Albert
Councilwoman, Roberta H. Hughan
City Clerk, Susanne E. Steinmetz
Police Chief, Gregory Cowart
Fire Chief, Albert L. Brittain
School Superintendent, Rodney Kelley
City Attorney, Bruce M. Jacobs

CITY OF GLENDALE

(County of Los Angeles)

Incorporated February 15, 1906
Legislative Districts: 22nd Congressional; 21st Senatorial; 41st and 42nd Assembly
Chartered city. Population 139,317.
Council meets every Tuesday at 2 p.m. and fourth Thursday at 8 p.m. of each month in Council Chambers, City Hall, 613 E. Broadway, 91205.
Central Telephone: 213-956-4000
Mayor: John F. Day
City Manager: Hugh McKinley
Councilman, Carroll W. Parcher
Councilwoman, Ginger Bramsberg
Councilman, Carl Mesech
Councilman, Robert W. Garcin
City Clerk, Merle H. Hagemeyer
Police Chief, Duane R. Baker
Fire Chief, Allan R. Stone
Treasurer, Pauline S. Lockhart
School Superintendent, Burtis E. Taylor
City Attorney, Frank R. Manzano

CITY OF GLENDORA

(County of Los Angeles)

Incorporated November 13, 1911
Legislative Districts: 26th Congressional; 25th Senatorial; 62nd Assembly
General law city. Population 38,180. Council meets second and fourth Tuesdays at 7:30 p.m. in Council Chamber, City Hall, 116 E. Foothill Blvd., 91740.
Central Telephone: 213-335-4071
Mayor: James W. Vincent
City Manager: James M. Evans
Mayor pro Tem: John E. Hackney
Councilman, John Gordon
Councilman, Ken Prestesater
Councilman, Guy A. Williams, Jr.
City Clerk, Culver E. Heaton, Jr.
Police Chief, Oliver B. Posey
City Treasurer, Sam Shwetz
School Superintendent, Patrick Bushman
City Attorney, Maurice O'Connor

CITY OF GONZALES

(County of Monterey)

Incorporated January 14, 1947
Legislative Districts: 16th Congressional; 17th Senatorial; 29th Assembly
General law city. Population 2,891. Council meets first and third Mondays at 8 p.m. in City Hall, 109 Fourth St., 93926.
Central Telephone: 408-675-2321
Mayor: Joe Sveinsson
City Manager: Berkley Brannon
Mayor pro Tem, Harry Singh
Councilman, John Kissinger
Councilman, Vernon Silver
Councilman, Charles Villegas
City Clerk, Berkley Brannon
Police Chief, George Garcia
Fire Chief, Richard Galvez
Treasurer, Shirley Piffero

CITY OF GRAND TERRACE

(County of San Bernardino)

Incorporated November 30, 1978
Legislative Districts: 36th Congressional; 32nd Senatorial; 66th Assembly
General law city. Population 10,203. Council meets first and third Thursdays of each month at 22731 Grand Terrace Road (Terrace View Elementary School), 92324.
Central Telephone: 714-824-6621
Mayor: Thomas A. Tillinghast
City Manager: Seth Armstead

Mayor pro Tem, Hugh J. Grant
Councilman, Tony Petta
Councilman, Roy Nix
Councilman, Jim Rigley
Fire Chief, Don Banghart
Police Chief, Capt. Phil Schuyler
City Attorney, Ivan Hopkins
City Clerk, Myrna Lindahl
City Engineer, Joe Kicak

CITY OF GRASS VALLEY

(County of Nevada)

Incorporated April 15, 1861
Legislative Districts: 1st Congressional; 1st Senatorial; 3rd Assembly
Chartered city. Population 6,203. Council meets second and fourth Tuesdays of month at 7:30 p.m. in City Hall, 125 E. Main St., 95945.
Central Telephone: 916-273-2203
*Mayor: Frank E. Knuckey

*Assistant Mayor, Dennis Hill
Councilman, Edward Scofield III
*Councilman, Jearold F. Brust
Councilman, Al Frisch, Sr.
City Clerk, Nellie L. Martin
Police Chief, Melvin Mouser
Fire Chief, John Straka
City Attorney, Dwight L. Moore
Council reorganization July 1981

CITY OF GREENFIELD

(County of Monterey)

Incorporated January 7, 1947
Legislative Districts: 16th Congressional; 17th Senatorial; 29th Assembly
General law city. Population 3,524. Council meets first and third Tuesdays of month at 213 El Camino Real, 93927.
Central Telephone: 408-674-5591
Mayor: Leonard Dart
City Manager: George Scarborough

Councilman, James R. Guerrero
Councilman, Ray Blach
Councilman, Bill Williams
Councilman, Elias DeLeon, Jr.
Treasurer, Charles Fields
Police Chief, A. Lamarr Sauer
Fire Chief, Chauncey McDonald
Interim School Superintendent, Richard Denure
City Attorney, John Hutton

CITY OF GRIDLEY

(County of Butte)

Incorporated November 23, 1905
Legislative Districts: 1st Congressional; 1st Senatorial; 1st and 3rd Assembly
General law city. Population 4,000. Council meets first and third Mondays of month in City Hall, 685 Kentucky St., 95948.
Central Telephone: 916-846-5695
Mayor: Doris Long

Councilman, Dan Boeger
Councilman, James Tupen
Councilman, Darwin W. Spurgeon
Councilman, Michael Greer
City Clerk, Evelene D. Payne
Police Chief, John B. Donnahoe
Fire Chief, Marvin Scott
City Engineer, Vacant
City Attorney, Bob Millington
Finance Director, Evelene D. Payne

CITY OF GROVER CITY

(County of San Luis Obispo)

Incorporated December 21, 1959
Legislative Districts: 19th Congressional; 17th Senatorial; 29th Assembly
General law city. Population 8,400. Council meets first and third Mondays of month in City Hall, 154 S. 8th St., 93433.
Central Telephone: 805-489-4040
Mayor: Robert H. Newdoll
City Administrator: Arnold Dowdy

Mayor pro Tem, Juanita J. Qualls
Councilmember, Alfred C. Dutra
Councilmember, Woody Lynn
Councilmember, Jack Kean
City Clerk, Arnold Dowdy
Police Chief, David Brown
Fire Chief, Lowell Forister
School Superintendent, Robert Hoagland
City Treasurer, Linda J. Maher
Deputy City Treasurer, Arnold Dowdy

CITY OF GUADALUPE

(County of Santa Barbara)

Incorporated August 3, 1946
Legislative Districts: 19th Congressional; 18th Senatorial; 35th Assembly
General law city. Population 3,250. Council meets second and fourth Mondays of month at 7:30 p.m. in Room 8, 918 Obispo Street, 93434.
Central Telephone: 805-343-1340
Mayor: Frank T. Almaguer

City Administrator: William Stanton, Jr.
Mayor pro Tem, Leo J. Gondolfi
Councilman, Eugene C. Groppetti
Councilman, Leo J. Gondolfi
Councilman, John Sherrell
City Clerk, Nancy C. Etteddgue
City Treasurer, Sandra DallaCosta
Fire Chief, Henry J. Lawrence
Police Chief, Leonard A. Chapman
School Superintendent, Alejandro Ochoa
City Attorney, Gerald W. Shipsey and John L. Seitz

CITY OF GUSTINE

(County of Merced)

Incorporated November 11, 1915
Legislative Districts: 15th Congressional; 14th Senatorial; 27th Assembly
General law city. Population 3,119. Council meets first and third Mondays of month in City-County Bldg., 682 Third Ave., 95322.
Central Telephone: 209-854-6471
Mayor: Daniel Serpa
City Manager: David K. Witter
Mayor pro Tem, Elizabeth Bettencourt
Councilman, Victor Martino
Councilman, Johnnie Borrelli
Councilman, Chester Bonta
City Clerk, David K. Witter
Police Chief, Robert Belmont
Fire Chief, Richard Vierra
Treasurer, Adelyne M. DeGregori
School Superintendent, Robert Lasley
City Attorney, Francis R. Ruggierri

CITY OF HALF MOON BAY

(County of San Mateo)

Incorporated July 15, 1959
Legislative Districts: 11th Congressional; 10th Senatorial; 20th Assembly
General law city. Population 7,134. Council meets first and third Tuesdays of month at 8 p.m. in Community Room, Half Moon Bay Library, 620 Correas St., 94019.
(Mailing Address: P.O. Box 67)
Central Telephone: 415-726-5566
Mayor: John H. Shaw, Jr.
City Manager: W. Fred Mortensen
Vice-Mayor, Dolores B. Mullin
Councilman, Melvin A. Mello, Sr.
Councilman, Helen R. Bedesem
Councilman, Jack C. Bishop
City Clerk, Ralphena R. Guest
Fire Chief, Lawrence Centoni
Police Chief, John E. Gonzales
School Superintendent, Dr. Michael Adams
City Attorney, James P. Fox

CITY OF HANFORD

(County of Kings)

Incorporated August 12, 1891
Legislative Districts: 17th Congressional; 15th Senatorial; 32nd Assembly
General law city. Population 20,812. Council meets first and third Tuesdays of month in Council Chambers, City Hall, 400 N. Douty, 93230.
Central Telephone: 209-582-2511
Mayor: Simon Lakritz
City Manager: Vincent G. Petersen
Councilman, Jeffrey S. Nicklas
Councilman, Joe H. Crain, Jr.
Councilman, Stan Ham
Councilman, J. Brent Madill
City Clerk, Dorothy A. Mattos
Police Chief, Curtis L. Henderson
Fire Chief, George Watson
Treasurer, Tom Dibble
City Attorney, Lawrence Clawson

CITY OF HAWAIIAN GARDENS

(County of Los Angeles)

Incorporated April 9, 1964
Legislative Districts: 34th Congressional; 31st Senatorial; 58th Assembly
General law city. Population 9,950. Council meets second and fourth Tuesdays each month at 8 pm in City Hall, 21815 Pioneer Boulevard, 90716.
Central Telephone: 213-420-2641
Mayor: Jack M. Myers
City Administrator: Ray D. Harris
Mayor pro Tem, Venn W. Furgeson
Councilman, Lupe A. Cabrera
Councilwoman, Margaret J. Vineyard
Councilman, Donald E. Schultze
City Clerk, Carol J. Dorfmeyer
City Treasurer, Helen Mork
Chief of Police, Peter J. Pitchess
Fire Chief, Clyde A. Bragdon
City Attorney, Graham A. Ritchie

CITY OF HAWTHORNE

(County of Los Angeles)

Incorporated July 12, 1922
Legislative Districts: 31st Congressional; 28th Senatorial; 53rd Assembly
General law city. Population 55,500. Council meets second and fourth Mondays of month at 8 p.m. in City Hall, 4455 W. 126th St., 90250.
Central Telephone: 213-970-7902
Mayor: Bruce Gies
City Manager: R. Kenneth Jue
Vice Mayor: Joseph Miller
Councilman, Guy Hocker
Councilwoman, Betty J. Ainsworth
Councilman, Larry Guyer, Jr.
Treasurer, Howard Wohlner
City Clerk, Joan C. Fitzsimmons (Acting)
Police Chief, Kenneth R. Stonebraker (Acting)
Fire Chief, Ralph Hardin

CITY OF HAYWARD

(County of Alameda)

Incorporated March 11, 1876
Legislative Districts: 9th and 10th Congressional; 8th Senatorial; 15th Assembly
Chartered city. Population 97,004. Council meets first four Tuesdays of each month at 8 p.m. in Council Chambers, City Center Building, 22300 Foothill Blvd., 94541.
Central Telephone: 415-581-2345
Mayor: Illene Weinreb
City Manager: Donald A. Blubaugh

Councilman, George P. Oakes
Councilman, Alex Giuliani
Councilman, Lawrence J. Ratto
Councilwoman, Shirley Campbell
Councilman, Julio J. Bras
Councilman, Gail Steele
City Clerk, (Mrs.) Paloma R. Weaver
Police Chief, Charles Plummer
Fire Chief, William T. Neville
School Superintendent, Dr. Allen C. Bushnell

CITY OF HEALDSBURG

(County of Sonoma)

Incorporated February 20, 1867
Legislative Districts: 2nd Congressional; 1st Senatorial; 2nd Assembly
General law city. Population 7,137. Council meets first and third Mondays of month in City Hall, 126 Matheson St., 95448.
Central Telephone: 707-433-9425
Mayor: Robert J. Haviland
City Manager. Michael W. McDonald

Councilman, Paul Dix
Councilman, William Proctor
Councilman, James Stanfield
Councilwoman, Rita Schroeder
City Clerk, Katy Gladden
Police Chief, Louis E. Bertoli
Fire Chief, Ken Hanley
Treasurer, Kenneth Hampton
School Superintendent, Robert L. Malone
City Attorney, John Klein

CITY OF HEMET

(County of Riverside)

Incorporated January 20, 1910
Legislative Districts: 37th Congressional; 38th Senatorial; 67th and 75th Assembly
General law city. Population 22,411. Council meets second and fourth Tuesday of month at 7:30 p.m. in City Offices, 450 E. Latham Ave., 92343.
Central Telephone: 714-658-9411
Mayor: Patricia L. Herron
City Manager: William R. Hoeft (Acting)

Vice-Mayor, Thomas Hutchings
Councilman, Loren Morgan
Councilman, Donald Young
Councilman, David Kahn
City Clerk, Edward J. Rodeghier
Police Chief, Roger Miller
Fire Chief, Richard Fuerestein
Treasurer, Thomas Wilson
City Attorney, Robert Henderson

CITY OF HERCULES

(County of Contra Costa)

Incorporated December 15, 1900
Legislative Districts: 7th Congressional; 7th Senatorial; 11th Assembly
General law city. Population 5,907. Council meets second and fourth Wednesdays of month at 7:30 p.m. at Hercules Elementary School, 1919 Lupine, 94547.
Central Telephone: 415-724-2489
Mayor: Charles N. Collins
City Manager: Ralph Snyder

Vice-Mayor, Lynn Judnich
Councilman, Michael R. Freeman
Councilman, Gorgonio Solidum
Councilman, Fred S. Wachowicz
Clerk Clerk, Joe R. Valles
City Attorney, Robert Anderson
Treasurer, Joe R. Valles
City Engineer, William Chapman
City Planner, Gary Odaffer
Chief of Police, Russell Quinn

CITY OF HERMOSA BEACH

(County of Los Angeles)

Incorporated January 14, 1907
Legislative Districts: 27th Congressional; 27th Senatorial; 51st Assembly
General law city. Population 22,000. Council meets second and fourth Tuesdays of month in Council Chambers, City Hall, 1315 Valley Drive, 90254.
Central Telephone: 213-376-6984
Mayor: George G. Barks
City Manager: Gregory Meyer

Mayor pro Tem, Lance Widman
Councilwoman, Edie MacFaden
Councilwoman, Mary Tyson
Councilman, George Schmeltzer
City Clerk, Charlotte Ann Malone
City Treasurer, Rosemary Foreman
Police Chief, Capt. John Doukakis
Fire Chief, Capt. Joseph Geonetta, Coordinator
School Superintendent, Marilyn Harris

CITY OF HIDDEN HILLS

(County of Los Angeles)

Incorporated October 19, 1961
Legislative Districts: 20th Congressional; 19th Senatorial; 38th Assembly
General law city. Population 1,685. Council meets first Tuesday of month at 8 p.m. in City Hall,

24549 Long Valley Road, 91302.
Central Telephone: 213-888-9281
Mayor: Colleen M. Hartman
Mayor pro Tem, Thomas Lindholm
Councilman, John Smith
Councilman, Christian Van Peski
Councilwoman, Ruth Ann Matheson
City Clerk, Dee Marie Dainty

TOWN OF HILLSBOROUGH

(County of San Mateo)

Incorporated May 5, 1910
Legislative Districts: 11th Congressional; 6th Senatorial; 19th Assembly
General law city. Population 10,300. Council meets second and fourth Mondays of month in Town Hall, 1600 Floribunda Ave., 94010.
Central Telephone: 415-343-2795
Mayor: Henry W. Howard
City Manager: Robert M. Davidson
Councilman, Fred T. Clifton
Councilman, Patrick W. Kelly
Councilman, Melvin A. Anderson
Councilman, Benjamin N. Follett
City Clerk, Virginia J. Hvid
Police Chief, William A. Key
Fire Chief, William W. Stremme, Jr.
School Superintendent, Quentin Taylor
City Attorney, Frank B. Ingersoll, Jr.

CITY OF HOLLISTER

(County of San Benito)

Incorporated March 26, 1874
Legislative Districts: 16th Congressional; 11th Senatorial; 24th Assembly
General law city. Population 11,400. Council meets first and third Mondays of month at 7:30 p.m. in Council Chambers, City Hall, 375 Fifth St., 95023
Central Telephone: 408-637-4491
Mayor: Fernando Gonzalez
City Manager: Roger A. Grimsley
Mayor pro Tem, John Hodges
Councilman, Gordon Machado
Councilman, Leonard Poletti
Councilwoman, Ann Carpenter
City Clerk, Frank D. Felice
Police Chief, Wayne Purves
Fire Chief, Tony Aguirre
Treasurer, Frank Vesley
City Attorney, John O'Brian

CITY OF HOLTVILLE

(County of Imperial)

Incorporated July 1, 1908
Legislative Districts: 43rd Congressional; 38th Senatorial; 75th Assembly
General law city. Population 4,450. Council meets second and fourth Mondays of month in the office of the City Clerk, 121 West 5th St., 92250.
Central Telephone: 714-356-2912
Mayor: Gary Rodgers
Councilman, Joe Patzloff
Councilman, William Carrico
Councilwoman, Colleen Ludwig
Councilman, Stanley Banks
City Clerk, Martha Miller
Police Chief, Arlie P. Henthorne
Fire Chief, Glen Wilson
Treasurer, Arona G. Farris
School Superintendent, Wesley F. Pittman
City Attorney, Joseph C. Daly

CITY OF HUGHSON

(County of Stanislaus)

Incorporated November 30, 1972
Legislative Districts: 14th Congressional; 13th Senatorial; 26th Assembly
General law city. Population 2,908. Council meets second and fourth Mondays of month at 7:00 p.m. at 7018 Pine Street, 95326.
Central Telephone: 209-883-4054
Mayor: Jack Parker
City Manager: James M. Buell
Vice-Mayor, James King
Councilman, Jerry Thoms
Councilman, William "Bush" Trieweiler
Councilman, Ronald Lema
City Clerk, Gayle Robertson
City Treasurer, Gloria McGill
Public Works Superintendent, Troy Presley
Police Chief, Larry D. Bussard
City Attorney, Stewart W. James

CITY OF HUNTINGTON BEACH

(County of Orange)

Incorporated February 17, 1909
Legislative Districts: 34th, 38th and 40th Congressional; 36th Senatorial; 71st and 73rd Assembly
Chartered city. Population 175,000. Council meets first and third Mondays of month at 7:30 p.m. in Council Chambers, 2000 Main Street, 92648.
Central Telephone: 714-536-5511
Mayor: Ruth Bailey
City Administrator: Frank B. Arguello (Acting)
Mayor pro Tem, Ruth Finley
Councilman, Ronald R. Pattinson
Councilman, Don MacAllister
Councilman, Robert P. Mandie, Jr.
Councilman, John A. Thomas
City Clerk, Alicia M. Wentworth
Attorney, Gail Hutton
Police Chief, Earle Robitaille
Fire Chief, Raymond C. Picard
Treasurer, Warren G. Hall

CITY OF HUNTINGTON PARK

(County of Los Angeles)

Incorporated September 1, 1906

Legislative Districts: 29th Congressional; 29th Senatorial; 47th Assembly

General law city. Population 46,083. Council meets first and third Mondays of month in City Hall, 6550 Miles Ave., 90255.

Central Telephone: 213-582-6161

Mayor: Jim Roberts

Administrative Officer: Harold M. Campbell

Mayor pro Tem, Herbert A. Hennes, Jr.
Councilman, Jack W. Parks
Councilman, William P. Cunningham
Councilman, Thomas E. Jackson
City Clerk, Marilyn A. Boyette
Police Chief, Loren J. Russell
Treasurer, Francis J. Bradley
City Attorney, Colin Lennard

CITY OF HURON

(County of Fresno)

Incorporated May 3, 1951

Legislative Districts: 15th Congressional; 14th Senatorial; 30th Assembly

General law city. Population 2,710. Council meets first and third Wednesdays of each month in City Hall, 93234.

Central Telephone: 209-945-2241

Mayor: Forrest M. Roth

City Administrator: Frank Rodriguez

Councilmember, Ted Cruz
Councilmember, Dennis Baron
Councilmember, Steve Robles
Councilmember, Tony E. Silva
City Clerk, Frank Rodriguez
Police Chief, Oscar Gongora
City Attorney, Henry T. Leckman

CITY OF IMPERIAL

(County of Imperial)

Incorporated July 12, 1904

Legislative Districts: 43rd Congressional; 38th Senatorial; 75th Assembly

General law city. Population 3,400. Council meets first and third Wednesdays of each month at 7:30 p.m. in the City Hall, 420 S. Imperial Ave., 92251.

Central Telephone: 714-355-4371

Mayor: Patricia M. Burk

Mayor pro Tem, Steven W. Shaner
Councilmember, Thomas D. Ludlow
Councilmember, Leamon Murphy
Councilmember, Dean A. Shores
City Clerk, Betty Willett
Public Service Director, Stacy D. Chase
Police/Fire Chief, Lon Hettinger
Treasurer, Patricia Wendell
City Attorney, John Penn Carter

CITY OF IMPERIAL BEACH

(County of San Diego)

Incorporated July 18, 1956

Legislative Districts: 42nd Congressional; 40th Senatorial; 80th Assembly

General law city. Population 22,750. Council meets first and third Mondays of each month in Council Chambers, 825 Imperial Beach Blvd. 92032.

Central Telephone: 714-423-8300

Mayor: Brian P. Bilbray

City Manager: George Field (Acting)

Vice-Mayor, Thomas P. Stark
Councilman, John B. Bennett
Councilwoman, Hazel F. Bailey
Councilwoman, Jacqueline Palmer
City Clerk, A. George Ramos
Police Chief, Curtis McCleskey
Fire Chief, David Engleman
City Attorney, Clifton E. Reed

CITY OF INDIAN WELLS

(County of Riverside)

Incorporated July 14, 1967

Legislative Districts: 37th Congressional; 38th Senatorial; 75th Assembly

General law city. Population 1,600. Council meets first and third Thursdays, 3:00 p.m., at 45-300 Club Dr., 92260.

Central Telephone: 714-345-2831

Mayor: Frank Chilson

City Manager: Prince E. Pierson

Vice-Mayor, Walter Pearce
Councilman, Frank Hall
Councilman, Richard Oliphant
Councilman, Henry Ure
City Clerk, Prince E. Pierson
City Attorney, Paul Selzer

CITY OF INDIO

(County of Riverside)

Incorporated May 16, 1930

Legislative Districts: 37th Congressional; 38th Senatorial; 75th Assembly

General law city. Population 20,700. Council meets first and third Wednesdays of month at 7 p.m. in Council Chambers, 150 Civic Center Mall, 92202

Central Telephone: 714-347-2351

Mayor: Philip A. Reed

City Manager: W. Phillip Hawes

Vice-Mayor, David V. Hernandez
Councilman, Roger M. Harlow
Councilwoman, Regena Zokosky
Councilman, Marcos S. Lopez
City Clerk, Saundra L. Juhola
Police Chief, Curtis Cross
Fire Chief, John Payne
Treasurer, Evelyn Thompson
City Attorney, David J Erwin

CITY OF INDUSTRY

(County of Los Angeles)

Incorporated June 18, 1957

Legislative Districts: 30th and 33rd Congressional; 26th and 33rd Senatorial; 60th and 64th Assembly

Chartered city. Population 668. Council meets every 2nd Thursday at 8:00 a.m. and every fourth Thursday of each month at 9:00 a.m. in City Hall, 15651 Stafford Street, 91744.
Central Telephone: 213-333-2211

Mayor: John Ferrero

Councilman, Samuel J. Parriott
Councilman, Darius F. Johnson
Councilman, Charles J. Rowland
Councilman, John P. Ferrero
City Clerk, Marynelle Bussola
City Treasurer, Phyllis Tucker

CITY OF INGLEWOOD

(County of Los Angeles)

Incorporated February 14, 1908

Legislative Districts: 28th and 31st Congressional; 28th and 30th Senatorial; 49th, 50th and 53rd Assembly

Chartered city. Population 89,985. Council meets every Tuesday at 1:30 p.m. in Council Chamber, City Hall, 1 Manchester Blvd., 90301.
Central Telephone: 213-649-7111

Mayor: Lee Weinstein
Administrative Officer: Paul Eckles

Councilman, George F. Gerard
Councilman, Andrew Q. Isaacs
Councilman, Bruce U. Smith
Councilman, Edward Vincent
City Clerk, Iris A. Crochet
Police Chief, Jay R. Stroh
Fire Chief, Robert Osby
Treasurer, H. Stanley Jones
School Superintendent, Dr. Frances Worthington
City Attorney, Howard Rosten

CITY OF IONE

(County of Amador)

Incorporated March 23, 1953

Legislative Districts: 14th Congressional; 13th Senatorial; 7th Assembly

General law city. Population 2,482. Council meets first Monday of month at 8 p.m. in Council Chambers, City Hall, No. 1 East Main St., 95640.
Central Telephone: 209-274-2412

Mayor: Robert R. Patterson

Councilman, Dwight E. Jennings, D.D.S.
Councilman, Louis D. Stewart
Councilman, Dominic D. Vimini
Councilman, Robert K. Claytor, M.D.
City Clerk, Sue Guadagnolo
Treasurer, George E. Kohler
Police Chief, Ramon F. Drehobl
Fire Chief, Darrell Haller
School Superintendent, Robert O. Briggs
City Attorney, James E. Deasy

CITY OF IRVINE

(County of Orange)

Incorporated December 28, 1971

Legislative Districts: 40th Congressional; 36th Senatorial; 74th Assembly

Charter city. Population 63,500. Council meets 2nd and 4th Tuesdays of each month in Irvine City Hall, 17200 Jamboree, 92714.
Central Telephone: 714-754-3600

Mayor: Art Anthony
City Manager: William Woollett, Jr.

Mayor pro Tem, David G. Sills
Councilman, Bill Vardoulis
Councilwoman, Mary Ann Gaido
Councilman, Larry Agran
City Clerk, Nancy C. Rowland

CITY OF IRWINDALE

(County of Los Angeles)

Incorporated August 6, 1957

Legislative Districts: 26th Congressional; 25th Senatorial; 61st Assembly

General law city. Population 1,030. Council meets second and fourth Thursdays of each month in Community Center Bldg., 5050 N. Irwindale Ave., 91706.
Central Telephone: 213-962-3381

Mayor: Michael Miranda
City Manager: Charles Martin (Acting)

Mayor pro Tem, Arthur F. Tapia
Councilman, Pat S. Miranda
Councilman, Jose (Sal) Castellanos
Councilman, Henry V. Barbosa
City Clerk, Margaret S. Barbosa
Police Chief, Julian Miranda
City Attorney, Charles Martin

CITY OF ISLETON

(County of Sacramento)

Incorporated May 14, 1923

Legislative Districts: 4th Congressional; 4th Senatorial; 4th Assembly

General law city. Population 950. Council meets second Tuesday of month in City Hall, Second St., 95641.
Central Telephone: 916-777-6082

Mayor: George M. Apple

Councilman, Fred V. Wilson
Councilman, John S. Perez
Councilman, Paul deMesa
Councilman, Larry L. Gardiner
City Clerk, John E. Golden
Police Chief, Frank Mayberry
Fire Chief, Cecil L. Tomlin
Treasurer, C. R. Wilson
City Attorney, Philip C. Mering

CITY OF JACKSON

(County of Amador)

Incorporated December 5, 1905
Legislative Districts: 14th Congressional; 13th Senatorial; 7th Assembly
General law city. Population 2,500. Council meets first and third Mondays of each month in City Hall, 33 Broadway, 95642.
Central Telephone: 209-223-1646
Mayor: Michael F. Spinetti
Councilman, Anthony Pohmajevich
Councilman, Marven H. Vicini
Councilman, Dennis M. King
Councilman, Wade Selman, Jr.
City Administrator, Robert L. Van Nort
Police Chief, Paul Pietronave
Fire Chief, Patrick M. Tallon, Sr.
Treasurer, John A. Huberty
City Attorney, Kristine Cazadd
City Clerk, Jimmie L. Jackson

JAMESTOWN - TUOLOME

CITY OF KERMAN

(County of Fresno)

Incorporated July 2, 1946
Legislative Districts: 15th Congressional; 14th Senatorial; 30th Assembly
General law city. Population 3,954. Council meets first and third Mondays of each month at 7:30 p.m. in City Hall, 850 S. Madera Ave., 93630.
Central Telephone: 209-846-9384
Mayor: Leopold Sciacqua
Administrative Officer: Clifford L. Swanson
Councilman, Harry Pedersen
Councilman, W. M. Morgan
Councilman, Donald Slumberger
Councilwoman, Yvonne Brown
City Clerk, Edith M. Forsstrom
Police Chief, Harold F. Grant
City Treasurer, Gladys Slumberger

CITY OF KING

(County of Monterey)

Incoporated February 9, 1911
Legislative Districts: 12th Congressional; 17th Senatorial; 29th Assembly
General law city. Population 5,450. Council meets second and fourth Tuesdays of the month in City Hall, 212 S. Vanderhurst Ave., 93930.
Central Telephone: 408-385-3281
Mayor: Irving J. Copley
City Manager: Dan Givens (Acting)
Mayor pro Tem, William Metz
Councilman, Reno Bacciarini
Councilman, Wilson T. Prewett
Councilwoman, Evelyn H. DaRosa
City Attorney, John Hutton
City Clerk, Majorie Sarina
Police Chief, Daniel Givens
Fire Chief, Floyd Owens
Treasurer, William Dye

CITY OF KINGSBURG

(County of Fresno)

Incorporated May 19, 1908
Legislative Districts: 17th Congressional; 15th Senatorial; 31st Assembly
General law city. Population 5,094. Council meets first and third Mondays of month in City Hall, 1401 Draper St., 93631.
Central Telephone: 209-897-5821
Mayor: Gordon Satterberg
City Administrator, Vacant
Councilman, Lenn Henslee
Councilman, Steven C. Wigh
Councilman, J. Robert Lankford
Councilwoman, Sylvia S. Johnson
City Clerk-Treasurer, Frances Marks
Police Chief, Myron Galchutt
Fire Chief, Don Huddleston
City Attorney, Richard H. Hargrove and R. R. Campagna

CITY OF LA CAÑADA FLINTRIDGE

(County of Los Angeles)

Incorporated December 8, 1976
Legislative Districts: 22nd Congressional; 21st Senatorial; 42nd Assembly
General law city. Population 20,171
Council meets first and third Mondays, 7:30 p.m. La Canada High School Library, 4463 Oak Grove Dr., 91011
Central Telephone: 213-790-8880
Mayor: Edmund P. Krause
City Manager, George Caswell
Vice Mayor Barbara G. Pieper
Councilman, Thomas B. Curtis
Councilman, O. Warren Hillgren
Councilman, Michael C. Mount
City Attorney, J. Kenneth Brown
City Clerk, Patricia Anderson

CITY OF LAFAYETTE

(County of Contra Costa)

Incorporated July 29, 1968
Legislative Districts: 8th Congressional; 9th Senatorial; 12th Assembly
General law city. Population 19,628. Council meets second Monday of each month at 7:30 p.m., in the Veterans Memorial Building, 3491 Mt. Diablo Blvd.; City Mailing Address: 251 Lafayette Circle, 94549
Central Telephone: 415-284-1968
Mayor: William M. Chilcote
City Manager: Ernest C. Marriner
Councilman, LaVaughn A. Craig
Councilwoman, Gayle B. Uilkema
Councilman, Ned Robinson
Councilman, S. Thomas Cleveland

City Clerk, Ernest C. Marriner
City Attorney, Charles J. Williams

CITY OF LAGUNA BEACH

(County of Orange)

Incorporated June 29, 1927
Legislative Districts: 40th Congressional; 36th Senatorial; 74th Assembly
General law city. Population 17,800. Council meets first and third Tuesdays of month in City Hall Council Chambers, 505 Forest Ave., 92651.
Central Telephone: 714-497-3311
Mayor: Wayne J. Baglin
City Manager: Kenneth C. Frank

Councilmember, Neil Fitzpatrick
Councilmember, Sally R. Bellerue
Councilmember, Kelly H. Boyd
Councilmember, Howard D. Dawson
City Clerk, Verna L. Rollinger
Police Chief, Jon J. Sparks
Fire Chief, Charlie Kuhn
Treasurer, Frances S. Engelhardt
School Superintendent, Dr. Robert A. Sanchis

CITY OF LA HABRA

(County of Orange)

Incorporated January 20, 1925
Legislative Districts: 39th Congressional; 35th Senatorial; 69th Assembly
General law city. Population 45,750. Council meets first and third Tuesdays of month at 7:30 p.m. in Council Chambers, City Hall, Civic Center, 90631.
Central Telephone: 213-694-1011 or 714-526-2227
Mayor: Burton Ward
City Manager: Lee Risner

Mayor pro Tem, Earl C. Roget
Councilmember, John Holmberg
Councilmember, Vacant
Councilmember, Dorothy Wedel
City Clerk, Lee Risner
Police Chief, Ronald Meehan
Fire Chief, Verl Griffin
School Superintendent, Richard Hermann
City Attorney, Robert Hobson
Council reorganization end of 4/81

CITY OF LA HABRA HEIGHTS

(County of Los Angeles)

Incorporated December 4, 1978
Legislative Districts: 33rd Congressional; 33rd Senatorial; 64th Assembly
General law city. Population 5,300. Council meets second and fourth Thursdays of each month at 7:30 p.m. at City Hall, 1245 N. Hacienda Blvd.
Central Telephone: 213-694-6302
Mayor: Jean Good
City Manager: James E. Emmons

Mayor pro Tem, Gene Beckman
Councilman, Charles Wolfarth
Councilperson, Glenda Tuppan
Councilman, James Littlejohn
City Clerk, James E. Emmons
Treasurer, Ruth Morris
Fire Chief, Richard Jerome
Police Chief, subcontract from L.A.
City Attorney, Patrick Coughlan

CITY OF LAKE ELSINORE

(County of Riverside)

Incorporated April 20, 1888
Legislative Districts: 43rd Congressional; 38th Senatorial; 75th Assembly
General law city. Population 5,557. Council meets second and fourth Tuesdays of month at 7:30 p.m. in City Hall, 130 S. Main St., 92330.
Central Telephone: 714-674-3124
Mayor: Jerry Stewart
City Manager: Ira B. Pace

Councilman, John Unsworth
Councilman, Howie Torn
Councilman, Nap Harris
Councilman, Allen Baldwin
City Clerk, Florence Marshall
Building Inspector, Dwayne Frazier
Treasurer, Charles R. Morgan
School Superintendent, Dr. Denton Palmer
City Attorney, John M. Porter

CITY OF LAKEPORT

(County of Lake)

Incorporated April 30, 1888
Legislative Districts: 2nd Congressional; 2nd Senatorial; 2nd Assembly
General law city. Population 4,010. Council meets first and third Mondays of month in City Hall, 445 N. Main St., 95453.
Central Telephone: 707-263-5682
Mayor: Terry R. Norton

Mayor pro Tem, Gary L. Waterman
Councilmember, Alden H. Jones
Councilmember, John Dye
Councilmember, Karan Mackey
City Clerk, Bernice M. Hudson
Police Chief, James Campbell
Fire Chief, Donald DeBolt

CITY OF LAKEWOOD

(County of Los Angeles)

Incorporated April 16, 1954
Legislative Districts: 34th Congressional; 31st Senatorial; 57th and 58th Assembly
General law city. Population 83,900. Council meets second and fourth Tuesdays of month at 7:30 p.m. in City Council Chambers, 5050 Clark Ave., 90714.
Central Telephone: 213-866-9771

Mayor: Jacqueline Rynerson
City Administrator: Howard Chambers
Vice-Mayor, Larry Van Nostran
Councilmember, G. C. "Dee" DeBaun
Councilmember, Robert G. Wagner
Councilmember, Paul E. Zeltner
City Clerk, Joann Jelly
City Attorney, John S. Todd
City Treasurer, Nancy Hicks

CITY OF LA MESA

(County of San Diego)

Incorporated February 16, 1912
Legislative Districts: 41st Congressional; 39th Senatorial; 77th Assembly
General law city. Population 49,911. Council meets second and fourth Tuesdays of month in Council Chambers, City Hall, 8130 Allison Ave., 92041.
Central Telephone: 714-463-6611
Mayor: George F. Bailey
City Manager: Ronald E. Bradley
Councilman, Vacant
Councilman, Arthur E. Madrid
Councilman, Jerri Lopez
Councilman, Fred Nagel
City Clerk, Marie G. Mangan
Police Chief, Donald Fach
Fire Chief, Robert O. Sever
Treasurer, Kenneth W. Trent
City Attorney, LeRoy W. Knutson

CITY OF LA MIRADA

(County of Los Angeles)

Incorporated March 23, 1960
Legislative Districts: 33rd Congressional; 33rd Senatorial; 64th Assembly
General law city. Population 41,230. Council meets second and fourth Tuesdays of each month at 7:30 p.m. in Council Chambers, 13700 La Mirada Blvd., 90638.
Central Telephone: 213-943-0131
Mayor: Wayne Rew
City Administrator: Claude J. Klug
Mayor pro Tem, Lou Piltz
Councilman, Ben Ashley
Councilman, C. David Peters
Councilman, Wilfred L. Simendinger
City Clerk, Anna J. Martin

CITY OF LANCASTER

(County of Los Angeles)

Incorporated November 22, 1977
Legislative Districts: 18th Congressional; 16th Senatorial; 34th Assembly
General law city. Population 48,000. Council meets 1st Monday of each month at 7:00 p.m. in the Board Room at 44711 N. Cedar Avenue, 93534.
Central Telephone: 805-945-1811
Mayor: Fred M. Hann
City Administrator: Vern Lawson, Jr.
Vice Mayor, Jack Murphy
Councilman, Timothy Hayes
Councilman, Lou Bozigian
Councilman, Stan Kleiner
Police Chief, Captain Andrew Kuchta (L.A. County Sheriff)
Fire Chief, George Taylor (L.A. County)
School Superintendent, Dr. Lou Joseph
City Clerk, Christine Ellen Walters
City Attorney, Thomas J. Ward
City Council reorganization 5/81

CITY OF LA PALMA

(County of Orange)

Incorporated October 26, 1955
Legislative Districts: 38th Congressional; 37th Senatorial; 71st Assembly
General law city. Population 15,444. Council meets first and third Mondays of each month in Council Chambers, City Hall, 7822 Walker St., 90623.
Central Telephone: 714-523-7700
Mayor: Anthony E. van Dyke
City Manager: Vacant
Vice-Mayor, Daniel D. Collins
Councilman, Edward J. Byrne
Councilman, Ronald O. Nyborg
Councilman, Henry R. Frese
City Clerk, Ronald H. Dallas
Police Chief, Norman Hansen
City Attorney, Roger Grable

CITY OF LA PUENTE

(County of Los Angeles)

Incorporated August 1, 1956
Legislative Districts: 30th Congressional; 26th Senatorial; 60th Assembly
General law city. Population 30,550. Council meets second and fourth Tuesdays of month at 8:00 p.m. in City Hall, 15900 E. Main St., 91744
Central Telephone: 213-330-4511
Mayor: Louis F. Guzman
City Manager: Gordon L. Oehl
Mayor pro Tem, Allen J. Martin
Councilman, Gerald M. Singer
Councilman, Francis M. Palacio
Councilman, Charles H. Storing
City Clerk, Gordon L. Oehl
School Superintendent, Russell J. Ribb
City Attorney, Samuel Siegel

CITY OF LARKSPUR

(County of Marin)

Incorporated March 1, 1908
Legislative Districts: 5th Congressional; 2nd Senatorial; 9th Assembly
General law city. Population 12,500. Council meets first and third Wednesdays of month in

City Hall, 400 Magnolia Ave., 94939.
Central Telephone: 415-924-2405
Mayor: Donald L. Graff
City Manager: Harlan Barry
Vice-Mayor, Karen Kunze
Councilman, Charles H. Curley
Councilman, Alfred J. Malvino
Councilman, Michael Wornum
City Clerk, Nancy Anthony
Police Chief, Phillip D. Green
Fire Chief, Craig Shurtz
City Attorney, Joseph Forest

CITY OF LA VERNE

(County of Los Angeles)

Incorporated August 20, 1906
Legislative Districts: 35th Congressional; 25th Senatorial; 62nd Assembly
General law city. Population 23,500. Council meets first and third Mondays of month at 7:30 p.m. in City Hall, 3660 D St., 91750.
Central Telephone: 714-593-4571
Mayor: Frank R. Johnson
City Manager: Perry Beck
Mayor pro Tem, Robert T. Neher
Councilman, Jon Blickenstaff
Councilman, Vacant (3-2-81)
Councilman, Craig Walters
City Clerk, Kathy Hamm
Police Chief, Jack L. Baker
Fire Chief, Robert S. Lapp
Treasurer, Geraldine H. Peck

CITY OF LAWNDALE

(County of Los Angeles)

Incorporated December 28, 1959
Legislative Districts: 31st Congressional: 28th Senatorial; 53rd Assembly
General law city. Population 24,825. Council meets first and third Mondays of month at 7:30 p.m. in Council Chambers, City Hall, 14717 Burin Avenue, 90260.
Central Telephone: 213-973-4321
Mayor: Sarann Kruse
City Administrator: Brice Stephenson
Mayor pro Tem, Edward C. Roberts
Councilman, Harold Hofmann
Councilman, James Ramsey
Councilman, Calvin Ehinger
City Clerk, Lucille G. Eby
School Superintendent, Richard L. Moodey
City Treasurer, Joyce Catalde
City Attorney, Thomas Winfield, III

CITY OF LEMON GROVE

(County of San Diego)

Incorporated July 1, 1977
Legislative Districts: 42nd Congressional; 40th Senatorial; 79th Assembly
General law city. Population 21,200. Council meets 1st and 3rd Mondays of each month at 7:30 p.m. at Lemon Grove Community Center, 3146 School Lane, 92045.
Central Telephone: 714-464-6934
Mayor: James V. Dorman
City Manager: Jack D. Shelver
Vice Mayor, Robert F. Burns
Councilwoman, Lois M. Heiserman
Councilman, Jack Doherty
Councilman, Dell Lake
Police Chief, John Duffy
Fire Chief, Robert N. Adams
City Clerk-Treasurer, Karen Thomson
City Attorney, Donald F. McLean, Jr.

CITY OF LEMOORE

(County of Kings)

Incorporated August 4, 1900
Legislative Districts: 17th Congressional; 15th Senatorial; 32nd Assembly
General law city. Population 8,823. Council meets first and third Tuesdays of month at Council Chambers, City Hall, 119 Fox St., 93245.
Central Telephone: 209-924-5396
Mayor: James J. Forte
City Manager: William R. Drennen
Councilman, Donald W. Casten
Councilman, Larry E. Souza
Councilman, Tim Y. Lee
Councilwoman, Karen L. Nicks
City Clerk, Gloria Ornellas
Police Chief, William L. Young
Fire Chief, Russell Kreps
Treasurer, J. T. Armstrong
City Attorney, Lynn C. Atkinson

CITY OF LINCOLN

(County of Placer)

Incorporated August 7, 1890
Legislative Districts: 1st Congressional; 1st Senatorial; 3rd Assembly
General law city. Population 4,430. Council meets second and fourth Tuesdays of month in City Hall, Council Chambers, 511 5th Street, 95648
Central Telephone: 916-645-3314
Mayor: Michael McCartney
City Administrator: Lois Watts
Mayor pro Tem, Robert Flocchini
Councilmember, David Frausto
Councilmember, Leah Nevarez
Councilmember, Nello Stefani
City Clerk, Lois M. Watts
City Treasurer, Barbara Lyda
Police Chief, Bob Barroso
Fire Chief, A. S. Gulliford
School Superintendent, John Bozzo (Acting)

CITY OF LINDSAY

(County of Tulare)

Incorporated March 5, 1910

Legislative Districts: 17th Congressional; 15th Senatorial; 32nd Assembly

General law city. Population 6,575. Council meets third Monday of month in Council Chambers, City Hall, 251 E. Honolulu Street, 93247.

Central Telephone: 209-562-2511

Mayor: Jim Chapman

Vice-Mayor, Douglas Bodine
Councilman, Michael Lenihan
Councilman, Waymon Roberson
Councilman, Peggy Brown
City Clerk, ReDoy Kiesz
Public Safety Director (Fire & Police), John Beene
Treasurer, Loida Archbold
School Superintendent, Donald Schroeder
City Attorney, ReDoy Kiesz

CITY OF LIVE OAK

(County of Sutter)

Incorporated January 22, 1947

Legislative Districts: 4th Congressional; 1st Senatorial; 3rd Assembly

General law city. Population 2,112. Council meets first and third Wednesdays of month in City Hall, 9867 O Street, 95953.

Central Telephone: 916-695-2112

Mayor: Philip Peoples

Vice-Mayor, Leo Chesney
Councilman, Elmer Wussler
Councilman, Douglas Dollar
Councilman, Joseph C. Berry
City Clerk, Blanche Gillespie
Police Chief, contracted from Sutter County
Fire Chief, William N. Gillespie
Treasurer, Lucille Berry
School Superintendent, Donald Soli
City Attorney, John Sanbrook

CITY OF LIVERMORE

(County of Alameda)

Incorporated April 1, 1876

Legislative Districts: 9th Congressional; 8th Senatorial; 15th Assembly

General law city. Population 48,105. Council meets second and fourth Monday of month at 8 p.m. in Municipal Court Chambers, 39 So. Livermore Avenue. City Hall located at 1052 So. Livermore Avenue, 94550

Central Telephone: 415-449-4000

Mayor: Dale Turner
City Manager: Leland J. Horner

Councilman, Marshall Kamena
Councilman, John Staley
Councilman, Ayn Wieskamp
Councilman, Marlin J. Ebert
City Clerk, Carol Greany (Acting)
Police Chief, Mel Nelson
Fire Chief, Michael Sample
Treasurer, Fred Noyes, Jr.
School Superintendent, Leo R. Croce

CITY OF LIVINGSTON

(County of Merced)

Incorporated September 11, 1922

Legislative Districts: 15th Congressional; 14th Senatorial; 27th Assembly

General law city. Population 4,630. Council meets second and fourth Thursdays of month in Courthouse Chambers, 604 Third St., 95334.

Central Telephone: 209-394-8041

Mayor: Leonard C. Blevins
City Manager: Paul E. Lawrence

Mayor pro Tem, Frederick L. Worden
Councilman, Everett E. Beason
Councilman, John C. Morrison
Councilman, Lonnie K. Baker
City Clerk, Elwood E. Campini
Police Chief, Harold D. McKinney
Fire Chief, Virgil Quinn
Treasurer, Betty Cota.

CITY OF LODI

(County of San Joaquin)

Incorporated December 6, 1906

Legislative Districts: 14th Congressional; 13th Senatorial; 7th Assembly

General law city. Population 35,450. Council meets first and third Wednesdays of month at 8:00 p.m. in Council Chambers, City Hall, 221 W. Pine St., 95240.

Central Telephone: 209-334-5634

Mayor: Walter J. Katnich
City Manager: Henry A. Glaves, Jr.

Mayor pro Tem, James McCarty
Councilman, Richard L. Hughes
Councilman, James W. Pinkerton, Jr.
Councilman, Robert G. Murphy
City Clerk, Alice M. Reimche
Police Chief, Marcus P. Yates
Fire Chief, Vacant
School Superintendent, Ellerth E. Larson
City Attorney, Ronald M. Stein

CITY OF LOMA LINDA

(County of San Bernardino)

Incorporated September 29, 1970

Legislative Districts: 37th Congressional; 34th Senatorial; 67th Assembly

General law city. Population 10,000. Council meets second and fourth Tuesdays of each month in City Council Chambers, 11128 Anderson St., 92354.

Central Telephone: 714-796-2531

Mayor: Ardyce H. Koobs
City Manager: Robert R. Mitchell

Mayor pro Tem, Elmer J. Digneo

Councilman, T. Milford Harrison
Councilman, Norman H. Meyer
Councilwoman, Jeanne S. Wiesseman
Director of Public Safety, Peter R. Hills

CITY OF LOMITA

(County of Los Angeles)

Incorporated June 30, 1964
Legislative Districts: 32nd Congressional; 27th Senatorial; 52nd Assembly
General law city. Population 20,294.
Council meets first and third Mondays of each month at 7 p.m. at 24300 Narbonne Ave., 90717
Central Telephone: 213-325-7110
Mayor: Jerry Moore
City Administrator: Chris Rope

Mayor pro Tem: Hal Hall
Councilman, Hal Croyts
Councilman, Leonard Loy
Councilman, Charles Belba
City Clerk, Dawn Tomita
City Attorney, Lee Dolley

CITY OF LOMPOC

(County of Santa Barbara)

Incorporated August 13, 1888
Legislative Districts: 19th Congressional; 18th Senatorial; 35th Assembly
General law city. Population 26,750. Council meets first and third Tuesdays of month in Council Chamber, City Hall, 100 Civic Center Plaza, 93438.
Central Telephone: 805-736-1261
Mayor: Tom Green
City Administrator: Gene L. Wahlers

Councilman, Joe H. Valencia
Councilman, Andrew Salazar
Councilman, E. G. Stevens
Councilwoman, Charlotte Benton
City Clerk, Mineva Blades
Police Chief, James D. Smith
Fire Chief, Mike Ellison
City Attorney, David H. Hirsch

CITY OF LONG BEACH

(County of Los Angeles)

Incorporated December 13, 1897
Legislative Districts: 32nd and 34th Congressional; 31st Senatorial; 57th and 58th Assembly
Chartered city. Population 359,000. Council meets every Tuesday at 9 a.m. in Council Chambers, City Hall, 333 W. Ocean Blvd., 90802
Central Telephone: 213-590-6555
Mayor: Eunice Sato
City Manager: John E. Dever

Mayor pro Tem, Marc A. Wilder
Councilman, Dr. Thomas J. Clark
Councilwoman, Jan Hall
Councilman, Wallace Edgerton
Councilman, Ernie Kell
Councilman, James H. Wilson
Councilman, Edd Tuttle
Councilman, Russ Rubley
City Clerk, Shelba Powell
City Attorney, Robert Parkin
Police Chief, Charles Ussery
Fire Chief, Robert E. Leslie
City Auditor, Robert E. Fronke
City Prosecutor, John A. Vander Lans
School Superintendent, Dr. Francis Laufenberg

CITY OF LOS ALAMITOS

(County of Orange)

Incorporated March 1, 1960
Legislative Districts: 38th Congressional; 35th Senatorial; 71st and 73rd Assembly
Chartered city. Population 11,493. Council meets second and fourth Mondays of month at 7:00 p.m. in City Council Chambers, 3191 Katella, 90720.
Central Telephone: 213-431-3538
Mayor: Kenneth Zommick
City Manager: Michael A. Graziano

Mayor pro Tem, Charles E. Sylvia
Councilman Paul Bernal
Councilman, Tim Bunner
Councilman, David A. Lander
City Clerk, Michael A. Graziano
Police Chief, Kelson McDaniel
School Superintendent, Charles E. McCully
City Attorney, Thomas W. Allen

CITY OF LOS ALTOS

(County of Santa Clara)

Incorporated December 1, 1952
Legislative Districts: 12th Congressional 12th Senatorial; 21st and 22nd Assembly
General law city. Population 27,800. Council meets second and fourth Tuesdays of month at 8:00 p.m. in City Hall, 1 N. San Antonio Rd., 94022
Central Telephone: 415-948-1491
Mayor: Harry C. Kallshian
Chief Administrative Officer: S. George Sanregret

Councilman, Roger S.C. Eng
Councilman, Robert A. Grimm
Councilwoman, Jane B. Reed
Councilman, Roy E. Lave, Jr.
City Clerk, S. George Sanregret
Police Chief, Richard G. Brannan
Fire Chief, John T. Sanders

TOWN OF LOS ALTOS HILLS

(County of Santa Clara)

Incorporated January 27, 1956
Legislative Districts: 12th Congressional; 12th Senatorial; 22nd Assembly
General law city. Population 7,500. Council meets first and third Wednesdays of each month, 7:30 p.m. in

Town Hall, 26379 Fremont Road, 94022
Central Telephone: 415-941-7222
Mayor: James C. Nystrom
Town Manager: Robert E. Crowe
May pro Tem, David G. Proft
Councilwoman, Lucile Hillestad
Councilman, William A. Perkins
Councilman, Thomas P. McReynolds
Deputy Town Clerk, Patricia Dowd
Town Treasurer, Pearl C. Croy
Town Attorney, Frank Gillio

CITY OF LOS ANGELES

(County of Los Angeles)

Incorporated April 4, 1850
Legislative Districts: 20th–35th Congressional; 19th–33rd Senatorial; 57th–65th Assembly
Chartered city. Population 2,816,600. Council meets 10 a.m. daily in Room 340, City Hall, 200 N. Spring St., 90012.
Central Telephone: 213-485-2121
*Mayor: Thomas Bradley
City Administrative Officer: C. Erwin Piper
*Councilman, Zev Yaroslavsky
*Councilman, Bob Ronka
Councilman, Joel Wachs
*Councilman, Joy Picus
Councilman, John Ferraro
*Councilwoman, Peggy Stevenson
Councilwoman, Pat Russell
*Councilman, Ernani Bernardi
Councilman, Robert Farrell
*Councilman, Gilbert W. Lindsay
Councilman, Dave Cunningham
*Councilman, Marvin Braude
Councilman, Hal Bernson
Councilman, Arthur K. Snyder
*Councilman, John S. Gibson, Jr.
City Clerk, Rex E. Layton
*City Attorney, Burt Pines
Police Chief, Daryl Gates
Fire Chief, John C. Gerard
City Controller, Ira Reiner
School Superintendent, William J. Johnston
*Election 6/2/81

CITY OF LOS BANOS

(County of Merced)

Incorporated May 8, 1907
Legislative Districts: 15th Congressional; 14th Senatorial; 27th Assembly
General law city. Population 10,100. Council meets first and third Wednesdays in City Hall, 520 J St., 93635.
Central Telephone: 209-826-5119
Mayor: Philip R. Castellucci
City Manager: Loris T. Broddrick
Mayor pro Tem, Robert H. Lynn
Councilman, Elmer K. Austin
Councilman, Gerald "Obie" O'Brien
Councilwoman, Marjorie Robinson
City Clerk, Tesse J. Mazzina
Police Chief, Charles J. Martin
Fire Chief, Roland M. Pimentel
Treasurer, James J. Johnson
City Attorney, Donald O. Germino

TOWN OF LOS GATOS

(County of Santa Clara)

Incorporated August 10, 1887
Legislative Districts: 13th Congressional; 12th Senatorial; 22nd Assembly
General law city. Population 25,500. Council meets first and third Mondays of each month in Council Chambers, Town Hall, 110 E. Main St., 95030.
Central Telephone: 408-354-6833
Mayor: Thomas J. Ferrito
Town Manager: David R. Mora
Vice Mayor, Peter W. Siemens
Councilmember, Ruth Cannon
Councilmember, MarLyn J. Rasmussen
Councilmember, Brent N. Ventura
Town Clerk, Rose E. Aldag
Police Chief, Harold Johnson
Treasurer, James A. Stoops

CITY OF LOYALTON

(County of Sierra)

Incorporated September 21, 1901
Legislative Districts: 1st Congressional; 1st Senatorial; 3rd Assembly
General law city. Population 1,027. Council meets second and fourth Tuesdays of month at 7:00 p.m. in Council Chambers, City Hall, 96118.
Central Telephone: 916-993-4622
Mayor: Milton T. Gottardi
Vice Mayor, Robert McDonald
Councilman, Richard Powers
Councilwoman, Kathryne Peterson
Councilwoman, Pattie Fritz
City Clerk/Controller, Patsy Belli
Fire Chief, Joseph Marin
Treasurer, Edith Snider

CITY OF LYNWOOD

(County of Los Angeles)

Incorporated July 16, 1921
Legislative Districts: 31st Congressional; 28th Senatorial; 54th Assembly
General law city. Population 43,354. Council meets first and third Tuesdays of month at 7:30 p.m. in City Hall, 11330 Bullis Road, 90262.
Central Telephone: 213-638-8511
Mayor: Eugene R. Green
City Manager: James Weaver
Mayor pro Tem, John D. Byork
Councilman, Louis A. Thompson
Councilman, E. L. Morris

Councilman, James E. Rowe
City Clerk, Laurene Coffey
Fire Chief, Ronald Lathrope
Treasurer, Dave M. Richman

CITY OF MADERA

(County of Madera)

Incorporated March 27, 1907
Legislative Districts: 15th Congressional; 14th Senatorial; 30th Assembly
General law city. Population 21,675. Council meets first and third Mondays of month at 7:30 p.m. in City Hall, 205 W. 4th St., 93637.
Central Telephone: 209-674-8802
Mayor: Paul T. Sanders
City Administrator: Robert H. Kelley

Councilman, Edward J. Boyle
Councilwoman, Margaret M. Medellin
Councilman, Ralph V. Larsen
Councilman, Roy Ben Lyon
City Clerk, Edith J. Fischer
Police Chief, Gordon E. Skeels
Fire Chief, Larry Sunia
School Superintendent, Duane E. Furman
City Attorney, Axel E. Christiansen

CITY OF MANHATTAN BEACH

(County of Los Angeles)

Incorporated December 12, 1912
Legislative Districts: 27th Congressional; 27th Senatorial; 51st Assembly
General law city. Population 32,661. Council meets first and third Tuesdays of month at 7:30 p.m., City Hall located at 1400 Highland Ave., 90266.
Central Telephone: 213-545-5621
Mayor: Russell F. Lesser
City Manager: David J. Thompson

Mayor pro Tem, Michael W. Sweeney
Councilman, Stephen K. Blumberg
Councilman, Charles Robert Holmes
Councilman, William Switzer
City Clerk, John Allan Lacey
Police Chief, Harry Kuhlmeyer
Fire Chief, Tom P. Wilson
Treasurer, Duncan Kelly
School Superintendent, J. Byron Burgess
City Attorney, Carl K. Newton

CITY OF MANTECA

(County of San Joaquin)

Incorporated June 5, 1918
Legislative Districts: 14th Congressional; 13th Senatorial; 26th Assembly
General law city. Population 25,007. Council meets first and third Mondays in Council Chambers, City Hall, 1001 W. Center Street, 95336.
Central Telephone: 209-239-9511
Mayor: Trena T. Kelley
City Manager: Richard W. Jones

Vice Mayor, Jack C. Snyder
Councilmember, Walter Edwards
Councilmember, Chuck Shaefer
Councilmember, Bob Davis
City Clerk, Nell Cornell
Police Chief, Leonard Taylor
Fire Chief, Larry Drager
Treasurer, George Dadasovich
School Superintendent, Richard J. Cherry
City Attorney, John Brinton

CITY OF MARICOPA

(County of Kern)

Incorporated July 25, 1911
Legislative Districts: 18th Congressional; 16th Senatorial; 33rd Assembly
General law city. Population 764. Council meets first and third Wednesdays of month in City Hall, 93252.
Central Telephone: 805-769-8291
Mayor: Kennell W. Martin

Mayor pro Tem, James H. Wolfe
Councilman, Joe Kindred
Councilwoman, Mary Lu Princeton
Councilwoman, June "Penny" Johnson
City Clerk, Barbara Covington
Police Chief, L. Grant Grisedale
Fire Commissioner, Melvin Throop
School Superintendent, Wm. Meese
Acting City Treasurer, Barbara Covington

CITY OF MARINA

(County of Monterey)

Incorporated November 13, 1975
Legislative Districts: 16th Congressional; 17th Senatorial; 28th and 29th Assembly
General law city. Population 20,679. Council meets first and third Tuesdays of each month, Council Chambers, 211 Hillcrest Avenue, 93933.
Central Telephone: 408-384-5220
Mayor: Robert T. Ouye
City Manager: Douglas Flautt

Mayor pro Tem, George Takahashi
Councilwoman, Barbara Bird
Councilman, Paul Davis
Councilwoman, Drema Laden
City Clerk, Douglas Flautt
Public Safety Director, Vacant
City Planner, Robert Larsen
Treasurer, Douglas Flautt
Public Works Director, Vincent DiMaggio

CITY OF MARTINEZ

(County of Contra Costa)

Incorporated April 1, 1876
Legislative Districts: 7th Congressional; 7th Senatorial; 11th Assembly
General law city. Population 22,000. Council meets first

and third Wednesdays of month in City Hall, 525 Henrietta St., 94553.
Central Telephone: 415-372-4905
Mayor: Eric Schaefer
City Manager: Paul D. Brotzman
Vice-Mayor, H. Kenneth Dothee
Councilman, Charles Feyh
Councilman, James L. Thelen
Councilwoman, Diana Patrick
City Clerk, Lawrence J. Kowalski
Police Chief, Jack Garner
Treasurer, Josephine Heruth
School Superintendent, John D. Searles
City Attorney, Dennis Lee

CITY OF MARYSVILLE

(County of Yuba)

Incorporated February 5, 1851
Legislative Districts: 1st Congressional; 1st Senatorial; 3rd Assembly
Chartered city. Population 9,325. Council meets first and third Mondays of month in Council Chambers, City Hall, 526 "C" Street, 95901
Central Telephone: 916-674-6633
Mayor: John O. Blevins
Mayor pro Tem, Ronald A. Haedicke
Councilman, J. William Young
Councilman, William S. Huntley
Councilman, Robert M. Galligan
City Clerk, William A. Carlson
Police Chief, Harold A. Fischer
Fire Chief, Les Drehobl (Acting)
City Administrator, William A. Carlson
School Superintendent, George Smith

CITY OF MAYWOOD

(County of Los Angeles)

Incorporated September 2, 1924
Legislative Districts: 30th Congressional; 24th Senatorial; 56th Assembly
General law city. Population 16,996. Council meets second and fourth Tuesdays of month at 7:30 p.m. in Council Chambers, City Hall, 4319 E. Slauson Ave., 90270.
Central Telephone: 213-587-7281
Mayor: Robert E. Paltz
City Administrator: Leonard R. Locher
Mayor pro Tem, William A. Hamilton
Councilman, Stephen Hegstrom
Councilwoman, Betty Lou Rogers
Councilwoman, Rose Marie Busciglio
City Clerk, Leonard R. Locher
Police Chief, Theodore R. Heidke
City Treasurer, Ruth S. Hogrefe
City Attorney, E. Edward Dilkes

CITY OF McFARLAND

(County of Kern)

Incorporated July 18, 1957
Legislative Districts: 18th Congressional; 15th Senatorial; 32nd Assembly
General law city. Population 4,881. Council meets second Thursday of each month at 7:30 p.m. in City Hall Council Chambers, 401 West Kern, 93250.
Central Telephone: 805-792-3091
Mayor: Donnie Campbell
Mayor pro Tem, Carl Boston
Councilwoman, Ruth Patterson
Councilman, Leon Shults
Councilman, Ruben Garza, Jr.
City Administrator, Vacant
Police Chief, Raynaldo Flores
City Clerk, Doris L. Wood

CITY OF MENDOTA

(County of Fresno)

Incorporated June 17, 1942
Legislative Districts: 15th Congressional; 14th Senatorial; 30th Assembly
General law city. Population 4,840. Council meets second and fourth Tuesdays of month at 7:00 p.m. in City Hall, 643 Quince Street, 93640.
Central Telephone: 209-655-3291
Mayor: Leo Capuchino
City Administrator: Paul Owhadi
Councilman, Victor Lozano
Councilman, Russell Long
Councilman, Fidel De La Cruz
Councilman, Vacant
City Clerk, J. La Rae White
Police Chief, Silverio Sanchez
Fire Chief, Ken Strickland
Treasurer, Leticia Allison
School Superintendent, Alfred Negrete

CITY OF MENLO PARK

(County of San Mateo)

Incorporated November 23, 1927
Legislative Districts: 11th and 12th Congressional; 10th Senatorial; 20th and 21st Assembly
General law city. Population 26,826. Council meets second and fourth Tuesdays of month in Council Chambers, 701 Laurel St., 94025.
Central Telephone: 415-325-3211
Mayor: Billy Ray White
City Manager: Michael A. Bedwell
Mayor pro Tem, *Vacant
Councilman, Gerry B. Andeen
Councilman, Douglas W. Dupen
Councilman, Peg Gunn
City Clerk, Margaret E. Snowden
Police Chief, Gerald E. McNamara
Fire Chief, Vincent Del Pozzo
City Attorney, John D. Jorgenson
* June election

CITY OF MERCED

(County of Merced)

Incorporated April 1, 1889
Legislative Districts: 15th Congressional; 14th Senatorial; 27th Assembly
Chartered city. Population 36,424. Council meets first and third Mondays of month in City Hall, 18th and "M" Sts., 95344.
Central Telephone: 209-722-4131
Mayor: Robert L. Hart
City Manager: Allan R. Schell

Mayor pro Tem, Carol Gabriault
Councilman, Tom Archer
Councilman, Samuel C. Pipes
Councilman, Norman Herman
Councilman, Joseph G. Trudel, Jr.
Councilwoman, Carolyn Goings
City Clerk, Allan R. Schell
Police Chief, Harold Kulbeth
Fire Chief, Joe W. Ortiz
School Superintendent, Vacant
City Attorney, Steven F. Nord

CITY OF MILLBRAE

(County of San Mateo)

Incorporated January 14, 1948
Legislative Districts: 11th Congressional; 6th Senatorial; 19th Assembly
General law city. Population 21,250. Council meets second and fourth Tuesdays of month in Council Chambers, City Hall, 621 Magnolia Ave., 94030.
Central Telephone: 415-877-3954
Mayor: Arthur Lepore
City Administrator: William Huston

Vice Mayor, Tullio Bertini
Councilman, Mary Griffin
Councilman, Paul Van Iderstine
Councilman, Frank T. Cannizzaro
City Clerk, Marie McKechnie
Police Chief, John Dineen
Fire Chief, Michael P. Dolder
Treasurer, Daniel F. Quigg
School Superintendent, Dr. Edward J. Muehlhausen
City Attorney, Frank Gillio

CITY OF MILL VALLEY

(County of Marin)

Incorporated September 4, 1900
Legislative Districts: 5th Congressional; 2nd Senatorial; 9th Assembly
General law city. Population 12,716. Council meets first and third Mondays of each month in Council Chambers, City Hall, 26 Corte Madera Ave., 94941.
Central Telephone: 415-388-4033
Mayor: Joan Boessenecker
City Manager: Vernon Hazen

Councilman, Douglas Binderup
Councilman, Richard Spotswood
Councilwoman, Flora Praszker
Councilman, John Jaeger
City Clerk, Elaine Carry
City Treasurer, John Tweedie
Fire and Police Services Director, William Walsh
School Superintendent, Byron Mauzy (Interim)
City Attorney, Leland Jordan

CITY OF MILPITAS

(County of Santa Clara)

Incorporated January 26, 1954
Legislative Districts: 10th Congressional; 11th Senatorial; 25th Assembly
General law city. Population 36,412. Council meets first and third Tuesdays of each month in City Hall, 455 E. Calaveras Blvd., 95035.
Central Telephone: 408-262-2310
Mayor: Peter A. "Primo" McHugh
City Manager: John L. Maltbie

Mayor pro Tem, James Rodgers
Councilman, Philip James (Jim) Bargabus
Councilman, Gilbert Gonzalez
Councilman, Elwood "EJ" Johnson
City Clerk, W. E. Smith
Police Chief, James B. Murray
Fire Chief, Michael N. Harwood
School Superintendent, Richard P. Mesa
City Treasurer, W. E. Smith
City Attorney, Haskell M. Goodman

CITY OF MODESTO

(County of Stanislaus)

Incorporated August 6, 1884
Legislative Districts: 14th and 15th Congressional; 13th and 14th Senatorial; 26th and 27th Assembly
Chartered city. Population 103,400. Council meets first and third Tuesdays at 4:00 p.m. and second and fourth Tuesdays at 7:30 p.m. in Council Chambers, City Hall, 801 11th St., 95353.
Central Telephone: 209-577-5200
Mayor: Peggy Mensinger
City Manager: Garth Lipsky

Councilmember, Sue Siefkin
Councilmember, Tom Bright
Councilmember, Richard A. Lang
Councilmember, Frank Muratore
Councilmember, Richard Patterson
Councilmember, Robert T. Elliott
City Clerk, Norrine Coyle
Police Chief, Gerald McKinsey
Fire Chief, Bruce Simons
School Superintendent, Robert C. Otto

CITY OF MONROVIA

(County of Los Angeles)

Incorporated December 15, 1887
Legislative Districts: 26th Congressional; 25th Senatorial; 61st Assembly

General law city. Population 30,015. Council meets first and third Tuesdays of month in City Hall, 415 S. Ivy Ave., 91016.
Central Telephone: 213-359-3231
Mayor: Paul Stuart
City Manager: Robert Ovrom

Mayor pro Tem, Robert Bartlett
Councilman, Eric Faith
Councilwoman, Mary Wilcox
Councilman, Ed Zoolalian
City Clerk, Patricia Ostrye
Police Chief, Billie Tubbs
Fire Chief, George Kahl
Treasurer, Hilda Herb
School Superintendent, Gwen Collier

CITY OF MONTAGUE

(County of Siskiyou)

Incorporated January 28, 1909
Legislative Districts: 1st Congressional; 1st Senatorial; 1st Assembly
General law city. Population 890. Council meets first and third Thursdays each month at 7:30 p.m. in City Hall, 1030 13th St., 96064.
Central Telephone: 916-459-3030
Mayor: Walter Bray

Councilman, Carl Carlson
Councilman, Glenn Ruddell
Councilman, Vacant
Councilman, Trudi Soli
City Clerk, Gloria Jean Jones
Police Chief, Chris Vasquez
Fire Chief, Gene Frost
Treasurer, Alta C. Coatney
School Superintendent, Richard A. Woodruff

CITY OF MONTCLAIR

(County of San Bernardino)

Incorporated April 25, 1956
Legislative Districts: 35th Congressional; 32nd Senatorial; 65th Assembly
General law city. Population 22,400. Council meets first and third Mondays of month in City Hall, 5111 Benito St., 91763.
Central Telephone: 714-626-8571
Mayor: Harold M. Hayes
City Administrator: G. Michael Milhiser

Mayor pro Tem, William Nelson Gentry
Councilman, Walter H. Hackett, Jr.
Councilman, George C. Klotz
Councilman, Leonard Paulitz
City Clerk, Gertrude L. Hill
Police Chief, Roger M. Moulton
Fire Chief, Harold G. Duncan
City Attorney, Eugene A. Demchuk

CITY OF MONTEBELLO

(County of Los Angeles)

Incorporated October 16, 1920
Legislative Districts: 30th Congressional; 26th Senatorial; 59th Assembly
General law city. Population 50,000. Council meets second and fourth Mondays of month at 7:30 p.m. in City Hall, 1600 Beverly Blvd., 90640.
Central Telephone: 213-725-1200
Mayor: Art Payan
City Administrator: Joseph Goeden

Mayor pro Tem, Richard M. Tafoya
Councilman, Phillip M. Ramos
Councilman, Richard M. Tafoya
Councilman, William O. Nighswonger
City Clerk, Andrew T. Lambo
Police Chief, Les Sourisseau
Fire Chief, Robert King
Treasurer, Phillip J. Pace

CITY OF MONTEREY

(County of Monterey)

Incorporated June 14, 1889
Legislative Districts: 16th Congressional; 17th Senatorial; 28th Assembly
Chartered city. Population 27,700. Council meets first and third Tuesdays of month in Council Chambers, Few Memorial Hall of Records, 93940.
Central Telephone: 408-646-3750
Mayor: Gerald T. Fry
City Manager: John O. Dunn

Councilman, Dan Albert
Councilman, Louis B. Gold
Councilman, Theodore Hooker
Councilman, Alvin Andrus
City Clerk, Patricia O'Hearn
Police Chief, Harold Benadom
Fire Chief, John Montenero
School Superintendent, James Harrison
City Attorney, William C. Marsh

CITY OF MONTEREY PARK

(County of Los Angeles)

Incorporated May 29, 1916
Legislative Districts: 30th Congressional; 26th Senatorial; 59th Assembly
General law city. Population 54,298. Countil meets second and fourth Mondays of month at 7:30 p.m. in Council Chambers, City Hall, 320 W. Newmark Ave., 91754.
Central Telephone: 213-573-1211
Mayor: Louise Davis
City Manager: Lloyd R. deLlamas

Mayor pro Tem, G. Monty Manibog
Councilman, George W. Westphaln
*Councilman, Vacant
Councilman, Harry E. Couch
City Clerk, Theresa M. Amador
Police Chief, Jon Elder
Fire Chief, Harry Greenland

Treasurer, George Ige
City Attorney, Norman Lieberman
*election 6/81

CITY OF MONTE SERENO

(County of Santa Clara)

Incorporated May 14, 1957
Legislative Districts: 13th Congressional; 12th Senatorial; 22nd Assembly
General law city. Population 3,388. Council meets first and third Tuesdays each month in Red Cross Chapter House, 18011 Saratoga-Los Gatos Rd., 95030.
Central Telephone: 408-354-7635
Mayor: William C. Short
City Administrator: Donald C. Wimberly

Vice Mayor, Barbara F. Winckler
Councilman, John F. Foley
Councilman, John J. Cody
Councilman, James P. Burgard
City Clerk, Fay Furtado
City Engineer, Donald C. Wimberly
City Attorney, Frank Gillio
City Treasurer, Howard Asp

TOWN OF MORAGA

(County of Contra Costa)

Incorporated November 13, 1974
Legislative Districts: 8th Congressional; 9th Senatorial; 12th Assembly
General law city. Population 15,000. Council meets first, third and fifth Wednesdays of each month at Joaquin Moraga Intermediate School, 1010 Camino Pablo, 94556.
Central Telephone: 415-376-5200
Mayor: Michael T. Cory

Vice-Mayor, William G. Combs
Councilman, John W. Fowler
Councilman, Barry R. Gross
Councilwoman, Margaret DePriester
Town Clerk, Gary C. Chase
Treasurer, Gary E. Irwin
Fire Chief, Donald Skinner
Police Chief, Lawrence G. Olson
School Superintendent, Dr. Harold J. Maves

CITY OF MORGAN HILL

(County of Santa Clara)

Incorporated November 10, 1906
Legislative Districts: 13th Congressional; 11th Senatorial; 24th Assembly
General law city. Population 16,600. Council meets first and third Wednesdays of month in Council Chambers, Civic Center, 17555 Peak Avenue, 95037.
Central Telephone: Administration 408-779-7271
Mayor: Neil Heiman
City Manager: Charles R. Cate

Councilwoman, Beth Wyman
Councilman, Steve Pearson
Councilman, Daniel C. Bertelli
Councilman, Jeff Pederson
City Clerk, Madge W. Soares
Police Chief, William S. Dodeward
Fire Chief, Bradley R. Spencer
School Superintendent, Robert Stannard
City Treasurer, Betty G. Busk
City Attorney, Walter V. Hays

CITY OF MORRO BAY

(County of San Luis Obispo)

Incorporated July 17, 1964
Legislative Districts: 16th Congressional; 17th Senatorial; 29th Assembly
General law city. Population 9,078. Council meets second and fourth Mondays at City Recreation Hall, Dunes St. and Shasta Ave., 93442.
Central Telephone: 805-772-1214
Mayor: Warren M. Dorn
City Administrator: Paul Baxter

Mayor pro Tem, John Lemons
Councilman, Rodger Anderson
Councilwoman, Dorotha Deutsch
Councilwoman, Herminia Ward
City Clerk, Paul Baxter
Police Chief, Al Olson
Fire Chief, Bernard Zerr
City Attorney, Michael T. LeSage

CITY OF MOUNTAIN VIEW

(County of Santa Clara)

Incorporated November 7, 1902
Legislative Districts: 12th Congressional; 10th Senatorial; 21st and 22nd Assembly
Chartered city. Population 59,500. Council meets the second and last Mondays of each month at 7:30 p.m. in City Hall, 540 Castro St., 94041.
Central Telephone: 415-966-6305
Mayor: Marilyn S. Perry
City Manager: Bruce W. Liedstrand

Vice-Mayor, Patricia Figueroa
Councilman, Richard J. Wilmuth
Councilwoman, Angelo Frosolone
Councilman, Leslie C. Nichols
Councilman, Ronald D. Packard
Councilman, Matthew A. Allen
City Clerk, Alice Roylance
Police Chief, Robert K. Schatz
Fire Chief, Robert Burns
City Attorney, Peter D. Bulens

CITY OF MT. SHASTA

(County of Siskiyou)

Incorporated May 31, 1905
Legislative Districts: 1st Congressional; 1st Senatorial; 1st Assembly
General law city. Population 2,832. Council meets

second and fourth Mondays of the month in City Hall, 305 N. Mt. Shasta Blvd., 96067.
Central Telephone: 916-926-2141
Mayor: Charles D. Seeley
Councilmember, Richard Derwingson
Councilmember, Jack Smith
Councilmember, Clarice Vacent
Councilmember, Dennis Engdahl
City Clerk, Gino Marconi
Police Chief, Harold L. Barnum
Fire Chief, Frank Melo
Treasurer, Everett V. Lee
City Attorney, David E. Otis

CITY OF NAPA

(County of Napa)

Incorporated March 23, 1872
Legislative Districts: 2nd Congressional; 4th Senatorial; 8th Assembly
Chartered city. Population 49,892. Council meets first and third Tuesdays of month in City Hall, 955 School St., 94558.
Central Telephone: 707-252-7711
Mayor: Phyllis Moore
City Manager: William L. Bopf
Councilman, Alan R. Young
Councilman, Floyd E. Stone
Councilwoman, Dorothy G. Searcy
Councilman, Leonard A. Austin
City Clerk, Allen R. Thorpe, CMC
Police Chief, Kenneth D. Jennings
Fire Chief, Milton Ochs
City Attorney, Malcolm A. Mackenzie

CITY OF NATIONAL CITY

(County of San Diego)

Incorporated July 28, 1887
Legislative Districts: 42nd Congressional; 40th Senatorial; 80th Assembly
General law city. Population 48,567. Council meets first four Tuesdays of month in Council Chambers, 1243 National City Blvd., 92050.
Central Telephone: 714-477-1181
Mayor: Kile Morgan
City Manager: Tom G. McCabe
Vice-Mayor, Jess E. Van Deventer
Councilman, George H. Waters
Councilman, J. Louis Camacho
Councilman, Michael R. Dalla
City Clerk, Ione Campbell
Police Chief, Terry E. Hart
Fire Chief, Richard Bridges
Treasurer, Ida Mae H. Kerr

CITY OF NEEDLES

(County of San Bernardino)

Incorporated October 30, 1913
Legislative Districts: 37th Congressional; 16th Senatorial; 34th Assembly
Chartered city. Population 4,115. Council meets first and third Mondays of month at 7:30 p.m. in Council Chambers, City Hall, 92363.
Central Telephone: 714-326-2113
Mayor: Huey M. O'Dell
City Manager: Vernon Bailey
Mayor pro Tem, David B. Daniel
Councilwoman, Shirley Lackey
Councilman, Leon O. Willman
Councilman, Robert G. Prochaska
Councilwoman, Louise T. Corey
Councilman, Peter F. Dwyer
City Clerk, Vernon Bailey
Police Chief, Bruce Weekley
Fire Chief, Herb Eberhardt
School Superintendent, Anthony Johnson

CITY OF NEVADA CITY

(County of Nevada)

Incorporated April 19, 1856
Legislative Districts: 1st Congressional; 1st Senatorial; 3rd Assembly
General law city. Population 2,451. Council meets second Monday of month at 7 p.m. in Council Chambers, City Hall, 317 Broad St., 95959.
Central Telephone: 916-265-2496
Mayor: Paul J. Matson
City Manager: Beryl P. Robinson, Jr.
Councilman, Lynn Bramkamp, Jr.
Councilman, Ernest J. Pello
Councilman, James A. Moon
Councilwoman, Cathy Wilcox-Barnes
City Clerk, Judy A. Schwein
Police Chief, Billy E. Beard
Fire Chief, Doug Towne
Treasurer, Jack P. Gooch
City Attorney, James P. Young

CITY OF NEWARK

(County of Alameda)

Incorporated September 22, 1955
Legislative Districts: 10th Congressional; 11th Senatorial; 25th Assembly
General law city. Population 30,898. Council meets second and fourth Thursdays at 8 p.m. in Council Chambers, 37101 Newark Blvd., 94560.
Central Telephone: 415-793-1400
Mayor: David W. Smith
City Manager: Richard W. Turnlund
Mayor pro Tem, Shirley D. Sisk
Councilman, Jerry C. Foster
Councilman, Louis M. Cortez
Councilman, Alan L. Nagy
City Clerk, A. T. Huezo
Police Chief, Carl W. Pierce
Fire Chief, F. Preston Spalding
School Superintendent, Evelyn Kipp
City Attorney, Anthony J. Garcia

CITY OF NEWMAN

(County of Stanislaus)

Incorporated June 10, 1908
Legislative Districts: 14th Congressional; 14th Senatorial; 27th Assembly
General law city. Population 2,590. Council meets second and fourth Tuesdays of month, 7:30 p.m., City-County Bldg., 1200 O St., 95360.
Central Telephone: 209-862-3725
Mayor: Hurd Barrington, Jr.
City Manager: Leslie L. Doolittle

Mayor pro Tem, Robert C. Bagley
Councilmember, Janet H. Carlsen
Councilmember, Frank M. Dompe, Jr.
Councilmember, Glee C. William
City Clerk, Leslie L. Doolittle
Police Chief, Thomas W. Engstrom
Fire Chief, Thomas W. Powell
Treasurer, Ray S. Wade
School Superintendent, Robert Fisher
City Attorney, Harold R. Densmore

CITY OF NEWPORT BEACH

(County of Orange)

Incorporated September 1, 1906
Legislative Districts: 40th Congressional; 36th Senatorial; 74th Assembly
Chartered city. Population 65,750. Council meets second and fourth Mondays of month at 7:30 p.m., City Hall, 3300 Newport Blvd., 92663.
Central Telephone: 714-640-2251
Mayor: Jacqueline E. Heather
City Manager: Robert L. Wynn

Mayor pro Tem, Evelyn R. Hart
Councilwoman, Ruthelyn Plummer
Councilman, Philip R. Maurer
Councilman, John C. Cox, Jr.
Councilman, Paul L. Hummel
Councilman, Donald A. Strauss
City Clerk, Wanda E. Andersen
Police Chief, Charles Gross
Fire Chief, Jim Reed
City Attorney, Hugh R. Coffin

CITY OF NORCO

(County of Riverside)

Incorporated December 28, 1964
Legislative Districts: 36th Congressional; 34th Senatorial; 68th Assembly
General law city. Population 20,976. Council meets first and third Wednesdays of each month at 7:30 p.m. at 3954 Old Hamner Ave., 91760.
Central Telephone: 714-735-3900
Mayor: Naomi R. Feagan
City Manager: Robert L. Williams (Interim)

Mayor pro Tem, Steve M. Nathan
Councilman, Lori Gregg
Councilman, F. R. "Phil" Jones
Councilman, Ron Wildfong
City Clerk, Muriel A. Ruthrauff
Fire Chief, Donald L. Johnson

CITY OF NORWALK

(County of Los Angeles)

Incorporated August 26, 1957
Legislative Districts: 33rd Congressional; 33rd Senatorial; 63rd Assembly
General law city. Population 91,827. Council meets second and fourth Mondays, 7:30 p.m., in City Hall, 12700 Norwalk Blvd., 90650.
Central Telephone: 213-868-3254
Mayor: Cecil N. Green
City Administrator: William H. Kraus

Mayor pro Tem, John Zimmerman, Jr.
Councilman, Robert E. White
Councilwoman, Margaret I. Nelson
Councilman, Arthur F. Gerdes
City Clerk, William H. Kraus
City Attorney, J. Kenneth Brown

CITY OF NOVATO

(County of Marin)

Incorporated January 20, 1960
Legislative Districts: 5th Congressional; 2nd Senatorial; 9th Assembly
General law city. Population 42,620. Council meets first and third Tuesdays of month in Council Chambers, Machin and DeLong Sts., 94947.
Central Telephone: 415-897-6111
Mayor: Frank U'ren
City Manager: Phillip J. Brown

Mayor pro Tem, Robert Stockwell
Councilman, Ernest Gray
Councilman, Susan Stompe
Councilman, Hugh Turner
City Clerk, Peggy Lehigh
Police Chief, William Kirkpatrick
Fire Chief, James Berthenier
School Superintendent, Ron Franklin

CITY OF OAKDALE

(County of Stanislaus)

Incorporated November 24, 1906
Legislative Districts: 14th Congressional; 13th Senatorial; 26th Assembly
General law city. Population 8,500. Council meets first and third Mondays of month at 7 p.m. in Council Chambers, City Hall, 280 N. 3rd Avenue, 95361.
Central Telephone: 209-847-3031
Mayor: Eldon L. Kitterman
City Administrator: Michael W. Huse

Mayor pro Tem, Robert C. Chicou
Councilman, Robert E. Chicou
Councilman, Elmo Garcia
Councilman, Robert E. Wikoff
City Clerk, Rebecca A. Peluso

Police Chief, David Sundy
Fire Chief, Jack Criswell
Treasurer, Roche J. Husing
School Superintendent, Rodger Irvine

CITY OF OAKLAND

(County of Alameda)

Incorporated May 4, 1852

Legislative Districts: 8th and 9th Congressional; 8th and 9th Senatorial; 12th through 14th Assembly

Chartered city. Population 362,100. Council meets Tuesdays at 7:30 p.m. in City Hall, 14th and Washington Streets, 94612.
Central Telephone: 415-444-2489

Mayor: Lionel J. Wilson
City Manager: David A. Self

Councilman, Marge Gibson
Councilman, Carter Gilmore
Councilman, Frank H. Ogawa
Councilman, Wilson Riles, Jr.
Councilman, Dick Spees
Councilman, Mary Moore
Councilman, Dr. Raymond L. Eng
Councilman, John Sutter
City Clerk, Arrece Jameson
Police Chief, George T. Hart
Fire Chief, Walter Pierson
City Auditor, Norma Ng Lau
School Superintendent, Ruth Love

CITY OF OCEANSIDE

(County of San Diego)

Incorporated July 3, 1888

Legislative Districts: 40th and 43rd Congressional; 36th and 38th Senatorial; 74th and 76th Assembly

General law city. Population 77,800. Council meets second and fourth Wednesdays of month at 9:00 a.m. in Council Chambers, 323 N. Nevada St., 92054.
Central Telephone: 714-439-7300

Mayor: Lawrence Bagley
City Manager: Robert S. Bourcier

Deputy Mayor, John Casey
Councilman, Ray Burgess
Councilwoman, Melba Bishop
Councilman, William Bell
City Clerk, Barbara Bishop
Police Chief, Rolf A. Henze
Fire Chief, Jack W. Rosenquist
Treasurer, Earl H. "Ted" Ritz
School Superintendent, Roderic V. Moore
City Attorney, Charles Revlett

CITY OF OJAI

(County of Ventura)

Incorporated August 5, 1921

Legislative Districts: 19th Congressional; 18th Senatorial; 36th Assembly

General law city. Population 6,425. Council meets second and fourth Tuesdays of month at 7:30 p.m. in City Hall, 401 S. Ventura St., 93023.
Central Telephone: 805-646-5581

Mayor: Derald Chisum
City Manager: Carl Hatfield, Jr.

Mayor pro Tem, Frank McDevitt
Councilman, James D. Loebl
Councilman, John F. Fay
Councilwoman, Katherine Van Dellen
City Clerk, Cyndi Reynolds
Police Chief, Vincent France
School Superintendent, Dr. Albert Marley

CITY OF ONTARIO

(County of San Bernardino)

Incorporated December 10, 1891

Legislative Districts: 35th Congressional; 32nd Senatorial; 65th Assembly

General law city. Population 87,800. Council meets first and third Tuesdays of month in Council Chambers, City Hall, 303 East "B" Street, 91764.
Central Telephone: 714-986-1151

Mayor: R. E. Ellingwood
City Manager: Roger Hughbanks

Mayor pro Tem, Faye Myers Dastrup
Councilman, Homer F. Briggs
Councilman, Robert K. Abel
Councilman, Beecher Medlin
City Clerk, De Loris E. Arterburn
Police Chief, Leroy Kolbrek
Fire Chief, David Lee
Treasurer, Kenneth Keenly

CITY OF ORANGE

(County of Orange)

Incorporated April 6, 1888

Legislative Districts: 39th Congressional; 35th Senatorial; 70th Assembly

General law city. Population 87,900. Council meets second, third, and fourth Tuesdays of month at 4:00 p.m. and 7:00 p.m. in Council Chambers, Civic Center, 300 E. Chapman Ave., 92666.
Central Telephone: 714-532-0341

Mayor: James H. Beam
City Manager: Joseph N. Baker

Mayor pro Tem, Don E. Smith
Councilman, Fred L. Barrera
Councilman, Eugene Beyer
Councilman, Jess F. Perez
City Clerk, Marilyn J. Jensen
Police Chief, vacant
Fire Chief, Harold Bougher
Treasurer, Lorraine Schade
School Superintendent, Donald W. Ingwerson
City Attorney, Furman B. Roberts

CITY OF ORANGE COVE

(County of Fresno)

Incorporated January 20, 1948
Legislative Districts: 17th Congressional; 15th Senatorial; 31st Assembly
General law city. Population 3,801. Council meets second and fourth Wednesdays of month in City Hall, 555 Sixth St., 93646.
Central Telephone: 209-626-4488
Mayor: Victor P. Lopez
City Administrator: Ismael Rodriquez

Mayor pro Tem, Roy Rodriguez
Councilman, Claude D. Holt
Councilman, Eugene E. Pinedo
Councilman, Olegano Villarreal
City Clerk, Patricia A. Riley
Fire Chief, Mose C. Story
City Attorney, Ernest H. Tuttle

CITY OF ORLAND

(County of Glenn)

Incorporated November 11, 1909
Legislative Districts: 1st Congressional; 1st Senatorial; 1st Assembly
General law city. Population 3,973. Council meets second and fourth Mondays of each month at 8 p.m. in Carnegie Community Center, 912 Third Street, 95963.
Central Telephone: 916-865-4741
Mayor: Bette J. Schmidt

Councilwoman, Anne H. Rucker
Councilman, James D. Millert
Councilman, Dave Gomez
Councilman, Larry Hefty
City Clerk, Myra Trammel
Police Chief, William R. Gilcrease
Fire Chief, Robert Holvik
Treasurer, Sharon N. Schmidt
School Superintendent, Charles J. Hahn
City Attorney, Angus I. Saint-Evens

CITY OF OROVILLE

(County of Butte)

Incorporated January 3, 1906
Legislative Districts: 1st Congressional; 1st Senatorial; 1st and 3rd Assembly
Chartered city. Population 8,350. Council meets first and third Monday at 8:00 p.m. and 7:30 p.m. respectively, in Council Chambers, City Hall, 1735 Montgomery St., 95965.
Central Telephone: 916-533-9551
Mayor: Clayton W. D'Arcy
City Administrator: David M. Jinkens

Vice-Mayor, Jana Wilson
Councilman, R. Wayne Houseworth
Councilman, Harold Pietz
Councilman, Norman Roberts
Councilman, James A. Rossas
City Clerk, David M. Jinkens
Police Chief, Jan R. Duke
Fire Chief, Eugene W. Ludwig
Treasurer, Harold Kroeger
City Attorney, Charles F. Lueder

CITY OF OXNARD

(County of Ventura)

Incorporated June 30, 1903
Legislative Districts: 19th and 20th Congressional; 18th Senatorial; 36th Assembly
General law city. Population 102,100. Council meets first four Tuesdays of month at 1:30 p.m. and 7:30 p.m. in Council Chambers, City Hall, 305 W. Third St., 93030.
Central Telephone: 805-486-4311
Mayor: Dr. Tsujio Kato
Acting City Manager: Steven A. Cook

Mayor pro Tem, Manuel M. Lopez
Councilwoman, Dorothy S. Maron
Councilman, Nao Takasugi
Councilman, R. Blinn Maxwell
City Clerk, Miss Mabi Covarrubias
Police Chief, Robert P. Owens
Fire Chief, Henry A. Gustafson
Treasurer, Robert De La Cruz
City Attorney, K. Duane Lyders

CITY OF PACIFICA

(County of San Mateo)

Incorporated November 22, 1957
Legislative Districts: 11th Congressional; 6th Senatorial; 19th Assembly
General law city. Population 39,000. Council meets second and fourth Mondays of each month at 8:00 p.m. in Council Chambers, Sewage Treatment Plant, 2212 Beach Blvd.
City Hall located at 170 Santa Maria Ave., 94044.
Central Telephone: 415-877-8600
Mayor: Ellie McGuire Clark
City Manager: Gul Ramchandani (Acting)

Mayor pro Tem, Fred Howard
Councilmember, Ginny Silva Jaquith
Councilmember, Stanley M. Farber
Councilmember, Peter Murray
City Clerk, Gul Ramchandani (Acting)
Police Chief, Anthony Guardino
Fire Chief, Calvin Hinton

CITY OF PACIFIC GROVE

(County of Monterey)

Incorporated July 5, 1889
Legislative Districts: 16th Congressional; 17th Senatorial; 28th Assembly
Chartered city. Population 18,005. Council meets first and third Wednesdays of month in Council Chambers, City Hall, 300 Forest Avenue, 93950.
Central Telephone: 408-375-9861
Mayor: Florus C. Williams
City Manager: Gary W. Bales

Councilmember, Madelyn A. Sloan

Councilmember, Kris Franco
Councilmember, Don Martine
Councilmember, Morris Fisher
Councilmember, James R. Hughes
Councilmember, David J. Eaton
City Clerk, William S. Pitt
Police Chief, John Matteson
Fire Chief, Donald T. Gasperson
School Superintendent, Troy E. Bramlett
City Attorney, Theodore G. Morris

CITY OF PALMDALE

(County of Los Angeles)

Incorporated August 24, 1962
Legislative Districts: 18th Congressional; 16th Senatorial; 34th Assembly
General law city. Population 12,773. Council meets second Thursday of each month at 7:30 p.m. in Council Chambers, Palmdale City Hall, 708 East Palmdale Blvd., 93550.
Central Telephone: 805-273-3162
Mayor: Lynda Cook
City Administrator: Patrick K. Rossall

Vice-Mayor, Antonio Soza
Councilman, Harry Shaw
Councilman, Bob St. Clair
Councilman, Earl Sherburn
City Clerk, Patrick K. Rossall
City Attorney, James S. Kostas

CITY OF PALM DESERT

(County of Riverside)

Incorporated November 26, 1973
Legislative Districts: 37th Congressional; 38th Senatorial; 75th Assembly
General law city. Population 14,145. Council meets second and fourth Thursdays at 7:00 p.m. in Council Chambers, City Hall, 45-275 Prickly Pear Lane, 92260.
Central Telephone: 714-346-0611
Mayor: S. Roy Wilson
City Manager: Martin J. Bouman

Mayor pro Tem, Alexis D. Newbrander
Councilman, James E. McPherson
Councilman, Walter H. Snyder
Councilman, Romeo S. Puluqi
City Clerk, Sheila Gilligan
Police Chief, Contract Out
Fire Chief, Contract Out

CITY OF PALM SPRINGS

(County of Riverside)

Incorporated April 20, 1938
Legislative Districts: 37th Congressional; 38th Senatorial; 75th Assembly
General law city. Population 36,150. Council meets first and third Wednesdays of each month in Council Chambers, City Hall, 3200 Tahquitz-McCallum Way, P.O. Box 1786, 92263.
Central Telephone: 714-323-8201
Mayor: John F. Doyle
City Manager: Norm King

Mayor pro Tem, Elliot Field
Councilman, Robert Rose
Councilwoman, Vyola Ortner
Councilman, Russell Beirich
City Clerk, Norm King
Police Chief, Thomas Kendra
Fire Chief, Byron Chaney
School Superintendent, Larry Rutan
City Treasurer, Dallas Flicek
City Attorney, William Adams

CITY OF PALO ALTO

(County of Santa Clara)

Incorporated April 23, 1894
Legislative Districts: 12th Congressional; 10th Senatorial; 21st Assembly
Chartered city. Population 54,100. Council meets the first four Mondays of month at 7:30 p.m. in City Hall, 250 Hamilton Ave., 94301.
Central Telephone: 415-329-2571
*Mayor: Alan Henderson
City Manager: William Zaner

*Vice Mayor, Ellen Fletcher
Councilmember, Betsy Bechtel
Councilmember, Fred S. Eyerly
Councilmember, Gary P. Fazzino
Councilmember, Leland D. Levy
Councilmember, Emily M. Renzel
Councilmember, Anne R. Witherspoon
Councilmember, Vacant
City Clerk, Ann J. Tanner
Police Chief, James Zurcher
Fire Chief, Robert Wall (Acting)
School Superintendent, Dr. Newman Walker
City Attorney, Roy Abrams
*will change 7/1/81
General municipal election 11/3/81

CITY OF PALOS VERDES ESTATES

(County of Los Angeles)

Incorporated December 20, 1939
Legislative Districts: 27th Congressional; 27th Senatorial; 51st Assembly
General law city. Population 15,101. Council meets second and fourth Tuesdays of month at 7:30 p.m. in City Hall, 340 Palos Verdes Drive W., 90274.
Central Telephone: 213-378-0383
Mayor: Robert A. Welbourn
City Manager: Thomas A. Devereux

Mayor pro Tem, Jack F. Duston
Councilman, Edward Ritscher
Councilwoman, Barbara Culver
Councilman, Ronald Florance
City Clerk, Mary Waldo
Police Chief, John E. Dollarhide
Fire Chief, Richard Wendt

Treasurer, Hazel L. Elder
City Attorney, Mark C. Allen, Jr.

TOWN OF PARADISE

(County of Butte)

Incorporated November 27, 1979

Legislative Districts: 1st Congressional; 1st Senatorial; 3rd Assembly

General law city. Population 23,400. Council meets first and third Wednesday of each month at 7:30 p.m. in Town Hall, 5555 Skyway, 95969.
Central Telephone: 916-872-8696

Mayor: Warren H. Humbert
Town Manager: Hal C. Nelson

Vice Mayor: Dona D. Gavagan
Councilman, William S. Holding
Councilwoman, Alice R. Smith
Councilman, Dr. William R. Taylor
Police Chief, Gary J. Lester
Fire Chief, James P. Gilpatrick
Town Clerk, Donna M. Matteis
Town Attorney, Alan E. Burchett

CITY OF PARAMOUNT

(County of Los Angeles)

Incorporated January 30, 1957

Legislative Districts: 31st Congressional; 28th Senatorial; 54th Assembly

General law city. Population 38,000. Council meets first Tuesday of each month in City Hall, 16400 South Colorado Ave., 90723.
Central Telephone: 213-634-2123

Mayor: Charles R. Weldon
City Manager: William A. Holt

Vice-Mayor: Gerald A. Mulrooney
Councilman, Cornelius Boogaard
Councilwoman, Esther Caldwell
Councilman, Ted J. Mosier
City Clerk, William A. Holt
City Attorney, Maurice F. O'Shea

CITY OF PARLIER

(County of Fresno)

Incorporated November 15, 1921

Legislative Districts: 17th Congressional; 15th Senatorial; 31st Assembly

General law city. Population 2,080. Council meets first and third Tuesdays of month in City Hall, 580 Tulare St., 93648.
Central Telephone: 209-646-2767

Mayor: Raul S. Martinez

Mayor pro Tem, Pedro Cortez
Councilman, Albert Rodriquez
Councilman, Arcadio Viveros
Councilman, Armando Lopez
City Clerk, Ofelia Garcia
Police Chief, Joe B. Anaya
Fire Chief, Vacant
School Superintendent, Leo S. Cardona

CITY OF PASADENA

(County of Los Angeles)

Incorporated June 19, 1886

Legislative Districts: 22nd and 26th Congressional; 21st Senatorial; 42nd Assembly

Chartered city. Population 117,861. Directors meet every Tuesday in Council Chamber, Room 242, City Hall, 100 North Garfield Ave., 91109.
Central Telephone: 213-577-4000

Mayor: Jo Heckman
City Manager: Donald F. McIntyre

Vice Mayor, Loretta T. Glickman
Councilman, William J. "Bill" Bogaard
Councilman, no name submitted
Councilman, no name submitted
Councilman, John Crowley
Councilman: Stephen Acker
City Clerk, Harriett C. Jenkins
Police Chief, Robert H. McGowan
Fire Chief, James Shern
School Superintendent, Ramon C. Cortines
City Attorney, Evelynn M. Finn

CITY OF PASO ROBLES (EL PASO DE ROBLES)

(County of San Luis Obispo)

Incorporated March 11, 1889

Legislative Districts: 16th Congressional; 17th Senatorial; 29th Assembly

General law city. Population 9,133. Council meets first and third Tuesdays of month at 7:30 p.m. in Council Chambers, City Hall, 1030 Spring St., 93446.
Central Telephone: 805-238-1515

Mayor: Barney Schwartz
City Manager: Donald B. Keefer

Mayor pro Tem, Terry Minshull
Councilman, Orville Monroe
Councilman, Kenny Parish
Councilman, Gary Stemper
City Clerk, Donald B. Keefer
Police Chief, Vernon L. Mathison
Fire Chief, John A. Steaffens
Treasurer, Sidney J. Godsey
School Superintendent, William J. James
City Attorney, Michael T. LeSage

CITY OF PATTERSON

(County of Stanislaus)

Incorporated December 24, 1919

Legislative Districts: 14th Congressional; 14th Senatorial; 27th Assembly

General law city. Population 4,031. Council meets first and third Tuesdays of month at 7:30 p.m. in City Hall, 344 W. Las Palmas Ave., 95363.
Central Telephone: 209-892-2041

Mayor: Pat D. Maisetti
City Manager: Peter M. Milcovich

Mayor pro Tem, Phil Breasher
Councilman, Eusebio Cuellar
Councilman, J. Wade Bingham
Councilman, John Ramos
Police Chief, Lewis Ruddick
Fire Chief, Richard Gaiser
School Superintendent, Robert Lorentz
City Attorney, Harold Densmore

CITY OF PERRIS

(County of Riverside)

Incorporated May 26, 1911

Legislative Districts: 37th and 43rd Congressional; 34th Senatorial; 67th Assembly

General law city. Population 6,675. Council meets second and last Mondays of month at 7:30 p.m. in Council Chambers, City Hall, 101 N. D St., 92370.
Central Telephone: 714-657-5115

Mayor: Floyd T. Johnson
City Manager: Robert L. Briscoe

Vice-Mayor, James H. Adams
Councilwoman, Carmen Cox
Councilwoman, Pauline L. Rusher
Councilman, Joseph Beckley
City Clerk, Beti An Hynes
Police Chief, Aubrey Clayton
Fire Chief, Maurice LeBlanc
City Attorney, Ralph DeMichael

CITY OF PETALUMA

(County of Sonoma)

Incorporated April 12, 1858

Legislative Districts: 2nd and 5th Congressional; 2nd Senatorial; 9th Assembly

Chartered city. Population 32,923. Council meets first and third Mondays of month in Council Chambers City Hall, 94952.
Central Telephone: 707-763-2613

Mayor: Fred V. Mattei
City Manager: Robert H. Meyer

Vice-Mayor, Albert L. Battaglia
Councilman, John W. Cavanagh, Jr.
Councilman, G. Roland Bond
Councilman, John Balshaw
Councilman, James L. Harberson
Councilman, William A. Perry, Jr.
City Clerk, Patricia E. Bernard
Police Chief, Robert B. Murphy
Fire Chief, Robert Sharps
School Superintendent, John Gyves

Election 6/2/81 for 3 council seats and Mayor

CITY OF PICO RIVERA

(County of Los Angeles)

Incorporated January 29, 1958

Legislative Districts: 30th Congressional; 26th Senatorial; 59th Assembly

General law city. Population 53,303. Council meets first and third Mondays at 7:30 p.m. in City Hall 6615 Passons Blvd., 90660.
Central Telephone: 213-692-0401

Mayor: John G. Chavez
City Manager: John W. Donlevy

Mayor pro Tem, Garth G. Gardner
Councilman, James M. Patronite
Councilman, Frank Terrazas
Councilman, William J. Loehr
City Clerk, John W. Donlevy

CITY OF PIEDMONT

(County of Alameda)

Incorporated January 31, 1907

Legislative Districts: 8th Congressional; 9th Senatorial; 12th Assembly

Chartered city. Population 10,505. Council meets first and third Mondays of month in City Hall, 120 Vista Ave., 94611.
Central Telephone: 415-273-2000

Mayor: Steve Eigenberg
City Administrator: John D. Nolan

Vice-Mayor, Connie Shapiro
Councilwoman, Alice Creason
Councilwoman, Helen Herbert
Councilman, Ted Normart
Police Chief, Craig Steckler
Fire Chief, Leroy J. Phillips
School Superintendent, Walter Hale
City Attorney, George Peyton
City Clerk, John D. Nolan

CITY OF PINOLE

(County of Contra Costa)

Incorporated June 25, 1903

Legislative Districts: 7th Congressional; 7th Senatorial; 11th Assembly

General law city. Population 14,288. Council meets first and third Mondays of month at 8:00 p.m. in Council Chambers, City Hall, 2131 Pear St., 94564.
Central Telephone: 415-724-9000

Mayor: Ann Hansen
City Manager: Donald E. Bradley

Mayor pro Tem, Michael D. Baer
Councilmember, Thomas P. Cutino
Councilmember, John F. Goularte, Sr.
Councilmember, Anna E. McCarty
City Clerk, Elizabeth Grimes
Police Chief, Theodore A. Barnes
Fire Chief, Alex A. Clark
Treasurer, Margaret M. Berg
City Attorney, David J. Levy

CITY OF PISMO BEACH

(County of San Luis Obispo)

Incorporated April 25, 1946

Legislative Districts: 19th Congressional; 17th Senatorial; 29th Assembly

General law city. Population 5,200. Council meets second and fourth Mondays of month in City Hall, 1000 Bello St., 93449.
Central Telephone: 805-773-4657

Mayor: Nebb Eldwayen
City Administrator: Wayne H. Hoereth

Mayor pro Tem, Bob Carter
Councilwoman, Grace S. Dillon
Councilman, Bill Richardson, Jr.
Councilwoman, Marian Mellow
City Clerk, Marion L. Houston
Police Chief, Edward C. Williams
Fire Chief, Jon Frudden
School Superintendent, Robert G. Hoagland
Treasurer, Marion L. Houston

CITY OF PITTSBURG

(County of Contra Costa)

Incorporated June 25, 1903

Legislative Districts: 7th Congressional; 7th Senatorial; 10th Assembly

General law city. Population 32,623. Council meets first and third Mondays of month at 8:00 p.m. at 65 Civic Dr., 94565.
Central Telephone: 415-439-4850

Mayor: Frank R. Quesada
City Manager: S. Anthony Donato

Mayor pro Tem, Joseph S. Siino
Councilman, Ronald P. Rives
Councilman, Joseph L. DeTorres
Councilman, Ralph E. Downing
City Clerk, Mary Erbez
Police Chief, Leonard F. Castiglione
Treasurer, John R. Garcia

CITY OF PLACENTIA

(County of Orange)

Incorporated December 2, 1926

Legislative Districts: 39th Congressional; 35th Senatorial; 69th and 70th Assembly

Chartered city. Population 35,300. Council meets first and third Tuesdays of month in Council Chambers, 401 East Chapman Ave., 92670.
Central Telephone: 714-993-8231

Mayor: Norman Z. Eckenrode
City Administrator: Edwin T. Powell

Mayor pro Tem, Donald A. Holt
*Councilmember, Richard Acton
Councilmember, Peter Laborde
*Councilmember, Betty Mead
City Clerk, Doris B. Black
Police Chief, Norman A. Traub
Treasurer, Victor J. Michel

*Recall action pending

CITY OF PLACERVILLE

(County of El Dorado)

Incorporated May 13, 1854

Legislative Districts: 14th Congressional; 13th Senatorial; 7th Assembly

General law city. Population 7,225. Council meets second and fourth Tuesdays of month at 549 Main Street (Town Hall). City Hall Office, 487 Main St., 95667
Central Telephone: 916-622-3515

Mayor: James J. McIntire
City Administrator: Lee Yarborough

Councilman, Carl A. Borelli
Councilman, Allen H. Tuttle
Councilman, Thomas J. Sullivan
Councilwoman, Karen K. Tustin
City Clerk-Finance Director, Lennie L. Mills
City Attorney, Daryl McKinstry
Police Chief, Ted J. Mertens
Fire Chief, Albert G. Herzig
Treasurer, J. Leo Barrett

CITY OF PLEASANT HILL

(County of Contra Costa)

Incorporated November 14, 1961

Legislative Districts: 7th Congressional: 7th Senatorial; 11th Assembly

General law city. Population 25,342. Council meets first, third and fourth Mondays of each month at 7:30 p.m. in Council Chamber, City Hall, 3300 N. Main St., 94523.
Central Telephone: 415-934-6050

Mayor: John J. Mulhall
City Manager: James L. Alkire

Vice-Mayor, Oliver L. Holmes
Councilman, James G. Clarke
Councilman, Paul L. Cooper
Councilwoman, Dione Mustard
City Clerk, Wetona L. Crawford
Treasurer, J. Joan Butterfield
Police Chief, James R. Nunes
Fire Chief, William Maxfield
City Attorney, Dennis A. Lee

CITY OF PLEASANTON

(County of Alameda)

Incorporated June 18, 1894

Legislative Districts: 9th Congressional; 8th Senatorial; 15th Assembly

General law city. Population 34,383. Council meets second and fourth Tuesdays at 8:00 p.m., at Alameda County Fairgrounds Cafeteria, Pleasanton
Central Telephone: 415-846-3202

Mayor: Kenneth R. Mercer
City Manager: James R. Walker

Vice Mayor, Walter C. Wood
Councilman, Robert E. Butler
Councilman, Stanley L. Kephart
Councilmember, Karin Mohr
City Clerk, James R. Walker
Police Chief, Walter J. McCloud

Fire Chief, Joseph B. Hill
Director of Public Works, Robert Warnick
City Treasurer, John Wipfli
School Superintendent, William Berck

CITY OF PLYMOUTH

(County of Amador)

Incorporated February 8, 1917
Legislative Districts: 14th Congressional; 13th Senatorial; 7th Assembly
General law city. Population 690. Council meets second Thursday of month at 7:30 p.m. in City Hall, 95669.
Central Telephone: 209-245-6941
Mayor: Irene Cranford

Councilman, Ed Fulton
Councilman, Jack Tallman
Councilman, Wayne Holland
Councilman, Patricia Shackleton
City Clerk, Juanita Wilson
Fire Chief, Wayne Holland
Treasurer, Gloria Stoddard
City Attorney, Kristine Cazadd

CITY OF POINT ARENA

(County of Mendocino)

Incorporated July 11, 1908
Legislative Districts: 2nd Congressional; 2nd Senatorial; 2nd Assembly
General law city. Population 526. Council meets second and fourth Tuesdays of month in City Hall, 247 Main St., 95468.
Central Telephone: 707-882-2334
Mayor: F. S. Withrow

Councilman, John C. Ayres
Councilman, Billy M. Eastwood
Councilman, Joseph Scaramella
Councilman, William R. Robinson
City Clerk, Mary Spangler
Fire Chief, Fred Morgan
Treasurer, Floy Seymour
City Attorney, Robert C. Petersen

CITY OF POMONA

(County of Los Angeles)

Incorporated January 6, 1888
Legislative Districts: 33rd and 35th Congressional; 25th, 32nd, and 33rd Senatorial; 62nd, 64th, and 65th Assembly
Chartered city. Population 87,384. Council meets each Monday evening, 8 p.m., Council Chambers, City Hall, 505 S. Garey, 91769.
Central Telephone: 714-620-2341
Mayor: Adrian T. Wright
City Administrator: Ora E. Lampman

Vice Mayor, G. Stanton Selby
Councilman, E. J. Gaulding
Councilman, C. L. "Clay" Bryant
City Clerk, L. B. Thomas
Police Chief, Richard A. Slaght
Fire Chief, John M. Fowlkes
School Superintendent, Dr. Charles Carpenter
City Attorney, Patrick J. Sampson

CITY OF PORTERVILLE

(County of Tulare)

Incorporated May 7, 1902
Legislative Districts: 17th Congressional; 15th Senatorial; 32nd Assembly
Chartered city. Population 19,450. Council meets first and third Tuesdays of month in Council Chambers, City Hall, 291 North Main Street, 93257.
Central Telephone: 209-784-1400
Mayor: Mary Dougherty
City Manager: C. G. Huffaker

Mayor pro Tem, Aline Moran
Councilman, Clyde Ferrell
Councilman, Steven Tree
Councilman, Dennis Durbin
City Clerk, C. G. Huffaker
Police Chief, John Smith
Fire Chief, Ralph C. Beard
School Superintendent, Jacob Rankin

CITY OF PORT HUENEME

(County of Ventura)

Incorporated March 24, 1948
Legislative Districts: 20th Congressional; 18th Senatorial; 36th Assembly
General law city. Population 18,500. Council meets second and fourth Wednesdays of month in Council Chambers, 250 N. Ventura Road, 93041.
Central Telephone: 805-488-3625
Mayor: Dorill B. Wright
City Manager: John R. Velthoen

Mayor pro Tem, Benjamin L. Talbot
Councilman, Harold E. Wade
Councilman, Dean Green
Councilman, Herbert C. Templeman
City Clerk, Sue T. Harmon
Police Chief, Robert Anderson

CITY OF PORTOLA

(County of Plumas)

Incorporated May 16, 1946
Legislative Districts: 1st Congressional; 1st Senatorial; 1st Assembly
General law city. Population 1,890. Council meets first and third Mondays of month in City Hall, Gulling St., 96122.
Central Telephone: 916-832-4216
Mayor: Thomas Hervey

Councilman, J. R. Riehm
Councilman, Coleman Montgomery
Councilman, William Frerking, Jr.
Councilman, Glenn Howard
City Clerk, Maraha L. Lake

Fire Chief, Curtis Marshall
City Treasurer, Hugh G. Arnold
City Attorney, Robert Roney

TOWN OF PORTOLA VALLEY

(County of San Mateo)

Incorporated July 14, 1964

Legislative Districts: 12th Congressional; 10th Senatorial; 20th Assembly

General law city. Population 4,996. Council meets second Wednesday of month at Town Hall, 765 Portola Road, 94025.

Central Telephone: 415-851-1700

Mayor: Nancy Robertson
City Administrator: Linda Craig

Vice-Mayor, Jon C. Silver
Councilman, Kent Mitchell
Councilwoman, Patti Williams
Councilman, Robert V. Brown
Town Clerk, Linda Craig
Fire Chief, Stanley B. Larsen
School Superintendent, Del Alberti
Town Attorney, James T. Morton

CITY OF POWAY

(County of San Diego)

Incorporated December 1, 1980

Legislative Districts: 43rd Congressional; 38th Senatorial; 76th Assembly

General law city. Population 37,000. Council meets every Tuesday at 7:00 p.m. at City Hall, 13325 Remlap Way, 92064

Central Telephone: 714-748-3935

Mayor: Robert C. Emery
City Manager: James L. Bowersox

Councilmember, Clyde E. Rexrode
Councilmember, Bruce J. Tarzy
Councilmember, Linda L. Oravec
Councilmember, Mary L. Shepardson
City Clerk, Marjorie K. Wahlsten
City Attorney, Jean Leonard Harris
Fire Chief, William B. Bond

CITY OF RANCHO CUCAMONGA

(County of San Bernardino)

Incorporated November 30, 1977

Legislative Districts: 35th Congressional; 32nd Senatorial; 65th and 66th Assembly

General law city. Population 54,708. Council meets first and third Wednesdays of month at 7:00 p.m. at Lion's Park Community Building, 9161 Baseline Road, 91730.

Central Telephone: 714-989-1851

Mayor: Phillip D. Schlosser
City Manager: Lauren M. Wasserman

Councilman, James C. Frost
Councilman, Jon Mikels
Councilman, Michael Palombo
Councilman, Arthur H. Bridge
Sheriff's Captain, Tom Wickum
Fire Chief, Robert Lee
City Attorney, Samuel Crowe

CITY OF RANCHO MIRAGE

(County of Riverside)

Incorporated August 3, 1973

Legislative Districts: 37th Congressional; 38th Senatorial; 75th Assembly

General law city. Population 8,225. Council meets first and third Thursdays of each month at 6:30 p.m. in City Hall, 92270.

Central Telephone: 714-324-4511

Mayor: Michael S. Wolfson

Mayor pro Tem, Harold T. Jones
Councilman, C. Robert Hubbard
Councilman, Harold T. Jones
Councilman, William C. Hannon
City Manager, David F. Dixon
City Clerk, Barbara E. Dohn
City Treasurer, Henry Sherman
Police Chief, Ben Clark
Fire Chief, Bruce Cowie
City Attorney, George W. Wakefield

CITY OF RANCHO PALOS VERDES

(County of Los Angeles)

Incorporated September 7, 1973

Legislative Districts: 27th Congressional; 27th Senatorial; 51st Assembly

General law city. Population 30,940. Council meets first and third Tuesdays of month in Council Chambers, 30942 Hawthorne Boulevard.

Mayor: Barbara Hein
City Manager: Donald F. Guluzzy

Mayor pro Tem, Jacki Bacharach
Councilwoman, Ann Shaw
Councilman, Ken Dyda
Councilman, Robert Ryan

CITY OF RED BLUFF

(County of Tehama)

Incorporated March 31, 1876

Legislative Districts: 1st Congressional; 1st Senatorial; 1st Assembly

General law city. Population 8,933. Council meets first Tuesday of month in Council Chambers, City Hall, 555 Washington St., 96080.

Central Telephone: 916-527-2605

Mayor: Jay A. Barber, Jr.
City Manager: Herbert E. Nelson

Councilman, Ryan Sale
Councilman, Chet Christensen
Councilman, James H. Moore
Councilman, Forrest Flynn
City Clerk, Catherine I. Bunting

Police Chief, Marion L. Clay
Fire Chief, Tom Gauthier
Treasurer, Charles Hayden
School Superintendent, Edward A. Murphy
City Attorney, C. A. Stromsness

CITY OF REDDING

(County of Shasta)

Incorporated October 4, 1887
Legislative Districts: 1st Congressional; 1st Senatorial; 1st Assembly
General law city. Population 43,350. Council meets first and third Mondays of month, 7:00 p.m., Police Dept. and Council Chambers Bldg., 1313 California St., 96001. Business Office: City Hall, 760 Parkview, 96001.
Central Telephone: 916-246-1151
Mayor: Archer F. Pugh
City Manager: William M. Brickwood
Councilman, Lee D. Fulton, M.D.
Councilman, Howard D. Kirkpatrick
Councilman, Donald M. Demsher
Councilwoman, Barbara Allen Gard
City Clerk, Mildred L. Brayton
Police Chief, Robert H. Whitmer
Fire Chief, Kenneth A. Erichsrud
Treasurer, Pauline J. Brown

CITY OF REDLANDS

(County of San Bernardino)

Incorporated December 7, 1888
Legislative Districts: 37th Congressional; 34th Senatorial; 67th Assembly
General law city. Population 43,484. Council meets first and third Tuesdays of month in Council Chambers, Safety Hall, 212 Brookside Ave., Mailing Address P.O. Box 280, 92373.
Central Telephone: 714-793-2641
Mayor: Charles G. DeMirjyn
City Manager: Chris C. Christiansen
Vice-Mayor, James W. Gorman
Councilman, Oddie J. Martinez, Jr.
Councilman, Ken Roth
*Councilman, Barbara Cram Riordan
City Clerk, Peggy A. Moseley
Police Chief, Robert Brickley
Fire Chief, Raymond B. Mills
Treasurer, J. Michael Reynolds
School Superintendent, Dr. Warren F. Bryld
City Attorney, Edward F. Taylor
*Prefers title "Councilman"

CITY OF REDONDO BEACH

(County of Los Angeles)

Incorporated April 29, 1892
Legislative Districts: 27th Congressional; 27th Senatorial; 51st Assembly
Chartered city. Population 59,000. City Council meets each Monday, 7:30 p.m., in Council Chambers, City Hall, 415 Diamond St., 90277.
Central Telephone: 213-372-1171
*Mayor: David K. Hayward
City Manager: David P. Dolter
Councilman, Jerry Goddard
*Councilman, James Ebben
Councilman, Morgan McSweeney
Councilman, Archie Snow
Councilman, Gene King
City Clerk, Fred M. Arnold
City Attorney, Gordon Phillips
Police Chief, Frank V. Meehan
Fire Chief, James Black
Treasurer, Alice E. DeLong
* Run off Election May 12, 1981

CITY OF REDWOOD CITY

(County of San Mateo)

Incorporated March 27, 1868
Legislative Districts: 11th and 12th Congressional; 10th Senatorial; 20th Assembly
Chartered city. Population 55,750. Council meets on the first four Mondays of each month at 7:30 p.m. in the Board of Supervisors Chambers, 401 Marshall Street, City Hall, 1017 Middlefield Road, 94063.
Central Telephone: 415-369-6251
Mayor: Mario Biagi
City Manager: James M. Fales, Jr.
Vice-Mayor, William J. Stangel
Councilman, Brenton C. Britschgi
Councilman, Robert H. Bury
Councilman, Marguerite Leipzig
Councilman, Bill Rhodes
Councilman, Gerald R. Chandler
City Clerk, Jacqueline C. Hildebrand
Police Chief, George Bold
Fire Chief, Peter O'Brien
Scho Superintendent, Dr. Ralph Wilson
City Attorney, David E. Schricker
Finance Director, Jack Ference

CITY OF REEDLEY

(County of Fresno)

Incorporated February 18, 1913
Legislative Districts: 17th Congressional; 15th Senatorial; 31st Assembly
General law city. Population 9,045. Council meets first and third Tuesdays of month in City Hall, 845 G St., 93654.
Central Telephone: 209-638-6881
Mayor: Lawrence R. Wilder
City Manager: G. Lawrence Rihl
Councilman, Charles Y. Taguchi
Councilman, Ronald H. Nishinaka
Councilman, Harvey D. Pamelton
Councilman, Emery L. Huebert
City Clerk, Raymond L. Medcalf
Police Chief, Forrest Brown
Fire Chief, E. L. Remy
Treasurer, George Everett

CITY OF RIALTO

(County of San Bernardino)

Incorporated November 17, 1911

Legislative Districts: 36th Congressional; 32nd Senatorial; 66th Assembly

General law city. Population 37,048. Council meets first and third Tuesdays of month at 7:00 p.m. in Council Chambers, City Hall, 150 S. Palm Ave., 92376.

Mayor: Gerald R. Eaves
City Administrator: Walter Pudinski

Mayor pro Tem, Marvin T. Sawyer
Councilman, Richard H. Holland
Councilman, John Longville
Councilman, Sam V. Curtis
City Clerk, Joseph H. Sampson
Police Chief, Raymond E. Farmer
Fire Chief, Roger L. Purdie
Treasurer, Betty M. Taggart

CITY OF RICHMOND

(County of Contra Costa)

Incorporated August 7, 1905

Legislative Districts: 7th Congressional; 7th Senatorial; 11th Assembly

Chartered city. Population 79,043. Council meets every Monday, 8 p.m., in Council Chambers, City Hall, Civic Center Plaza 94804.

Mayor: Thomas J. Corcoran
City Manager: Joseph Salvato

Councilman, Lonnie C. Washington, Jr.
Councilman, Nathaniel Bates
Councilman, Albert E. Silva
Councilman, George Livingston
Councilman, Don Greco
Councilman, Don Wagerman
Councilman, Vacant
City Clerk, Harlan J. Heydon
Police Chief, Leo Garfield
Fire Chief, Charles Schwab
School Superintendent, Richard Lovette

CITY OF RIDGECREST

(County of Kern)

Incorporated November 29, 1963

Legislative Districts: 18th Congressional; 16th Senatorial; 34th Assembly

General law city. Population 15,700. Council meets first and third Wednesdays of each month in City Hall, 139 Balsam Street, 93555.
Central Telephone: 714-375-1321

Mayor: Harold J. Hockett
City Administrator: William L. Eichenberg

Councilman, Jeffery D. Grossman
Councilwoman, Anna-Marie Bergens
Councilwoman, Brenda B. Burnett
Councilman, Ron Cheshire
City Clerk, Jacqueline C. Reed
Police Chief, Robert G. Norman
City Attorney, Daniel J. Tobias

CITY OF RIO DELL

(County of Humboldt)

Incorporated February 23, 1965

Legislative Districts: 2nd Congressional; 2nd Senatorial; 2nd Assembly

General law city. Population 2,890. Council meets first and third Tuesdays each month at Rio Dell Council Chambers, City Hall, 95562.
Central Telephone: 707-764-3532

Mayor: Eddie Hogg

Councilmember, Catherine Crase
Councilmember, Gino Bianchi
Councilmember, Raymond Miller
Councilmember, Craige McKnight
City Clerk, Shirley Hizer
Police Chief, Bobby Chapman
Fire Chief, David Ghilarducci
School Superintendent, Harman Bonniksen

CITY OF RIO VISTA

(County of Solano)

Incorporated January 6, 1894

Legislative Districts: 4th Congressional; 4th Senatorial; 4th Assembly

General law city. Population 3,270. Council meets first and third Thursdays of month at 8 p.m. in Council Chambers, No. 1 Main St., 94571.

Mayor: Milton Wallace
City Administrator: Robert R. Brown

Councilman, Elger Vengley
Councilman, Jerry Rubier
Councilman, Howard R. Gambill
Councilman, Andrew M. Stephens
City Clerk, Geraldine McCormick
Police Chief, Richard Cook
Fire Chief, Stan Simi
Treasurer, Carl Kelly

CITY OF RIPON

(County of San Joaquin)

Incorporated November 27, 1945

Legislative Districts: 14th Congressional; 13th Senatorial; 26th Assembly

General law city. Population 2,930. Council meets first and third Tuesdays, 7:30 p.m. in City Hall, 311 W. 1st St., 95366.
Central Telephone: 209-599-2108

Mayor: Edmund F. Feichtmeir
City Administrator: Clarence Smit

Vice-Mayor, John De Jong
Councilman, David Reece
Councilman, Marvin Pater
City Clerk, Clarence Smit

Police Chief, Harvey A. Douma
Fire Chief, Morris De Jong
School Superintendent, Joseph C. O'Leary
City Attorney, Rolla L. Garretson

CITY OF RIVERBANK

(County of Stanislaus)

Incorporated August 23, 1922
Legislative Districts: 14th Congressional; 13th Senatorial; 26th Assembly
General law city. Population 5,025. Council meets second and fourth Mondays of each month in Council Chambers, City Hall, 6707 Third St., 95367.
Central Telephone: 209-869-3671
Mayor: Billie B. Mitchell
City Administrator: Gerald E. Robirds

Councilman, Jack Alpers
Councilman, Phil Overholtzer
Councilman, Charles Neal
Councilman, Allen Trawick
City Clerk, Gerald E. Robirds
Police Chief, Bernard J. Remas, Jr.
Fire Chief, Robert P. Tucker
Treasurer, Margery Cruz
School Superintendent, John Muzio

CITY OF RIVERSIDE

(County of Riverside)

Incorporated October 11, 1883
Legislative Districts: 36th Congressional; 34th Senatorial; 68th Assembly
Chartered city. Population 169,677. Council meets first four Tuesdays of each month (except July and August, when it meets the first and third Tuesdays) in City Hall, 3900 Main Street, 92522.
Central Telephone: 714-787-7312
* Mayor: Ab Brown
City Manager: Douglas G. Weiford

Councilman, Ronald Loveridge
* Councilman, Ed Shepard
Councilwoman, Jean Mansfield
* Councilman, Robert E. Bowers
Councilman, Robert A. Buster
* Councilman, Sam A. Digati
Councilwoman, Terry Frizzel
City Clerk, Alice A. Hare
Police Chief, Vic Jones
Fire Chief, Richard Bosted
City Attorney, John Woodhead

* Election 11/3/81

CITY OF ROCKLIN

(County of Placer)

Incorporated February 24, 1893
Legislative Districts: 1st Congressional; 1st Senatorial; 3rd Assembly
General law city. Population 7,298. Council meets first and third Mondays of month in Community Center, 7:30 p.m., 3980 Rocklin Road, 95677.
Central Telephone: 916-624-3351
Mayor: Clarke Dominguez
City Administrator: William E. Mitchell

Vice-Mayor, Peter Hill
Councilman, George Wofford
Councilman, Roger Barkhurst
Councilman, Will Linton
City Clerk, Marie A. Huson
Police Chief, James Simmons
Fire Chief, Randy Lavelock
Treasurer, Leroy C. Cook
City Attorney, William Holliman, Jr.

CITY OF ROHNERT PARK

(County of Sonoma)

Incorporated August 27, 1962
Legislative Districts: 2nd Congressional; 2nd Senatorial; 9th Assembly
General law city. Population 22,500. Council meets second and fourth Mondays in City Hall, 6750 Commerce Blvd., 94928.
Central Telephone: 707-795-2411
Mayor: Tony Carbone
City Manager: Peter M. Callinan

Mayor pro Tem, Bill Cavalli
Councilwoman, Mary L. Stewart
Councilman, Warren K. Hopkins
Councilman, Arthur N. Roberts
City Clerk, Peter M. Callinan
Director of Public Safety, Robert E. Dennett
City Treasurer-Finance Director, no name submitted
City Attorney, John D. Flitner

CITY OF ROLLING HILLS

(County of Los Angeles)

Incorporated January 24, 1957
Legislative Districts: 27th Congressional; 27th Senatorial; 51st Assembly
General law city. Population 2,058. Council meets second and fourth Mondays at 7:30 p.m. in City Hall, 2 Portuguese Bend Rd., 90274.
Central Telephone: 213-377-1521
Mayor: Donald Crocker
City Manager: Teena Clifton

Mayor pro Tem, Mason H. Rose, V
Councilman, Thomas F. Heinsheimer
Councilman, Godfrey Pernell
Councilman, Gordana Swanson
City Clerk, Teena Clifton
City Attorney, William Kinley

CITY OF ROLLING HILLS ESTATES

(County of Los Angeles)

Incorporated September 18, 1957
Legislative Districts: 27th Congressional; 27th Senatorial; 51st Assembly
General law city. Population 8,437. Council meets

second and fourth Tuesdays of each month in City Hall, 4045 Palos Verdes Dr., 90274.
Mayor: Nell Mirels
City Manager: Harry R. Peacock
Mayor pro Tem, Jerome Belsky
Councilman, Peter Weber
Councilman, Hugh Muller
Councilman, Warren Schwarzmann
City Clerk, Harry R. Peacock
City Attorney, Richard R. Terzian

CITY OF ROSEMEAD

(County of Los Angeles)

Incorporated August 4, 1959
Legislative Districts: 30th Congressional; 26th Senatorial; 59th and 60th Assembly
General law city. Population 40,972. Council meets second and fourth Tuesdays of month at 8:00 p.m. in Council Chambers, City Hall, 8838 E. Valley Blvd., 91770.
Central Telephone: 213-288-6671
Mayor: Louis Tury, Jr.
City Manager: Frank Tripepi
Mayor pro Tem, Marvin J. Cichy
Councilman, Herb Hunter
Councilman, Jay T. Imperial
Councilman, Gary A. Taylor
City Clerk, Ellen Poochigian
School Superintendents, Horace Stringham and Daniel R. Ellis

CITY OF ROSEVILLE

(County of Placer)

Incorporated April 10, 1909
Legislative Districts: 1st Congressional; 1st Senatorial; 3rd Assembly
Chartered city. Population 24,257. Council meets first Wednesday each month in City Hall, 316 Vernon St., 95678.
Central Telephone: 916-783-9151
Mayor: Harry Crabb, Jr.
City Manager: Robert G. Hutchison
Mayor pro Tem, George A. Buljan
Councilmember, Richard Roccucci
Councilmember, Byron Claiborne
Councilmember, June Wanish
City Clerk, Pauline S. Brockman
Fire Chief, Carl Green
Police Chief, James A. Hall
City Attorney, Dennis DeCuir

TOWN OF ROSS

(County of Marin)

Incorporated August 21, 1908
Legislative Districts: 5th Congressional; 2nd Senatorial; 9th Assembly
General law city. Population 2,658. Council meets second Thursday of month at 8 p.m. in Town Hall, 94957.
Central Telephone: 415-453-1453
Mayor: John H. Chase
Mayor pro Tem, Peter Brekhus
Councilman, Garrett P. Scales
Councilman, Roger S. Poore
Councilman, Leonard B. Stafford
Town Clerk, Virginia Stott
Police Chief, Roger Sciutto
Fire Chief, Thomas Casson
Treasurer, Marian E. Suther
School Superintendent, Margaret A. Elliott
Town Attorney, Robert W. Elliott

CITY OF SACRAMENTO

(County of Sacramento)

Incorporated February 27, 1850
Legislative Districts: 1st and 4th Congressional; 3rd, 4th and 13th Senatorial; 4th, 5th, 6th and 7th Assembly
Chartered city. Population 263,800. Council meets each Tuesday of month at 7:30 p.m. in Council Chambers, City Hall, 915 Eye St., 95814.
Central Telephone: 916-449-5011
Mayor: Phillip L. Isenberg
City Manager: Walter Slipe
Vice-Mayor, Daniel E. Thompson
Councilman, John Roberts
Councilman, Douglas N. Pope
Councilman, Blaine Fisher
Councilwoman, Anne Rudin
Councilman, Thomas R. Hoeber
Councilman, Lloyd G. Connelly
Councilwoman, Lynn Robie
City Clerk, Lorraine Magana
Police Chief, John P. Kearns
Fire Chief, William Powell
School Superintendent, E. Tom Giugni

CITY OF SALINAS

(County of Monterey)

Incorporated March 4, 1874
Legislative Districts: 16th Congressional; 17th Senatorial; 28th Assembly
Chartered city. Population 81,300. Council meets each Monday of month in Council Chambers, 200 Lincoln Ave., 93901.
Central Telephone: 408-758-7201
Mayor: James R. Woods
City Manager: Robert M. Christofferson
Councilman, Jim Barnes
Councilman, Paul D. Grennan
Councilman, R. C. Wherritt
Councilman, James M. Collins
City Clerk, Evelyn Reynolds
Police Chief, Fred Ferguson
Fire Chief, Paul A. Mehringer
City Attorney, David Kennedy
Council election (2 seats) 6/81

TOWN OF SAN ANSELMO

(County of Marin)

Incorporated April 9, 1907
Legislative Districts: 5th Congressional; 2nd Senatorial; 9th Assembly
General law city. Population 13,150. Council meets second and fourth Tuesdays of month in Town Hall, 94960.
Central Telephone: 415-453-0392
Mayor: Mike Convis
Town Administrator: Alan Bruce

Councilmember, Woodrow V. Capurro
Councilmember, Pieter Toal
Councilmember, Anne Wooliever
Councilmember, George Buckle
Town Clerk, Caroline Foster
Town Treasurer, M. G. Sheldon
Fire Chief, Robert Beedle
Police Chief, Bernard Del Santo
School Superintendent, Frank Elliott
Town Attorney, Hadden Roth

CITY OF SAN BERNARDINO

(County of San Bernardino)

Incorporated August 10, 1869
Legislative Districts: 36th and 37th Congressional; 32nd and 34th Senatorial; 66th and 67th Assembly
Chartered city. Population 108,100. Council meets first and third Mondays at 2:00 p.m. in the Council Chambers, 300 N. D St., 92418
Central Telephone: 714-383-5002
Mayor: W. R. "Bob" Holcomb
City Administrator: Marshall Julian

Councilman, Robert Casteneda
* Councilman, Edward S. Wheeler
Councilman, William Katona
* Councilman, Richard Gerwig
Councilman, Lionel E. Hudson
Councilman, John Hobbs
Councilman, Jack Strickler
City Clerk, Shauna Clark
Attorney, Ralph H. Prince
Police Chief, B. Warren Cocke
Fire Chief, Gerald Newcombe
* Treasurer, Lloyd E. Burcham
School Superintendent, Charles Terrell

* Election 5/81

CITY OF SAN BRUNO

(County of San Mateo)

Incorporated December 23, 1914
Legislative Districts: 11th Congressional; 6th Senatorial; 19th Assembly
General law city. Population 34,940. Council meets second and fourth Mondays of month, 7:30 p.m., in City Hall, 567 El Camino Real, 94066.
Central Telephone: 415-877-8897
Mayor: Robert A. Marshall
City Manager: Gerald D. Minford

Vice-Mayor, Edward Simon
Councilman, Chris Pallas
Councilman, Doug Dawkins
Councilman, Tom Ricci
City Clerk, Terri Rasmussen
Police Chief, Frank Hedley
Fire Chief, Harper A. Petersen
Treasurer, Karen Hornung
School Superintendent, John W. Mehl
City Attorney, Theodore R. Bresler

CITY OF SAN BUENAVENTURA

(County of Ventura)

Incorporated April 2, 1866
Legislative Districts: 19th Congressional 18th Senatorial; 36th Assembly
Chartered city. Population 70,000. Council meets each Monday of month at 7:30 p.m. in Council Chambers, City Hall, 501 Poli Street, Ventura, 93002.
Central Telephone: 805-648-7881
Mayor: Harriet Kosmo-Henson
City Manager: Edward E. McCombs

Deputy Mayor, Jim Monahan
Councilwoman, Patricia Ellison
Councilman, Ron Harrington
Councilman, Dennis Orrock
Councilman, John Chaudier
Councilman, John McWherter
City Clerk, Barbara J. Kam
Police Chief, Ray McLean
Fire Chief Bob Horne
School Superintendent, Patrick O. Rooney
City Attorney, Donald Greenberg

CITY OF SAN CARLOS

(County of San Mateo)

Incorporated July 8, 1925
Legislative Districts: 11th Congressional; 10th Senatorial; 20th Assembly
General law city. Population 26,050. Council meets second and fourth Mondays of month in Council Chambers, 666 Elm St., 94070
Central Telephone: 415-593-8011
Mayor: Patricia F. Bennie
City Administrator: Chas. R. Allen

Vice-Mayor, Gayton De Rosa
Councilman, William M. Steele
Councilman, John G. Buchanan
Councilman, Victor E. Stotz
City Clerk, Margaret R. Hanley
Police Chief, Owen McGuigan
Fire Chief, Gary Schmitz
Treasurer, Richard J. Lautze
School Superintendent, Nelson Burdett
City Attorney, Anthony Lagorio

CITY OF SAN CLEMENTE

(County of Orange)

Incorporated February 28, 1928

Legislative Districts: 40th Congressional; 36th Senatorial; 74th Assembly

General law city. Population 27,269. Council meets first and third Wednesdays of month at 7:00 p.m. in Council Chambers, Civic Center Bldg., 100 Avenida Presidio, 92672.
Central Telephone: 714-492-5101

Mayor: Karoline Koester
City Manager: George A. Caravalho

Councilman, Alan Korsen
Councilwoman, P. Patrick Lane
Councilman, Robert D. Limberg
Councilman, William C. Mecham
City Clerk, Max L. Berg
Police Chief, Gary Brown
Fire Chief, Ronny J. Coleman
Treasurer, Leonard G. Marks
City Attorney, Roger Grable

CITY OF SAND CITY

(County of Monterey)

Incorporated May 31, 1960

Legislative Districts: 16th Congressional; 17th Senatorial; 28th Assembly

General law city. Population 520. Council meets third Tuesday each month, 7:30 p.m., City Hall, No. 1 Sylvan Park, 93955.
Central Telephone: 408-394-3054

Mayor: David K. Pendergrass

Vice-Mayor, Michael Morris
Councilmember, Mark R. Meadows
Councilmember, Carl Ritter
Councilmember, Ronda Lewis
City Clerk, Gloria Fenton
Police Chief, John F. Staples
City Attorney, John B. Stohlton

CITY OF SAN DIEGO

(County of San Diego)

Incorporated March 27, 1850

Legislative Districts: 40th through 43rd Congressional; 36th and 38th through 40th Senatorial; 74th through 80th Assembly

Chartered city. Population 870,006. Council meets Mondays at 2:00 p.m., Tuesdays at 8:30 a.m. and 2:00 p.m. in Council Chamber, 12th Floor, City Administration Bldg., Community Concourse, 92101.
Central Telephone: 714-236-5555

Mayor: Pete Wilson
City Manager: Ray T. Blair, Jr.

Councilmember, Bill Cleator
Councilmember, Leon L. Williams
Councilmember, Bill Mitchell
Councilmember, Susan Golding
Councilmember, Mike Gotch
Councilmember, Fred Schnaubelt
Councilmember, Lucy Killea
Councilmember, Dick Murphy
City Clerk, Charles G. Abdelnour
City Attorney, John W. Witt
Police Chief, William B. Kolender
Fire Chief, Earle G. Roberts
School Superintendent, Thomas L. Goodman

CITY OF SAN DIMAS

(County of Los Angeles)

Incorporated August 4, 1960

Legislative Districts: 35th Congressional; 25th Senatorial; 62nd Assembly

General law city. Population 24,150. Council meets second and fourth Tuesdays, 7:30 p.m., City Hall, 245 E. Bonita Ave., 91773
Central Telephone: 714-599-6713

Mayor: Edmund M. Aleks
City Manager: Robert L. Poff

Vice-Mayor, Terry Dipple
Councilman, Marvin Ersher
Councilman, Donald G. Haefer
Councilman, Curtis W. Morris
City Clerk, Ruth V. Foster
School Superintendent, Dr. James T. Johnson, Jr.
City Attorney, J. Kenneth Brown

CITY OF SAN FERNANDO

(County of Los Angeles)

Incorporated August 31, 1911

Legislative Districts: 21st Congressional; 20th Senatorial; 39th Assembly

General law city. Population 16,571. Council meets first and third Mondays at 7:30 p.m. in Council Chambers, City Hall, 117 MacNeil Street, 91340.
Central Telephone: 213-365-2541

Mayor: Roy M. Richardson
Administrative Officer: Michael Y. Sagor

Councilman, Michael Majers
Councilman, Perry R. Harris
Councilman Dan F. Mackin
Councilman Pat J. Modugno
City Clerk, Therese M. Martin
Police Chief, Charles Sherwood
Treasurer, Elvira Orozco
City Attorney, Patrick C. Coughlan

CITY OF SAN FRANCISCO

(See County of San Francisco)

CITY OF SANGER

(County of Fresno)

Incorporated May 25, 1911

Legislative Districts: 17th Congressional; 15th Senatorial; 31st Assembly

General law city. Population 12,432. Council meets first

and third Tuesdays of month in City Hall,
1700 7th St., 93657.
Central Telephone: 209-875-4535
Mayor: Tanis Ybarra, Jr.
City Manager: Dennis W. Fisher
Mayor pro Tem, Jess Marquez
Councilman, Rene Gonzalez
Councilman, Thomas E. Olson
Councilwoman, Maria S. Davila
City Clerk, Harriett Stephens
Police Chief, Robert Galloway (Acting)
Fire Chief, Dean Mobley
School Superintendent, Dr. J. Donald Dorough
City Attorney, Richard H. Hargrove

CITY OF SAN GABRIEL

(County of Los Angeles)

Incorporated April 24, 1913
Legislative Districts: 26th Congressional;
25th Senatorial; 61st Assembly
General law city. Population 30,000. Council meets first and third Tuesdays of each month at 7:30 p.m. in
Council Chambers, City Hall,
532 West Mission Drive, 91778.
Central Telephone: 213-282-4104
Mayor: Sabino M. Cici
City Administrator: Robert D. Clute
Vice-Mayor, Michael L. Falabrino
Councilman, Edward T. Lara
Councilwoman, Helen Achilles
Councilwoman, Jeanne Parrish
City Clerk, S. S. Spencer
Police Chief, Don S. Tutich
Fire Chief, Charles F. Brown
Treasurer, C. C. Pearson
School Superintendent, Thomas W. Sullivan
City Attorney, Graham A. Ritchie

CITY OF SAN JACINTO

(County of Riverside)

Incorporated April 20, 1888
Legislative Districts: 37th Congressional;
34th Senatorial; 67th Assembly
General law city. Population 7,175. Council meets first and third Tuesdays after first Monday of month at
209 E. Main St., 92383.
Central Telephone: 714-654-7337
Mayor: Bertha J. Hazeltine
City Manager: Ross S. Nammar
Mayor pro Tem, Ray Visser
Councilman, R. J. Stevens
Councilman, Clifford E. Rose, Sr.
Councilman, Marc Divine
City Clerk, Margaret McLean
Fire Chief, Reed Pennell
Police Chief, Thomas Hicks
Treasurer, Willene Yeager
School Superintendent, Don Wickert
City Attorney, Donald Wickham

CITY OF SAN JOAQUIN

(County of Fresno)

Incorporated February 14, 1920
Legislative Districts: 15th Congressional;
14th Senatorial; 30th Assembly
General law city. Population 1,700. Council meets second and fourth Mondays each month at 7:00 p.m.
in City Hall, 21925 Nevada, 93660.
Central Telephone: 209-693-4311
Mayor: Arthur Pifferini
City Administrator: Hugh Ackerman
Mayor por Tem, James E. Fish
Councilman, Richard Maron
Councilman, George Nahhas
Councilman, Ray White
City Clerk, D. June Kelley
Treasurer, Annabella F. Fish
School Superintendent, James Waide
City Attorney, Jerry E. Henry

CITY OF SAN JOSE

(County of Santa Clara)

Incorporated March 27, 1850
Legislative Districts: 10th, 12th and 13th Congressional;
11th and 12th Senatorial;
22nd, 23rd, 24th and 25th Assembly
Chartered city. Population 587,689. Council meets every Tuesday in Council Chamber, City Hall,
First and Mission Streets, 95110.
Central Telephone: 408-277-4000
Mayor: Janet Gray Hayes
City Manager: Francis Fox
Councilman, Lu Ryden, District 1
Councilman, Jerry Estruth, District 2
Councilman, Thomas McEnery, District 3
Councilwoman, Shirley Lewis, District 4
Councilman, Blanca Alvarado, District 5
Councilwoman, Nancy Ianni, District 6
Councilman, Iola Williams, District 7
Councilwoman, Patricia Sausedo, District 8
Councilman, James Beall, Jr., District 9
Councilman, Claude Fletcher, District 10
City Clerk, Helen E. Jackson
Police Chief, Joseph McNamara
Fire Chief, Vince Clet
City Attorney, Robert Logan

CITY OF SAN JUAN BAUTISTA

(County of San Benito)

Incorporated May 4, 1896
Legislative Districts: 16th Congressional;
11th Senatorial; 24th Assembly
General law city. Population 1,270. Council meets first Tuesday of each month at 7:00 p.m. in
City Hall, 311 Second St., 95045.
Central Telephone: 408-623-4661
Mayor: Ray O. Gervais
City Manager: Kenneth Starbird

Vice-Mayor, Richard Pitschka
Councilman, Harvey S. Nyland
Councilman, Raymond C. Wilson
Councilwoman, Ann Baccala
City Clerk, Adela Gonzalez
Police Chief, Jon Michael Pellin
Fire Chief, George Dias, Jr.
Treasurer, Minnie Riphenburg
School Superintendent, Dr. David N. Evans
City Attorney, Robert Pinto

CITY OF SAN JUAN CAPISTRANO

(County of Orange)

Incorporated April 19, 1961
Legislative Districts: 40th Congressional; 36th Senatorial; 74th Assembly
General law city. Population 19,169. Council meets first and third Tuesdays at 7:00 p.m. in City Hall, 32400 Paseo Adelanto, 92675.
Central Telephone: 714-493-1171
Mayor: Gary L. Hausdorfer
City Manager: Vacant

Mayor pro Tem, Phillip R. Schwartze
Councilman, Lawrence F. Buchheim
Councilman, Anthony L. Bland
Councilman, Kenneth E. Friess
City Clerk, Mary Ann Hanover
School Superintendent, Jerome R. Thornsley
City Attorney, James S. Okazaki

CITY OF SAN LEANDRO

(County of Alameda)

Incorporated March 21, 1872
Legislative Districts: 9th Congressional; 8th Senatorial; 14th Assembly
Chartered city. Population 63,410. Council meets every Monday of month in Council Chambers, City Hall, 835 E. 14th St., 94577.
Mayor: Valance Gill
City Manager: LeRoy E. Riordan

Vice-Mayor, Richard D. Soares
Council Member District 1, Faith Frazier
Council Member District 2, Donald W. McGue
Council Member District 3, Johan Klehs
Council Member District 5, Gunther Seymon
Council Member District 6, L. N. Landis
City Clerk, Richard H. West, CMC
Police Chief, Donald F. Becker
Fire Chief, Harold H. Hamilton
School Superintendent, Dr. L. E. Holden

CITY OF SAN LUIS OBISPO

(County of San Luis Obispo)

Incorporated February 19, 1856
Legislative Districts: 16th Congressional; 17th Senatorial; 29th Assembly
Chartered city. Population 34,550. Council meets first and third Tuesdays at 4:00 p.m. and 7:30 p.m. in Council Chambers, City Hall, 990 Palm St., 93401.
Central Telephone: 805-541-1000
Mayor: Lynn Cooper
Administrative Officer: Leland M. Walton

Councilwoman, Melanie Billig
Councilman, Ron Dunin
Councilman, Jerry Munger
Councilman, Alan Bond
City Clerk, Vacant
Police Chief, Roger L. Neuman
Fire Chief, Richard L. Minor
School Superintendent, William Newman
City Attorney, George C. Thacher

CITY OF SAN MARCOS

(County of San Diego)

Incorporated January 28, 1963
Legislative Districts: 43rd Congressional; 38th Senatorial; 76th Assembly
General law city. Population 17,480. Council meets second and fourth Tuesdays at 6:30 p.m. in City Hall, 105 W. Richmar Ave., 92069.
Mayor: Robert L. Harman
City Manager: Henry E. Ford

Vice-Mayor, Richard R. Danover
Councilman, Charles G. Estenson
Councilman, F. H. Smith
Councilman, Lee B. Thibadeau
City Clerk, Sheila A. Kennedy
Fire Chief, Stan Mourning
School Superintendent, Vacant

CITY OF SAN MARINO

(County of Los Angeles)

Incorporated April 25, 1913
Legislative Districts: 26th Congressional; 25th Senatorial; 61st Assembly
General law city. Population 14,177. Council meets second Wednesday of month at 7:30 p.m. in Council Chambers, City Hall, 2200 Huntington Dr., 91108.
Central Telephone: 213-282-1155
Mayor: Lynn P. Reitnouer
City Manager: Charles R. Martin (Acting)

Vice-Mayor, Benjamin F. Hammon
Councilman, Joseph W. Lewis
Councilman, George Brandow
Councilman, Andrew B. Hallum, Jr.
City Clerk, Betty J. Groomes
Police Chief, James W. Moore
Fire Chief, Frank S. Storts
School Superintendent, David Brown

CITY OF SAN MATEO

(County of San Mateo)

Incorporated September 4, 1894
Legislative Districts: 11th Congressional; 6th and 10th Senatorial; 19th and 20th Assembly
Chartered city. Population 78,991. Council meets first

and third Mondays of month in Council Chambers, City Hall, 330 W. 20th Ave., 94403.
Central Telephone: 415-574-6760
Mayor: Donna S. Richardson
City Manager: Richard B. DeLong

Deputy Mayor, Jane Baker
Councilman, Florence P. Rhoads
Councilman, Hugh Wayne
Councilwoman, Aron H. Hoffman
City Clerk, Doris Christen
Police Chief, Lawrence D. Phipps
Fire Chief, Arthur N. Koron
School Superintendent, Dr. Julian D. Crocker
City Attorney, Douglas Dang

CITY OF SAN PABLO

(County of Contra Costa)

Incorporated April 27, 1948
Legislative Districts: 7th Congressional; 7th Senatorial; 11th Assembly
General law city. Population 19,000. Council meets first and third Mondays of month at 8:00 p.m. in Council Chambers, City Hall, No. 1 Alvarado Square, 94806.
Central Telephone: 415-234-6440
Mayor: Joseph M. Gomes
City Manager: Donald L. Russell

Vice-Mayor, Samuel W. Morrison
Councilmember, Marie H. Daniels
Councilmember, Kathryn L. Carmignani
Councilmember, John S. Koepke
City Clerk, Charlotte Maggard
Police Chief, Donald F. Oyaas
Fire Chief, Bill Helms
Treasurer, Allison Alter
City Attorney, Lawrence D. Saler

CITY OF SAN RAFAEL

(County of Marin)

Incorporated February 18, 1874
Legislative Districts: 5th Congressional; 2nd Senatorial; 9th Assembly
Chartered city. Population 43,861. Council meets first and third Mondays of month at 8:00 p.m. in Council Chambers, City Hall, 1400 Fifth Ave., 94901.
Mayor: Lawrence E. Mulryan
City Manager: Robert F. Beyer

Councilmember, Dorothy L. Breiner
Councilmember, Jack G. Nixon
Councilmember, Joseph A. Miskimen
Councilmember, Fred E. Jensen
City Clerk, Jeanne M. Leoncini
City Attorney, Edmund A. Duggan
Police Chief, Frank R. Benaderet
Fire Chief, Robert E. Marcucci
Treasurer, Ransom E. Coleman
School Superintendent, Carl Couch

CITY OF SANTA ANA

(County of Orange)

Incorporated June 12, 1886
Legislative Districts: 38th, 39th and 40th Congressional; 35th, 36th and 37th Senatorial; 70th, 72nd, 73rd and 74th Assembly
Chartered city. Population 204,089. Council meets first and third Mondays of month in Council Chambers, 22 Civic Center Plaza, 92701.
Central Telephone: 714-834-4251
Mayor: James E. Ward
City Manager: A. J. Wilson

Vice Mayor, Gordon Bricken
Councilman, Harry K. Yamamoto
Councilman, Daniel E. Griset
Councilman, J. Ogden Markel
Councilman, Alfred C. Serrato
Councilman, R. W. Luxembourger
City Clerk, Janice C. Guy
Police Chief, Raymond C. Davis
Fire Chief, William J. Reimer
School Superintendent, Howard R. Harrison
City Attorney, Edward J. Cooper

CITY OF SANTA BARBARA

(County of Santa Barbara)

Incorporated April 9, 1850
Legislative Districts: 19th Congressional; 18th Senatorial; 35th Assembly
Chartered city. Population 74,100. Council meets every Tuesday at 9:00 a.m. in City Hall, De la Guerra Plaza, 93102.
Central Telephone: 805-963-0611
Mayor: David T. Shiffman
City Administrator: Richard D. Thomas

Councilman, Sheila Lodge
Councilman, Hal Conklin
Councilman, Francis S. Lopez
Councilman, Patricia Fillippini
Councilman, Lyle G. Reynolds
Councilman, Jeanne Graffy
City Clerk, Richard D. Thomas
Police Chief, Neil J. Adkins
Fire Chief, Alfred L. Faoro (Acting)
School Superintendent, Dr. David Thomas
City Attorney, Frederick W. Clough

CITY OF SANTA CLARA

(County of Santa Clara)

Incorporated July 5, 1852
Legislative Districts: 12th Congressional; 12th Senatorial; 21st and 23rd Assembly
Chartered city. Population 87,206. Council meets every Tuesday of the month in City Hall 1500 Warburton Avenue, 95050.
Central Telephone: 408-984-3000
• Mayor: William A. Gissler
City Manager: Donald R. Von Raesfeld

• Vice Mayor, Daniel V. Texera
• Councilwoman, Auralee Street

* Councilman, Roger Martinez
Councilman, Everett N. Souza
Councilman, David D. Tobkin
Councilman, John I. Mahan
City Clerk, A. S. Belick
Police Chief, Donald C. Ferguson
Fire Chief, Donald P. Visconti
School Superintendent, Rudy R. Gatti
* Term expires 11/81

CITY OF SANTA CRUZ

(County of Santa Cruz)

Incorporated March 31, 1866
Legislative Districts: 16th Congressional; 17th Senatorial; 28th Assembly
Chartered city. Population 41,401.
Council meets second and fourth Tuesdays at 4:00 and 7:30 p.m. in Council Chambers, City Hall, 809 Center Street, 95060.
Central Telephone: 408-429-3784
Mayor: Joseph J. Ghio
City Manager: David C. Koester

* Vice-Mayor, Spiro Mellis
* Councilman, Lawrence A. Edler
* Councilman, Bert Muhly
Councilman, John G. Mahaney
Councilman, Michael Rotkin
Councilman, Bruce Van Allen
City Clerk, Patricia M. Kenyon
City Attorney, Rodney R. Atchison
Police Chief, Geno J. Pini
Fire Chief, Tony Pini
School Superintendent, Vacant
* Terms expire 11/4/81

CITY OF SANTA FE SPRINGS

(County of Los Angeles)

Incorporated May 15, 1957
Legislative Districts: 33rd Congressional; 33rd Senatorial; 63rd Assembly
General law city. Population 15,000. Council meets second and fourth Thursdays of each month at 7:30 p.m. in Council Chambers, City Hall, 11710 Telegraph Road, 90670.
Central Telephone: 213-868-0511
Mayor: Ronald S. Kernes
City Manager: Donald R. Powell

Mayor pro Tem, Betty Wilson
Councilman, Luis A. Escontrias
Councilman, William J. McCann
Councilman, Armando J. Mora
City Clerk, Donald R. Powell
Fire Chief, Bernard Cannard
City Attorney, William Camil

CITY OF SANTA MARIA

(County of Santa Barbara)

Incorporated September 12, 1905
Legislative Districts: 19th Congressional; 17th and 18th Senatorial; 29th and 35th Assembly
General law city. Population 35,539.
Council meets first and third Tuesdays of month in City Hall, 110 E. Cook Street, 93454.
Central Telephone: 805-925-0951
Mayor: George S. Hobbs, Jr.
City Administrator: Robert F. Grogan

Mayor pro Tem, Jack Adam
Councilmán, W. Allen Burke
Councilman, Toru Miyoshi
Councilman, Donald J. Shaw
City Clerk, Dorothy Lyman
Police Chief, Joseph Centeno
Fire Chief, C. Wright Crakes
Tresurer, Wm. W. Winter
City Attorney, Vacant

CITY OF SANTA MONICA

(County of Los Angeles)

Incorporated November 30, 1886
Legislative Districts: 27th Congressional; 22nd Senatorial; 44th Assembly
Chartered city. Population 88,122. Council meets 2nd and 4th Tuesdays of month at 7:30 p.m. in Council Chamber, City Hall, 1685 Main St., 90401.
Central Telephone: 213-393-9975
Mayor: Ruth Yannatta Goldway
City Manager: John Jalili (Acting)

Mayor pro Tem, Ken Edwards
Councilman, William H. Jennings
Councilwoman, Dolores M. Press
Councilman, Dennis Zane
Councilman, James P. Conn
Councilwoman, Christine Reed
City Clerk, Ann M. Shore
Police Chief, James Keane
Fire Chief, Thomas Tolman
School Superintendent, Dr. George L. Caldwell

CITY OF SANTA PAULA

(County of Ventura)

Incorporated April 22, 1902
Legislative Districts: 20th Congressional; 18th Senatorial; 36th Assembly
General law city. Population 19,600.
Council meets first and third Mondays of month at 7:30 p.m. in City Hall, 970 Ventura St., 93060.
Central Telephone: 805-525-3344
Mayor: Alfonso C. Urias
City Administrator: James W. Morrison

Mayor pro Tem, John A. F. Melton
Councilman, Leslie H. Maland
Councilman, Jim McCoy
Councilwoman, Eleanor Crouch
City Clerk, James E. Robbins
Police Chief, James R. Corrigan
Fire Chief, Lloyd Onstot, Jr.
Treasurer, Wilmer G. Nelson

City Planner, Kristin Duncan
City Attorney, Phillip H. Romney

CITY OF SANTA ROSA

(County of Sonoma)

Incorporated March 16, 1868
Legislative Districts: 2nd Congressional; 4th Senatorial; 8th and 2nd Assembly
Chartered city. Population 81,572. Council meets first four Tuesdays of month in Council Chambers, City Hall, 100 Santa Rosa Avenue, 95404.
Central Telephone: 707-528-5361
Mayor: Jerry Wilhelm
City Manager: Kenneth R. Blackman

Vice-Mayor, William H. Barone
Councilwoman, Donna M. Born
Councilman, John J. Healy
Councilman, Clement R. Guggiana
City Clerk, Kenneth R. Blackman
Police Chief, Salvatore V. Rosano
Fire Chief, Michael Turnick
School Superintendent, John Landis
City Attorney, Bruce Leavitt

CITY OF SANTEE

(County of San Diego)

Incorporated December 1, 1980
Legislative Districts: 43rd Congressional; 39th Senatorial; 76th and 77th Assembly
General law city. Population 50,000. Council meets second and fourth Mondays at Santee Elementary School District Headquarters, 9625 Cuyamaca Street; City Hall is located at 10765 Woodside Ave. 92071
Central Telephone: 714-562-6153
Mayor: Gene R. Ainsworth
City Manager: Stephen R. Thatcher

Councilmember,
Vice Mayor, E. T. "Woodie" Miller
Councilmember, Roy A. Woodard
Councilmember, Janice R. Claussen
Councilmember, James P. Bartell
City Clerk/Treasurer, R. E. Carter
Police Chief, C. Wigginton
Fire Chief, Ronald Berry
School Superintendent, Douglas Giles
City Attorneys, Donald F. Jr. and Gloria S. McLean

CITY OF SARATOGA

(County of Santa Clara)

Incorporated October 22, 1956
Legislative Districts: 13th Congressional; 12th Senatorial: 22nd Assembly
General law city. Population 30,300. Council meets first and third Wednesdays of month in City Council Chambers, 13777 Fruitvale Ave., 95070.
Central Telephone: 408-867-3438
Mayor: Linda Callon
City Manager: J. Wayne Dernetz (Acting)

Councilwoman, Martha Clevenger
Councilwoman, Cheriel Jensen
Councilman, John Mallory
Councilman, Dale Watson
City Clerk, Grace E. Cory (Acting)
Police Chief, John T. Ball
Fire Chief, Ernie Kraule
School Superintendent, Dr. Everett G. McNicholas
City Attorney, Paul Smith

CITY OF SAUSALITO

(County of Marin)

Incorporated September 4, 1893
Legislative Districts: 5th Congressional; 2nd Senatorial; 9th Assembly
General law city. Population 6,473. Council meets first and third Tuesdays of each month in Council Chambers, 420 Litho Street, 94965.
Central Telephone: 415-332-0310
Mayor: F. W. "Fritz" Warren
City Manager: Thomas J. Andrusky

Vice Mayor, Robin R. Sweeny
Councilman, Carol Singer Peltz
Councilman, Peter Van Meter
Councilwoman, Sally Stanford
City Clerk, Janet F. Tracy
Police Chief, James D. Wright
Fire Chief, Stephen H. Bogel
Treasurer, Carl Tregner
City Attorney, Leland H. Jordan

CITY OF SCOTTS VALLEY

(County of Santa Cruz)

Incorporated August 2, 1966
Legislative Districts: 16th Congressional; 17th Senatorial; 28th Assembly
General law city. Population 6,907. Council meets first and third Wednesdays of month at 7:30 p.m., San Agustin Church, 257 Glenwood Dr., 95066.
Central Telephone: 408-438-2324
Mayor: Jun Lee
City Administrator: Robert J. Rockett

Councilman, Rad Lyon
Councilman, Raymond F. Carl
Councilman, Richard Siltanen
Councilman, Friend W. Stone
City Clerk, Robert J. Rockett
Police Chief, Gerald C. Pittenger
Fire Chief, C. Bruce Scott
School Superintendent, Donald R. Slezak
City Attorney, Raymond Haight

CITY OF SEAL BEACH

(County of Orange)

Incorporated October 27, 1915
Legislative Districts: 34th Congressional; 36th Senatorial; 73rd Assembly

Chartered city. Population 27,671. Council meets second and fourth Mondays of month in City Hall, 211 8th St., 90740.
Central Telephone: 213-431-2527
*Mayor: Ronald A. Kredell
**City Manager: Denis Thomas

Councilman, Frank J. Laszlo
Councilman, George H. Supple
Councilman, Harold Kent Seitz
Councilman, Willemke Vanderstaay
City Clerk, Joanne M. Yeo
Police Chief, Stacy Picascia
Fire Chief, Ronald Adams
Treasurer-Finance Director, Denis Thomas
School Superintendents, Dr. Roger Lowney and George Plumleigh
City Attorney, Patrick C. Coughlan

*Until May 1, 1981
**Until April 1, 1981

CITY OF SEASIDE

(County of Monterey)

Incorporated October 13, 1954
Legislative Districts: 16th Congressional; 17th Senatorial; 28th Assembly
General law city. Population 36,291. Council meets first and third Thursdays in City Hall, 440 Harcourt Avenue, 93955.
Central Telephone: 408-394-8531
Mayor: Glen Olea
City Manager: Roger L. Kemp

Mayor pro Tem, Berdine "Bud" Houser
Councilman, Albert J. Lioi
Councilman, Melvin T. Mason
Councilman, George E. Austin
City Clerk, Roger Kemp
Police Chief, Bennie W. Cooper
City Attorney, Donald G. Freeman
Fire Chief, Joseph McNeill

CITY OF SEBASTOPOL

(County of Sonoma)

Incorporated June 13, 1902
Legislative Districts: 2nd Congressional; 2nd Senatorial; 2nd Assembly
General law city. Population 5,100. Council meets first and third Mondays of month in Forum Room, 7120 Bodega Ave., 95472.
Mayor: Robert E. Anderson
City Manager: Melvin K. Davis

Vice-Mayor, Gwen A. Anderson
Councilman, Tom Miller
Councilman, Juliana Doms
Councilman, Ed Nomura
City Clerk, Melvin K. Davis
Police Chief, Charles Baker
Fire Chief, Russ Shura
School Superintendent, Harry J. Burcell
Treasurer-Finance Officer, Charles Foster

CITY OF SELMA

(County of Fresno)

Incorporated March 15, 1893
Legislative Districts: 17th Congressional; 15th Senatorial; 31st Assembly
General law city. Population 10,914. Council meets first and third Mondays of month at 1814 Tucker St., 93662.
Central Telephone: 209-896-1064
Mayor: Emma E. Jensen
City Administrator: Nicholas Pavlovich

Vice-Mayor, Charles Rothgarn
Councilwoman, Pat Helm
Councilman, Ralph Garcia
Councilman, Ben Fry
City Clerk, Genevieve Grutzmacher
Police Chief, James E. Brockett
Fire Chief, Dave Haugen

CITY OF SHAFTER

(County of Kern)

Incorporated January 20, 1938
Legislative Districts: 18th Congressional 16th Senatorial; 33rd Assembly
General law city, Population 6,725.
Council meets second and fourth Mondays of month at 7:00 p.m. in City Hall, 320 James St., 93263.
Central Telephone: 805-746-6361
Mayor: Elmer R. Unruh
City Administrator: William Sheldon, Jr.

Councilman, Donald Little
Councilman, Rolf Jacobsen
Councilman, Loyd Link
Councilman, George Wise
City Clerk, Dolores Robinson
Police Chief, Gene Kaplan
Fire Chief, Clifford Ratzlaff
Treasurer, Bernice Atkinson
City Attorney, Alfred G. Mortimore

CITY OF SIERRA MADRE

(County of Los Angeles)

Incorporated February 2, 1907
Legislative Districts: 26th Congressional; 25th Senatorial; 61st Assembly
General law city. Population 12,200. Council meets second and fourth Tuesdays of month in Council Chambers, City Hall, 232 W. Sierra Madre Blvd., 91024.
Central Telephone: 213-355-7135
Mayor: Charles I. Corp
City Administrator: James E. McRea

Mayor pro Tem, Elaine T. Rudolph
Councilman, Clem L. Bartolai
Councilman, Thomas Edwards
Councilman, Carlyle D. Griffin
City Clerk, L. Marie Warfel
Treasurer, Douglas C. Berkshire
Police Chief, I. E. "Bill" Betts
Fire Chief, James Leonard Hall

CITY OF SIGNAL HILL

(County of Los Angeles)

Incorporated April 22, 1924
Legislative Districts: 34th Congressional
31st Senatorial; 58th Assembly
General law city. Population 6,550.
Council meets first and third Tuesdays of month in Council Chamber, City Hall, 2175 Cherry Ave., 90806.
Central Telephone: 213-426-7333
Mayor: George E. Papadakis
City Manager: David A. Caretto

Vice-Mayor, William F. Mendenhall
Councilman, Dr. David J. Bellis
Councilman, Keaton K. King
Councilman, Robert R. Price
City Clerk, Merle J. Hunt
Fire Chief, Clyde Bragdon
Treasurer, Kathleen Brady
City Attorney, "J" Kenneth Brown

CITY OF SIMI VALLEY

(County of Ventura)

Incorporated October 10, 1969
Legislative Districts: 20th Congressional;
19th Senatorial; 37th Assembly
General law city. Population 76,304. Council meets on second and fourth Mondays of month at 3200 Cochran St., 93065.
Central Telephone: 805-522-1333
Mayor: Elton Gallegly
City Manager: M. L. Koester

Mayor pro Tem, Greg Stratton
Councilman, Bill Baker
Councilman, Robert Huber
Councilwoman, Nancy Bender
City Clerk, M. L. Koester
Fire Chief, Stan Masson
School Superintendent, John Duncan
City Attorney, Mitchel Kahn

CITY OF SOLEDAD

(County of Monterey)

Incorporated March 9, 1921
Legislative Districts: 16th Congressional;
17th Senatorial; 29th Assembly
General law city. Population 5,610. Council meets second Tuesday and fourth Wednesday of month at City Hall, 647 Front St., 93960.
Central Telephone: 408-678-3963
Mayor: Frank Ledesma
City Manager: Larry W. Bagley

Councilman, A. J. de los Sontos
Councilwoman, Elaine Gutierrez
Councilman, Graig Stephens
Councilman, Joe O. Ledosma
City Clerk, Larry W. Bagley
Fire Chief, Vernon Hevrin
Police Chief, Benjamin Jiminez
Treasurer, Richard Perez
School Superintendent, Wendel Broom

CITY OF SONOMA

(County of Sonoma)

Incorporated September 3, 1883
Legislative Districts: 2nd Congressional;
4th Senatorial; 8th Assembly
General law city. Population 5,948.
Council meets second and fourth Mondays of month at 7:30 p.m. in Council Chambers, City Hall, No. 1, The Plaza, 95476.
Central Telephone: 707-938-3681
Mayor: Henry J. Riboni
City Manager: Brock T. Arner

Vice-Mayor, Nancy Parmelee
Councilman, Jerold Tuller
Councilman, Daniel T. Ruggles, Sr.
Councilman, Kenneth S. McTaggart
City Clerk, Eleanor Berto
Fire Chief, Albert C. Mazza
Police Chief, Billy D. Rettle
Treasurer, William J. Houston
School Superintendent, Robert Geurts
City Attorney, John A. Klein

CITY OF SONORA

(County of Tuolumne)

Incorporated May 1, 1851
Legislative Districts: 14th Congressional;
13th Senatorial; 7th Assembly
General law city. Population 3,840. Council meets first and third Mondays of month at 8:00 p.m. in Council Chambers, City Hall, 94 N. Washington St., 95370.
Central Telephone: 209-532-4541
Mayor: Stanley J. Churchill
City Administrator: William E. Thomas

Mayor pro Tem, Donald A. Calvert
Councilman, Ronald E. Stearn
Councilman, Louis R. Pound
Councilman, Larry A. Rotelli
City Clerk-Treasurer, Paul W. Vaughan
Police Chief, Ronald D. Wano
Fire Chief, Guy C. Mills
City Attorney, William E. Thomas

CITY OF SOUTH EL MONTE

(County of Los Angeles)

Incorporated July 30, 1958
Legislative Districts: 30th Congressional;
26th Senatorial; 59th and 60th Assembly
General law city. Population 17,342. Council meets second and fourth Thursdays each month at 7:30 p.m. in the Council Chambers, 1415 Santa Anita Ave., 91733.
Central Telephone: 213-579-6540
Mayor: Jim Kelly
City Administrator: Paul J. Philips

Vice-Mayor, Albert G. Perez
Councilman, John Gonzales
Councilman, Ignacio "Slim" Gracia
Councilman, Greg Meis
City Clerk, Margaret M. Garcia

CITY OF SOUTH GATE

(County of Los Angeles)

Incorporated January 20, 1923
Legislative Districts: 29th Congressional; 29th Senatorial; 48th Assembly
General law city. Population 67,555. Council meets second and fourth Mondays at 7 p.m. in Council Chambers, City Hall, 8650 California Avenue, 90280.
Central Telephone: 213-567-1331
Mayor: Odell L. Snavely
Chief Administrative Officer: Carl H. Zeise
Vice-Mayor, Harold Prukop
Councilman, William H. DeWitt
Councilwoman, Joan G. King
Councilman, Joseph Moore
City Clerk, Janet E. Stubbs
Police Chief, Robert R. Stewart
Treasurer, Martha L. Hunter
City Attorney, John J. Gottes

CITY OF SOUTH LAKE TAHOE

(County of El Dorado)

Incorporated November 30, 1965
Legislative Districts: 14th Congressional; 13th Senatorial; 7th Assembly
General law city. Population 22,950. Council meets first and third Tuesdays at 1021 Al Tahoe Blvd., 95705.
Central Telephone: 916-541-2900
Mayor: John N. Cefalu
City Manager: Richard Milbrodt
Councilman, Norman C. Woods
Councilman, Frank Benevento
Councilman, John Hubbell
Councilman, Terry Trupp
City Clerk, Evelyn L. Roberson
Police Chief, John Crow
Fire Chief, Bert Cherry
School Superintendent, Ken Lowry
City Attorney, J. Dennis Crabb

1210
95705

CITY OF SOUTH PASADENA

(County of Los Angeles)

Incorporated March 2, 1888
Legislative Districts: 26th Congressional; 21st Senatorial; 42nd Assembly
General law city. Population 22,624. Council meets first and third Wednesdays of month at 7:30 p.m. at 817 Mound Avenue, 91030.
Central Telephone: 213-799-9101
Mayor: Michael B. Montgomery
City Manager: Charles R. Martin
Mayor pro Tem, Alva Lee Arnold
Councilman, Samuel G. Knowles
Councilwoman, Helen E. Simmons
Councilman, Ted R. Shaw
City Clerk, Ruby W. Kerr
Police Chief, Samuel L. Buntyn
Fire Chief, Gene E. Murry
Treasurer, Edward Ristow
School Superintendent, Dr. Joan Wilson
City Attorney, Charles R. Martin

CITY OF SOUTH SAN FRANCISCO

(County of San Mateo)

Incorporated September 19, 1908
Legislative Districts: 11th Congressional; 6th Senatorial; 19th Assembly
General law city. Population 48,650. Council meets first and third Wednesdays of month at 7:30 p.m. at West Orange Ave. Library Auditorium, 94080.
Central Telephone: 415-877-8500
Mayor: Gus Nicolopulos
City Manager: C. Walter Birkelo
Vice Mayor, Roberta Cerri Teglia
Councilman, Mark N. Addiego
Councilman, Emanuele N. Damonte
Councilman, Ronald G. Acosta
City Clerk, Barbara A. Battaya
Police Chief, James L. Datzman
Fire Chief, John L. Drago
School Superintendent, Thomas J. Gaffney
City Attorney, Robert K. Rogers (Acting)

CITY OF ST. HELENA

(County of Napa)

Incorporated March 24, 1876
Legislative Districts: 2nd Congressional; 4th Senatorial; 8th Assembly
General law city. Population 4,661. Council meets second and fourth Tuesdays of month in Council Chambers, City Hall, 1480 Main St., 94574.
Central Telephone: 707-963-2741
Mayor: Lowell Smith
Administrative Coordinator: George R. Musso
Vice Mayor, David Whiting
Councilman, Guy Kay
Councilman, Mel Varrelman
Councilman, Anthony Holtzhauer
City Clerk, George R. Musso
Police Chief, Andrew V. Angel
Fire Chief, Ron Pincus
Treasurer, Kleo Mini
School Superintendent, Vance D. Baldwin

CITY OF STANTON

(County of Orange)

Incorporated June 4, 1956
Legislative Districts: 38th Congressional; 37th Senatorial; 71st and 72nd Assembly

General law city. Population 24,931. Council meets second and fourth Tuesdays of month, 7:30 p.m., in Council Chambers, City Hall, 7800 Katella Ave., 90680.

Mayor: Joseph M. Wheeler
City Manager: James E. Neal

Mayor pro Tem, Lawrence Romagnino
Councilman, Frank N. Marshott
Councilman, Charles J. Rell
Councilwoman, Martha V. Weishaupt
City Clerk, Andrew C. Lazzaretto
Police Chief, Ronald A. Johnson
Fire Chief, Jerold L. Hunter

CITY OF STOCKTON

(County of San Joaquin)

Incorporated July 23, 1850

Legislative Districts: 14th Congressional; 13th Senatorial; 7th and 26th Assembly

Chartered city. Population 145,841. Council meets every Monday, 7:00 p.m., in Council Chambers, City Hall, 425 N. El Dorado St., 95202.
Central Telephone: 209-944-8212

Mayor: Daniel A. O'Brien
City Manager: John B. Wentz

Vice-Mayor, William Sousa
Councilwoman, Barbara Fass
Councilman, Jesse L. Nabors
Councilman, Tom Madden
Councilman, Jack E. Clayton
Councilman, James M. Paige
Councilman, Ralph L. White
Councilman, Arnold I. Rue
City Clerk, John M. Jarrett
Police Chief, Julio Cecchetti
Fire Chief, James Clifton
School Superintendent, Dr. Leon Lessinger
City Attorney, Gerald A. Sperry

CITY OF SUISUN CITY

(County of Solano)

Incorporated October 9, 1868

Legislative Districts: 4th Congressional; 4th Senatorial; 4th Assembly

General law city. Population 11,050. Council meets first and third Tuesdays of each month in City Hall, 400 California St., 94585.

Mayor: William G. Jones
City Administrator: Robert J. Bounds

Mayor pro Tem, Ernest McClelland
Councilman, Manuel Baracosa
Councilman, Guido E. Colla
Councilman, James E. Buck
City Clerk, Anita L. Skinner
Police Chief, James R. West
Fire Chief, James W. Pennington
Treasurer, Terry P. Lawson

CITY OF SUNNYVALE

(County of Santa Clara)

Incorporated December 24, 1912

Legislative Districts: 12th and 13th Congressional; 10th and 12th Senatorial; 21st, 22nd and 23rd Assembly

Chartered city. Population 110,000. Council meets every Tuesday, 8 p.m., in Council Chambers, City Hall, 456 W. Olive Ave., 94086.
Central Telephone: 408-738-5411

Mayor: Dianne McKenna
City Manager: Thomas F. Lewcock

Vice-Mayor, Ron Gonzales
Councilmember, Lynn Briody
Councilmember, Dolowries Wulfhorst
Councilmember, Harry Cude
Councilmember, John Mercer
Councilmember, Lawrence E. Stone
City Clerk, Thomas F. Lewcock
City Attorney, Vacant

CITY OF SUSANVILLE

(County of Lassen)

Incorporated August 24, 1900

Legislative Districts: 1st Congressional; 1st Senatorial; 1st Assembly

General law city. Population 6,516. Council meets first Monday of month in Council Chambers, City Hall, 66 N. Lassen St., 96130.
Central Telephone: 916-257-2174

Mayor: Harold Grayson

Mayor pro Tem, Louis Templeton, Jr.
Councilmember, Linda Huggins
Councilmember, Helen M. Leve
Councilmember, Marion M. Jenkins
City Clerk, Mary A. Fahlen
Police Chief, Marcus D. Murphy
Fire Chief, Raymond A. Berettini
City Treasurer, George A. Farris
City Attorney, Donald P. Cady

CITY OF SUTTER CREEK

(County of Amador)

Incorporated February 11, 1913

Legislative Districts: 14th Congressional; 13th Senatorial; 7th Assembly

General law city. Population 1,700. Council meets first and third Mondays of month at 7:30 p.m., City Auditorium, P.O. Box 366, 95685.
Central Telephone: 209-267-5647

Mayor: George Maloney

Councilman, George Quinn
Councilman, Carl Kuhn
Councilman, William H. Larrigan
Councilman, M. J. "Mickey" Brown
City Clerk, Pearl Campbell
Police Chief, Robert W. Bugni
Treasurer, William Oehler, Jr.
School Superintendent, Ben C. Klotz
City Attorney, Michael H. Chisholm

CITY OF TAFT

(County of Kern)

Incorporated November 22, 1910
Legislative Districts: 18th Congressional; 16th Senatorial; 33rd Assembly
General law city. Population 4,714. Council meets first and third Mondays of month in Council Chambers, 209 E. Kern Street, 93268.
Central Telephone: 805-763-3144
Mayor: George L. McNeal
City Manager: Stephen L. Wright

Councilman, Donald N. Braun
Councilman, Kenneth E. Fuller
Councilman, Bill Lackey
Councilman, Steve Kennedy
City Clerk, Patricia R. Hollingsworth
Police Chief, Willard Schlieter
Fire Chief, James R. Gaither
Treasurer, Art V. Carlton
City Attorney, Rex Mull

CITY OF TEHACHAPI

(County of Kern)

Incorporated August 13, 1909
Legislative Districts: 18th Congressional; 16th Senatorial; 34th Assembly
General law city. Population 4,370. Council meets first and third Mondays of month in Council Chambers, City Hall, 129 E. "F" St., 93561.
Central Telephone: 805-822-3264
Mayor: Lawrence R. Redelsberger
City Administrator: Lawrence M. Cook

Councilman, John H. E. Rombouts
Councilman, Albert J. Pinheiro
Councilman, Raleigh B. Austin
Councilman, Frank E. Crumpacker
City Clerk, Kathryn L. Koski
Fire Chief, A. A. Anthony
Police Chief, John R. Smith
Treasurer, Evelyn Catalano
School Superintendent, Howard W. Hoover
City Attorney, M. Dwain Smith

CITY OF TEHAMA

(County of Tehama)

Incorporated July 5, 1906
Legislative Districts: 1st Congressional; 1st Senatorial; 1st Assembly
General law city. Population 360. Council meets first Wednesday of month in City Hall, Cavalier Ave., 96090.
Central Telephone: 916-384-2406
Mayor: C. A. Stromsness

Councilman, Harold E. Belbeck
Councilman, Winston Megorden
Councilman, Sandra Ward
Councilman, Edward B. Byram
City Clerk, Carolyn Steffan
Treasurer, Verna Hough
City Attorney, Rawlins Coffman

CITY OF TEMPLE CITY

(County of Los Angeles)

Incorporated May 25, 1960
Legislative Districts: 26th and 30th Congressional; 25th and 26th Senatorial; 60th and 61st Assembly
Chartered city. Population 30,118. Council meets first and third Tuesdays each month at 7:30 p.m. in Council Chambers, City Hall, 5938 N. Kauffman Ave., 91780.
Mayor: Tom D. Atkins
City Manager: Karl L. Koski

Mayor pro Tem, Kenneth G. Gillanders
Councilman, William I. Dennis
Councilman, Jack R. Tyrell
Councilman, Louis W. Merritt
City Clerk, Karl L. Koski
School Superintendent, Dr. Wes Bosson

CITY OF THOUSAND OAKS

(County of Ventura)

Incorporated October 7, 1964
Legislative Districts: 20th Congressional; 19th Senatorial; 38th Assembly
General law city. Population 81,850. Council meets first four Tuesdays of each month at 7:30 p.m. at 401 W. Hillcrest Dr., 91360.
Central Telephone: 805-497-8611
Mayor: Lawrence E. Horner
City Manager: Grant R. Brimhall

Mayor pro Tem, Alex T. Fiore
Councilwoman, Frances K. Prince
Councilman, A. Lee Laxdal
Councilman, Madge L. Schaefer
City Clerk, Suzanne Ota
Police Chief, Alfred Jalaty
Fire Chief, S. E. Mason
City Attorney, James Longtin

TOWN OF TIBURON

(County of Marin)

Incorporated June 23, 1964
Legislative Districts: 5th Congressional; 2nd Senatorial; 9th Assembly
General law city. Population 7,000. Council meets first and third Wednesdays at 8:00 p.m. in Council Chambers, Reed School, Room 9, 1155 Tiburon Blvd., 94920.
Central Telephone: 415-435-0956
Mayor: Philip Bass
Town Clerk/Manager: Robert L. Kleinert

Councilman, Hal Edelstein
Councilman, Dennis Rockey
Councilman, Kirk Hanson
Councilwoman, Joan Bergsund
Police Chief, John Bailey
Town Attorney, Robert Conn
Town Treasurer, F. G. Knight

CITY OF TORRANCE

(County of Los Angeles)

Incorporated May 12, 1921

Legislative Districts: 27th, 31st and 32nd Congressional; 27th Senatorial; 51st and 52nd Assembly

Chartered city. Population 129,511. Council meets every Tuesday of month in City Hall, 3031 Torrance Blvd., 90503.

Central Telephone: 213-328-5310

Mayor: James R. Armstrong
City Manager: Edward J. Ferraro

Councilman, Bill Applegate
Councilman, Daniel W. Walker
Councilman, Donald E. Wilson
Councilman, Doug Brown
Councilman, Dick Rossberg
Councilwoman, Katy Geissert
City Clerk, Sherie L. Nelson
Police Chief, Donald E. Nash
Fire Chief, Richard DeYoung
Treasurer, Thomas C. Rupert
City Attorney, Stanley E. Remelmeyer

CITY OF TRACY

(County of San Joaquin)

Incorporated July 22, 1910

Legislative Districts: 14th Congressional; 13th Senatorial; 26th Assembly

General law city. Population 18,488. Council meets first and third Tuesdays of month in Council Chambers, 325 E. 10th St., 95376.

Central Telephone: No central number at this time

Mayor: Robert A. Canclini
City Manager: Michael E. Locke

Vice-Mayor, Eleanor Kambeitz
Councilmember, C. D. Simpson
Councilmember, Dorothy M. Zanussi
Councilmember, Roy R. Sissell
City Clerk, Betty J. Dani
Treasurer, E. H. Hettervik, Jr.
Police Chief, Cloyce Brooksher
Fire Chief, Dan Watrous
School Superintendent, James R. French

CITY OF TRINIDAD

(County of Humboldt)

Incorporated November 7, 1870

Legislative Districts: 2nd Congressional; 2nd Senatorial; 2nd Assembly

General law city. Population 300. Council meets first Tuesday of month in City Hall, 409 Trinity St., 95570.

Mayor: George Collins

Councilmember, Dave Zebo
Councilmember, Betty Freeman
Councilmember, M. L. Patterson
Councilmember, John Wilson
City Clerk, Robin J. Ziegler
Fire Chief, Susan Morton
Treasurer, Catharine Cameron

CITY OF TULARE

(County of Tulare)

Incorporated April 12, 1888

Legislative Districts: 17th Congressional; 15th Senatorial; 32nd Assembly

Chartered city. Population 19,050. Council meets first and third Tuesdays of month in Civic Affairs Bldg., 93274.

Central Telephone: 209-688-2001

Mayor: Philip E. Vandegrift
City Manager: W. Lynn Dredge

Vice-Mayor, Ila O. Harmon
Councilwoman, Thelma J. Gomez
Councilman, Duane Miller
Councilman, Oliver Mefford
City Clerk-Auditor, William H. Fishbough
Police Chief, Dale Anderson
Fire Chief, Ken Bridges

CITY OF TULELAKE

(County of Siskiyou)

Incorporated March 1, 1937

Legislative Districts: 1st Congressional; 1st Senatorial; 1st Assembly

General law city. Population 985. Council meets first and third Mondays of month at 7:00 p.m. (winter) 8:00 p.m. (summer) in City Hall, 96134.

Central Telephone: 916-667-5522

Mayor: Ron Peterson

Councilwoman, Mary Rogers
Councilman, Al Kongslie
Councilman, Dick Williams
Councilman, William McBride
City Clerk, William C. Whitaker
Police Chief, no name submitted
Fire Chief, Marvin Jerzykowski
Treasurer, Ardis McMahon
City Attorney, John Baker

CITY OF TURLOCK

(County of Stanislaus)

Incorporated February 15, 1908

Legislative Districts: 15th Congressional; 14th Senatorial; 27th Assembly

General law city. Population 26,002. Council meets second and fourth Tuesdays of month in Council Chambers, City Hall, 900 North Palm, 95380.

Central Telephone: 209-632-2311

Mayor: D. Dale Pickney
City Manager: Steven H. Kyte

Councilman, Harold Logsdon
Councilwoman, Penny Wade

Councilman, Charles Bakke
Councilman, Tom Howard
City Clerk, Vera Sahlstrom
Police Chief, John R. Johnson
Fire Chief, Larry F. Hughes
Treasurer, Carl E. Hillberg
School Superintendent, Dr. George A. Gustafson
City Attorney, Lou Ann Watson

CITY OF TUSTIN

(County of Orange)

Incorporated September 21, 1927

Legislative Districts: 40th Congressional; 35th, 36th and 37th Senatorial; 70th, 72nd and 74th Assembly

General law city. Population 39,761. Council meets first and third Mondays of each month in Council Chambers, City Center, 300 Centennial Way, 92680.
Central Telephone: 714-544-8890

Mayor: Donald J. Saltarelli
City Administrator: Dan Blankenship

Mayor pro Tem, Richard B. Edgar
Councilwoman, Ursula Kennedy
Councilman, Ronald B. Hoesterey
Councilman, James B. Sharp
City Clerk, Mary E. Wynn
Police Chief, Charles Thayer
School Superintendent, Dr. Maury Ross
City Attorney, James G. Rourke

CITY OF UKIAH

(County of Mendocino)

Incorporated March 8, 1876

Legislative Districts: 2nd Congressional; 2nd Senatorial; 2nd Assembly

General law city. Population 11,995. Council meets first and third Wednesdays of each month in Council Chambers, City Hall, 203 S. School St., 95482.
Central Telephone: 707-462-2971

Mayor: Hays Hickey
City Manager: Lyell C. Cash (Acting)

Mayor pro Tem, Charles Myers
Councilwoman, Kate Riley
Councilwoman, Mary Snyder
Councilman, Ted Feibusch
City Clerk, Hattie M. Tillotson
Police Chief, David Johnson
Fire Chief, Kenneth Donohue
Treasurer, Ruby Orr
School Superintendent, W. O. Murphy
City Attorney, Merle Orchard

CITY OF UNION CITY

(County of Alameda)

Incorporated January 26, 1959

Legislative Districts: 10th Congressional; 8th Senatorial; 15th Assembly

General law city. Population 36,550. Council meets first and third Mondays, 8:00 p.m., in Council Chambers, 34009 Alvarado-Niles Road, 94587.
Central Telephone: 415-471-3232

Mayor: Tom Kitayama
City Manager: Karen Smith

Vice-Mayor, Delaine Eastin
Councilwoman, Cecilia Boyle
Councilwoman, Jean Westgard
Councilman, Manuel Garcia
City Clerk, Karen Smith
Police Chief, Jere Bashinski (Acting)
Fire Chief, Kenneth C. Garcia
School Superintendent, Guy Emanuele

CITY OF UPLAND

(County of San Bernardino)

Incorporated May 15, 1906

Legislative Districts: 35th Congressional; 32nd Senatorial; 65th Assembly

General law city. Population 47,647. Council meets first and third Mondays of month at 7:00 p.m. in Council Chamber, City Hall, 460 N. Euclid Ave., 91786.
Central Telephone: 714-982-1352

Mayor: John E. McCarthy
City Manager: S. Lee Travers

Mayor pro Tem, Ina Petokas
Councilman, Frank A. Hoover
Councilman, Albert A. Canestro
Councilman, Frank J. Carpenter
City Clerk, Doreen K. Carpenter
Police Chief, Coy D. Estes
Fire Chief, Donald F. Justis
Treasurer, Walter F. Reardon
City Attorney, Donald E. Maroney

CITY OF VACAVILLE

(County of Solano)

Incorporated August 9, 1892

Legislative Districts: 4th Congressional; 4th Senatorial; 4th Assembly

General law city. Population 42,500. Council meets second and fourth Tuesdays of month in Council Chambers, City Hall, 650 Merchant St., 95688.
Central Telephone: 707-446-6700

Mayor: William J. Carroll
City Manager: Walter V. Graham

Vice-Mayor, Robert B. Pokorny
Councilman, David A. Fleming
Councilman, Bill Maher
Councilman, John M. Vasquez
City Clerk, Corinne L. Grannen
Police Chief, Gary Tatum
Fire Chief, Dale Geldert
City Attorney, Linzie E. Kramer
City Treasurer, Shirley Conroy

VALENCIA - LOS ANGELES

CITY OF VALLEJO

(County of Solano)

Incorporated March 30, 1868

Legislative Districts: 4th Congressional; 4th Senatorial; 8th and 4th Assembly

Chartered city. Population 75,226. Council meets every Monday of month at 8:00 p.m. in Council Chambers, City Hall, 555 Santa Clara Street, 94590.
Central Telephone: 707-553-4227

Mayor: Terry A. Curtola, Jr.
City Manager: Ted A. MacDonell

Vice-Mayor, Anthony J. Intintoli, Jr.
Councilman, Robert E. Keith
Councilman, Frank R. Castillo
Councilwoman, Barbara Kondylis
Councilman, Sidney C. Berry
Councilman, Fred K. Sibley
City Clerk, Mildred Watson
Police Chief, Roland C. Dart III
Fire Chief, Bill Patchell
School Superintendent, Philip Bowman
City Attorney, John Powers

CITY OF VENTURA

COUNTY OF VENTURA

(See City of San Buenaventura)

CITY OF VERNON

(County of Los Angeles)

Incorporated September 22, 1905

Legislative Districts: 29th and 30th Congressional; 24th and 29th Senatorial; 47th and 56th Assembly

General law city. Population 89. Council meets first and third Tuesdays a month in City Hall, 4305 Santa Fe Ave., 90058.
Central Telephone: 213-583-8811

Mayor: Leonis C. Malburg
City Administrator: Bruce V. Malkenhorst

Mayor pro Tem, Thomas A. Ybarra
Councilman, Hilario Gonzales
Councilman, Keith K. Kaeser
Councilman, William M. McCormick
City Clerk, Bruce V. Malkenhorst
Police Chief, Luis A. Espinoza
Fire Chief, George F. Bass
City Attorney, David B. Brearley

CITY OF VICTORVILLE

(County of San Bernardino)

Incorporated September 21, 1962

Legislative Districts: 37th Congressional; 16th Senatorial; 34th Assembly

General law city. Population 14,183. Council meets first and third Tuesdays of month at 7 p.m. at 14343 Civic Dr., 92392.
Central Telephone: 714-245-3411

Mayor: Jean DeBlasis
City Manager: James L. Cox

Mayor pro Tem, Don Hand
Councilman, Terry E. Caldwell
Councilman, Robert Dolch
Councilwoman, Peggy Sartor
City Clerk, Paula Porter
Fire Chief, Rodolfo N. Cabriales

CITY OF VILLA PARK

(County of Orange)

Incorporated January 11, 1962

Legislative Districts: 39th Congressional; 35th Senatorial; 70th Assembly

General law city. Population 7,375. Council meets third Thursday of month at 7:30 p.m. in Civic Center, 17855 Santiago Blvd., 92667.
Central Telephone: 714-998-1500

Mayor: Carol H. Kawanami
City Administrator: Maureen Cassingham

Mayor pro Tem, Robert N. Helton
Councilman, Robert E. McGowan
Councilman, William J. Odlum
Councilman Wayne W. Silzel
City Clerk, Carolyn Veregge
City Treasurer, Harold F. Tipton, Jr.
City Attorney, Leonard Hampel

CITY OF VISALIA

(County of Tulare)

Incorporated February 27, 1874

Legislative Districts: 18th Congressional; 15th Senatorial; 32nd Assembly

Chartered city. Population 52,559. Council meets first and third Mondays of month in City Hall, 707 W. Acequia St., 93291.
Central Telephone: 209-625-6318

Mayor: Reinold A. Peterson
City Manager: Ted A. Gaebler

Vice-Mayor, Berkley R. Johnson
Councilman, Gregory Collins
Councilman, Bonnel Pryor
Councilwoman, Jane E. Fiala
City Clerk, Donna Hall
Chief of Police Operations, Roy Springmeyer
Chief of Fire Operations, Harold Tucker
School Superintendent, Robert Line
City Attorney, Walter McCormick

CITY OF VISTA

(County of San Diego)

Incorporated January 28, 1963

Legislative Districts: 43rd Congressional; 38th Senatorial; 76th Assembly

General law city. Population 35,150. Council meets second and fourth Mondays at 7:00 p.m. and first Wednesday at 7:30 p.m., 600 Eucalyptus Avenue, 92083.

Mayor: Gloria E. McClellan
City Manager: Morris B. Vance

Mayor pro Tem, Daniel Carr
Councilman, Nancy Wade
Councilman, R. Michael Flick
Councilman, Lloyd vonHaden

City Clerk, Jean Brooks
Fire Chief, Harry Kaylor
School Superintendent, Dr. Jack Price
City Attorney, Nancy M. Jones

CITY OF WALNUT

(County of Los Angeles)

Incorporated January 19, 1959
Legislative Districts: 35th Congressional; 33rd Senatorial; 64th Assembly
General law city. Population 12,360. Council meets second and fourth Wednesdays of month at 8:00 p.m. in City Hall, 20550 E. Carrey Rd., 91789.
Central Telephone: 714-595-7543
Mayor: James Zamary
City Manager: Donald Kemp

Mayor pro Tem, Harvey Holden
Councilmember, Bertha "Bert" Ashley
Councilman, William Daley
Councilman, Joe Hahn
City Clerk, Beverly Sherwood
School Superintendent, Dr. David Brown
City Attorney, Scott Nichols

CITY OF WALNUT CREEK

(County of Contra Costa)

Incorporated October 20, 1914
Legislative Districts: 7th Congressional; 7th Senatorial; 10th Assembly
General law city. Population 52,730. Council meets first and third Tuesdays of each month at 7:30 p.m. in Council Chambers, City Hall, 1666 N. Main Street, 94596.
Central Telephone: 415-943-5800
Mayor: William H. Armstrong
City Manager: Thomas G. Dunne

Mayor pro Tem, Bruce Martin
Councilman, James Hazard
Councilwoman, Margaret W. Kovar
Councilman, Richard Hildebrand
City Clerk, Mary Lou Lucas
Police Chief, Karel Swanson
City Treasurer, Harley W. J. King
School Superintendent, Elmo Giulieri

CITY OF WASCO

(County of Kern)

Incorporated December 22, 1945
Legislative Districts: 18th Congressional; 16th Senatorial; 33rd Assembly
General law city. Population 9,534. Council meets first and third Mondays of month in City Hall, 764 E St., 93280.
Central Telephone: 805-758-3003
Mayor: Robert Rupert
City Manager: J. David Bates

Councilman, Paul Neufeld
Councilman, Jesse H. Winn
Councilman, Roy M. Johnson
Councilman, Otis R. Johnson
City Clerk, Pat Davis
Police Chief, Robert E. Duke

CITY OF WATERFORD

(County of Stanislaus)

Incorporated November 7, 1969
Legislative Districts: 14th Congressional; 13th Senatorial; 26th Assembly
General law city. Population 2,700. Council meets first and third Mondays of each month in City Hall, 320 "E" Street, 95386.
Central Telephone: 209-874-2328
Mayor: Phillip Stine
City Administrator: Henry G. Hesling

Vice-Mayor, Edith Kirk
Councilwoman, Thelma Sandburg
Councilman, Holley Breshears
Councilman, Warren Rinehart
City Clerk, Leota Collins
City Treasurer, Loyce Henderson
Police Chief, Robert Fulton
School Superintendent, Martin Peterson

CITY OF WATSONVILLE

(County of Santa Cruz)

Incorporated March 30, 1868
Legislative Districts: 16th Congressional; 17th Senatorial; 28th Assembly
Chartered city. Population 24,304. Council meets second and fourth Tuesdays of each month at 7:30 p.m. in City Hall, 250 Main St., 95076.
Central Telephone: 408-728-6000
Mayor: William Johnston
City Manager: John Radin

Councilmember, Vido Deretich
Councilmember, Betty Murphy
Councilmember, Ann Soldo
*Councilmember, Jean M. McNeil
*Councilmember, Charles A. Palmtag
*Councilmember, Frank Osmer
City Clerk, Dorothy Bennett
Police Chief, Al Williams
Fire Chief, Vernon Hamilton
City Attorney, Donald Haile
Public Works Director, John Cooper
Planning Director, Bob Ellenwood
Administrative Services Director, Chuck Comstock
Recreation Director, Patricia Donohue

*Council election 5/12/81

CITY OF WEED

(County of Siskiyou)

Incorporated January 25, 1961
Legislative Districts: 1st Congressional; 1st Senatorial; 1st Assembly
General law city. Population 2,983. Council meets

second Thursday of each month in Council Chambers, City Hall, 780 S. Davis Avenue, 96094.
Central Telephone: 916-938-4842
Mayor: Ruth Wagner Aiello
City Administrator: Lyle W. Larson

Mayor pro Tem, D. Everett Warren
Councilmember, Tom Mulvihill
Councilmember, Dino Peruzzi
Councilmember, William Warren
City Clerk, Lyle W. Larson
Police Chief, Charles Byrd
Fire Chief, Lawrence Hogue
School Superintendent, John Hines
City Attorney, J. P. Correia

CITY OF WEST COVINA

(County of Los Angeles)

Incorporated February 17, 1923
Legislative Districts: 26th, 30th, and 35th Congressional; 25th, 26th, and 33rd Senatorial; 60th, 62nd, and 64th Assembly
General law city. Population 75,000. Council meets second and fourth Mondays of each month in City Hall, 1444 W. Garvey Ave., 91790.
Central Telephone: 213-962-8631
Mayor: Chester Shearer
City Manager: Herman R. Fast

Mayor pro Tem, Herb Tice
Councilman, Kenneth I. Chappell
Councilman, Robert Bacon
Councilman, Forest Tennant
City Clerk, Helene M. Mooney
Police Chief, Craig L. Meacham
Fire Chief, Robert E. McClelland
Treasurer, Yvonne Calmes
City Attorney, Colin Lennard

CITY OF WESTMINSTER

(County of Orange)

Incorporated March 27, 1957
Legislative Districts: 34th, 38th and 40th Congressional; 36th and 37th Senatorial; 71st, 72nd and 73rd Assembly
General law city. Population 70,000. Council meets second and fourth Tuesdays of each month at 7:30 p.m. in Council Chambers, 8200 Westminster Ave., 92683.
Central Telephone: 714-898-3311
Mayor: Kathy Buchoz
City Administrator: Carl E. Berry

Mayor pro Tem, Evar Peterson
Councilman, Guinn "Gil" Hodges
Councilman, Conner Collacott
Councilman, Elden F. Gillespie
City Clerk, Mary Lou Morey
Police Chief, Jack Shockley
Fire Chief, W. E. Knowles
City Attorney, Paul Morgan

CITY OF WESTMORLAND

(County of Imperial)

Incorporated June 30, 1934
Legislative Districts: 43rd Congressional; 38th Senatorial; 75th Assembly
General law city. Population 1,417. Council meets first and third Wednesdays of month in City Hall, 355 S. Center St., 92281.
Central Telephone: 714-344-3411
Mayor: Ron Rodriquez

Councilman, Raul Rodriguez
Councilman, H. D. Graham
Councilwoman, Paula Riley
Councilman, Joe R. Reyna
City Clerk, Nadine K. Hale
Police Chief, George Wallet
Fire Chief, Andy Brown
Treasurer, M. A. Graham
School Superintendent, Ben Randi

CITY OF WHEATLAND

(County of Yuba)

Incorporated April 12, 1874
Legislative Districts: 1st Congressional; 1st Senatorial; 3rd Assembly
General law city. Population 1,480. Council meets first Monday of month in City Hall, 313 Main St., 95692.
Central Telephone: 916-633-2761
Mayor: Frank D. Chamberlain

Vice-Mayor, John C. Fleace
Councilwoman, Margaret A. Luyster
Councilman, Juanita M. Neyens
Councilman, Kenneth Kesterson
City Clerk, Helen J. Rose
Police Chief, Kee Han Ha
Fire Chief, Karl Nichols
Treasurer, Gladys H. Williges
City Attorney, Phillip F. Mohr

CITY OF WHITTIER

(County of Los Angeles)

Incorporated February 25, 1898
Legislative Districts: 33rd Congressional; 33rd Senatorial; 59th, 63rd and 64th Assembly
Chartered city. Population 71,199. Council meets first and third Tuesday after first Friday of month in Council Chambers, City Hall, 13230 Penn St., 96062.
Central Telephone: 213-698-2551
Mayor: Victor Lopez
City Manager: Thomas G. Mauk

Mayor pro Tem, Robert Henderson
Councilman, Lee Strong
Councilman, Myron Claxton
Councilman, Jere E. McDonald
City Clerk-Treasurer, Jenny Young
Police Chief, James F. Bale
City Attorney, Robert Flandrick

CITY OF WILLIAMS

(County of Colusa)

Incorporated May 10, 1920
Legislative Districts: 4th Congressional; 1st Senatorial; 3rd Assembly
General law city. Population 1,571. Council meets first and third Mondays of month in City Hall, 810 E St., 95987.
Central Telephone: 916-473-5421
Mayor: George D. Rollins

Councilman, Nancy Manor
Councilman, Gary J. Davis
Councilwoman, Kay K. Nordyke
Councilwoman, Emma G. Mock
City Clerk, Zelna Lee Morrow
Police Chief, Richard H. Kolos
Fire Chief, Tom Bascochea
City Attorney, Kenneth A. Wilson

CITY OF WILLITS

(County of Mendocino)

Incorporated November 19, 1888
Legislative Districts: 2nd Congressional; 2nd Senatorial; 2nd Assembly
General law city. Population 4,420. Council meets second and fourth Wednesdays of month in Council Chambers, City Hall, 111 E. Commercial St., 95490.
Central Telephone: 707-459-4601
Mayor: William L. Schrage
City Manager: George W. Gardner

Vice-Mayor, R. Wayne Bashore
Councilman, Wilma L. Sweazey
Councilman, Patricia L. Kearney
Councilman, Robert Comings
City Clerk, Frances Helton
Police Chief, Gerald Konoske
Fire Chief, David Thomen
Treasurer, Robert Fry
School Superintendent, Harold G. Engstrom
City Attorney, James F. King

CITY OF WILLOWS

(County of Glenn)

Incorporated January 16, 1886
Legislative Districts: 1st Congressional; 1st Senatorial; 1st Assembly
General law city. Population 4,715. Council meets Second Tuesday of each month in Civic Center, 201 N. Lassen St., 95988.
Central Telephone: 916-934-7041
Mayor: Ernest Matlock
City Manager: Russell L. Melquist

Vice-Mayor, Stephen J. Rath
Councilwoman, Barbara Fleming
Councilman, Jim "Jake" Jacobs
Councilman, R. B. Saint-Evens
City Clerk, Kathryn H. Lewis
Police Chief, Joseph E. Barnett, Jr.
Fire Chief, Bradley H. Mallory
Treasurer, Debbi Fonseca

CITY OF WINTERS

(County of Yolo)

Incorporated February 9, 1898
Legislative Districts: 4th Congressional; 4th Senatorial; 4th Assembly
General law city. Population 2,648. Council meets first and third Tuesdays of month in Council Chambers, City Hall, 318 First St., 95694.
Mayor: Jack J. Losoya

Vice Mayor, J. Robert Chapman
Councilman, John R. Martin
Councilman, John Kammerer
Councilman, Jack L. Atherton
City Clerk, Gale A. Bruhn
Police Chief, Steven C. Godden
Fire Chief, Vernon C. Bruhn
School Superintendent, Jack Graf

CITY OF WOODLAKE

(County of Tulare)

Incorporated September 23, 1941
Legislative Districts: 17th Congressional; 15th Senatorial; 31st Assembly
General law city. Population 5,413. Council meets second and fourth Mondays of month, 7:00 p.m., in City Hall, 350 N. Valencia Blvd., 93286.
Central Telephone: 209-564-8055
Mayor: Bill Diamond
City Manager: Dolph Frisius

Councilman, Norman McCoy
Councilman, Joseph Lapp
Councilman, Robert Johnson
Councilman, Jesse Reynoso
City Clerk, Ruth Gonzalez
Police Chief, Raymond Skerry

CITY OF WOODLAND

(County of Yolo)

Reincorporated March 24, 1874
Legislative Districts: 4th Congressional; 4th Senatorial; 4th Assembly
General law city. Population 29,814. Council meets first and third Tuesdays of month at 7:30 p.m. in Council Chambers, City Hall, 300 First Street, 95695.
Central Telephone: 916-662-5416
Mayor: Harry O. Walker
City Manager: Thomas A. Peterson

Councilmember, Daniel Partish
Councilmember, Dudley R. Holman
Councilmember, Darlene Jameson
Councilmember, William Keller
City Clerk, Jean Winnop
Police Chief, William Colston
Fire Chief, Al Feuerstein
Treasurer, John Dark

City Attorney, David T. Romney
Finance Director, John Dark

TOWN OF WOODSIDE

(County of San Mateo)

Incorporated November 16, 1956
Legislative Districts: 12th Congressional; 10th Senatorial; 20th Assembly
General law city. Population 5,151. Council meets second Tuesday of month at 7:30 p.m., 3155 Woodside Road, 94062.
Central Telephone: 415-851-7764
Mayor: Allan Newlands
Town Manager: Robert E. Myers

Mayor pro Tem, Melvin Yocum
Councilman, Robert S. Burgess
Councilman, Stanley Golden
Councilman, Robert Kirkwood
Councilman, Allan Newlands
Councilwoman, Joan Stiff
Town Clerk, Joan Olson
Fire Chief, Richard Figoni
Treasurer, William Jackson, Jr.
School Superintendent, George W. Sellman, Jr.

CITY OF YORBA LINDA

(County of Orange)

Incorporated November 2, 1967
Legislative Districts: 39th Congressional; 35th Senatorial; 70th Assembly
General law city. Population 29,150. Council meets first and third Mondays of month at 6:30 p.m., in the Yorba Linda School District Offices, 4999 Casa Loma Avenue, 92686.
Central Telephone: 714-524-5000
Mayor: Irwin M. Fried
City Manager: Arthur C. Simonian

Councilman, Robert McRoberts
Councilman, Rob Cromwell
Councilman, Henry W. Wedaa
Councilman, J. Todd Murphy
City Clerk, Dianna M. Higdon
Police Chief, Donald Forkus
Fire Chief, Carl Downs
School Superintendent, Sterling L. Fox
City Attorney, Leonard Hampel

TOWN OF YOUNTVILLE

(County of Napa)

Incorporated February 4, 1965
Legislative Districts: 2nd Congressional; 4th Senatorial; 8th Assembly
General law city. Population 2,949. Council meets second and fourth Tuesdays of each month at 7:00 p.m. in Town Hall, 6550 Yount Street, 94599.
Central Telephone: 707-944-8851
Mayor: Thomas Jordan
Town Administrator: Jon A. Lander

Mayor pro Tem, Donald R. Schmitt
Councilman, Earl Arnold
Councilman, Stephen Bardessono
Councilman, Warren Nelson
Town Clerk, Frances E. Field
Town Treasurer, Mrs. Barbara J. Dulinsky
Town Engineer, Jon A. Lander

CITY OF YREKA

(County of Siskiyou)

Incorporated April 21, 1857
Legislative Districts: 1st Congressional; 1st Senatorial; 1st Assembly
General law city. Population 5,929. Council meets first and third Thursdays of month in City Hall, 701 Fourth Street.
Central Telephone: 916-842-4386
Mayor: James W. Eckman
City Manager: James L. Dillon

Mayor pro Tem, Robert J. Ohlund
Councilwoman, Edna Barr
Councilman, James W. Eckman
Councilman, Donald Pierce
Councilman, Ronald Black
City Clerk, James L. Dillon
Police Chief, William E. Duncan
Fire Chief, Deane Jefferson
Treasurer, Jay F. Gamsby
City Attorney, Larry Bacon

CITY OF YUBA CITY

(County of Sutter)

Incorporated January 23, 1908
Legislative Districts: 4th Congressional; 1st Senatorial; 3rd Assembly
General law city. Population 18,770. Council meets first and third Mondays of month in City Hall, 1201 Civic Center Bldg., 95901.
Central Telephone: 916-674-1210
Mayor: Charles Pappageorge
City Administrator: Dwane Milnes

Councilman, Tom Pfeffer
Councilman, Lawrence Mark
Councilman, Joseph Fraser
Councilman, Ronald Southard
City Clerk, Al Johnson
Police Chief, Ismael Flores
Fire Chief, Chuck Lowden
Treasurer, Jack Kurtz
City Attorney, John Sanbrook

29. Everett, L.G., et al. "Constraints and Categories of Vadose Zone Monitoring Devices," Ground Water Monitoring Review, Winter 1984, pp 26-32

2646
2648

Constraints and Categories of Vadose Zone Monitoring Devices

by Lorne G. Everett, Edward W. Hoylman, L. Graham Wilson and Leslie G. McMillion

Abstract

Traditional monitoring methods using chemical analysis of ground water samples to detect pollutant migration are being superseded or used in conjunction with innovative approaches. A need to detect pollutants before they reach the water table has drawn interest to vadose (unsaturated) zone monitoring and brought together hydrogeologists, soil scientists and agricultural engineers who have been working on this subject for years.

Recent studies have identified over 50 different types of vadose zone monitoring devices and methods that have optimum utility in varying hydrogeologic settings. In general, measurements made in the vadose zone are trying to define storage, transmission of liquid waste in terms of flux and velocity, and pollutant mobility.

Criteria for the selection of alternative vadose zone monitoring methods are important for the development of site-specific systems. These criteria include: type of site; applicability to new, active, and abandoned sites; power requirements; depth limitations; multiple use capability; type of data collection system; reliability and life expectancy; degree of operational complexity; direct versus indirect methods; applicability to alternate media; effect on flow regime; and effect of hazardous waste on sampling or measurements. Application of the selection criteria is discussed in Everett et al. (1982a).

Vadose Zone Defined

The vadose zone is the geological profile from the ground surface to the upper surface of the principal water bearing strata. Figure 1 is an idealized cross section showing the vadose and saturated zones. The term "vadose zone" is preferable to the often-used term "unsaturated zone" for this region because saturated conditions are frequently present. The term "zone of aeration" is also often used as a synonym for vadose zone.

The vadose zone has been subdivided into three regions, designated as the soil zone, the intermediate vadose zone, and the capillary fringe (Davis and deWiest 1966). Weathering of native geological material, together with the process of eluviation and illuviation of colloidal materials, to develop more or less well-developed soil profiles is generally recognized to take place and thus defines the limits of the soil zone. Water movement in the soil zone is generally in the unsaturated state, i.e., that state in which the soil water exists under pressures that are less than atmospheric. The principal transport mechanisms associated with unsaturated flow are infiltration, percolation, redistribution and evaporation. Saturated regions may develop in the soil zone in response to surface flooding, especially in soils that contain horizons of low permeability. A large number of monitoring methods for the soil zone have been compiled by Black (1965) in a two-volume set entitled "Methods of Soil Analysis."

The soil zone gradually merges with the underlying intermediate vadose zone through a transition from weathered to generally unweathered native material.

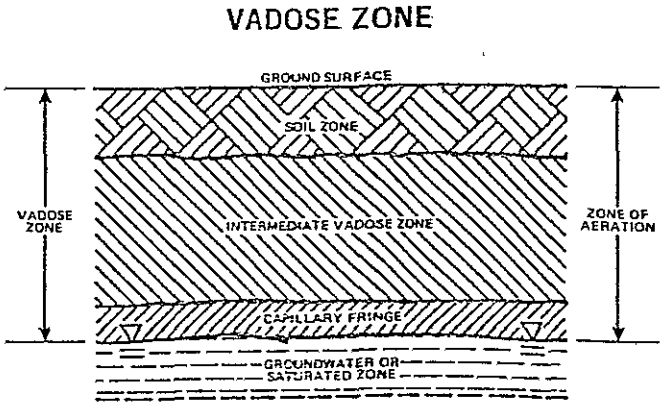


Figure 1. Idealized cross section of vadose and ground water zones

Figure 2, an alluvial basin in California, shows that the intermediate vadose zone is rarely uniform throughout. In some regions it may be practically non-existent, when soils merge directly with bedrock. Water movement through the intermediate vadose zone has been studied by McWhorter and Brookman (1972). Wilson (1979) provides additional information and references regarding the intermediate vadose zone.

The base of the vadose zone, the capillary fringe, merges with underlying saturated material of the principal water bearing formation. This zone is not characterized as much by the nature of geological materials as by the presence of water under conditions of saturation or near-saturation. In general, the thickness of the capillary fringe is greater in fine materials than in coarse deposits. Transient flow in the capillary fringe has been investigated by Taylor and Luthin (1969).

The thickness of the vadose zone will not necessarily be constant as shown in Figure 2. Pumping from the principal water bearing formation will lower the water table and modify the overall thickness of the zone of aeration. Conversely, waste disposal operations commonly create a mound throughout the capillary fringe reducing the thickness of the vadose zone.

Monitoring in the Vadose Zone

Monitoring in the saturated zone utilizes well-defined techniques familiar to hydrologists, geologists, and engineers. Hydraulic conductivity (permeability), storage coefficient and specific yield are parameters derived from well tests that define aquifer characteristics. Pumping tests provide adequate information to assess the storage and water movement through the formation. Chemical analysis of ground water samples generally completes the required information needed to assess the condition of the aquifer. In the vadose zone, where a large percentage of the flow is unsaturated, standard pump tests cannot always be used although researchers are still interested in similar parameters, i.e. storage, transmission of liquid through the strata, and chemical characteristics or pollutant mobility. A wide variety of alternative methods are used to derive information on these vadose zone characteristics. Table 1 gives alternative sampling methods and equipment used to define vadose zone characteristics along with constraint categories discussed by Everett et al. (1982a).

Categories of Vadose Zone Monitoring Techniques

Vadose zone monitoring techniques, i.e., collecting data on storage, transmission of fluids, and pollutant mobility, can be arbitrarily divided into two categories based on whether sample material is removed from the test location. Sampling methods can obtain either liquid or solid material. Extraction techniques of pore fluid from soil samples is dependent on whether inorganics, organics, or microorganisms are under investigation. Liquid sampling methods are dependent on whether fluid is taken from the saturated or unsaturated regions of the vadose zone. A detailed discussion of sampling techniques is given in Wilson (1979).

Non-sampling methods do not remove material from the test location and therefore provide indirect indication of the vadose zone characteristics. They include surface and downhole geophysical methods, numerical, and water budget-type techniques. These methods can be subdivided, depending on the specific property of the vadose zone that is being studied. Alternative methods for determining salinity, infiltration rate, flux, and velocity, using non-sampling techniques, are given in Everett et. al. (1982b).

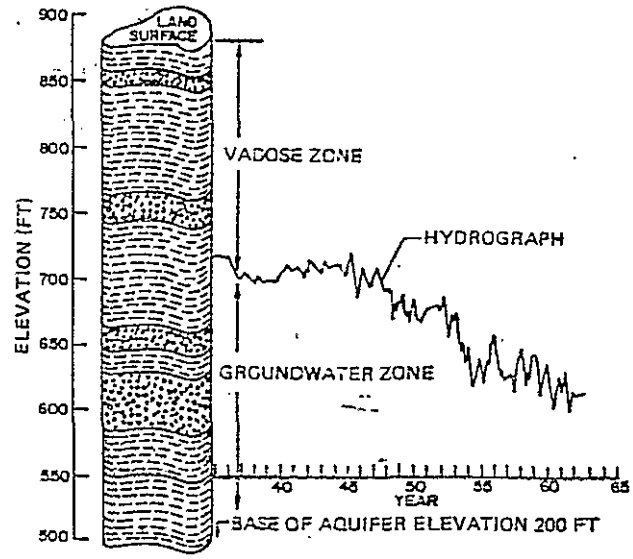


Figure 2. Cross section through the vadose zone and ground water zone (Ayers and Branson 1973)

Constraints on the Operation of Suction-type Sampling Devices

Factors that affect the operation of suction-type devices may be grouped as follows: (1) soil-physical properties, (2) hydraulic factors, (3) cup-waste water interactions, and (4) climatic factors. Specific constraints in each of these categories are summarized in Table 2.

Physical Properties

Soil texture refers to the size distribution of constituent particles, i.e. gravels, sand, silt, and clay. Successful operation of suction samplers requires continuity of pore sequences in the cup with those in the surrounding matrix. When soils are very coarse, particularly when gravels are present, ensuring good contact between the cup and the finer pore sequences may be difficult and the flow continuum may be destroyed. To ensure contact under such conditions, the usual procedure is to place the cup in a segment of an auger hole filled with silica flour.

Soil structure refers to the aggregation of the textural units into blocks. A well-structured soil has two distinct flow regions for liquids applied at the land surface: (1) through the cracks between blocks, i.e. interpedal flow, and (2) through the finer pore sequences inside the blocks, i.e. intrapedal flow. Simpson and Cunningham (1982) have shown that rapid flow of waste water through interpedal cracks may lessen the renovating capacity of the soil because of reduced surface area and contact face. Similarly, because of the rapid flushing of pollutants through larger interconnected soil pores, the movement of such pollutants into the finer pores of the soil blocks may be limited. Because suction-cup samplers collect water from these finer pore sequences, the resultant samples will not be representative of the bulk flow. Thus, Shaffer et al. (1979) concluded that "... surface installed, porous cup soil water samplers are unsuited to test leachate water composite when a highly structured soil is kept in a state of high water content."

A similar problem arises when suction cups are placed in fractured media or in a material containing

Table 1
Summary, vadose zone monitoring techniques—sampling methods

Property	Type of site: New	Type of site: Old	Applicability: Lab	Applicability: Field	Power requirements: ac	Power requirements: dc	Power requirements: Eng	Depth limit: No	Depth limit: Surf.	Depth limit: <30ft	Depth limit: >30ft	Mult use capability: Samp	Mult use capability: Meas	Data collection system: Man	Data collection system: Auto	Data collection system: Remote	Continuous sampling: Yes	Continuous sampling: No
Pollutant Mobility																		
I. Chemical/microbial properties w/liquid wastes in unsat region																		
A. Solids samples/extraction of pore fluid																		
1. Obtaining solids samples																		
a. Hand auger	•	•		•					•	•		•	•	N/A	N/A	N/A	N/A	N/A
b. Power auger	•	•		•			•		•	•	•	•	•	N/A	N/A	N/A	N/A	N/A
2. Obtaining solution samples																		
a. Hydraulic squeezer	•	•		•				•	•	•	•	N/A	N/A	N/A	N/A	N/A	N/A	N/A
b. Field sat. extract.	•	•		•				•	•	•	•	N/A	N/A	N/A	N/A	N/A	N/A	N/A
C. Lab sat. extract.	•	•		•				•	•	•	•	N/A	N/A	N/A	N/A	N/A	N/A	N/A
B. In-situ pore water samples																		
1. Lysimeters, vac oper	•			•				•	•	•		•	•	N/A	N/A	N/A	•	
2. Lysimeters, vac pres	•			•	•				•	•	•	•	•	N/A	N/A	N/A	•	
3. Lysimeters, high-pres vac	•			•					•	•	•	•	•	N/A	N/A	N/A	•	
4. Filter candle	•			•	•				•			•	•	N/A	N/A	N/A	•	
5. Hollow fiber filters	•		•	•				•	•			•		N/A	N/A	N/A	•	
6. Membrane filters	•		•	•				•	•			•		N/A	N/A	N/A	•	
II. Chemical/microbial properties w/liquid wastes in sat. regions																		
A. Integrated samples																		
1. Wells	•	•		•	•		•	•	•	•	•	•	•	N/A	N/A	N/A	•	
2. Collection pans	•	•		•	•		•		•	•		•		N/A	N/A	N/A	•	
3. Tile outflow	•	•		•				•		•	•	•		N/A	N/A	N/A	•	
B. Depthwise samples																		
1. Profile samples	•	•		•	•		•			•	•	•		N/A	N/A	N/A	•	
2. Multilevel sampler	•	•		•	•		•			•		•	•	N/A	N/A	N/A	•	•
3. Piezometers	•	•		•			•			•	•	•	•	N/A	N/A	N/A	•	

Property	Sample meas vol: Point/line	Sample meas vol: Bulk	Reliability and life expectancy: Good	Reliability and life expectancy: Quest.	Degree of complexity: Simple	Degree of complexity: Comp	Direct/indirect: Dir	Direct/indirect: Ind	Media: Porous	Media: Fract	Effect on flow region: Yes	Effect on flow region: No	Effect of haz waste type on res: Yes	Effect of haz waste type on res: No
Pollutant Mobility														
I. Chemical/microbial properties w/liquid wastes in unsat region														
A. Solids samples/extraction of pore fluid														
1. Obtaining solids samples														
a. Hand auger	•		•		•		•		•	•	•			•
b. Power auger	•		•		•		•		•	•	•			•
2. Obtaining solution samples														
a. Hydraulic squeezer	•		•	•	•		•		•			•	•	•
b. Field sat. extract.	•		•	•	•		•		•			•		•
C. Lab sat. extract.	•		•	•	•		•		•			•		•
B. In-situ pore water samples														
1. Lysimeters, vac oper	•		•		•		•		•	•	•			•
2. Lysimeters, vac pres	•		•		•		•		•	•	•			•
3. Lysimeters, high-pres vac	•		•		•		•		•	•	•			•
4. Filter candle	•		•		•		•		•	•	•			•
5. Hollow fiber filters	•			•	•		•		•	•	•			•
6. Membrane filters	•			•	•		•		•	•	•			•
II. Chemical/microbial properties w/liquid wastes in sat. regions														
A. Integrated samples														
1. Wells	•		•		•		•		•	•	•			•
2. Collection pans	•		•		•		•		•	•		•		•
3. Tile outflow		•	•		•		•		•	•		•		•
B. Depthwise samples														
1. Profile samples	•		•		•		•		•	•	•			•
2. Multilevel sampler	•		•		•		•		•	•	•			•
3. Piezometers	•		•		•		•		•	•	•			•

Table 2
Factors limiting the operation of suction-type sampling devices

Soil physical properties		Hydraulic factors	Cup waste water interactions	Climatic factors
1. Contact between cup and soils difficult to maintain in very coarse textured soils (e.g. gravels).	1. In highly structured soils and fractured material, the composition of fluid in cracks may differ from that in pores. Cups sample only from small pores. Consequently, cup samples may not be representative of "average" fluid.	1. Samples cannot be obtained when soils dry to the point that soil-water suction is great enough to allow air to enter cups when applying vacuum. 2. For very wet conditions fluid will move more rapidly in layer pores and cracks. Because of time lag, sample for cups may not be representative.	1. Solids moving with fluid may plug cups. 2. Bacteria may plug cups. 3. Trace metals may be attenuated during flow through cups. 4. Sorption of NH_4-N may occur. 5. Sorption of some organics (e.g. chlorinated hydrocarbons) may occur.	1. In frozen soils, the tension of unfrozen water is greater than air entry value of cups. 2. In freezing-thawing soils, the unit may shift in the profile and lose contact.

solution cavities. For these cases, high flow velocities through conducting channels may drain solutions before the cups can obtain a representative sample.

Hydraulic Factors

It is well established (Everett 1981) that suction-cup samplers fail as the soil-water suction increases to the point that air bubbles enter the cups. The soil-water pressure equivalent to this point is about -0.8 bar. In practice, however, many units fail at a pressure of about -0.5 bar. This appears to be a serious limitation in operating suction samplers. However, as Hillel (1971) pointed out, "Though the suction range of 0 to 0.8 bars is but a small part of the total range of suction variation encountered in the field, it generally encompasses the greater part of the soil wetness range."

Also, as noted under soil physical properties, when waste water is applied to a well-structured soil, the initial flow velocity may be quite high. Consequently, samples collected from cups installed within soil peds may not be representative of the bulk flow at that time.

Cup-Waste Water Interactions

An initial concern with lysimeters was that plugging may occur with time, limiting their effective lifetime (U.S.EPA 1980). In fact, this was the principal reason for not recommending suction samplers for monitoring at hazardous waste landfills and impoundments. Johnson, Cartwright, and Schuller (1981) conducted laboratory studies to evaluate the plugging of suction lysimeters with particulate matter in landfill leachate. They noted a distinct loss in yield from samplers in direct contact with leachate. A concomitant decrease in yield of identical lysimeters placed beneath a landfill was not observed, however. Apparently, particulate matter moving through the soil profile is filtered out before contacting the cups.

Dazzo and Rothwell (1974) conducted laboratory studies to determine the extent to which fecal coliforms are strained during suction-cup sampling. They observed a 100- to 10,000,000-fold reduction in fecal coliform in manure slurry during sampling, and 65 percent of the cups yielded coliform-free samples. Dazzo and Rothwell concluded that "... porcelain cup water samplers do not yield valid water samples for fecal coliform analyses."

Tsai et al. (1980) conducted laboratory studies to determine the attenuation of trace metals during movement of liquid through ceramic cups. They observed that nickel, copper, zinc, iron, manganese, and lead were consistently reduced by 5 to 10 percent during percolation through cups. Wagner (1962) found that NO_3-N was not adsorbed by cups, but sorption of NH_6-N did occur. Hansen and Harris (1975) found evidence that phosphorus was strongly adsorbed by cups, but concluded that sorption is only serious when "... the ceramic sorptive capacity is significantly greater than that of the adjacent soil."

Because a major concern at land treatment areas is the fate of organic pollutants, the effect of organic-cup interactions on sampling results is of paramount importance. According to Morrison and Tsai (1981), "Laboratory studies by Tsai et al. (1980) found that several pesticide species were substantially reduced when leached through a 0.32 cm thick ceramic cup with a pore size of 2.5 micron. Concentrations of the chlorinated hydrocarbons pp DDD', pp DDE', and pp DDT" were reduced 90 percent, 70 percent and 94 percent respectively."

Climatic Factors

A major factor limiting the operation of suction samplers (and tensiometers) in frozen soil is that the soil water suction is about -0.8 bar. This means that the air entry value of the cups is exceeded and samples cannot be obtained. Another effect of freezing temperatures is that some soils tend to heave during freezing-thawing. Consequently, suction-cup samplers may be displaced in that soil profile, resulting in a break in contact. Another undocumented problem that conceivably could occur is freezing of samples within the cups, precluding bringing them to the surface. In addition, if the cups are full when frozen, the cups may be fractured during expansion of the freezing liquid.

Flow velocity in porous media is inversely related to the viscosity of the fluid moving in the pores. An increase in temperature of a waste water, e.g. by hot ambient temperatures, would consequently increase the flow rate in soils at a disposal site. If the flow rate is excessive, suction samples may not obtain a true sample of the bulk fluid because of time lag effects.

Alternative Methods for Vadose Zone Sampling

When constraints limit the use of suction-type sampling devices, three alternatives are suggested for compiling data in the vadose zone. These are: (1) soil sampling, (2) sampling at the water table, and (3) vapor sampling.

The recently issued standards for land treatment areas (U.S. EPA 1982) specify soil sampling in addition to sampling pore fluids directly by suction sampling devices. Consequently, if these devices cannot be used for some reason, conducting soil sampling as carefully as possible is all the more important. The major disadvantage of soil sampling, however, is that it is essentially a destructive method; the same location cannot be resampled as with suction lysimeters. Consequently, delineating changes through time in constituents of interest is difficult. Since samples are required only from a relatively shallow depth, sampling can be carried out using hand augers or simple power equipment. Tube-type augers have been used extensively for soil sampling. The Veihmeyer tube is an example of a tube sampler used by soil scientists. E.R. de Vera et al. (1980) suggested using Veihmeyer tubes (Figure 3) when sampling for hazardous waste constituents. The end of the steel tube is beveled and sharpened to facilitate insertion into the soil. A drive hammer is used to force the tube to the desired depth and an intact core is obtained. Another technique is the so-called "dry tube" method developed by Dunlap et al. (1977). This method consists of augering a hole to the desired depth and forcing a dry tube core sampler into the sampling region. Contamination problems are avoided because drilling fluid is not used. Care in sample storage and preservation is important to prevent loss or dissipation of constituents of interest, especially when sampling for organics. Fenn et al. (1977) describe techniques for extracting pore water from unsaturated soil, including a hydraulic squeezer. Dao and Levy (1978) describe a simple centrifugation method for extracting soil solution in the laboratory. Extraction of volative organics from undisturbed soil cores required displacing pore gases with an inert gas, such as helium, and analyzing the displaced gas with a gas chromatograph (GC).

Many proposed and existing land treatment areas are probably in regions where water tables are in close proximity to the lower limit of the treatment zone. For such sites, shallow well installations are highly recommended to permit sampling near the water table. Such samples will represent fluid that has passed through the vadose zone. The preferred method is the multilevel sampler, developed by Pickens et al. (1978) (Figure 4). This sampler is particularly advantageous in that shallow plumes can be easily identified by locating sampling ports at staggered intervals beneath the water table. In addition, ports can be included above the low water table level to facilitate sampling during periods of water table rise, and also gas sampling. All-metal construction should be employed instead of the usual PVC to avoid interference when sampling for organics.

Finally, at sites where volative organics are being disposed of, installing screened well points beneath the treatment zone to collect soil gas samples may be desirable. (This approach may be desirable even when suction lysimeters cannot be used.) Multilevel samplers, of all-metal construction to avoid contamination, can also be used to collect soil gas samples. Gas samples can be analyzed directly in the field using portable GC units.

References

Ayers, R.S. and R.L. Branson, editors. 1973. Nitrates in the Upper Santa Ana River Basin in relation to ground water pollution. California Agric. Exp. Station. Bulletin 861.

Black, C.A., editor. 1965. Methods of soil analyses (in two parts). Agronomy no. 9. Am. Soc. of Agronomy. Madison, Wisconsin.

Dao, T.H. and T.L. Levy. 1978. Extraction of soil solution using a simple centrifugation method for possible adsorption - desorption studies. J. Soil Sci. Soc. Amer., v. 42, pp. 375-377.

Davis, S.N. and R.J.M. deWiest. 1966. Hydrogeology. John Wiley and Sons Inc. New York

Dazzo, F.B. and D.F. Rothwell. 1974. Evaluation of porcelain cup samplers for bacteriological sampling. App.

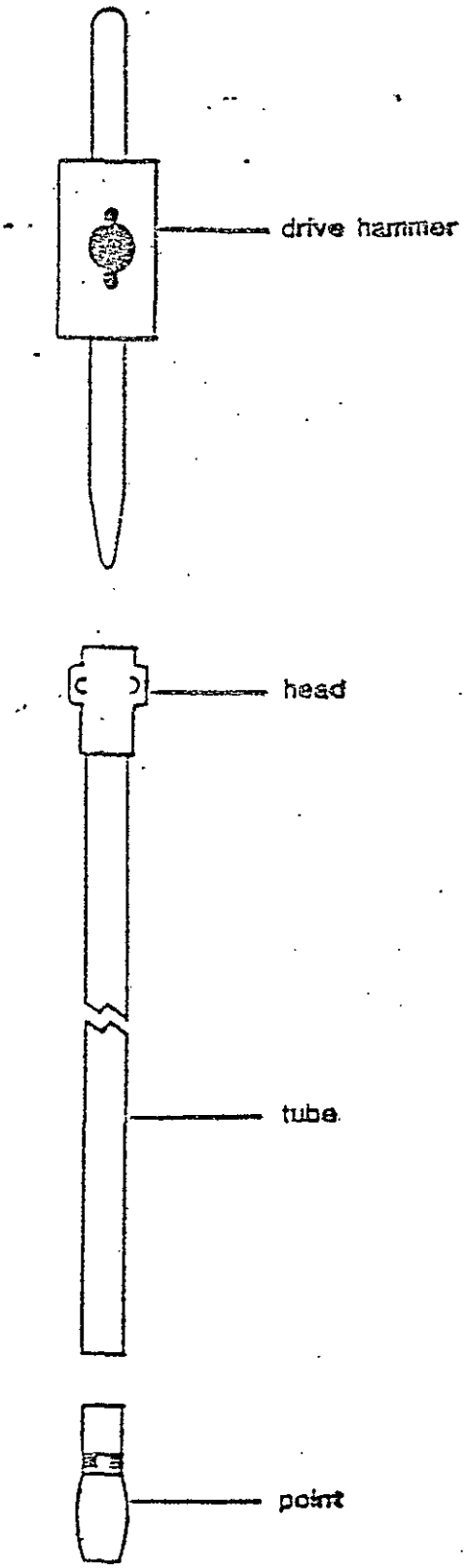


Figure 3. Veihmeyer tube

Microbiology, v. 27, pp. 1172-1174.
deVera, E.R., B.P. Simmons, R.D. Stephens and D.L. Storm. 1980. Samplers and sampling procedures for hazardous waste streams. U.S. EPA, Municipal Env. Res. Lab. Cincinnati, Ohio. EPA-600/2-77-176.
Dunlap, W.J., J.R. McNabb, M.R. Scalf and R.L. Cosby. 1977. Sampling for organic chemicals and microorganisms in the subsurface. U.S. EPA. Ada, Oklahoma. EPA-600/2-80-018.
Everett, L.G., L.G. Wilson and L.G. McMillion. 1982a. Vadose zone monitoring concepts for hazardous waste sites. Ground Water, v. 20, no. 3, pp. 312-324.
Everett, L.G., E.W. Hoylman and L.G. Wilson. 1982b. Vadose zone monitoring for hazardous waste sites. Kaman Tempo.
Everett, L.G. 1981. Monitoring in the vadose zone. Ground Water Monitoring Review, v. 1, no. 2, pp. 44-51.
Fenn, D., E. Cocozza, J. Isbister, O. Briads, B. Yare and P. Roux. 1977. Procedures manual for ground water monitoring at solid waste disposal facilities. U.S. EPA, Office of Solid Waste. EPA/530/SW-618.
Hansen, E.A. and A.R. Harris. 1975. Validity of soil-water samples collected with porous ceramic cups. Soil Sci. Soc. Amer. Proc., v. 39, pp. 528-536.
Hillel, D. 1971. Soil and water. Academic Press. New York.
Johnson, T.M., K. Cartwright and R.M. Schuller. 1981. Monitoring of leachate migration in the unsaturated zone in the vicinity of sanitary landfills. Ground Water Monitoring Review, v. 1, no.3, pp. 47-54.
McWhorter, D.B. and U.A. Brookman. 1972. Pit recharge influenced by subsurface spreading. Ground Water, v. 10, no. 5, pp. 6-11.
Morrison, R.D. and T.C. Tsai. 1981. Modified vacuum-pressure lysimeter for vadose zone sampling. Calscience Research Inc. Huntington Beach, California.
Pickens, J.F., J.A. Cherry, G.E. Gisak, W.F. Merritt and B.A. Risto. 1978. A multilevel device for ground water sampling and piezometer monitoring. Ground Water, v. 17, no. 4, pp. 393-397.
Shaffer, K.A., D.D. Fritton and D.E. Baker. 1979. Drainage water sampling in a wet, dual-pore soil system. J. Env. Qual., v. 8, no. 2, pp. 241-246.
Simpson, T.W. and R.L. Cunningham. 1982. The occurrence of flow channels in soils. J. Env. Qual., v. 11, no. 1, pp. 29-30.
Taylor, G.S. and J.N. Luthin. 1969. The use of electronic computers to solve subsurface drainage problems. Water Resources Research, v. 5, no. 1, pp. 144-152.
Tsai, T.C., R.D. Morrison and R.J. Stearns. 1980. Validity of the porous cup vacuum/suction lysimeter as a sampling tool for vadose waters. Unpublished report.

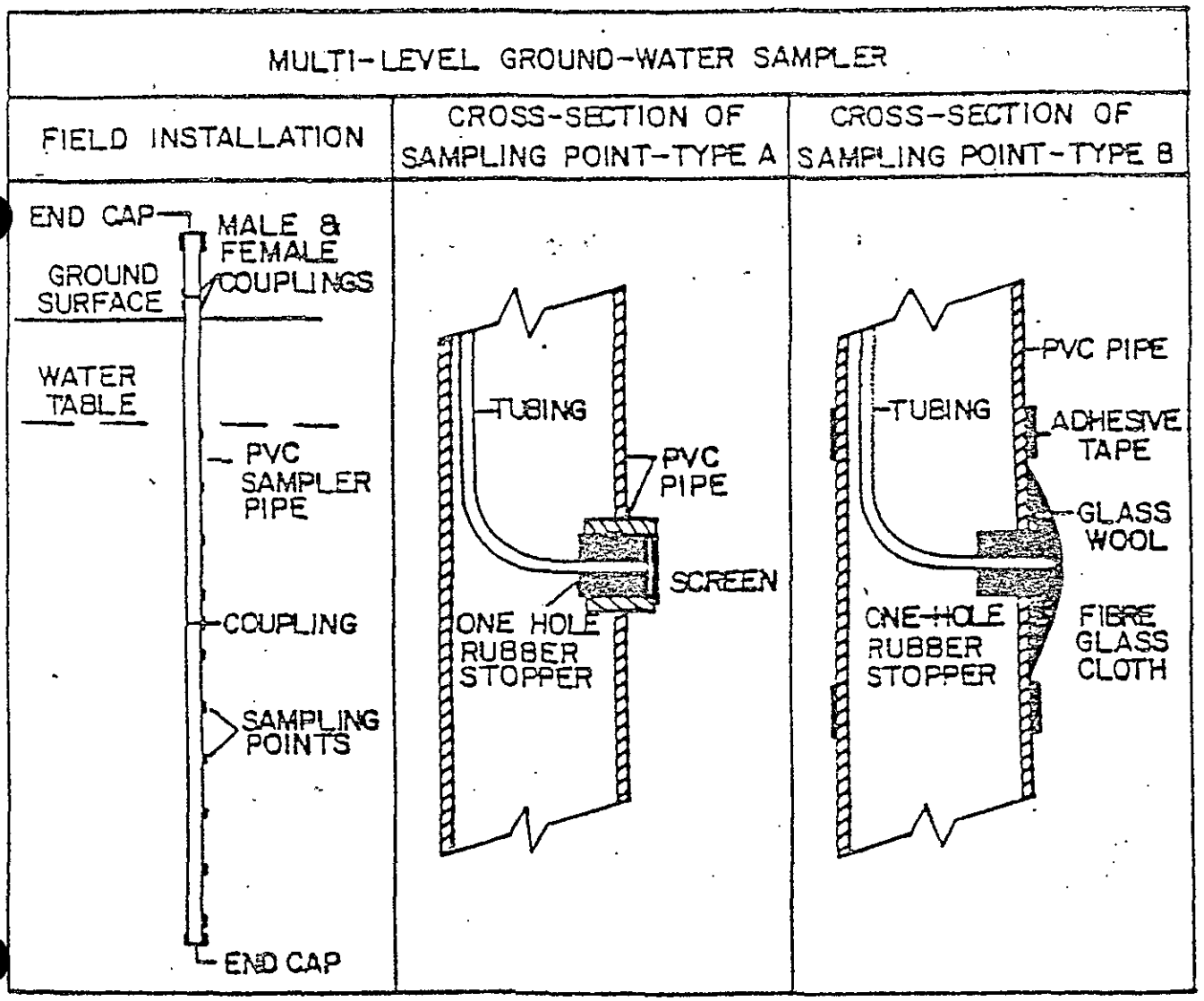


Figure 4. Multilevel sampler (Pickens et al. 1978)

Calscience Research Inc. Huntington Beach, California. pp. 1-11.
U.S. Environmental Protection Agency. 1982. Hazardous waste management system; permitting requirements for land disposal facilities. Federal Register, v. 47, no. 143, pp. 32274-32382.
U.S. Environmental Protection Agency. 1980. Hazardous waste and consolidate permit regulation. Federal Register, v. 45, no. 98, book 2, pp. 33063-33588.
Wagner, G.H. 1962. Use of porous ceramic cups to sample soil water within the profile. Soil Sci., no. 94, pp. 379-386.
Wilson, L.G. 1979. Monitoring in the vadose zone: A review of technical elements land methods. Kaman Tempo. Santa Barbara, California.

Biographical Sketches

E.W. Hoylman (Kaman Tempo, Natural Resources Program, 816 State Street, P.O. Drawer QQ, Santa Barbara, CA 93102) is a senior hydrogeologist who received his B.S. in hydrology and geology from the University of Hawaii in 1970 and his M.S. in geology in 1974. He is a co-author of several papers developing vadose zone monitoring concepts. His recent research focuses on application of geophysical methods for use in the vadose zone.

Lorne G. Everett (Kaman Tempo, Natural Resources Program, 816 State Street, P.O. Drawer QQ, Santa Barbara, CA 93102) is the manager of the Natural Resources Program at Kaman Tempo, Santa Barbara, California. In addition to authoring more than 75 professional papers, Dr. Everett is the author of the handbook entitled "Ground Water Monitoring."

L.G. Wilson (Water Resources Research Center, University of Arizona, A.E. Douglas Building, #28, Tucson, AZ 85721) is a hydrologist with the Water Resources Research Center at the University of Arizona, Tucson, Arizona. Dr. Wilson is the author of the state-of-the-art report titled "Monitoring in the Vadose Zone: A Review of Technical Elements and Methods."

L.G. McMillion (U.S. EPA, Environmental Monitoring Systems Lab., P.O. Box 15027, Las Vegas, NV 89114) is a senior hydrologist with the EPA Environmental Systems Laboratory, Las Vegas, Nevada. McMillion is the EPA project officer who has been responsible for major research programs directed toward establishing national monitoring strategies and ground water monitoring guidelines for energy extraction sites.

30. Everett L.G., et al. "Monitoring Ground Water Quality: Methods and Costs," USEP A, Las Vegas, Nevada, 1976, pp. 87-88

SACRAMENTO OFFICE
610 BERCUT DRIVE
SACRAMENTO, CA 95
PB-257 133

Monitoring Groundwater Quality: Methods and Costs

L. G. Everett, et al

General Electric Company -TEMPO
Santa Barbara, California

May 1976

U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
NTIS

EPA-600/4-76-023
May 1976

MONITORING GROUNDWATER QUALITY: METHODS AND COSTS

by

Lorne G. Everett
Kenneth D. Schmidt
Richard M. Tinlin
David K. Todd

General Electric Company—TEMPO
Center for Advanced Studies
Santa Barbara, California 93101

Contract No. 68-01-0759

Project Officer

George B. Morgan
Monitoring Systems Research and Development Division
Environmental Monitoring and Support Laboratory
Las Vegas, Nevada 89114

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RESEARCH AND DEVELOPMENT
ENVIRONMENTAL MONITORING AND SUPPORT LABORATORY
LAS VEGAS, NEVADA 89114

TABLE OF CONTENTS

	Page
ACKNOWLEDGMENTS	iii
ABSTRACT	iv
LIST OF ILLUSTRATIONS	vi
LIST OF TABLES	viii
SECTION I — INTRODUCTION	1
Purpose	1
Scope	1
Hydrogeological Framework	2
Groundwater Monitoring Methods	4
Types of Cost	5
SECTION II — MONITORING AT THE LAND SURFACE	11
Introduction	11
Nonsampling Methods	11
Sampling Methods	25
SECTION III — MONITORING IN THE VADOSE ZONE	29
Introduction	29
Soil Sampling and Well Drilling	31
Determination of Water Content	33
Determination of Water Movement	42
Water Movement in the Unsaturated State	44
Water Sampling in the Vadose Zone	49
SECTION IV — MONITORING IN THE ZONE OF SATURATION	57
Introduction	57
General Monitoring Procedures	57
Specific Monitoring Methods	62
SECTION V — ANALYSIS OF SAMPLES	100
Introduction	100
Custody Control	100
Quality Control	103
Soil	105
Water	113
REFERENCES	130
APPENDIX — METRIC CONVERSION TABLE	140

LIST OF ILLUSTRATIONS

Figure No.	Title	Page
1	Schematic diagram of groundwater pollution from surface sources.	3
2	Small-diameter well costs index and the ENR materials component.	6
3	Large-capacity well costs index and the ENR construction cost index.	7
4	Cost of testing submerged tanks of various volumes, November 1974.	14
5	Alerting procedure chart for hazardous material spills.	24
6	Cost of power-augering 8-inch diameter sample holes to various depths and hole densities, November 1974.	32
7	Sketch of neutron moisture logger and accessories.	34
8	Moisture logs showing growth and dissipation of mounds in the vadose zone.	37
9	Cost of neutron moisture logging for various depths and sample space densities, December 1974.	38
10	A single manometer tensiometer.	38
11	Cost of tensiometers for various depths and sample space densities, December 1974.	39
12	Cost of multiple electrical resistance blocks and soil moisture meter for various depths and sampling densities, December 1974.	40
13	Relationship between grain size and water-storage properties of alluvium from large valleys.	41
14	Cost of piezometers for various depths and sampling densities, November 1974.	44
15	Cross section of suction cup assembly and backfilling material.	53
16	Cross section of porous cup assembly with pressure control.	54

ILLUSTRATIONS (continued)

Figure No.	Title	Page
17	Cost of soil salinity sensors and a salinity bridge for various depths and sampling densities, November 1974.	56
18	Cost of shallow, small-diameter monitor wells, October 1974.	66
19	Updated (1975) cost of 4-, 5-, and 6-inch wells in sand and gravel.	77
20	Updated (1975) cost of 4-, 5-, and 6-inch wells in consolidated rock.	78
21	Generalized cost of coring in unconsolidated and consolidated formations, October 1974.	81
22	Cost of electrical conductivity (EC) and gamma logging, September 1974.	83
23	Cost of steel tapes, September 1974.	84
24	Cost of electric sounder and cable, September 1974.	85
25	Approximate cost of sampling wells (one round), December 1974.	90
26	Cost of cable and flex hose for use with portable submersible pumps, October 1974.	92
27	Power costs for continuous pumping of 1 hour, 1 day, 1 week, for specific pumping heads and specific discharge rates, December 1974.	97
28	Costs for determinations of water content and bulk density in soils, September 1974.	105
29	Modified Haines Apparatus for obtaining soil-water characteristic curves.	108
30	Soil-water characteristic curve, showing hysteresis.	109

LIST OF TABLES

Table No.	Title	Page
1	Example of ENR indexes for September 12, 1974	8
2	Example of EROS data center standard costs—satellite products, October 1974	17
3	Land-use classification system for use with remote-sensor data	20
4	Total cost of aerial surveillance for land-use mapping, July 1974	21
5	Specific yield values assumed for the southern part of the Central Valley, California	42
6	Earth resistivity survey costs, December 1974	64
7	Costs in dollars for well drilling in unconsolidated formations, EPA Regions III and IV, October 1974	70
8	Costs in dollars for well drilling in consolidated formations, EPA Regions III and IV, October 1974	71
9	Black pipe casing costs for wells in dollars, EPA Region IX, October 1974	72
10	PVC pipe costs for wells in dollars, EPA Region IX, October 1974	72
11	Average cost of submersible water pumps, found in EPA Region IX, October 1974	93
12	Hydrologic laboratory tests and cost schedule, September 1974	110
13	Recommended sampling and preservation techniques for inorganic chemical determinations	119
14	Costs of inorganic chemical determinations for groundwater pollution, October 1974	122
15	Costs of organic chemical determinations for groundwater pollution, October 1974	125
16	Recommended sampling and preservation techniques for organic chemical determinations	126

TABLES (continued)

Table No.	Title	Page
17	Costs of bacterial analysis for groundwater pollution, October 1974	128
18	Costs of radiochemical analysis in groundwater pollution, October 1974	129

SECTION III

MONITORING IN THE VADOSE ZONE

INTRODUCTION

Topsoil

The topsoil is the region that manifests the effects of weathering of geological materials, together with the processes of eluviation and illuviation of colloidal materials, to form more or less well developed profiles (Simonson, 1957). Water movement in the topsoil usually occurs in the unsaturated state, where soil water exists under less-than-atmospheric pressures. The physics of unsaturated, soil-water movement have been intensively studied by soil physicists, agricultural engineers, and others. Copious literature is available on the subject in periodicals (Soil Science Society of America Proceedings, Soil Science, and Journal of Environmental Quality) and textbooks (Childs, 1969; Kirkham and Powers, 1972). Saturated zones may develop over horizons of low permeability. A number of books are available on the theory of flow in perched water tables (Luthin, 1957; van Schilfgaarde, 1974). Soil chemists and soil microbiologists have also attempted to quantify the chemical-microbiological transformations during soil-water movement (Rhoades and Bernstein, 1971; Dunlap and McNabb, 1973).

Vadose Zone

Weathered materials of the topsoil gradually merge with underlying materials such as igneous or metamorphic rocks, alluvium, lake deposits, eolian deposits, or lacustrine beds. The region beneath the topsoil and overlying the water table, where water exists primarily in the unsaturated state, is known as the vadose zone. Perched water tables may develop above interfaces between layers having greatly different textures. Saturated conditions may also develop beneath recharge sites as a result of prolonged infiltration. In contrast to the large number of studies on water movement in the topsoil, parallel studies in the vadose zone have been few. Meinzer (1942) coined the term "no-man's land of hydrology" to describe the limited knowledge of this zone.

Monitoring Techniques

A number of techniques have been developed for monitoring water movement and water quality in the topsoil. Detailed descriptions, specifications, and methods of many of these techniques were compiled in American Society

of Agronomy Monograph No. 9, "Methods of Soil Analysis" (Black, 1969). Monitoring in the vadose zone requires an extension of topsoil monitoring technology. Examples are available where this approach has been used; Apgar and Langmuir (1971), for example, successfully used suction cups, developed for sampling soil solutions, to sample at depths up to 50 feet below a sanitary landfill. Of primary interest are flow rates to the water table and the storage capacity of the materials above the water table.

Water Content

Soil and underlying geologic materials consist of a solid and porous matrix. Porosity is a measure of the amount of water which could be stored by the materials under saturated conditions. Field capacity of a soil is represented by its water content (on a dry weight basis) at a certain time after the initiation of drainage following an irrigation cycle (Peters, 1965). The definition of specific retention for geologic materials is essentially the same, except that the water content is expressed on a volumetric basis. Specific yield or effective porosity of geologic materials is the difference between porosity and specific retention. At a given time, the volumetric water content of a material is a reflection of various forces acting on the soil-water system, including gravity, capillary, and osmotic forces. Soil-water pressure is a measure of capillary forces and is expressed in terms of negative pressure; the relation between water content and pressure may be determined in the laboratory. This relation is essential to calculate water flow rates in the vadose zone.

Water Flow

Infiltration is the movement of water across the soil surface from an applied water source. Factors affecting infiltration capacity, or the maximum rate of infiltration, include soil texture, initial water content, and soil stratification. Determination of the rate of water flow out of a given soil depth may be determined from sequential drainage profiles (curves showing the relation between soil depth and water content for various times after the cessation of infiltration). The salinity and composition of the solution may have a pronounced effect on water movement.

For saturated materials the pressure is positive and measured by piezometers. For unsaturated materials the pressure is negative and measured by tensiometers.

Chemical Changes

The interactions of infiltrating water and soil have been reviewed by Ellis (1973), Rhoades and Bernstein (1971), Murrmann and Koutz (1972) and McNeil (1974). Among the main reactions are: precipitation, dissolution, ion exchange, adsorption, and oxidation-reduction.

Changes in the concentration of a soil solution following surface application include water removal by evaporation and transpiration. Precipitation of slightly soluble salts, primarily calcium carbonate or calcium sulfate, may occur as the soil solution is concentrated during evapotranspiration. Dissolution of soil minerals contributes to the salinity of the soil solution. Ion exchange represents an important soil-water interaction for altering the composition of the soil solution. Ion exchange is a function of the cation exchange capacity of the soil, which in turn is related to colloidal clay minerals, soil organic matter, iron and aluminum sesquioxides, and hydrous oxides.

Adsorption of metals onto the surface of soils is the most important process for removing some chemicals from wastewater (Murrmann and Koutz, 1972). In contrast to ion exchange, in which ions retain their mobility, in adsorption reactions ions are held so tightly that they become essentially immobile. Methods to quantify the extent of adsorption of ions onto solids have been developed. Oxidation and reduction reactions are of special importance in the case of sulfur and nitrogen compounds in water, as well as for many trace elements. These reactions affect the mobility of some elements and may result in the production of gases which can be lost from the soil-groundwater system.

SOIL SAMPLING AND WELL DRILLING

A test drilling program may be necessary to supplement existing data on the vadose zone at a site. Soil sampling and well drilling are generally necessary for all types of monitoring in the vadose zone. Test wells can also function as observation wells, piezometers, or access wells.

Shallow Wells

In general, samples from the soil zone are obtained to (1) characterize the average soil texture, water content, or chemistry in depth increments (e.g., 15 cm), (2) observe the precise depth distribution of soil texture, or (3) determine the bulk density, or water-release curves, of soil increments. For the first purpose land samplers such as post-hole augers, screw or sleeve type augers, or power-driven augers are useful. For the second purpose, cores are obtained by driving small-diameter (e.g., 2.5 cm) tubes into the soil to the desired depth. For the third purpose, larger diameter core samplers are used—these may be hand-driven or power-driven. Cores of a specific volume are obtained by each method. More information on coring is presented by Blake (1965).

The cost of a "bucket" type hand auger is about $35. These augers are available to cut core sizes from 2 to 4 inches in diameter. Four-foot extensions for deeper sampling cost about $6 each. For deeper samples a hand-driven soil sampler system can be purchased. These systems include soil

sampling tubes, a drop hammer, and a tube puller jack to withdraw the tubes. The soil sampling tubes vary from 4 to 16 feet in length and cost from $65 to $115, respectively. The cost of the hammer and puller jack is about $200.

Deeper Wells

To sample throughout the vadose zone it may be necessary to drill deep wells using standard techniques. Such techniques include jetting, rotary, cable tool, augering, and air drilling. Of these methods perhaps augering, using continuous flights, and air drilling provide the most usable samples—problems develop in characterizing the distribution of indigenous salt and water content with cable tool and rotary methods because of water additions during the drilling process. The cost of power-augering multiple depth and density holes is given in Figure 6. These augering costs are developed for 8-inch diameter holes.

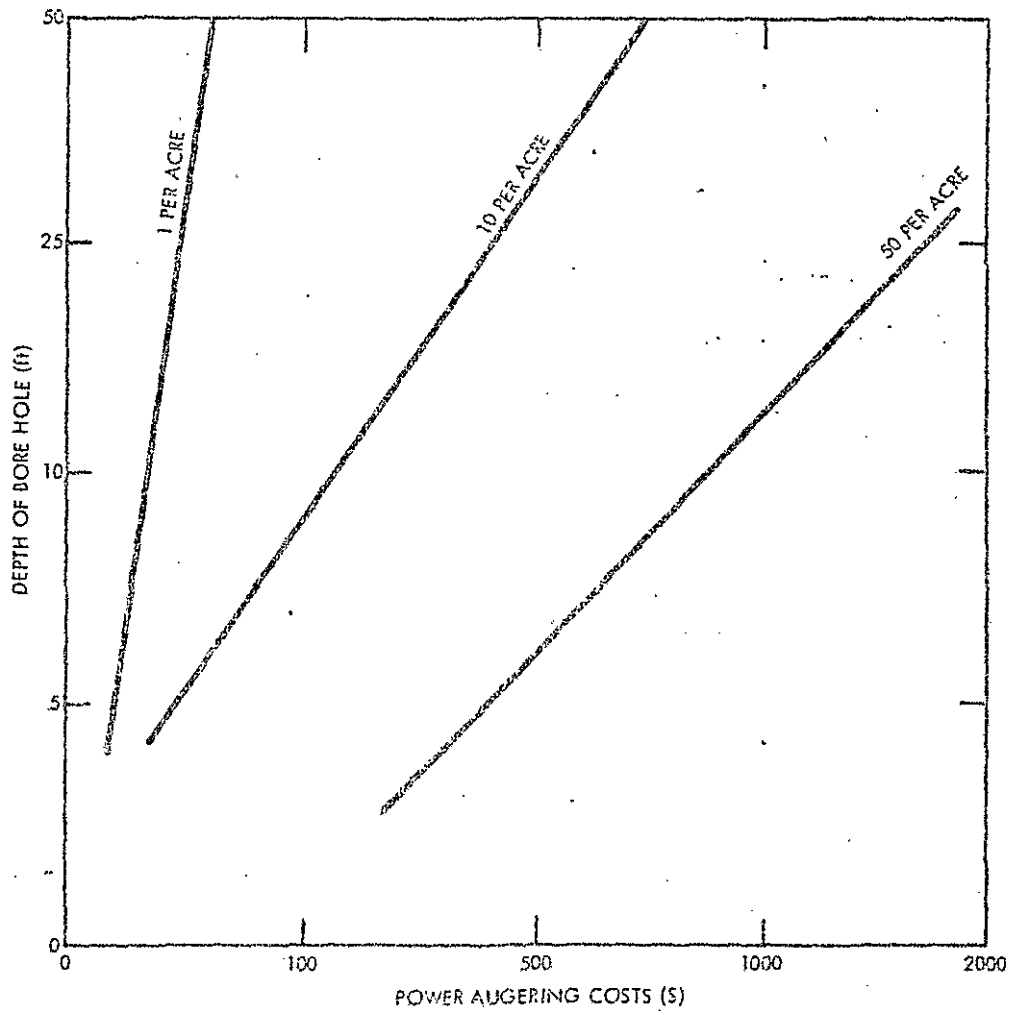


Figure 6. Cost of power-augering 8-inch diameter sample holes to various depths and hole densities, November 1974.

One air-drilling technique (Becker Drills, Inc., Denver, Colo.) involves driving a double-wall tube by a pile hammer while concurrently forcing air under pressure down the annulus of the pipe. Air and entrained material cut by the bit return to the surface through the inside pipe. The sample, available continuously, is diverted into a cyclone sampler where it is bagged for laboratory analyses. Changes in formation can be determined within a few centimeters; furthermore, water seams can be determined immediately. This feature is advantageous in locating the depth and thickness of perching layers. Whichever technique is used, samples should be taken in specified increments throughout the vadose zone.

DETERMINATION OF WATER CONTENT

Although a major concern of a monitoring program may be the movement of water in the vadose zone, it is also important to account for the storage capabilities of this zone. In western valleys with deep alluvium the vadose zone may constitute a vast reservoir for such in-transit storage.

Examining this water content requires the extension of techniques employed in the soil zone downward to the water table. Fortunately, many of the methods may also be used simultaneously to monitor water movement.

Neutron Moderation or Moisture Logging

For many years agriculturists have employed the principle of neutron moderation or thermalization to measure the volumetric water content of soils in situ. Recently, the technique has been used to monitor water storage in the vadose zone, particularly to delineate perching layers and mounds, and also to estimate flow rates.

The method of water content evaluation by neutron moderation depends on two properties relating to the interaction of neutrons with matter: scattering and capture (Gardner, 1965). High-energy neutrons, emitted from a radioactive source are slowed down, or thermalized, by collisions with atomic nuclei. Hydrogen has a greater thermalizing effect on fast neutrons than occurs with many elements commonly found in soils. This forms the basis for detecting the concentration of water in a soil (Van Bavel, 1963). The second property of interest in the neutron moderation method is capture of slow neutrons by elements present in the soil with the release of energy. The property of energy release during capture serves as a means of detecting the concentration of slow neutrons.

When a source of fast neutrons is lowered into a soil through a suitable well bore or casing, a cloud of thermalized neutrons is established. If a suitable calibration is made to isolate the moderating effects of soil nuclei other than hydrogen, changes in the volume of the thermalized cloud will reflect changes in water content. Finally, a detector which relies on capture

of thermalized neutrons is used, in conjunction with suitable electronic circuitry, to measure the water content (on a volume basis).

Instrumentation used to measure water content by neutron thermalization requires three principal components: (1) a source of fast neutrons, (2) a detector of slow neutrons, and (3) an instrument to determine the count rate from the detection equipment, as shown in Figure 7.

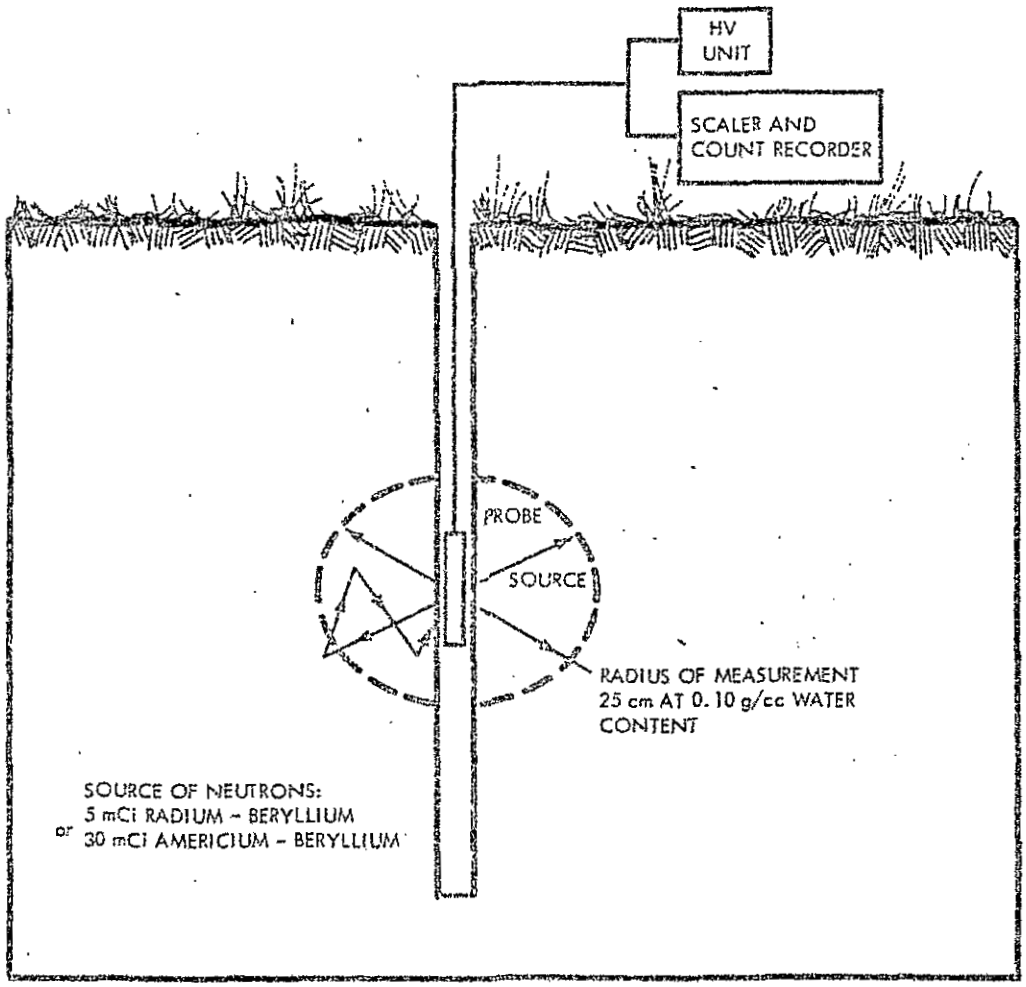


Figure 7. Sketch of neutron moisture logger and accessories (after Holmes et al., 1967).

Americium-beryllium is commonly used as a source of fast neutrons. Detectors of slow neutrons rely on high capture cross sections of detecting materials (e.g., boron). A charged particle is emitted during capture, which can be detected by a solid or gaseous counting device. The predominant detector is lithium-enriched BF_3. Both the source and detector are

located in a cylindrical probe, or tool, which is lowered via a cable into access tubing either by hand or by motor-drive. The depth of measurement is determined by graduations on the cable or, alternatively, by some type of counter (Van Bavel, 1963).

The pulse emitted during the nuclear reaction resulting from capture is amplified within the down-hole tool and transmitter through the cable to an above-ground meter for counting. Count rate is converted to water content via suitable calibration curves. The type of equipment that has been available for soils work is hand operated. Its use requires placing the down-hole tool at a discrete depth, taking a count or number of counts, and then moving the tool by hand to another discrete depth. This process is not troublesome for shallow soils studies. However, for deeper access wells, in the vadose zone, an inordinate amount of time would be involved. Recently, a motorized unit became available (Well Reconnaissance of Dallas, Texas) which permits lowering the tool in the well at a constant rate, via a motor drive. Internal electronic components concurrently translate pulse rate into water content, which is automatically recorded.

The individual neutron moisture logger should be calibrated against samples of known water content. Such calibration may be done in the field by comparing a count at a given soil depth with the water content of soil cores from the same depth.

Access tubes for neutron moisture logging are usually constructed of seamless steel or aluminum. Polyvinylchloride-cased wells may cause difficulty in that hydrogen or chlorine atoms in the tubing may moderate the thermal neutrons, interfering with soil moisture evaluation. Aluminum-cased wells may deteriorate in saline groundwaters. The inside diameter of wells should be as close as possible to the outside diameter of the probe. Work by Ralston (1967) showed that for a 100-millicurie (mCi) Am-Be source in a 3.8-cm OD tool, the water content could not be accurately evaluated in well casings with an ID greater than 10 cm.

Wells drilled for shallow water content monitoring can be easily installed by successively augering and driving the tube. Myhre et al. (1969) reported on a simple power-driven auger for installing wells to 150-cm depths. For deeper wells standard drilling techniques are necessary. During installation by drilling techniques it is essential to establish a tight fit between the well shaft and casing, to minimize the amount of vertical leakage of water. Drilling mud, although facilitating the drilling operation, is not recommended since it interferes with water content observations. In situations requiring a tight fit, drilling techniques which do not require a drilling mud (jetting, augering) are used.

The principal advantage of neutron moisture logging is that water content profiles are obtained <u>in situ</u> with minimal soil disturbance. A history of

profiles can be established during a monitoring program. Moisture logs clearly show the presence of perched water tables, together with their growth and dissipation (see Figure 8). Such logs may also be used to estimate unsaturated flow rates. Water content exchanges at a given depth in a succession of wells may provide clues on lateral flow velocities (Wilson, 1971).

Certain limitations should be noted. First of all, the presence of excessive concentrations of other fast neutron moderators (e.g., boron, chlorine) may cause erroneous water content determinations. Neutron moisture logs indicate only the water content of soils, and may not always manifest water movement. However, water content values may be translated to equivalent soil-water suction values via a soil-water characteristic curve.

The cost of a neutron moisture logger including the neutron source, slow neutron detector, and surface counter is about $3000. Figure 9 gives the cost of neutron moisture logging with various numbers of well loggings performed at depth intervals of 2 feet. The costs in Figure 9 do not include the capital cost of the instrument, but only the time required to conduct the log.

Tensiometers

Tensiometers are used to measure soil-water pressures during unsaturated flow. If caution is exercised, they may also provide estimates of soil-water content via suitable soil-water characteristic curves. Basically, a tensiometer consists of a porous ceramic cup cemented to a rigid plastic tube, small-diameter tubing leading to a manometer and terminating in a reservoir of mercury, and a filler plug in the rigid plastic tube (see Figure 10). Except for the reservoir and the portion of the small-diameter tubing filled with mercury, the internal volume of the system is completely filled with water. When properly emplaced in the soil the pores in the cup form a continuum with the pores in the soil. Water moves either into or out of the tensiometer system until an equilibrium is attained across the ceramic cup. The mercury level in the manometer tubing adjusts correspondingly.

Holmes et al. (1967) have noted the precautions to be taken during installation of tensiometers. Prior to field installation, the system should be purged of as much entrained air as possible and its response checked. The tensiometer unit should be placed into soil cavities larger than the outside diameter of the unit. The cup should be forced into the soil at the base of the hole to ensure good contact. The hole is then backfilled with soil.

The principal limitation of tensiometers is that they are useful in measuring soil-water pressures only up to about 1.0 atmosphere. Furthermore, the determination of water content via tensiometer values is subject to hysteresis: i.e., different water content versus pressure curves will be followed depending on whether the soil is wetting or drying.

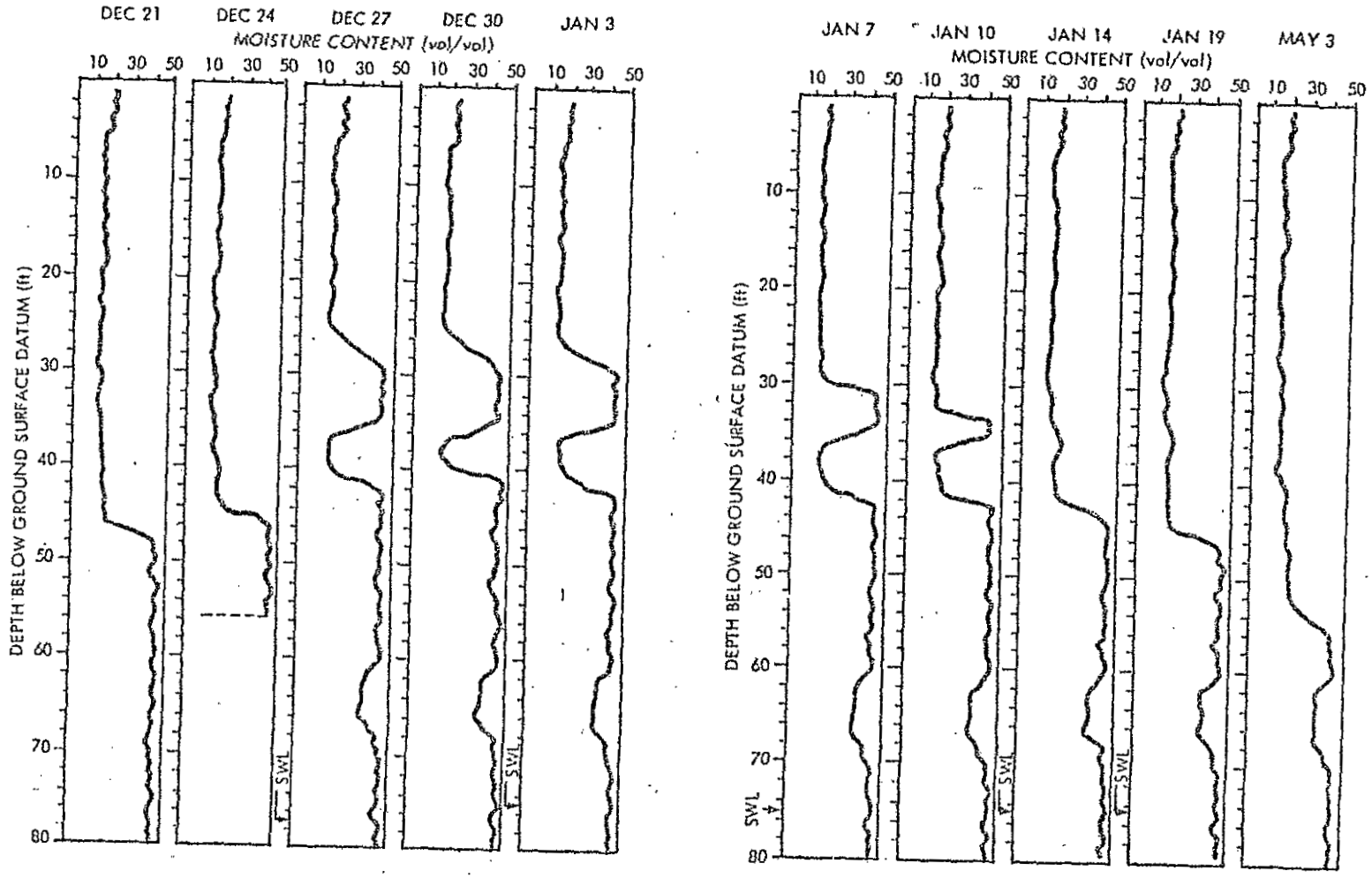


Figure 8. Moisture logs showing growth and dissipation of mounds in the vadose zone (after Wilson and DeCook, 1968).

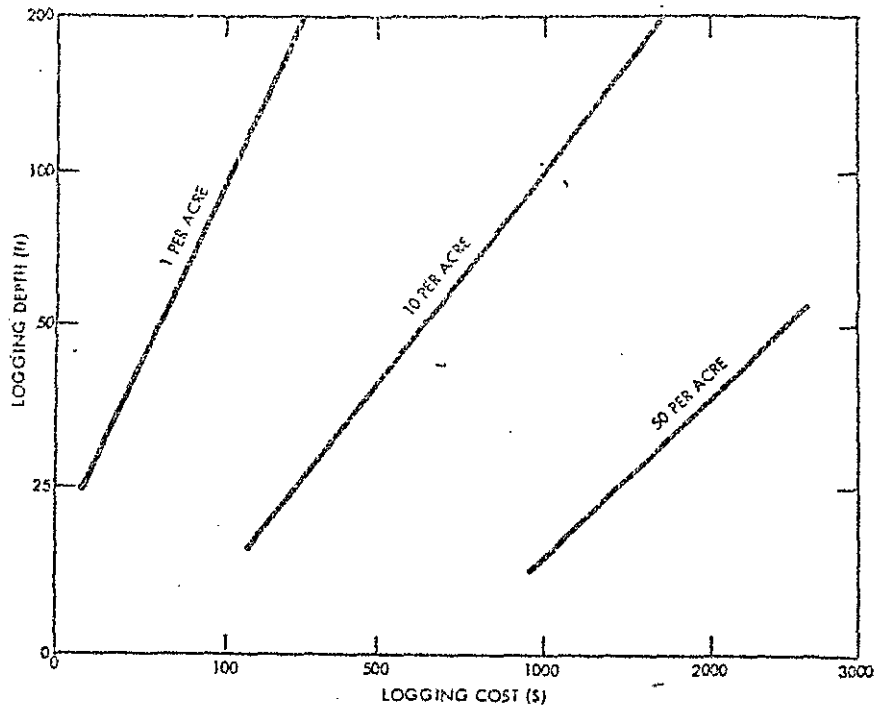


Figure 9. Cost of neutron moisture logging for various depths and sample space densities, December 1974.

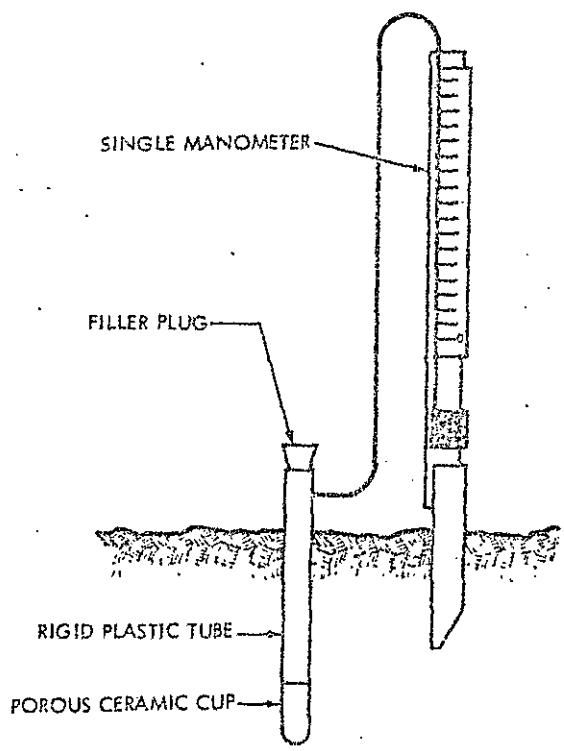


Figure 10. A single manometer tensiometer.

The cost of a tensiometer including a 6-foot plastic tube is about $30. Figure 11 gives the capital costs of tensiometers placed at various depths and at various sampling densities. The costs presented in Figure 11 do not include installation.

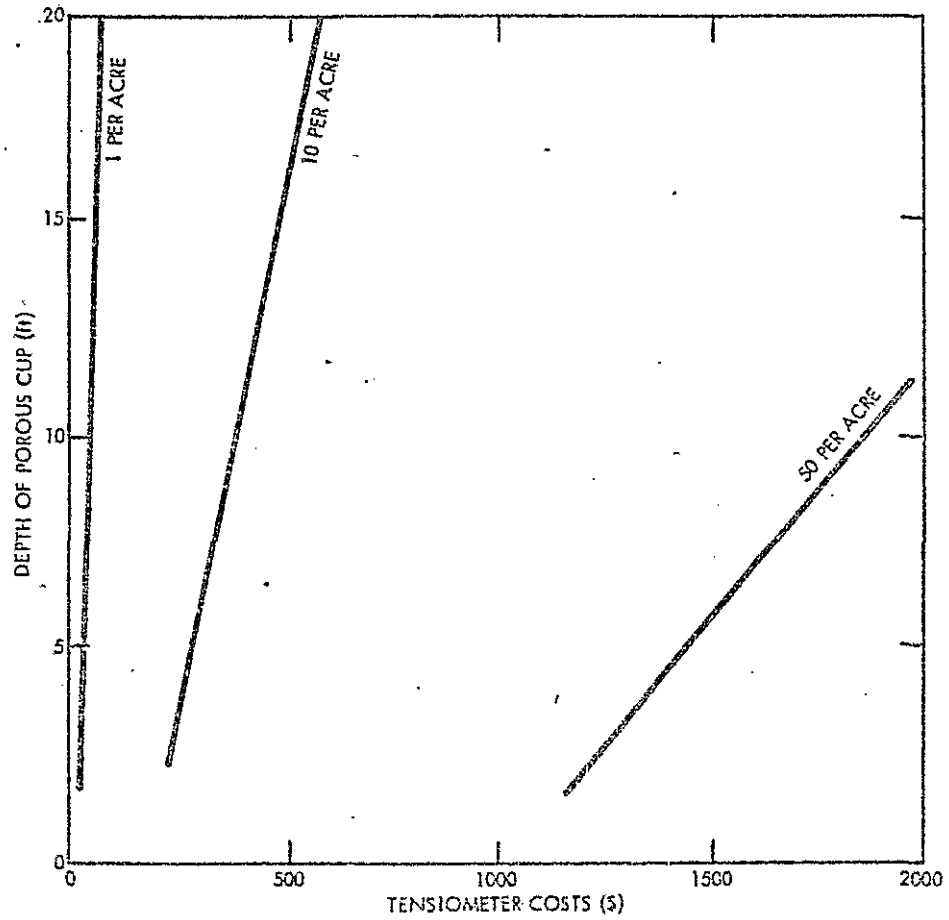


Figure 11. Cost of tensiometers for various depths and sample space densities, December 1974.

Electric Resistance Blocks

Electrical resistance blocks, used to measure either soil-water content or soil-water pressure, consist of electrodes embedded in a suitable porous material such as plaster of paris, fiberglass, or nylon cloth. The principal of operation of these blocks (Holmes et al., 1967) is that water content (or negative pressure) within the blocks responds to the water content (or suction) of the soil with which the blocks are in intimate contact and the electrical resistance properties of the blocks change correspondingly. Moisture blocks are calibrated in soil from the site at which they are to be installed. Such calibration involves evaluating resistance readings against a range of soil-water contents or negative pressures.

Holmes et al. discuss the advantages of resistance blocks, indicating that (1) they appear to be best suited for general use in the study of soil-water relations, (2) they are inexpensive, and (3) they can be calibrated for either suction or water content. Generally, for agricultural applications the blocks are used for negative soil-water pressures greater than 0.8 atmosphere.

The cost of a soil moisture block is about $4. The leads to the soil moisture blocks are very nominal in cost. A soil moisture meter costs about $120. The capital cost, excluding emplacement, of electrical resistance blocks, leads, and a soil moisture meter for various depths and sampling densities is given in Figure 12.

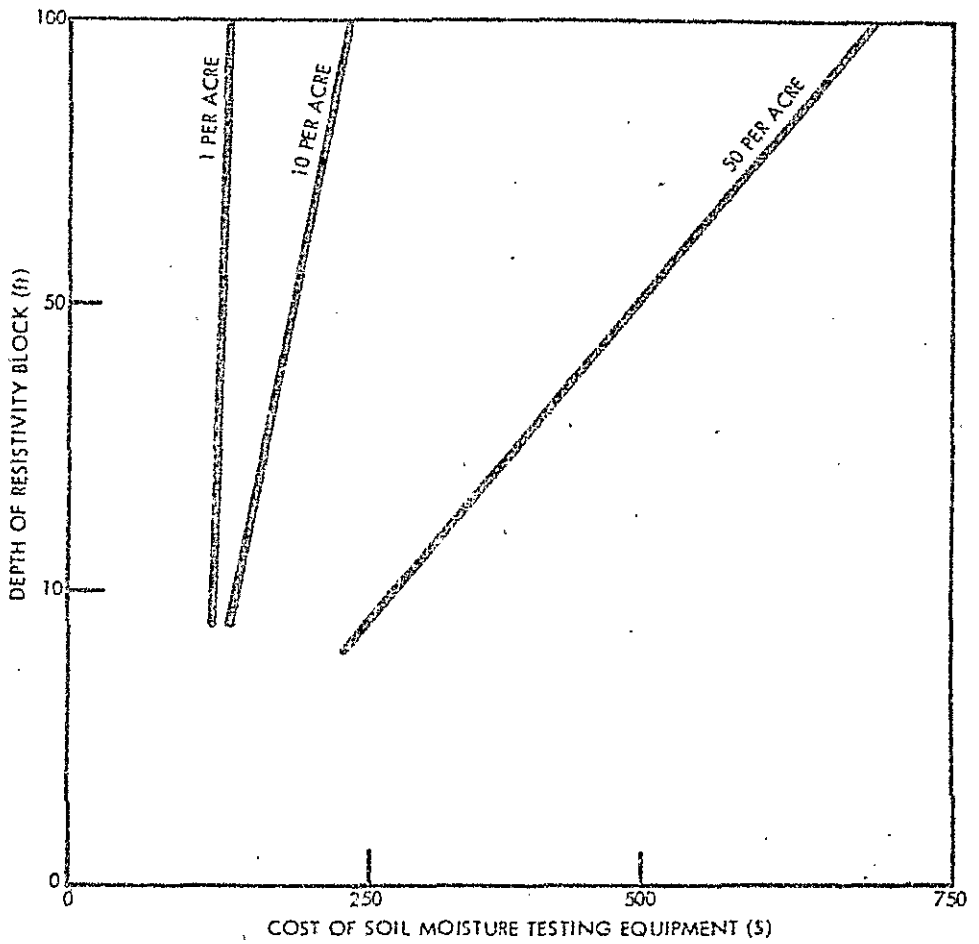


Figure 12. Cost of multiple electrical resistance blocks and soil moisture meter for various depths and sampling densities, December 1974.

Calculation of Water Content

In-situ measurement of water content at some locations, such as beneath waste disposal sites with large areas and relatively deep water tables, may be too cumbersome and expensive to perform. One alternative is to evaluate maximum storage capacity. Porosities for common geologic materials are given in Figure 13. The storage capacity in the vadose zone will be less than that indicated by the porosity because all of the materials are not saturated.

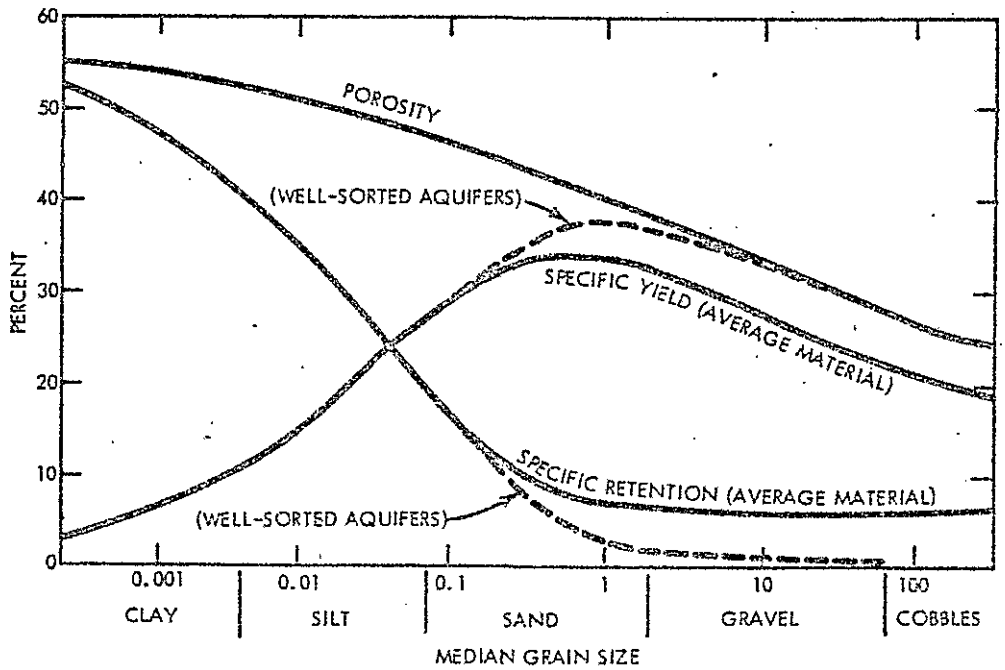


Figure 13. Relationship between median grain size and water-storage properties of alluvium from large valleys (Davis and DeWiest, 1966).

Many areas can be divided into two types of vadose zones: those where the specific retention of geologic materials has already been satisfied, and those where it has not. The first case occurs primarily in humid areas where water levels are relatively shallow and an abundant source of recharge has been present for many years. This case also occurs beneath many alluvial basins of the arid west where water tables are within 100 to 200 feet of the land surface and water has been artificially applied at the land surface for decades. The second case is common in arid areas with relatively deep (300 or more feet) water tables. Low natural recharge at the land surface for many years, combined with the presence of soil or subsurface restricting layers, may prohibit natural percolation to the water table. In these cases, the geologic materials may be virtually devoid of water.

The storage capacity for percolated water in cases where the specific retention is satisfied is defined by the specific yield. Representative specific yields for geologic materials are given in Table 5. Where the specific retention has not been satisfied, significant amounts of percolated water will be stored in the vadose zone to make up this deficiency. The total storage capability will then be some value less than the porosity.

TABLE 5. SPECIFIC YIELD VALUES ASSUMED FOR THE SOUTHERN PART OF THE CENTRAL VALLEY, CALIFORNIA (Davis and DeWiest, 1966)

Driller's Description	Assumed Specific Yield %
Gravel, sand and gravel, and similar materials	25
Fine sand, tight sand, tight gravel, and similar materials	10
Clay and gravel, sandy clay, and similar materials	5
Clay and related materials	3
Crystalline rock (fresh)	0

DETERMINATION OF WATER MOVEMENT

An evaluation of water movement above the saturated zone should account for (1) infiltration across the soil surface and movement through the topsoil, (2) movement in perched water tables, and (3) downward movement through the vadose zone. Flux (volume per unit area per unit time) is the principal flow characteristic to be defined in studying water movement in the vadose zone. An important factor in calculating flux is the hydraulic conductivity.

Infiltration Across the Soil Surface

Flux across the soil surface is termed infiltration, the maximum value of which is the infiltration capacity. This characteristic is important in land disposal operations because it indicates the rate at which effluent may percolate to groundwater. Bouwer (1973) categorizes land disposal systems as high-rate or low-rate, reflecting the infiltration rates used to effect effluent treatment.

For existing land disposal operations, effluent can be metered onto each treatment area via suitable flumes, weirs, or flowmeters. Differences in flow rate represent the amount of water which infiltrates on the area. The

flux can be calculated (it may be necessary to account for evaporation losses) if the surface area contacted and time that a given volume infiltrated are known.

Movement in Perched Water Tables

Results of neutron logging observations during infiltration tests or examination of data on stratigraphy may indicate the locations of perched water tables in the vadose zone. The principal techniques for monitoring movement in these saturated zones are by the use of piezometers or observation wells.

PIEZOMETERS. Piezometers consist of small-diameter pipes, driven, augered or jetted into a known or expected saturated soil zone. The level of water measured at the base of the piezometer indicates the water level in the saturated zone.

Reeve (1965) discusses in detail the techniques for installing and cleaning new piezometers. In general, it is important to maintain tight contact between the outer wall of the piezometer and the soil. For shallow units, piezometers may be installed by augering and driving with a sledge hammer. Deeper units will require jetting, or use of standard drilling equipment. It may be necessary to fill the cavity between the well and borehole with grout to ensure tightness of fit. As with regular wells, piezometers should be developed by pumping, bailing, etc. to open up material at the base of the unit. In some situations, it may be necessary to install piezometers with screened well points to prevent upward movement of saturated material into the unit.

Depth to water in piezometer units is measured by chalked tape, electric sounders, or air lines. The use and cost of these tools is considered in detail under "Monitoring in the Saturated Zone." By referencing these measurements to a common datum, groundwater levels can be determined for the perched zones. The slope of these elevations indicates the direction of lateral water movement.

Many field soils exhibit anisotropy. That is, the hydraulic conductivity in the horizontal direction may be much greater than in the vertical direction. For such soils it may be advisable to install more than one array or battery of piezometers in a lateral direction away from a recharge source. The bottom openings of piezometers in sequential arrays should terminate at the same elevation. Such an arrangement permits observing lateral head differences resulting from horizontal flow.

The costs of 2- and 4-inch piezometers for various depths and sampling densities are given in Figure 14. The piezometer costs presented do not include installation.

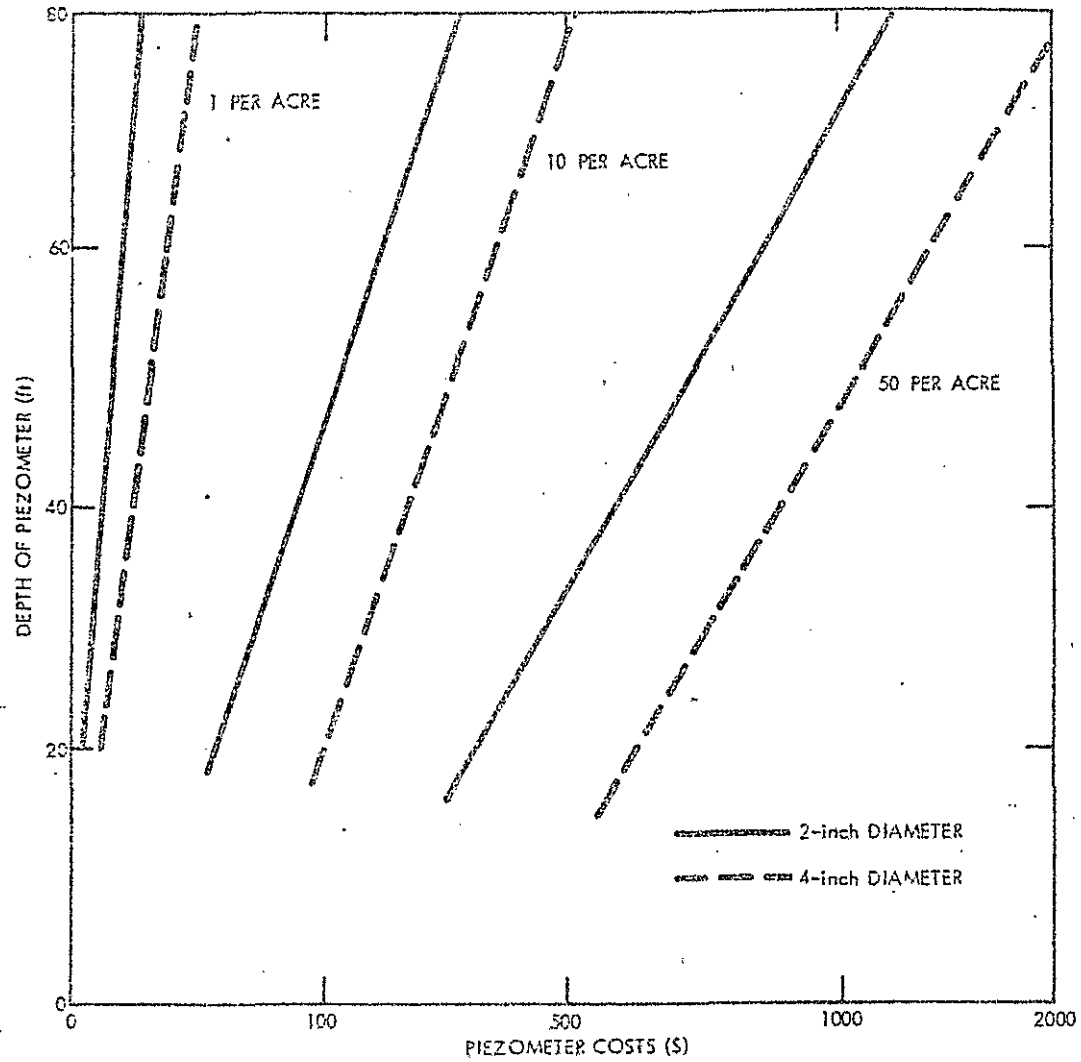


Figure 14. Cost of piezometers for various depths and sampling densities, November 1974.

OBSERVATION WELLS. An observation well consists of an uncased borehole or perforated pipe extending from ground surface into a perched water table. This is similar to a piezometer, except that diameters and depths may be greater.

WATER MOVEMENT IN THE UNSATURATED STATE

Methods for monitoring water movement in saturated regions cannot be used to monitor unsaturated flow because water will not freely enter a soil cavity unless the soil-water pressure is greater than atmospheric. Consequently, special methods must be used in unsaturated soils. Of the available methods the three most commonly used to infer unsaturated flow employ

tensiometers, psychrometers, and neutron moisture logging. Several newer techniques, although not extensively field tested, may also have applicability.

Tensiometers

The principles of operation, methods of installation, and limitation of tensiometers are discussed above. In general, tensiometers appear to be the most effective technique for monitoring flow in the soil-water pressure range down to about 0.8 atmosphere (atm). Nielsen et al. (1973) observe that tensiometers are still routinely used and nothing as reliable, accurate, and inexpensive has replaced them in the past 35 years. The application of tensiometers to depths greater than the soil zone is now possible with the advent of pressure transducer units developed by Watson (1967) and others. In characterizing the direction of water movement, a battery of tensiometers must be installed, with units terminating at successive depths throughout the region of interest.

As with piezometers, it is necessary to install more than one array of tensiometers to detect horizontal flow. Thus, if individual arrays terminate at varying depths, differences in total hydraulic heads between corresponding units in successive arrays may suggest lateral movement in the unsaturated state. Because of heterogeneity in soil properties, however, conclusions on lateral flow may not be definitive.

Psychrometers

Tensiometers cannot be used to measure soil-water pressure below about -1 atm because of air-entry problems. To measure lower negative pressures, therefore, other instrumentation is required. In recent years, progress has been made in developing the thermocouple psychrometer for this purpose. According to Watson (1974) in-situ pressure measurements down to -30 atm are possible with these units. The principle of psychrometric measurement of soil-water potential, discussed by Rawlens and Dalton (1967), is that a relationship exists between soil—water potential and the relative humidity of soil water.

Psychrometers consist of a porous bulb comprising a chamber to sample relative humidity of a soil, a sensitive thermocouple, heat sink, reference electrode, and associated electronic circuitry. Two types of thermocouple psychrometers are available. One type, which is installed in access tubes, consists of mounting psychrometers in porous cups at the base of tubing. This unit may be withdrawn for recalibration. The second type, called "sealed-cup" psychrometers by Merrill and Rawlens (1972), contains the thermocouple unit permanently sealed into a porous enclosure.

Each unit must be calibrated prior to field installation—techniques for such calibration are given by Merrill and Rawlens. Also, in field installations it is important to record and correct for diurnal changes in temperature. Installation of a sensitive thermistor is recommended for diurnal studies. Enfield et al. (1973) have used thermocouple psychrometers to estimate the direction and rate of water flux in material above a water table at a depth of 94 meters in a desert environment in Washington. Individual psychrometric units were placed 3 meters apart within a specially designed well casing..

Neutron Moisture Logging

Although the neutron thermalization technique is used mainly to determine changes in volumetric water content of materials in the vadose zone, the method may also be used to infer water movement. In particular, if a soil-water characteristic curve is available for incremental depths throughout the vadose zone, it may be possible to relate water content values to water pressure. Hydraulic head gradients and, therefore, flow directions can then be inferred. Unfortunately, the accuracy of the method may not be great enough to detect slight water content changes, particularly in the dry range. Wilson and DeCook (1968) and Wilson (1971) have used moisture logs from a network of 30-meter deep access wells to infer the rates of lateral movement of recharge waves in the vadose zone during river recharge and artificial recharge. The arrival of such waves was inferred by the change in water content in a perched mound at about 10 meters.

Moisture Blocks

Moisture blocks of the type described earlier may be used to measure soil-water pressure if suitable soil-water characteristic curves are available. A unit relying on the sensing of heat dissipation within the block (Phene et al., 1971) may have future promise.

Quantification of Flux in Unsaturated Media

Two of the physical characteristics of interest in the vadose zone are soil-water flux and hydraulic conductivity. Under continuous flooding at waste disposal facilities, the steady-state value of infiltration approaches the saturated hydraulic conductivity. Presumably, the steady-state value of flux below the soil surface also approaches this value; therefore an approximation of the flux value in the wetted soil profile can be obtained during a wetting cycle.

Of equal interest is the flux during drying periods. Three major approaches to evaluating flux in the vadose zone during a drying cycle are: (1) measuring water content changes in profiles as a function of time; (2) using appropriate mathematical expressions and empirically determined

relationships between soil-water pressure, soil-water content, and hydraulic conductivity; and (3) direct measurements using flowmeters.

RELATING WATER CONTENT CHANGES TO FLUX. The difference in water content stored in a wetted profile between successive time measurements above a certain depth is a measure of the amount of water which has flowed out of that depth. The water content versus depth curves may have been obtained from tensiometer data, moisture logs, etc. This relationship assumes that the water in storage from the surface to the first tensiometer equals the value at the first tensiometer times the thickness of materials above this point.

EXPRESSIONS FOR FLUX AND HYDRAULIC CONDUCTIVITY. Field plots instrumented with tensiometers are required to determine flux and hydraulic conductivity (Nielsen et al., 1973). Infiltration is allowed to progress in each plot to the point that steady-state values are reached. After recession of the water surface, the soil surface is covered to prevent evaporation. When drainage has occurred to the point that the hydraulic gradient becomes unity, tensiometer readings are taken in incremental time steps from successive tensiometer units. At the completion of the study, intact cores of soil are taken in increments throughout the profile. Such samples are used for the laboratory determination of soil-water characteristic curves. Subsequently, the soil-water pressure data taken by tensiometers during the field study are translated to equivalent water content values. Spatial variations occur in the soil properties; consequently, a sufficient number of field plots are needed to provide a measure of this variability. Furthermore, even though the assumption of unit hydraulic gradient is fulfilled, problems may arise if subsurface heterogeneities affect flow. Problems of anisotropy and stratification will be accentuated with depth in the vadose zone. Realistically, it may be expected that flux expressions are most useful in the soil zone.

DIRECT MEASUREMENT OF FLUX. Attempts have been made in recent years to develop equipment to measure soil-water flux in the unsaturated state which do not require information on the hydraulic conductivity.

Two types of flowmeters reported by Cary (1973) involve (1) direct flow measurement, and (2) the displacement of a thermal field by water in motion. The direct flow unit measures the flow of soil water intercepted by a porous tube containing a sensitive flow transducer. The second unit measures very accurately the transfer of a heat pulse in water moving within a porous cup buried in the soil. Because of the intimate contact between the soil and porous cup, the water moving in the cup forms a continuum with soil water. Laboratory calibration curves are prepared to relate the output of a sensitive millivolt recorder, during imposition of heat pulses, to empirically measured flow rates.

For field installation, porous discs containing either flow transducers or heat sources are mounted in cylinders which are buried in the soil. A limitation, therefore, is that flow is measured in disturbed soils. To date, no data are available on the use of such flowmeters in deep vadose zones.

Calculation of Approximate Flow Rates

Vertical flow in the vadose zone is related to the infiltration rate of waters applied at the land surface, storage capacity of the vadose zone, and depth to the water table. If the water table remains at a relatively constant depth and a specific amount of water percolates from the topsoil, then the flow rate of water in the vadose zone is partly controlled by the available storage space therein. With point or line sources, significant lateral movement can occur in layered deposits above the water table; however, for diffuse sources of large areal extent, such as agricultural return flow, these lateral movements may be neglected.

For example, assume that 25 feet of water is applied per acre per year at the land surface and 20 feet percolate from the topsoil. Assume the depth to water is 55 feet and the vadose zone beneath the topsoil is 50 feet thick. Assuming that the porosity is 30 percent and the specific yield is 15 percent, and that the specific retention has already been satisfied, then the storage capacity in the zone is a maximum of 50 times 0.15, or 7.5 feet. It is clear that the vadose zone could hold this water for only a few months at the most.

As a second example, assume that 5 feet of water is applied per acre per year at the land surface and 2 feet percolate from the topsoil. Assume the depth to the water table is 310 feet and the vadose zone is 300 feet thick. Assume that the porosity is 40 percent and the specific retention is 15 percent but that the moisture content is only 5 percent. Thus, the storage capacity in the zone is a maximum of 300 feet times 0.10 or 30 feet of water. As a result it would require 15 years for the percolating water to satisfy storage before reaching the water table.

Use of Tracers

Tracers such as salts, dyes, and radioisotopes can be employed to measure flow rates in the vadose zone. Care must be taken to insure that the tracer moves at the same velocity as the water (which, however, is not necessarily the velocity of a specific groundwater pollutant). The practical problem of detecting or sampling a tracer at increasing depths under unsaturated conditions should not be minimized. Smith (1974) reports on using tritium as a tracer in the unsaturated zone.

WATER SAMPLING IN THE VADOSE ZONE

In a program to monitor quality in the vadose zone samples may be needed from both unsaturated and saturated (perched water table) regions.

Sampling in Saturated Regions

WELLS AND PIEZOMETERS. Preliminary hydrogeological surveys will often delineate existing or potential perched water table regions. Many of these regions may be instrumented with wells or piezometers which can be modified or used directly for sampling water quality. In general, observation wells are unperforated throughout the vadose zone to prevent cascading water from perched layers affecting water level measurements and water quality at the water table. It may be possible, however, to modify such wells for sampling without causing cascading. For example, the results of neutron logging in a well may reflect the presence of perched layers. It is possible to perforate the casing of abandoned wells at these depth intervals and install packer assemblies to isolate these regions for sampling and prevent cascading. Alternatively, if information on the location of perched layers is known prior to the construction of a new well, the well can be designed to permit sampling of these regions.

An array of piezometers can be used for water sampling in perched zones. If the locations of such zones are known, individual units can be designed with screened well points. If units in the individual arrays terminate at varying depths, samples from such an array will indicate vertical quality changes from movement of effluent. Similarly, if a number of arrays are distributed in a horizontal transect, samples from individual units terminating at the same elevation will manifest quality changes from lateral spread of effluent.

For programs to monitor the spread of heavy metals in effluent water it is necessary to construct wells or piezometers from materials which will not contribute metals to the sample. Wells cased with PVC pipe will avoid this problem, particularly if screens are also of plastic, but require special construction techniques.

To obtain water samples from wells it is necessary to employ some type of sampling device. A simple bailer may often be used with success. This unit consists of a tube with an open top and a ball check-valve at the bottom to admit water samples.

Another commonly used sampler consists of a sampling tube or body with an air inlet line and a sample outflow line extending to the surface. The lower end of the body contains a spring-loaded flap valve. The sampling line extends to the base of the sampler and the air inlet line terminates a slight distance below the top. In operation, the sampler is lowered into a

well to the sampling depth below the water table. After permitting the sampler to fill, air pressure is applied to the air line and the sample is forced to the surface through the sampler line. Advantages of this unit are that it need not be removed from the well between samples. Also, samples are obtainable at various depths below the water table. A disadvantage is that air is introduced into the sample, possibly interfering with certain chemical determinations. This possibility can be avoided by using compressed nitrogen gas.

Allison (1971) discusses a simple device for sampling water in auger holes, which also could be used in cased wells. Basically, the unit consists of plastic tubing of sufficient length to extend into the water table. The upper end of the tube terminates in a collector flask. A second line from the flask is connected to a hand-held vacuum pump. When the pump evacuates the flask and tubing, water is forced up into the flask. According to Allison such a system is capable of sampling water to a depth of 7.4 meters.

In addition to these samplers several other types are available, including positive displacement pumps. Some operations may warrant the purchase of a small-diameter submersible pump mounted on a flexible line.

With any sampling method it is important to ensure that an uncontaminated sample is obtained. The well should be bailed or pumped extensively at the beginning of each collection period to ensure the movement of fresh groundwater into the well. Similarly, the bailer or sampling lines should be flushed out several times before a sample is collected.

SAMPLING TILE DRAIN OUTFLOW. If a tile drainage system has been installed to promote rapid drainage of a perched water table, samples can be collected from the tile outfall. In some cases it may be desirable to install commercially available composite or discrete sampling devices.

Willardson et al. (1973) discuss a "flow-path ground water sampler," which enables collection of water in different flow paths around a tile.

FIBERGLASS PROBES. Hansen and Harris (1974) describe a sampler capable of discrete simultaneous sampling at several depths below a water table. The unit consists of a series of isolated fiberglass probes in a wellpoint, with individual lines from each probe running to the surface. Each isolated area is filled with a sand matrix. During collection, all probes are sampled simultaneously, via a vacuum pump, to minimize interference with natural flow within the sampling region.

LYSIMETERS OR SAMPLING CHAMBERS. In the context of this discussion, a lysimeter, or sampling chamber, consists of a trench or large-diameter culvert sunk vertically into a waste disposal area. Lysimeters are installed to permit sampling of the soil solution throughout a vertical

profile, usually several meters in thickness. Culvert type lysimeters were used by McMichael and McKee (1966) in their studies on wastewater reclamation at Whittier Narrows. Parizek and Lane (1970) used trench lysimeters to collect samples from forest soil during effluent irrigation in Pennsylvania.

The lysimeters developed by McMichael and McKee (1966) employed pan samplers for the collection of water during periods of saturation in a profile to a depth of about 3 meters. These samplers were conical in shape, 61 cm in diameter and 23 cm deep. The samplers were installed at various depths at a radial distance of about 3 meters from the central well. Individual sampling pans were filled with gravel to prevent clogging, and each was connected to the central culvert via tubing. Excavations used for installation of the samplers were carefully backfilled. During sampling, percolate intercepted by the pans flowed by gravity to the central well and into collection flasks.

The trench lysimeter described by Parizek and Lane (1970) also used pan samplers. The largest such lysimeter consisted of a 1.2-meter wide, 4-meter long trench excavated to a depth of about 6 meters. The sides of the trench were braced and lined with wood. Sampling pans were installed at 30-cm vertical intervals to the 6-meter depth of the lysimeter. The pans, constructed from galvanized metal, were 30 cm by 45 cm with copper tubing to permit sample drainage. Each unit was sunk into the soil a short distance from the side walls of the lysimeter. During application of effluent, samples of percolate intercepted by the pans were collected in flasks within the lysimeter.

A basic problem with collection pans, pointed out by Parizek and Lane (1970) is that samples are collected only when the soil-water pressure is greater than atmospheric. Consequently, after cessation of infiltration the soil-water system may shift rapidly to the unsaturated state, prohibiting sample collection. The same problem exists for piezometers, auger holes, or other sampling methods requiring saturation.

Sampling in Unsaturated Regions

SOIL SAMPLING. One method for determining the quality of the soil solution in unsaturated soils is to obtain field samples from which saturated extracts can be obtained. An extensive program of soil sampling throughout the duration of a waste disposal operation could be prohibitively expensive, however, particularly if samples were required from the entire vadose zone.

SUCTION CUPS. An alternative to soil sampling for characterization of the water quality of unsaturated soils is to utilize ceramic cups like those used in tensiometers. When placed in the soil, the pores in these cups become an extension of the pore space of the soil so that the soil-water content in the soil and cup become equilibrated at the existing soil-water pressure.

Applying a slight vacuum to the interior of the cup causes the soil solution to flow into the cup. The quality of the soil solution can be determined by bringing this sample to the surface. Although ceramic cups have limitations, at the present time they appear to be the best tool available for sampling unsaturated media.

The basic design of the sampling unit is as follows: a ceramic cup is sealed onto a rigid-plastic body tube that is equal in length to the desired sampling depth. Small-diameter tubing is inserted through a rubber stopper, which seals the top of the body tube, down to the inside base of the cup. The other end of the tubing is attached to a collection flask through a two-hole rubber stopper. Vacuum is applied to a second line in the flask causing the air pressure inside the system to become less than the ambient pressure at the cup's location. Soil solution is drawn into the cup and sucked through the vacuum line to the collection flask. The technique used to emplace suction cups is the same as that for tensiometers. In particular, good contact should be obtained between the cup and the soil.

Recently, alternative designs have been reported in the literature, most notably by Parizek and Lane (1970) and by Wood (1973), that allow raising samples from greater depths than is possible by vacuum withdrawal. The design used by Parizek and Lane is shown schematically in Figure 15. The body tube of the sampling unit is 2 feet long and holds about a liter of sample. Two copper lines are forced through a two-hole rubber stopper which seals the body tube. One line, the sample discharge line, extends to the base of the ceramic cup, as shown, and the other, a pressure-vacuum line, terminates a short distance below the rubber stopper. The discharge line connects to a suitable vacuum-pressure pump. In operation, a vacuum is applied to the system with the discharge tube clamped shut. When sufficient time has elapsed for the unit to fill with soil solution, the vacuum is released, the clamp on the outlet line is opened, and air pressure is applied to the system to force the sample into the collection flask.

Figure 15 also illustrates another feature of the design of Parizek and Lane. The installation method shown does not require an intimate contact between the cup and the soil. Instead, a cavity larger than the cup is drilled to permit backfilling with silica sand around the cup and with tamped backfill for the remainder of the length. This design permits the installation of more than one unit in a hole, although three is about the maximum. Each unit is sealed from adjoining units with bentonite. According to the authors the silica sand provides a clean medium for soil moisture moving toward the cup, ensures contact between soil and cup, eliminates unevenness in the void space, and precludes clogging of the cup by colloidal material. Samples were recovered from a depth of 15 meters; 17 meters is about the maximum expected recovery depth with this basic design.

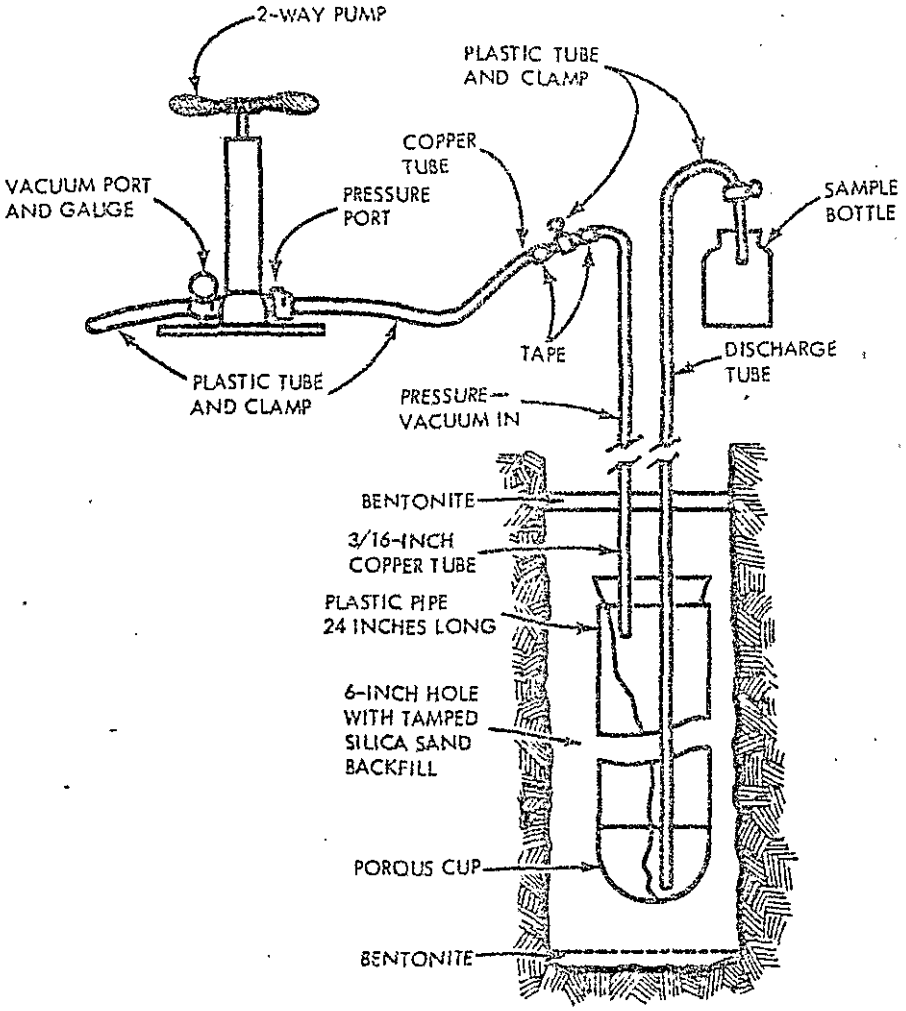


Figure 15. Cross section of suction cup assembly and backfilling material (after Parizek and Lane, 1970).

Wood (1973) reports on a modified version of the design of Parizek and Lane that overcomes a basic problem with their system, i.e., solution being forced back into the soil during the release of vacuum and application of pressure. A sketch of Wood's design is shown in Figure 16; details are presented in his paper. The important feature, however, is that a check-valve is included in the pressure-delivery tube assembly within the cup. In operation, vacuum is applied to the system, inducing a flow of water into the cup and tube assembly. Nitrogen gas pressure is applied to one tube and the sample is forced to the surface. The check-valve prohibits pressurization of the porous cup and, therefore, a sample within the cup does not flow back into the soil.

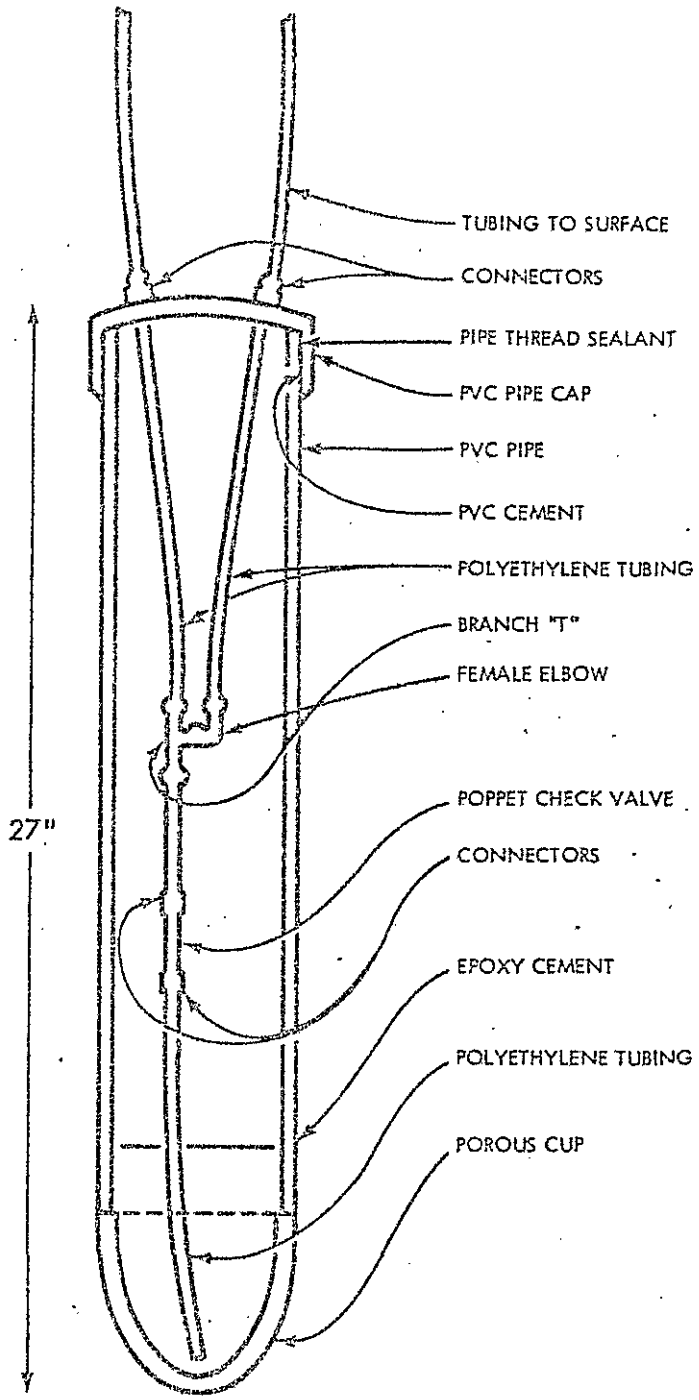


Figure 16. Cross section of porous cup assembly with pressure control (after Wood, 1973).

Wood's installation procedure consisted of drilling a 10-cm hole with a continuous flight auger to 45 cm from the desired depth. The auger was then installed in the lowermost auger flight and the ensemble pressed back into the hole to the final depth. The assembly was again withdrawn and a suction cup unit was placed into the hole. Only one unit was installed per hole; samples were collected from depths ranging to 36 meters.

Although suction cup assemblies are the best available techniques for obtaining samples of the soil solution in situ, certain problems accompany their usage. One is that samples cannot be obtained over the entire range of soil-water pressures: suction cups are capable of sampling only at pressures greater than about −1.0 atmosphere. Because of the very small pores in ceramic cups, inflow of suspended solids is inhibited, making tests for biochemical oxygen demand (BOD) on collected samples inaccurate. Similarly, bacteria may be filtered out. During application of vacuum to the cups, it is important that the negative pressure closely match the pressure of the soil-water system. If the vacuum differential is excessive, the additional suction can influence the movement of soil water in the vicinity of the cup.

SALINITY SENSORS. A recent development for in-situ evaluation of soil salinity is the so-called "salinity sensor." The basis of these devices is the relationship between specific electrical conductance (EC) of soil solution and the total concentration of salts in solution.

The salinity sensor described by Richards (1966) uses electrodes embedded in porous ceramic to form a hydraulic continuum with soil water and measure the specific conductance of the soil solution directly. EC values can then be directly related to the total salt content by suitable calibration relations. The unit described by Richards comprises a plate about 1 mm thick with platinum electrodes fixed in place on opposing faces. An interesting feature of the sensor is that the unit is spring loaded to ensure good contact with soil. Because of the strong dependency of EC on temperature, it is important to measure accurately the temperature of the soil solution. Richards used a thermistor to provide temperature compensation.

Oster and Willardson (1971) have reviewed problems arising from calibration and field use of salinity sensors. Of particular importance is their observation that sensors should not be used at soil-water pressures less than −2 atmospheres. Also they indicate that when sensors are placed in trenches at field sites, the permeability of the materials in the back-filled trench tends to be greater than in indigenous soil. During leaching trials, therefore, the salinity measured with the sensors tended to be lower than in adjacent soil. Differences were attributed to greater leaching in the trench, probably because pore sizes in the trench soil were of a different range than indigeneous soil.

While salinity sensors may be useful to gage changes in the total salinity of a soil solution, in waste disposal operations, concentrations of individual constituents may be of more importance. Furthermore, the water pressure of materials in the lower reaches of the vadose zone may be less than −2 atmospheres, thereby rendering the unit inoperative.

The cost of a salinity bridge is about $620. Each salinity sensor costs about $35. Sensor cable costs about $0.50 per foot. Figure 17 gives the cost for a salinity bridge and various depths and sampling densities for the sensors.

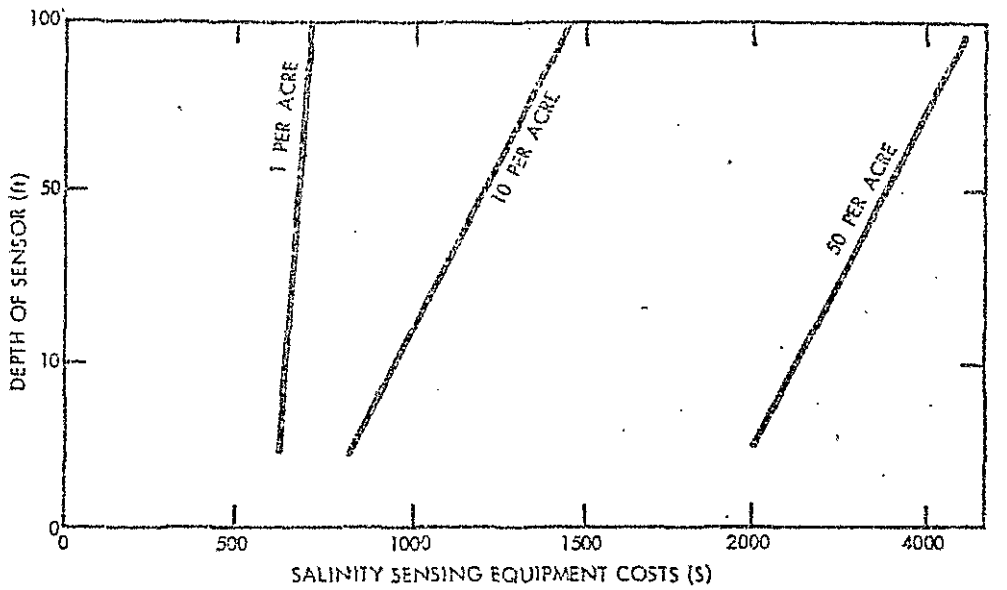


Figure 17. Cost of soil salinity sensors and a salinity bridge for various depths and sampling densities, November 1974.

31. Everett, L.G., et al. Unsaturated Zone Monitoring for Hazardous Waste Land Treatment Units, Kaman Tempo, June 21, 1983

2645
2646

Eagle ~~Permit~~

DRAFT

JUN 21 1983

Permit Guidance Manual on

UNSATURATED ZONE MONITORING FOR HAZARDOUS WASTE LAND TREATMENT UNITS

EPA/530-SW-84-016
December 1984
Draft for public comment

by

L.G. Everett
L.G. Wilson

Kaman Tempo
Santa Barbara, California 93102

Contract No. 68-03-3090

Project Officer:

L.G. McMillion
Environmental Monitoring Systems Laboratory
Las Vegas, Nevada

Environmental Monitoring Systems Laboratory
Office of Research and Development
U.S. Environmental Protection Agency

higher permeability overlies a region of lower permeability in the unsaturated zone.

The base of the unsaturated zone, the capillary fringe, merges with underlying saturated deposits of the principal water-bearing formation. This zone is not characterized as much by the nature of geological materials as by the presence of water under conditions of saturation or near saturation. Studies by Luthin and Day (1965) and Kraijenhoff van deLeur (1962) have shown that both the hydraulic conductivity and flux may remain high for some vertical distance in the capillary fringe, depending on the nature of the materials. In general, the thickness of the capillary fringe is greater in fine materials than in coarse deposits. Apparently, few studies have been conducted on flow and chemical transformations in this zone. Taylor and Luthin (1969) reported on a computer model to characterize transient flow in this zone and compared results with data from a sand tank model. Freeze and Cherry (1979) indicated that oil reaching the water table following leakage from a surface source flows in a lateral direction within the capillary fringe in close proximity to the water table. Because oil and water are immiscible, oil does not penetrate below the water table, although some dissolution may occur.

The overall thickness of the unsaturated zone is not necessarily constant. For example, as a result of recharge at a water table during a waste disposal operation, a mound may develop throughout the capillary fringe extending into the intermediate zone. Such mounds have been observed during recharge studies (e.g., Wilson, 1971) and efforts have been made to quantify their growth and dissipation (Hantush, 1967; Bouwer, 1978).

As already indicated, the state of knowledge of water movement and chemical-microbiological transformations is greater in the soil zone than elsewhere in the unsaturated zone. Renovation of applied wastewater occurs primarily in the soil zone. This observation is borne out by the well-known studies of McMichael and McKee (1966), Parizek et al. (1967), and Sopper and Kardos (1973). These studies indicate that the soil is essentially a "living filter" that effectively reduces certain microbiological, physical, and chemical constituents to safe levels after passage through a relatively short distance (e.g., Miller, 1973; Thomas, 1973). As a result of such favorable observations, a certain complacency may have developed with respect to the need to monitor only in the soil zone.

Dunlap and McNabb (1973) point out that microbial activity may be significant in the regions underlying the soil. They recommend that investigations be conducted to quantify the extent that such activity modifies the nature of pollutants travelling through the intermediate zone.

For the soil zone, numerous analytical techniques were compiled by Black (1965) into a two-volume series entitled "Methods of Soil Analyses." Monitoring in the intermediate zone and capillary fringe will require the extension of technology developed in both the soil zone and in the groundwater zone. Examples are already available where this approach has been used. For example, Apgar and Langmuir (1971) successfully used suction cups developed for in situ sampling of the soil solution at depths up to 50 feet below a sanitary landfill. W.R. Meyer (personal communication, 1979) reported that suction cups were used to sample at depths greater than 100 feet below land surface at cannery and rock phosphate disposal sites in California.

Type of Sampler	Obtains Core Sample: Yes	Obtains Core Sample: No	Most Suitable Core Types: Coh	Most Suitable Core Types: Coh'less	Most Suitable Core Types: Elt	Operation in Stony Soils: Fav	Operation in Stony Soils: Unfav	Most Suitable Soil Moisture Conditions: Wet	Most Suitable Soil Moisture Conditions: Dry	Most Suitable Soil Moisture Conditions: Inter	Access to Sample Sites During Poor Soil Conditions: Yes	Access to Sample Sites During Poor Soil Conditions: No	Relative Sample Size: Sm	Relative Sample Size: Lg	Labour Requirements: Sngl	Labour Requirements: 2/More
A. Hand Auger																
1. Screw-Type Augers		X			X		X	X			X		X		X	
2. Barrel Augers																
a. Post-Hole Auger		X	X			X		X			X			X	X	
b. Dutch Auger		X	X			X		X								
c. Regular Barrel Auger	X		X			X				X	X		X		X	
d. Sand Augers	X			X		X				X	X			X	X	
e. Mud Augers	X		X			X		X			X			X	X	
3. Tube-Type Samplers																
a. Soil Probes																
(1) Wet Tips	X				X		X	X			X					
(2) Dry Tips	X				X		X	X			X		X		X	X
b. Vethmeyer Tubes	X				X					X			X		X	
c. Thin-Walled Tube Samplers	X		X				X			X	X			X		X
d. Peat Samplers	X		X				X	X			X			X		X
B. Power Auger																
1. Hand-Held Screw Type Power Auger		X			X	X				X	X			X		X
2. Truck Mounted Auger					X											
a. Screw Type		X			X	X		X				X		X		X
b. Drive Sampler	X		X			X				X		X		X		X
3. Tripod Mounted Drive Sampler	X		X							X		X		X		X

3.2.2 Soil Types

Land treatment sites located on soils of intermediate texture (i.e., loams), require the use of regular augers. The soils below the treatment zone may be predominately cohesive (e.g., clay types) or cohesionless (e.g, sands). For either of these extreme conditions some tools are more effective than others for obtaining and retaining the samples. Alternatively, special tools are available when either of these conditions is encountered. For example, sand augers are a variation of the standard barrel auger designed for sampling in cohesionless soils. Similarly, Dutch augers and mud augers are best suited for cohesive soils.

As described in a later section, special attachments, called core catchers, are available to assist in retaining core samples in thin-walled samplers when dry cohesionless soils are being sampled.

3.2.3 Soil Moisture

It may be difficult to retain soil samples within a sampler in very wet, sticky soils. Hand-held samplers which are particularly suited for such soils include Dutch augers, mud augers, and special soil sampling tubes. Thin-walled drive samplers with built in sampler retainers could also be used.

Peat samplers are designed for sampling in wet, organic soils. The operating principles of each of these units were described in previous sections of this chapter.

3.2.3.1 Dry-Cohesionless Soils--

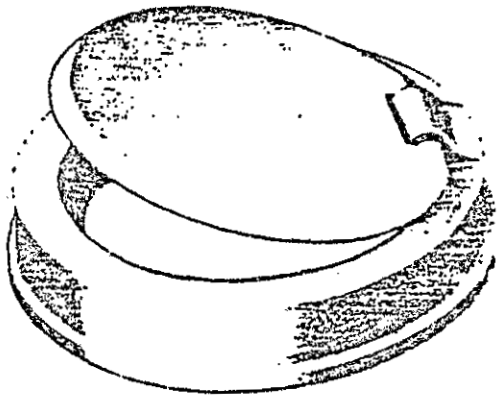
As with saturated samples, it may not be possible to retain samples of very dry, cohesionless soils within a sampler. Sand augers and specially designed soil-sampling tubes are useful for sampling in these soils. Alternatively, thin-walled drive samplers with sample retainers, or "core catchers" could be used. Two types of sample retainers, shown in Figure 3-11, include a one-way solid flap valve, and a segmented, spring-type basket retainer. Core catchers are inserted inside the sampler between the shoe and the sample barrel.

3.2.4 Site Accessibility

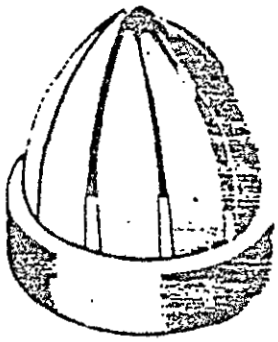
Generally, site accessibility refers to the ease of reaching on-field monitoring sites. Specifically, the surface soils at a field may become virtually intractable following liquid waste application or after a heavy rainfall. For such conditions, power-driven units mounted in pickup trucks cannot be used, whereas, an operator may (albeit with difficulty) be able to reach the site on foot with the sampling equipment.

3.2.5 Relative Sample Size

A review of the discussion on sampling tools will show that the sample size obtained by the different samplers varies. For example, hand-driven screw-type augers generally obtain samples from a bore hole which is less than 2 inches in diameter, whereas, barrel augers are available for obtaining 5 inch cores. The choice of a unit may be based on sample size requirements.



(a)



(b)

Figure 3-11. Soil Core Retainers for Sampling in Very Wet Soils and Cohesionless Soils. (a) One-Way Solid Flap Valve, (b) Spring-Type, Segmented Basket Retainer

the number and kind of analysis to be done on the soil sample will determine the volume of sample required. In addition, in rocky and stoney soils larger units may be necessary to obtain a useable mass of sample once the rocks have been discarded.

3.2.6 Labor Requirements

Generally speaking, it is probably good practice to send at least two individuals into the field to obtain samples. That is, hand-sampling is often tedious and two individuals can take turns on the sampler. In addition, note-taking and sample labelling is facilitated when two individuals are involved. Strictly speaking, however, the majority of sampling tools only require the presence of one individual, the exception being where power equipment is used.

3.2. Sampling in Rocky and Stoney Soils

Rocky or stoney soils in the treatment zone will generally impede the progress of most tools. The problem will be accentuated with small diameter tools such as soil probes, and alternate tools such as larger diameter barrel augers may be nessary.

3.3 RANDOM SOIL-CORE MONITORING SITE SELECTION

The RCRA guidance document on land treatment recommends that soil-core monitoring sites be randomly selected (EPA, 1983; Brown & Associates, 1983).

If n random sites are to be selected, a simple random sample is defined as a sample obtained in such a manner that each possible combination of n sites has an equal chance of being selected. In practice, each site is selected separately, randomly, and independently of any sites previously drawn. For soil-core monitoring, each site to be included in the "sample" is a volume of soil (soil core).

It is convenient to spot the field location for soil-coring devices by selecting random distances on a coordinate system and using the intersection of the two random distances on a coordinate system as the location at which a soil core should be taken (see Figure 3-12). This system works well for fields of both regular and irregular shape, since the points outside the area of interest are merely discarded, and only the points inside the area are used in the sample.

The location, within a given uniform area of a land treatment unit (i.e., active portion monitoring), at which a soil core should be taken should be determined using the following procedure:

(1) Divide the land treatment unit (Figure 3-12) into uniform areas (aa, bb, cc, dd). A uniform area is an area of the active portion of a land treatment unit which is composed of soils of the same soil series and to which similar wastes or waste mixtures are applied at similar application rates. A certified professional soil scientist should be consulted in completing this step.

obtain a sufficiently large sample exceeds the maximum holding time for analysis. Similarly, there may be cases where the soil is so dry that the units simply will not yield a sample. This may be particularly true in arid regions where rainfall is not great enough to wet up the soil profile. Note that sampling should be timed to occur immediately after a rainfall or significant waste application events which may alleviate this problem in certain cases.

4.9.2 Physical Properties: Soil Texture and Soil Structure

Soil texture refers to the relative proportion of the various soil peparates (particles 2 mm) in a soil (EPA, 1983). Examples of soil texture classes include silt loam, silty clay, and sand. The successful operation of suction samplers requires a continuity between pore sequences in the porous segment of the sampler and those in the surrounding soils. When soils are very coarse-textured, a good contact between the porous segment of a sampler and the fine pore sequences may be difficult to maintain and the flow continuum may be destroyed. Unlike the problem of sampling in very dry soils, the problem of poor soil contact is mainly an operational problem which can be circumvented by using the silica sand method of cup installation (see Figure 4-18). In this method, the porous segment of the sampler is placed in close contact with the silica sand, which in turn contacts a larger area of the surrounding soil. This method helps to maintain a continuity in the flow paths that soil water follows in moving from the soil through the silica sand and porous segment into the interior of the sampler.

Soil structure refers to the aggregation of the textural units into blocks. A well-structured soil has two distinct flow regions for liquids applied at the land surface: (1) through the cracks between blocks, i.e., interpedal flow, and (2) through the finer pore sequences inside the blocks, i.e., intrapedal flow. Liquids move more rapidly through the cracks than through the fine pores. Because of the rapid flushing of pollutants through larger interconnected soil openings, the movement of liquid-borne pollutants into the finer pores of the soil blocks may be limited. Inasmuch as suction-cup samplers collect water from these finer pore sequences, the resultant samples will not be representative of the bulk flow.

A primary goal of soil-pore liquid sampling is to detect the presence of fast moving hazardous constituents. This goal may not be realized if samplers are placed in highly structured soils leading to a flow system such as that described in the last paragraph. The structure of a soil profile is best examined by constructing trenches near the proposed monitoring sites to a depth corresponding to the maximum depth at which the sampling segments will be installed. The extent of large interpedal cracks should be documented at each profile. If such cracks appear to be widespread, alternative sites should be examined. However, it should be borne in mind that even large cracks frequently diminish in width in deeper reaches of the profile. If it is found that structural cracks "pinch out" at the monitoring depth, samplers could be installed. In fact, their operation may be enhanced if the soil moisture content of soils near the cups is increased by flow in nearby cracks.

4.9.3 Cup-Wastewater Interactions

For simplicity, the interactions between pore-liquid samplers and wastewater can be grouped into (1) those affecting the operation of the porous segment, principally by plugging, and (2) those that change the composition of pollutants moving through the porous segment.

4.9.3.1 Plugging--

A basic concern in the use of porous type samples to detect the movement of hazardous waste substances in soils is that the porous segment may become plugged either by particulate matter (e.g., fine silt and clay) moving with the liquid, or because of chemical interactions. The problem of clogging by particulate matter is not as severe as once thought. Apparently, soils have the capacity to filter out the fine material before reaching the porous segments. Several studies have been reported involving the use of suction-type samplers for monitoring pollutant movement at land treatment units. Generally, it appears that the sampling units operated favorably without clogging by particulate matter. An example of such studies include those by (1) Smith and McWhorter (1977), in which ceramic candles were used to sample pollutant movement in soil during the injection of liquid organic wastes; (2) Grier, Burton, Tiwari (1977) involving the use of depth-wise suction samplers on fields used for disposal of animal wastes; and (3) Smith et al. (1977), in which depth-wise suction samples were installed in fields irrigated with wastes from potato processing plants.

Chemical reactions at the surface of a suction sampler may clog the porous network. One type of chemical reaction is precipitation (e.g. of ferric compounds). However, considering the wide variety of chemical wastes which are disposed of at land treatment units, other effects are also possible, leading to the inactivation of suction samplers.

The operator of a land treatment facility may wish to determine the possibility of clogging from either particulates or chemical interactions before installing units in the field. For example, test plots could be employed (e.g., plots intended for the "treatment" demonstration). A cluster of suction samplers should be installed in the monitoring zone at each plot and waste applied at the proposed rate. The yield of each cup should be determined throughout the trial. Devices for measuring the suction of the soil water (e.g., tensiometers) should also be installed to ensure that the soil-water suction is within the operating range of the cups. This will demonstrate that cups fail to operate because of clogging and not because the soil is too dry.

Even though suction samplers may fail because of clogging, the problem may still be an operational difficulty that can be overcome. For example, installing silica sand around the cup may filter out particulate matter. Unless this filter becomes clogged, the samplers should continue to operate. However, this approach may not be sufficient to prevent clogging by chemical interactions.

4.9.3.2 Change in the Composition of Hazardous Constituents During Movement Through Pore-Liquid Samplers--

It is fairly-well established that the porous segments of suction samplers filter out bacteria but not virus. Similarly a reduction may occur in the metal content of liquids moving into samplers because of interactions within the ceramic segment. This problem can be reduced by acid leaching the cups before they are installed in the field, as described in another section of this report.

Because a major concern at land treatment areas is the fate of hazardous organic constituents, the amount of organic-cup interactions should be estimated before field installing sampling units. Change in the composition of hazardous constituents during liquid movement through suction samplers can be demonstrated by laboratory studies. Basically, during such studies suction samplers are placed in liquids of known composition contained in beakers. Samples are drawn into the cups and extracted for analysis. The change in composition is then easily calculated. In preparing these tests it is essential that each cup be preconditioned in accordance with recommended practice, i.e., flushing with 8N HCl, followed by rinsing with distilled water.

4.9.4 Climatic Factors

A major factor limiting the operation of suction samplers in very cold climates is that the soil water may become frozen near the cups. This means that a sample cannot be obtained during freezing conditions. Another undocu-

mented problem which conceivably could occur is freezing of samples within the cups and lines, so that the samples cannot be brought to the surface. Since the samplers are located at depths greater than 1.5 m (5 ft), it is unlikely that freezing would occur at this depth. Prior to winter setting in, the lines should be flushed. Inasmuch as land treatment is not recommended during winter months in very cold regions these problems may be academic.

Another effect of freezing temperatures is that some soils tend to heave during freezing and thawing. Consequently, suction samplers may be displaced in the soil profile, resulting in a break in contact. In addition, if the cups are full of liquid when frozen, the cups may be fractured as a result of expansion of the frozen liquid. The extent of these problems, however, has not been determined.

4.9.5 Safety Precautions

Worker safety is of paramount importance when installing systems of pore-liquid samplers in active land treatment sites, and during sample handling. In some cases all contact with the waste and liquid samples should be avoided, and toxic fumes should not be inhaled. Similarly, certain wastes are highly flammable and precautions should be taken to avoid creation of sparks. No smoking should be allowed. The degree of precaution that should be exercised, including the type of protective clothing, must be decided on a case-by-case basis. Further safety precautions are discussed in Section 3.

32. Fetter, C.W. "Potential Sources of Contamination in Ground Water Monitoring", Ground Water Monitoring Review, Spring 1983, pp. 60-64

2647
2648

POTENTIAL SOURCES OF CONTAMINATION IN GROUND-WATER MONITORING

This article discusses potential sources of error that can lead to contamination, including drilling techniques, construction materials and sample collection methods.

by C.W. Fetter Jr.

Introduction

Under the provisions of the Resource Conservation and Recovery Act (RCRA) and related regulations, ground-water monitoring is required at facilities where hazardous materials have been stored or disposed. This includes landfills, sludge, holding ponds, seepage pits, treatment lagoons, landfarms and drum storage areas. Ground-water monitoring is frequently required as part of the permitting process for new municipal and hazardous waste landfills. It is generally presumed that ground-water monitoring gives an accurate representation of the concentration of solutes in the ground water. This article identifies possible sources of contamination and error which may result in non-representative ground-water sampling. Because of the nature of many of these error sources, controlled experiments would be difficult to conduct and interpret. However, by recognizing possible sources of contamination, the necessary steps can be taken to minimize their occurrence.

There have been a number of recent publications on methods of drilling boreholes and design and installation of ground-water monitoring wells (Scalf et al. 1981, McLemore 1981 and U.S. EPA 1977). These reports provide an excellent background on this topic.

There are numerous opportunities for sample contamination to occur. This article will focus on drilling equipment and techniques, construction materials and techniques, design errors and sample collection methods and equipment, but will not include a discussion of potential sources of error due to storage, transportation and analysis of water samples.

Drilling Equipment and Techniques

The first opportunity for contamination is during the process of drilling a borehole. Boreholes are drilled for both subsurface investigations as well as the installation of piezometers and monitoring wells. The drilling equipment can be a source of such contaminants as gasoline, diesel fuel, hydraulic fluid, lubricating oils and greases and paint. Soil and scale from drilling operations at other locations could cling to the rig and drill pipe and spread contamination.

Before drilling begins, the drilling rig to be used should be carefully inspected. Any leaking oil should be cleaned up and hydraulic seals replaced. The rig, drill pipe, bits and tools should be cleaned to remove surface oil, grease, soil and other potentially contaminating materials. At a minimum, the equipment should be steam cleaned. The steam cleaning should be followed by a detergent wash and a clear water rinse. If trace organic contamination of the ground water is suspected, the rig and equipment should be decontaminated with a methanol rinse followed by a rinse with organic-free water. A sample of the rinse water from the rig should be collected and saved. If unusual contamination shows up in monitoring wells, the saved sample may implicate or vindicate the drilling rig as the source. The rig should be filled with oil, gasoline, diesel fuel and other fluids before being set up on the job site. No grease should be used on drill stem joints or other surfaces where it may come in direct contact with the soil or ground water. Externally greased points on the drill rig should have only a very light coating of grease.

The need to clean drilling equipment cannot be overstressed. The author is aware of one interesting case involving augers used to sample soil from an area containing spoils from a phosphate processing plant. The waste contained elemental phosphorous. The equipment was cleaned after the job and the drill rig parked for the night. When the soil clinging to the flight augers dried, the phosphorous ignited and started to burn. Fortunately, it was dis-

covered before the entire rig was destroyed.

At some sites the surface soil may be contaminated. If this happens a surface casing should be installed below the depth of the soil contamination. This will prevent contaminated soil from caving and being dragged down the borehole during drilling. Care should be taken to assure that contaminated soil does not become entrained in the drilling mud, if mud is used. The best way to avoid this is to install the surface casing by some means other than circulating drilling mud such as by driving or with flight augers. Following installation of the surface casing, the drill bit and tools should be cleaned as necessary to remove all traces of contaminated soil.

It should always be assumed that the ground surface is contaminated. No drilling equipment, tools or casing should be placed on the ground during work at the site. New plastic sheeting should be laid on the ground surface as a work surface to store flight augers, screen, casing and fittings. This sheeting should be discarded after each hole is drilled.

Boreholes for monitoring wells will generally be installed by one of four methods: hand augers, truck-mounted flight augers, mud rotary or air rotary. Hand-augered holes are shallow and if the equipment has been properly cleaned, should present no cross-contamination potential. Flight augers present the usual potential fuel and lubricant problems associated with any power equipment. Air and mud rotary drilling have some additional concerns associated with them.

Wash borings may be made using clear water in some unconsolidated formations. Minimal amounts of drilling mud should be used when needed. The use of organic polymer based drilling additives should be avoided, if possible. The organic material in these additives breaks down in the ground water and contributes chemical oxygen demand, biochemical oxygen demand and total organic carbon. This contamination can persist for some time. Figure 1 shows the change in chemical oxygen demand with time in four monitoring wells drilled with a commercial organic polymer. All started with a high level of COD (370 to 740 mg/l). With time three of the four wells had much lower concentrations (24 to 76 mg/l). The COD in the fourth well did not appreciably decline, indicating that the COD was due to ground-water contamination, not the drilling fluid.

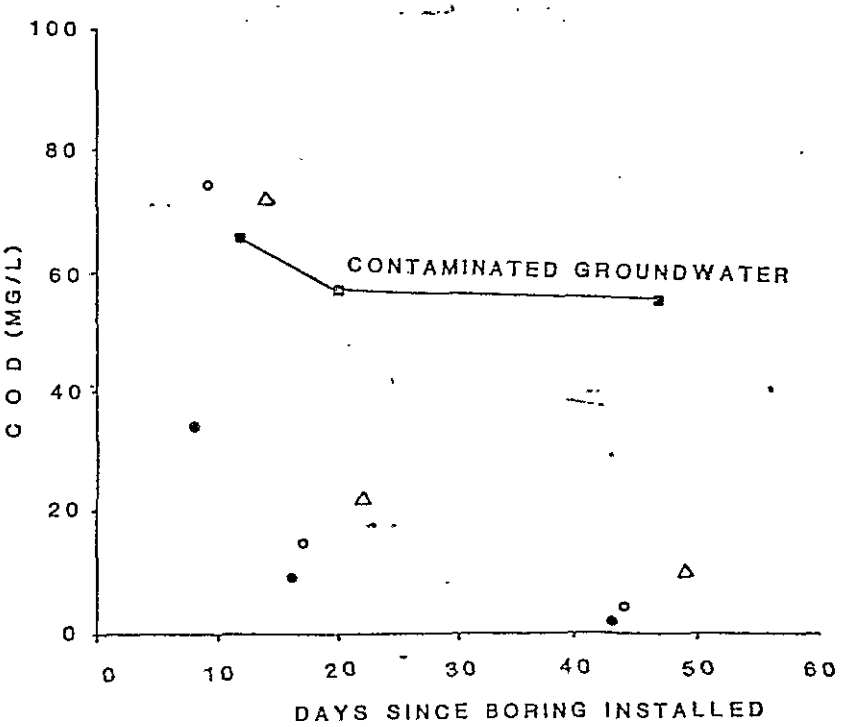


Figure 1. Reduction with time of biochemical oxygen demand of water bailed from monitoring wells drilled with an organic polymer drilling fluid. Note: The well indicated by solid squares is most likely sampling actual contamination. Source: R.B. Brobst and P.M. Buszka (in prep.)

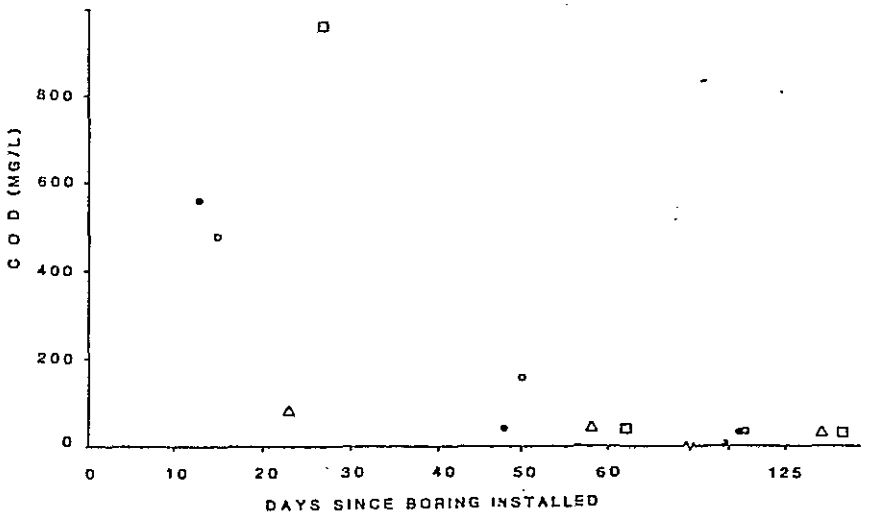


Figure 2. Reduction with time of biochemical oxygen demand of water bailed from monitoring wells drilled with commercial bentonite drilling mud. Source: Robert Brobst and P.M. Buszka (in prep.)

Commercial bentonite for drilling muds usually contains some organic polymer to aid its mixing with water. As is the case with wells drilled with organic polymers, ground water from wells drilled with bentonite can yield high levels of COD. In one such set of wells, ground-water samples contained initial values of 40 to 90 mg/l of COD. Some 60 days after installation, COD had declined to a background level of 4 mg/l (Figure 2).

Air-rotary drilling is generally used for installing wells in hard rock. Drill cuttings are brought to the surface by a stream of compressed air. If the borehole is below the water table, the compressed air will also blow spray to the surface. The compressed air can contain small quantities of oil and exhaust gases which might contaminate the borehole. These can be filtered from the air stream prior to entering the borehole, thus avoiding potential

contamination. In case the borehole should encounter contaminated ground water, drilling personnel should be protected from the exhaust air and water coming from the borehole.

In order to protect drillers' health and maintain the integrity of the monitoring wells, drillers should wear protective equipment appropriate to the known or suspected waste. Minimum equipment commonly includes impervious gloves, boots, coveralls and splash goggles. Disposable gloves, overboots and overalls are available; new gear should be used for each separate monitoring well installation so that contamination is not transferred from one well to another.

Construction Techniques and Materials

Selection of the type of material from which a ground-water monitoring well is constructed is very important. The designer must make a trade-off between cost and potential sampling interference. Two types of interference are possible; the casing might contribute a contaminate not already in the ground water, or it might absorb contaminants which are in the aquifer. The cement used to join PVC pipe has been shown to bleed organic chemicals into water in contact with the PVC. (Sosebee et al. 1982, Miller 1982 and Boettner 1981). Various types of flexible tubing, including polyethylene, polypropylene, black latex, PVC and "garden hose" were found to bleed compounds into organic-free water. This effect persisted even though the tubing was flushed out with organic-free water for some time (Junk et al. 1974). It has been reported that Teflon tubing does not leach organics into water (Miller 1982). Pettyjohn et al. (1981) suggest that the preferred order of casing materials for sampling for trace organics in ground water is glass, Teflon, stainless steel, polypropylene, polyethylene, other plastics, metals and rubber. However, Miller (1982) showed that PVC was superior to polypropylene and polyethylene when tested for adsorption and leaching of six common volatile organic compounds. All three plastics were found to absorb lead but not chromium.

Selection of Teflon casing for monitoring wells exposed to both organic and metallic contamination is preferred if the budget allows. Otherwise stainless steel or PVC pipe with threaded couplings is probably the best choice. Rigid PVC appears to avoid some of the problems associated with PVC tubing since the compounds bled from the tubing come primarily from the plasticizers. Installation of a monioring well in an uncontaminated area can be used as a background check to determine if the casing is contributing contamination (Pettyjohn et al. 1981).

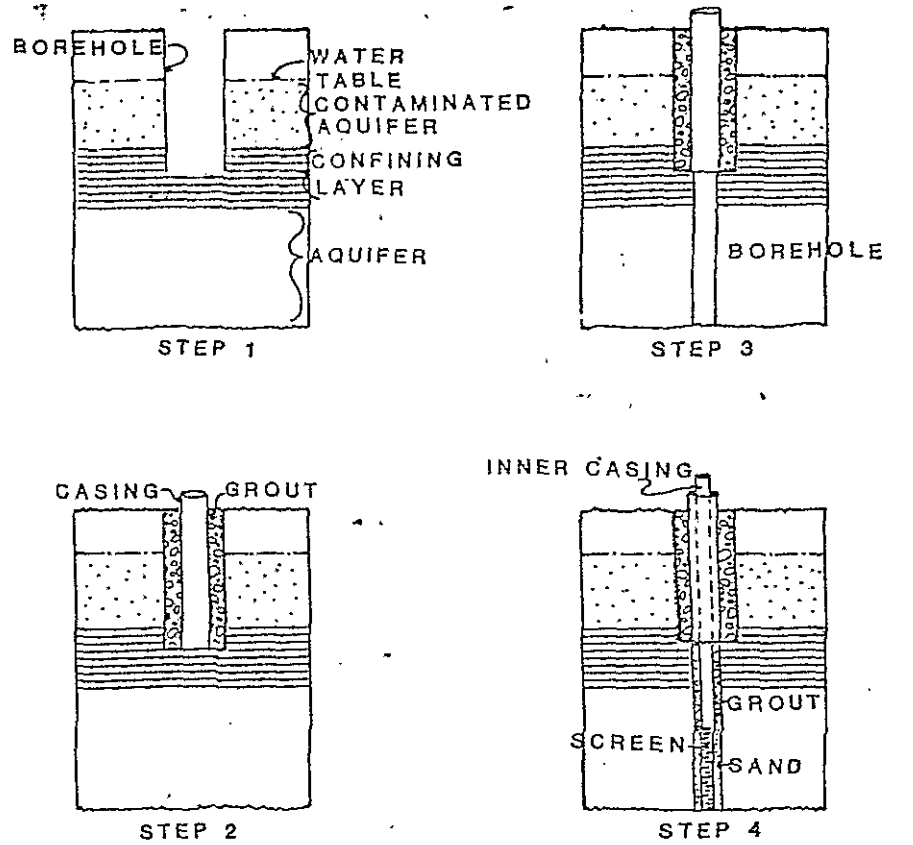


Figure 3. Steps in installing a double-cased well to prevent cross-contamination of aquifers

Pipe should be selected and the well designed with the specific application in mind. The designer must make a judgment as to the expected or potential contaminants and select the material which will provide the least interference.

If an aquifer to be sampled lies below a contaminated zone, proper well installation techniques must be applied to avoid cross-contamination between aquifers. This can be accomplished by double-cased wells especially if there is a confining layer present between the two aquifers.

Figure 3 shows the steps in the installation of a double-cased well. In the first step, a boring is made using mud rotary equipment to drill through the contaminated aquifer and into an underlying clay confining layer. A casing is then installed in the borehole and cemented from the bottom to the surface (Step 2). The casing is then thoroughly flushed with water to remove any drilling fluid. A water sample should be collected at this point from the outer casing and tested for contamination. In the third step, a smaller diameter borehole is drilled inside the outer casing through the confining layer and into the aquifer which is to be sampled. Finally, the monitoring well is placed inside the outer casing and cemented from the top of the lower aquifer to the surface (Step 4).

If there is soil contamination, but no confining layer, then a surface casing should be installed below the level of the contaminated soil. The depth of soil contamination must first be determined. This can be conveniently done by hand augering in many cases. The installation of a double-cased well using the surface casing as the outer casing is then accomplished as detailed above.

Installation of double-cased monitoring wells is expensive, but not nearly as expensive as remedial measures which may have to be taken to restore an aquifer contaminated by a cross-connection.

Ground-water monitoring wells should be developed thoroughly and carefully after drilling. Development

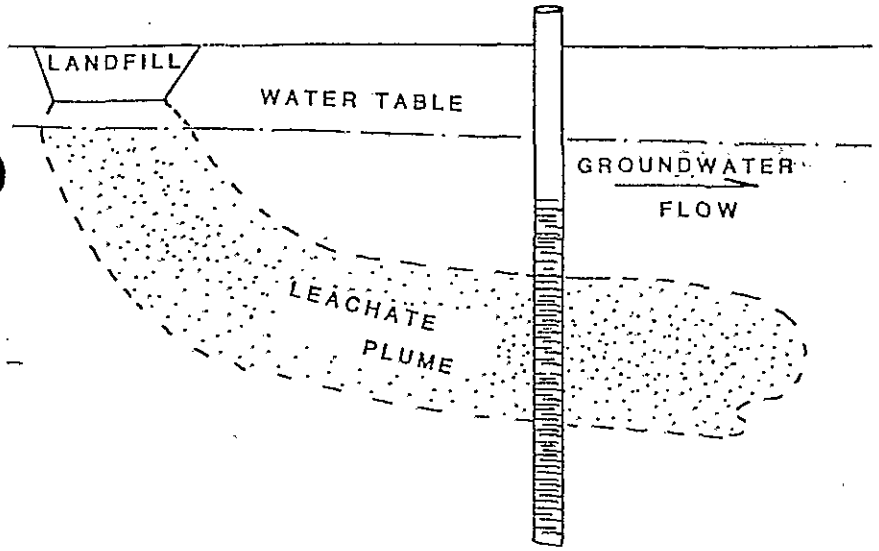


Figure 4. Monitoring well which by improper design fails to detect maximum concentration of ground-water contamination due to dilution of plume by uncontaminated water

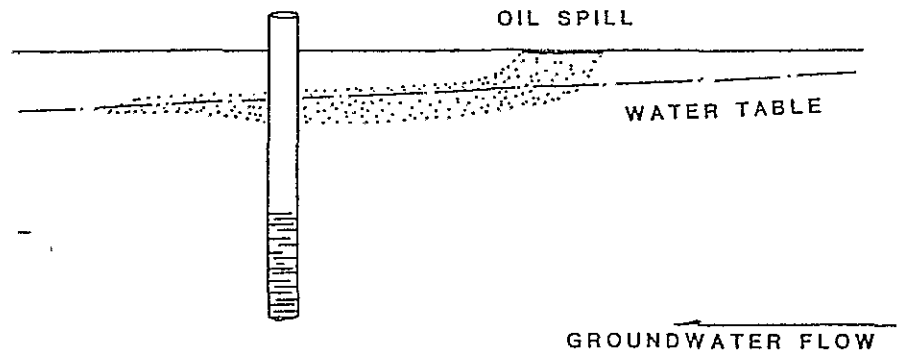


Figure 5. Monitoring well which by improper design fails to detect the presence of a low density fluid

increases the well efficiency and removes fine materials which may cause turbidity and therefore interfere with chemical testing. It is especially important to break down and remove any bentonite which is in the borehole. Bentonite can absorb heavy metals and interfere with the water-quality testing. Introducing water into the well during development should be avoided. Block surging and pumping are preferred methods of development. If water must be added to the borehole, it should come from a source which is known to be free of contamination. If water is added during development, the well should be pumped to remove several times the volume of the introduced water.

In situ permeability tests, using pumping, bailing or displacement techniques may also be conducted in monitoring wells. If clear, uncontaminated water is poured into the well for a slug test, the well should be pumped to remove several times the volume of introduced water prior to water-quality sampling. Uncontaminated water can dilute contaminated ground water and result in incorrect water-quality analyses.

Incorrect Location of Monitoring Wells and Sampling Intervals

Improperly located ground-water monitoring wells or poorly selected screen depths can result in water samples which have solute concentrations lower than those actually existing in the aquifer. The sample is, in a manner of speaking, being "contaminated" by background ground-water quality.

The locations for monitoring wells should be selected on the basis of site hydrology. It is entirely possible to have one upgradient and three downgradient wells, as required by RCRA, and still miss a contaminant plume. The pathway of the plume will be determined by local hydrogeologic conditions; it will follow the most permeable pathway and may not move normal to the hydraulic gradient (Fetter 1981). The importance of proper judgment in designing the monitoring well network cannot be overstressed.

In Figure 4, for example, a monitoring well is located downgradient of a landfill. The monitoring well is screened to the bottom of the aquifer, and a leachate plume is located in the top of the aquifer. The monitoring well intercepts the leachate plume, but also draws uncontaminated water. Results of sampling the monitoring well may indicate that the ground water is not as contaminated as it actually is due to dilution. In order to determine the maximum concentrations in a plume, multiple-level monitoring wells, with sampling devices at several intervals, can be used (Pickens et al. 1981, Gillham and Johnson 1981).

Low density liquids, such as petroleum products, may be difficult to detect because they tend to move either in the capillary zone or be dispersed only into the very top of the phreatic zone. Monitoring wells which are installed too deeply may not detect the contamination (Figure 5).

Monitoring Equipment and Techniques

Once a well has been correctly designed, installed and developed, a sample must be properly withdrawn from the well. Water sitting in the well for a period of time will not have the same chemistry as water in the aquifer. Solutes may be sorbed or desorbed from the casing and screen material, oxidation may occur and biologic activity is always possible (Scalf et al. 1981).

Water may be removed from the well by means of bailers, peristaltic pumps, air-lift pumps, nitrogen-lift pumps and submersible pumps. Research has shown that the chemical quality of the water withdrawn from a monitoring well will vary with the amount of water pumped prior to sampling and the type of pump used (Gibb et al. 1981). Peristaltic or submersible pumps and bailers have been found to be more reliable than air- or nitrogen-lift pumps. The former types of pumps change the pH of the water during sampling, thus affecting the water chemistry. Gibb et al. (1981) suggest that from five to 10 well volumes of water should be removed from the wells before consistent chemical quality results can be obtained. Monitoring pH and conductivity in

the field during sampling will indicate when chemical quality has stabilized.

In the case of volatile organic compounds, peristaltic or air-lift pumps should not be used as they tend to strip the volatile organics. Designs are available for all-glass and Teflon positive displacement pumps (Thompson et al. 1980) and an all Teflon-glass bailer (Scalf et al. 1981) Either is appropriate for sampling for volatile organics.

A standard procedure used during sampling is to field-filter ground-water samples through a 45 micron filter at the time of collection. This can be accomplished by using an in-well pump with an in-line filter in the discharge line. The advantage of this setup is that samples can be isolated from the atmosphere during the entire pumping, filtering and sample-bottle filling process. Field measurements of pH, Eh and specific conductance should be made in the well or in a closed cell to avoid sample oxidation.

All sampling, collecting and filtering equipment should be thoroughly rinsed and cleaned between wells. For wells with suspected trace organics, sampling equipment should be washed with detergent or acid and then rinsed thoroughly with tap water and then deionized water. Glass sample containers can be heated to 560 degrees for two hours to drive off any remaining volatile organics (Scalf et al. 1981). Steel or electric tapes used for water-level measurements in one well should be cleaned before measurements are taken in other monitoring wells. Disposable plastic or rubber gloves of a type appropriate to the contaminant should be worn by personnel during the cleaning of sampling equipment and also during sampling. New disposable gloves should be used for each monitoring well.

Conclusions

Monitoring wells are subject to many potential sources of contamination during drilling, construction, development and sampling. Analytical techniques are routinely used which measure chemical concentrations in parts per billion. If contaminated water samples are drawn from a monitoring well, there will be substantial sums expended for further study, and perhaps for remedial and closure actions. With improperly designed, constructed and tested monitoring wells, there is a potential that the contamination detected is an artifact. Properly constructed monitoring wells will be expensive, but in the final analysis they may be far cheaper than an inexpensive monitoring well which produces false indications of ground-water contamination.

Acknowledgments

Bruce Jernigan, Don Miller, Charles Spiers and Dave Wheeless, all of Law Engineering Testing Company, provided many of the ideas contained in this article. I would like to thank them for their careful review of this manuscript and many helpful comments. Robert Brobst of the City of Antigo, Wisconsin, kindly provided some data from monitoring wells drilled for the city.

Biographical Sketch

Dr. C.W. Fetter Jr. is a professor of geology at the University of Wisconsin-Oshkosh. At the time this article was written, he was manager of the ground-water resources program of Law Engineering Testing Company, Marietta, Georgia. He is a certified professional geologist and a registered professional engineer and was formerly chairman of the Department of Geology at Oskhosh.

References

Boettner, E.A. 1981. Organic and organotin compounds leached from PVC and CPVC pipe. U.S. EPA Report. EPA 60011-81-062.

Brobst, R.B. and P.M. Buszka. In preparation. Effects of two selected drilling muds on ground-water sample chemistry.

Fetter, C.W. Jr. 1981. Determining the direction of ground-water flow. Ground Water Monitoring Review, v. 1, no. 3, pp. 28-31.

Gibb, R., R.M. Schuller and R.A. Griffin. 1981. Collection of representative water quality data from monitoring wells. Proceedings of the Seventh Annual Research Symposium, U.S. EPA. EPA-600/9-81-002a. pp. 126-137.

Gillham, R.W. and P.E. Johnson. 1981. A positive displacement ground-water sampling device. Ground Water Monitoring Review. v. 1, no. 2, pp. 33-35.

McLemore, W.H. 1981. Monitoring well construction for hazardous-waste sites in Georgia. Georgia Geologic Survey Circular 5. 14 pp.

Miller, G.D. 1982. Uptake and release of lead, chromium and trace level volatile organics exposed to synthetic well casings. Proceedings of the Second National Symposium on Aquifer Restoration and Ground Water Monitoring. National Water Well Association, pp. 236-245.

Pettyjohn, Wayne A., W.J. Dunlap, Roger Cosby and Jack W. Keeley. 1981. Sampling ground water for organic contaminants. Ground Water, v. 19, no. 2, pp. 180-189.

Pickens, J.F., J.A. Cherry, R.M. Coupland, G.E. Grisak, W.F. Merritt and B.A. Risto. 1981. A multi-level device for ground-water sampling. Ground Water Monitoring Review, v. 1, no. 1, p. 51.

Scalf, M.R., J.F. McNabb, W.J. Dunlap, R.L. Crosby and J.S. Fryberger. 1981. Manual of ground-water quality sampling procedures. National Water Well Association and U.S. EPA, 93 pp.

Sosebee, J.B. Jr., P.C. Geiszler, D.C. Winegardner, C.R. Fisher. 1982. Contamination of ground-water samples with PVC adhesives and PVC primer from monitoring wells. Technical Paper, Environmental Science and Engineering, Gainesville, Florida. 24 pp.

Tomson, M.B., Steve Hutchins, Joe M. King and C.H. Ward. 1980. A nitrogen powered continuous delivery, all-glass-Teflon pumping system for ground-water sampling from below 10 meters. Ground Water, v. 18, no. 5, pp. 444-446.

Turk, G.A., H.J. Svec, R.D. Vick and M.J. Avery. 1974. Contamination of water by synthetic polymer tubes. Environmental Science and Technology, v. 8, no. 13, pp. 1100-1106.

U.S. EPA. 1981. Procedures manual for ground-water monitoring at solid waste disposal facilities. SW-611. 269 pp.

33. Fishbaugh, Timothy. "Monitoring in the Vadose and Saturated Zones Utilizing Fluoroplastic," Ground Water Monitoring Review, Fall 1984, pp. 183-187

2645

Monitoring in the Vadose and Saturated Zones Utilizing Fluoroplastic

by Timothy Fishbaugh

Abstract

A ground water monitoring program should include an investigation of all possible areas of concern. To be completely effective, the program should include soil-sampling, soil analysis and water-quality examination of both the saturated and unsaturated zones. A well-tooled drill rig can take all the proper soil samples, perform all necessary tests and install a functional monitoring well. With the introduction of the fluoropolymer (Teflon®) sleeve lysimeter, a single monitoring well can be constructed to monitor both the saturated and unsaturated zones in one installation. The monitoring well screen and casing may also be completely constructed of fluoropolymer.

The sleeve lysimeter is designed with a threaded hollow inner diameter, allowing it to be attached between the joints of a casing string. This hollow I.D. acts as an extension of the casing; the lysimeter surrounds the casing. This creates an isolated vessel for sampling the vadose zone. Access to the screened monitoring well below is unaffected. Tests have shown that when properly installed, these porous fluoropolymer filter units can collect samples with no interaction between the filter and collected fluids.

Introduction

A well-executed ground water monitoring program entails the study of both the saturated zone and the unsaturated (vadose) zone. The saturated zone has been extensively studied in attempts to document the presence of ground water contamination.

The unsaturated zone on the other hand, has not been studied in detail until very recently. Many sampling devices are now available to sample soil pore water from the unsaturated zone. These include vacuum plates and tubes, membrane filter samples, absorbent devices and the vacuum pressure lysimeter (Morrison 1983).

Due to increased reliance on monitoring at waste sites (landfills, lagoons, etc.) as an "early warning" detection system, monitoring of the vadose zone has become a more standard practice. This must be a complete cost-effective system. Most important is that representative samples are obtained.

The ability to monitor both the unsaturated and saturated zones in one bore hole is not new. A major

TABLE 1

Relative Compatibility of Rigid Well-Casing Material
(After Barcelona et al 1983)

	PVC 1	Galvanized steel	Carbon steel	Lo-Carbon steel	Stainless steel 304	Stainless steel 316	Teflon
Buffered weak acid	100	56	51	59	97	100	100
Weak acid	98	59	43	47	96	100	100
Mineral acid/high solids	100	48	57	60	80	82	100
Aqueous/organic mixtures	64	69	73	73	98	100	100
Percent overall rating	91	58	56	59	93	96	100

advancement in the monitoring of these zones, however, is the use of one casing string, constructed of Teflon (fluoropolymer), and a Teflon sleeve lysimeter.

Chemical Inertness

Advancements in ground water monitoring systems are due to the inertness of Teflon sleeve lysimeters. The Teflon medium of the sleeve lysimeter does not exhibit the water quality problems inherent with other lysimeters (Morrison 1983). No other substance has surpassed Teflon in chemical inertness, except for laboratory glass (Timco 1984).

In a report released by the Illinois State Water Survey (Barcelona et al. 1983) Polyvinyl chloride (PVC) has been shown to release and absorb trace amounts of various organic constituents to water. In the report comparative tests of ferrous metals, PVC and Teflon were performed. The results are shown in Table 1 and the following conclusions are made:

- PVC is a particularly problematic material, showing both the absorption/release of organic compounds and the leaching of compounding ingredients.
- Teflon represents a nearly ideal well construction material. The structural properties of Teflon are sufficient for the most exacting environments. Teflon has not been reported to contribute organic or inorganic contaminants to aqueous solutions.
- Well casing and screen materials, in order of preference, for most monitoring situations are: Teflon, stainless steel, and rigid-threaded PVC. (Table 2).

TABLE 2

Ranking of Rigid Materials
(After Barcelona et al 1983)

Teflon
Stainless steel 316
Stainless steel 304
PVC 1
Lo-Carbon steel
Galvanized steel
Carbon steel

It can be concluded from this report that PVC is a source of contamination and that it is capable of causing bias in a sample. Because of Teflon's overall chemical resistance this material is especially useful when dealing with PVC contaminants or unknown trace elements.

The Sleeve Lysimeter

The sleeve lysimeter is used to monitor pollution in the unsaturated zone. By applying a vacuum to the lysimeter moisture is drawn into the unit. The water collected in the unit is then forced to the surface by inert pressurized gas. The filter is a tubular design, originally developed by Timco™, which allows for the collection of larger samples at a faster rate than cup designs (Dupont 1982).

The sleeve lysimeter and all other installation materials can be constructed of 100 percent Teflon. The unit is constructed of an inner casing surrounded by the sampling section to allow access to the monitoring well below. The outside diameter of the sleeve lysimeter measured 88.9mm (3.5 inches) and can accommodate 38.1mm or 50.8mm (1.5 inches or 2.0 inches) inside diameter flush-threaded casing. Standard length is 609.6mm (24.0 inches) with optional lengths available for varied sample storage (Timco 1984).

The unit consists of the following components (Figure 1):

- Threaded cap with tubing connectors
- Blank casing
- Threaded porous Teflon section
- Blank casing
- End cap
- Inner casing

All components are Timco flush-threaded and are constructed of either Teflon or PVC, excluding the porous medium. The porous medium is made up of 100 percent Teflon and has a pore size averaging 70 microns. This has been found to be the optimum pore

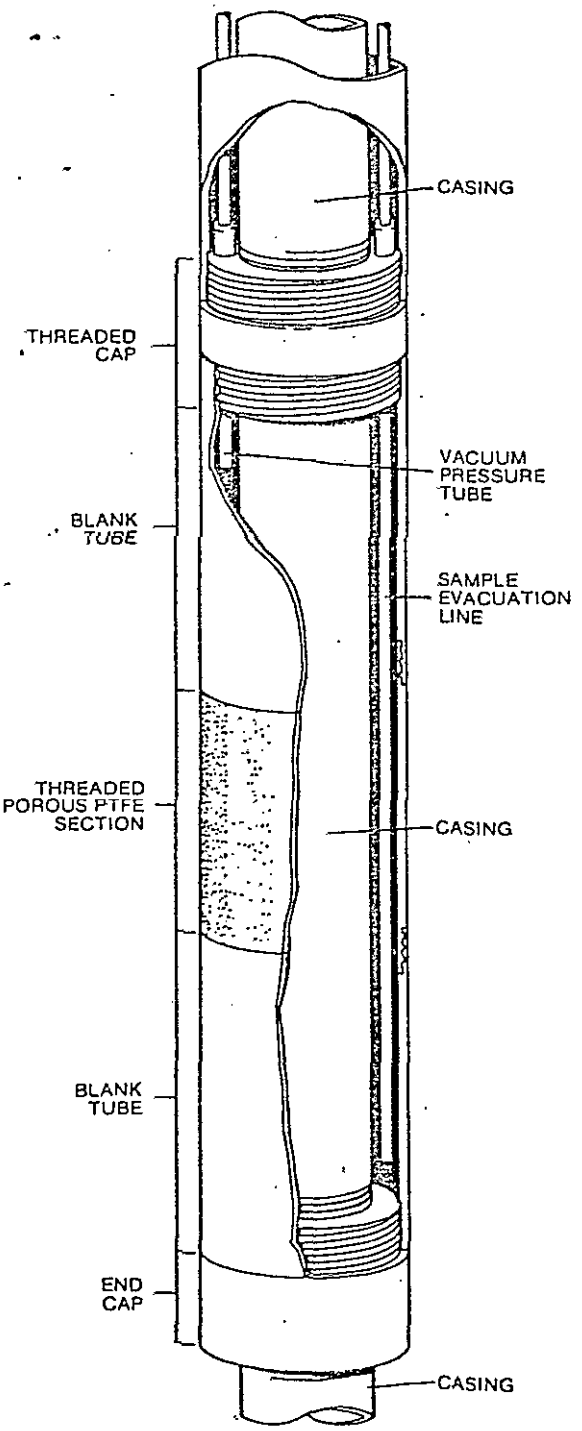


Figure 1. Sleeve lysimeter in cross section

size, as determined by comparative laboratory studies at Timco during the development of Timco lysimeters. The flush-threaded design allows the sleeve lysimeter to be constructed to suit the specific soil characteristics.

The Sleeve Lysimeter System

The monitoring system for the saturated/unsaturated zone is a versatile assembly of Teflon construction materials. The components of the system, the sleeve lysimeter and the casing and screen can be selected for the most reliable, yet economical system possible.

If chemical inertness is not necessary, the sleeve lysimeter and the casing and screen can be constructed of PVC. If chemical inertness is required, but only in certain zones, Teflon materials are used in those areas being monitored, while less inert materials are used in areas that will not affect the sampling zone. These less inert materials include PVC or stainless steel adapted to the Teflon. Using less inert materials helps to cut costs provided sampling bias does not occur. If total chemical inertness is necessary, a complete Teflon construction is recommended, which would include the screen, casing and sleeve lysimeter and all tubing and sampling devices. This is the only way to assure a pure sample, especially in monitoring areas of unknown contamination. The use of PVC or stainless steel construction materials would cause uncertainties as to the type and level of contamination.

Installation

The installation of a monitoring system utilizing the sleeve lysimeter has also proven to be advantageous. Many methods of unsaturated/saturated zone monitoring have been conducted, including a monitoring well surrounded by lysimeters (Figure 2), or a monitoring well with separate lysimeters installed in the same borehole (Figure 3a).

Both of these installation methods have their drawbacks. In the first method, in which a well is surrounded by lysimeters, it is necessary to drill three to five boreholes. Not only is this expensive but it creates correlation problems. In the second method in which separate lysimeters are installed in the same borehole, two to four conductor pipes with multiple seals are needed, thus increasing the risk of surface water channelization. Correlation between the lysimeter to the well is yet another problem with this method.

Therefore, a more cost-effective and reliable system consists of a pipe by which the lysimeters and screens can be suspended. A sleeve lysimeter enables this type of setup (Figure 3b).

The sleeve lysimeter system is installed in a 20.32 cm (8-inch) borehole (Figure 4). The screen is set, gravel-packed and sealed with bentonite. At the same time the sleeve lysimeter is set as part of the same casing string as the screen. Once the backfill is just below the sleeve lysimeter, another bentonite seal is set. Then a silica slurry of 150ml of distilled water to .45kg of 99.8 percent pure silica flour (.04 gallon water to 1 pound flour) is poured around the sleeve lysimeter, creating contact between the soil and the sleeve lysimeter and deterring clogging of the filter pores. The silica pack is poured completely over and above the sleeve lysimeter. This allows for slumping of the slurry. A bentonite seal is then placed above the lysimeter and the hole is backfilled and grouted.

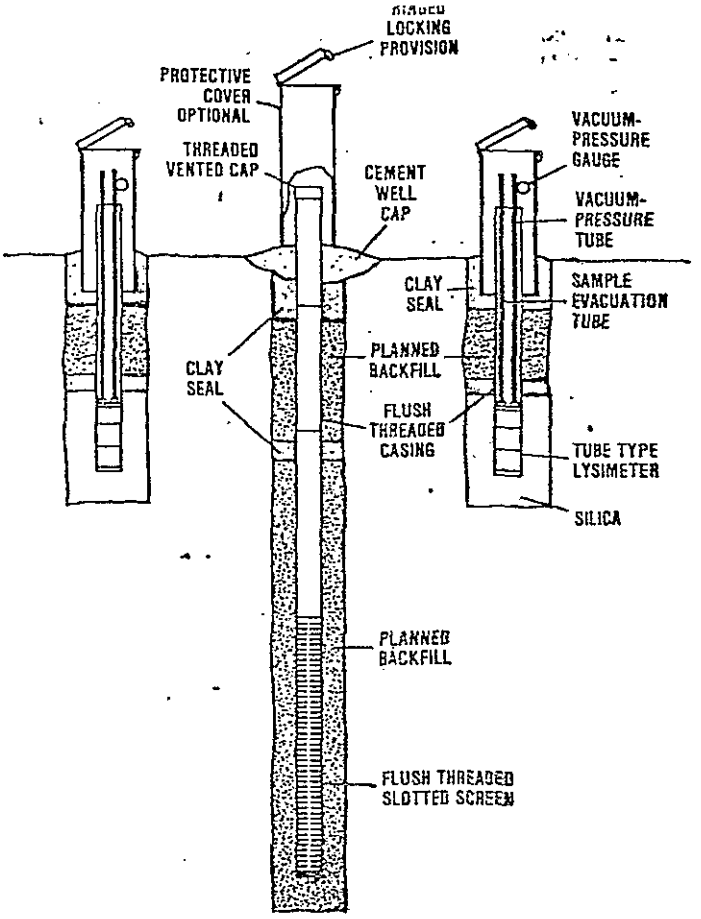


Figure 2. Monitoring well installation surrounded by lysimeter installations

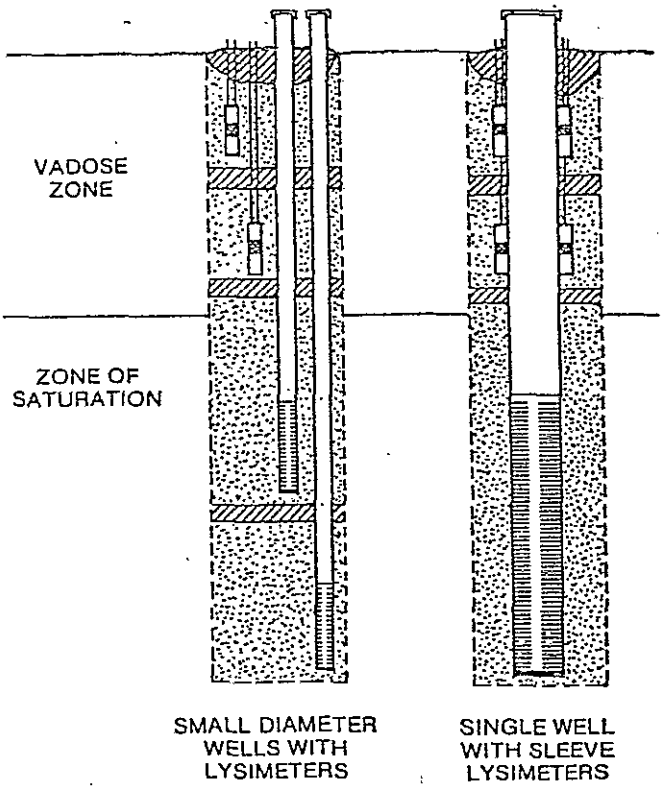


Figure 3. a. Small-diameter wells with separate lysimeters; b. single well with sleeve lysimeters.

The sleeve lysimeter also makes it possible to stack more than one lysimeter in the same installation. Studies show that the lysimeters can be stacked less than 1m apart, if necesary (Morrison and Szecsdoy 1984). In most applications, however, spacing is not a limiting factor.

Laboratory Evaluation

A test was run by Timco Technical Services to evaluate the ability of the sleeve lysimeter in drawing a sample from the unsaturated zone. The test was designed to measure both the sample received and the percentage of soil moisture present.

The porous medium of the sleeve lysimeter was constructed of Teflon while the body was made of PVC. This was done to reduce costs. A standard 88.9mm O.D. by 609.6mm long (3.5 inches O.D. x 24 inches long) sleeve lysimeter was used with a 50.8mm I.D. (2 inches I.D.) flush-threaded casing.

Standard Timco lysimeter evaluation installation procedures were followed. This involved installing the unit in a 121L (32 gallon) plastic container holding a moist 40-50 mesh masonry grade silica sand. The container was designed with holes bored in the side to allow sampling of the sand for moisture content and bottom holes to simulate natural drainage.

Approximately 4-6 inches of soil was placed in the bottom of the container. A casing approximately 7.6 cm (3 inches) larger than the lysimeter was then set in the sand to act as a standpipe. Sand was then added in around the standpipe filling the container to capacity. A silica slurry made up of 150ml of distilled water to .45kg of 99.8 percent pure silica flour (.04 gallon water to 1 pound flour), was then poured to a depth of 7.6 to 10.2cm (3 to 4 inches) in the standpipe. Next, the sleeve lysimeter was placed in the center of the standpipe and the balance of the slurry added until the lysimeter was well-covered. Care was taken to ensure that the lysimeter was centered. The standpipe was then removed by twisting and pulling so as not to allow the silica to adhere to the standpipe walls. By removing the standpipe the silica slurry was allowed to make contact with the soil medium.

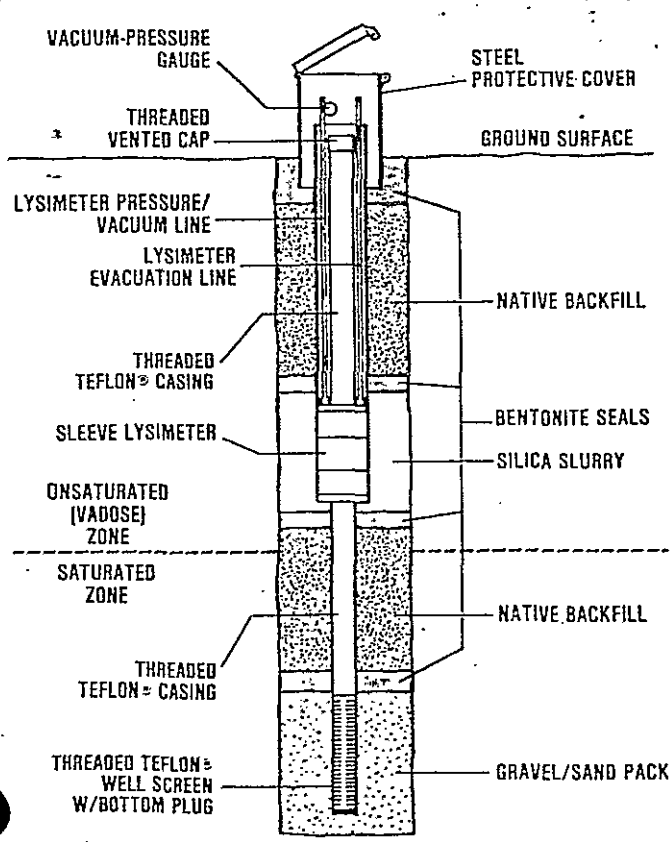


Figure 4. Monitoring well and sleeve lysimeter installation

A vacuum of 508mm of Hg (20 inches of Hg) was applied immediately after installation using a vacuum-pressure hand pump. The tubing was then closed off to ensure no loss of vacuum. At approximately 24-hour intervals the lysimeter was sampled (Timco Technical Services Division 1983).

A glass flask with a two-hole stopper was used to retrieve the sample. The evacuation or sampling tube was inserted into one side of the stopper. Another tube was inserted into the other side in order to apply a vacuum. A vacuum was applied until sampling ceased. This procedure was repeated at 24-hour intervals, producing the data in Table 3. Soil moisture data was also collected and recorded at intermittent intervals (Table 3) (Timco 1983).

Samples were collected down to a soil moisture of .4 percent at which time the lysimeter failed to collect any sample. To remedy this problem 3,000ml (.79 gallon) distilled water was added after which the unit started to function again. It should be noted that field installations of the sleeve lysimeter have continued to perform well.

Conclusion

The development of the sleeve lysimeter has alleviated many of the problems involved in monitoring the saturated/unsaturated zone. With the sleeve lysimeter attached directly to the casing string, correlation problems between the zones are eliminated. Installation time is reduced because the entire system is installed at the same time and because the number of seals and conductor pipes is at a minimum.

The sleeve lysimeter's threaded design enables the other components of the monitoring well to be variable in design and construction. This affords a monitoring well suited for the soil characteristics and contamination present and also allows the design to have more flexibility with costs. It should be emphasized that savings in initial installation costs can be misleading in the overall long-term monitoring program.

The development of the Teflon lysimeter and monitoring well has made it possible to install a totally inert monitoring system: a system in which the materials used in construction do not interfere with the integrity of the well or the samples withdrawn.

References

Barcelona, M.J., J.P. Gibb and R.A. Miller. 1983. A guide to the selection of materials: for monitoring well construction and ground water sampling. Illinois State Water Survey. 78 pp.

Dupont. 1982. Industry news. Dupont Co. Marketing Communications Department, Wilmington, Delaware. pp. 2.

Morrison, Robert D. 1983. Ground water monitoring technology: procedures, equipment and applications. Timco Mfg. Inc. Prairie du Sac, Wisconsin. pp. 48-52.

Morrison, Robert and James Szecsody. 1984. Sleeve and casing lysimeters for soil pore water sampling. Unpublished. pp. 12.

TABLE 3

Sleeve Lysimeter Performance Data
(Timco Technical Services Division 1983)

Time (Hrs.) After Installation	Vacuum Remaining	Sample Received ML	% Moisture of Media
24	11	252	.9
48	12	284	—
72	17	138	—
96	20	70	.96
120	Weekend	No sample	—
144	Weekend	No sample	—
168	12	8	.8
192	17	8	—
216	16	10	.7
240	20	20	—
264	16	5	.5
288	Weekend	No sample	—
312	Weekend	No sample	—
336	14	0	.4
360	17	0	—
384	18	0	—
408	16	0	.4
432	16	0	—
456	Weekend	No sample	—
480	Weekend	No sample	—
504	Added 3000 ML distilled water applied 20 inch Hg. VAC		
528	2	460	1.8
552	11	248	—
576	8	400	1.73
600	10	250	—
624	14	188	1.5
	Total Sample Received	2,341	

Timco Mfg. Inc. 1984. Introduction and sleeve lysimeter. Timco Product Catalog, Timco Mfg. Inc. Prairie du Sac, Wisconsin. 49 pp.

Timco Mfg. Inc. 1983. Installation of a Timco lysimeter. Timco Mfg. Inc. Prairie du Sac, Wisconsin.

Timco™ Technical Services Division. 1983. Sleeve lysimeter laboratory evaluation. Timco Mfg. Inc. Prairie du Sac, Wisconsin.

Biographical Sketch

Timothy Fishbaugh is employed by Timco Manufacturing Inc. Technical Services Division, manufacturers of ground water monitoring equipment. He is involved with customer service and research in ground water monitoring technology. Prior to Timco, Fishbaugh received his bachelor of arts in geological sciences/ground water technology and an associate degree of applied science in mechanical drafting and design at Wright State University. He was also an intern-geologist with the Ohio Environmental Protection Agency.

34. Freyberg, David, et al. "Advection and Dispersion in an Experimental Groundwater Plume," Presentation on Groundwater Quality Modeling, ASCE Hydraulics Div. Spec. Conf., MIT, 1983

Eagle 2640 2647

For presentation at the Special Session on Groundwater Quality Modeling,
ASCE Hydraulics Division Specialty Conference,
Massachusetts Institute of Technology, August 1983

Advection and Dispersion in an Experimental Groundwater Plume

David L. Freyberg,[1] A. M. ASCE, Douglas M. Mackay[2], and John A. Cherry[3]

ABSTRACT

In August 1982, a known mass of selected solutes was injected as a pulse into an uncontaminated portion of an unconfined, glaciofluvial sand aquifer at Canadian Forces Base Borden in Ontario, Canada. Transport of the resulting plumes by the natural gradient has been monitored using a detailed three-dimensional array of sampling points. Initial analyses of the data for chloride using estimated spatial concentration moments reveal the tracer plume to be moving at a constant and spatially uniform mean velocity of 10 cm/day, and less certainly, equal longitudinal and transverse dispersivities of about 0.06 m.

INTRODUCTION

Recent theoretical advances e.g., (1), (3), have greatly improved our understanding of the role of spatial variability in controlling the behavior of solute plumes in groundwater. However, validation of the results of these studies is extremely difficult using readily available data on existing contamination plumes. In addition, few data exist which can be used to assess how well our theoretical and laboratory-scale understanding of solute-solid matrix interactions can be applied to the interpretation and prediction of field-scale behavior. Motivated by these issues, a group of investigators from Stanford University and the University of Waterloo designed and initiated a large-scale, long-duration, natural gradient field experiment. Some initial results from the first three months of experimental observations, focusing on advection and dispersion, are reported in this paper.

THE EXPERIMENT

The experiment is being conducted in an unconfined, glaciofluvial sand aquifer at Canadian Forces Base Borden in Ontario, Canada. The site is an inactive sand quarry downgradient from an abandoned municipal landfill. The water table is 0.5-1 m below the quarry floor and the

1,2 Assistant Professor and Research Associate, respectively, Department of Civil Engineering, Stanford University, CA 94305.

3 Professor, Department of Earth Sciences, University of Waterloo, Waterloo, Ontario, N2L3G1, Canada.

base of the aquifer is defined by a relatively impermeable layer at a depth of 9 m. The bottom 3 m of the aquifer are occupied by a leachate plume from the abandoned landfill. The aquifer sediments are characterized by distinct small-scale (1-10 cm) horizontal bedding with relatively weak horizontal continuity.

On 23 August 1982 11.95 m^3 of a solution containing two inorganic tracers and five halogenated organic compounds was injected into the aquifer. The solution was injected for 14.75 hr at a constant rate of 1.5 ℓ/min into each of the nine injection wells shown on Figure 1. The wells were screened over a 1.6 m thickness of the aquifer from 2.0 to 3.6 m below the quarry floor. The injected solution composition was chosen to include organic chemicals with a range of expected mobility and biodegradability in the aquifer. Concentrations were selected to minimize density effects, maximize the duration over which measured concentrations can be distinguished from background, and to simplify laboratory analytical procedures.

The solute plumes are being monitored using multilevel sampling wells similar to those developed by the University of Waterloo for previous field studies at the site (4). The three-dimensional spatial distribution of sample points installed as of April 1983 is shown on Figure 1. Samples are drawn simultaneously from all points on a multilevel well using a specially-designed sampling manifold and a peristaltic pump. Approximately 56 mℓ are drawn from each sampling point per sample, with 14 mℓ retained for laboratory analysis. The tracers, chloride and bromide, are quantified using ion chromatography, while the organic compounds are analyzed using gas chromatography following pentane extraction. Hydraulic head is monitored at each multilevel well with a shallow and deep piezometer. A more detailed description of the experimental design and procedures has been presented elsewhere (2).

As of April 1983, over 4400 samples from a network of nearly 1800 points have been collected and analyzed. The majority were taken during seven sampling sessions at intervals of 1-3 weeks. Five additional "snapshot" sampling sessions are planned for May-December 1983. More frequent sampling (every 1-5 days) is being conducted at several individual points within the well field to provide detailed concentration time series data.

MOMENT ANALYSIS

Estimated moments of the concentration distributions provide a useful means for assessing the advective and dispersive characteristics of the solute plumes. For example, defining the ijk^{th} moment of the concentration distribution as

$$M_{i,j,k} = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} x^i y^j z^k n\, C\, dx dy dz$$

where n is the porosity and C the concentration, leads to the following results when transport is assumed Fickian in a homogeneous aquifer with uniform steady flow and an instantaneous source:

$$\frac{dM_{000}}{dt} = 0 \qquad (1)$$

$$\frac{dx_c}{dt} = V_x; \qquad \frac{dy_c}{dt} = V_y; \qquad \frac{dz_c}{dt} = V_z \qquad (2)$$

$$\frac{d\sigma_x^2}{dt} = 2D_{xx}; \qquad \frac{d\sigma_y^2}{dt} = 2D_{yy}; \qquad \frac{d\sigma_z^2}{dt} = 2D_{zz} \qquad (3)$$

Here M_{000} is the mass of solute in the initial plume, $x_c = (M_{100})/(M_{000})$ is the x-coordinate of the center of mass of the plume, V_x is the x-component of the mean velocity vector, $\sigma_x^2 = (M_{200})/(M_{000}) - x_c^2$ is the variance of the plume about $x = x_c$, and D_{xx} is the diagonal component of the dispersion tensor for the x-direction. Additional terms for the other coordinate directions are defined analogously. More generally, Eq. (3) may be taken as a definition of dispersion. Furthermore Gelhar and Axness (1) and others have shown that 1) D_{xx}, D_{yy}, and D_{zz} may not be constants for short travel distances, and that 2) asymtotically constant values of the dispersion coefficients can be related to the statistical properties of aquifer heterogeneity.

MOMENT ESTIMATES

Moments estimates have been obtained from the experimental data collected to date. Because, as expected, there is very little evidence of vertical motion or dispersion, early attention has focused on the horizontal coordinate directions (x,y). Assuming k = 0 allows the definition of the ijk^{th} moment to be expressed as:

$$M_{i,j,o} = b \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} x^i y^j n \, \overline{C} \, dxdy$$

where $\overline{C}$ is the vertically-averaged concentration over a specified thickness, b. Use of $\overline{C}$ permits convenient, although incomplete, graphical representations of plume size and structure.

Moments are estimated using snapshot data by first calculating $\overline{C}$ at each sampling well using trapezoidal quadrature. These data are then interpolated to a relatively dense, regular grid (0.6 x 0.6 m) using spatial interpolating routines available in the SURFACE-II plotting package. Numerical quadrature is used to estimate the moments from the gridded data. This procedure introduces a small systematic bias and smoothing of the data, but both are maintained small enough to minimize their impact on estimated moments.

INITIAL RESULTS

Figure 2 presents contour plots of vertically-averaged chloride concentration immediately and 35 days after injection. Figure 3 shows

the coordinates of the estimated center of mass of the chloride plume. From these data, we estimate that the plume is traveling at a quite steady mean velocity of 10 cm/day at an angle of 24° to the x-axis. Plumes of other constituents fellow the same direction as the chloride but move at retarded velocities. Because the x-axis was the initially expected direction of the mean hydraulic gradient, we are currently examining hydraulic head observations to assess the nature of this behavior.

Figure 4 presents the development of the estimated horizontal concentration variances as a function of time since injection. While σ_x^2 and σ_y^2 appear to be increasing linearly with time, these data are difficult to interpret at this early stage of the experiment because of sampling variability and the short overall travel distance. Straight line fits to the data points yield equal estimates of 0.06 m for the lateral and transverse dispersivity, α_L and α_T. These values are not atypical for this aquifer, but they must be interpreted with great caution. We expect that the additional concentration data and the detailed observations of hydraulic conductivity variability being collected during summer 1983 will enhance interpretation.

ACKNOWLEDGMENTS

This work is support by the R. S. Kerr Environmental Research Laboratory of the U.S. Environmental Protection Agency under CR-808851. Pat Fennessy programmed the moment estimation routines. The authors gratefully acknowledge the invaluable participation of many individuals at the Department of Earth Sciences, University of Waterloo, and the Department of Civil Engineering, Stanford University.

REFERENCES

1. Gelhar, L. W. and C. L. Axness. Three-Dimensional Stochastic Analysis of Macrodispersion in Aquifers. Water Resources Research, 19(1): 161-183, 1983.

2. Mackay, D. M., J. A. Cherry, D. L. Freyberg, G. D. Hopkins, P. L. McCarty, M. Reinhard, and P. V. Roberts. Implementation of a Field Experiment on Groundwater Transport of Organic Solutes. Paper presented at the Groundwater Contamination Session of the 1983 National Conference on Environmental Engineering, ASCE, Boulder, Colorado, July, 1983.

3 Matherson, G. and G. deMarsily. Is Tranport in Porous Media Always Diffusive? A Counterexample. Water Resources Research, 16(5): 901-917, 1980.

4. Pickens, J. F. et al. A Multi-Level Device for Groundwater Sampling and Piezometric Monitoring. Groundwater, 16(3): 322-327, 1978.

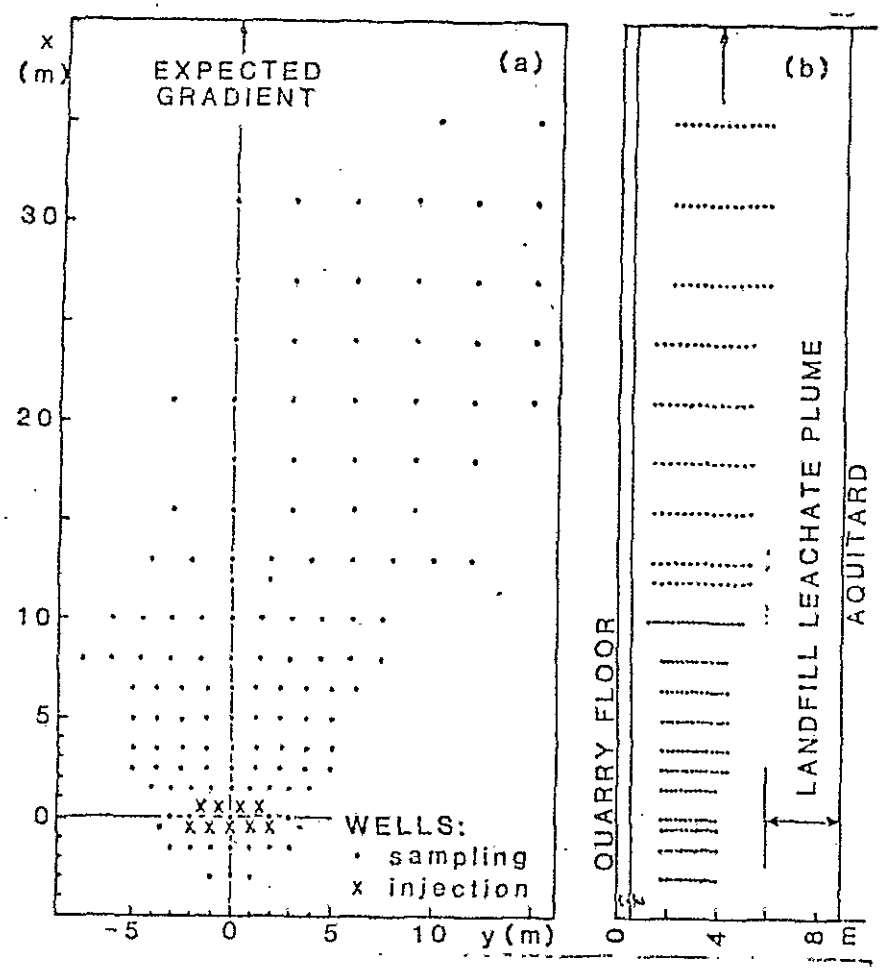


Figure 1. Monitoring system. Multilevel wells in place as of April 1983 are shown in plan view in (a). Vertical position of sampling points is shown in (b).

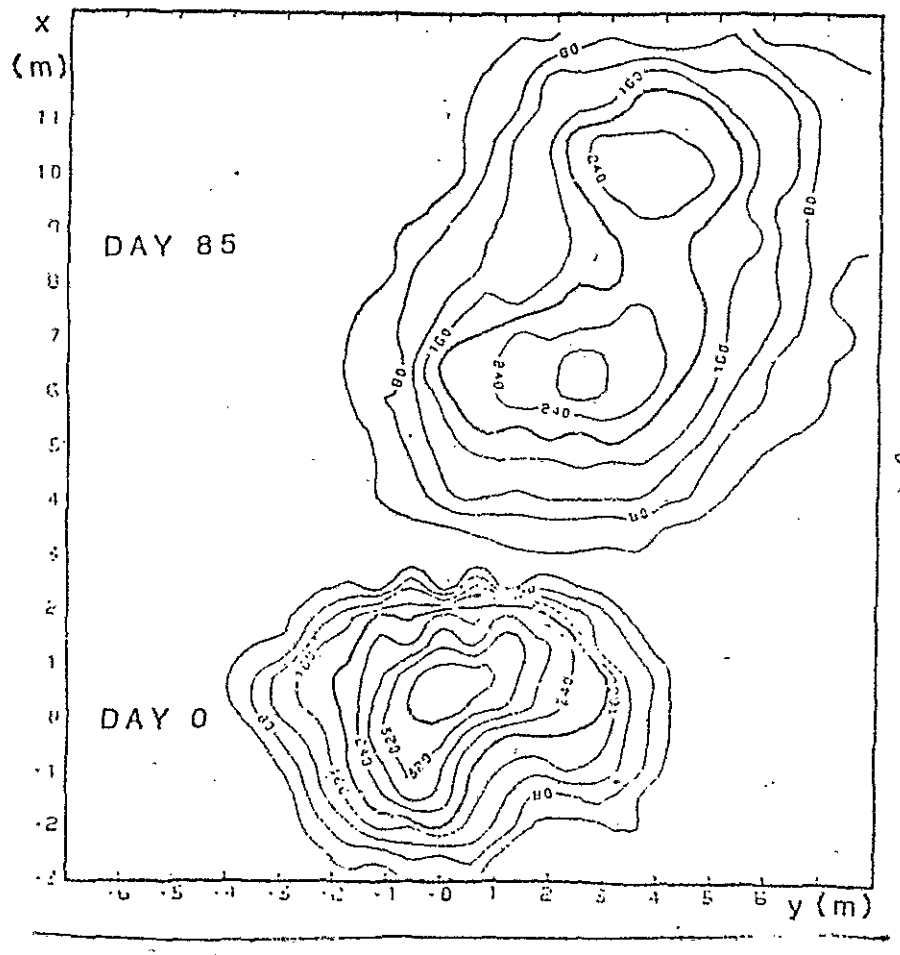


Figure 2. Plan view contour plots of depth-averaged chloride concentration immediately after injection (Day 0) and 85 days later.

Freyberg

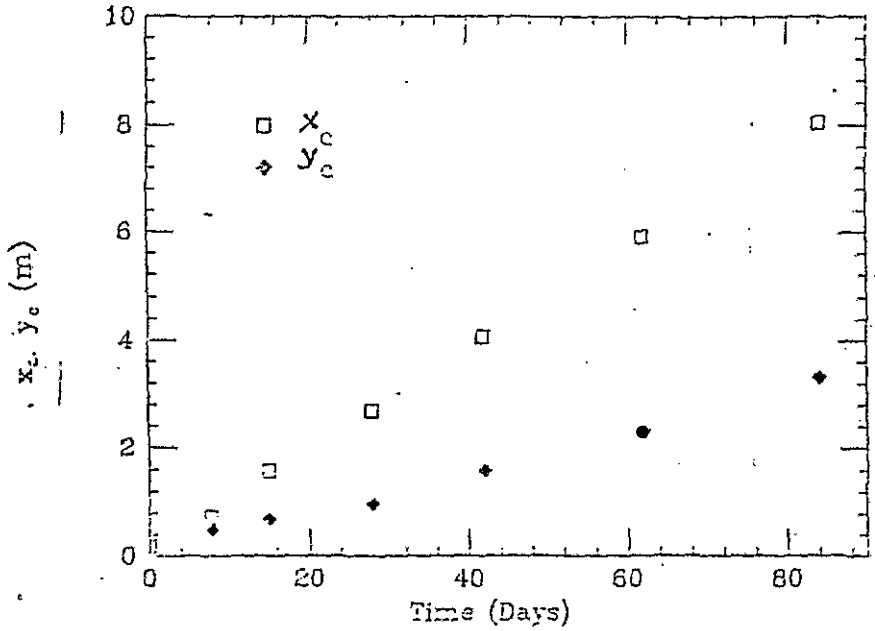


Figure 3. Trajectory of center of mass of chloride plume.

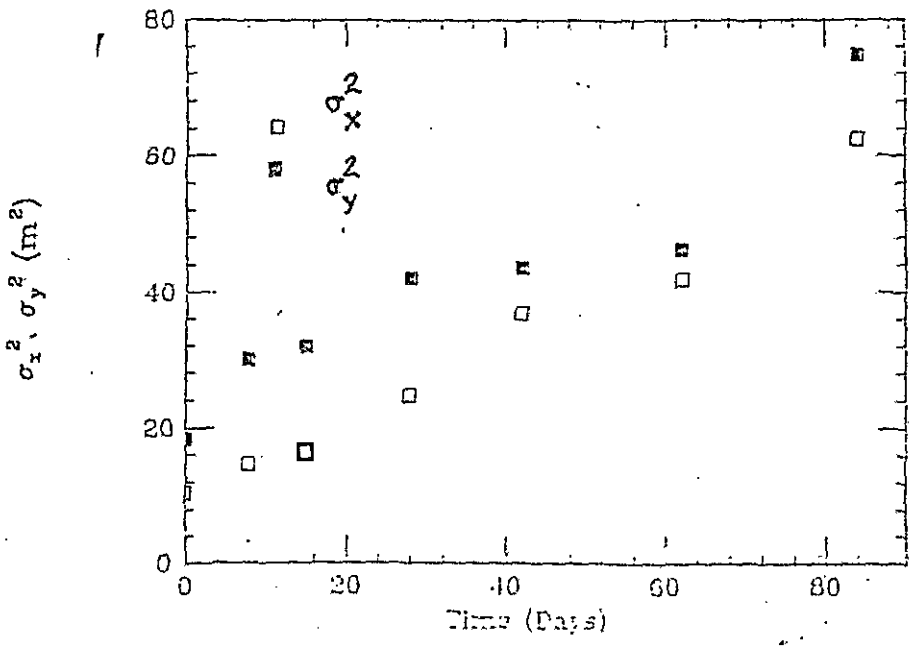


Figure 4. Variance of the chloride plume as a function of time.

35. Gass, T.E. "Methodology for Monitoring Wells," Water Well Journal, June 1984, pp. 30-31

 Eagle

Methodology for Monitoring Wells

2648

by Tyler E. Gass

As a consultant who frequently participates in seminars and conferences pertaining to ground water quality monitoring, I am often asked which method of drilling I prefer for the installation of a monitoring well. Unfortunately, the person with the question is often disappointed by my response, for I have no particular preference. I try to explain that the selection of a method of drilling is based on several factors. This person could easily find someone else who will give him a more direct answer, for it seems that there are some "professionals" who either have a bias toward a particular method, or never bother to consider that the appropriate method of drilling should be selected after considering:

- types of formations to be drilled
- accessibility of the drilling site
- depth of the completed well
- casing diameter that will be required to accommodate the sampling apparatus or monitoring equipment
- the quality of the samples derived during the drilling process
- the potential for cross contamination during drilling
- the ease of cleaning equipment before drilling the next hole
- the ease of gravel packing or installing grout
- equipment availability
- cost
- etc., etc.

Are all of these factors important? Some are more important than others, but if the job is to be done efficiently and achieve the client's objectives, then they are all important.

Some drilling methods seem to be preferred on a regional basis. For example, hollow stem augers are very popular for installing 2-inch diameter wells to depths of 100 feet in unconsolidated formations in the Midwest and East Coast, but that does not ensure that they are not being used in areas where rotary drilling or cable tool drilling would be more advantageous.

As a means of providing some guidelines for proper equipment selection, I have summarized the advantages and disadvantages of different drilling methods here along with some pertinent remarks.

Drive Points

The use of drive points provides a quick, inexpensive way of installing monitoring wells in unconsolidated formations where the water table is shallow.

Advantages

1. Inexpensive
2. Fast
3. Excellent mobility

Disadvantages

1. Limited to the use of metallic casing
2. Limited depth
3. Limited to unconsolidated formations
4. Inability to get a good seal between casing and formation
5. No formation samples

Jetting

Like drive points, jetting provides a fast, inexpensive method of installing monitoring wells in unconsolidated formations. However, the method's disadvantages place severe restrictions on its use for monitoring many ground water quality parameters.

Advantages

1. Fast
2. Highly mobile
3. Relatively inexpensive

Disadvantages

1. Requires large quantitie of water
2. Difficult to get a good sea between casing and boreho
3. Limited casing diameter
4. Limited depth capability
5. Poor sample acquisitio during drilling
6. Potential for cross contamin ation during drilling

Solid-Stem Auger

This method is relatively rapi and inexpensive. It is best suite for formations where caving o sloughing is unlikely; therefore i is limited to unconsolidated for mations and where wells are ter minated close to the top of th water table.

Advantages

1. Fast drilling in unconsoli dated formations
2. Inexpensive
3. Good mobility
4. Requires no drilling fluid
5. Relatively easy to clean tools
6. Can permit installation of casing with diameters up to 12 inches

Disadvantages

1. Limited depth capability
2. Possible borehole collapse when augers are removed
3. Geologic sampling difficult

Hollow-Stem Auger

The use of hollow-stem augers is very popular for installing monitoring wells in unconsolidated formations to depths of approximately 150 feet. Convenient use of a split-spoon sampling device or shelby-tube sampler permits good delineation of geologic materials. However, drilling problems can occur while drilling below the water table, especially into artesian formations.

Advantages
1. Good equipment mobility
2. Hole caving is minimal during sampling and casing installation
3. Excellent for geologic sampling
4. Permits the use of a variety of materials for well casing and screen

Disadvantages
1. Can only be used in unconsolidated formations
2. Limited depth capability
3. Limited casing diameter (2-4 O.D.)
4. Grouting and gravel pack installation may be difficult

Bucket Augers

A bucket auger permits the installation of shallow large diameter wells or multiple completions in unconsolidated formations. However, drilling below the water table may present some difficulties.

Advantages
1. No drilling fluid is required above the water table
2. Gravel pack and grout installation is easy
3. Permits multiple completions or the installation of several wells in a single borehole
4. Permits excellent formation sampling

Disadvantages
1. Limited depth capability
2. Water or drilling fluid may be necessary below the water table
3. This type of drilling equipment may not be readily available in all parts of the U.S.

Cable Tool

The cable tool rig is increasing in popularity as a method for monitoring well installation in both unconsolidated and consolidated formations. Although its drilling rates are relatively slow, this method of drilling provides flexibility of well design and excellent formation sampling capability.

Advantages
1. Good formation sample recovery
2. Good delineation of water bearing zones during drilling
3. Good equipment mobility
4. Capability of drilling in most types of formations
5. Permits a wide variety of monitoring well designs
6. Permits easy gravel pack and grout installation

Disadvantages
1. Slow rate of formation penetration
2. Temporary steel casing is required while drilling in unconsolidated formations

Conventional Mud Rotary

Conventional rotary might be used in areas where the concern was for future monitoring contamination. The drilling process can result in cross-contamination, if contaminants are present and drilling mud is likely to seal-off low permeability formations. However, the method is fast, capable of drilling holes to great depths of various diameters in most geologic formations.

Advantages
1. Equipment is readily available
2. Satisfactory drilling in most geologic formations
3. Excellent depth capability
4. Permits a wide variety of formation logging tools
5. Well design flexibility
6. Permits easy gravel pack installation and grouting

Disadvantages
1. Requires a drilling fluid
   a. difficult to remove during well development
   b. may affect sample integrity
   c. circulates contaminants throughout the borehole
2. Equipment mobility is limited
3. Poor formation recovery

Air Rotary

Air rotary drilling has regional popularity, especially where monitoring wells will be installed to depths of several hundred feet or more. Like conventional mud rotary, there are difficulties in obtaining formation samples and personnel may be exposed to contaminants blown out of the hole during drilling.

Advantages
1. Excellent penetration rates
2. Offers good diameter and depth capability
3. Installation of grout and gravel pack is relatively easy

Disadvantages
1. Casing of unconsolidated or caving formations may be required during drilling
2. Cross-contamination of the aquifers can occur
3. Difficult formation sampling
4. Relatively high drilling costs

It is important to note that a casing hammer, if used in conjunction with air rotary drilling, can eliminate many of these potential problems.

Double-Wall Reverse Circulation Drilling

Interest is expanding in the use of double-wall reverse circulation drilling for installing monitoring wells. This method of drilling eliminates many of the disadvantages associated with conventional mud or air rotary drilling while maintaining most of their advantages. Unfortunately, this type of drilling equipment is not readily available in several parts of the U.S.

Advantages
1. Formation water is not contaminated by drilling fluids
2. Good sample recovery
3. Prevents formation caving and sloughing

Disadvantages
1. Equipment is not readily available
2. Costs are moderate to expensive
3. Placement of gravel pack or grout may be difficult

Conclusion

There are many factors involved in the selection of the proper piece of drilling equipment for the installation of monitoring wells. Personal bias toward the use of one particular type of drilling equipment should be avoided. Instead, consideration should be given to all the pertinent factors before a decision is made.

JUNE 1984 VOL. 38 NO. 6

water well journal

IN THIS ISSUE...

39 Ground Water Research—Oklahoma Style
44 A New Look at Water Testing for Wells
46 International Water Well Expo
47 Ground Water Research Update
71 South Atlantic JUBILEE
83 National Housing Form

MONTHLY FEATURES...

8 Editor's Page:
NWWA research opens doors for the ground water industry.
30 Consultants Collection:
Selecting a drilling methodology for monitoring wells.
32 Any Way You Figure It:
Costing for profits.
35 Something to Crow About:
Mad Mary and friends.
72 Puzzle Well

DEPARTMENTS

6 Issue in Review
11 Industry News and Views
20 Literature
25 Coming Events
74 Industry Changes
79 Industry Products and Services
91 Marketplace: Classified Advertising
93 Saftey Tip
95 Letters
96 Index of Advertisers

36. Geraghty, J. J. "What Monitor Wells Can and Cannot Do," Waste Age, 1983, pp. 50-54

2646
2647
2648

What Monitor Wells Can and Cannot Do

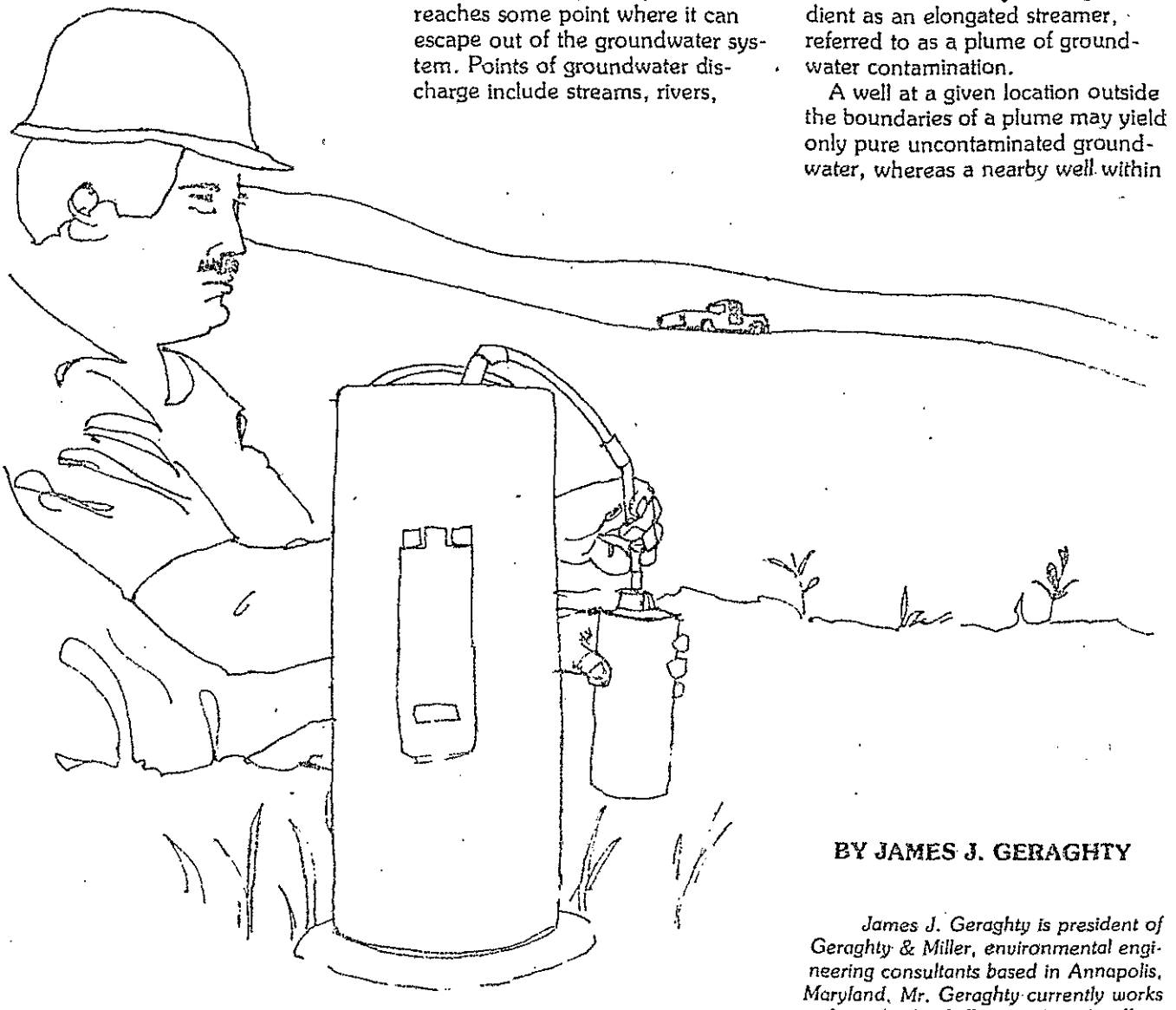
Monitor well systems for detecting ground water contaminants include several shortcomings of technology and procedure.

Any ground water system always is in a more or less hydraulic balance, in the sense that water entering the system continuously moves through the earth to some point of discharge so that new water can enter. After rainwater has moved downward into the water-table zone, it begins to flow, mostly laterally, following what hydrologists call the water-table gradient, or slope.

The groundwater travels at slow rates, commonly measured in terms of a fraction of an inch to perhaps a couple of feet per day, until it reaches some point where it can escape out of the groundwater system. Points of groundwater discharge include streams, rivers, bays, lakes, swamps, and oceans, and most importantly, wells used for water-supply purposes. In many instances, the pumping from water wells changes natural groundwater flow patterns radically, in effect pulling groundwater into the wells. Thus, contaminated liquids that enter an aquifer may pose a threat to public health where water wells are in operation nearby.

Contrary to common belief, contaminated liquids in a groundwater system do not mix easily with the native groundwater. Instead they tend to follow the hydraulic gradient as an elongated streamer, referred to as a plume of groundwater contamination.

A well at a given location outside the boundaries of a plume may yield only pure uncontaminated groundwater, whereas a nearby well within



BY JAMES J. GERAGHTY

James J. Geraghty is president of Geraghty & Miller, environmental engineering consultants based in Annapolis, Maryland. Mr. Geraghty currently works from the firm's Tampa, Florida office.

the plume boundaries may be withdrawing contaminated groundwater.

The real problem is how to find plumes in the hidden subsurface environment in order to derive some early warning of the threat posed by the contamination.

Monitor wells

A basic requirement of the EPA regulations is that monitor wells be installed at new landfill sites, drilled and located in such a way that any contaminants seeping from the landfill will ultimately move into the wells and be detected through sampling and water analysis. The idea is that the monitor wells initially may yield only uncontaminated water, but that ultimately, after the landfill has been in operation for some time, may detect degradation of the groundwater caused by downward seepage of contaminants

EPA has not yet established precise guidelines on how to locate and install the monitor system, but simply indicates that at least one monitor well be upgradient from a landfill site and at least several monitor wells be located in the downgradient direction.

> ***"Contrary to common belief, contaminated liquids do not mix easily with native ground water."***

The logic is that water moving naturally through the earth toward a landfill normally will be uncontaminated, whereas water emerging from beneath the landfill in the downgradient direction may become contaminated.

In the prescribed monitoring-well procedures, all of the wells are to be sampled periodically, with the analyses from the downgradient wells being averaged and compared with the analyses from the upgradient wells. If a plume is discovered, the owner or operator of the landfill then must take further action to either define in detail the plume dimensions and concentrations of contaminants, or to begin some type of remedial program to halt or reverse the slow drift of the contaminants toward nearby water wells.

Checklist for monitor well sampling

- Check equipment; make arrangements with laboratory and for sample transportation.
- Measure the static water level in the well.
- Flush the well to remove standing water. An amount equal to five times the volume of the casing should be removed in high-yield formations. (In low permeability strata, one volume will suffice.)
- Allow the well to recharge to the static water level, which may require more than one day.
- Clean and/or flush sampling equipment with distilled or drinking water between samples.
- Where appropriate, filter the sample during collection. Non-aerated conditions must be maintained; therefore, do not allow the water to bubble or splash into the sample container and filter.
- Preserve the sample and pack it in ice if necessary for shipment.
- Clean equipment. Make sure well is securely capped.

Shortcomings of system

In recent years, several shortcomings of monitor well systems have become apparent. First, at many landfill sites, contaminants already may be present in the groundwater system as a result of seepage from some other source.

It is not uncommon to find that upgradient wells are contaminated to the same degree as downgradient wells, simply because the groundwater moving toward the landfill already has been degraded through operations of one kind or another. In such cases, it obviously becomes difficult to be able to assess the extent of contamination, if any, caused by the landfill itself.

In addition to landfills, other sources of groundwater contamination include municipal and industrial surface impoundments, leaky sewer lines, buried oil storage tanks, applications of pesticides and herbicides on agricultural lands, cesspools, and septic tanks, and poor housekeeping in places where contaminants are stored or used on the land surface. A rough estimate is that bodies of subsurface contamination originating from such sources in the United States probably number in the millions, with only a tiny percentage of them ever having been drilled into and adequately evalutated.

A second shortcoming is that a typical monitor well does not pull in water from a great distance during a short sampling interval, but instead takes water from a very restricted zone that may extend outward no more than a few feet from the well. Thus, a monitor well could be only a short distance from a plume of contamination but still deliver perfectly fresh groundwater not showing any evidence of the existence of the plume.

Sample is diluted

Another shortcoming is that it is almost impossible to pump from a monitor well penetrating a plume of contamination without drawing in some uncontaminated groundwater from nearby. As a result, the water analysis returned from the laboratory may show concentrations of chemical contaminants below those in the plume, simply because both fresh water and contaminated water have been mixed inside the well before being brought up to the land surface.

Evidence along these lines suggests that may of the chemical analyses now being turned in to regulatory agencies show less contamination than actually exists in specific plumes of contamination.

The rate of flow of groundwater also may be so slow that repeated sampling over many months or even years will show little or no net change in chemical concentrations in the water. In other words, sampling at frequent intervals may be of dubious value if the contaminated groundwater is not capable of moving more than a few inches or perhaps a couple of feet over the course of many months.

Still another deficiency of some monitor-well systems is that the metals or plastics used in construct-

ing and sealing a well may contribute trace amounts of contaminants to the water being pumped, misleading the investigator into thinking that the groundwater is contaminated. Also, if the well has not been properly sealed into the ground, potentially contaminated water from the land surface may move directly downward along the outside of the well, again giving a false clue to groundwater contamination.

"The real problem is how to find plumes of contamination in the hidden subsurface environment."

Monitor well technology in summary offers a safeguard against groundwater contamination, but the protection is far from complete and the methods in practice suggest the need for continuing improvements.

Constructing monitor wells

In order to allow states to identify open dumps, the EPA in 1980 issued the *Guidance Manual for Classifying Solid Waste Disposal Facilities* (SW828). Eighteen states assisted EPA in the development of the manual. Assistance was also provided by the National Solid Wastes Management Association, the Governmental Refuse Collection and Disposal Association, and the American Public Works Association.

The manual makes the following statements with regard to monitor-well placement and construction.

The system should have a minimum of one well hydraulically upgradient from the site and at least two downgradient. Test borings or geophysical studies may have to be made to determine the water-table gradient and location.

The downgradient wells should be located as close as practicable to the solid waste boundary without being drilled through the waste. Downgradient wells should be placed at the point where contamination is most likely.

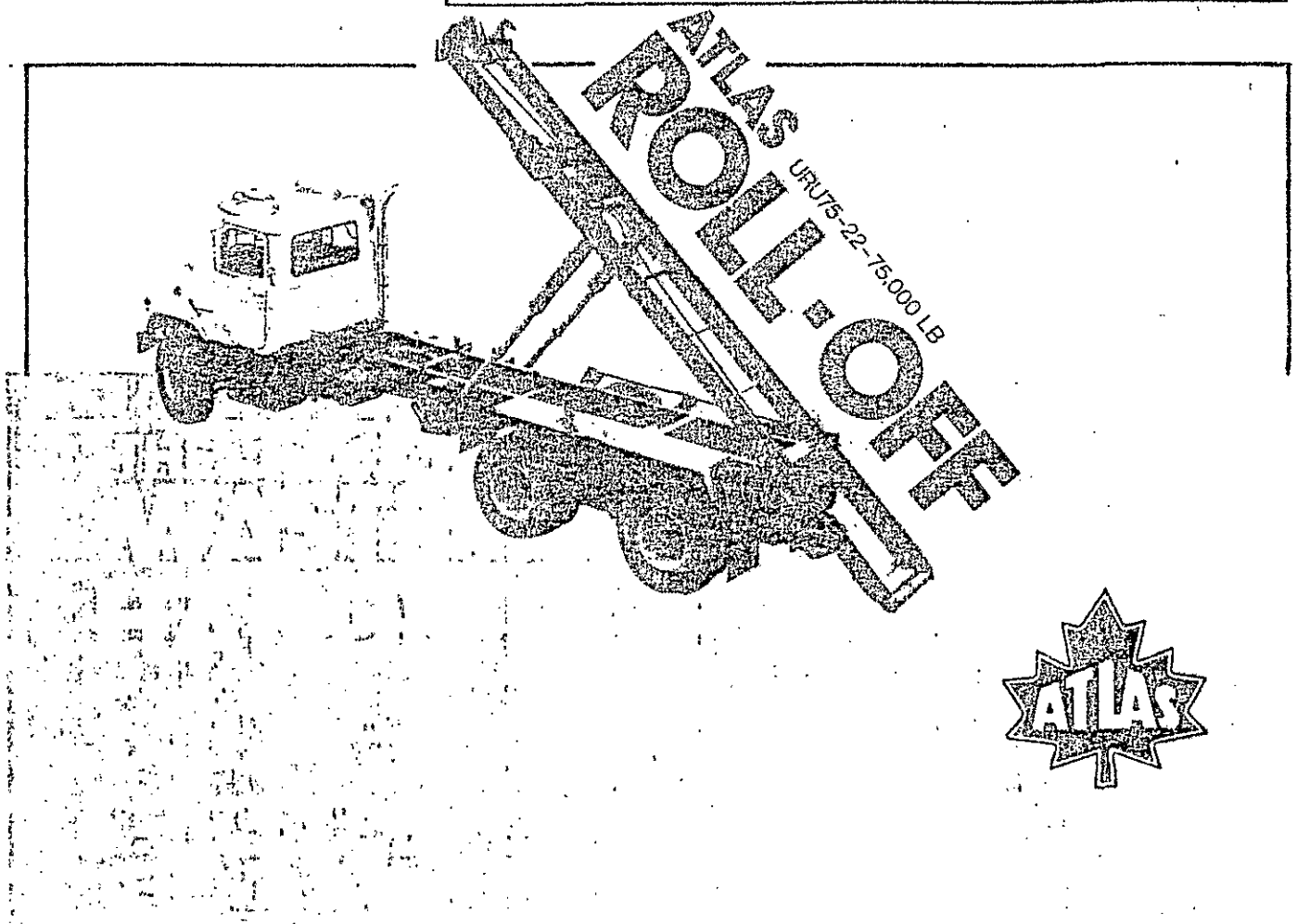
Upgradient and downgradient wells should be located so that samples are obtained from the same horizon of water-bearing material.

Well casing should be a minimum of two inches in diameter, and preferably four inches, to allow for ease of pumping and sampling.

A bentonite clay or cement seal or plug should be in place around the casing.

The well should be finished at the surface with a cement or earth mound sloped away from the well to prevent surface drainage down the casing.

For most wells less than 100 feet in depth, casing and well screens should be plastic, unless the waste type involved contains organic pollutants or is corrosive to plastic. In these instances, it will be necessary to use steel well casing, which, however, may give misleading analyses for concentrations of metals. In wells deeper than 100 feet, steel casings and stronger screens should be used to prevent compression and closing of the casing and screen. WA



Circle No. 10 on reader service card

37. Gerhardt, R. A. "Landfill Leachate Migration and Alteration in the Unsaturated Zone in Layered and Nonlayered Coarse - Grained Soils," Ground Water Monitoring Review, Spring 1984, pp. 56-65

Landfill Leachate Migration and Attenuation in the Unsaturated Zone in Layered and Nonlayered Coarse-Grained Soils

by Roger A. Gerhardt

Introduction

The majority of landfill sites in existence today have been located above the water table in the unsaturated zone. Natural attenuation sites rely upon the unsaturated zone to renovate leachate to acceptable levels prior to reaching the ground water. Sites designed with impermeable liners and leachate collection systems also depend upon the unsaturated zone to attenuate any leachate that is not removed by the collection system and to act as a backup system to possible engineering design failures. An understanding of the mechanisms of leachate attenuation and migration within the unsaturated zone will help to define the favorable characteristics of unsaturated earth materials that minimize the potential for ground water contamination. Monitoring the unsaturated zone may also provide the earliest possible indication of leachate migration away from a landfill site. In Wisconsin, for example, several landfill sites with deep water tables have been required to install pressure-vacuum lysimeters as part of overall ground water monitoring programs.

A research project was initiated with the primary purpose of generating data on the migration and attenuation of leachate in the unsaturated zone beneath several landfills in Wisconsin (Gerhardt 1977). It was hoped that the results could then be used to establish regulations and requirements specifying separating distances between natural attenuation landfills and the water table. This report summarizes the data obtained from pressure-vacuum lysimeters installed in the unsaturated zone beneath two unlined landfill sites located in layered and nonlayered coarse-grained soils.

Previous Investigations

Research conducted over the last several decades has demonstrated the successful use of pressure-vacuum lysimeters in obtaining landfill leachate samples from the unsaturated zone.

Wagner (1962) originally described the design and operation of the type of soil-water sampler (pressure-vacuum or "suction" lysimeter) used in this project. This sampler consisted of a porous ceramic cup cemented to a section of plastic pipe. Water samples were recovered by applying a vacuum to a single capillary tube inserted through a single copper access tube. This method restricted sample recovery to relatively shallow depths.

The pressure-vacuum (suction) lysimeter described by Wagner (1962) was modified for use on a research project at the State College (Pennsylvania) Regional Sanitary Landfill (Lane and Parizek 1968; Lane 1969; and Parizek and Lane 1970). Modification was necessary in order to collect soil-moisture samples from greater depths. This was accomplished by fitting the unit with two access tubes. One access tube was used to pressurize and evacuate the unit. The other tube was used to discharge the water sample. Seventeen suction lysimeters were installed within the unsaturated zone beneath the State College Regional Sanitary Landfill to study the changes in leachate quality with depth. Results of the chemical analyses of soil-moisture/leachate samples from the State College Landfill revealed that a leachate wave front could be traced in the unsaturated zone beneath the landfill trench. Apgar and Langmuir (1971) continued and extended the previous study. They concluded that leachate beneath the landfill cells was moving downward at an approximate rate of 1.8 to 3.6 m (6 to 11 feet) per year and although leachate attenuation did take place within the unsaturated zone, it was not sufficient in preventing contamination of the underlying ground water.

Wood (1973) described a further modification and improvement of the suction lysimeter, allowing collection of soil water samples at any depth without loss of sample. The new procedure incorporated a check valve

in the lysimeter assembly, preventing pressurization of the porous cup while gas pressure was applied to force the sample to the surface.

Johnson and Cartwright (1980) and Johnson, Cartwright and Schuller (1981) investigated leachate migration beneath three landfill sites in Illinois. Although monitoring wells appeared to be virtually unaffected, migration of leachate through the unsaturated zone was detected at each site. Evidence from the study also suggested that under unsaturated conditions, some landfill liners may not be highly effective barriers to the flow of leachate out of the refuse. A laboratory study was also conducted to evaluate the validity of highly contaminated landfill leachate collected with pressure-vacuum lysimeters. Samples from the lysimeters were generally found to be representative of the surrounding leachate composition for the major ions.

Wilson (1981, 1982 and 1983) discussed, in detail, methods for monitoring water content in the unsaturated (vadose) zone, transmission of liquid wastes in the vadose zone and methods for monitoring the vadose zone.

Method of Study

Site Selection

Two natural attenuation landfill sites, one near Prairie du Sac in Sauk County, Wisconsin, and the other near Reedsburg, also in Sauk County (Figure 1) were selected for study with the help of the Wisconsin Department of Natural Resources-Solid Waste Management Section. The Prairie du Sac landfill is located approximately 4 km (2.5 mi) west of the village of Prairie du Sac. The Sauk County landfill is located approximately 8.8 km (5.5 miles) east of the City of Reedsburg.

Lysimeter Network

Leachate and soil-moisture samples were collected from the refuse and the unsaturated soils by means of pressure-vacuum lysimeters. Pressure-vacuum lysimeters were chosen as sampling devices because previous researchers have demonstrated their efficiency and reliability in obtaining soil-moisture samples and they were the only devices available that allow collection of in situ soil moisture samples from specific depths over extended periods of time.

The design and operation of suction lysimeters has been discussed in detail by Wagner (1962), Lane and Parizek (1968), and Parizek and Lane (1970). The suction lysimeters used in this study (Figure 2) consisted of a plastic cylinder 64 cm (25 inches) long and 5 cm (1.9 inches) in diameter with a 6 cm (2.5 inches) porous ceramic cup attached to the bottom. When the ceramic cup is in contact with soil moisture, capillary suction causes the pores of the cup to become filled with water. Due to the small pore size (one micron or less) water is held tightly enough to become sealed against an air pressure of at least 1 kg/cm^2 (15 psi). Thus, soil moisture flow can be induced into the lysimeter by creating and maintaining a vacuum. Two access tubes (6.35 polyethylene tubing) inserted through separate holes in a neoprene stopper provide ports for sample discharge and for pressurization and evacuation. The capacity of the lysimeter was 1 liter. Collected sample volumes ranged

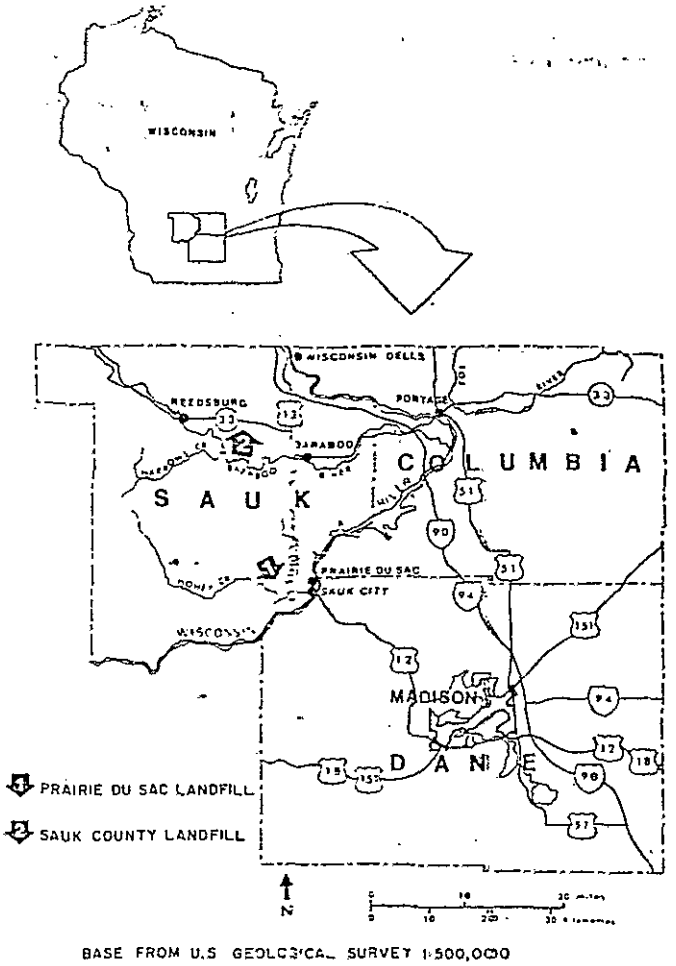


Figure 1. Location of study areas

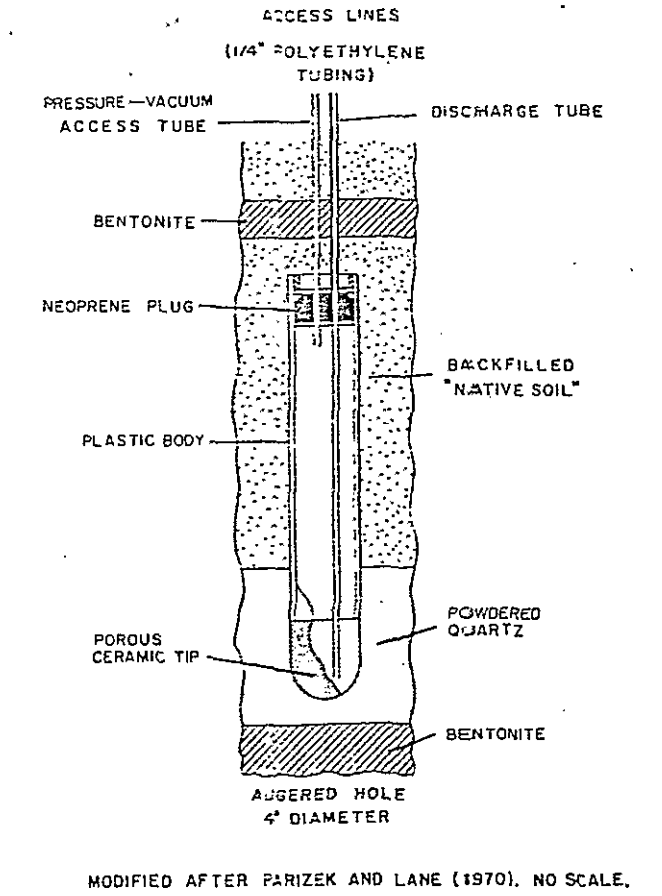


Figure 2. Cross section of a pressure vacuum lysimeter and typical installation

from 50 mL to 700 mL.

A typical lysimeter installation is illustrated in Figure 2. Powdered quartz passing a standard 200 sieve was placed around the lysimeter to ensure a good contact with the lysimeter and the surrounding soil. Bentonite pellet seals were placed above and below each lysimeter unit, at the base of the refuse and at the surface. Two lysimeter nests were installed at each landfill study site. Each nest contained from 2 to 6 lysimeter units terminating at various intervals in the unsaturated zone (including units within the refuse). A total of four nests containing 20 lysimeters were installed at the two study landfills. These lysimeter nests provided data on the vertical movement of leachate and changes in contaminant concentrations within the unsaturated zone. Two single lysimeter units were installed outside the waste disposal area at the Prairie du Sac landfill during the second year of the study to provide additional data. Ground water observation wells were also installed at each site to determine leachate impact on ground water quality.

Results of the Study

Introduction

It was expected that changes in leachate component concentrations with time and depth in the unsaturated sands and gravels beneath the Prairie du Sac and Sauk County landfills would exhibit one or more of three consistent and predictable patterns. (1) A regular pattern of decreasing concentrations with depth due to soil attenuation was expected to be observed most frequently. (2) Increases in the concentrations of leachate components with depth due to leachate extraction of soluble material from the soil matrix was also expected to be observed. (3) The occurrence of maximum concentrations at different depths for different parameters was also expected, indicating a differentiated leachate front moving through the unsaturated zone reflecting the mobility of various chemical parameters.

During the first year of the study, the lysimeter data from the Prairie du Sac landfill showed that a complex pattern of leachate component concentration changes had developed within the unsaturated zone. It was also apparent from the data collected that a single pattern of leachate concentration changes did not exist and that all three of the patterns discussed above may exist beneath the site. The observed patterns of leachate component concentration changes appeared to be further complicated by the differences in the quality of leachate from the refuse, the effects the layered sands and gravels had upon water movement in the unsaturated zone and leachate chemistry.

The study was originally designed and funded for one year. Additional funding became available to extend the study for a second year. In order to better understand the complex pattern of leachate component concentration changes that were being observed beneath the Prairie du Sac landfill, the Sauk County landfill site was added to the study during the second year. It was intended that the pattern of leachate component concentration changes within the homogeneous, nonlayered soils beneath the Sauk County site could be compared to the data from the Prairie du Sac landfill to better understand the factors that might be affecting leachate component concentrations within the unsaturated zone. The limited results from the Sauk County landfill did show a more consistent and predictable pattern of decreasing leachate component concentrations with depth in the unsaturated zone.

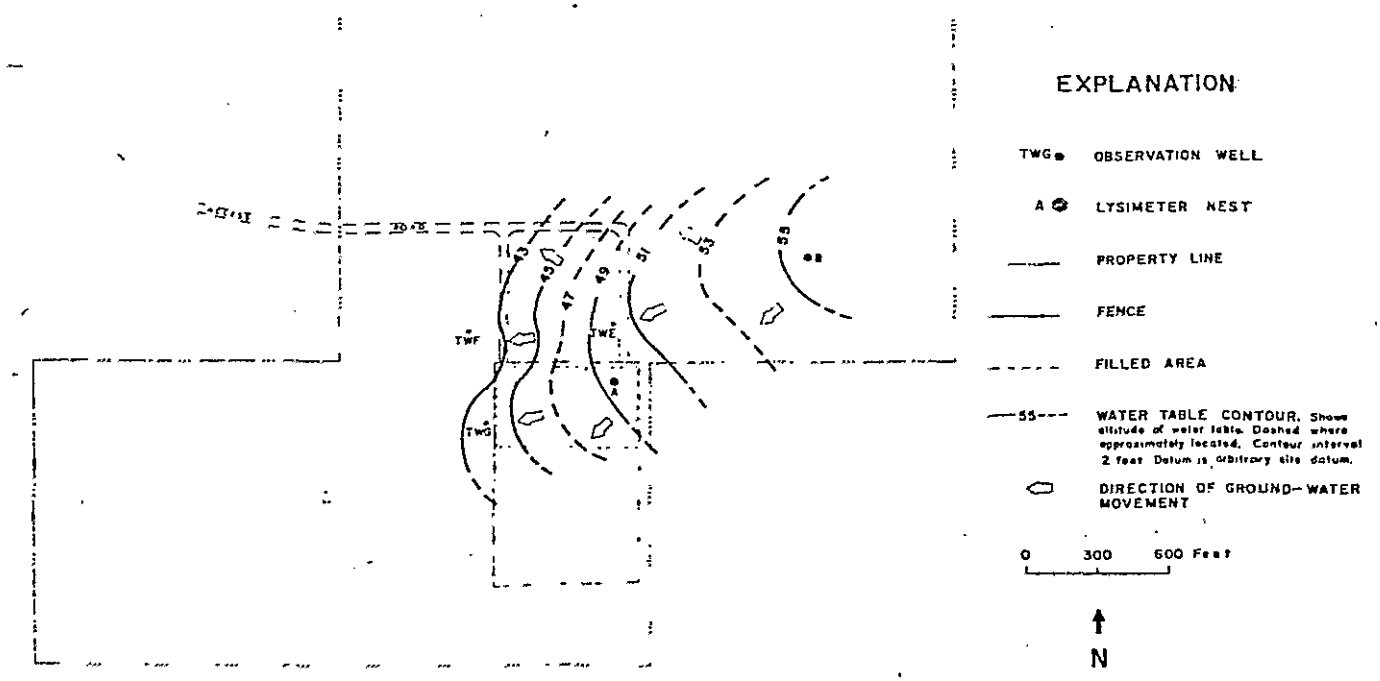


Figure 3. Map of the Sauk County landfill showing monitoring network and water table. Water level measurements made on November 7, 1975

Sauk County Landfill

The Sauk County landfill (Figure 3) began disposal operations in 1973. The site is situated in a clean, uniform fine sand that represents glacial lake sediments. Grain-size analyses of soil samples collected during the site investigation indicate that more than 95 percent of the on-site soils fall within the fine or medium sand range with less than 4 percent silt or smaller sized material. The site is underlain by approximately 12.2 to 18.3 m (40 to 60 feet) of the fine sand, resting upon sandstone bedrock. Ground water generally occurs about 14.3 (47 feet) below land surface with ground water movement beneath the site to the west (Figure 3).

Two lysimeter nests were installed at the Sauk County landfill (Figure 4). One nest (SCB) was placed outside the disposal area with lysimeters installed at depths of 4.6, 7.6, 10.7 and 13.1 m (15, 25, 35 and 43 feet) below land surface. A second nest (SCA) was placed beneath the refuse with lysimeters placed within the refuse and at depths of 0.3, 2.7, 4.6 and 6.4 m (1, 9, 15 and 21 feet) below the base of the refuse. The lysimeter unit placed at the 2.7 m (9 feet) depth was never operational.

Analyses of soil-moisture samples collected from the Sauk County landfill indicate that leachate was present in the unsaturated zone beneath the landfill. The leachate was characterized by concentrations ranging from 2 to 170 times greater than the surrounding unaffected soil moisture (Tables 1 and 2). A consistent and systematic reduction in most leachate component concentrations occurred as the leachate moved downward through the unsaturated zone. Individual leachate components showed a 4 to 5 percent reduction in concentrations per foot of soil when the concentrations recorded within the refuse (SCA-refuse) are compared to the lysimeter installed 6.4 m (21 feet) below the base of the refuse (SCA-21). This comparison does not imply that the concentration reductions per foot of soil were truly linear. However, the comparison does serve to illustrate the consistent reductions in all leachate component concentrations observed between all sampling depths, with the exception of ammonium, nitrate plus nitrite and magnesium, which showed concentration increases with depth between individual lysimeter units (Table 1). Total contaminant concentrations were reduced 75 to 99 percent by the time the leachate had reached the 6.4 m (21 feet) depth (SCA-21). Leachate component concentrations from lysimeter SCA-21 were generally two to 10 times higher than background soil moisture, as represented by samples from SCB-43 (Table 2).

Despite the apparent attenuation of leachate within the unsaturated zone, ground water beneath the refuse contained leachate component concentrations (1) two to 45 times higher than soil moisture unaffected by leachate, (2) two to 20 times higher than background ground water samples, and (3) two to seven times higher than leachate from the deepest (SCA-21) lysimeter unit (Tables 1 and 2). Subsequent ground water monitoring at the Sauk County site following completion of this study has shown that the ground water is severely contaminated. Recent ground water data have confirmed that the attenuation capacity of the unsaturated sandy soils beneath the site was insufficient in providing adequate ground water protection. These results also indicated that a single lysimeter nest may not be adequate to characterize the leachate from an entire landfill.

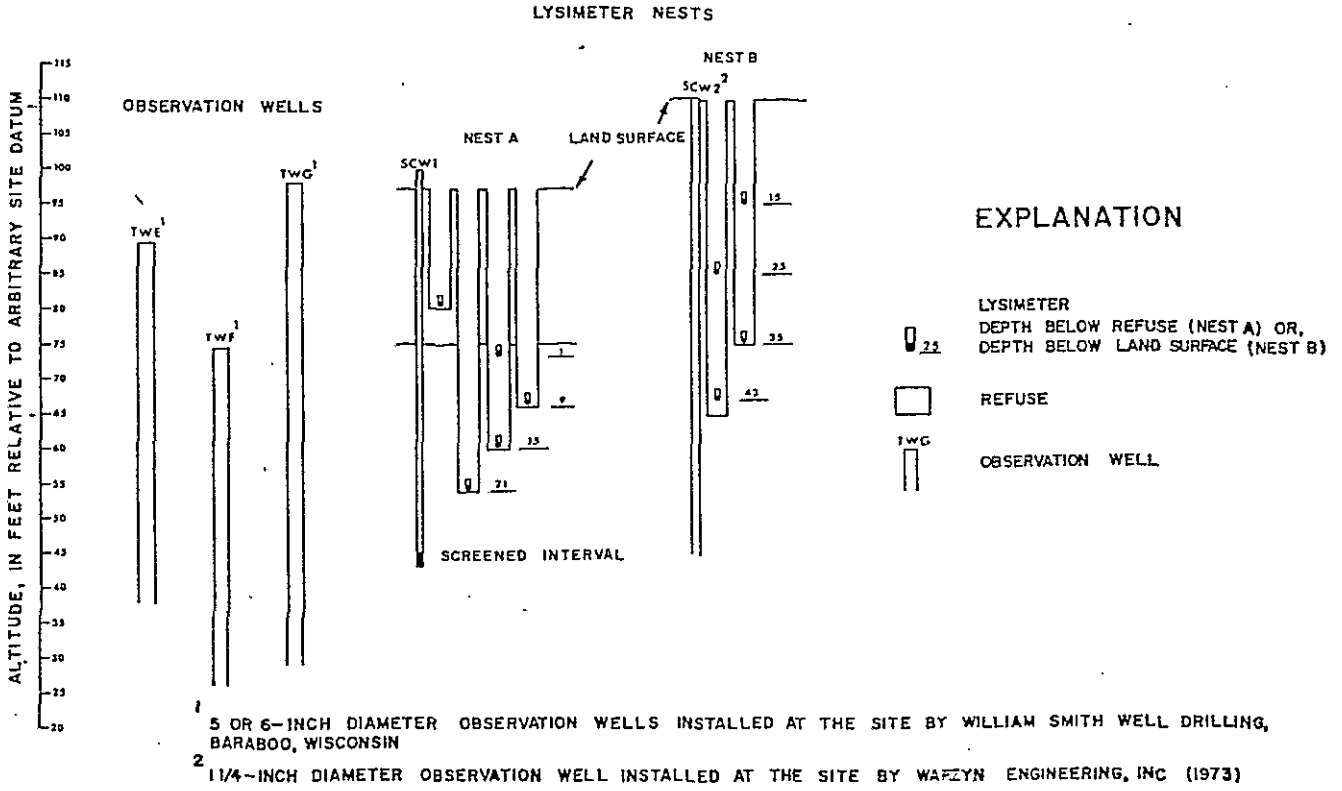


Figure 4. Vertical distribution of monitoring well/ lysimeter network at the Sauk County landfill

The Prairie du Sac landfill (Figure 5), which began disposal operations in 1968, is underlain by glacial outwash deposits consisting of fine-to coarse-grained sand with numerous interbedded discontinuous gravel layers. The sediments generally became coarser with depth. Ground water was encountered at a depth of about 13.7 m (45 feet) below the base of the refuse with ground water movement to the southwest (Figure 5).

Two lysimeter nests (Figure 6) were installed beneath refuse at the Prairie du Sac landfill. Nest A (PDSA) had lysimeters placed within the refuse and at 1.2, 4, 5.2 and 7 m (4, 13, 17 and 23 feet) below the base of the refuse. Nest B (PDSB) had lysimeters installed within the refuse and at 1.3, 3, 4.9, 6.7 and 11.3 m (6, 10, 16, 22 and 37 feet) below the base of the refuse. The prefix PDSA or PDSB identifies lysimeter nests A and B respectively, followed by the depth in feet of the individual lysimeter below the base of the refuse. In addition, single lysimeter units were placed near wells PDSW1 and PDSW2 (Figure 6). Both lysimeters were installed at a depth of 10.4 m (34 feet) below land surface.

Figure 7 shows the concentrations for selected parameters from the lysimeters installed beneath the landfill. Concentrations of the various parameters were generally 30 to 70 percent higher within the refuse at lysimeter nest PDSB as compared to nest PDSA. As expected, leachate produced within the

Table 1
Average chemical concentrations and concentration reductions for leachate samples from lysimeter nest SCA

	Average Concentration				Total Concentration Reduction Between SCA-refuse & SCA-21	Concentration Reduction per Ft Between SCA-refuse & SCA-21
	SCA-refuse[b]	SCA-1[c]	SCA-15[c]	SCA-21[b]		
Specific Conductance (micromhos/cm.)	8633	5281	2012	675	92%	4.4%
Calcium (mg/L)	283	176	116	70	75%	3.6%
Magnesium (mg/L)	148	163[a]	97	31	79%	3.8%
Sodium (mg/L)	788	665	158	16	98%	4.7%
Potassium (mg/L)	479	163	8	8	98%	4.7%
Chloride (mg/L)	933	660	313	83	91%	4.3%
Alkalinity (mg/L)	3130	1986	483	239	92%	4.4%
Total P (mg/L)	0.67	0.24	0.18	0.05	92%	4.4%
Total N (mg/L)	181.8	57.1	2.5	0.67	99%	4.7%
NH_4 – N (mg/L)	165.7	53.2	0.40	0.63[a]	99%	4.7%
NO_3,NO_2 – N (mg/L)	1.72	3.5[a]	0.25	<0.03	99%	4.7%

[a] Average value exceeds value at shallower sampling interval.
[b] Average of three samples.
[c] Average of four samples.

Table 2
Chemical concentrations in the ground water and uncontaminated soil-moisture at the Sauk County landfill

Parameter	Uncontaminated Soil-Moisture SCB-43[a]	Ground Water Beneath Refuse SCW-1[b]	Uncontaminated Ground Water SCW-2[b]
Specific Conductance (micromhos/cm.)	50	1900	200
Calcium (mg/L)	2.1	247	12
Magnesium (mg/L)	3.6	10	2
Sodium (mg/L)	3.8	108	2.4
Potassium (mg/L)	4	10	2
Chloride (mg/L)	8.7	148	10
Alkalinity (mg/L, as $CaCO_3$)	22	992	123
Total P (mg/L)	0.03	1.75	1.43
Total N (mg/L)	0.17	1.44	0.026

[a] Average concentration of three samples.
[b] Single sample collected on 7/28/75.
3072A

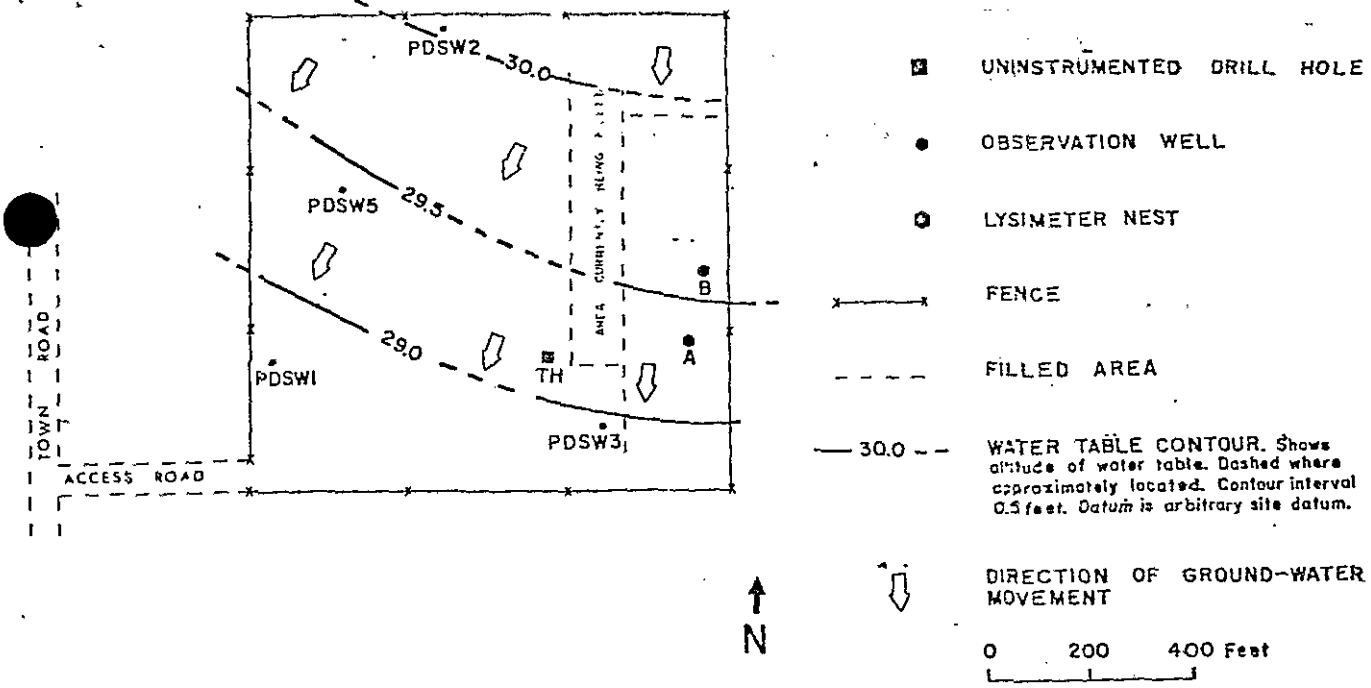


Figure 5. Map of the Prairie du Sac landfill showing network and water table. Water level measurements made on December 10, 1974

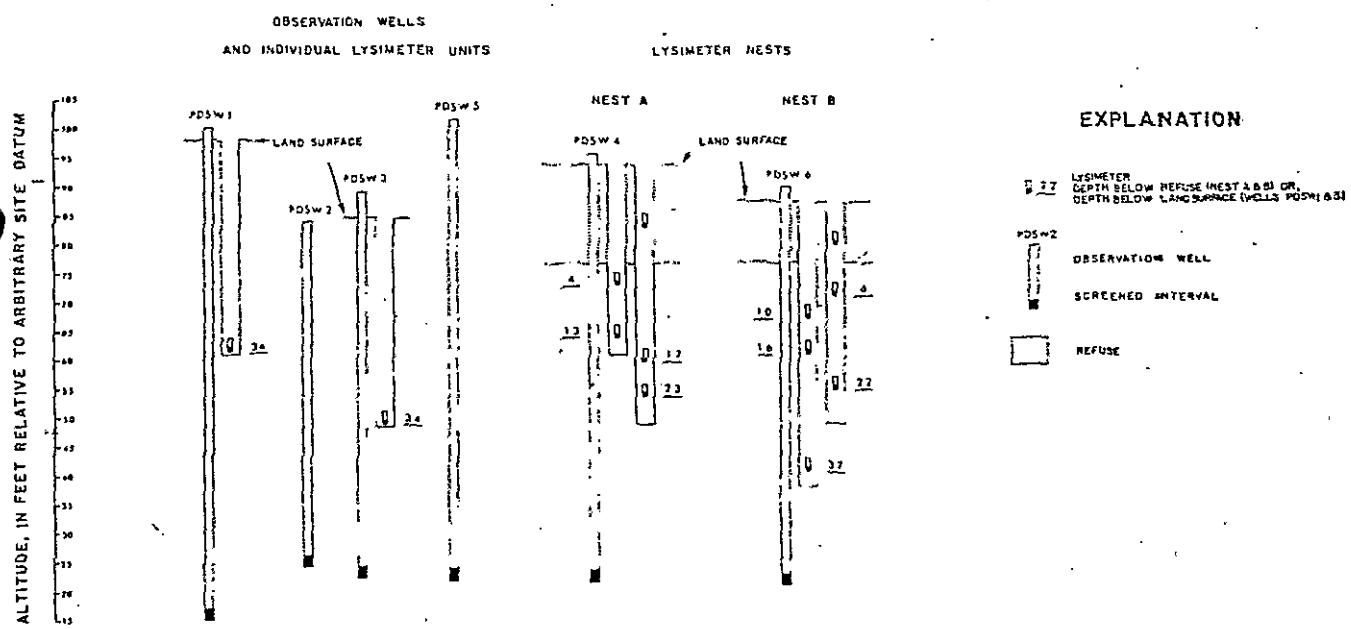


Figure 6. Vertical distribution of monitoring well/lysimeter network at the Prairie du Sac landfill

refuse is not of uniform quality. Leachate samples collected 1.2 m (4 feet) below the base of the refuse, generally showed higher concentrations that those observed within the refuse. The changes in leachate concentrations within the unsaturated zone will reflect to some degree differences in the quality of the raw leachate. The data also indicate the pressure-vacuum lysimeters placed in the refuse do not completely characterize the chemical quality of leachate produced within an entire landfill.

The concentration of most parameters decreased with depth in the samples from lysimeter nest PDSB (Figure 7). The concentration of calcium (Figure 7) was observed to increase with depth, apparently due to the release of calcium from exchange sites on the soils in contact with the leachate. This is similar to the hardness halo often observed in ground water beneath landfills. Although not shown, the same trend was observed for magnesium (Gerhardt 1977). Only chloride showed consistent decreasing concentrations within the unsaturated zone in the samples from lysimeter nest PDSA. Since chloride does not generally react with soil, the reduction in concentrations with depth is most likely due to dilution with less contaminated soil moisture or dispersion, although this was not determined. The most obvious pattern of leachate concentration changes (Figure 7) that developed at nest PDSA was the occurrence of maximum and minimum concentrations at 5.2 m (17 feet) depth from lysimeter PDSA-17. Maximum concentrations for

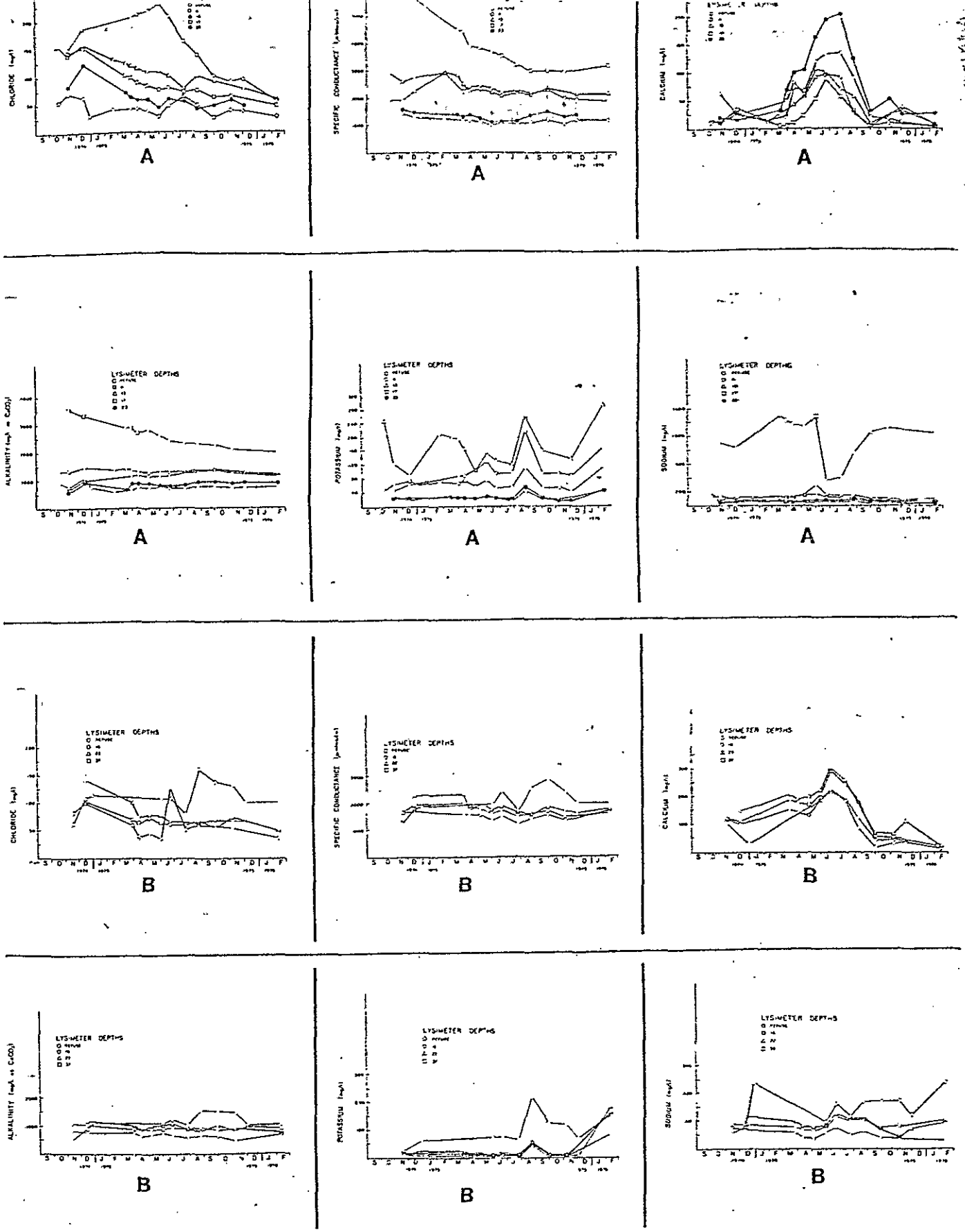


Figure 7. Leachate component concentrations from lysimeter nest PDSA (A) and nest PDSB (B). Sample notation indicates depth of lysimeter in feet below the base of the refuse

sodium, alkalinity and specific conductance were recorded at the 5.2 m (17 feet) depth. Minimum concentrations for calcium occurred in the samples from the 5.2 m (17 feet) depth (Figure 7). Although not shown, the same trend was observed for magnesium, total iron, total nitrogen and nitrate plus nitrite (Gerhardt 1977). The above parameters generally showed an increase in concentration in the samples from the next deeper lysimeter at the 7 m (23 feet) depth.

There are three possible explanations for the observed patterns of leachate component concentration changes with depth beneath the Prairie du Sac landfill. First, lysimeter PDSA-18 was placed within a 1.2 m (4 feet) gravel layer encountered between the 4.9 m (16 feet) depth and the 6 m (20 feet) depth. A grain-size analysis of a split-spoon soil sample from the 5.2m (17 feet) depth indicated that 65 percent of the sample by weight was larger than 2 mm. Chemical reactions between the gravel layer and leachate may have accounted for many of the concentration maximums and minimums observed at lysimeter PDSA-17. For example, sodium analysis of distilled water brought to equilibrium with soil samples from different site soil types indicated that sodium values varied significantly with soil composition. However, the highest sodium soil value (20 micrograms sodium/gram soil) was from the gravel layer (Armstrong and Neidinger 1977). Also, the average sodium concentration from lysimeter PDSA-17 was more than four times greater than the average value recorded in the refuse (PDSA-refuse), suggesting either the source of the sodium is the soil matrix or release of sodium from the refuse has declined. The nature of the sodium contribution from the gravel was not determined. Numerous gravel layers were encountered in all of the site boreholes. They appear to be discontinuous lenses. The gravel layers at lysimeter nest PDSB were generally less than 0.3 m (1 feet) thick and no lysimeter was placed within a gravel layer at nest PDSB. Therefore, this same trend was not observed in the samples from lysimeter nest PDSB.

Secondly, in an unsaturated soil, water occurs only in the finer pores and not in the larger ones because the total amount of available water is insufficient to fill all the pores. The smaller pores can exert stronger capillary forces and thus get filled. In the case of a fine material overlying a coarse material, movement of water into the coarse layer can occur only when the rate of water application exceeds the capacity of the fine material to disperse the water laterally by capillary action. Water will not move into the coarser material until the finer material approaches saturation, at which time gravitational forces exceed capillary forces and drainage into the coarser material occurs.

The pattern of leachate concentration in the samples from the 5.2m (17 feet) depth and, to a lesser extent, the 4m (13 feet) depth suggest that when the soil system is unsaturated, the gravel layer may act as a partial impeding layer to the downward movement of leachate. Such a situation promotes the lateral flow of leachate in the sands above the gravel. Johnson and Cartwright (1980) also observed the lateral movement of leachate to a distance of at least 4.6m (15 feet) away from the refuse at the Savanna landfill. Lateral flow and retention of significant portions of the leachate in the sand above the gravel (maximum average concentration of potassium occurred at the 4m (13 feet) depth) may be responsible for some of the high concentrations observed in the sand layer. Therefore, the attenuation capacity of the sand may no longer be effective for certain leachate components. For example, concentration values for magnesium and calcium (shown in Figure 7) decreased with depth in the samples from nest PDSA, reaching minimum values in the samples from PDSA-17. This pattern may suggest that much of the calcium and magnesium on soil exchange sites has been previously released to the leachate beneath this portion of the site. The additional contact time between the leachate and the soils above the gravel layer may have contributed to the loss of calcium and magnesium from the leachate. This pattern of decreasing concentrations may also indicate that less calcium and magnesium are being leached from the refuse.

Two additional lines of evidence seem to support the contention that the lateral flow of landfill leachate has occurred in the sand above the gravel layer. First, high chloride concentrations were observed in soil samples collected from the 7.3 to 11.6m (24 to 38 feet) intervals of the TH borehole site (Figure 5), approximately 12m (40 feet) outside the active fill area. The zone in which the high chloride concentrations occurred (Table 3) included the gravel layer and the sands immediately above the gravel layer. The high chloride values in this zone would seem to indicate that landfill leachate has moved approximately 12m (40 feet) laterally beyond the fill area, generally in the layers above, and including, the gravel layer. Chloride concentrations in soil samples collected from the surface to a depth of 19.5m (64 feet) at well site PDSW5 (Figure 5) ranged from 27 to 53 micrograms of chloride per gram of soil (Gerhardt 1977). This indicates that the high chloride values found in the TH borehole do not represent natural conditions. Second, a single lysimeter unit (PDSD-34) was installed near well PDSW3 (Figures 5 and 6), 10.4m (34 feet) below land surface, at the top of a gravel layer encountered at this depth. Lysimeter PDSD-34 was sampled in order to determine if soil-moisture quality at the sand/gravel contact downslope from the fill area

Table 3.
Chloride Concentrations in Soil Samples Collected from the TH Borehole

Soil depth (below surface)	Chloride concentration (micrograms per gram soil)
4	4
12	2
24	116
28	170
34	111
38	341
44	50
48	30
54	8
58	11

was affected by lateral movement of landfill leachate. For comparative purposes, an additional lysimeter unit (PDSC-34) was placed at a sand/gravel contact 10.4m (34 feet) below land surface, near well PDSW1 (Figures 5 and 6) to provide background soil-moisture quality. The data from the lysimeter placed 5.2m (17 feet) below the base of the refuse at nest A (PDSA-17) is also 10.4m (34 feet) below land surface and is included for comparison. As shown in Table 4, concentrations in the PDSD-34 samples were generally higher than background concentrations (PDSC-34) in a similar horizon. The higher concentrations in the PDSD-34 samples suggest that landfill leachate has moved approximately 15.2m (50 feet) laterally beyond the boundary of the fill area in the sands above the gravel layer.

Table 4
Chemical Concentrations in Leachate and Soil Moisture Collected from Lysimeters Placed in Gravel

Parameter	Lysimeter PDSA-17	Lysimeter PDSD-34	Lysimeter PDSC-34
Specific conductance (micromohs/cm)	3,100	900	275
Chloride (mg/L)	62	24	17
Alkalinity (mg/L, as $CaCO_3$)	2,121	598	177
Calcium (mg/L)	10	13	17
Magnesium (mg/L)	15	70	25
Potassium (mg/L)	24	3.5	2
NH_4-N (mg/L)	4.5	0.05	0.03
NO_2 + NO_3 (mg/L)	0.42	0.26	0.14
Sodium (mg/L)	1,140	15	8

Lysimeter PDSA-17 placed within the gravel layer should not consistently yield a sample because leachate would be prevented from entering the coarse material. The fact that only small sample volumes could be extracted from this lysimeter suggests that much of the leachate was derived from the sand/gravel contacts rather than from the gravel layer itself. The addition of the powdered quartz during lysimeter installation also created an artificial medium for leachate movement to the lysimeter from the sand above the gravel layers. A portion of the leachate would probably always migrate vertically because (1) the gravel was not well sorted and (2) an equilibrium flow rate through the gravel would ultimately be established for a given moisture content. The gravel deposits appear to be discontinuous and leachate flow around the gravel layers would also occur. The generally low, stable concentrations observed in the samples collected from the deepest lysimeter in lysimeter nest A at the 7m (23 feet) depth below the gravel layer apparently reflect attenuation and/or dilution of leachate that has moved downward through, or around, the gravel layer. Significant amounts of the leachate would likely move through the gravel layer during the spring recharge period when the soil system approached saturation. The effects of a gravel layer on leachate migration in the unsaturated zone are illustrated in Figure 8.

Finally, the maximum leachate component concentrations at the various sampling depths, especially in the samples from nest A (Figure 7) may represent the maximum depth to which a given component has moved or they may represent the position of a slug of leachate moving through the soil. Concentration plots for most leachate parameters, as illustrated by alkalinity, sodium and calcium indicate that other processes must be responsible for the concentration peaks observed for most of the leachate components. Concentration peaks for many individual leachate components at the various sampling depths remained fairly constant throughout the study. If these concentration peaks represented leaching fronts or the maximum depth of penetration, then concentrations should have shown a gradual reduction as the front moved downward through the soil and concentrations should have increased with time at the next deeper sampling point as the leachate moved downward. This was not observed. Also, changes in concentrations often occurred simultaneously at all sampling depths, which argues against a leachate front moving through the subsoil.

Summary and Conclusions

The observed concentrations of the leachates, or any leachate component, at depth in the unsaturated zone beneath the landfills have apparently resulted from the interaction of several factors: (1) the chemical quality of the leachates being produced within the refuse material, (2) chemical interactions between the soil and the leachate, and (3) unsaturated soil-moisture/leachate movement. At the Sauk County landfill, changes in leachate concentrations varied systematically with respect to depth. This apparently was a direct consequence of the uniform nature of the fine sands beneath the landfill. A much more complicated and less systematic pattern of leachate concentration changes was observed in the subsoils beneath the Prairie du Sac landfill. This apparently resulted from the layered nature of the sands and gravels beneath the site, promoting the lateral movement of leachate within the unsaturated zone.

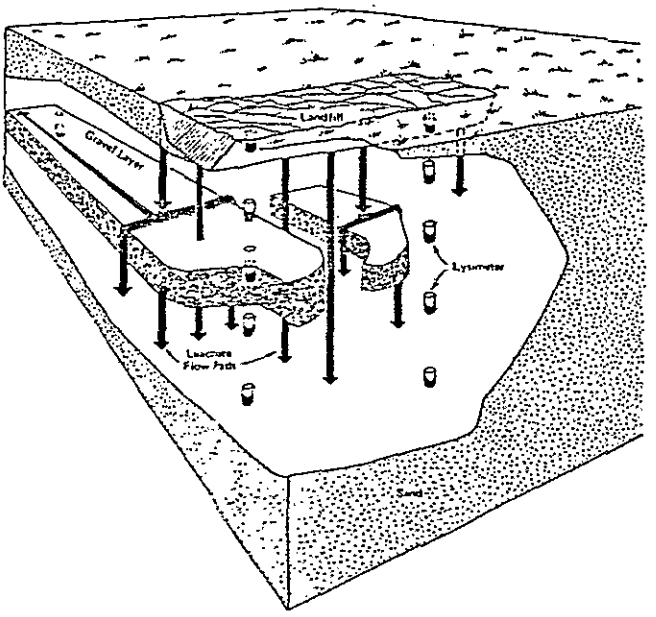


Figure 8. Schematic diagram of the effects of a gravel layer on leachate migration in the unsaturated zone

The attenuation of leachate within the unsaturated zone was observed beneath the Sauk County and Prairie du Sac landfills. However, ground water beneath both sites was found to be contaminated. Apgar and Langmuir (1971) reported similar findings. The limited attenuation capacity of the unsaturated sands and gravels beneath the two sites was apparently incapable of preventing ground water contamination. The operation of these landfills as natural attenuation sites did not prevent ground water contamination. The results also indicate that sampling from one or two lysimeter nests in the unsaturated zone may not be indicative of the actual ground water contamination potential of a landfill. However, careful placement of lysimeters within the unsaturated zone beneath landfill sites with deep water tables can still provide the earliest possible indication of leachate production, movement of the leachate within the unsaturated zone and an evaluation of the attenuation capacity of the unsaturated zone.

In the case of layered soils in the unsaturated zone, the possibility of horizontal leachate movement must also be considered. At the Prairie du Sac landfill, leachate was detected in the unsaturated zone at least 15.2m (50 feet) beyond the fill limits. If the patterns of leachate concentration changes at depth within the unsaturated zone are always assumed to be the result of strictly vertical leachate flow, erroneous conclusions could be drawn concerning leachate attenuation and migration.

It was hoped that the results from this study could be used to establish the minimum separating distance necessary between natural attenuation landfill sites and the water table to prevent contamination. However, the capacity of the unsaturated zone to attenuate leachate depends upon a variety of factors that will vary greatly from one hydrogeologic environment to another. Also, any changes in soil type within a layered soil environment will affect the movement and chemistry of percolating leachate to some degree. Absolute requirements specifying a separating distance between the base of natural attenuation landfills and the water table may never be obtainable, or desirable. Separation requirements should be formulated on a case-by-case basis, taking into account the concepts of leachate movement in the unsaturated zone.

References

Apgar, M.A. and D. Langmuir. 1971. Ground water pollution potential of a landfill above the water table. Ground Water, v. 9, no. 6, pp. 76-93.

Armstrong, D.E. and J.G. Neidinger. 1977. Mobility of leachate components in the unsaturated zone beneath a sanitary landfill. Water Chemistry Program Report. Madison, Wisconsin, 43 pp.

Gerhardt, R.A. 1977. Leachate attenuation in the unsaturated zone beneath three sanitary landfills in Wisconsin. Wisconsin Geological and Natural History Survey. Information Circular 35, 93 pp.

Johnson, T.M. and K. Cartwright. 1980. Monitoring of leachate migration in the unsaturated zone in the vicinity of sanitary landfills. Illinois State Geological Survey Circular 514, 82 pp.

Johnson, T.M., K. Cartwright and R.M. Schuller. 1981. Monitoring of leachate migration in the unsaturated zone in the vicinity of sanitary landfills. Ground Water Monitoring Review, v. 1, no. 2, pp. 62-67.

Lane, B.E. 1969. Sanitary landfill leachate interactions with a carbonate-rock derived soil in central Pennsylvania. M.S. Thesis. Dept. of Geology and Geophysics. Penn. State University. 197 pp.

Lane, B.E. and R.R. Parizek. 1968. Leachate movement in the subsoil beneath a sanitary landfill trench traced by means of suction lysimeters. Proceedings of 2nd Mid-Atlantic Industrical Waste Conference, pp. 261-277.

Parizek, R.R. and B.E. Lane. 1970. Soil-water sampling using pan and deep pressure vacuum lysimeters. Journal Hydrology, v. 11, pp. 1-21.

Wagner, G.H. 1962. Use of porous ceramic cups to sample soil water within the profile. Soil Science, v. 94, no. 6, pp. 379-386.

Warzyn Engineering Inc. 1973. Soils investigation report. Sanitary landfill, former Henry Pagel property, portions of Sec. 15, T12N, R5E, Town of Excelsior, Sauk County, Wisconsin. Madison, Wisconsin, 5 pp.

Wilson, L.G. 1981. Monitoring in the vadose zone part I: storage changes. Ground Water Monitoring Review, v. 1, no. 3, pp. 32-41.

Wilson, L.G. 1982. Monitoring in the vadose zone: part II. Ground Water Monitoring Review, v. 2, no. 1, pp. 31-42.

Wilson, L.G. 1983. Monitoring in the vadose zone: part III. Ground Water Monitoring Review, v. 3, no. 1, pp. 155-166.

Wood, W.W. 1973. A technique using porous cups for water sampling at any depth in the unsaturated zone. Water Resources Research, v. 9, no. 2, pp. 486-488.

Biographical Sketch

Roger A. Gerhardt received a B.S. in geology (1971) from the University of Wisconsin-Madison and an M.S. in geology (1974) from the University of Iowa. He is currently a hydrogeologist with the Wisconsin Department of Natural Resources, Bureau of Water Supply. Prior to this he worked as a hydrogeologist for the Wisconsin Geological and Natural History Survey, where he was involved with the research described in this paper.

38. Hodel v. Virginia Surface Mining & Reclamation Association, Inc., 101 S. Ct. 2352 (1981)

452 U.S. 264, 69 L.Ed.2d 1

Donald Paul HODEL, Acting Secretary of the Interior, Appellant,

v.

VIRGINIA SURFACE MINING AND RECLAMATION ASSOCIATION, INC., et al.

VIRGINIA SURFACE MINING AND RECLAMATION ASSOCIATION, INC., et al., Appellants,

v.

Donald Paul HODEL, Acting Secretary of the Interior, et al.

Nos. 79-1538, 79-1596.

Argued Feb. 23, 1981.

Decided June 15, 1981.

Association of coal producers brought preenforcement challenge to the constitutionality of the Surface Mining Control and Reclamation Act. The United States District Court for the Western District of Virginia, 483 F.Supp. 425, rejected the producers' commerce clause challenge to the Act, but held that the Act violated the Tenth Amendment, that various provisions of the Act effected an uncompensated taking of private property in violation of the just compensation clause and that some of the Act's enforcement provisions violated procedural due process requirements. Appeal and cross appeal were taken. The Supreme Court, Justice Marshall, held that: (1) the Act did not violate the commerce clause; (2) the provisions of the Act prescribing performance standards on "steep-slopes," did not violate the Tenth Amendment; (3) the Act's "steep-slope" provisions and the provision prohibiting mining in certain locations, did not, on their face, violate the just compensation clause; (4) the provisions of the Act pertaining to the Secretary of Interior's issuance of orders for immediate cessation of the surface mining operations determined to be in violation of the Act did not violate due process; and (5) the challenge to the Act's provisions for the imposition of civil penalties were premature.

Affirmed in part, reversed in part, and remanded.

Chief Justice Burger filed a concurring statement.

Justice Powell filed a concurring opinion.

For Justice Rehnquist's separate opinion concurring in the judgment, see 101 S.Ct. 2389.

1. Constitutional Law ⟹48(7)

Courts must defer to congressional finding that regulated activity affects interstate commerce if there is any rational basis for such finding. U.S.C.A.Const. Art. 1, § 8, cl. 3.

2. Commerce ⟹52.10

Surface Mining Control and Reclamation Act did not violate commerce clause as regulating use of private lands rather than interstate commerce effects of surface coal mining. Surface Mining Control and Reclamation Act of 1977, § 101 et seq., 30 U.S.C.A. § 1201 et seq.; U.S.C.A.Const. Art. 1, § 8, cl. 3.

3. Commerce ⟹7(2)

Denomination of activity as "local" or "intrastate" activity does not resolve question whether Congress may regulate it under commerce clause, but commerce power extends to those activities intrastate which so affect interstate commerce, or exertion of power of Congress over it, as to make regulation of them appropriate means for attainment of legitimate end, the effective execution of the granted power to regulate interstate commerce. U.S.C.A.Const. Art. 1, § 8, cl. 3.

4. Commerce ⟹52.10

Power conferred on Congress by commerce clause is broad enough to permit congressional regulation of activities causing air or water pollution, or other environmental hazards that may have effects on more than one state. U.S.C.A.Const. Art. 1, § 8, cl. 3.

States ⟹4.17

Provisions of Surface Mining Control and Reclamation Act prescribing performance standards for surface mining on "steep-slopes," including requirement that operator return site to its "approximate original contour," and authorizing variances from contour requirement, did not violate Tenth Amendment limitation on congressional exercise of commerce power as interfering with state's traditional governmental function of regulating land use. Surface Mining Control and Reclamation Act of 1977, § 515(d, e), 30 U.S.C.A. § 1265(d, e); U.S.C.A.Const. Amend. 10.

States ⟹4.17

In order to succeed, claim that congressional commerce power legislation is invalid under Tenth Amendment must satisfy three elements: there must be showing that challenged statute regulates states as states; federal regulation must address functions that are indisputably attributes of state sovereignty; and it must be apparent that states' compliance with federal law would directly impair their ability to structure integral operations in areas of traditional functions. U.S.C.A.Const. Amend. 10.

States ⟹4.17

Tenth Amendment does not limit congressional power to preempt or displace state regulation of private activities affecting interstate commerce. U.S.C.A.Const. Art. 1, § 8, cl. 3; Amend. 10.

States ⟹4.17

Congress does not invade areas reserved to states by Tenth Amendment simply because it exercises its authority under commerce clause in manner that displaces state exercise of their police powers. U.S.C.A. Const. Art. 1, § 8, cl. 3; Amend. 10.

Federal Courts ⟹13

Issue of whether "steep-slope" provisions of Surface Mining Control and Reclamation Act and provision of the Act prohibiting in certain locations violate just compensation clause was not ripe for judicial resolution in context of facial challenge, since it presented no concrete controversy concerning either application of Act to particular surface mining operations or its effect on specific parcels of land. Surface Mining Control and Reclamation Act of 1977, §§ 515(d, e), 522(e), 30 U.S.C.A. §§ 1265(d, e), 1272(e); U.S.C.A.Const. Amend. 5.

10. Eminent Domain ⟹2(7)

Provisions of Surface Mining Control and Reclamation Act prescribing performance standards for "steep-slopes" including requirement that operator return site to its "approximate original contour," and authorizing variances from contour requirement, and provision prohibiting mining in certain locations, did not, on their face, violate just compensation clause, since they did not deny owner economically viable use of his land. Surface Mining Control and Reclamation Act of 1977, §§ 515(d, e), 522(e), 30 U.S.C.A. §§ 1265(d, e), 1272(e); U.S.C.A. Const. Amend. 5.

11. Constitutional Law ⟹278.1
Mines and Minerals ⟹92.6

Provisions of Surface Mining Control and Reclamation Act instructing Secretary of Interior immediately to order total or partial cessation of surface mining operation whenever he determines, on basis of federal inspection, that operation is in violation of Act or special condition required by Act and that operation creates immediate danger to health or safety of public or can reasonably be expected to cause significant, imminent environmental harm, and allowing mine operator aggrieved by cessation order to immediately request temporary relief from Secretary, to which Secretary must respond within five days, did not deny due process. Surface Mining Control and Reclamation Act of 1977, §§ 521, 525, 526, 30 U.S.C.A. §§ 1271, 1275, 1276; U.S.C.A. Const. Amend 5.

12. Constitutional Law ⟹251.6

Ordinarily, due process requires opportunity for some kind of hearing prior to deprivation of significant property interest,

but summary administrative action may be justified in emergency situations. U.S.C.A. Const. Amend. 5.

13. Constitutional Law ⟹253.1

Protection of health and safety of public is paramount governmental interest which justifies summary administrative action. U.S.C.A.Const. Amend. 5.

14. Constitutional Law ⟹46(1)

Due process challenge to Surface Mining Control and Reclamation Act provisions for imposition of civil penalties for violation of cessation orders was premature where mine operators did not allege that they, or any one of them, had had civil penalties assessed against them, and there was no finding that any of the operators had been affected or harmed by any of the statutory procedures for assessment and collection of fines. Surface Mining Control and Reclamation Act of 1977, § 518, 30 U.S.C.A. § 1268.

Syllabus *

A pre-enforcement challenge to the constitutionality of the Surface Mining Control and Reclamation Act of 1977 (Act) was presented in a Federal District Court action wherein the plaintiffs were an association of coal producers engaged in surface coal mining operations in Virginia, some of its member coal companies, individual landowners, the Commonwealth of Virginia, and a town (hereinafter appellees). The Act is designed to establish a nationwide program to protect society and the environment from the adverse effects of surface coal mining operations. The Secretary of the Interior (Secretary) has primary responsibility for administering the Act by promulgating regulations and enforcing its provisions. A two-stage program for the regulation of surface mining—an interim phase and a permanent phase—is established; and environmental protection performance standards are prescribed. Ultimately, a regulatory program is to be adopted for each State, either by approval of a State's proposed permanent program that meets federal minimum standards, or by adoption of a federal program for any State that chooses not to submit a program. Enforcement of the permanent programs rests either with the *participating* State or with the Secretary as to nonparticipating States. The District Court, although rejecting appellees' Commerce Clause, equal protection, and substantive due process challenges to the Act, held that the Act violates the Tenth Amendment, that various provisions of the Act effect an uncompensated taking of private property in violation of the Just Compensation Clause of the Fifth Amendment, and that some of the Act's enforcement provisions violate procedural due process requirements.

Held: In the context of a facial challenge, the Act is constitutional. Pp. 2359–2375.

(a) The Act does not violate the Commerce Clause as regulating the use of private lands rather than the interstate commerce effects of surface coal mining. In view of the legislative record, which includes extended hearings concerning the effects of surface mining on the Nation's environment and economy and the need for uniform minimum nationwide standards, it cannot be said that Congress did not have a rational basis for its findings, set out in the Act itself, that surface coal mining has substantial effects on interstate commerce. And the Act's regulatory scheme is reasonably related to the goals Congress sought to accomplish—the Act's restrictions on the practices of mine operators all serving to control the environmental and other adverse effects of surface coal mining. Pp. 2359–2364.

(b) Sections 515(d) and (e) of the Act, which prescribe performance standards on "steep slopes," including a requirement that an operator return the site to its "approxi-

* The syllabus constitutes no part of the opinion of the Court but has been prepared by the Reporter of Decisions for the convenience of the reader. See *United States v. Detroit Lumber Co.*, 200 U.S. 321, 337, 26 S.Ct. 282, 287, 50 L.Ed. 499

mate original contour," and which authorize variances from the contour requirement, do not violate any Tenth Amendment limitation on congressional exercise of the commerce power as interfering with the States' "traditional governmental function" of regulating land use. The steep-slope provisions govern only the activities of coal mine operators who are private individuals and businesses, and do not regulate the "States as States." Cf. *National League of Cities v. Usery*, 426 U.S. 833, 96 S.Ct. 2465, 49 L.Ed.2d 245. Appellees' contentions that the threat of federal usurpation of their regulatory roles coerces the States into enforcing the Act and that the Act regulates the States as States because it establishes mandatory minimum federal standards are without merit, since the Tenth Amendment does not limit congressional power to preempt or displace state regulation of private activities affecting interstate commerce. Moreover, Congress does not invade areas reserved to the States by the Tenth Amendment simply because it exercises its authority under the Commerce Clause in a manner that displaces the States' exercise of their police powers. Pp. 2364–2369.

(c) The issue whether the Act's steep-slope provisions and § 522(e), which prohibits mining in certain locations, violate the Just Compensation Clause of the Fifth Amendment is not ripe for judicial resolution. Because appellees' taking claim arose in the context of a facial challenge, it presented no concrete controversy concerning either application of the Act to particular surface mining operations or its effect on specific parcels of land. And the "mere enactment" of the Act does not constitute a taking since it does not deny an owner economically viable use of his land, the Act, except for § 522(e) neither categorically prohibiting surface coal mining nor purporting to regulate alternative uses to which coal-bearing lands may be put. Pp. [illegible] 2371.

(d) The provisions of §§ 521, 525, and [illegible] of the Act pertaining to the Secretary's issuance of orders for immediate cessation of surface mining operation determined to be in violation of the Act do not violate the Fifth Amendment's Due Process Clause. Summary administrative action resulting in deprivation of a significant property interest without a prior hearing is justified when, as here, it responds to situations in which swift action is necessary to protect the public health and safety. The objective criteria for the issuance of immediate cessation orders, established by the Act, and the Secretary's implementing regulations, are specific enough to control governmental action and reduce the risk of erroneous deprivation, and mine operators are afforded a prompt and adequate postdeprivation administrative hearing and an opportunity for judicial review. And the District Court erred in reducing to 24 hours the statutorily prescribed 5-day period for the Secretary's response to mine operators' requests for temporary relief from an immediate cessation order. The record does not show that the Secretary has not responded or will not respond in less than five days, which is the statutory maximum, and appellees have not demonstrated that they have been adversely affected by the 5-day period in a particular case or that it is generally unreasonable. In addition, no evidence was introduced to show that a shorter reply period is administratively feasible. Pp. 2371–2374.

(e) Appellees' due process challenge to the Act's provisions for the imposition of civil penalties for violations of cessation orders is premature. Appellees did not allege that they, or any one of them, have had civil penalties assessed against them, and there was no finding that any of appellee coal mine operators have been affected or harmed by any of statutory procedures for the assessment and collection of fines. P. 2374.

D.C., 483 F.Supp. 425, affirmed in part, reversed in part, and remanded.

Peter Buscemi, Washington, D. C., for appellant in 78-1598 and for appellees in 79-1596.

Marshall Coleman, Richmond, Va., for appellees in 79–1538 and for appellants in 79–1596.

[268] Justice MARSHALL, delivered the opinion of the Court.

These cases arise out of a pre-enforcement challenge to the constitutionality of the Surface Mining Control and Reclamation Act of 1977 (Surface Mining Act or Act), 91 Stat. 447, 30 U.S.C. § 1201 *et seq.* (1976 ed., Supp.III). The United States District Court for the Western District of Virginia declared several central provisions of the Act unconstitutional and permanently enjoined their enforcement. 483 F.Supp. 425 (1980). In these appeals, we consider whether Congress, in adopting the Act, exceeded its powers under the Commerce Clause of the Constitution,[1] or transgressed affirmative limitations on the exercise of that power contained in the Fifth and Tenth Amendments. We conclude that in the context of a facial challenge, the Surface Mining Act does not suffer from any of these alleged constitutional defects, and we uphold the Act as constitutional.

I

A

The Surface Mining Act is a comprehensive statute designed to "establish a nationwide program to protect society and the environment from the adverse effects of surface coal mining operations." § 102(a), 30 U.S.C. § 1202(a) (1976 ed., Supp.III). Title II of the Act, 30 U.S.C. § 1211 (1976 ed., Supp.III), creates the Office of Surface Mining Reclamation and Enforcement (OSM), within the Department of the Interior, and the Secretary of the Interior (Secretary) acting through OSM, is charged with primary responsibility for administering and implementing the Act by promulgating regulations and enforcing its provisions. § 201(c), 30 U.S.C. § 1211(c) (1976 ed., Supp.III). The principal regulatory and enforcement provisions are contained in Title V of the Act, 91 Stat. 467–514, 30 U.S.C. §§ 1251–1279 (1976 ed., Supp.III). Section 501, 30 U.S.C. § 1251 (1976 ed., Supp.III), establishes a two-stage program for the regulation of surface coal mining: an initial, or interim regulatory phase, and a subsequent, permanent phase. The interim program mandates immediate promulgation and federal enforcement of some of the Act's environmental protection performance standards, complemented by continuing state regulation. Under the permanent phase, a regulatory program is to be adopted for each State, mandating compliance with the full panoply of federal performance standards, with enforcement responsibility lying with either the State or Federal Government.

Section 501(a) directs the Secretary to promulgate regulations establishing an interim regulatory program during which mine operators will be required to comply with some of the Act's performance standards, as specified by § 502(c), 30 U.S.C. § 1252(c) (1976 ed., Supp.III). Included among those selected standards are requirements governing: (a) restoration of land after mining to its prior condition; (b) restoration of land to its approximate original contour; (c) segregation and preservation of topsoil; (d) minimization of disturbance to the hydrologic balance; (e) construction of coal mine waste piles used as dams and embankments; (f) revegetation of mined areas; and (g) spoil disposal. § 515(b), 30 U.S.C. § 1265(b) (1976 ed., Supp.III).[2] The interim regulations were published on De-

1. The Commerce Clause empowers Congress "[t]o regulate Commerce with foreign Nations and among the several States, and with the Indian Tribes." U.S.Const., Art. I, § 8, cl. 3.

2. Other provisions of the Act are, by their own terms, made effective during the interim period. One example is § 522(e), 30 U.S.C. § 1272(e) (1976 ed., Supp.III), which prohibits, with some exceptions, surface coal mining on

cember 13, 1977, see 42 Fed.Reg. 62639,[3] and they are currently in effect in most States, including Virginia.[4]

The Secretary is responsible for enforcing the interim regulatory program. § 502(e), 30 U.S.C. § 1252(e) (1976 ed., Supp. III). A federal enforcement and inspection program is to be established for each State, and is to remain in effect until a permanent regulatory program is implemented in the State. States may issue permits for surface mining operations during the interim phase, but operations authorized by such permits must comply with the federal interim performance standards. § 502(b), 30 U.S.C. § 1252(b) (1976 ed., Supp. III). States may also pursue their own regulatory and inspection programs during the interim phase, and they may assist the Secretary in enforcing the interim standards.[5] The States are not, however, required to enforce the interim regulatory standards and, until the permanent phase of the program, the Secretary may not cede the Federal Government's independent enforcement role to States that wish to conduct their own regulatory programs.

Section 501(b), 30 U.S.C. § 1251(b) (1976 ed., Supp. III), directs the Secretary to promulgate regulations establishing a permanent regulatory program incorporating all the Act's performance standards. The Secretary published the permanent regulations on March 13, 1979, see 44 Fed.Reg. 14902, but these regulations do not become effective in a particular State until either a permanent state program, submitted and approved in accordance with § 503 of the Act, or a permanent federal program for the State, adopted in accordance with § 504, is implemented.

Under § 503, any State wishing to assume permanent regulatory authority over the surface coal mining operations on "non-Federal lands"[6] within its borders must submit a proposed permanent program to the Secretary for his approval. The proposed program must demonstrate that the state legislature has enacted laws implementing the environmental protection standards established by the Act and accompanying regulations, and that the State has the administrative and technical ability to

certain lands or within specified distances of particular structures or facilities.

3. Under §§ 502(b), (c) of the Act, 30 U.S.C. §§ 1252(b), (c) (1976 ed., Supp. III), the interim standards are applicable only to surface mining operations in States that were themselves regulating surface mining when the Act became law. All States in which surface mining was conducted on private lands had regulatory programs of their own when the Act was passed in 1977. Accordingly, the interim program became applicable in all relevant areas throughout the country, including Virginia.

4. New surface mining operations, excluding those on "Federal lands" or "Indian lands," commencing on or after February 3, 1978, must comply with the performance standards established by the interim regulatory program at the start of operations. And, with certain limited exceptions, surface mining operations begun prior to February 3, 1978, were required to be in compliance with the interim regulations as of May 3, 1978. §§ 502(b), (c), and 701(11), 30 U.S.C. §§ 1252(b), (c) and 1291(11) (1976 ed., Supp. III).

Some of the interim regulations were challenged in the United States District Court for the District of Columbia pursuant to § 526(a)(1) of the Act, 30 U.S.C. § 1276(a)(1) (1976 ed., Supp. III). *In re Surface Mining Regulation Litigation*, 452 F.Supp. 327 (1978); *In re Surface Mining Regulation Litigation*, 456 F.Supp. 1301 (1978), aff'd in part and rev'd in part, 201 U.S.App.D.C. 360, 627 F.2d 1346 (1980). The plaintiffs in the District of Columbia litigation also challenged the validity of a number of the statutory provisions that are at issue in the instant cases. The District Court sustained the validity of those provisions, 456 F.Supp., at 1319-1321, and the attack was not renewed on appeal.

5. Congress encouraged such assistance by providing for financial reimbursements to States that activity assist the federal enforcement effort during the interim phase. See 30 U.S.C. § 1252(e)(4) (1976 ed., Supp. III).

6. A separate regulatory program governing "Federal lands" is established by § 523 of the Act, 30 U.S.C. § 1273 (1976 ed., Supp. III). The term "Federal lands" is defined in § 701(4), 30 U.S.C. § 1291(4) (1976 ed., Supp. III). Section 710 of the Act, 30 U.S.C. § 1300 (1976 ed., Supp. III), regulates surface mining on "Indian lands."

enforce these standards. 30 U.S.C. § 1253 (1976 ed., Supp. III). The Secretary must approve or disapprove each such proposed program in accordance with time schedules and procedures established by §§ 503(b)(c), 30 U.S.C. §§ 1253(b), (c) (1976 ed., Supp. III).[7] [272] In addition, the Secretary must develop and implement a federal permanent program for each State that fails to submit or enforce a satisfactory state program. § 504, 30 U.S.C. § 1254 (1976 ed., Supp. III). In such situations, the Secretary constitutes the regulatory authority administering the Act within that State and continues as such unless and until a "state program" is approved. No later than eight months after adoption of either a state-run or federally administered permanent regulatory program for a State, all surface coal mining and reclamation operations on "non-Federal lands" within that State must obtain a new permit issued in accordance with the applicable regulatory program. § 506(a), 30 U.S.C. § 1256(a) (1976 ed., Supp. III).

B

On October 23, 1978, the Virginia Surface Mining and Reclamation Association, Inc., an association of coal producers engaged in surface coal mining operations in Virginia, 63 of its member coal companies, and 4 individuals landowners filed suit in Federal District Court seeking declaratory and injunctive relief against various provisions of the Act. The Commonwealth of Virginia and the town of Wise, Va., intervened as plaintiffs.[8] Plaintiffs' challenge was primarily directed at Title V's performance standards.[9] Because the permanent regulatory program was not scheduled to become effective until June 3, 1980, plaintiffs' challenge was directed at the sections of the Act establishing the interim regulatory program. Plaintiffs alleged that these provisions violate the Commerce Clause, the equal protection and due process guarantees of the Due Process Clause of the Fifth Amendment,[10] the Tenth Amendment,[11] and

7. The proposed state programs were to have been submitted by February 3, 1979—18 months after the Act was passed. Exercising his authority under § 504(a), the Secretary extended the deadline until August 3, 1979. See 44 Fed.Reg. 15324 (1979). Because the Secretary's March 1979 publication of the permanent regulations occurred seven months after the date set by the Act, see 30 U.S.C. § 1251(b) (1976 ed., Supp. III), the United States District Court for the District of Columbia further extended the deadline for submission of state programs to and including March 3, 1980. *In re Permanent Surface Mining Regulation Litigation*, Civ. No. 79-1144 (DC July 25 and Aug. 21, 1979). See also 44 Fed.Reg. 60969 (1979) (announcing conforming changes in the Secretary's regulations governing submission of state programs).

With the exception of Alaska, Georgia, and Washington, all States in which surface mining is either conducted or is expected to be conducted submitted proposed state programs to the Secretary by March 3, 1980. The Secretary has made his initial decisions on these programs. Three programs were approved, 8 were approved on condition that the States agree to some modifications, 10 were approved in part and disapproved in part, and 3 were disapproved because the state legislatures had failed to enact the necessary implementing statutes. Virginia's program was among those approved in part and disapproved in part. See 45 Fed. Reg. 69977 (1980). Under § 503 of the Act, a State may revise a plan that has been disapproved in whole or in part and resubmit it to the Secretary within 60 days of his initial decision.

8. The Virginia Citizens for Better Reclamation, Inc., and the town of St. Charles, Va., intervened as defendants in support of the Secretary.

9. Plaintiffs also challenged Title IV of the Act, 30 U.S.C. §§ 1231-1243 (1976 ed., Supp. III), which establishes a reclamation program for abandoned mines. The District Court, held, however, that it would exercise its discretion by "not grant[ing] declaratory judgments as to the provisions of that title." 483 F.Supp. 425, 429 (1980). There is no appeal from this portion of the District Court's judgment.

10. The Due Process Clause of the Fifth Amendment states that no person shall "be deprived of life, liberty, or property, without due process of law."

11. Under the Tenth Amendment, "[t]he powers not delegated to the United States by the Constitution, nor prohibited by it to the States, are reserved to the States respectively, or to the people."

the Just Compensa
Amendment.[12]

The District Cou
plaintiffs' request
tion. The court
order and opinion
provisions of the A
F.Supp. 425 (1980
plaintiffs' Commer
tion, and substantiv
to the Act. The c
the Act "operates
freedom to structu
areas of tradition
therefore, is in con
Amendment." *Id.*,
League of Cities v.
96 S.Ct. 2465, 2474,
The court also rule
of the Act effect a
of private property
Compensation Claus
ment. Finally, the
tiffs' due process c
Act's enforcement
permanently enjoin
enforcing various

In No. 79-1538,
from that portion

12. The Compensatio
ing of private proper
just compensation."

13. The District Cou
motion for a stay pe
Court. At the same
order and opinion c
earlier order. App.
79-1538, pp. 1a-16a
retary's application,
the District Court's
timely filing and dis
this Court." 100 S.
(1980).

14. Plaintiffs do not a
the District Court's
equal protection an
challenges to the Act

15. The jurisdiction o
under 28 U.S.C. §
direct appeal to this
by a court of the Uni
Act of Congress in an
States, its agencies,
parties.

the Just Compensation Clause of the Fifth Amendment.[12]

The District Court held a 13-day trial on plaintiffs' request for a permanent injunction. The court subsequently issued an order and opinion declaring several central provisions of the Act unconstitutional. 488 F.Supp. 425 (1980). The court rejected plaintiffs' Commerce Clause, equal protection, and substantive due process challenges to the Act. The court held, however, that the Act "operates to 'displace the States' freedom to structure integral operations in areas of traditional functions,' ... and, therefore, is in contravention of the Tenth Amendment." *Id.*, at 435, quoting *National League of Cities v. Usery*, 426 U.S. 833, 852, 96 S.Ct. 2465, 2474, 49 L.Ed.2d 245 (1976). The court also ruled that various provisions of the Act effect an uncompensated taking of private property in violation of the Just Compensation Clause of the Fifth Amendment. Finally, the court agreed with plaintiffs' due process challenges to some of the Act's enforcement provisions. The court permanently enjoined the Secretary from enforcing various provisions of the Act.[13]

In No. 79-1538, the Secretary appeals from that portion of the District Court's judgment declaring various sections of the Act unconstitutional and permanently enjoining their enforcement. In No. 79-1596, plaintiffs cross-appeal from the District Court's rejection of their Commerce Clause challenge to the Act.[14] Because of the importance of the issues raised, we noted probable jurisdiction of both appeals,[15] 449 U.S. 817, 101 S.Ct. 67, 66 L.Ed.2d 19 (1980), 1275 and consolidated the two cases.[16] For convenience, we shall usually refer to plaintiffs as "appellees."

II

On cross-appeal, appellees argue that the District Court erred in rejecting their challenge to the Act as beyond the scope of congressional power under the Commerce Clause. They insist that the Act's principal goal is regulating the use of private lands within the borders of the States and not, as the District Court found, regulating the interstate commerce effects of surface coal mining. Consequently, appellees contend that the ultimate issue presented is "whether land *as such* is subject to regulation under the Commerce Clause, *i. e.* whether land can be regarded as 'in commerce.'" Brief for Virginia Surface Mining & Recla-

12. The Compensation Clause prohibits the taking of private property "for public use, without just compensation."

13. The District Court denied the Secretary's motion for a stay pending direct appeal to this Court. At the same time, the court issued an order and opinion clarifying and modifying its earlier order. App. to Juris. Statement in No. 79-1538, pp. 1a-16a (J.S.App.). Upon the Secretary's application, we issued an order staying the District Court's judgment "pending the timely filing and disposition of the appeal[s] in this Court." 100 S.Ct. 1306, 63 L.Ed.2d 755 (1980).

14. Plaintiffs do not appeal from that portion of the District Court's judgment rejecting their equal protection and substantive due process challenges to the Act.

15. The jurisdiction of this Court was invoked under 28 U.S.C. § 1252, which provides for direct appeal to this Court from any decision by a court of the United States invalidating an Act of Congress in any suit to which the United States, its agencies, officers, or employees are parties.

16. We also agree to hear the appeal in No. 80-231, *Hodel v. Indiana*, which involves similar constitutional challenges to different provisions of the Surface Mining Act, and which we also decide today. 452 U.S. 314, 101 S.Ct. 2376, 69 L.Ed.2d 40. At least three other District Courts have considered constitutional challenges to provisions of the Surface Mining Act. In *Concerned Citizens of Appalachia, Inc. v. Andrus*, 494 F.Supp. 679 (ED Tenn.1980), appeal pending, No. 80-1488 (CA6), the District Court upheld the Act in the face of challenges similar to those raised by plaintiffs in the instant case. In *Star Coal Co. v. Andrus*, No. 79-171-2 (SD Iowa, Feb. 13, 1980), appeal dism'd, No. 80-1284 (CA8), the District Court rejected challenges based on the Fifth and Tenth Amendments, but enjoined some of the Act's enforcement provisions. And in *Andrus v. P-Burg Coal Co.*, 495 F.Supp. 82 (SD Ind. 1980), aff'd, 644 F.2d 1231 (CA7 1981), the District Court rejected a Commerce Clause challenge to the Act.

mation Association, Inc., et al. 12 (emphasis in original). In urging us to answer "no" to this question, appellees emphasize that the Court has recognized that land-use regulation is within the inherent police powers of the States and their political subdivisions,[17] and]276 argue that Congress may regulate land use only insofar as the Property Clause [18] grants it control over federal lands.

[1] We do not accept either appellees' framing of the question or the answer they would have us supply. The task of a court that is asked to determine whether a particular exercise of congressional power is valid under the Commerce Clause is relatively narrow. The court must defer to a congressional finding that a regulated activity affects interstate commerce, if there is any rational basis for such a finding. *Heart of Atlanta Motel, Inc. v. United States*, 379 U.S. 241, 258, 85 S.Ct. 348, 358, 13 L.Ed.2d 258 (1964); *Katzenbach v. McClung*, 379 U.S. 294, 303–304, 85 S.Ct. 377, 383, 13 L.Ed.2d 290 (1964). This established, the only remaining question for judicial inquiry is whether "the means chosen by [Congress] must be reasonably adapted to the end permitted by the Constitution." *Heart of Atlanta Motel, Inc. v. United States, supra*, at 262, 85 S.Ct., at 360. See *United States v. Darby*, 312 U.S. 100, 121, 61 S.Ct. 451, 460, 85 L.Ed. 609 (1941); *Katzenbach v. McClung*, 379 U.S., at 304, 85 S.Ct., at 383. The judicial task is at an end once the court determines that Congress acted rationally in adopting a particular regulatory scheme. *Ibid.*

Judicial review in this area is influenced above all by the fact that the Commerce Clause is a grant of plenary authority to Congress. See *National League of Cities v. Usery, supra*, at 840, 96 S.Ct., at 2468; *Cleveland v. United States*, 329 U.S. 14, 19, 67 S.Ct. 13, 15, 91 L.Ed. 12 (1946); *NLRB v. Jones & Laughlin Steel Corp.*, 301 U.S. 1, 37, 57 S.Ct. 615, 624, 81 L.Ed. 893 (1937). This power is "complete in itself, may be exercised to its utmost extent, and acknowledges no limitations other than are prescribed in the constitution." *Gibbons v. Ogden*, 9 Wheat. 1, 196, 6 L.Ed. 23 (1824). Moreover, this Court has made clear that the commerce power extends not only to "the use of channels of interstate or foreign commerce" and]277 to "protection of the instrumentalities of interstate commerce ... or persons or things in commerce," but also to "activities affecting commerce." *Perez v. United States*, 402 U.S. 146, 150, 91 S.Ct. 1357, 1359, 28 L.Ed.2d 686 (1971). As we explained in *Fry v. United States*, 421 U.S. 542, 547, 95 S.Ct. 1792, 1795, 44 L.Ed.2d 363 (1975), "[e]ven activity that is purely intrastate in character may be regulated by Congress, where the activity, combined with like conduct by others similarly situated, affects commerce among the States or with foreign nations." See *National League of Cities v. Usery*, 426 U.S., at 840, 96 S.Ct., at 2468; *Heart of Atlanta Motel, Inc. v. United States, supra*, 379 U.S., at 255, 85 S.Ct., at 356; *Wickard v. Filburn*, 317 U.S. 111, 127–128, 63 S.Ct. 82, 90, 87 L.Ed. 122 (1942); *United States v. Wrightwood Dairy Co.*, 315 U.S. 110, 119, 62 S.Ct. 523, 526, 86 L.Ed. 726 (1942); *United States v. Darby, supra*, 312 U.S., at 120–121, 61 S.Ct., at 460.

[2] Thus, when Congress has determined that an activity affects interstate commerce, the courts need inquire only whether the finding is rational. Here, the District Court properly deferred to Congress' express findings, set out in the Act itself, about the effects of surface coal mining on interstate commerce. Section 101(c), 30 U.S.C. § 1201(c) (1976 ed., Supp. III), recites the congressional finding that

"many surface mining operations result in disturbances of surface areas that bur-

17. Appellees cite cases such as *Village of Belle Terre v. Boraas*, 416 U.S. 1, 94 S.Ct. 1536, 39 L.Ed.2d 797 (1974); *Berman v. Parker*, 348 U.S. 26, 75 S.Ct. 98, 99 L.Ed. 27 (1954); *Euclid v. Ambler Realty Co.*, 272 U.S. 365, 47 S.Ct. 114, 71 L.Ed. 303 (1926).

18. The Property Clause provides: "The Congress shall have Power to dispose of and make all needful Rules and Regulations respecting the Territory or other Property belonging to the United States." U.S.Const., Art. IV, § 3, cl. 2.

den and adve
the public we
minishing the
cial, industria
agricultural,
causing erosio
uting to floods
destroying fis
impairing nat
the property o
ards dangerou
degrading the
munities, and
mental progra
soil, water, an

19. Hearings on p
surface coal mi
Mining Reclamat
ate Committee o
90th Cong., 2d S
additional hearin
both the House a
Strip Mining: He
tee on Mines and
tee on Interior a
1st Sess. (1971);
fore the Subcom
and Fuels of the
and Insular Affai
The Committees
tion by their res
passed H.R.6482,
fore the Senate c

Similar bills w
Congress and furt
ulation of Surfac
ings before the S
and Insular Affair
Regulation of Sur
the Subcommittee
Subcommittee on
House Committee
fairs, 93d Cong.,
quest of the Chai
tee, the Council o
pared a report e
and Reclamation:
nomic Assessme
Print 1973), and
additional hearin
Coal Surface Min
ings before the Su
terials and Fuels
Interior and Insu
Sess. (1973). The
tees reported bill
Houses, and Cong
vetoed by Preside

den and adversely affect commerce and the public welfare by destroying or diminishing the utility of land for commercial, industrial, residential, recreational, agricultural, and forestry purposes, by causing erosion and landslides, by contributing to floods, by polluting the water, by destroying fish and wildlife habitats, by impairing natural beauty, by damaging the property of citizens, by creating hazards dangerous to life and property by degrading the quality of life in local communities, and by counteracting governmental programs and efforts to conserve soil, water, and other natural resources."

The legislative record provides ample support for these statutory findings. The Surface Mining Act became law only after six years of the most thorough legislative consideration.[19] Committees of both Houses of Congress held extended hearings during which vast amounts of testimony and documentary evidence about the effects of surface mining on our Nation's environment and economy were brought to Congress' attention. Both Committees made detailed findings about these effects and the urgent need for federal legislation to address the problem. The Senate Report explained that

> The surface mining legislation was reintroduced in the 94th Congress in 1975, and the Senate Committee held a hearing on administration objections to the bill. Surface Mining Briefing: Briefing before the Senate Committee on Interior and Insular Affairs, 94th Cong., 1st Sess. (1975). Both Committees reported bills to the House and Senate, which again passed a bill reported by the Conference Committee. President Ford again vetoed the bill.
>
> The protracted congressional endeavor finally bore fruit in 1977. The relevant House and Senate Committees held extensive hearings shortly after the opening of the 95th Congress to consider bills introduced at the very beginning of the new legislative session. Surface Mining Control and Reclamation Act of 1977: Hearings on S.7 before the Subcommittee on Public Lands and Resources of the Senate Committee on Energy and Natural Resources, 95th Cong., 1st Sess. (1977) (1977 Senate Hearings); Surface Mining Control and Reclamation Act of 1977: Hearings on H.R.2 before Subcommittee on Energy and the Environment of the House Committee on Interior and Insular Affairs, 95th Cong., 1st Sess. (1977) (1977 House Hearings). The legislation was reported to both Houses and passage in both chambers followed, after lengthy floor debate. 123 Cong. Rec. 12861–12886, 15691–15755 (1977). The Conference Committee Report was issued in July 1977, H.R.Conf.Rep.No.95–493 (1977), and after further floor debate, both Houses agreed to the bill recommended by the conferees. 123 Cong.Rec. 23967–23988, 24419–24429 (1977). President Carter signed the Act into law on August 3, 1977. The legislative history of the Act is summarized in S.Rep.No.95–128, pp. 59–61 (1977), and in H.R.Rep.No.95–218, pp. 140–141 (1977), U.S.Code Cong. & Admin.News 1977, p. 593. See also Note, 81 W.Va.L.Rev. 775 (1979).

19. Hearings on proposed legislation regulating surface coal mining began in 1968. Surface Mining Reclamation: Hearings before the Senate Committee on Interior and Insular Affairs, 90th Cong., 2d Sess. (1968). Three years later, additional hearings were held by Committees of both the House and the Senate. Regulation of Strip Mining: Hearings before the Subcommittee on Mines and Mining of the House Committee on Interior and Insular Affairs, 92d Cong., 1st Sess. (1971); Surface Mining: Hearings before the Subcommittee on Minerals, Materials and Fuels of the Senate Committee on Interior and Insular Affairs, 92d Cong., 1st Sess. (1972). The Committees reported bills for consideration by their respective Houses. The House passed H.R.6482, but Congress adjourned before the Senate could act on the measure.

Similar bills were reintroduced in the 93d Congress and further hearings were held. Regulation of Surface Mining Operations: Hearings before the Senate Committee on Interior and Insular Affairs, 93d Cong., 1st Sess. (1973); Regulation of Surface Mining: Hearings before the Subcommittee on the Environment and the Subcommittee on Mines and Mining of the House Committee on Interior and Insular Affairs, 93d Cong., 1st Sess. (1973). At the request of the Chairman of the Senate Committee, the Council on Environmental Quality prepared a report entitled Coal Surface Mining and Reclamation: An Environmental and Economic Assessment of Alternatives (Comm. Print 1973), and the Senate Committee held additional hearings to consider the report. Coal Surface Mining and Reclamation: Hearings before the Subcommittee on Minerals, Materials and Fuels of the Senate Committee on Interior and Insular Affairs, 93d Cong., 1st Sess. (1973). The House and Senate Committees reported bills for consideration by both Houses, and Congress passed a bill that was vetoed by President Ford in 1974.

"[s]urface coal mining activities have imposed large social costs on the public . . . in many areas of the country in the form of unreclaimed lands, water pollution, erosion, floods, slope failures, loss of fish and wildlife resources, and a decline in natural beauty." S.Rep.No.95–128, p. 50 (1977).

See *id.*, at 50–54.

Similarly, the House Committee documented the adverse effects of surface coal mining on interstate commerce as including:

"'Acid drainage which has ruined an estimated 11,000 miles of streams; the loss of prime hardwood forest and the destruction of wildlife habitat by strip mining; the degrading of productive farmland; recurrent landslides; siltation and sedimentation of river systems. . . .'" H.R.Rep.No.95–218, p. 58 (1977), U.S.Code Cong. & Admin.News 1977, p. 596, quoting H.R.Rep.No.94–1445, p. 19 (1976).

And in discussing how surface coal mining affects water resources and in turn interstate commerce, the House Committee explained:

"The most widespread damages . . . are environmental in nature. Water users and developers incur significant economic and financial losses as well.

"Reduced recreational values, fishkills, reductions in normal waste assimilation capacity, impaired water supplies, metals and masonry corrosion and deterioration, increased flood frequencies and flood damages, reductions in designed water storage capacities at impoundments, and higher operating costs for commercial waterway users are some of the most obvious economic effects that stem from mining-related pollution and sedimentation." H.R.Rep.No.95–218, at 59, U.S. Code Cong. & Admin.News 1977, p. 597.

See *id.*, at 96–122.

The Committees also explained that inadequacies in existing state laws and the need for uniform minimum nationwide standards made federal regulations imperative. See S.Rep.No.95–128, at 49; H.R.Rep. No.95–218, at 58. In light of the evidence available to Congress and the detailed consideration that the legislation received, we cannot say that Congress did not have a rational basis for concluding that surface coal mining has substantial effects on interstate commerce.

Appellees do not, in general, dispute the validity of the congressional findings.[20] Rather, appellees' contention is that the "rational basis" test should not apply in this case because the Act regulates land use, a local activity not affecting interstate commerce. But even assuming that appellees correctly characterize the land use regulated by the Act as a "local" activity, their argument is unpersuasive.

[3] The denomination of an activity as a "local" or "intrastate" activity does not resolve the question whether Congress may regulate it under the Commerce Clause. As previously noted, the commerce power "extends to those activities intrastate which so affect interstate commerce, or the exertion of the power of Congress over it, as to make regulation of them appropriate means to the attainment of a legitimate end, the effective execution of the granted power to regulate interstate commerce." *United States v. Wrightwood Dairy Co.*, 315 U.S., at 119, 62 S.Ct., at 526. See *Fry v. United States*, 421 U.S., at 547, 95 S.Ct., at 1795; *NLRB v. Jones & Laughlin Steel Corp.*, 301 U.S., at 37, 57 S.Ct., at 624. This Court has long held that Congress may regulate the conditions under which goods shipped in

20. Appellees do contend that surface mining enhances rather than diminishes the utility of land in the steep-slope areas of Virginia. Congress, however, made contrary findings, and it is sufficient for purposes of judicial review that Congress had a rational basis for concluding as it did. See *Kleppe v. New Mexico*, 426 U.S. 529, 541, n. 10, 96 S.Ct. 2285, 2292, n. 10, 49 L.Ed.2d 34 (1976); *United States v. Carolene Products Co.*, 304 U.S. 144, 152–154, 58 S.Ct. 778, 783–784, 82 L.Ed. 1234 (1938).

interstate comme
the "local" acti
goods itself affe
See, e. g., *United*
100, 61 S.Ct. 451, 8
ard v. Filburn, 31
L.Ed. 122 (1942);
lin Steel Corp., s
Walling, 316 U.S
L.Ed. 1638 (194
McClung, 379 U.
L.Ed.2d 290 (1964
pute that coal is a
interstate comme
tionally determine
face coal mining
interstate comme
that may result f
congressional findi
the Act as a val
power under the C

Moreover, the A
sional finding th
mining and reclar
sential in order to
in interstate com
coal produced in di
used to undermine
States to improve
standards on coal
their borders." 30
ed., Supp. III). Th
of destructive int
traditional role for
der the Commer
States v. Darby, s
similar rationale t
of federal minimu
hour regulations
goods shipped in in
Court explained t
mented Congress'

21. See, e. g., *Unite*
1204, 1209–1210 (C
Corp. v. Train, 544
Sierra Club v. EPA,
540 F.2d 1114, 113
U.S. 959, 97 S.Ct. 1
District of Columbia
311, 328, 521 F.2d 9
remanded on other
Brown, 431 U.S. 99

interstate commerce are produced where the "local" activity of producing these goods itself affects interstate commerce. See, *e. g., United States v. Darby*, 312 U.S. 100, 61 S.Ct. 451, 85 L.Ed. 609 (1941); *Wickard v. Filburn*, 317 U.S. 111, 63 S.Ct. 82, 87 L.Ed. 122 (1942); *NLRB v. Jones & Laughlin Steel Corp., supra; Kirschbaum Co. v. Walling*, 316 U.S. 517, 62 S.Ct. 1116, 86 L.Ed. 1638 (1942). Cf. *Katzenbach v. McClung*, 379 U.S. 294, 85 S.Ct. 377, 13 L.Ed.2d 290 (1964). Appellees do not dispute that coal is a commodity that moves in interstate commerce. Here, Congress rationally determined that regulation of surface coal mining is necessary to protect interstate commerce from adverse effects that may result from that activity. This congressional finding is sufficient to sustain the Act as a valid exercise of Congress' power under the Commerce Clause.

Moreover, the Act responds to a congressional finding that nationwide "surface mining and reclamation standards are essential in order to insure that competition in interstate commerce among sellers of coal produced in different States will not be used to undermine the ability of the several States to improve and maintain adequate standards on coal mining operations within their borders." 30 U.S.C. § 1201(g) (1976 ed., Supp. III). The prevention of this sort of destructive interstate competition is a traditional role for congressional action under the Commerce Clause. In *United States v. Darby, supra*, the Court used a similar rationale to sustain the imposition of federal minimum wage and maximum hour regulations on a manufacturer of goods shipped in interstate commerce. The Court explained that the statute implemented Congress' view that "interstate commerce should not be made the instrument of competition in the distribution of goods produced under substandard labor conditions, which competition is injurious to the commerce and to the states from and to which the commerce flows." *Id.* 312 U.S., at 115, 61 S.Ct., at 457. The same rationale applies here to support the conclusion that the Surface Mining Act is within the authority granted to Congress by the Commerce Clause.

[4] Finally, we agree with the lower federal courts that have uniformly found the power conferred by the Commerce Clause broad enough to permit congressional regulation of activities causing air or water pollution, or other environmental hazards that may have effects in more than one State.[21] Appellees do not dispute that the environmental and other problems that the Act attempts to control can properly be addressed through Commerce Clause legislation. In these circumstances, it is difficult to find any remaining foundation for appellees' argument that, because it regulates a particular land use, the Surface Mining Act is beyond congressional Commerce Clause authority. Accordingly, we turn to the question whether the means selected by Congress were reasonable and appropriate.

Appellees' essential challenge to the means selected by the Act is that they are redundant or unnecessary. Appellees contend that a variety of federal statutes such as the Clean Air Act, 42 U.S.C. § 7401 *et seq.* (1976 ed. Supp. III), the Flood Control Acts, 33 U.S.C. § 701 *et seq.* (1976 ed., and Supp. III), and the Clean Water Act, 33 U.S.C. § 1251 *et seq.* (1976 ed., and Supp. III), adequately address the federal interest in controlling the environmental effects of

21. See, *e. g., United States v. Byrd*, 609 F.2d 1204, 1209–1210 (CA7 1979); *Bethlehem Steel Corp. v. Train*, 544 F.2d 657, 663 (CA3 1976); *Sierra Club v. EPA*, 176 U.S.App.D.C. 335, 360, 540 F.2d 1114, 1139 (1976), cert. denied, 430 U.S. 959, 97 S.Ct. 1610, 51 L.Ed.2d 811 (1977); *District of Columbia v. Train*, 172 U.S.App.D.C. 311, 328, 521 F.2d 971, 988 (1975), vacated and remanded on other grounds *sub nom. EPA v. Brown*, 431 U.S. 99, 97 S.Ct. 1635, 52 L.Ed.2d 166 (1977); *United States v. Ashland Oil & Transportation Co.*, 504 F.2d 1317, 1325 (CA6 1974); *Pennsylvania v. EPA*, 500 F.2d 246, 259 (CA3 1974); *South Terminal Corp. v. EPA*, 504 F.2d 646, 677 (CA1 1974); *United States v. Bishop Processing Co.*, 287 F.Supp. 624 (Md. 1968), aff'd, 423 F.2d 469 (CA4), cert. denied, 398 U.S. 904, 90 S.Ct. 1695, 26 L.Ed.2d 63 (1970).

surface coal mining without need to resort to the land-use regulation scheme of the Surface Mining Act. The short answer to this argument is that the effectiveness of existing laws in dealing with a problem identified by Congress is ordinarily a matter committed to legislative judgment. Congress considered the effectiveness of existing legislation and concluded that additional measures were necessary to deal with the interstate commerce effects of surface coal mining. See H.R.Rep.No.95-218, at 58-60; S.Rep.No.95-128, at 59-63.. And we agree with the court below that the Act's regulatory scheme is reasonably related to the goals Congress sought to accomplish. The Act's restrictions on the practices of mine operators all serve to control the environmental and other adverse effects of surface coal mining.

In sum, we conclude that the District Court properly rejected appellees' Commerce Clause challenge to the Act. We therefore turn to the court's ruling that the Act contravenes affirmative constitutional limitations on congressional exercise of the commerce power.

III

[5] The District Court invalidated §§ 515(d) and (e) of the Act, which prescribe performance standards for surface coal mining on "steep slopes,"[22] on the ground that they violate a constitutional limitation on the commerce power imposed by the Tenth Amendment. These provisions require "steep-slope" operators: (i) to reclaim the mined area by completely covering the highwall and returning the site to its "approximate original contour";[23] (ii) to refrain from dumping spoil material on the downslope below the bench or mining cut; and (iii) to refrain from disturbing land above the highwall unless permitted to do so by the regulatory authority. § 515(d), 30 U.S.C. § 1265(d) (1976 ed., Supp. III). Under § 515(e), a "steep-slope" operator may obtain a variance from the approximate-original-contour requirement by showing that it will allow a postreclamation use that is "deemed to constitute an equal or better economic or public use" than would otherwise be possible. 30 U.S.C. § 1265(e)(3)(A) (1976 ed., Supp. III).[24]

The District Court's ruling relied heavily on our decision in *National League of Cities v. Usery*, 426 U.S. 833, 96 S.Ct. 2465, 49 L.Ed.2d 245 (1976). The District Court viewed the central issue as whether the Act governs the activities of private individuals, or whether it instead regulates the governmental decisions of the States. And although the court acknowledged that the Act "ultimately affects the coal mine operator," 483 F.Supp., at 432, it concluded that the Act contravenes the Tenth Amendment because it interferes with the States' "traditional governmental function" of regulating land use. The court held that, as applied to Virginia, the Act's steep-slope provisions impermissibly constrict the State's ability to make "essential decisions."[25] The court found the Act accomplishes this result "through forced relinquishment of state control of land use planning; through loss of state control of its economy; and through economic harm, from expenditure

22. Section 515(d)(4), 30 U.S.C. § 1265(d)(4) (1976 ed., Supp. III), defines a "steep slope" as "any slope above twenty degrees or such lesser slope as may be defined by the regulatory authority after consideration of soil, climate, and other characteristics of a region or State."

23. The term "approximate original contour" is defined as "that surface configuration achieved by backfilling and grading of the mined area so that the reclaimed area, including any terracing or access roads, closely resembles the general surface configuration of the land prior to mining and blends into and complements the drainage pattern of the surrounding terrain, with all highwalls and spoil piles eliminated." § 701(2), 30 U.S.C. § 1291(2) (1976 ed., Supp. III).

24. Section 515(c), 30 U.S.C. § 1265(c) (1976 ed., Supp. III), establishes a separate variance procedure for mountaintop mining operations.

25. The court reasoned that although the Act allows a State to elect to have its own regulatory program, the "choice that is purportedly given is no choice at all" because the state program must comply with federally prescribed standards. 483 F.Supp., at 432.

of state funds to
from destruction
certain counties, c
435.[26] The court t
joined enforcemen

The District Cou
League of Cities r
of the actual basis
sion in that case.
constitutional chall
ments to the Fai
which had extende
and maximum ho
state and local gov
cause it was conce
regulations were '
scope of the Comm
841, 96 S.Ct., at
presented was whet
cise of the commer
a ... constitution
regulations] applie
and subdivisions o
Ibid. We began b
tinction between
of private persons a
ily subject to the
government of the
in which they reside
2471, and federal r
to private citizens,
States," *ibid.* As t
no Tenth Amendm
gressional action.
our consistent rule:

26. On the basis of
trial, the court foun
tion of steep slopes i
nal contour" is "e
physically impossibl
noted that the stee
larly affect Virginia
reserves are located
court indicated that
tors had been forced
were unable to com
ments, with adverse
omies of various to
dependent on coal
found that there is a
counties of the Virgi
cluded that the Ac
would prevent "forw
ning" by the State.

of state funds to implement the act and from destruction of the taxing power of certain counties, cities, and towns." *Id.*, at 435.[26] The court therefore permanently enjoined enforcement of §§ 515(d) and (e).[27]

The District Court's reliance on *National League of Cities* requires a careful review of the actual basis and import of our decision in that case. There, we considered a constitutional challenge to the 1974 amendments to the Fair Labor Standards Act which had extended federal minimum wage and maximum hour regulations to most state and local government employees. Because it was conceded that the challenged regulations were "undoubtedly within the scope of the Commerce Clause," 426 U.S., at 841, 96 S.Ct., at 2469, the only question presented was whether that particular exercise of the commerce power "encounter[ed] a ... constitutional barrier because [the regulations] applied directly to the States and subdivisions of States as employers." *Ibid.* We began by drawing a sharp distinction between congressional regulation of private persons and businesses "necessarily subject to the dual sovereignty of the government of the Nation and of the State in which they reside," *id.*, at 845, 96 S.Ct., at 2471, and federal regulation "directed, not to private citizens, but to the States as States," *ibid.* As to the former, we found no Tenth Amendment impediment to congressional action. Instead, we reaffirmed our consistent rule:

"Congressional power over areas of private endeavor, even when its exercise may pre-empt express state-law determinations contrary to the result that has commended itself to the collective wisdom of Congress, has been held to be limited only by the requirement that 'the means chosen by [Congress] must be reasonably adapted to the end permitted by the Constitution.' *Heart of Atlanta Motel, Inc. v. United States*, 379 U.S. 241, 262, 85 S.Ct. 348, 360, 13 L.Ed.2d 258 (1964)." *Id.*, at 840, 96 S.Ct., at 2469.

The Court noted, however, that "the States as States stand on a quite different footing from an individual or corporation when challenging the exercise of Congress' power to regulate commerce." *Id.*, at 854, 96 S.Ct., at 2475. It indicated that when Congress attempts to directly regulate the States as States the Tenth Amendment requires recognition that "there are attributes of sovereignty attaching to every state government which may not be impaired by Congress, not because Congress may lack an affirmative grant of legislative authority to reach the matter, but because the Constitution prohibits it from exercising the authority in that manner." *Id.*, at 845, 96 S.Ct., at 2471. The Court held that the power to set the wages and work hours of state employees was "an undoubted attribute of state sovereignty." *Ibid.* And because it further found that the challenged regulations would "displace the States' freedom to

26. On the basis of the evidence presented at trial, the court found that postmining restoration of steep slopes to their "approximate original contour" is "economically infeasible and physically impossible." *Id.*, at 434. The court noted that the steep-slope provisions particularly affect Virginia because 95% of its coal reserves are located on such lands. And the court indicated that several coal mine operators had been forced to shut down because they were unable to comply with the Act's requirements, with adverse consequences for the economies of various towns and counties that are dependent on coal mining. The court also found that there is a need for level land in the counties of the Virginia coal fields, and it concluded that the Act's reclamation provisions would prevent "forward-looking land use planning" by the State. *Ibid.* Finally, the court found that restoration of mined land to its original contour would diminish the value of the land from the $5,000–$300,000-an-acre value of level land to the $5–$75-per-acre value of steep-slope land.

27. In its order and opinion accompanying its denial of the Secretary's request for a stay of its judgment pending appeal, see n. 13, *supra*, the District Court explained that the injunction against enforcement of the steep-slope standards was not intended to "allo[w] spoil to be placed on the downslope in an uncontrolled manner." The court stated that "[a]ny such downslope spoil placement shall be in a controlled manner meeting environmental protection standards specified by the regulatory authority." J.S.App. 2a.

structure integral operations in areas of traditional governmental functions," *id.*, at 852, 96 S.Ct., at 2474, the Court concluded that Congress could not, consistently with the Tenth Amendment, "abrogate the States' otherwise plenary authority to make [these decisions]." *Id.*, at 846, 96 S.Ct., at 2471.[28]

[6] It should be apparent from this discussion that in order to succeed, a claim that congressional commerce power legislation is invalid under the reasoning of *National League of Cities* must satisfy *each* of three requirements. First, there must be a showing that the challenged statute regulates the "States as States." *Id.*, at 854, 96 S.Ct., at 2475. Second, the federal regulation must address matters that are indisputably "attribute[s] of state sovereignty." *Id.*, at 845, 96 S.Ct., at 2471. And, third, it must be apparent that the States' compliance with the federal law would directly impair their ability "to structure integral operations in areas of traditional governmental functions." *Id.*, at 852, 96 S.Ct., at 2472.[29] When the Surface Mining Act is examined in light of these principles, it is clear that appellees' Tenth Amendment challenge must fail because the first of the three requirements is not satisfied. The District Court's holding to the contrary rests on an unwarranted extension of the decision in *National League of Cities*.

As the District Court itself acknowledged, the steep-slope provisions of the Surface Mining Act govern only the activities of coal mine operators who are private individuals and businesses. Moreover, the States are not compelled to enforce the steep-slope standards, to expend any state funds, or to participate in the federal regulatory program in any manner whatsoever. If a State does not wish to submit a proposed permanent program that complies with the Act and implementing regulations, the full regulatory burden will be borne by the Federal Government. Thus, there can be no suggestion that the Act commandeers the legislative processes of the States by directly compelling them to enact and enforce a federal regulatory program. Cf. *Maryland v. EPA*, 530 F.2d 215, 224–228 (CA4 1975), vacated and remanded *sub nom. EPA v. Brown*, 431 U.S. 99, 97 S.Ct. 1635, 52 L.Ed.2d 166 (1977); *District of Columbia v. Train*, 172 U.S.App.D.C. 311, 330–334, 521 F.2d 971, 990–994 (1975), vacated and remanded *sub nom. EPA v. Brown*, 431 U.S. 99, 97 S.Ct. 1635, 52 L.Ed.2d 166 (1977); *Brown v. EPA*, 521 F.2d 827, 837–842 (CA9 1975), vacated and remanded, 431 U.S. 99, 97 S.Ct. 1635, 52 L.Ed.2d 166 (1977). The most that can be said is that the Surface Mining Act establishes a program of cooperative federalism that allows the States, within limits established by federal minimum standards, to enact and administer

28. *National League of Cities* expressly left open the question "whether different results might obtain if Congress seeks to affect integral operations of state governments by exercising authority granted it under other sections of the Constitution such as the spending power, Art. I, § 8, cl. 1, or § 5 of the Fourteenth Amendment." 426 U.S., at 852, n. 17, 96 S.Ct., at 2474, n. 17. In *Fitzpatrick v. Bitzer*, 427 U.S. 445, 96 S.Ct. 2666, 49 L.Ed.2d 614 (1976), the Court upheld Congress' power under § 5 of the Fourteenth Amendment to authorize private damages actions against state governments for discrimination in employment. The Court explained that because the Amendment was adopted with the specific purpose of limiting state autonomy, constitutional principles of federalism do not restrict congressional power to invade state autonomy when Congress legislates under § 5 of the Fourteenth Amendment. *Id.*, at 452–456, 96 S.Ct., at 2669–2671. Similarly, in *City of Rome v. United States*, 446 U.S. 156, 179, 100 S.Ct. 1548, 1562, 64 L.Ed.2d 119 (1980), we held that the Tenth Amendment places no restrictions on congressional power "to enforce the Civil War Amendments 'by appropriate legislation.'"

29. Demonstrating that these three requirements are met does not, however, guarantee that a Tenth Amendment challenge to congressional commerce power action will succeed. There are situations in which the nature of the federal interest advanced may be such that it justifies state submission. See *Fry v. United States*, 421 U.S. 542, 95 S.Ct. 1792, 44 L.Ed.2d 363 (1975), reaffirmed in *National League of Cities v. Usery*, 426 U.S., at 852–853, 96 S.Ct., at 2474–2475. See also *id.*, at 856, 96 S.Ct., at 2476 (BLACKMUN, J., concurring).

their own regula
to meet their ow
re Permanent S
Litigation, 199 U
F.2d 807, 808 (19
Act resembles a
statutes that hav
ment challenges
courts.[30]

Appellees argue
of federal usurpa
roles coerces the
Surface Mining A
tend that the Ac
States as States b
datory minimum i
sence, appellees ur
Court in looking b
ally regulated by t
effects on the Stat
sions in areas of
functions." And
did the court below
with the States'
police powers by re

[7] Appellees' c
terize the Act inso
al minimum stand
coal mining, which
plement itself or
administered regul
ject to this scheme,
assume that the T
congressional pow
place state regulat
affecting interstat
sumption is incorre

A wealth of prec
sional authority t
state laws regulat
fecting interstate
laws conflict with
Jones v. Rath Pa
525–526, 97 S.Ct.
L.Ed.2d 604 (1977)

30. See, *e. g.*, *Unite*
784 (CA9 1979) (up
ing Act, 16 U.S.C.
Earth, Inc. v. Care
(upholding the Clea
et seq. (1976 ed., S

their own regulatory programs, structured to meet their own particular needs. See *In re Permanent Surface Mining Regulation Litigation*, 199 U.S.App.D.C. 225, 226, 617 F.2d 807, 808 (1980). In this respect, the Act resembles a number of other federal statutes that have survived Tenth Amendment challenges in the lower federal courts.[30]

Appellees argue, however, that the threat of federal usurpation of their regulatory roles coerces the States into enforcing the Surface Mining Act. Appellees also contend that the Act directly regulates the States as States because it establishes mandatory minimum federal standards. In essence, appellees urge us to join the District Court in looking beyond the activities actually regulated by the Act to its conceivable effects on the States' freedom to make decisions in areas of "integral governmental functions." And appellees emphasize, as did the court below, that the Act interferes with the States' ability to exercise their police powers by regulating land use.

[7] Appellees' claims accurately characterize the Act insofar as it prescribes federal minimum standards governing surface coal mining, which a State may either implement itself or else yield to a federally administered regulatory program. To object to this scheme, however, appellees must assume that the Tenth Amendment limits congressional power to pre-empt or displace state regulation of private activities affecting interstate commerce. This assumption is incorrect.

A wealth of precedent attests to congressional authority to displace or pre-empt state laws regulating private activity affecting interstate commerce when these laws conflict with federal law. See, *e. g., Jones v. Rath Packing Co.*, 430 U.S. 519, 525–526, 97 S.Ct. 1305, 1309, 1310, 51 L.Ed.2d 604 (1977); *Perez v. Campbell*, 402 U.S. 637, 649–650, 91 S.Ct. 1704, 1711, 29 L.Ed.2d 233 (1971); *Florida Lime & Avocado Growers, Inc. v. Paul*, 373 U.S. 132, 141–143, 83 S.Ct. 1210, 1216–1217, 10 L.Ed.2d 248 (1963); *Bethlehem Steel Co. v. New York State Labor Relations Bd.*, 330 U.S. 767, 772–776, 67 S.Ct. 1026, 1029–1031, 91 L.Ed. 1234 (1947); *Hines v. Davidowitz*, 312 U.S. 52, 67–68, 61 S.Ct. 399, 404, 85 L.Ed. 581 (1941). Moreover, it is clear that the Commerce Clause empowers Congress to prohibit all—and not just inconsistent—state regulation of such activities. See, *e. g., City of Burbank v. Lockheed Air Terminal, Inc.*, 411 U.S. 624, 93 S.Ct. 1854, 36 L.Ed.2d 547 (1973); *Campbell v. Hussey*, 368 U.S. 297, 82 S.Ct. 327, 7 L.Ed.2d 299 (1961); *Rice v. Santa Fe Elevator Corp.*, 331 U.S. 218, 67 S.Ct. 1146, 91 L.Ed. 1447 (1947); *Transit Comm'n v. United States*, 289 U.S. 121, 53 S.Ct. 536, 77 L.Ed. 1075 (1933). Although such congressional enactments obviously curtail or prohibit the States' prerogatives to make legislative choices respecting subjects the States may consider important, the Supremacy Clause permits no other result. See *Chicago & North Western Transp. Co. v. Kalo Brick & Tile Co.*, 450 U.S. 311, 317–319, 101 S.Ct. 1124, 1130–1131, 67 L.Ed.2d 258 (1981); *Sanitary District v. United States*, 266 U.S. 405, 425–426, 45 S.Ct. 176, 178, 69 L.Ed. 352 (1925); *The Minnesota Rate Cases*, 230 U.S. 352, 399, 33 S.Ct. 729, 739, 57 L.Ed. 1511 (1913); *Gibbons v. Ogden*, 9 Wheat., at 211. As the Court long ago stated: "It is elementary and well settled that there can be no divided authority over interstate commerce, and that the acts of Congress on that subject are supreme and exclusive." *Missouri Pacific R. Co. v. Stroud*, 267 U.S. 404, 408, 45 S.Ct. 243, 245, 69 L.Ed. 683 (1925).

Thus, Congress could constitutionally have enacted a statute prohibiting any state

30. See, *e. g., United States v. Helsley*, 615 F.2d 784 (CA9 1979) (upholding the Airborne Hunting Act, 16 U.S.C. § 742j-1); *Friends of the Earth, Inc. v. Carey*, 552 F.2d 25, 36–39 (CA2) (upholding the Clean Air Act, 42 U.S.C. § 7401 *et seq.* (1976 ed., Supp. III)), cert. denied, 434 U.S. 902, 98 S.Ct. 296, 54 L.Ed.2d 188 (1977); *Sierra Club v. EPA*, 176 U.S.App.D.C. 335, 359, 540 F.2d 1114, 1140 (1976) (upholding the Clean Water Act, 33 U.S.C. § 1251 *et seq.*), cert. denied, 430 U.S. 959, 97 S.Ct. 1610, 51 L.Ed.2d 811 (1977).

regulation of surface coal mining. We fail to see why the Surface Mining Act should become constitutionally suspect simply because Congress chose to allow the States a regulatory role. Contrary to the assumption by both the District Court and appellees, nothing in *National League of Cities* suggests that the Tenth Amendment shields the States from pre-emptive federal regulation of *private* activities affecting interstate commerce. To the contrary, *National League of Cities* explicitly reaffirmed the teaching of earlier cases that Congress may, in regulating private activities pursuant to the commerce power, "pre-empt express state-law determinations contrary to the result which has commended itself to the collective wisdom of Congress. . . ." 426 U.S., at 840, 96 S.Ct., at 2469. The only limitation on congressional authority in this regard is the requirement that the means selected be reasonably related to the goal of regulating interstate commerce. *Ibid.* We have already indicated that the Act satisfies this test.[31]

[8] This conclusion applies regardless of whether the federal legislation displaces laws enacted under the States' "police powers." The Court long ago rejected the suggestion that Congress invades areas reserved to the States by the Tenth Amendment simply because it exercises its authority under the Commerce Clause in a manner that displaces the States' exercise of their police powers. See *Hoke v. United States*, 227 U.S. 308, 320–323, 33 S.Ct. 281, 283–284, 57 L.Ed. 523 (1913); *Athanasaw v. United States*, 227 U.S. 326, 33 S.Ct. 285, 57 L.Ed. 528 (1913); *Cleveland v. United States*, 329 U.S., at 19, 67 S.Ct., at 15; *United States v. Darby*, 312 U.S., at 113–114, 61 S.Ct., at 456–457; *United States v. Wrightwood Dairy Co.*, 315 U.S., at 119, 62 S.Ct., at 526. Cf. *United States v. Carolene Products Co.*, 304 U.S. 144, 147, 58 S.Ct. 778, 781, 82 L.Ed. 1234 (1938) ("it is no objection to the exertion of the power to regulate interstate commerce that its exercise is attended by the same incidents which attend the exercise of the police power of the states");[32] accord, *FPC v. Natural Gas Pipeline Co.*, 315 U.S. 575, 582, 62 S.Ct. 736, 741, 86 L.Ed. 1037 (1942); *Hamilton v. Kentucky Distilleries & Warehouse Co.*, 251 U.S. 146, 156, 40 S.Ct. 106, 108, 64 L.Ed. 194 (1919); *Seven Cases v. United States*, 239 U.S. 510, 514, 36 S.Ct. 190, 191, 60 L.Ed. 411 (1916). This Court has upheld as constitutional any number of federal statutes enacted under the commerce power that pre-empt particular exercises of state police power. See, e. *g., United States v. Walsh*, 331 U.S. 432, 67 S.Ct. 1283, 91 L.Ed. 1585 (1947) (upholding Federal Food, Drug, and Cosmetic Act, 21 U.S.C. §§ 301–392); *NLRB v. Jones & Laughlin Steel Corp.*, 301 U.S. 1, 57 S.Ct. 615, 81 L.Ed. 893 (1937) (upholding National Labor Relations Act, 29 U.S.C. §§ 151–168); *United States v. Darby, supra* (upholding Fair Labor Standards Act, 29 U.S.C. §§ 201–219). It would therefore be a radical departure from long-established precedent for this Court to hold that the Tenth Amendment prohibits Congress from displacing state police power laws regulating private activity. Nothing in *National League of Cities* compels or even hints at such a departure.[33]

31. See *supra*, at 2363. It is significant that the Commonwealth of Virginia presses its Tenth Amendment challenge to the Act simply as another regulator of surface coal mining whose regulatory program has been displaced or pre-empted by federal law. As indicated in text, there are no Tenth Amendment concerns in such situations.

32. This holding disposes of the contention by appellees and various *amici* that the Surface Mining Act is unconstitutional because it presumes the existence of a federal police power. As the Court has stated: " 'The authority of the federal government over interstate commerce does not differ in extent or character from that retained by the states over intrastate commerce.' " *United States v. Darby*, 312 U.S., at 116, 61 S.Ct., at 458, quoting *United States v. Rock Royal Co-operative*, 307 U.S. 533, 569–570, 59 S.Ct. 993, 1010–1011, 83 L.Ed. 1446 (1939).

33. The remaining justification asserted by the District Court for its Tenth Amendment ruling, one that appellees urge here, is that the steep-slope mining requirements will harm Virginia's economy and destroy the taxing power of some

In sum, appel
challenge to the
fail because here,
tion in *National I*
ute at issue regul
nesses necessarily
eignty of the gove
the State in whic
League of Cities v
96 S.Ct., at 2471.[34]
the District Cour
contravenes other
congressional actio

[9] The District
the Act's provision
pensation Clause o
First, the court fo

towns and counties
this regard, the cou
by the discussion i
about the likely eff
lations on the fin
governments. *Nati*
Usery, 426 U.S., at
2472. But as the C
minative factor in t
the federal action,
impact on the State
2472. Moreover, eve
requirements will ha
Virginia's economy,
alone, is insufficient
the Tenth Amendme
son Co., 313 U.S. 50
1063–1064, 85 L.Ed.
rejected the assertio
on state and local e
Congress' exercise of
merce Clause to reg
fecting interstate con
suaded that there
presented in the insta
Court's position.

34. We have assume
correctly held that
"integral governmen
was used in *Nationa*
resolution of the Ten
to the Act makes it u
cide whether this is a

35. The District Court
ence of a statutory
variances from the ste
the court suggested th
ment that highwalls o

sum, appellees' Tenth Amendment challenge to the Surface Mining Act must fail because here, in contrast to the situation in *National League of Cities*, the statute at issue regulates only "individual businesses necessarily subject to the dual sovereignty of the government of the Nation and the State in which they reside." *National League of Cities v. Usery*, 426 U.S., at 845, 96 S.Ct., at 2471.[34] Accordingly, we turn to the District Court's ruling that the Act contravenes other constitutional limits on congressional action.

IV

[9] The District Court held that two of the Act's provisions violate the Just Compensation Clause of the Fifth Amendment. First, the court found that the steep-slope provisions discussed above effect an uncompensated taking of private property by requiring operators to perform the "economically and physically impossible" task of restoring steep-slope surface mines to their approximate original contour. 483 F.Supp., at 437.[35] The court further held that, even if steep-slope surface mines could be restored to their approximate original contour, the value of the mined land after such restoration would have "been diminished to practically nothing." *Ibid.* Second, the court found that § 522 of the Act effects an unconstitutional taking because it expressly prohibits mining in certain locations and "clearly prevent[s] a person from mining his own land or having it mined." *Id.*, at 441.[36] Relying on this Court's decision in *Pennsylvania Coal Co. v. Mahon*, 260 U.S. 393, 43 S.Ct. 158, 67 L.Ed. 322 (1922), the District

1294

towns and counties in the Commonwealth. In this regard, the court may have been influenced by the discussion in *National League of Cities* about the likely effects of the challenged regulations on the finances of state and local governments. *National League of Cities v. Usery*, 426 U.S., at 846–847, 96 S.Ct., at 2471–2472. But as the Court made clear, the determinative factor in that case was the nature of the federal action, not the ultimate economic impact on the States. *Id.*, at 847, 96 S.Ct., at 2472. Moreover, even if it is true that the Act's requirements will have a measurable impact on Virginia's economy, this kind of effect, standing alone, is insufficient to establish a violation of the Tenth Amendment. In *Oklahoma v. Atkinson Co.*, 313 U.S. 508, 534–535, 61 S.Ct. 1050, 1063–1064, 85 L.Ed. 1487 (1941), the Court rejected the assertion that an adverse impact on state and local economies is a barrier to Congress' exercise of its power under the Commerce Clause to regulate private activities affecting interstate commerce. We are not persuaded that there are compelling reasons presented in the instant cases for reversing the Court's position.

34. We have assumed that the District Court correctly held that land-use regulation is an "integral governmental function" as that term was used in *National League of Cities*. Our resolution of the Tenth Amendment challenge to the Act makes it unnecessary for us to decide whether this is actually the case.

35. The District Court acknowledged the existence of a statutory procedure for requesting variances from the steep-slope provisions. But the court suggested that the statutory requirement that highwalls of reclaimed mining cuts be completely covered makes this variance procedure "meaningless" to steep-slope mine operators. 483 F.Supp., at 437. This conclusion was premature. See n. 39, *infra*.

36. With certain specified exceptions, and subject to "valid existing rights," § 522(e) prohibits surface mining operations in national parks and forests, or where they will adversely affect publicly owned parks or places that are included in the National Register of Historic Sites. 30 U.S.C. §§ 1272(e)(1), (2), and (3) (1976 ed., Supp. III). It also prohibits surface mining within 100 feet of a cemetery or the right-of-way of a public road, and within 300 feet of an occupied dwelling, public building, school, church, community or institutional building, or public park. §§ 522(e)(4) and (5).

Sections 522(a), (c), and (d), which become applicable during the permanent phase of the regulatory program, require the establishment of procedures for designating particular lands as unsuitable for some or all surface mining. 30 U.S.C. §§ 1272(a), (c), and (d) (1976 ed., Supp. III). The District Court's ruling that these latter provisions effect an unconstitutional taking of private property is puzzling and cannot stand. Since these provisions do not come into effect until the permanent phase of the Act's regulatory program, they have not been applied to appellees or any other private landowner in Virginia. In these circumstances, there was no justiciable case or controversy with regard to these sections of the Act. See *United Public Workers v. Mitchell*, 330 U.S. 75, 89–91, 67 S.Ct. 556, 564–565, 91 L.Ed. 754 (1947).

Court held that both of these provisions are unconstitutional because they "depriv[e] [coal mine operators] of any use of [their] land, not only the most profitable ...." 483 F.Supp., at 441.

We conclude that the District Court's ruling on the "taking" issue suffers from a fatal deficiency: neither appellees nor the court identified any property in which appellees have an interest that has allegedly been taken by operation of the Act. By proceeding in this fashion, the court below ignored this Court's oft-repeated admonition that the constitutionality of statutes ought not be decided except in an actual 295 factual setting that makes such a decision necessary. See *Socialist Labor Party v. Gilligan*, 406 U.S. 583, 588, 92 S.Ct. 1716, 1719, 32 L.Ed.2d 317 (1972); *Rescue Army v. Municipal Court*, 331 U.S. 549, 568–575, 584, 67 S.Ct. 1409, 1419–1423, 91 L.Ed. 1666 (1947); *Alabama State Federation of Labor v. McAdory*, 325 U.S. 450, 461, 65 S.Ct. 1384, 1389, 89 L.Ed. 1725 (1945). Adherence to this rule is particularly important in cases raising allegations of an unconstitutional taking of private property. Just last Term, we reaffirmed that

> "this Court has generally 'been unable to develop any "set formula" for determining when "justice and fairness" require that economic injuries caused by public action be compensated by the government, rather than remain disproportionately concentrated on a few persons.' Rather, it has examined the 'taking' question by engaging in essentially ad hoc, factual inquiries that have identified several factors—such as the economic impact of the regulation, its interference with reasonable investment backed expectations, and the character of the government action—that have particular significance." *Kaiser Aetna v. United States*, 444 U.S. 164, 175, 100 S.Ct. 383, 390, 62 L.Ed.2d 332 (1979) (citations omitted).

These "ad hoc, factual inquiries" must be conducted with respect to specific property, and the particular estimates of economic impact and ultimate valuation relevant in the unique circumstances.

[10] Because appellees' taking claim arose in the context of a facial challenge, it presented no concrete controversy concerning either application of the Act to particular surface mining operations or its effect on specific parcels of land. Thus, the only issue properly before the District Court and, in turn, this Court, is whether the "mere enactment" of the Surface Mining Act constitutes a taking. See *Agins v. Tiburon*, 447 U.S. 255, 260, 100 S.Ct. 2138, 2141, 65 L.Ed.2d 106 (1980). The test to be applied in considering this facial challenge is fairly straightforward. A statute regulating the 296 uses that can be made of property effects a taking if it "denies an owner economically viable use of his land ...." *Agins v. Tiburon, supra*, at 260, 100 S.Ct., at 2141. See *Penn Central Transp. Co. v. New York City*, 438 U.S. 104, 98 S.Ct. 2646, 57 L.Ed.2d 631 (1978). The Surface Mining Act easily survives scrutiny under this test.

First, the Act does not, on its face, prevent beneficial use of coal-bearing lands. Except for the proscription of mining near certain locations by § 522(e), the Act does not categorically prohibit surface coal mining; it merely regulates the conditions under which such operations may be conducted.[37] The Act does not purport to regulate

37. Although § 522(e) prohibits any surface coal mining in certain areas, appellees' "taking" challenge to this provision is premature. First, appellees made no showing in the District Court that they own tracts of land that are affected by this provision. Second, § 522(e) does not, on its face, deprive owners of land within its reach of economically viable use of their land since it does not proscribe nonmining uses of such land. Third, § 522(e)'s restrictions are expressly made subject to "valid existing rights." Appellees contend that this exception "applies only to specific surface mining operations for which all required permits were issued prior to August 3, 1977, the effective date of the Act." Brief for Virginia Surface Mining Reclamation Association, Inc., et al., 48. This interpretation of the exception is not compelled by either the statutory language or its legislative history. See H.R.Rep.No.95–218, p. 95 (1977). It is apparently based on 30 CFR § 761.5(a)(2)(i) (1980), a regulation promulgat-

alternative uses
may be put.[38]
297 which these ca
no reason to
ment" of the S
prived appellees
of their propert

Moreover, ap
ture legitimate
Court about the
lenged provisio
will be applied
about their effe
operations. Th
record that ap
selves of the op
Act to obtain a
questing either
imate-original-c
§ 515(d) or a wa
ing restrictions
were to seek a
these procedures
lution might wel
individual prope
need to addres
tions.[39] The pot

ed by the Secret
was remanded to
tion by the Unite
District of Colum
Mining Regulati
1091 (D.C.1980),
et al. (CADC),
Court of Appeals
District Court's j

38. If, as the Dist
the steep-slope
$5,000–$300,000
presumably retai
the land without
over, if flat benc
the court below
nancial impedime
flat areas on the
ations, once those
stabilized in the

39. The District
steep-slope variar
not offer a meani
trative relief was
identify any inst
obligation to cove
a mine operator
variance procedu

alternative uses to which coal-bearing lands may be put.[38] Thus, in the posture in which these cases comes before us, there is no reason to suppose that "mere enactment" of the Surface Mining Act has deprived appellees of economically viable use of their property.

Moreover, appellees cannot at this juncture legitimately raise complaints in this Court about the manner in which the challenged provisions of the Act have been or will be applied in specific circumstances, or about their effect on particular coal mining operations. There is no indication in the record that appellees have availed themselves of the opportunities provided by the Act to obtain administrative relief by requesting either a variance from the approximate-original-contour requirement of § 515(d) or a waiver from the surface mining restrictions in § 522(e). If appellees were to seek administrative relief under these procedures, a mutually acceptable solution might well be reached with regard to individual properties, thereby obviating any need to address the constitutional questions.[39] The potential for such administrative solutions confirms the conclusion that the taking issue decided by the District Court simply is not ripe for judicial resolution.[40]

IV

A

[11] The District Court next ruled that the Act contravenes the Fifth Amendment because a number of its enforcement provisions offend the Amendment's Due Process Clause. One such provision is § 521(a)(2), 30 U.S.C. § 1271(a)(2) (1976 ed., Supp. III), which instructs the Secretary immediately to order total or partial cessation of a surface mining operation whenever he determines, on the basis of a federal inspection, that the operation is in violation of the Act or a permit condition required by the Act and that the operation

> "creates an immediate danger to the health or safety of the public, or is causing, or can reasonably be expected to cause significant, imminent environmental harm to land, air, or water resources . . . ."[41]

ed by the Secretary. That regulation, however, was remanded to the Secretary for reconsideration by the United States District Court for the District of Columbia. *In re Permanent Surface Mining Regulation Litigation*, 14 ERC 1083, 1091 (D.C.1980), appeals pending, No. 80-1810 et al. (CADC). The Secretary did not ask the Court of Appeals to review this portion of the District Court's judgment.

38. If, as the District Court found, level land in the steep-slope areas of Virginia is worth $5,000-$300,000 per acre, some landowners presumably retain the option of simply leveling the land without first mining the coal. Moreover, if flat benchland is truly as valuable as the court below found, there should be no financial impediment to the re-establishment of flat areas on the sites of some old mining operations, once those areas have been restored and stabilized in the manner required by the Act.

39. The District Court's conclusion that the steep-slope variance procedure in § 515(e) does not offer a meaningful opportunity for administrative relief was premature. Appellees did not identify any instance in which the statutory obligation to cover the highwall had prevented a mine operator from taking advantage of the variance procedure.

40. Although we conclude that "mere enactment" of the Act did not effect a taking of private property, this holding does not preclude appellees or other coal mine operators from attempting to show that as applied to particular parcels of land, the Act and the Secretary's regulations effect a taking. Even then, such an alleged taking is not unconstitutional unless just compensation is unavailable. See *Duke Power Co. v. Carolina Environmental Study Group, Inc.*, 438 U.S. 59, 94, n. 39, 98 S.Ct. 2620, 2641, n. 39, 57 L.Ed.2d 595 (1978); *Regional Rail Reorganization Act Cases*, 419 U.S. 102, 125-136 (1974); *Larson v. Domestic & Foreign Commerce Corp.*, 337 U.S. 682, 697, n. 18, 69 S.Ct. 1457, 1465, n. 18, 93 L.Ed. 1628 (1949).

41. Where the Secretary determines that a violation of the Act or of a permit condition does not entail such a serious threat, he must issue a notice of violation fixing a reasonable time for abatement. § 521(a)(3), 30 U.S.C. § 1271(a)(3) (1976 ed., Supp. III). If the violation is not abated within the prescribed period, the Secretary must immediately order total or partial cessation of the offending mining operation.

A mine operator aggrieved by an immediate cessation order issued under § 521(a)(2) or by a cessation order issued after a notice of violation and expiration of an abatement period under § 521(a)(3) may immediately request temporary relief from the Secretary, and the Secretary must respond to the request within five days of its receipt. § 525(c), 30 U.S.C. § 1275 (1976 ed., Supp. III). Section 526(c) of the Act, 30 U.S.C. § 1276(c) (1976 ed., Supp. III), authorizes judicial review of a decision by the Secretary denying temporary relief. In addition, cessation orders are subject to informal administrative review under § 521(a)(5), and formal administrative review, including an adjudicatory hearing, under § 525(b), 30 U.S.C. § 1275(b) (1976 ed., Supp. III).[42] The Secretary's decision in the formal review proceeding is subject to judicial review pursuant to § 526(a)(2), 30 U.S.C. § 1276(a)(2) (1976 ed., Supp. III).

The District Court held that § 521(a)(2)'s authorization of immediate cessation orders violates the Fifth Amendment because the statute does not provide sufficiently objective criteria for summary administrative action. In this regard, the court relied on its finding that OSM inspectors had issued against a particular company three immediate cessation orders which were later overturned on appeal, and that the company involved had suffered significant losses. The court enjoined the Secretary from issuing any immediate cessation orders "until such time as Congress makes provisions to correct the use of subjective criteria by OSM inspectors." 483 F.Supp., at 448.[43] In addition, the court ruled that even if the Act is amended to correct this problem, the 5-day response period prescribed by the Act does not meet the requirements of due process. Instead, the court held that the Secretary must respond within 24 hours to a mine operator's request for temporary relief from an immediate cessation order. We find both aspects of the District Court's reasoning unpersuasive.

[12] Our cases have indicated that due process ordinarily requires an opportunity for "some kind of hearing" prior to the deprivation of a significant property interest. See *Parratt v. Taylor*, 451 U.S. 527, 540, 101 S.Ct. 1908, 1915, 68 L.Ed.2d 420 (1981); *Boddie v. Connecticut*, 401 U.S. 371, 379, 91 S.Ct. 780, 786, 28 L.Ed.2d 113 (1971). The Court has often acknowledged, however, that summary administrative action may be justified in emergency situations. See, *e. g., Calero-Toledo v. Pearson Yacht Leasing Co.*, 416 U.S. 663, 677–680, 94 S.Ct. 2080, 2088–2090, 40 L.Ed.2d 452 (1974); *Boddie v. Connecticut, supra*, 401 U.S., at 378–379, 91 S.Ct., at 786; *Ewing v. Mytinger & Casselberry, Inc.*, 339 U.S. 594, 599–600, 70 S.Ct. 870, 872–873, 94 L.Ed. 1088 (1950); *Fahey v. Mallonee*, 332 U.S. 245, 253–254, 67 S.Ct. 1552, 1555–1556, 91 L.Ed. 2030 (1947); *Yakus v. United States*, 321 U.S. 414, 442–443, 64 S.Ct. 660, 675–676, 88 L.Ed. 834 (1944); *Bowles v. Willingham*, 321 U.S. 503, 519–520, 64 S.Ct. 641, 649–650, 88 L.Ed. 892 (1944); *Phillips v. Commissioner*, 283 U.S. 589, 595–599, 51 S.Ct. 608, 611–612, 75 L.Ed. 1289 (1931); *North American Cold Storage Co. v. Chicago*, 211 U.S. 306, 315–321, 29 S.Ct. 101, 104–106, 53 L.Ed. 195 (1908). The question then, is whether the issuance of immediate cessation orders under § 521(a) falls under this emergency situation exception to the normal rule that due process requires a hearing prior to deprivation of a property right. We believe that it does.

[13] The immediate cessation order provisions reflect Congress' concern about the

42. Under § 521(a)(5), 30 U.S.C. § 1271(a)(5) (1976 ed., Supp. III), cessation orders automatically expire after 30 days, "unless a public hearing is held at the site or within such reasonable proximity to the site that any viewings of the site can be conducted during the course of the public hearing."

43. The District Court's January 21, 1980, supplemental order and opinion, see n. 13, *supra*, explained that its injunction did not apply to immediate cessation orders issued pursuant to § 521(a)(3) against mine operators who had failed to abate violations within the time period specified in the notice of violation. J.S.App. 2a–3a.

devastating dan
mining disasters
tempt to reach a
the legitimate d
to be heard befo
trative regulatio
terest in protect
safety and the e
danger. Protect
ty of the public i
tal interest which
istrative action.
property to prot
safety is "[o]ne c
permissible summ
tinger & Casselb
at 599, 70 S.Ct
v. *Montrym*, 443
2612, 2620–2621,
at 21, n. 1, 25, 9
(Stewart, J., diss
Cold Storage Co
U.S., at 315–316,
over, the admin
through immedi
sponds to situatio
necessary to prot
safety. This is p
gency situation i
found summary a
fied. See *Ewing*
ry, Inc., supra; N
age Co. v. Chicago

Rather than ta
these principles, th
the Act does not

44. The legislative
cates that Congr
power to issue im
critical, and that
intended to avert
such disasters as t
H.R.Rep.No.95–218
No.95–128, pp. 9
Creek flood was ca
of a coal mine wast
near Buffalo Creek
persons dead an
homeless. See H
(1976).

45. The Secretary's
cant, imminent envi
lowing terms:

devastating damage that may result from mining disasters.[44] They represent an attempt to reach an accommodation between the legitimate desire of mining companies to be heard before submitting to administrative regulation and the governmental interest in protecting the public health and safety and the environment from imminent danger. Protection of the health and safety of the public is a paramount governmental interest which justifies summary administrative action. Indeed, deprivation of property to protect the public health and safety is "[o]ne of the oldest examples" of permissible summary action. *Ewing v. Mytinger & Casselberry, Inc., supra,* 339 U.S., at 599, 70 S.Ct., at 872. See *Mackey v. Montrym,* 443 U.S. 1, 17–18, 99 S.Ct. 2612, 2620–2621, 61 L.Ed.2d 321 (1979); *id.,* at 21, n. 1, 25, 99 S.Ct., at 2622, n. 1, 2624 (Stewart, J., dissenting); *North American Cold Storage Co. v. Chicago, supra,* 211 U.S., at 315–316, 29 S.Ct., at 104. Moreover, the administrative action provided through immediate cessation orders responds to situations in which swift action is necessary to protect the public health and safety. This is precisely the type of emergency situation in which this Court has found summary administrative action justified. See *Ewing v. Mytinger & Casselberry, Inc., supra; North American Cold Storage Co. v. Chicago, supra.*

Rather than taking issue with any of these principles, the District Court held that the Act does not establish sufficiently objective criteria governing the issuance of summary cessation orders. We disagree. In our judgment, the criteria established by the Act and the Secretary's implementing regulations are specific enough to control governmental action and reduce the risk of erroneous deprivation. Section 701(8) of the Act, 30 U.S.C. § 1291(8) (1976 ed., Supp. III), defines the threat of "imminent danger to the health and safety of the public" as the existence of a condition or practice which could

> "[r]easonably be expected to cause substantial physical harm to persons outside the permit area before such condition, practice, or violation can be abated. A reasonable expectation of death or serious injury before abatement exists if a rational person, subjected to the same conditions or practices giving rise to the peril, would not expose himself or herself to the danger during the time necessary for abatement."[45]

If anything, these standards are more specific than the criteria in other statutes authorizing summary administrative action that have been upheld against due process challenges. See, e. *g., Ewing v. Mytinger & Casselberry, Inc., supra,* 339 U.S., at 595–596, 70 S.Ct., at 871 ("'dangerous to health . . . or would be in a material respect misleading to the injury or damage of the purchaser or consumer'"); *Fahey v. Mallonee, supra,* 332 U.S., at 250–251, n. 1, 67 S.Ct., at 1554, n. 1 ("is unsafe or unfit to

44. The legislative history of § 521(a)(2) indicates that Congress viewed the Secretary's power to issue immediate cessation orders as critical, and that the measure was primarily intended to avert the possible occurrence of such disasters as the Buffalo Creek flood. See H.R.Rep.No.95–218, pp. 129–130 (1977); S.Rep. No.95–128, pp. 90–91 (1977). The Buffalo Creek flood was caused by the sudden collapse of a coal mine waste impoundment dam in 1972 near Buffalo Creek, W. Va. The flood left 124 persons dead and rendered 4,000 persons homeless. See H.R.Rep.No.94–1445, p. 19 (1976).

45. The Secretary's regulations define "a significant, imminent environmental harm" in the following terms:

> "(a) An environmental harm is any adverse impact on land, air, or water resources, which resources include, but are not limited to, plant and animal life.
>
> "(b) An environmental harm is imminent, if a condition, practice, or violation exists which—(1) Is causing such harm, or, (2) May reasonably be expected to cause such harm at any time before the end of the reasonable abatement time that would be set under Section 521(a)(3) of the Act.
>
> "(c) An environmental harm is significant if that harm is appreciable and not immediately reparable." 30 CFR §§ 700.5 and 701.5 (1980).

manage a Federal savings and loan association" or "[i]s in imminent danger of becoming impaired"); *Air East, Inc. v. National Transportation Safety Board*, 512 F.2d 1227, 1232 (CA3) ("'emergency requiring immediate action ... in respect to air safety in commerce'"), cert. denied, 423 U.S. 863, 96 S.Ct. 122, 46 L.Ed.2d 92 (1975).

The fact that OSM inspectors have issued immediate cessation orders that were later overturned on administrative appeal does not undermine the adequacy of the Act's criteria but instead demonstrates the efficacy of the review procedures. The relevant inquiry is not whether a cessation order should have been issued in a particular case, but whether the statutory procedure itself is incapable of affording due process. *Yakus v. United States*, 321 U.S., at 434–435, 64 S.Ct., at 671–672. The possibility of administrative error inheres in any regulatory program; statutory programs authorizing emergency administrative action prior to a hearing are no exception.[46] As we [303] explained in *Ewing v. Mytinger & Casselberry, Inc.*, 339 U.S., at 599, 70 S.Ct., at 872:

> "Discretion of any official action may be abused. Yet it is not a requirement of due process that there be judicial inquiry before discretion can be exercised. It is sufficient, where only property rights are concerned, that there is at some stage an opportunity for a hearing and a judicial determination."

Here, mine operators are afforded prompt and adequate post-deprivation administrative hearings and an opportunity for judicial review. We are satisfied that the Act's immediate cessation order provisions comport with the requirements of due process.

We also conclude that the District Court erred in reducing the statutorily prescribed time period for the Secretary's response to requests for temporary relief. In the first place, the 5-day period is a statutory maximum and there is no indication in the record that the Secretary has not responded or will not respond in less than five days. Second, appellees have not demonstrated that they have been adversely affected by the 5-day response period in a particular case or that it is generally unreasonable. In addition, no evidence was introduced to show that a shorter reply period is administratively feasible. In these circumstances, there simply is no basis for the District Court's decision to substitute a judicial policy preference for the scheme adopted by Congress. Cf. *Vermont Yankee Nuclear Corp. v. Natural Resources Defense Council, Inc.*, 435 U.S. 519, 98 S.Ct. 1197, 55 L.Ed.2d 460 (1978). Accordingly, we turn to the District Court's holding that other sections of the Act violate the Fifth Amendment's Due Process Clause.

B

[14] The District Court ruled that the Act's civil penalty provisions do not comport with the requirements of due process. Under these provisions, the Secretary is to notify the recipient of a notice of violation or a cessation order of the proposed amount [304] of any civil penalty that is to be assessed against it. § 518(c), 30 U.S.C. § 1268(c) (1976 ed., Supp. III). Section 518(c) further states that, if the operator "wishes to contest either the amount of the penalty or the fact of the violation," it must "forward the proposed amount to the Secretary for placement in an escrow account."[47] Once the escrow requirement is met, the operator receives a full adjudicatory hearing before an administrative law judge, with a right of

46. A different case might be presented if a pattern of abuse and arbitrary action were discernible from review of an agency's administration of a summary procedure. Although the District Court sought to characterize the OSM's record in issuing cessation orders in these terms, a showing that three cessation orders were overturned on administrative appeal is far from sufficient to establish a pattern of abuse and arbitrary action.

47. However, no penalties are finally imposed until the alleged offender has been provided an opportunity for a public hearing. Section 518(b) provides: "A civil penalty shall be assessed by the Secretary only after the person charged with a violation ... has been given an opportunity for a public hearing." 30 U.S.C. § 1268(b) (1976 ed., Supp. III).

appeal to an
cial review
U.S.C. § 1276
after adminis
determined
that the am
should be rec
must prompt
with interest
Supp. III).

In challeng
visions appell
any one of t
assessed agai
trict Court di
on the immed
that any of
have been aff
statutory pro
collection of
these cases b
is a concrete
the operation
circumstances
pellees' challe
was improper
a decision on

Our exami
tional challen
[305] persuades us
to their pre
cordingly, we
District Cou
appellees' Co
1596), and w
insofar as it
Act unconsti
cases are re
with instruct
issued again
ther proceed
ion.

So ordered

THE CHI

1. We assum
this probabl
ronmental g

appeal to an administrative board and judicial review of the final decision. See 30 U.S.C. § 1276(a)(2) (1976 ed., Supp. III). If, after administrative or judicial review, it is determined that no violation occurred or that the amount of the proposed penalty should be reduced, the appropriate amount must promptly be refunded to the operator with interest. 30 U.S.C. § 1268(c) (1976 ed., Supp. III).

In challenging the Act's civil penalty provisions appellees did not allege that they, or any one of them, have had civil penalties assessed against them. Moreover, the District Court did not find, as it did in ruling on the immediate cessation order provisions, that any of appellee coal mine operators have been affected or harmed by any of the statutory procedures for the assessment and collection of fines. Thus, the record in these cases belies any suggestion that there is a concrete case or controversy concerning the operation of these provisions. In these circumstances, we must conclude that appellees' challenge is premature, and that it was improper for the court below to render a decision on this claim.

VI.

Our examination of appellees' constitutional challenges to the Surface Mining Act [305] persuades us that the Act is not vulnerable to their pre-enforcement challenge. Accordingly, we affirm the judgment of the District Court upholding the Act against appellees' Commerce Clause attack (No. 79-1596), and we reverse the judgment below insofar as it held various provisions of the Act unconstitutional (No. 79-1538). The cases are remanded to the District Court with instructions to dissolve the injunction issued against the Secretary, and for further proceedings consistent with this opinion.

So ordered.

THE CHIEF JUSTICE, concurring.

I agree largely with what Justice REHNQUIST has said about the "fictions" concerning delegation, and the gradual case-by-case expansion of the reach of the Commerce Clause.

I agree fully with his view that we often seem to forget the doctrine that laws enacted by Congress under the Commerce Clause must be based on a *substantial* effect on interstate commerce. However, I join the Court's opinions in these cases and in No. 80-231 because in them the Court acknowledges and reaffirms that doctrine. See, e. g., *ante*, at 2362.

Justice POWELL, concurring.

The Surface Mining Act mandates an extraordinarily intrusive program of federal regulation and control of land use and land reclamation, activities normally left to state and local governments. But the decisions of this Court over many years make clear that, under the Commerce Clause, Congress has the power to enact this legislation.

The Act could affect seriously the owners and lessees of the land and coal in the seven westernmost counties of Virginia. The Federal Government is required by the Fifth Amendment to pay just compensation for any "taking" of private property for [306] public use.[1] See *San Diego Gas & Electric Co. v. City of San Diego*, 450 U.S. 621, 654, 101 S.Ct. 1287, 1305, 67 L.Ed.2d 551 (1981) (BRENNAN, J., dissenting).[2] But whether there has been such a "taking" and, if so, the amount of just compensation, are questions to be decided in specific cases. *Agins v. Tiburon*, 447 U.S. 255, 260, 100 S.Ct. 2138, 2141, 65 L.Ed.2d 106 (1980); *Kaiser Aetna v. United States*, 444 U.S. 164, 175, 100 S.Ct. 383, 390, 62 L.Ed.2d 332 (1979). I agree with the Court, therefore, that it is premature to consider in these cases questions under the Compensation Clause. *Ante*, at

1. We assume, of course, that Congress weighed this probable cost against the desirable environmental goals of the Act.

2. The "taking" question considered by Justice BRENNAN and the three Justices who joined him was not reached by a majority of the Court.

2369–2371. Appellees have identified no specific property that is alleged to have been taken. The Court's decision thus is confined to a holding that the Act in this respect is not *facially* unconstitutional. *Ante*, at 2371, n. 40. The "taking" issue remains available to, and may be litigated by, any owner or lessee whose property interest is adversely affected by the enforcement of the Act.[3]

I add a word about the area of Virginia that will be affected by this Act, as its location, topography, and geology are highly relevant to an understanding of the "taking" question. Bituminous coal, Virginia's most valuable natural resource,[4] is found in a region marked by steep mountain slopes, sharp ridges, massive outcrops of rock, and narrow valleys—conditions that severely limit alternative uses of the land. Because of thin soil and rugged terrain, the land in its natural state is not suited for agricultural use or the growing of merchantable timber. Its value lies, in most instances, solely in its coal. Mining the coal is a major industrial activity in an otherwise impoverished area of Virginia.[5]

A number of the Act's provisions appear to have been written with little comprehension of its potential effect on this rugged area. For example, the requirement in § 515(d) that steep-slope areas be restored approximately to their original contours seems particularly unrealistic. As the District Court found, 95% of the strippable coal lands in Virginia are located on slopes in excess of 20 degrees. 483 F.Supp. 425, 434 (1980). The cost of restoration in some situations could exceed substantially the value of the coal. In any event restoring steep mountain slopes often would diminish rather than increase the land's worth.

3. In *Agins*, 447 U.S., at 260, 100 S.Ct., at 2141, we observed that the "determination that government action constitutes a taking is, in essence, a determination that the public at large, rather than a single owner, must bear the burden of an exercise of state power in the public interest."

In sum, if the Act is implemented broadly in accordance with its terms, the consequences to individual lessees and owners, and to the area as a whole, could be far-reaching. But adjudication of claims arising from such implementation is for the future. I agree with the Court that we cannot say that the Act is facially invalid, and I therefore join its opinion.

452 U.S. 314, 69 L.Ed.2d 40

Donald Paul HODEL, Acting Secretary of the Interior, et al., Appellants,

v.

State of INDIANA et al.

No. 80-231.

Argued Feb. 23, 1981.

Decided June 15, 1981.

Action was brought challenging the constitutionality of the "prime farmland" provisions and certain general provisions of the Surface Mining and Reclamation Control Act of 1977. The United States District Court for the Southern District of Indiana, 501 F.Supp. 452, sustained each of the constitutional challenges and permanently enjoined enforcement of the challenged provisions. Secretary of the Interior appealed. The Supreme Court, Justice Marshall, held that: (1) the provisions in question did not violate the commerce clause or the Tenth Amendment; (2) the approximate original contour provisions did not violate the equal protection or due proc-

4. The District Court found that the mining of coal is a $2 billion per year industry in the Commonwealth.

5. It is said, perhaps frivolously now, that bootlegging was the second most remunerative activity in that part of the State.

ess guarantees
(3) the Act did
al taking of
challenge to th
the Act was
operators had
ever assessed c
the statutory p
ever applied to
injury.

Reversed a

For Chief
concurring stat

For Justice
ion concurring
S.Ct. 2389.

1. Commerce

Court may i
ed under commer
that there is no
sional finding th
fects interstate c
no reasonable co
tory means sele
U.S.C.A.Const. A

2. Commerce

Congress did
under commerce
farmland" provis
Control and Re
Mining Control
1977, §§ 508(a)(
U.S.C.A. §§
1269(c)(2); U.S.C.

3. Mines and Mi

Goals of Su
Reclamation Act
ing air and wate
was also concerne
tive capacity of n
public from healt
may result from
face Mining Cont
of 1977, § 101 et
seq.

39. Hunkin, G.G., et al. "Some Observations on Field Experiences with Monitor Wells," Ground water Monitoring Review, Winter 1984, pp. 43-45

2648

2648

Some Observations on Field Experiences With Monitor Wells

by Geoffrey G. Hunkin, Thomas A. Reed and Gregory N. Brand

Abstract

In recent years we have seen major advances in the variety and quality of ground water sampling instrumentation, in almost every case involving increases in sensitivity of one or more orders of magnitude. Software number-crunching ability brings us the capability of running sophisticated mathematical and statistical programs, while modern analytical chemistry routinely makes determinations of metals, organics and radioactive elements accurate in the parts per billion range.

The construction of sample points rarely supports these levels of precision. The well is the basic sampling machine for the ground water industry and its ability to produce a truly representative sample underpins all [illegible] and conclusions. Regardless of the type of instrumentation employed, a sample point that cannot be shown to be truly representative and that fails to provide a series of reliable samples over the long term—let us say 25 years minimum—is a negative investment.

In the authors' professional sampling work, it has been observed that, wherever it is possible to improve the quality of the ground water sample point, a reduction in the measured level of pollutant elements in the sample is found and the confidence level improves. Volatile organic values are the sole exception to this observed reduction in concentration, the reason being that sample point and method improvements capture the fully representative water sample, thus reducing volatile losses.

It is not possible to address all hydrogeologic environments and sampling methods in this review. Instead, features were selected that had been found to be important in commercial, high-precision, water quality sampling in Western U.S. environments. In this area, water movement is slow and little or no exchange of water occurs between wells and the surrounding aquifer without artificial stimulation. Water quality stabilization requires multiple casing volume evacuations in wells ranging to 1,000 feet deep. High-volume pumping or mechanized bailing is an economic requirement. Dedicated installations cannot supply the volume of water required for comprehensive analytical programs.

It is the nature of these sources, as well as practical [illegible]mmendations for corrective action, that will be [illegible]ressed in this article.

Any attempted improvement in utilization of data by mathematical processing or statistical treatment will be inadequate because:

- Samplings are infrequent and often accumulate at rates of only two or four sample suites per year. Seasonal variations may obscure evidence of passage of a low-intensity pollution front and some years may elapse before the true situation becomes apparent from statistical analyses. By such time, the problem pollutant may have escaped from the treatment area.
- Powerful biases occur due to the failure of the sample point to eliminate false contributions to the sample from sources other than the natural environment or a pollution source, most frequently originating in casing materials and annular seal leakage.

The Ground Water Instrumentation—Core Sample Connection

When we move ahead from the measurement of fluctuation in ground water levels, which are measurements of quantity, into the field of ground water quality investigation, it is apparent that a much more detailed understanding of the aquifer is necessary. In particular, predictions of pollutant migration rates will be erroneous without knowledge of both the permeability variations within the aquifer and the geologic/hydrologic controls and mineralogy involved.

The evolution of geophysical and geochemical field instrumentation in the mineral field teaches that at some point a core must be retrieved and, in general, the sooner the better. Until the core is examined, instrument data is speculative. Only when detailed understanding of the physical-chemical-mineralogical characteristics obtained from such cores is gained can we accurately interpret the data from the black boxes that are later lowered into the wells, or that develop from surface instrumentation.

Figure 1 illustrates the advance of an oxidizing leachate through a low-permeability, poorly consolidated, fluvial sandstone.

It is possible to observe that:

- The boundaries between rock permeated by liquid pollutants and unaltered rock are very sharp and distinctive. The boundary between altered and unaltered rock is characterized by a sharp change in permeability.
- Downhole instrumentation response will vary with the location of the instrument within the formation. Interpretation requires knowledge of the position of the instrument with respect to intrusion boundaries.

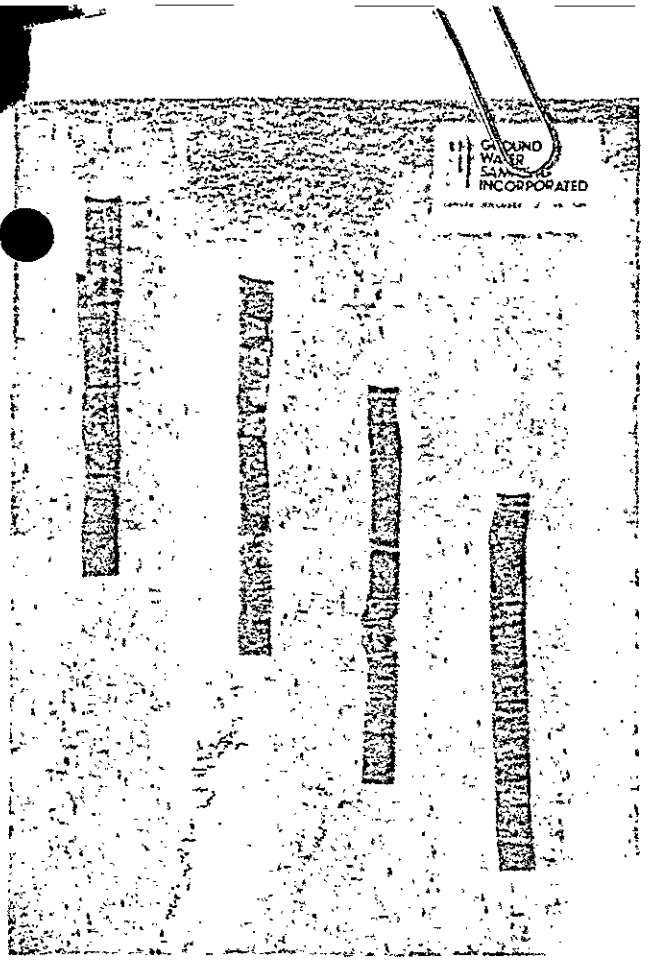


Figure 1. Advance of oxidizing leachate

- Small changes in instrument location will affect responses from:
  - —Redox sensors, Eh and dissolved oxygen probes
  - —pH probes
  - —Water velocity detectors
  - —Downhole geophysical sensors.
- Leachate flow velocities based upon drawdown tests will seriously underestimate the advancing position of the leading edge of a pollutant plume due to local geological and structural controls.

It seems clear that it is most important to correlate instrument responses with actual local subsurface conditions and that correlation demands sampling of undisturbed core or some other means of access to the subsurface.

In the authors' experience, hollow core auger samples are a poor substitute for a true undisturbed core taken with a multiple-tube core barrel using a diamond bit and a controlled synthetic mud system (used also to demarcate oxidized zones from reduced zones).

From the undisturbed core sample we can readily determine:

- Interstitial fluid chemical makeup, truly representative of fluids moving through the formation at the point of sampling. If called for, analyses can be run every foot.
- Vertical permeability profile from which true veloc- of leachate plumes can be estimated.
- Volume of leachate present in the formation.
- Optimum location of ports of multiple-point sample devices.
- Optimum depths of well clusters or nests.
- Effect of leachate on formation mineralogy.
- Mobilization or precipitation effect of traveling leachate on trace metals in the formation.
- Ion exchange activity potential of various sections of the target formation, selecting test samples from each lithological division.
- Oxidation capacity and buffering capability of the formation and interstitial fluids.

Coring need not be expensive or slow. Provided that equipment and drill mud is carefully selected and specific procedures are followed, coring can be fast and core recovery kept at nearly 100 percent in most formations. In general, reasonably spaced two-cored holes, selection based on geological data, will provide an accurate basis for correlation of follow-up, low-cost, open hole, instrument based, site investigation extending for several miles in each direction.

Selection of Casing Material

From the examination of many hundreds of ground water samples taken at quarterly intervals from a wide range of sources, the authors' experience clearly shows that pumped samples are more consistent in water quality when compared with bailed or gas lifted samples. Even inert gases used in gas-lift samples scrub pollutants from the sample—this is a standard chemical engineering technique—while volatile losses from open bailers are unacceptably high.

Within the pumped sample group, those samples originating from steel cased wells are readily singled out, not only for the iron and alloy metal levels, but also for the byproducts of bacterial growth and corrosion. Data from these wells should not be used when evaluating water quality because the induced chemical reactions between the casing and water will introduce sampling errors. PVC or other plastic casing may contaminate ground water with dissolved organic species that can be detected only when samples are analysed for volatile organic priority pollutants (Sosebee 1983; Curran and Tomson 1983).

Wells open to more than one formation, or lacking in annular seals and open to surface or vadose zone runoff can be identified by the patterns of variation in on-stream pH, conductivity, turbidity and color. Only by continued moderate pumping and selective completion techniques can a representative sample be obtained that can be duplicated at later samplings. Selection of the time of sampling can only be reliably determined by instrument identification of water quality stabilization where a particular aquifer has been isolated.

In-house investigations of the feasibility of using stainless steel or Teflon casing material in sensitive locations showed that both materials have serious drawbacks in lack of bond strength to the vital exterior well seal. Detailed investigation of the classes of stainless steel and Teflon tubing available for well casing work also strongly suggests that both chemical stability and porosity are suspect.

The authors' search for superior casing materials led to the selection of epoxy fiberglass composites (Table 1) as being of uniform composition, completely inert to critical volatile organics and of superior mechanical strength, while offering a savings in cost. This composite material will also provide a more reliable environment for subsurface instrument installations.

Table 1

The advantages of the composite material casing:

- Chemical integrity - zero volatile leaching

- Virtually indestructible, easy maintenance with hard tools
- Foolproof installation, short rig time, low cost
- Available with custom screen slots
- No adapters, special fittings, welding, glues, or packers to complicate installation. Joints are made with tapered acme threads.
- Access for commercial pumps allowing wide range of pumping rates
- Does not become brittle at low temperatures
- The casing is readily slotted for multiple sampling intercepts without the complications of adding couplings or other pipe fittings.

The zero priority pollutant leach-out of this material was demonstrated by laboratory leach tests on pulverized samples, following a test protocol proposed by the Colorado Department of Health, the Denver City and County Environmental Division, and Region 8 U.S. Environmental Protection Agency (EPA) representatives. The analytical procedures conformed with EPA Methods 624 and 625, with detection limits taken below the requirements of these procedures. The result is a casing and integral slot material that is ideal for critical installations such as those used for pollution plume tracing.

Until recently, the trend has been to smaller wells, but we are now experiencing a strong reversal to the 4-inch casing as property owners have gained experience. The installation cost of a 4-inch well, competently installed, is often less than smaller diameter wells, while the operating cost for sampling the larger well is always lower. The industrial client is interested in his cost per sample, as he is going to be around for some time and can understand the difference between capital cost of well construction and operating cost of sampling.

The authors are frequently called in to sample wells that were originally installed as small diameter piezometers. It is logical to expect that a high proportion of piezometers will eventually be sampled because of placement in areas of suspected pollutant movement. It is good economic sense to look ahead and to make all piezometers a minimum of 4-inch internal diameter, which provides the necessary versatility to handle any future instrumentation requirements (Tables 2 and 3).

Table 2

Problems with wells of less than 4-inch I.D.:

- Inherent restriction in functions
- Access limited to small diameter probes
- External packers and seals unreliable
- No commercial tools to fish for lost instruments
- Development and work-overs slow and costly
- Doglegs severe
- High cost per sample
- Very difficult to develop (remove mud, formation sediment, etc.).

Table 3

The advantages of greater than 4-inch I.D. casings:

- Accepts complete range of monitoring equipment and instrumentation
- Accessible to commercial work-over and maintenance equipment
- Physical strength, long life
- Low cost per sample.

Conclusions

Without precise knowledge of the formation, one can only speculate on formation conditions and correct positioning of the instrumentation becomes unreliable. A cored hole is essential if today's instruments are to yield their full potential.

If the sample point, i.e. monitor well, is not properly completed, sealed and cased, analytical results are compromised. Results are likely to be erratic and have unacceptable variations in successive samplings.

Small diameter wells were tried because they were thought to be cost-effective. In retrospect, it is seen that cost per sample and sample integrity are the true criteria for selecting well size and the 4-inch I.D. composite casing is the choice of experience.

References

Sosebee, Jack. 1983. Contamination of ground water supplies with PVC adhesives and PVC primers. Colorado Ground Water Association Newsletter, pp. 9-10.

Curran, C.M. and M.B. Tomson. 1983. Leaching of trace organics into water from five common plastics. Ground Water Monitoring Review, v. 3, no. 3, pp. 68-71.

Biographical Sketches

Geoffrey G. Hunkin, P.E. (Ground Water Sampling Inc., 1855 W. Union, Suite B-5, Englewood, CO 80110) is president of Ground Water Sampling Inc. and president of Hunkin Engineers Inc.

Thomas A. Reed (Ground Water Sampling Inc., 1855 W. Union, Suite B-5, Englewood, CO 80110) is vice president of operations for Ground Water Sampling Inc.

Gregory N. Brand (Ground Water Sampling Inc., 1855 W. Union, Suite B-5, Englewood, CO 80110) is a water quality engineer with Ground Water Sampling Inc.

40. Hunter Environmental Services, Inc. Case Against Inventory Management as the Primary Means of Detecting Leaks, September12, 1983

THE CASE AGAINST INVENTORY MANAGEMENT AS THE PRIMARY MEANS OF DETECTING LEAKS

Hunter Environmental Services, Inc.
September 12, 1983

1. GASOLINE HAS THE COEFFICIENT OF EXPANSION OF .0006/°F

This high expansion/contraction rate when applied to the volumes of product that are delivered, stored and dispensed at an average service station can cover up an existing leak of falsely signal that one exists in a tight system. Recent API sponsored temperature surveys have dramatically shown that temperature variations can and do occur. Although changes well in excess of 10°F have been substantiated, even variations of few degrees farenheit have a noticable effect upon the inventory records at a service station. For example:

If a 20,000 gallon per month station had its gasoline delivered at 62°F but dispensed it at 60°F, a monthly 24 gallon shrinkage would have occurred.

20,000	gallons
x.0006	coef. of expansion/°F
12	gallons
x 2	°F change
24	gallon change

2. VAPORIZATION OF GASOLINE

Gasoline is a volatile liquid, therefore, it vaporizes or evaporates quite readily. A Stanford Research Institute survey found that "every transfer of gasoline from one container to another will show a loss of one half to one percent." Although this figure seems abnormally high, some evaporation, no doubt, does occur.

Although in some areas evaporation has been diminished with the elimination of splash deliveries and the use of vapor recovery procedures, at many service stations evaporation does effect inventory records. For example:

> Even if the evaporation at a 20,000 gallon per month station were kept to 1/10 of 1%, this would still account for a monthly loss of 20 gallons.

20,000	gallons
x .001	evaporation loss
20	gallons

3. GALLON CALIBRATIONS OF SALES AND DELIVERIES

A. Dispenser computers by Weights and Measures standards must be calibrated to within a tolerance of 7 cu. in. to a 5 gallon test measure. These computers allow for the sale of gasoline to consumers in very precise gallon measurements. However, when slight calibration variances are multiplied by the thousands of gallons that are sold monthly at a service station, inventory control discrepancies will occur. For example:

If the computers at a 20,000 gallon per month station were within 50% of the maximum tolerances established by Weights and Measures, a discrepancy of 60 gallons would occur in the inventory records.

	231	cu. in. per gallon
	x 5	gallons
	1155	cu. in./5 gallon test measure
	7	cu. in. W/M variation
	1155	cu. in = .006 variation
.0052	.006	W/M maximum
.5	x .5	actual variation at example station
.0026	.003	variation figure at example station
	20,000	gallons per month
	x .003	
52gal	60,000	gallon per month variation

B. Product deliveries to service stations by Weight and Measures Standards must be within a ±.0022 volume tolerance. For the reason mentioned in the previous example, inventory figures would, therefore, be somewhat incorrect. For example:

If a 20,000 gallon per month station were to receive deliveries which were within 50% of the tolerances established by Weights and Measures, a discrepancy of 22 gallons would occur in the inventory records.

.0022	variation
x .5	actual variation in deliveries
.0011	variation at example station
20,000	gallons per month
x.0011	variation at example station
22	gallon per month variation

4. ACCURACY OF TANK STICK READINGS

A. As underground tanks are cylindrical in shape, gallonage is difficult to determine when product height is near the center of the tank. Gauge sticks currently in use can be read to the accuracy of 1/8". Since guage stick readings will fluctuate slightly because of the angle of the stick when dipped into the tank, the condition of the tank bottom and gasoline creep, gauging of the stick into smaller increments would not increase accuracy. Therefore, the gallonage represented by 1/8" is the possible error which will be recorded into the inventory records whenever tanks are sticked.

By using the attached calibration charts and some simple calculations, it can be determined how many gallons are represented by each 1/8" in various size tanks. For example:

The amount of gallons needed to raise the product level in a 10,000 gallon tank from 47" to 48" is 5,029 - 4,895 or 134 gallons. When 134 gallons is divided by 8 to determine the amount of gallons represented by 1/8" the result if 16.7 gallons. Therefore, a possible 16.7 gallon error can occur when a half full 10,000 gallon tank is stick measured. By using the same calculation procedure the stick reading error factor can be determined for any product level.

Although the greatest possibility for error exists when a tank is half full, substantial measuring erors will occur even when tanks are nearly empty or full. For example:

If a 10,000 gallon tank contains any product amount between 1,000 and 9,000 gallons, each 1/8" increment will represent more than 12 gallons.

Even when tanks are of smaller capacities, the 1/8" measuring range amounts to substantial gallonages as can be noted in the following examples:

8,000 gallon tank

When 1/2 full — 1/8" represents 13 gallons
When containing 1,000 - 7,000 gallons — 1/8" represents more than 10 gallons .

6,000 gallon tank

When 1/2 full — 1/8" represents 10 gallons
When containing 1,000 - 5,00 gallons — 1/8" represents more than 8 gallons

4,000 gallon tank

When 1/2 full — 1/8" represents 10 gallons
When containing 750 -.3,250 gallons — 1/8" represents more than 8 gallons

B. VIRTUALLY, ALL TANKS ARE NOT CALIBRATED

Underwriters Laboratories does not require tanks to be of an exact capacity -- a 5% tolerance is allowed. Some capacity tolerance obviously is necessary so that construction costs remain within reasonable limits. Guage charts used when sticking tanks, however, all are uniform -- they are not calibrated for individual tanks. Even when tanks are new, an inherent stick measuring error exists.

C. TANK DIMENSIONS AND CAPACITIES CHANGE ONCE INSTALLED AND CONTINUE TO CHANGE WITH AGE

Even if a tank were calibrated and a custom chart were made for it at the factory, tank dimensions would change and stick readings would be inaccurate after installation.

Through the years, tank configurations change from corrosion, settling and the differential pressures of backfill. Those companies that have calibrated their tanks have found that recalibration, an expensive and time-consuming process, must be performed yearly if stick readings are to be accurate.

D. TANKS DO NOT REMAIN PERFECTLY LEVEL ONCE INSTALLED

Some tanks are purposely installed with a few degrees of tilt to facilitate water removal. If the fill area is located at either end of a tilted tank, the stick readings will obviously be inaccurate.

Since many tanks are 24 or more feet in length, it is practically impossible to install them perfectly horizontal. Even if a tank is installed as nearly horizontal as possible, some tilting will occur because of settling. A tilt of less than 1" off horizontal will create significant stick reading errors as was noted in the exercise where the amount of gallons per 1/8" was calculated.

A STANDARD PERCENTAGE FOR INVENTORY ERROR CANNOT BE ESTABLISHED

Inventory records vary because of the aforementioned conditions. A simple percentage for inventory discrepancy cannot be developed because some service stations will receive warmer or cooler product deliveries than others. Gasoline at one station may be dispensed with computers reading slightly over a gallon while another station's may read slightly under. Stick readings may consistently be on the plus side at one location while on the minus at another. Inventory records will fluctuate seasonally because the temperature of delivered and stored product will change with weather conditions. Of course, some of these factors could offset each other.

The fact that no one percentage figure can be established is apparent from the data which was obtained in a 1961 Treasury Department survey of retail service station gasoline shortages or overages. You will note in the following chart which tabulates those results, the inventory records in one district revealed a .59% loss while another district showed a .25% gain. Of the twelve districts surveyed, eight showed losses while four showed gains.

DISTRICT	# OF STATIONS	SHORTAGE OR (OVERAGE) In Gallons	SHORTAGE OR (OVERAGE) As Percent
Augusta	7	8,779	.4588
Austin	10	(11,844)	(.2549)
Baltimore	12	9,532	.1760
Columbia	8	35,147	.5948
Dallas	4	1,827	.1133
Des Moines	5	(3,004)	(.2004)
Hartford	4	478	.0304
Jacksonville	6	(1,866)	(.0742)
Kansas City	10	(746)	(.0147)
Oklahoma City	5	580	.0364
Richmond	7	11,443	.3546
St. Paul (Minneapolis)	10	1,751	.0266

If the petroleum industry were to set a figure of 1/2 of 1% for the allowable inventory loss before a leak should be suspected, then a station operating in Austin, where a .2549% growth was experienced, could actually lose over 3/4 of 1% of its gasoline but not suspect a leak. On the other hand, a service station in Augusta, where a .4588% loss was noted, would be forced to operate on the "border line," since a discrepancy of only .0422% (an amount not within inventory measurement capabilities) would require the needless testing of tanks. A station in Columbia, where losses of .5948% were detected, would usually be in the range where leaks should be suspected.

STATION STATISTICS

Average service station (Major Oil Company Owned):

Sells:	1977	43,000 gallon per month
	1982	47,600 gallon per month

Oil Jobber or Personally Owned:

20,000 to 40,000 gallon per month

8,000 gallons per tanker load (for comparative understanding)

Over 50% of locations are owned by jobbers and independents

A major substantial number do not keep inventory records

At 40,000 gallons per station per month, the following sheet details that if all factors were contributing, a 290 gallon per month leak could be taking place.

CUMMULATIVE ERROR FACTORS ASSOCIATED WITH INVENTORY MANAGEMENT

		Gallons Error
1. Coefficient of Expansion		
2°F change per month		
-- 40,000 $\frac{\text{gallons}}{\text{month}}$ x $\frac{0.00065}{°F}$ x 2°F =	17% ~~52~~ Temp	
15,000 gal x .00065 x 2 = 19.5 gal (½ full)	19.5 gal	
2. Vaporization - 0.1% less		
-- 40,000 $\frac{\text{gallons}}{\text{month}}$ x 0.001 =	13%	40
3. Calibrations of Sales and Deliveries		
A. 0.3% Variation in dispensers		
-- 40,000 $\frac{\text{gallons}}{\text{month}}$ x ~~0.003~~ .026 =	40%	~~120~~ 104 gal outgoing retail
B. 0.11% Variation in deliveries		
-- 40,000 $\frac{\text{gallons}}{\text{month}}$ x 0.0011 =	14%	44 incoming wholesale
4. Stick Readings		
A. 1/8" accuracy; ~~6~~ 10,000 gallon tank double two readings	3%	~~10~~ 30
B. 5% calibration tolerance		
-- mid tank 80 gallons/inch x .05 =	1%	4 1000 gal day 50 gal
C. Deflection with age -- 1/8" error	3%	10
D. Unlevel installation -- 1/8" error	3%	10
TOTAL GALLONS PER MONTH		~~290~~ 274 gal
TOTAL GALLONS PER YEAR		3,480

API SURVEY 1979

1500 tanks found leaking by:

29.7%	Inventory Control
35.9%	Water in Tank
5.8%	Leak Detector (wells, etc.)
13.2%	Tank Testing
5.9%	Product in Area
9.4%	Other

The implications of this survey would indicate that additional measures should be employed if good monitoring is to be expected, and the fact that approximately 20% were after the fact findings leads one to further question inventory control as the sole means of controlling underground pollution.

Reasons for Not Having Good Records

Many stations are reluctant to keep good inventory records. Some reasons may include theft of product, dealers purchasing from suppliers other than their contracted suppliers and theft of money. Two additional reasons for concern is mid-point volume stick readings which has the greatest margin of error, and utilizing inexperienced minimum wage employees to take inventory readings and recordings.

75% are independent dealers -- if the major oil companies loose ownership control of tanks, they loose control of inventory control(s).

Additional Factors

1983

Most leaks today are found by 3rd party complaints.

Temperature Variable

In inventory control, no compensation for temperature variation is taken into consideration for product expansion or contraction (Coefficient of expansion).

Example: 10,000 gallon tank
$1^{o}F$ change in 1 hour

Produces: .05 gallon leak per hour or
roughly 500 gallons per year

as station tanks threaten wells

contamination that officials say is occurring elsewhere in New Jersey and around the United States at an alarming rate.

There are nearly 5,000 service stations in New Jersey and tens of thousands more nationwide. Most have buried gasoline storage tanks, typically holding 6,000 gallons of fuel.

Many of them, officials said, were installed when major suburban development began throughout the country in the late 1950s and gas stations sprang up to accommodate new residents.

"The life of the tanks are about 20 years and now they're starting to leak," said Richard Cahill of the U.S. Environmental Protection Agency's Region II office in New York.

"Wherever development occurred 20 to 25 years ago in a rapid fashion, we're finding the problem cropping up at an increasing rate," he said.

New Jersey, New York, and Pennsylvania are particularly vulnerable to the threat of the leaking tanks, although so far no public or municipal wells, which are much deeper, seem to have been affected, officials said.

Those states are heavily dependent on groundwater, and soil conditions are right for aging tanks to corrode and leak, said Arnold Schiffman, director of the water resources division in New Jersey's Department of Environmental Protection.

Gasoline comprises many chemical components, including benzene—a known carcinogen.

"It doesn't take much of a leak to contaminate a lot of water," said Mr. Schiffman. "Leaking tanks are fairly common, but people don't realize it."

"Right now we have 200 working cases and a number of those date back to 1979, and we keep getting more and more," said Bruce Comfort, of the Department of Environmental Protection's waste management division.

"We have loads of leaks here," said Andrew Yerman of the New York State Department of Environmental Conservation. "We have 300 to 400 that we know of [that] have knocked out private wells."

State and federal environmental officials say there are no uniform regulations requiring companies to safeguard against leaking.

Mr. Comfort said "we don't have a mandate to deal with a gasoline spill before the fact."

Gas stations are being urged to monitor inventories daily to determine whether they are losing gasoline, said Jerry Ferrara, president of the New Jersey Gasoline Retailers Association.

But, said Mr. Comfort, it is difficult to detect a leak of less than 10 gallons a day.

Oil companies—which own the tanks although the station may belong to an independent dealer—are conducting multimillion-dollar programs to replace aging metal tanks with non-corrosive fiberglass tanks, said Jerry Schanke of the American Petroleum Institute in Washington, an industry group.

State Assemblyman Raymond Lesniak said he plans to introduce legislation in the fall mandating periodic inspections and replacement with noncorrosive tanks.

Bonnie Staples said such inspections might have saved her mother's bar.

Mrs. Staples said that after her 6-year-old daughter began vomiting almost daily, she realized the contamination had hit her home—across an intersection from the gas station.

Mrs. Staples and her husband are paying $400 monthly to rent a second house, on top of the $400 monthly mortgage on their first home. Mrs. Bongiovanni lives above the bar, but she can't afford electricity or heat now that her income from the bar is gone.

The women have filed an $8 million damage suit against Exxon, which owns the tanks. The company offered to sink a new well and run surface lines to the inn, but the women refused, saying they would wait for a court settlement

The gas station owner, Andrew Polowy, Sr., said Exxon relined the tanks with fiberglass after the leak. "It's not my responsibility they started to leak," he said. "Exxon owns the tanks. We're sorry that it happened."

Jack McDonnell, an Exxon spokesman, said he could not comment on the lawsuit

Bonnie Staples (right) and her mother, Stella Bongiovanni, outside New Jersey inn they had to close when gasoline leaked into its water supply

Corrosive Issue

Leaking Gasoline-Storage Tanks Risk Explosions And Contaminated Water Near Service Stations

By BILL PAUL
Staff Reporter of THE WALL STREET JOURNAL

Last May, an explosion leveled a Haysi, Va., gasoline station, injuring four persons, one of them critically. The police chief said gas fumes that had collected in the basement of the service station had been ignited, probably by a spark from a compressor. The source of the fumes: a leaking gasoline-storage tank.

Recently, such tank leaks have contaminated drinking water in several towns and forced dozens of families to leave their homes. "This is becoming one hell of a national problem," says Warren Rogers, the head of a Newport, R.I., consulting firm that has predicted, based on soil tests, that there will be as many as 100,000 leaking tanks in the U.S. by the end of next year, up from perhaps 75,000 today.

The current increase in gas leaks is an indirect result of the road-construction boom of the 1950s and early 1960s, a time when service-station construction increased apace. Some 350,000 steel storage tanks, each holding up to 10,000 gallons of gasoline, were installed beneath about 200,000 new or modernized service stations. Many of those tanks now are rusting through because of their age, acidic soil conditions and improper installation. What makes the leaks a health and safety problem is their proximity to populous areas and the likelihood that leaks will go undetected.

Indeed, Mr. Rogers believes that as many as 50,000 leaking tanks have yet to be identified. Because a corroded tank tends to leak slowly, a dealer might not even know he is losing fuel. And some dealers are lax in keeping track of their gasoline inventories. Moreover, until gas contaminates ground water or seeps into a basement or sewer system, there often isn't anything to smell or otherwise detect.

A Possible Explosion

One leak went undetected until gasoline seeped into a sewer line running under the parking lot of a suburban Birmingham, Ala., shopping center last July. Police kept people away from the Cahaba Heights Plaza temporarily because of the danger of an explosion. Holes were dug to vent fumes and a gasoline-storage tank was removed from a nearby filling station, thus ending the emergency.

New York City subway-maintenance crews have found several gasoline leaks. In most cases, firemen have hosed down the area where fuel was entering a tunnel so as to disperse fumes until fans could suck the gasoline to the surface. In a few instances, subway service has had to be suspended temporarily. Officials say that track inspections are so frequent that gasoline leaks have always been detected in time to prevent explosions.

water, a municipal well field. To prevent gasoline from being sucked into its wells, the town reduced the field's output to 250,000 gallons a day from 1.2 million gallons. In summer, water needs have since been satisfied by wells on an Air Force base and in a national park.

But because of above-ground piping that freezes in the winter, Provincetown has found it necessary to overpump another of its well fields and in doing so has caused unhealthful amounts of salt from ocean water to infiltrate Provincetown's drinking water. People on low-salt diets "have had to buy bottled water," as a result, says Paul Daley, Provincetown's water superintendent. A proposed water-treatment facility, if built, should eventually restore the well field's normal pumping limit.

Fixing Responsibility

Provincetown is suing Standard Oil Co. (Indiana) and others for $25 million, charging that a leaky tank beneath a station selling Amoco gasoline contaminated the town's ground water. Amoco's local attorney doesn't dispute the existence of the leaky tank but argues that for about 13 years the oil company's only connection with the station has been as a supplier of Amoco gasoline. The station is leased by a dealer from a local gasoline distributor; both of them are being sued, too.

Courts generally have been holding oil companies responsible for leak-caused property damage that runs nationally into the hundreds of millions of dollars. A federal court jury in Denver, for example, last year found the Chevron U.S.A. unit of Standard Oil Co of California liable for 1980 leaks at a Northglenn, Colo., station leased by Chevron. The company has since paid about $5 million to buy some 40 homes in the vicinity of the station and to relocate families. It expects ultimately to spend as much as $15 million to settle claims and to clean up the spill.

Checking Supplies

While the oil industry knows it has a problem, it has yet to agree on a solution. Two types of corrosion-resistant tanks—one made of glass fiber and the other of treated steel—have been available for more than a decade. Both are used widely, but both have detractors. Glass fiber, the critics say, cracks easily, and the treated steel isn't guaranteed to be impervious to corrosion. "The guy who comes up with a tank people believe in is going to make a lot of money," says Richard Southers, the manager of operations and engineering at the American Petroleum Institute.

Major oil companies are urging their dealers to keep better track of their gasoline inventories. Some have put clauses into station leases requiring dealers to monitor gasoline supplies daily. New Jersey legislators are considering legislation to make proper inventory control mandatory.

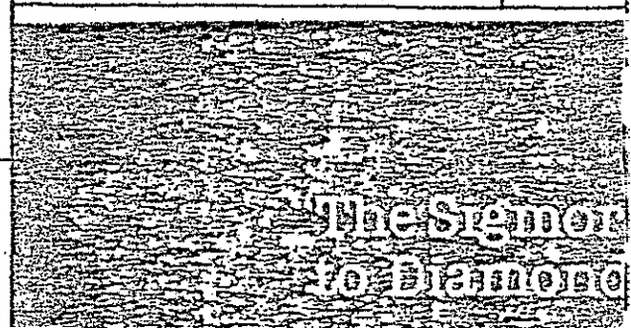
More effort also is going into studying the cancer-causing properties of gasoline-contaminated water. Gasoline is toxic, but because of its recognizable odor, people immediately are aware of its presence in drinking water. But not so the odorless benzene, a component of gasoline (about one percent) and a known carcinogen. Benzene dissolves in water, unlike other components of gasoline that tend to float on the surface. It thus is possible that one might drink benzene-contaminated water after the gasoline has been removed.

Work is being done to predict, based on soil conditions, when an underground tank is likely to start leaking gasoline, and to track down tanks that have already sprung leaks. One such trouble-shooter is Jerry Ainley, a chemist with 30 years' experience in the field who goes from town to town assisting local officials in tracing leaks to their sources.

Mr. Ainley recalls doing such a job for the town of Bishop, Calif., a few years ago. Gasoline was in the sewers. "You could smell it everywhere," he says. Using his "key instrument," a vapor tester, Mr. Ainley determined that the fumes were thick enough to cause an explosion.

He took vapor readings at every manhole cover and made the initial determination that the leak was coming from one of nine service stations in the area. He then drilled holes to the water table until he found a substantial amount of gasoline in the water near one station. Finally, a gasoline "tank tester" was called in, and he determined that a tank beneath the station was indeed losing gas. The leak had been discovered in time to be corrected before further damage could be done.

Vepco Ends Work On Third Reactor



41. Johnson, A.I. "Specific Yield-Compilation of Specific Yields for Various Materials," USGS Water Supply Paper 1662-D, U. S. Government Printing Office, Washington, 1967

Date Due

DEC 1 1967			
JAN 2 1968			
MAR 1 5 1968			
NOV 20 '81			

Library Bureau Cat. No. 1137

Eagle

Specific Yield—Compilation of Specific Yields for Various Materials

By A. I. JOHNSON

HYDROLOGIC PROPERTIES OF EARTH MATERIALS

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1662-D

Prepared in cooperation with the California Department of Water Resources

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1967

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price 50 cents (paper cover)

CONTENTS

	Page
Abstract	D1
Introduction	1
Purpose and scope	1
Definition of terms	2
Acknowledgments	3
Some factors affecting specific yield	3
Methods of determining specific yield	5
Laboratory methods	5
Sample saturation and drainage	5
Correlation with particle size	7
Centrifuge-moisture equivalent	7
Moisture-tension techniques	9
Field methods	11
Field saturation and drainage	11
Sampling after lowering of water table	11
Pumping method	12
Recharge method	13
Review of literature	14
Summary	68
References cited	71

ILLUSTRATIONS

	Page
FIGURE 1. Soil-classification triangle showing relation between particle size and specific yield	D8
2–7. Graphs showing—	
2. Relation of moisture equivalent to specific retention	10
3. Porosity, specific retention, and specific yield for sediments of the South Coastal Basin, Calif	22
4. Relation of porosity to depth in certain types of sedimentary materials of the South Coastal Basin, Calif	24
5. Relation between texture and specific yield of materials that were drained for approximately 100 days	29
6. Relation between moisture equivalent and specific retention of water-bearing materials that were drained for 50–400 days	30
7. Variation of specific yield in relation to duration of pumping for a pumping test at Grand Island, Nebr	31

Page

URE 8. Map showing ground-water storage units of Sacramento Valley, Calif. D34

9–17. Graphs:

9. Textural features and hydrologic properties of the dominant unweathered sediments in the ground-water reservoir of the Friant-Kern Canal service area 39

10. Mechanical-analysis data and hydrologic properties of four representative course and medium sands in the ground-water reservoir of the Friant-Kern Canal service area 40

11. Mechanical-analysis data and hydrologic properties of five representative fine sands and silty sands in the ground-water reservoir of the Friant-Kern Canal service area 41

12. Mechanical-analysis data and hydrologic properties of seven representative silts and clays in the ground-water reservoir of the Friant-Kern Canal service area 42

13. Grade-size distribution of cored samples from the Tia Juana Basin, Calif. 44

14. Porosity, specific yield, and specific retention of sediments from the Tia Juana Basin, Calif. 46

15. Distribution and specific yield of sediments from the Tia Juana Basin, Calif. 47

16. Relation of specific retention to sorting coefficient in alluvium of the Little Bighorn River valley, Montana 59

17. Relation of specific yield to particle size for sediments sampled at Rechna Doab, West Pakistan 63

18. Map showing specific yield of sediments of Rechna Doab, West Pakistan 64

19. Graph showing colinear plot of D_{50} to specific yield for various values of porosity 69

TABLES

Page

LE 1. Quantity of water retained and given up by different sands that were drained for 2½ years D15

2–29. Specific yield:

2. Alluvial deposits in the Morgan Hill area, Santa Clara Valley, Calif. 15

3. Valley-fill materials in San Diego County, Calif. 16

4. Water-bearing materials in the Mokelumne area, near Lodi, Calif. 18

5. Unconsolidated sediments in the Escalante Valley, Utah 20

TABLE 2–29. Specific yield—Continued Page

6. Estimated values for sediments of the South Coastal Basin, Calif. D21

7. Water-bearing sediments in the Platte River valley, Nebraska 26

8. Water-bearing sediments of the Mokelumne area, California 31

9. Water-bearing sediments in the Sacramento Valley, Calif. 33

10. Water-bearing sediments in the Lompoc plain, Santa Barbara County, Calif. 36

11. (Effective porosity) of core samples from Bureau of Reclamation test holes in the Friant-Kern Canal service area, as determined from measured porosities and moisture equivalents 36

12. Water-bearing sediments in Santa Margarita Valley, Calif. 37

13. Sediments in Ventura County, Calif. 43

14. Values for the various lithologic materials used in estimating ground-water storage on the Smith River plain, California 43

15. Water-bearing sediments in Tia Juana Basin, Calif. 46

16. Water-bearing sediments in San Luis Obispo County, Calif. 48

17. Water-bearing sediments in the San Joaquin Valley, Calif. 49

18. Alluvial deposits of the Eel, Van Duzen, and Mad Rivers, Humboldt County, Calif. 54

19. Sediments from Beaverdam Creek basin, Maryland 55

20. Alluvial deposits of the Santa Ynez River basin, California 56

21. Alluvium in Napa and Sonoma Valleys, Calif. 57

22. Unconsolidated materials in the Little Bighorn River valley, Montana 58

23. Used to estimate total ground-water storage capacity in the Putah area, California 60

24. Values used in coastal plain of Los Angeles County, Calif. 62

25. Alluvium from Rechna Doab, West Pakistan 63

26. Water-bearing sediments in the Sacramento Valley, Calif. 65

27. Alluvial deposits in the Humboldt River valley, Humboldt County, Nev. 66

28. Unconsolidated alluvium 68

29. Compilation of specific yields for various materials 70

USGS Water Supply
Paper 1662-D
1967

HYDROLOGIC PROPERTIES OF EARTH MATERIALS

SPECIFIC YIELD—COMPILATION OF SPECIFIC YIELDS FOR VARIOUS MATERIALS

By A. I. Johnson

ABSTRACT

Specific yield is defined as the ratio of (1) the volume of water that a saturated rock or soil will yield by gravity to (2) the total volume of the rock or soil. Specific yield is usually expressed as a percentage. The value is not definitive, because the quantity of water that will drain by gravity depends on variables such as duration of drainage, temperature, mineral composition of the water, and various physical characteristics of the rock or soil under consideration. Values of specific yield, nevertheless, offer a convenient means by which hydrologists can estimate the water-yielding capacities of earth materials and, as such, are very useful in hydrologic studies.

The present report consists mostly of direct or modified quotations from many selected reports that present and evaluate methods for determining specific yield, limitations of those methods, and results of the determinations made on a wide variety of rock and soil materials. Although no particular values are recommended in this report, a table summarizes values of specific yield, and their averages, determined for 10 rock textures. The following is an abstract of the table:

Specific yields, in percent, of various materials

[Rounded to nearest whole percent]

Material	Number of determinations	Specific yield		
		Maximum	Minimum	Average
Clay	15	5	0	2
Silt	16	19	3	8
Sandy clay	12	12	3	7
Fine sand	17	28	10	21
Medium sand	17	32	15	26
Coarse sand	17	35	20	27
Gravelly sand	15	35	20	25
Fine gravel	17	35	21	25
Medium gravel	14	26	13	23
Coarse gravel	14	26	12	22

INTRODUCTION

PURPOSE AND SCOPE

The purpose of this report is to assist hydrologists in estimating the quantity of water in storage in ground-water reservoirs by providing

a compilation of specific yields representative of a variety of aquifer materials. The data presented here were compiled from published reports which have presented specific yields in relation to the texture of rock and soil materials. No attempt is made to evaluate the specific-yield data, but a table summarizes the published values for the convenience of the reader.

Not all specific yields from all published reports are listed in this report. However, this report does present a representative cross section of the publications noted as a result of rather lengthy library research. Along with pertinent tables or illustrations of data on specific yield, those parts of the text describing special methodology or the limitations of the data are quoted directly from each publication. Also presented are brief descriptions of all laboratory and field methods for determining specific yield and specific retention, to assist the reader in understanding the data compiled herein.

This report was prepared as a part of the specific-yield research studies made by the U.S. Geological Survey in cooperation with the California Department of Water Resources. The research testing was done at the Hydrologic Laboratory of the U.S. Geological Survey at Denver, Colo. The project was under the general supervision of Fred Kunkel, then district geologist of the Ground Water Branch of the Survey, Sacramento, Calif., and was under the direct supervision of A. I. Johnson, chief of the Hydrologic Laboratory.

DEFINITION OF TERMS

Most rock or soil materials contain interstices, or void spaces. The space commonly is described quantitatively by a property known as porosity. Porosity is defined by the American Society for Testing and Materials (1961) as the ratio, usually expressed as a percentage, of the volume of voids of a given soil mass to the total volume of the soil mass. For all practical purposes, ground water fills all void spaces in the saturated zone. From the previous definition, therefore, it follows that porosity is a measure of the quantity of water contained per unit volume (Todd, 1959).

Not all water contained in the saturated zone can be removed from the rock or soil by drainage or by pumping wells. Gravity ground water is that part of the water that will drain by gravity and thus be available to wells. That part of the water retained by molecular and surface tension forces in the void spaces of the rock and soil materials usually is known as retained water. The water-yielding capacity and water-retaining capacity of rock or soil materials are known as specific yield and specific retention. The specific yield plus the specific retention of a rock or soil is equal to the porosity of the rock or soil.

Meinzer (1923a, p. 28) defined the specific yield (ω_y) of a rock or soil, with respect to water, as the ratio of the volume of water that will drain by gravity from a saturated rock to the total volume of the rock, This ratio usually is expressed as a percentage.

Because specific yield represents the void space that will yield water to wells and is effective in furnishing water supplies, it is also known as effective porosity. However, because of the possible confusion with similar terms with slightly different meanings used by soil scientists (who also occasionally call it "noncapillary porosity") and by petroleum geologists, the term "specific yield" is preferred by the author and is used in this report exclusively.

The specific retention (ω_r) of a rock or soil, with respect to water, has been defined by Meinzer (1923a, p. 28) as the ratio that will be retained against gravity drainage from a saturated rock to the total volume of the rock. It usually is expressed as a percentage. Soil scientists and engineers use a similar measure called "water-holding capacity," but it is expressed as a percentage of the dry weight rather than of the volume. Water-holding capacity is defined (Am. Soc. Testing Materials, 1961, p. 1418) as "the smallest value to which the water content of a soil can be reduced by gravity drainage." The water-holding capacity can be converted to specific retention by multiplying by the dry unit weight of the rock or soil and then dividing by the unit weight of the water.

ACKNOWLEDGMENTS

Valuable information on publications suitable for this report was provided by Robert T. Bean, Hal C. Hanson, Helen J. Peters, and Raymond Richter of the California Department of Water Resources, and by Joseph F. Poland, U.S. Geological Survey, all of Sacramento, Calif. Their assistance is gratefully acknowledged.

SOME FACTORS AFFECTING SPECIFIC YIELD

Meinzer (1923b, p. 52) indicated that the distinction between gravity water and retained water is not definitive, because the quantity of water that will drain from a rock or soil material depends on the length of time the rock or soil is allowed to drain, on the temperature and the mineral composition of the water—both of which affect its surface tension, viscosity, and specific gravity—and on various physical characteristics of the rock or soil under consideration. He noted (1923a, p. 29), for example, that a smaller proportion of water will drain from a short sample than from a long sample of the same material because a larger proportion of the short sample will remain sat-

263-312 O—67——2

urated as part of the capillary fringe. Meinzer pointed out that methods for determining specific yield have been so little standardized that specific-yield data always should be accompanied by a statement indicating the methods used and, particularly, the size of sample and the period of draining under consideration.

The quantity of water yielded to wells from a body of saturated rock or soil thus depends upon the specific yield of the rock or soil and not on its porosity. For example, the specific yield is 8 percent if a volume of saturated rock 10 feet thick and 100 feet square (100,000 cu ft) will supply 60,000 gallons (8,000 cu ft) of water when drained by pumping wells. If the rock still retains a total of 13,000 cubic feet of water in its void spaces after drainage, its specific retention would be 13 percent and its porosity would be 21 percent (8+13). Certain materials, such as clay, have high porosities and, thus, are capable of holding large quantities of water but yield only a small part of it under gravity drainage, even after a long period of time; consequently, these materials usually are worthless as aquifers.

The effect of duration of drainage upon specific yield has been noted by a number of hydrologists. Meinzer (1923b, p. 65) stated that most of the gravity water in a rock or soil material is yielded early in the drainage cycle but that there is apparently almost no limit to the duration that the slow draining will continue. He noted that fine-textured materials not only yield less water than coarse-textured materials but also yield it more slowly. He also indicated that, for most water-bearing materials, the volume of water drained by the rapid lowering of the water table in the immediate vicinity of a heavily pumped well is definitely much less than the total that would be yielded by long-term draining, but that the draining that accompanies the annual fluctuation of the water table is virtually complete.

Williams and Lohman (1949, p. 213, 220) stated that the true value of specific yield is obtained only after the saturated material has been drained for a long period of time. Using pumping-test methods in the field, the above authors concluded that their laboratory determination of about 25 percent specific yield were probably correct and that the apparent specific yield of 15 percent obtained near the beginning of the pumping period would have increased to about 19 percent by the end of the second year of pumping and probably would have reached the true value of 25 percent sometime during the third year of pumping. A report by Prill, Johnson, and Morris (1965, p. 51) presents quantitative information on the phenomenon of time-of-drainage effects on specific yield, as determined by laboratory drainage of long columns of material. These authors concluded that, even for sand-size materials, a period of 2 months to more than 1 year would be required

for the drainage to reach equilibrium and, thus, give the maximum specific yield.

METHODS OF DETERMINING SPECIFIC YIELD

The specific yield of the rock or soil materials composing the zone of water-table fluctuation must be determined in order to estimate the available water supply represented by each increment of rise in the water table during a period of recharge. The specific yield is also needed to estimate the water supply obtainable from the materials for each increment that the water table is lowered. Although most field methods determine specific yield directly, most laboratory methods determine specific retention, and specific yield is found indirectly by subtracting the specific retention from the porosity.

Todd (1959, p. 24) stated that all methods have limitations—laboratory samples may be disturbed or may not be representative. The measurement and control of variables in field tests is difficult and many estimates lack accuracy.

Tolman (1937, p. 482) noted that "perhaps the greatest difficulty in the application of quantitative methods lies in the variability in the texture and hence in the hydrologic properties of the water-bearing materials. The hydrologic properties vary greatly, even with apparently slight differences in texture. Hence the ordinary geologic descriptions are quite inadequate for hydrologic purposes, and quantitative descriptions based on laboratory determinations have become essential."

During the past 6 or 7 decades, a number of laboratory and field methods have been developed for the determination of specific yield or specific retention. However, from the early 1900's until the writer started the specific-yield research project discussed in the report by Johnson, Morris, and Prill (1961), little work had been done by hydrologists in this country to determine specific yield by laboratory methods. To assist the reader in understanding the data compiled in this report, the various laboratory and field methods for determining specific yield are summarized briefly in the following paragraphs. (Also see Meinzer, 1923b, p. 53–76.)

LABORATORY METHODS

SAMPLE SATURATION AND DRAINAGE

The method of sample saturation and drainage consists of draining columns of saturated materials by gravity and determining both the volume of material drained and the volume of water yielded. The volume of water yielded can be measured directly or can be computed from the porosity and the moisture content after draining, but the

columns must be long enough to avoid having an undue percentage of the column occupied by the capillary fringe. Meinzer (1932, p. 114) pointed out that care must be taken to prevent loss by evaporation and that the tests must be made at a uniform temperature or corrections for temperature variations must be applied. Because drainage continues for a long time at a diminishing rate, Meinzer also noted that the specific yield should be determined for specific periods of drainage.

As early as 1892 Hazen studied the water-retaining and water-yielding capacities of filter sands as related to their particle size. By alternately saturating and draining different-size sands, he found that the amount of water retained after the sand had drained increased as the particle size decreased. He found that the percentage of water retained by the fine materials was greater in the lower part of the bed than in the upper part. He explained this by stating that the height to which capillary attraction was effective was in inverse proportion to the square of the effective size of particles.

King (1899) published results of tests of the water-yielding and water-retaining capacities of five different sizes of sand. Five galvanized-iron cylinders 8 feet long and 5 inches in diameter were filled with sand, and water was introduced at the bottom of each cylinder until the sand was saturated. The columns were then allowed to drain for a period of 2½ years. Discharged water was measured or weighed at frequent intervals initially, and later only every few days, weeks, or months. At the conclusion of the tests, the quantity of water remaining in each 3-inch-thick layer of sand was determined. The results of King's tests showed discrepancies of about 5–7 percent between the porosity (representing the total water content possible under saturated conditions) and the total quantity of water accounted for. King's tests seemed to give lower values for specific retention than Hazen's tests, especially for the coarser samples.

Meinzer (1923b, p. 57) stated that the results obtained by Hazen and King are inadequate and cannot be used as a reliable basis for very definite conclusions as to water-yielding capacity. He concluded that many more tests of the same sort obviously were needed.

More recently, Johnson, Prill, and Morris (1963) made a detailed study of the column-drainage method and determined many of the factors affecting specific yield as determined by this method.

After a standard method was developed for packing columns of porous media (Morris and Kulp, 1961), the research determined that the column diameter (1- to 8-in.) made little difference in the moisture distribution after drainage, that the drainage characteristics made little difference when the media were cleaned with acid, and that similar results were obtained no matter what procedure was used for saturating the media. The distribution of moisture after drainage was similar when any one of four designs of column was used for the tests. Later research (Prill, Johnson, and Morris, 1965) studied the effect of time on column drainage and concluded that even for the sand-size materials used in the study, a very long time would be required to reach drainage equilibrium.

CORRELATION WITH PARTICLE SIZE

Particle-size analysis can be considered as one method of estimating specific yield. By determining the specific retention by some other method and the effective size, or median diameter, by particle-size analysis, the relation of the two can be graphically represented by a curve (Meinzer, 1923b, p. 64). By determining the effective size, or median diameter, of a sample and referring to the curve, the approximate specific retention can be obtained. After determining the porosity, the specific yield can then be obtained, as mentioned before. Probably, at best, this method represents a speedy but only approximate means for estimating specific yield.

Briggs and Shantz (1912, p. 72) determined the water-holding capacity by interpreting particle-size analyses and developed the following equation: Water-holding capacity = (0.03 sand + 0.35 silt + 1.65 clay) + 21, where the water-holding capacity and the sand, silt, and clay are expressed as percentages of the weight of the dry sample. Middleton (1920, p. 160) developed several similar equations which appeared to provide more precise relations than those of Briggs and Shantz.

As a part of the specific-yield-research study discussed earlier, Prill and Johnson (unpub. data, 1966) developed a relation between specific yield and soil texture for samples from the San Joaquin and Antelope Valleys, Calif. The data are shown by lines of equal specific yield on a trilinear graph of textural classification (fig. 1). The specific yields were determined by both laboratory and field methods, and the textural classes were determined by particle-size analysis of samples.

CENTRIFUGE-MOISTURE EQUIVALENT

Specific yield can also be estimated from the centrifuge-moisture equivalent. The latter is defined as the moisture content of a soil after it has been saturated with water and then subjected for 1 hour to a force equal to 1,000 times that of gravity (Am. Soc. Testing Materials, 1961, p. 1404). The centrifuge-moisture equivalent is multiplied by the dry unit weight of the soil and divided by the unit weight of water to obtain the moisture equivalent, expressed as a percentage of the volume.

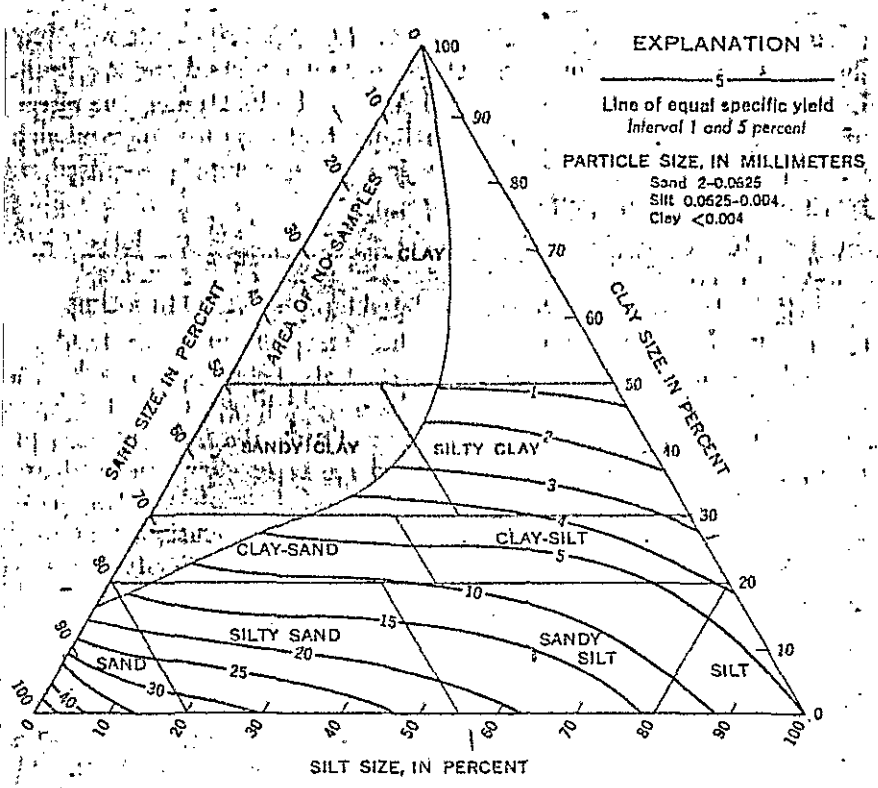


FIGURE 1.—Soil-classification triangle showing relation between particle size and specific yield.

The concept of moisture equivalent was introduced by Briggs and McLane (1907) by determinations made on more than 100 soils of the moisture retained under a centrifugal force 3,000 times the force of gravity. Stearns (1927) pointed out that the moisture-equivalent method is based on the theory of applying a centrifugal force great enough to reduce the capillary fringe enough that it can be ignored without introducing much error, even in small samples, and yet not so great as to withdraw a large proportion of the water that is held more securely above the capillary fringe. Stearns noted that if a material will lift water 100 inches by capillarity acting against gravity, the material will theoretically be able to hold the water only 0.1 inch against a centrifugal force that is 1,000 times greater than the force of gravity. Prill (1961) discussed this relation in more detail and pointed out that water retention after centrifuging is comparable to that obtained by gravity drainage of long columns.

Briggs and McLane (1907) made their early determinations under a centrifugal force of 3,000 times gravity, but in a later publication Briggs (1910) suggested that a force 1,000 times gravity could be used.

In 1912 Briggs and Shantz conducted moisture-equivalent tests employing a force 1,000 times gravity, and since then, that force has been accepted as standard by most investigators, including the U.S. Bureau of Public Roads (1942), American Society for Testing and Materials (1961), and American Association of State Highway Officials (1942). However, many studies have been made since 1912 concerning the relation of many other factors to the moisture equivalent obtained.

Considerable experimental work has indicated that for at least some medium-textured materials the moisture equivalent approximately equals specific retention. Israelson (1918) stated that correlations between the moisture equivalent and the water retention after irrigation closely correspond. In 1933 Piper determined a relation (fig. 2) between centrifuge-moisture equivalent and specific retention, as determined by the field drainage of long columns of various materials. Since that time, the centrifuge-moisture equivalent, as a percentage of the volume, has been adjusted to specific retention by multiplying by the ratio-correction factor determined by Piper (1933). This value is then subtracted from the porosity to obtain the specific yield.

In 1963 Johnson, Prill, and Morris reported a detailed study of the centrifuge-moisture-equivalent method. This research showed, for example, that the effect of temperature was of sufficient magnitude to warrant establishment of a standard temperature for the test (Prill and Johnson, 1959). Since 1959, centrifuge-moisture equivalents determined by the Hydrologic Laboratory have been made at a constant temperature of 20°C., and the American Society for Testing and Materials now (1966) has adopted this temperature as their standard for the test. (Prill and Johnson, 1966).

MOISTURE-TENSION TECHNIQUES

Moisture tension has been defined as the equivalent negative gage pressure, or suction, in the soil moisture. It is equal to the equivalent negative pressure to which water must be subjected to be in hydraulic equilibrium—*through a porous permeable plate or membrane*—with the water in the soil.

For tensions less than one atmosphere, the moisture-tension relations are determined by porous-plate apparatus consisting of a light-duty pressure chamber in which porous ceramic plates are installed. An air compressor maintains the air within the pressure chamber at a value equivalent to a given tension force.

Duplicate samples of the soil, retained in ½-inch-high plastic rings, are placed on the porous plates in the pressure chamber and are al-

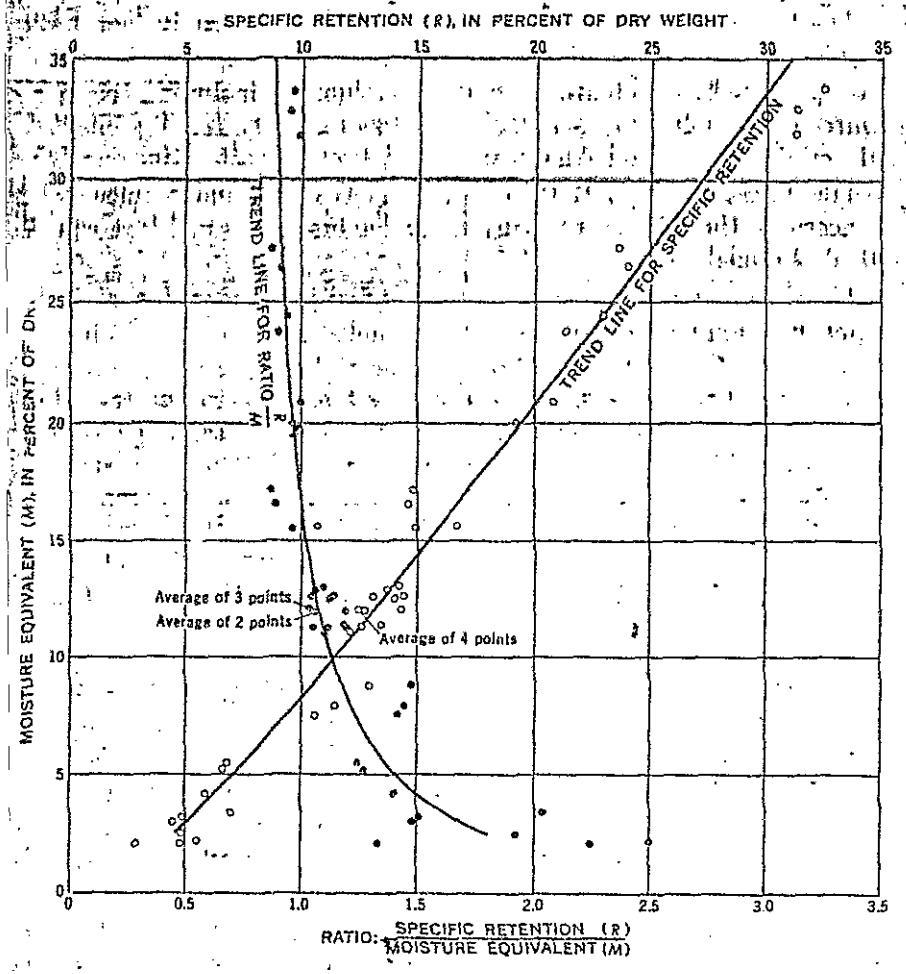


FIGURE 2.—Relation of moisture equivalent to specific retention. (After Piper, 1933.)

lowed to saturate by capillary action. The samples are subjected to a pressure equivalent to the desired tension until the water outflow from the pressure chamber has attained equilibrium. The samples are then removed from the pressure chamber, and the moisture content, by weight, is determined.

The moisture content at 1/10- to 1/3-atmosphere tension has been considered as approximately equivalent to the field capacity (Coleman, 1947; Richards and Weaver, 1944), which if converted to moisture content by volume, would approximate specific retention. Prill and Johnson (1967) investigated moisture-tension techniques in detail in the interest of applying these techniques to the routine determination of specific retention. They found, for example, that the

moisture distribution in porous media as determined by moisture-tension techniques was comparable to that determined by gravity drainage of long columns.

Petroleum-reservoir engineers have used a mercury-injection method (Purcell, 1949) to determine the variation of capillary pressures (somewhat similar to moisture tensions) above the water table. The Hydrologic Laboratory currently is studying the adaptability of this method to the estimation of specific retention and specific yield.

FIELD METHODS

FIELD SATURATION AND DRAINAGE

The field saturation and drainage method is similar in principle to the laboratory method. Meinzer (1932, p. 115) indicated that a plot of land should be selected where the water table and capillary fringe are at sufficient depth below the surface to permit gravity drainage. The material underlying the plot should then be thoroughly wetted and allowed to drain, and care should be taken to avoid all possible evaporation. After a sufficient period of drainage, samples are taken for determination of moisture content and porosity, and the specific yield is computed as the difference between these two.

Israelson (1918) conducted a series of field tests of the water-retaining capacities of different-type soils in Sacramento Valley, Calif. His method was to determine the porosity of the different soils and their water content at successive depths immediately before irrigation and again about 4 days after irrigation. This second determination gave the approximate specific retention to be expected in a limited drainage time.

SAMPLING AFTER LOWERING OF WATER TABLE

After appreciable lowering of the water table, samples are collected from the zone immediately above the capillary fringe. The moisture content and porosity of the samples are determined, and the specific retention and specific yield are calculated. Meinzer (1932, p. 116) cautioned that, when making tests of this kind, it is essential to ascertain that the part of the deposit from which the sample is taken has not received any recent contribution of water from rain or irrigation, or that it has not been exposed to evaporation or to absorption by plants—both of which consume water that is retained against gravity by molecular attraction.

Experiments were made by Lee (Ellis and Lee, 1919) on samples of fill from the major stream valleys of San Diego County, Calif. His method was to collect samples immediately above the capillary fringe after the water table had been appreciably lowered, as commonly hap-

263-312 O—67——3

ens in summer and autumn. Johnson and Kunkel (1963) discussed the esults of this method in conjunction with moisture-content determi-ation by nuclear meter, to determine the specific yield in the area of vater-table lowering in the immediate vicinity of a large well field ear Fresno, Calif. They found that the moisture distribution deter-nined by this field method could be closely reproduced by data obtained v the centrifuge, moisture-tension, and column-drainage techniques in laboratory.

PUMPING METHOD

This method consists of lowering of the water table by pumping measured volume of water and then determining the volume of sedi-nents drained. The specific yield is then obtained as the ratio of the volume of water pumped to the volume of sediments drained (Meinzer, 932).

Pumping water from a well lowers the piezometric surface around he well and creates a cone of depression. In a carefully controlled umping test, data are obtained on rate of discharge, water levels, nd duration of pumping. The drawdown data are then used in various ormulas to calculate the magnitude of one of the most important ydraulic characteristics of an aquifer—the coefficient of storage. Venzel (1942, p. 87) defined the coefficient of storage as the cubic feet f water discharged from each vertical column of the aquifer with a ase 1 foot square as the water level falls 1 foot. For water-table condi-ions, the coefficient of storage is equal to the specific yield of the ma-erial de-watered during the pumping. For artesian conditions the oefficient is equal to the water obtained from storage by compression f a column of water-bearing material whose height equals the thick-ess of the water-bearing material and whose base is 1 foot square.

Thiem (1906) apparently was the first hydrologist to develop a ormula to determine aquifer characteristics by a well-pumping nethod. However, the greatest advance in aquifer analysis by well ydraulics was probably made through the development of the non-quilibrium formula by Theis (1935). The theory advanced by Theis ntroduced both the time factor and the coefficient of storage. Since 935, many modifications of formulas or methods of interpretation, ave been developed.

Methods for computing storage coefficient (specific yield) by the umping method were described in detail by Wenzel (1942), Ferris 1948), Brown (1953), Bruin and Hudson (1955), Remson and Lang 1955), Ramsahoye and Lang (1961), and Ferris, Knowles, Brown, nd Stallman (1962). Most of the methods are based on the following ssumptions: (a) The aquifer is homogenous and isotropic, (b) the aquifer has infinite areal extent, (c) the discharging well penetrates and receives water from the entire thickness of the aquifer, (d) the well diameter is infinitesimal, and (e) water removed from storage is discharged instantaneously with the decline of head. Although very few field conditions meet these specified limitations, successful application of the pumping method seems to be possible for many ground-water problems. Ferris (1948) pointed out that these methods can assist in the interpretation of local geology, but he also emphasized that any discrepancy between the hydraulic and geologic evidence in a given problem is untenable and points to incorrect interpretation of either or both sets of data.

Specific yield can also be estimated from moisture contents determined by sampling or by nuclear-meter logging in the cone of depression around a pumped well.

RECHARGE METHOD

The recharge method is the converse of the pumping method and consists of observing the seepage losses from streams or canals, or determining the amount of water recharged into an aquifer through a recharge well, and making corresponding observations on the resulting rise of the water table. From these observations, the volume of sediments saturated by the measured recharge is determined, and the specific yield can be computed (Meinzer, 1932, p. 116).

Moulder and Frazor (1957) used the recharge method to analyze aquifer characteristics near Amarillo, Tex., and found that water levels may have risen as much as 5 feet during a 4-month recharge period. Moulder noted that slow drainage or slow filling of sediments with water made the data collected early in the test unusable for analysis by the nonequilibrium method. He concluded that conformance to theoretical conditions requires longer periods of time at greater distances from the pumping or recharging well.

Sniegocki (1963) made a detailed study of the fundamental principles of artificially recharging aquifers through wells. Results of his study show that recharge data may be satisfactory for calculating absolute values for hydraulic characteristics, such as the specific yield (or coefficient of storage), for an aquifer. He concluded (Sniegocki, 1963, p. 22–23) that, if under certain conditions the field situation is readily adaptable for a recharge test, the testing period generally required to determine absolute hydraulic constants could be shortened as much as 90 percent. He noted that the coefficient of storage (specific yield) for the aquifer in his study was 0.30 (30 percent) after cyclical recharge for about 9 days; whereas, in the discharge situation,

a value of 0.30 could not be obtained until pumping had continued for more than 100 days. Meinzer suggested earlier (1932, p. 136) that "better results can doubtless be obtained, however, if the specific-yield test is made during a period immediately after the well has been shut down, when the quantity of water taken into storage in the cylinder [cone of depression] will be equal to the total inflow during the period and the volume of material saturated can be computed from the rise of the water levels."

REVIEW OF LITERATURE

The following paragraphs present the results of library research to compile a list of specific yields for rock and soil materials of various textures. Pertinent parts of the publications describing the methods or limitations of the data have been quoted. All the following text is direct or only slightly modified quotation. Additions to quotations are indicated by brackets, and omissions are indicated by asterisks. Figure and table numbers, however, have been changed to fit their order of appearance in this report.

Clark, W. O., 1917, Ground water for irrigation in the Morgan Hill area, California, in Contributions to the hydrology of the United States, 1916: U.S. Geol. Survey Water-Supply Paper 400, p. 82–83.

The alluvium is composed, according to 69 well logs, of about 69 percent clay, 29 percent gravel, and 2 percent sand. From the available data on porosity * * * it has been concluded that the porosity of the sand and gravel is about 35 percent of its volume, that of the clay 32 percent, and that of the alluvium as a whole about 33 percent.

The vital question in this connection is not so much the total porosity of the materials and the total quantity of ground water present as the quantity of water that these materials will yield under a pump. Different materials by no means give up water to a pump in the proportion of the total water they contain. Fine materials are usually better sorted than coarser materials and therefore when saturated they may contain even more water than the coarser materials, but they permanently retain a large percentage of this water, whereas the coarser materials readily part with a large percentage of their water content. The fine materials are therefore of comparatively little value as water producers and the coarse materials are the important water-bearing formations.

The following table [table 1] shows the relative amount of water retained by sands of different degrees of fineness.

It will be seen from this table that the coarsest of the five sands tested gives up a quantity of water equal to 32.29 percent of the total volume of the sand, or somewhat more than 83 percent of the water it contains. The gravel and sand of the Morgan Hill district are on the whole considerably coarser than this sand and would give up a larger proportion of their water. For purposes of calculation it is assumed that they would give up about 90 percent of their total water content. If the alluvium includes 29 percent of gravel and 2

TABLE 1.—*Quantity of water retained and given up by different sands that were drained for 2½ years*

[Based on tables given by King (1899)]

Effective diameter of sand grains, in millimeters	Porosity of sands, expressed in percentage of total volume	Quantity of water retained, expressed in percentage of total volume of the sands	Quantity of water given up by the saturated sands, expressed in percentage of total volume of the sands
0.47	38.86	6.57	32.29
.18	40.07	7.37	33.70
.16	40.76	10.35	30.41
.12	40.57	12.49	28.08
.08	39.73	14.09	25.64

percent of sand, these materials will hold a quantity of water equal to 10.85 percent of the total volume of the saturated alluvium; if they will yield 90 percent of this water they will furnish a quantity of water equal to 9.77 percent of the total volume of the saturated alluvium [table 2]. The clays form about 69 percent of the alluvium, and their average porosity is about 33 percent of their total volume. Clays give up a very small percentage of the water they contain. It is stated by King [1899] that clays of fine texture may retain as much as 32 percent of their dry weight of water.

TABLE 2.—*Specific yields for alluvial deposits in the Morgan Hill area, Santa Clara Valley, Calif.*

Material	*Specific yield (percent)*
Gravel, with sand	10
Clay loam	2

The materials called clay in the Morgan Hill area are not true clays but perhaps more nearly clay loam, so that the quantity of water they retained would be considerably less than that retained by fine clay. The porosity of fine clays would be greater, but the clays from which the porosity data here used were obtained were not true clays, and hence it is believed that their average porosity represents the porosity of the clays of the Morgan Hill area. It is thought that 90 percent of the amount required for saturation is a liberal estimate for the quantity of water retained by the clays of the Morgan Hill area—that is, they would give up 10 percent of the amount required to saturate them. As about 69 percent of the alluvium is clay and the porosity of this clay is taken as 33 percent of its volume, the pore space in the clay is equal to about 22.77 percent of the total volume of the alluvium. If it gives up 10 percent of the water required for saturation the clay would yield a quantity of water equal to 2.28 percent of the volume of the saturated alluvium [table 2]. The total water that the saturated alluvium will give up is therefore calculated to be 12.06 percent of its volume.

Ellis, A. J., and Lee, C. H., 1919, Geology and ground waters of the western part of San Diego County, California: U.S. Geol. Survey Water-Supply Paper 446, p. 121–123.

Experiments made by the writer on 36 samples from the fill of the major river valleys of San Diego County, the material varying from coarse sand to silt,

indicated total voids expressed as percent by volume as follows: Coarse sand, 39 to 41 percent; medium sand, 41 to 48 percent; fine sand, 44 to 49 percent; fine sandy loam, 50 to 54 percent. The average porosity of all 36 samples was 45.1 percent. The classification of materials is that used by the Bureau of Soils of the United States Department of Agriculture. These percentages represent the porosity of the material under natural condition as to size and arrangement of grains [table 3].

* * * * * * *

TABLE 3.—*Specific yields of valley-fill materials in San Diego County, Calif.*

Material	*Specific yield (percent)*
Coarse sand	34
Medium sand	37
Fine sand	37
Fine sandy loam	30

A certain proportion of the moisture that occupies the voids of any saturated porous material does not readily drain out, even when the zone of saturation has fallen below the depth from which the capillary rise of water is rapid. This moisture can not be extracted by pumping nor does it represent water that drains out and is replenished during the natural fall and rise of the water table. To determine the water-retaining capacity of various valley-fill materials, six experiments were made after the annual summer lowering of the water table had taken place. The water-retaining capacity was found to range from 6 to 10 percent in the coarse, medium, and fine sands, but no finer materials were examined where the depth to the water table was great enough to enable the field capacity to be determined with certainty. Etcheverry [1915], quoting from Widtsoe's extensive experiments, gives the water-retaining capacity of sandy loam as 14½ percent by weight, which is equal to about 22 percent by volume, and this percentage can be considered as representing roughly the condition in sandy loam soils of the major river valleys under consideration. The total volume of water that might be drained from the valley fill by the slow lowering of the water table can be estimated as ranging from about 33 to 37 percent by volume. Such complete drainage, however, requires considerable time, and the relatively quick drainage resulting from the artificial lowering of the water table by pumping undoubtedly represents the extraction of far less of the total water content. In practice the proportionate volume that could be extracted from the valley fill of the major valleys probably does not exceed 20 to 25 percent. * * *.

Stearns, H. T., Robinson, T. W., and Taylor, G. H., 1930, Geology and water resources of the Mokelumne area, California: U.S. Geol. Survey Water-Supply Paper 610, p. 151–172.

Experimental field tests were made on undisturbed soil columns to determine the specific yield of the soil directly above the water table. These soil columns were obtained during the fall, when the water table was at its lowest level. In this way a test was made of the soil within the belt of fluctuation of the water table.

A cylinder 18 inches in diameter and 36 inches long made of 16-gage galvanized iron was used for the tests. The cylinder was butt-jointed and riveted, and the joints were floated with solder and scraped smooth on the inside. A 3-inch iron collar was riveted and spot welded to the top of the cylinder to prevent damage

to the cylinder in driving it. The bottom outside edge of the cylinder was beveled with a file to facilitate driving, and three equally spaced holes were drilled near the top, through which wires were placed to lift it.

A 4-foot square pit was dug within 3½ or 4 feet of the water table. The cylinder was then driven into the bottom of the pit, and the soil was excavated around the cylinder as driving progressed. A driving cap of 2-inch planking was used on top and a 4 by 4 inch timber about 14 feet long, handled by two men, was used in a manner similar to a pile driver. Constant care was taken to keep the cylinder in a vertical position while it was being driven. Special care was taken as the soil neared the top of the cylinder to keep the soil from being compacted by the driving cap. Driving was stopped when the bottom of the cylinder was within a few inches of the water table. A strong flexible wire was then used to saw through the soil column at the bottom edge. Heavy wires were strung through the holes near the top of the cylinder by means of which the cylinder was lifted a fraction of an inch by either a lever or block and tackle. The cylinder was suspended only long enough to allow a 24 by 24 inch 16-gage galvanized-iron base plate to be slipped under it. If the soil was not compact enough to remain in the cylinder when lifted this much, the plate was forced under the cylinder by means of an automobile jack, special care being used to keep the plate flush with the bottom edge of the cylinder. The latter method proved to be the simpler of the two. The cylinder was then centered on the plate and leveled. It was found that for the base plate 12-gage galvanized iron is preferable to 16-gage.

Two 1½-inch holes were then drilled in the confined soil column about 4 inches from diametrically opposite sides of the cylinder. These holes were drilled to the bottom of the soil column with a wood auger welded to an extension handle. They were then cased with 1½-inch nickel-plated brass pipes. One of the pipes was perforated the entire length, except 6 inches on the upper end, and the other pipe was perforated only in the lower 6 inches. The perforations were one-sixteenth of an inch in diameter and were drilled in parallel rows about half an inch center to center. * * *.

Water was added to the soil in the cylinder by pouring it into the 1½-inch hole in which only the lower 6 inches of the casing was perforated. The water was removed from the cylinder by drawing it up into a glass tube or rubber hose, and the amount of water removed or added was measured in a glass graduate.

The distance to the water level in the small holes was measured with a steel tape from the bottom edge of a spirit level placed across the top of the cylinder. A small lead weight, with a blunt point, was placed on the end of the tape, and the measurement was taken when the point of the weight broke the mirror surface of the water in the 1½-inch holes. Measurements were made in one hole immediately after measurements had been made in the other, to ascertain whether or not the water table in the cylinder was level.

* * * * * *

* * * the resulting specific yield would have been larger and more nearly the actual specific yield if the time interval between changes of water in the cylinder had been greater. Experiments conducted the following year proved that an interval of several days is necessary to obtain accurate results.

Tests 1, 2, and 5 are completed, but the remainder of the tests are still in progress, and the data obtained will be given in a later report. Additional observations are necessary and may change the results given here, hence these data are of a preliminary nature and subject to revision [table 4].

To determine which grain diameter was the most representative, the average deviation of specific yield values within plus or minus one standard error of estimate was plotted against the representative grain diameter. * * * It indicates that a representative grain diameter of about D_{50} has the least degree of specific yield deviation.

* * * * * * * * * *

It appears that a maximum value of specific yield occurs with a D_{50} of between 0.4 and 0.6 of a millimeter. As the grain sizes become smaller beyond this point, the interstices also become smaller producing increased capillary forces. These increased forces result in greater retention of the water so that specific yield decreases. The large range in specific yield for any particular grain size can be largely attributed to variations in porosity.

A relationship between uniformity coefficient and grain size resulted in no definite conclusions. However, it was noted generally that, for the samples used in this study, the uniformity coefficient decreases as the grain size decreases. * * *.

The results * * * indicate that porosity has perhaps the greatest single effect upon specific yield. It appears that a peak specific yield of 32.5 percent occurs at a porosity of between 41 and 42 percent. After the peak the specific yield seems to diminish quite rapidly.

* * * * * * * * * *

[Table 28 was interpreted by A. I. Johnson from data in this report.] * * * The resulting colinear graph [fig. 19] shows the relation of D_{50} to specific yield for various porosities.

TABLE 28.—*Specific yields of unconsolidated alluvium*

Material	*Specific yield (percent)*
Coarse gravel	12
Medium gravel	13
Fine gravel	17
Gravelly sand	22
Coarse sand	28
Medium sand	28
Fine sand	23
Very fine sand	16
Silt	4

It is interesting to note that the family of lines has a characteristic shape. The range of specific yield is relatively broad for the same grain size. This broad range shows the importance of porosity. The flattening of the lines of porosity toward a constant specific yield value, always less than the porosity, indicates that specific retention approaches a finite value greater than zero.

SUMMARY

Table 29 summarizes the specific yields used in many of the previously listed investigations. A specific yield averaged from all values reported in the table also is reported for each texture of rock or soil material. The reported specific yields, in general, are representative of the ultimate amount of time for drainage. Corrections to lower values would have to be made for short drainage periods.

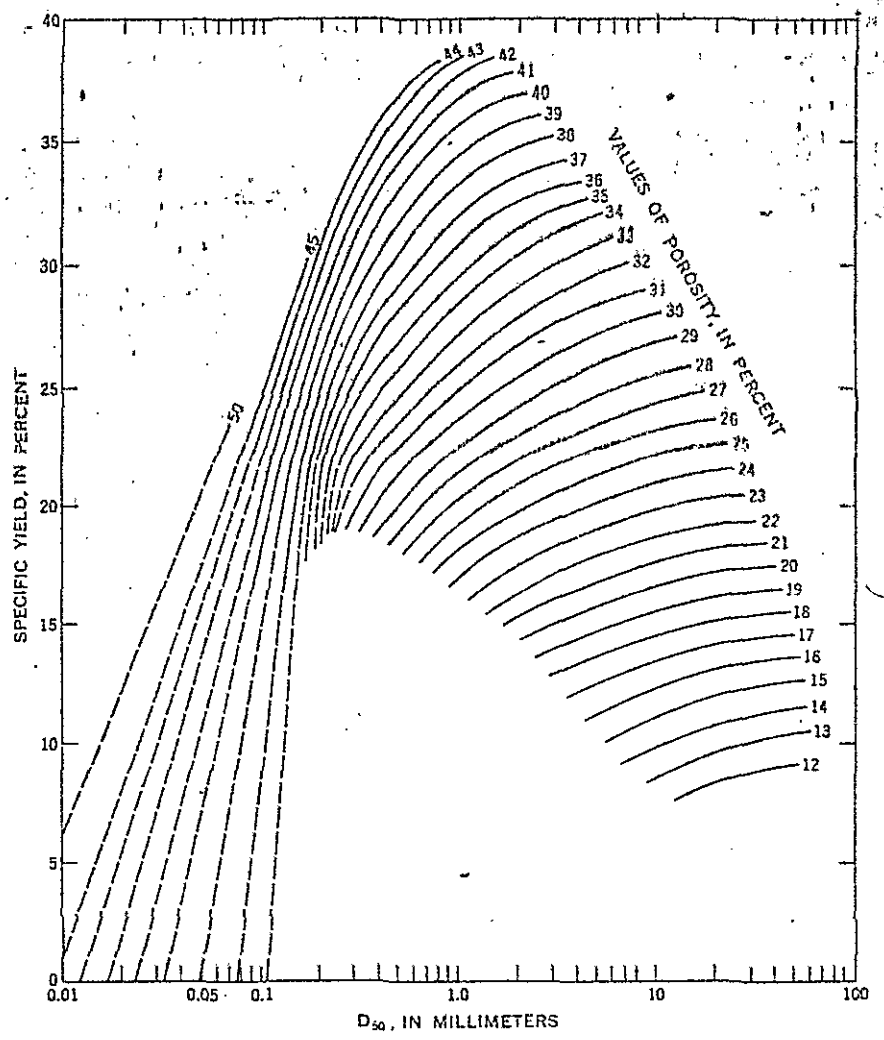


FIGURE 19.—Colinear plot of D_{50} to specific yield for various values of porosity. (After Preuss and Todd, 1963.)

It should be remembered that the textures listed are, in general, broad classifications based on the predominate particle size. One can observe that the highest specific yields tend to be around the medium and coarse sand texture—this is due to the fact that these sands normally have a more uniform size distribution than do the gravels or the finer sands, silts, and clays.

Research on specific yield completed by the Hydrologic Laboratory indicates that many of the specific yields used in the past—especially for fine-textured materials such as the silts, sandy clays, and fine sands—are too small. Johnson and Kunkel (1963) pointed out that this

USGS Water Supply Paper 1662-D 1967

TABLE 29.—*Compilation of specific yields for various materials*

[All values rounded off to nearest whole percentage]

Material	Valley fill, California (Eckis, 1934)	Stockdumb area, California (Piper and others, 1939)	South Yuba River basin, California (Upson and Thomasson, 1951)	Sacramento Valley, Calif. (Poland and others, 1949)	Smith River plain, California (Back, 1957)	Ventura County, Calif. (Calif. Water Resources Board, 1956)	Santa Margarita Valley, Calif. (Calif. Dept. Public Works, 1956)	Tia Juana Basin, Calif. (Calif. Water Rights Board, 1957)	San Luis Obispo County, Calif. (Calif. Water Resources Board, 1958)	San Joaquin Valley, Calif. (Davis and others, 1959)	Bureka area, California (Evenson, 1959)	Santa Ynez Basin, Calif. (Wilson, 1959)	Hesperia Dosh, Pakistan (Kazmi, 1961)	Napa-Sonoma Valleys, Calif. (Kunkel and Upson, 1960)	Humboldt River Valley, Nev. (Cohen, 1963)	Unconsolidated alluvium (Freeze and Todd, 1963)	Little Bighorn River valley, Montana (Mundorf and others, 1960)	Average specific yield
Clay	1	4	2	3	1	0	1	1	3	3	3	5	3	3	1			2
Silt	10	4	12	3	5	3	10	10	5	5	10	5	5	5	12	4	17	8
Sandy clay	10	4	12	10	10	5	5	5	5	10	10	10	17	10				7
Fine sand	21	26	12	20	15	25	26	25	25	25	20	20	28	20	26	28	22	21
Medium sand	31	28	30	20	25	25	28	30	25	25	20	30	28	29	28	28	22	26
Coarse sand	31	35	35	25	25	25	28	32	25	25	20		23	29	27	28	22	27
Gravelly sand	31	35	35	20	25	21	22	28	21	25	25	25	22	25	19	22	22	25
Fine gravel	27	35		25	25	21	22	28	21	25	25	25	26	25		17	22	25
Medium gravel	21			25	25	21	22	28	21	25	25	25	26	25		22	22	25
Coarse gravel	14			25	25	21	22	18	21	25	25	25	26	25		22	22	25

conclusion is indicated by specific yields obtained by various field tests as well as by the centrifuge, column-drainage, and moisture-tension tests in the laboratory. These authors also noted that the specific yield varies depending on the interrelation of textures; for example, a silt over a sand may not have as high a specific yield as would the same silt over a clay.

REFERENCES CITED

American Association of State Highway Officials, 1942, Standard specifications for highway materials and methods of sampling and testing: Am. Assoc. State Highway Officials, p. 178–179.

American Society for Testing and Materials, 1961, Standard definitions of terms and symbols relating to soil mechanics, *in* 1961 Book of ASTM standards: Am. Soc. Testing Materials, pt. 4, p. 1402–1419.

Back, William, 1957, Geology and ground-water features of the Smith River plain, Del Norte County, California: U.S. Geol. Survey Water-Supply Paper 1254, p. 43–45.

Briggs, L. J., 1910, Moisture equivalent determinations and their application: Am. Soc. Agronomy Proc., v. 2, p. 138–147.

Briggs, L. J., and McLane, J. W., 1907, The moisture equivalents of soils: U.S. Bur. Soils Bull. 45.

Briggs, L. J., and Shantz, H. L., 1912, The wilting coefficient for different plants and its indirect determination: U.S. Bur. Plant Industry Bull. 230, p. 1–82.

Brown, R. H., 1953, Selected procedures for analyzing aquifer test data: Am. Water Works Assoc. Jour., v. 45, no. 8, p. 844–866.

Bruin, Jack, and Hudson, H. E., Jr., 1955, Selected methods for pumping test analysis: Illinois Water Survey Rept. Inv. 25, 54 p.

California Department of Public Works, 1956, Santa Margarita River Investigation: California Div. Water Resources Bull. 57, v. 2, app., p. B65–B67.

California Department of Water Resources, 1961, Planned utilization of the ground water basins of the coastal plain of Los Angeles County: California Dept. Water Resources Bull. 104, app. A, p. 121, Attachment 2, p. 2–3, 2–4.

California Water Resources Board, 1956, Geology and ground water of Ventura County, California: California Water Resources Board, Ventura County Inv., Bull. 12, v. 2, app. B, p. 40–41.

———1958, Geology and ground water of San Luis Obispo County, California: California Water Resources Board, San Luis Obispo County Inv., app. B, p. 26–27.

California Water Rights Board, 1957, Determination of specific yield and storage capacity: California Water Rights Board Spec. Rept. 2 of Referee Tia Juana Basin, app. C., p. C12–C23.

Clark, W. O., 1917, Ground water for irrigation in the Morgan Hill area, California, *in* Contributions to the hydrology of the United States, 1916: U.S. Geol. Survey Water-Supply Paper 400, p. 61–105.

Cohen, Philip, 1963, Specific-yield and particle-size relations of Quaternary alluvium, Humboldt River valley, Nevada: U.S. Geol. Survey Water-Supply Paper 1669-M, p. 20–23.

Coleman, E. A., 1947, A laboratory procedure for determining the field capacity of soils: Soil Sci., v. 63, p. 277–283.

Davis, G. H., Green, J. H., Olmsted, F. H., and Brown, D. W., 1959, Ground-water conditions and storage capacity in the San Joaquin Valley, California: U.S. Geol. Survey Water-Supply Paper 1469, p. 206–210.

Eckis, Rollin, 1934, Geology and ground water storage capacity of valley fill: California Div. Water Resources Bull. 45, p. 91–246.

Ellis, A. J., and Lee, C. H., 1919, Geology and ground waters of the western part of San Diego County, California: U.S. Geol. Survey Water-Supply Paper 446, p. 121–123.

Cheverry, B. A., 1915, Irrigation practice and engineering: New York, McGraw-Hill Book Co., v. 1, p. 4.

Evenson, R. E., 1959, Geology and ground-water features of the Eureka area, Humboldt County, California: U.S. Geol. Survey Water-Supply Paper 1470, p. 35.

Ferris, J. G., 1948, Ground-water hydraulics as a geophysical aid: Michigan Geol. Survey Tech. Rept. 1, 23 p.

Ferris, J. G., Knowles, D. B., Brown, R. H., and Stallman, R. W., 1962, Theory of aquifer tests: U.S. Geol. Survey Water-Supply Paper 1536–E, 174 p.

Hazen, Allen, 1892, Experiments upon the purification of sewage and water at the Lawrence Experiment Station: Massachusetts State Board of Health, 23d Ann. Rept., 1891, p. 428–434.

Israelsen, O. W., 1918, Studies in capacities of soils for irrigation water: Jour. Agr. Research, v. 13, p. 1–28.

Johnson, A. I., and Kunkel, Fred, 1963, Some research related to ground-water recharge—A progress report from the U.S. Geological Survey: Ground-water Recharge and Ground-water Basin Management Biennial Conf., Proc., California Univ., Berkeley, 17 p.

Johnson, A. I., Morris, D. A. and Prill, R. C., 1961, Specific yield and related properties—An annotated bibliography: U.S. Geol. Survey open-file report, 245 p.

Johnson, A. I., Prill, R. C., and Morris, D. A., 1963, Specific Yield—Column drainage and centrifuge moisture content: U.S. Geol. Survey Water-Supply Paper 1662–A, 60 p.

Kazmi, A. H., 1961, Laboratory tests on test drilling samples from Rechna Doab, West Pakistan, and their application to water resources evaluation studies: Athens, Internat. Assoc. Sci. Hydrology Pub. 57, p. 496, 500.

King, F. H., 1899, Principles and conditions of the movements of ground water: U.S. Geol. Survey 19th Ann. Rept., pt. 2, p. 86–91.

Krul, W. F. J. M., and Liefrinck, F. A., 1946, Recent ground-water investigations in the Netherlands: Monograph on the progress of research in Holland, New York-Amsterdam, Elsevier Publishing Co., 78 p.

Kunkel, Fred, and Upson, J. E., 1960, Geology and ground water in Napa and Sonoma Valleys, Napa and Sonoma Counties, California: U.S. Geol. Survey Water-Supply Paper 1495, p. 64–65, 78–79.

Lugn, A. L., and Wenzel, L. K., 1938, Geology and ground-water resources of South-Central Nebraska: U.S. Geol. Survey Water-Supply Paper 779, p. 89–96.

Meinzer, O. E., 1923a, Outline of ground-water hydrology, with definition: U.S. Geol. Survey Water-Supply Paper 494, 71 p.

———1923b, The occurrence of ground water in the United States, with a discussion of principles: U.S. Geol. Survey Water-Supply Paper 489, 321 p.

———1932, Outline of methods for estimating ground-water supplies: U.S. Geol. Survey Water-Supply Paper 638–C, 144 p.

Middleton, H. E., 1920, The moisture equivalent in relation to the mechanical analysis of soils: Soil Sci., v. 9, no. 2, p. 159–167.

Morris, D. A., and Kulp, W. K., 1961, Mechanical uniform packing of porous media in Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424–D, p. D31–D32.

Moulder, E. A., and Frazor, D. R., 1957, Artificial-recharge experiments at McDonald well field, Amarillo, Texas: Amarillo, Texas Board Water Engineers Bull. 5701, 34 p.

Moulder, E. A., Klug, M. F., Morris, D. A., and Swenson, F. A., 1960, Geology and ground-water resources of the lower Little Bighorn River valley, Big Horn County, Montana: U.S. Geol. Survey Water-Supply Paper 1487, p. 42–43.

Olmsted, F. H., and Davis, G. H., 1961, Geologic features and ground-water storage capacity of the Sacramento Valley, California: U.S. Geol. Survey Water-Supply Paper 1497, p. 150–152.

Piper, A. M., 1933, Notes on the relation between the moisture equivalent and the specific retention of water-bearing materials: Am. Geophys. Union Trans., v. 14, p. 481–487.

Piper, A. M., Gale, H. S., Thomas, H. E., and Robinson, T. W., 1939, Geology and ground-water hydrology of the Mokelumne area, California: U.S. Geol. Survey Water-Supply Paper 780, p. 101–121.

Poland, J. F., Davis, G. H., Olmsted, F. H., and Kunkel, Fred, 1951, Ground-water storage capacity of the Sacramento Valley, California, Appendix D of Water resources of California: California Water Resources Board Bull. 1, p. 624–627.

Preuss, F. A., and Todd, D. K., 1963, Specific yield of unconsolidated alluvium: Berkeley, California Univ. Water Resources Center Contr. 76, p. 2–4, 13, 16, 19.

Prill, R. C., 1961, Comparison of drainage data obtained by the centrifuge and column drainage methods in Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424–D, p. D399–D401.

Prill, R. C., and Johnson, A. I., 1959, Effect of temperature on moisture contents as determined by centrifuge and tension techniques: Am. Soc. Testing Materials Spec. Tech. Pub. 254, p. 340–349.

——— 1967, Specific Yield—Moisture-tension techniques: U.S. Geol. Survey open-file report, 65 p.

Prill, R. C., Johnson, A. I., and Morris, D. A., 1965, Specific Yield—Laboratory experiments showing the effect of time on column drainage: U.S. Geol. Survey Water-Supply Paper 1662–B, 55 p.

Purcell, W. R., 1949, Capillary pressures—Their measurement using mercury and the calculation of permeability therefrom: Am. Inst. Mining Metall. Engineers Trans., v. 186, p. 39–48.

Ramsahoye, L. E., and Lang, S. M., 1961, A simple method for determining specific yield from pumping tests: U.S. Geol. Survey Water-Supply Paper 1536–C, p. 41–46.

Rasmussen, W. C., and Andreasen, G. E., 1959, Hydrologic budget of the Beaverdam Creek basin, Maryland: U.S. Geol. Survey Water-Supply Paper 1472, p. 89–92.

Remson, Irwin, and Lang, S. M., 1955, A pumping-test method for the determination of specific yield: Am. Geophys. Union Trans., v. 36, no. 2, p. 321–325.

Richards, L. A., and Weaver, L. R., 1944, Moisture retention by some irrigated soils as related to soil-moisture tension: Jour. Agr. Research, v. 69, no. 6, p. 215–235.

Sniegocki, R. T., 1963, Problems in artificial recharge through wells in the Grand Prairie Region, Arkansas: U.S. Geol. Survey Water-Supply Paper 1615-G, 25 p.

Stearns, H. T., Robinson, T. W., and Taylor, G. H., 1930, Geology and water resources of the Mokelumne area, California: U.S. Geol. Survey Water-Supply Paper 619, p. 151–172.

Stearns, N. D., 1927, Laboratory tests on physical properties of water-bearing materials: U.S. Geol. Survey Water-Supply Paper 596-F, 55 p.

Theis, C. V., 1935, The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: Am. Geophys. Union Trans., pt. 2, p. 519–524.

Thiem, Gunter, 1906, Hydrologische methoden (hydrologic methods): Leipzig, Germany, J. M. Gebhardt, 56 p.

Tomasson, H. G., Jr., Olmsted, F. H., and LeRoux, E. F., 1960, Geology, water resources, and usable ground-water storage capacity of part of Solano County, California: U.S. Geol. Survey Water-Supply Paper 1464, p. 284–286, 366–368.

Todd, D. K., 1959, Ground water hydrology: New York, John Wiley & Sons, 336 p.

Tolman, C. F., 1937, Ground water: New York, McGraw-Hill Book Co., 593 p.

Upson, J. E., and Thomasson, H. G., Jr., 1951, Geology and water resources of the Santa Ynez River basin, Santa Barbara County, California: U.S. Geol. Survey Water-Supply Paper 1107, p. 130–133.

U.S. Bureau of Public Roads, 1942, Classification of soils and control procedures used in construction: Public Roads, v. 22, no. 12, p. 263–284.

Wenzel, L. K., 1942, Methods of determining permeability of water-bearing materials: U.S. Geol. Survey Water-Supply Paper 887, 192 p.

Wenzel, L. K., Cady, R. C., and Waite, H. A., 1946, Geology and ground-water resources of Scotts Bluff County, Nebraska: U.S. Geol. Survey Water-Supply Paper 943, p. 66–67, 86.

White, W. N., 1932, A method of estimating ground-water supplies based on discharge by plants and evaporation from soil, in Contributions to the hydrology of the United States: U.S. Geol. Survey Water-Supply Paper 659, p. 74–76.

Williams, C. C., and Lohman, S. W., 1949, Geology and ground-water resources of a part of south-central Kansas: Kansas Geol. Survey Bull. 79, 455 p.

Wilson, H. D., Jr., 1959, Ground-water appraisal of Santa Ynez River basin, Santa Barbara County, California, 1945–52: U.S. Geol. Survey Water-Supply Paper 1467, p. 24–25.

42. Johnson, A. I. "Specific Retention, Specific Yield, and Centrifuge Moisture Equivalent", Paper dated March 1954; and ASTM DJ425-79, "Standard Test Method for Centrifuge Moisture Equivalent of Soils," pt. 19, D425-79, American Society for Testing and Materials, Philadelphia, Pennsylvania, 1981, pp. 1-14

A. I. Johnson
March, 1954

Specific Retention, Specific Yield, and Centrifuge Moisture Equivalent

Definition

The specific retention (ω_r) of a rock is the percentage of its total volume that is occupied by water which is not gravity ground water and which will not be yielded to wells.

The specific yield (ω_y) of a rock is the percentage of its total volume that is occupied by water which is yielded by gravity to wells. The specific yield of a rock is equal to its porosity (n) minus its specific retention.

The centrifuge moisture equivalent of a rock is the amount of water expressed as a percentage of the dry weight, retained by the material which has been first saturated with water and then subjected to a force equal to 1000 times the force of gravity for one hour. The centrifuge moisture equivalent is multiplied by the apparent specific gravity (dry unit weight, γ_d) to obtain the moisture equivalent by volume.

Laboratory Methods

The specific yield of the sample was determined by an indirect laboratory method. The centrifuge moisture equivalent (ω_e) by volume was determined and was then adjusted by a correction factor (N_r) proposed by Piper (1933). This adjusted value, considered to be specific retention, was then subtracted from the porosity (n) to obtain the value for the specific yield.

$$\omega_r = N_r \, \omega_e \, \gamma_d$$

$$\omega_y = n - \omega_r$$

AMERICAN NATIONAL STANDARD

ASTM D 425 – 79[ε1]

AMERICAN SOCIETY FOR TESTING AND MATERIALS
1916 Race St., Philadelphia, Pa. 19103
Reprinted from the Annual Book of ASTM Standards, Copyright ASTM
If not listed in the current combined index, will appear in the next edition.

Standard Test Method for CENTRIFUGE MOISTURE EQUIVALENT OF SOILS[1]

This standard is issued under the fixed designation D 425; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

[ε1] NOTE—The equation in 6.1 was editorially corrected in May 1980.

1. Scope

1.1 This method covers the determination of the moisture equivalent of soil by means of a centrifuge technique.

1.2 The centrifuge moisture equivalent is defined as the water content of a soil after it has been saturated with water (by soaking) and then subjected for 1 h to a centrifugal force equal to 1000 times that of gravity. It is usually expressed as a percentage.

1.3 The centrifuge moisture equivalent can be used to approximate the "air-void ratio," the "water-holding capacity," or the "specific retention." See Section 5.

1.4 The method is temperature-dependent, and consistent comparable results can be obtained only if the tests are determined under a constant-temperature condition.

2. Applicable Documents

2.1 *ASTM Standards*:

D 653 Definitions of Terms and Symbols Relating to Soil and Rock Mechanics[2]

E 11 Specification for Wire-Cloth Sieves for Testing Purposes[3]

3. Summary of Method

3.1 The centrifuge moisture equivalent of soils is determined by initially air-drying the soil, selecting two 5-g test specimens, thoroughly soaking each test specimen, and then determining the water content of each specimen after it has been centrifuged for 1 h at a force equal to 1000 times that of gravity at a controlled temperature of 20 ± 1°C.

4. Significance and Use

4.1 The centrifuge moisture equivalent can be used to approximate the "air-void ratio" (geotechnical term), the "water-holding capacity" (soil scientist term), or the "specific retention" (hydrologist term).

4.2 Not all water contained in a saturated soil can be removed by gravity drainage or by pumping of wells. All of the previously mentioned terms represent the ability of a soil to retain water against gravity drainage. The amount of water retained after gravity drainage varies with time, the texture (particle-size distribution) of the soil, and the plasticity of soils (in general, increasing in value with an increase in liquid limit).

4.3 In general, the centrifuge moisture equivalent is based on the theory of applying a centrifugal force great enough to reduce the capillary fringe enough that it can be ignored without introducing much error, even in small specimens, and yet not so great as to withdraw a large proportion of the water that is held securely above the capillary fringe. For example, if a soil will hold water 100 mm by capillarity acting against gravity, the soil will theoretically be able to hold the water only 0.1 mm against a centrifugal force that is 1000 times greater than the force of gravity. It has been determined that for at least medium-textured soils (sandy to silty particle-size distribution) the centrifuge moisture equivalent (when con-

[1] This method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.03 on Texture, Plasticity, and Density Characteristics of Soils.

Current edition approved June 29, 1979. Published August 1979. Originally published as D 425 – 35 T. Last previous edition D 425 – 69.

[2] *Annual Book of ASTM Standards*, Part 19.

[3] *Annual Book of ASTM Standards*, Part 41.

verted to moisture content by volume) approximates specific retention, air-void ratio, or water-holding capacity (converted to moisture content by volume).[4]

5. Definitions

5.1 *air-void ratio*—the ratio of the volume of air space to the total volume of voids in a given soil or rock mass.

5.2 *specific retention*—the ratio of the volume of water that cannot be drained from a saturated soil under the action of force of gravity to the total volume of voids.

5.3 *water-holding capacity*—the smallest value to which the water content of soil can be reduced by gravity drainage.

5.4 *water (moisture) content by volume*—the ratio, expressed in percent, of the volume of water in a given volume of material to the total volume of the material.

6. Apparatus

6.1 *Moisture Equivalent Centrifuge*—A centrifuge of such a size and so driven that a force equal to 1000 times the force of gravity may be exerted on the center of gravity of the soil specimen for 1 h. The centrifuge chamber shall be capable of maintaining a controlled temperature of 20 ± 1°C. The revolutions per minute, N, required to provide a centrifugal force of 1000 times gravity is determined from the equation:

$$N = \sqrt{\frac{\mathrm{RCF}}{0.0000111\, rm}}$$

where:

N = revolutions per minute,
RCF = relative centrifugal force (1000),
r = radius of rotation to center of gravity of the test specimen, cm, and
m = mass of the body, taken as unity.

For normal equipment installation, N will equal approximately 2300 rpm.

6.2 *Trunnion Cup*—Babcock trunnion cups fitted with a cap with suitable holder for supporting the Gooch crucible 13 mm above the bottom of the cup (Fig. 1). The holder should support the cup in such a manner that the water ejected during the centrifuging operation does not come in contact with the crucible and soil and have sufficient clearance to fit freely within the cup. Cups and crucible holders should be balanced in pairs opposite each other in the centrifuge and should be numbered in pairs (for example, 1, 1A, 2, 2A, etc.)

6.3 *Gooch Crucible*—A porcelain Gooch crucible having a perforated bottom, a capacity of approximately 25 ml, and the following outside dimensions: height of about 37.5 mm, diameter at the top of about 25 mm, and diameter at bottom of about 20 mm (Fig. 1). Crucibles should be numbered in balanced pairs to be placed opposite each other in the centrifuge trunnion cups (for example, 1A, 1B, 2A, 2B, etc).

6.4 *Filter Paper*—A circular piece of filter paper (Note 1) just large enough to cover the inside bottom of the Gooch crucible.

NOTE 1—Filter papers may be purchased already cut to size from a scientific supply company. A qualitative medium flow rate paper or equivalent is suggested.

6.5 *Balance*, having a precision (repeatability) of ±0.01 g.

6.6 *Humidifier*—A large desiccator with water in the lower half works satisfactorily. The desiccator plate should be covered with hardware cloth on which to set the crucibles and soil specimens.

6.7 *Oven*—A thermostatically controlled drying oven, preferably of the forced-draft type, capable of maintaining a uniform temperature of 110 ± 5°C throughout.

6.8 *Water Content Containers*—Suitable containers made of material resistant to corrosion and change in mass upon repeated heating, cooling, and cleaning. Containers shall have close-fitting lids to prevent loss of moisture from the soil before initial weighing and to prevent absorption of moisture from the atmosphere following oven drying and before final weighing. One container is needed for each moisture content determination (Note 2). Containers should be 60 to 90-ml capacity.

NOTE 2—It is recommended that the containers be numbered in pairs to coincide with the crucible numbers.

6.10 *Mortar and Pestle*—A mortar and rubber-covered pestle suitable for breaking up the aggregations of soil particles.

6.11 *Sieve*, 2.00-mm, of square mesh woven wire cloth, conforming to Specification E 11.

[4] Johnson, A. I., Prill, R. C., and Morris, D. A., "Specific Yield—Column Drainage and Centrifuge Moisture Content," U.S. Geological Survey Water Supply Paper 1662-A, 1963, p. 60.

7. Test Specimen

7.1 Expose the soil sample, as received, to the air at room temperature until dried thoroughly (Note 3). Break up the aggregations thoroughly in the mortar with a rubber-covered pestle. Dry sieve this material on a 2.00-mm sieve.

NOTE 3—If the sample, as received, has a mass much greater than required to perform this test, the sample can be thoroughly mixed and a sample weighing about 50 g split out for air drying.

7.2 Take a 5-g specimen from the material passing the 2.00-mm sieve after it has been thoroughly mixed. Material that does not pass the 2.00-mm sieve should not be used for this test.

7.3 Make tests in duplicate, with duplicates placed in cups opposite each other in the centrifuge.

8. Procedure

8.1 Place the specimen loosely but evenly in the Gooch crucible, in which previously has been placed a piece of wet filter paper that just covers the bottom of the crucible. Place the crucible in a pan of distilled or demineralized water of a depth at least 5 mm greater than the height of soil in the cup and allow the soil to take up water until "saturated." Eight hours or overnight usually is satisfactory, as indicated by the presence of free water covering the surface of the soil. Place the crucible and specimen in a humidifier for at least 12 h to ensure uniform distribution of moisture throughout the soil mass. Pour off all free water then remaining on the surface of the specimen, and place the crucible in a Babcock trunnion cup fitted as described in 6.2. Place the paired crucibles in Babcock cups opposite each other in the centrifuge.

8.2 Control the centrifuge at a temperature 20 ± 1°C. Bring the centrifuge to the required speed within 5 min by five successive equal steps of the rheostat, with 1 min at each step. Maintain the centrifuge for 60 min at a constant speed which, for the diameter head used, will exert a centrifugal force 1000 times the force of gravity upon the center of gravity of the test specimen. Following this period of centrifuging at required speed, allow the centrifuge to come to rest with as little braking as possible, but not to exceed a 5-min time interval.

8.3 Immediately after centrifuging, place the contents (without filter paper) of each crucible in a clean, dry water content container of known mass and set the lid securely in position. Do not take time to get all the material out of the crucible. Speed is most essential to prevent loss of moisture from the soil. Determine the mass of the container and moist soil. Record these values.

8.4 When free water is observed on the top of the soil after centrifuging, the soil is said to have water-logged, and this information should be noted in the report of the results.

8.5 Remove the lid and place the container with moist soil in a drying oven maintained at 110 ± 5°C and dry to a constant mass.

8.6 After drying to constant mass, remove the container from the oven and replace the lid. After cooling to room temperature, determine the mass of the container and dry soil. Record this value.

9. Calculations

9.1 Calculate the centrifuge moisture equivalent of the soil as follows:

$$w_e = [(W_1 - W_2)/(W_2 - W_c)] \times 100 = (W_w/W_s) \times 100$$

where:

w_e = centrifuge moisture equivalent, %,
W_1 = mass of container plus wet soil, g,
W_2 = mass of container plus dry soil, g,
W_c = mass of container, g,
W_w = mass of water, g, and
W_s = mass of solid particles, g.

The final centrifuge moisture equivalent is obtained by taking the average of the values received from the paired samples.

10. Report

10.1 The report shall include the following:

10.1.1 Identification of sample (material) being tested, by boring number, sample number, test number, etc.

10.1.2 Average centrifuge moisture equivalent of the specimen to the nearest 1 %.

10.1.3 Indication of which test specimen, if any, water-logged.

11. Precision and Accuracy

11.1 *Repeatability*—The variation between two values obtained in duplicate tests in the same laboratory shall not exceed 1 percentage

point for values of the centrifuge moisture equivalent up to 15 % and 2 percentage points for values above 15 %. The sample should be retested if the variation exceeds these values.

11.2 Requirements for the reproducibility and accuracy of this test method have not yet been developed.

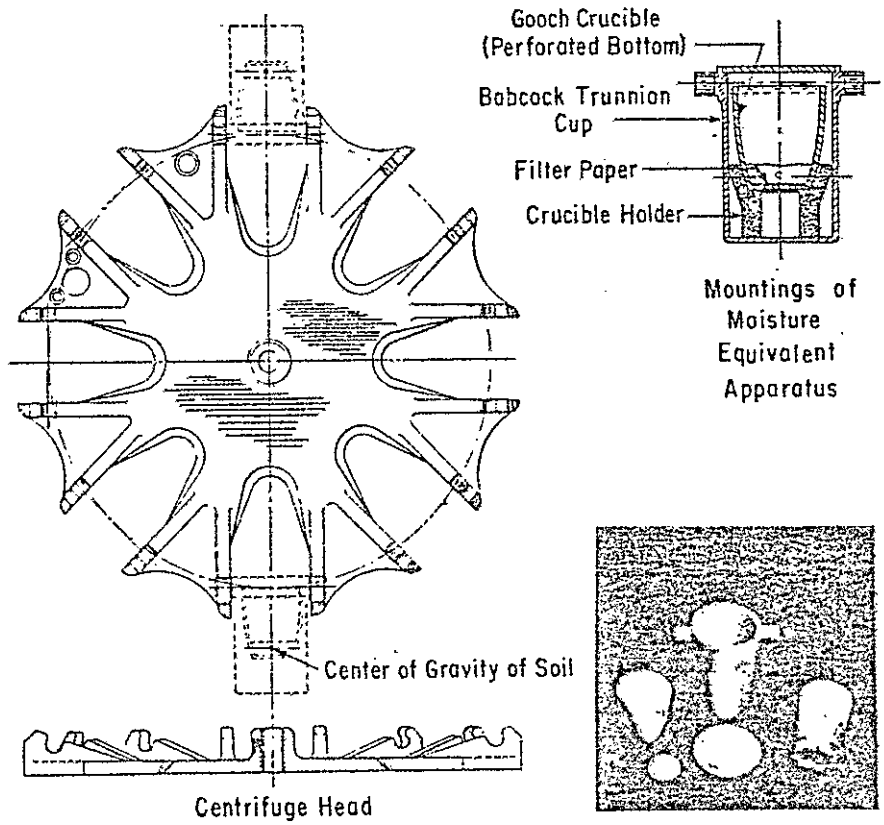


FIG. 1 Crucible, Trunnion Cup, and Cup Holder.

The American Society for Testing and Materials takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 1916 Race St., Philadelphia, Pa. 19103, which will schedule a further hearing regarding your comments. Failing satisfaction there, you may appeal to the ASTM Board of Directors.

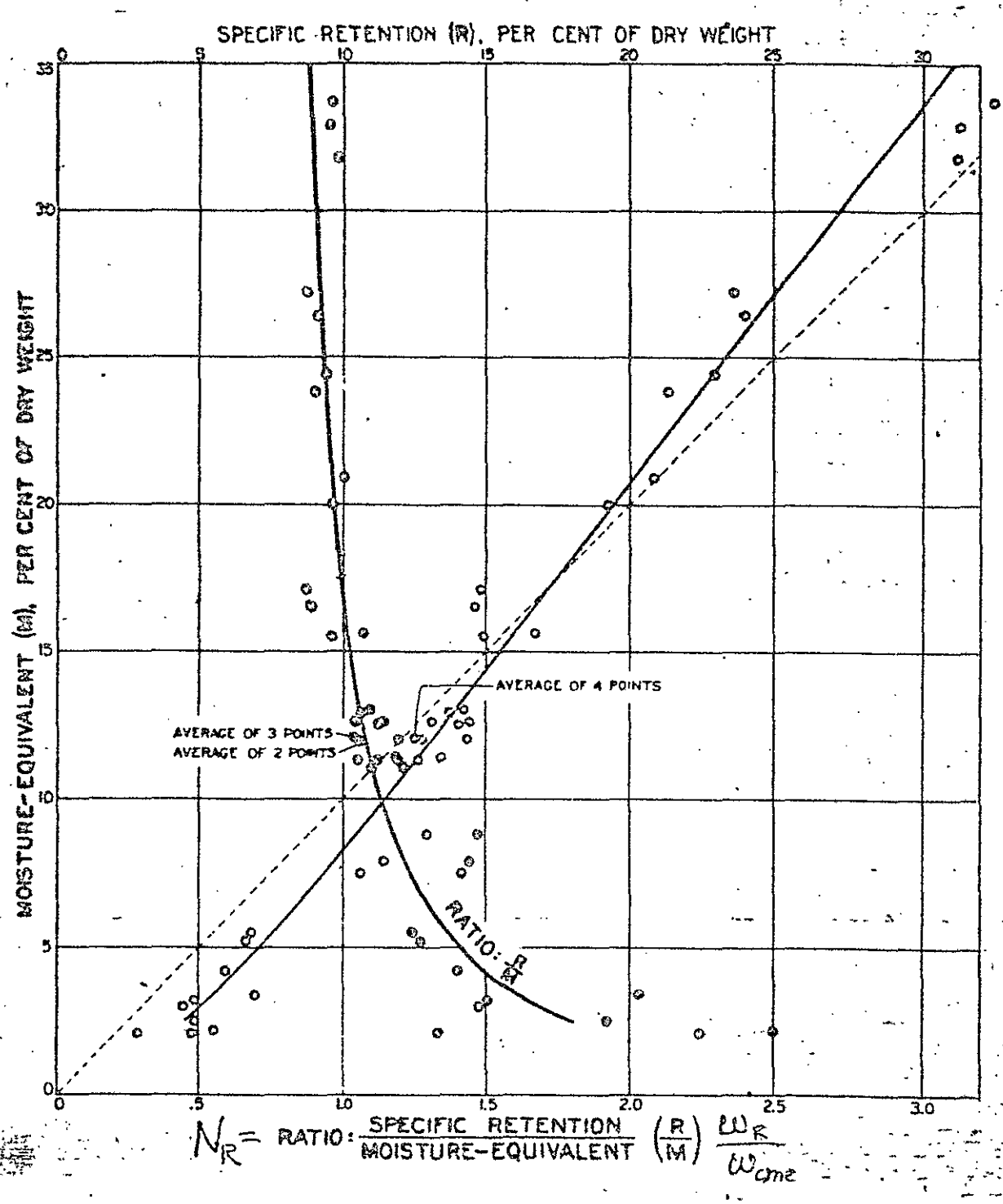


Figure 2.--Relation of moisture-equivalent to specific retention [After Piper, 1933].

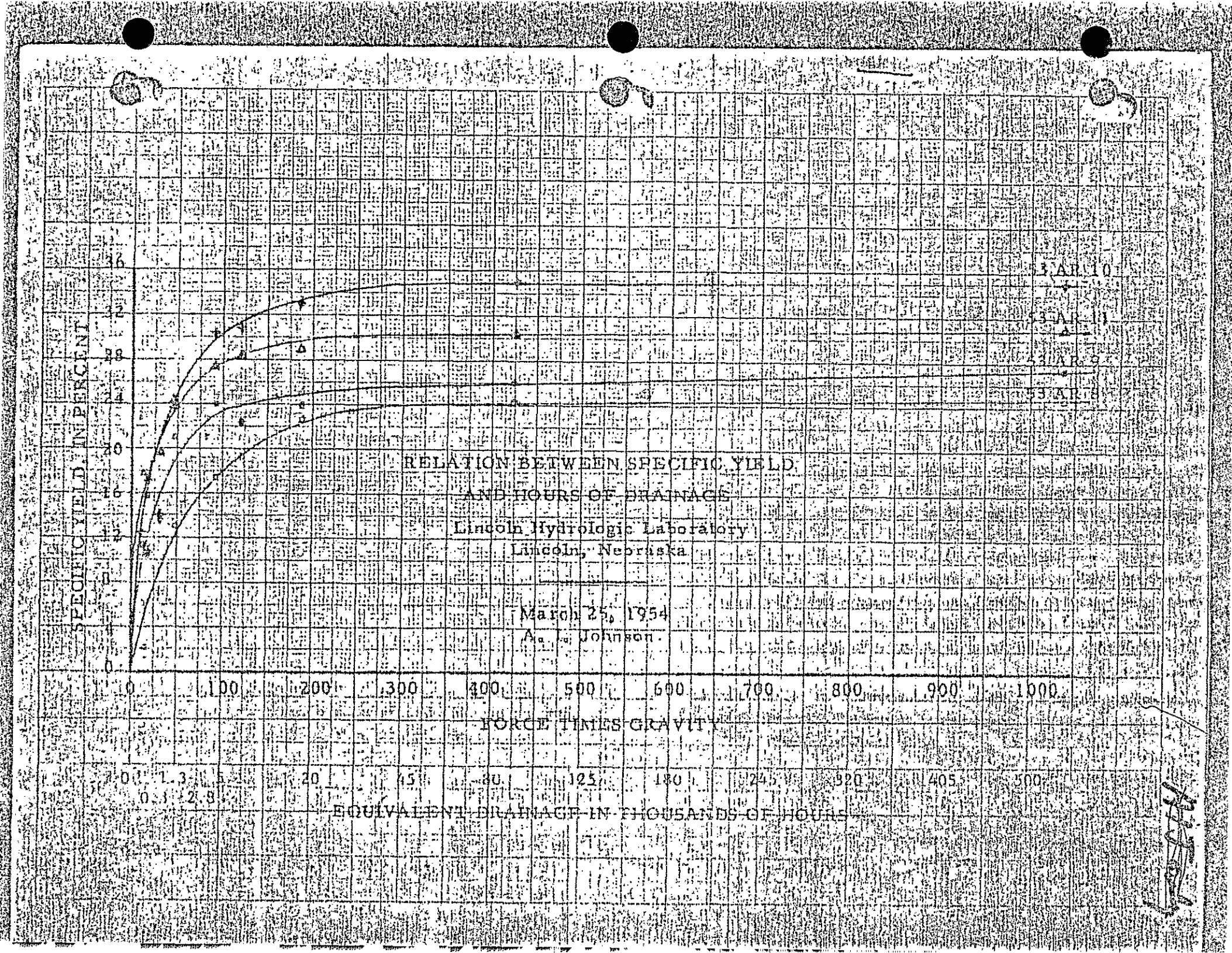
11AJ57a

Location _____

SPECIFIC RETENTION and SPECIFIC YIELD
(Centrifuge Moisture Equivalent Method)

1 Sample Laboratory Number	2 Date	3 Computer	4 Centrifuge moisture equivalent, ω_{cme} (%)	5 Correction factor N_r (ω_r/ω_{cme}) (tables)	6 Dry Unit Wt. App.Spec. Grav.) γ_d (gm/cc)	7 Specific retention ω_r (%) (4x5x6)	8 Porosity, n (%) (From form No. 6)	9 Specific Yield, ω_y (%) (8-7)

GPO 850265


SPECIFIC YIELD IN PERCENT
36
32
28
24
20
16
12
8
4
0
0
100
200
300
400
500
600
700
800
900
1000
FORCE TIMES GRAVITY
0
1.3
5
20
45
80
125
180
245
320
405
500
0
2.8
EQUIVALENT DRAINAGE IN THOUSANDS OF HOURS
53 AR 10
53 AR 11
53 AR 9
53 AR 8
RELATION BETWEEN SPECIFIC YIELD
AND HOURS OF DRAINAGE
Lincoln Hydrologic Laboratory
Lincoln, Nebraska
March 25, 1954
A. J. Johnson

43. Johnson, T.M., et al. "Monitoring of Leachate Migration in the Unsaturated Zone in the Vicinity of Sanitary Landfills - Ground Water Monitoring Review, Fall 1981, pp. 55-63

MONITORING OF LEACHATE MIGRATION IN THE UNSATURATED ZONE IN THE VICINITY OF SANITARY LANDFILLS

2646

This article discusses the use of observation wells and pressure-vacuum lysimeters for monitoring water quality in the unsaturated zone below three sanitary landfills. It also offers laboratory tests on pressure-vacuum lysimeter intake rates and changes in leachate concentrations over time.

homas M. Johnson,
os Cartwright and
olph M. Schuller

roduction

Guidelines for the siting and ign of landfills have generally uired that waste disposal take e above the zone of saturation. gulatory agencies usually require mall-diameter observation e used to monitor changes in quality of ground water in the nity of sanitary landfills. Unsatu-ed soils often will not yield water vells because moisture is held in soil under surface tension at s-than-atmospheric pressures. us, monitoring of the unsaturated ne beneath landfills has been glected. By the time ground-water ntamination is detected via moni-ing wells, corrective action is pensive and time-consuming. Be-use the unsaturated zone beneath landfill represents a buffer zone tween refuse and potential aqui-s, monitoring of this zone would ow for early detection of leachate igration. In addition, monitoring e changes in water quality in the saturated zone provides informa-n on the attenuation capacities unsaturated materials and the tes of ground-water movement, th of which are very difficult to timate.

The usefulness and reliability of ethods for monitoring water qual-unsaturated materials have emonstrated, but their practi-l application in pollution control ograms has been limited. Also, though several types of remedial easures are applicable to leachate migration in the saturated zone, corrective actions for leachate migration in the unsaturated zone are severely limited.

Pressure-Vacuum Lysimeters

One method of sampling soil moisture is with porous ceramic cups similar to those used in tensiometers. Soil sampling requires repeated drilling for extended analyses; the use of soil-moisture samplers, called suction, or pressure-vacuum, lysimeters, allows repeated sample collection from a single installation.

The original design of the pressure-vacuum lysimeter permitted sampling only at shallow depths. This lysimeter was modified during several studies in Pennsylvania concerning the effects of the infiltration of waste water and the migration of landfill leachate (Parizek and Lane, 1970; Apgar and Langmuir, 1971). Sampling at greater depths was achieved by the use of two access tubes and a ceramic cup attached to a sample accumulation chamber of PVC pipe which held approximately one liter (Figure 1). To collect a soil-moisture sample, a partial vacuum is applied to the sampler through one of the access tubes, which is then clamped shut. Soil moisture held under tension moves into the sampler under the potential gradient created by the vacuum, and water generally accumulates. When the vacuum is released and pressure is applied to one access tube, the accumulated water sample is forced to the surface through the other access tube.

In studies of landfills in Pennsylvania, several pressure-vacuum lysimeters were installed in individual boreholes at depths to 16.8 m (55 ft.) The movement and attenuation of leachate were monitored by standard indicators of water quality. Apgar and Langmuir (1971) concluded that improperly designed landfills located above the water table in permeable materials can result in serious ground-water pollution.

Wood (1973) described a modification of the lysimeters used by Apgar and Langmuir that permitted the sampling of water from any depth within the unsaturated zone. The use of a check valve prevents pressurization of the porous cups; in deeply placed lysimeters, pressures in excess of one atmosphere in the sampler would force the water sample back through the cup rather than up to the surface.

More recent applications have included the use of suction lysimeters to monitor the quality of water in the unsaturated zone at depths to 33 m (108 ft.) below artificial recharge sites in Texas (Wood, 1978). In Wisconsin, three operating landfills were instrumented with suction lysimeters to monitor leachate migration and attenuation in the unsaturated zone (Gerhardt, 1977).

The validity of soil-moisture samples collected by suction lysimeters with ceramic cups is extremely important if the results are to be used for regulatory purposes. Because some studies have indicated that ceramic cups can alter the chemical composition of samples, such samples may not be representative of actual soil-moisture quality.

Substantial bias and variability have been found in soil-water samples of NO_3-N, PO_4-P, Na, K and Ca by previous investigators (Hansen and Harris, 1975; Grover and Lamborn, 1970). Factors including intake rate, plugging of ceramic-cup pores, and sorption and screening of some ions produced as much as 60 percent range in sample concentrations. Ceramic cups contributed excessive amounts of Ca, Na and K to samples of soil moisture having low solute concentrations and significant amounts of P were adsorbed on the ceramic cups. Rinsing of the cups with dilute HCl reportedly reduced Na and K contamination and P adsorption to acceptable levels.

Dazzo and Rothwell (1974) found that large-scale screening and adsorption of bacteria by ceramic cups with a pore size of 3 to 8 μm invalidated their use for the analysis of fecal coliform. The effective pore diameter of the porous ceramic cup used in the lysimeters is approximately 1μm, which may allow colloidal particles to pass through. Wolf (1967) found that new ceramic cups yield several milligrams per liter of Ca, Mg, Na, HCO_3 and SiO_2, after cleaning with dilute HCl. Wagner (1962) found no measurable sorption of NO_3-N. Levin and Jackson (1977) indicated that concentrations of Ca, Mg and PO_4-P in soil solutions were unaltered by ceramic cup samplers and that clogging was not a problem; however, their suitability for NO_3-N was questionable.

Each of the previous studies utilized solutions of relatively low solute concentrations where the effects of sampling errors and sample variability are significant. Despite these problems, soil-water samplers are now commonly used for monitoring highly contaminated soil solutions such as landfill leachate. The ability of these samplers to obtain samples that are truly representative of highly concentrated leachate has not been examined.

Description of the Study

A project was undertaken to investigate the movement and quality of leachate in the unsaturated zone beneath several landfills in Illinois and to evaluate methods of monitoring soil-moisture and ground-water conditions (Johnson and Cartwright, 1980). Three landfills (Figure 2) representing different geologic environments and disposal practices were studied. Contaminant migration was monitored by means of observation wells and soil-water samplers (pressure-vacuum lysimeters) and by chemical analysis of soil samples. In addition, a laboratory study was conducted in a preliminary attempt to determine if there are any factors that significantly affect the validity of samples of highly contaminated landfill leachate collected with pressure-vacuum lysimeters.

The pressure-vacuum lysimeters used in this study were obtained from Soil Moisture Equipment Corp. (Model 1920), Santa Barbara, California.* A typical lysimeter installation is illustrated in Figure 1. The lysimeter device, which holds one liter of water, consists of a plastic cylinder, 64 cm (25 in.) long and 5 cm (2 in.) in diameter, having a porous ceramic cup 6 cm (2.5 in.) long. An envelope of silt-sized, powdered quartz is typically emplaced around the ceramic cup to establish uniform continuity with surrounding soils. The suction lysimeters were placed at varying depths beneath each site, one to three lysimeters in each borehole. Bentonite clay was used to seal the borehole between units.

Sample collection periods ranged from three days to three months. After a sample had accumulated, a hand pump was used to apply pressure to one access tube to force the water sample to the surface through

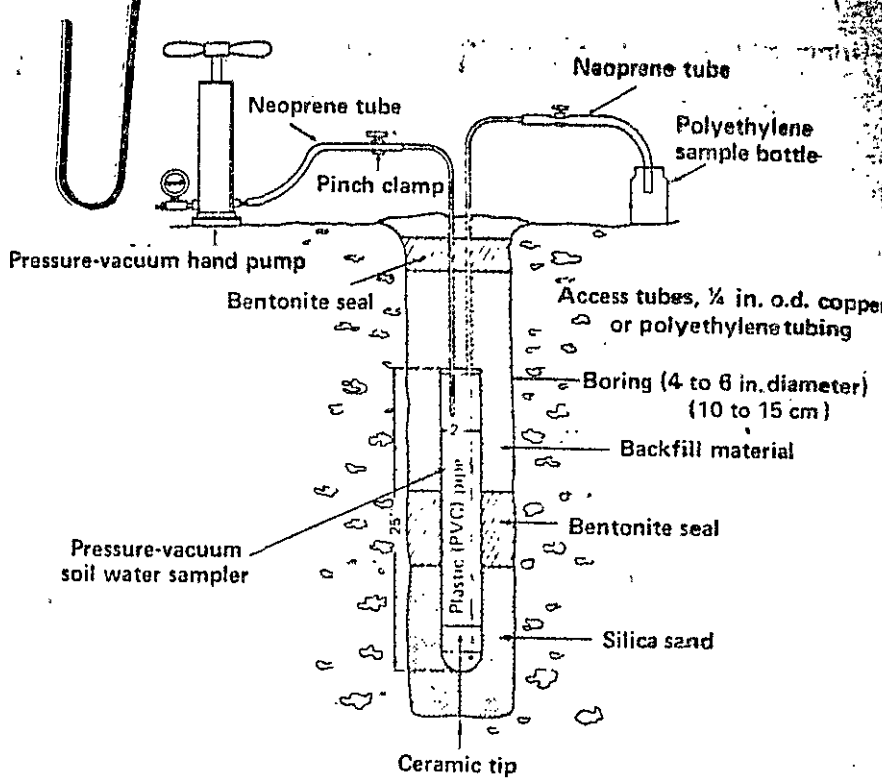


Figure 1. Typical installation of pressure-vacuum lysimeter.

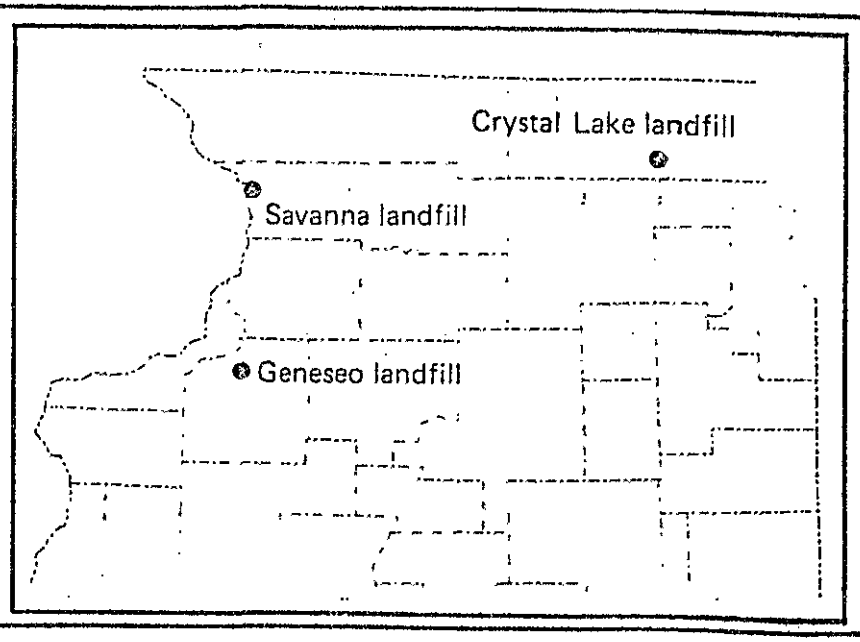


Figure 2. Locations of study sites.

ne discharge tube that extends to the base of the sampler. (Gas pressure (argon, nitrogen, CO_2, etc.) could be used for sample collection; however, the effects of these gases on sample integrity are unknown.)

Soil-moisture and ground-water samples were collected and analyzed for Na, Ca, Mg, Zn, K, Fe, Pb, Hg, Cl, SO_4, NO_3-N, NH_4-N; hardness; pH; total dissolved solids (TDS); and chemical oxygen demand (COD). Field measurements of pH, Eh, specific conductivity, and alkalinity were also made. In addition to water quality analyses, soil samples collected from the unsaturated zone beneath each landfill were analyzed to determine their attenuation capabilities and the extent of their contamination by the infiltrating leachate.

In the laboratory study, one new sampler that was not cleaned (designated as NC in subsequent figures) and one sampler that was cleaned with dilute hydrochloric acid and rinsed with distilled water (designated as C) were placed in separate plastic carboys, each containing approximately 15 liters of leachate. A constant flow of carbon dioxide gas was bubbled over the leachate in an effort to maintain reducing conditions and a constant pH.

The leachate was collected from a monitoring well (BL-2) finished in the refuse at the Blackwell Forest Preserve landfill in Du Page County (Hughes, Landon and Farvolden, 1971). This leachate was chosen because of its relatively high concentrations of constituents and ready availability of large volumes. In order to measure the validity of the lysimeters for sampling trace metals, each leachate was "spiked" with an additional 2.5 mg/l of Pb, Hg and Cu. A vacuum of 55 centibars (413 mm Hg) was initially placed on each sampler using a portable hand pump.

Duplicate samples of raw leachate were collected from each carboy for 10 days using air pressure applied with a hand pump. One sample (denoted AFNC or AFC) was immediately acidified to a pH <2.0 with concentrated nitric acid and, after centrifuging, was filtered through a 0.7 μm pore-size membrane filter. A similar sample (denoted FANC or FAC) was centifuged, filtered and then acidified prior to storage at 4°C. The large amount of suspended particulate matter in the raw leachate required that the samples be centrifuged prior to filtration. Samples of raw leachate were filtered through a 0.7 μm pore-size membrane filter in an attempt to simulate the pore diameter of the porous ceramic cups. The samples were analyzed for Ca, Mg, Na, K, Fe, Zn, Pb, Hg, Cu and Cl. The mean standard deviation and statistical analyses of the differences in mean concentrations (Student's t-test) and a comparison of the concentration variances (F-statistic) were determined for lysimeter samples (NC, C) and leachate (FANC, AFNC, AFC, FAC) in an effort to determine the effects on sample integrity of the leachate passing into the porous cup.

Results of the Field Study

Savanna Landfill

Located in an abandoned sand pit in the Mississippi River Lowland (Figure 2), the Savanna landfill is underlain by silty sand to coarse sand and gravel. Water levels generally range from 3 to 4 m (10 to 13 ft.) below the base of the refuse. Although the landfill has been operating since 1967, there has been no evidence of contamination in the monitoring wells or in the Plum River immediately south of the site. However, soil moisture both below and adjacent to the refuse is contaminated.

The lysimeters installed at the site yielded samples of soil moisture with an average volume of 300 ml. Analysis of these samples indicated that the migration of landfill leachate through the unsaturated zone was occurring beneath the site. Figure 3 shows a decrease of Cl in soil moisture and ground water with distance from the refuse. Similar patterns were observed for several other parameters, including COD, K, Na and Fe. Dilution and dispersion may be partly responsible for this apparent attenuation. Continued production of leachate by the landfill was indicated by the lack of reduction in the levels of chloride and COD in the soil moisture. Levels of most parameters are reduced to nearly background concentrations at depths of two to three m (6.5 to 10 ft.) below the refuse. Samples taken from the lysimeters also indicated that significant lateral migration of leachate occurred through the unsaturated zone adjacent to the refuse. Chemical analysis of soil samples below the landfill revealed that only Zn was present at levels slightly greater than background.

The Savanna landfill is situated in a permeable environment generally considered unsuitable for waste disposal. Samples of soil moisture indicate that the migration of highly contaminated leachate is occurring. The limited impact on water resources in the vicinity of the site is probably due to the limited quantities of leachate produced by the relatively small volume of refuse.

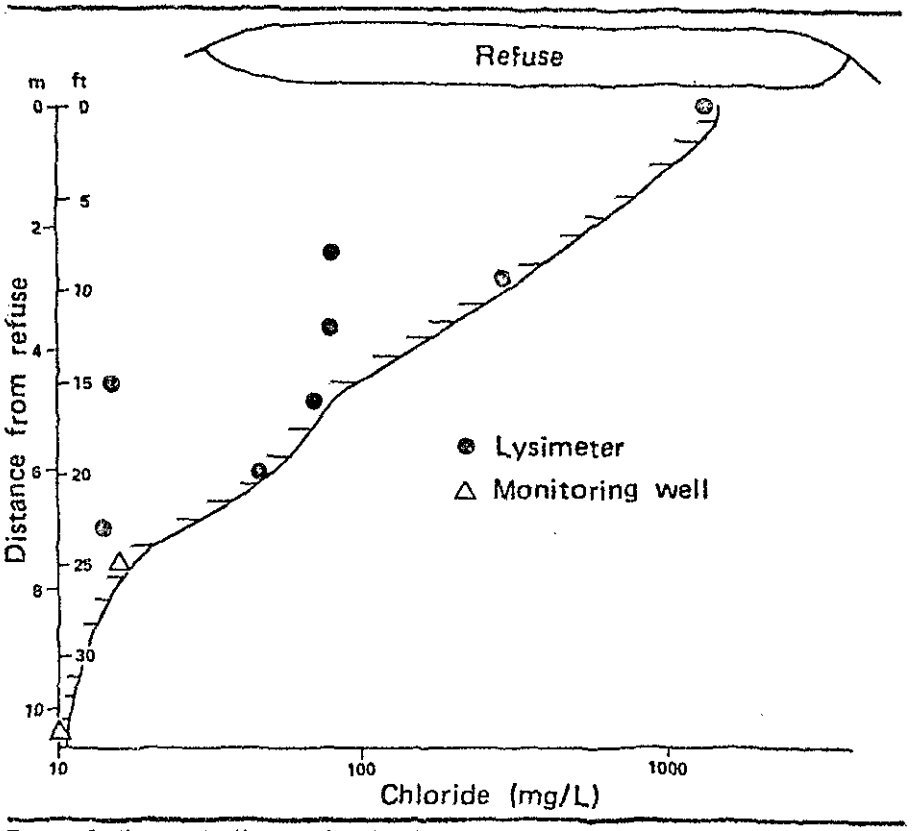


Figure 3. Concentration of chloride in water beneath the Savanna landfill, March 17, 1977.

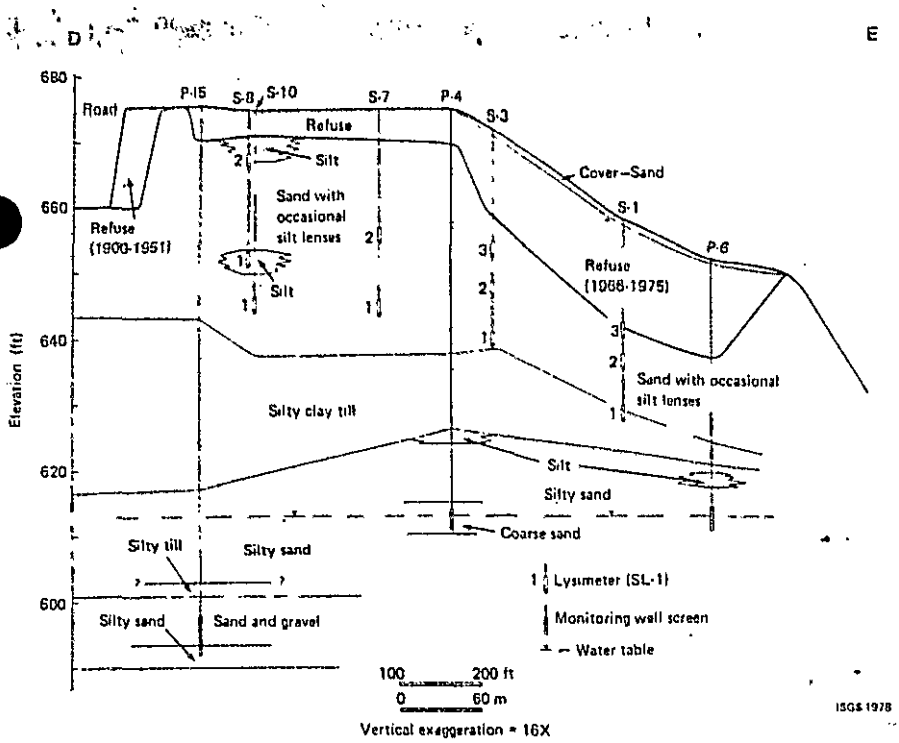


Figure 4. Cross section D-E of the Geneseo landfill and underlying materials showing a portion of the monitoring well-lysimeter network.

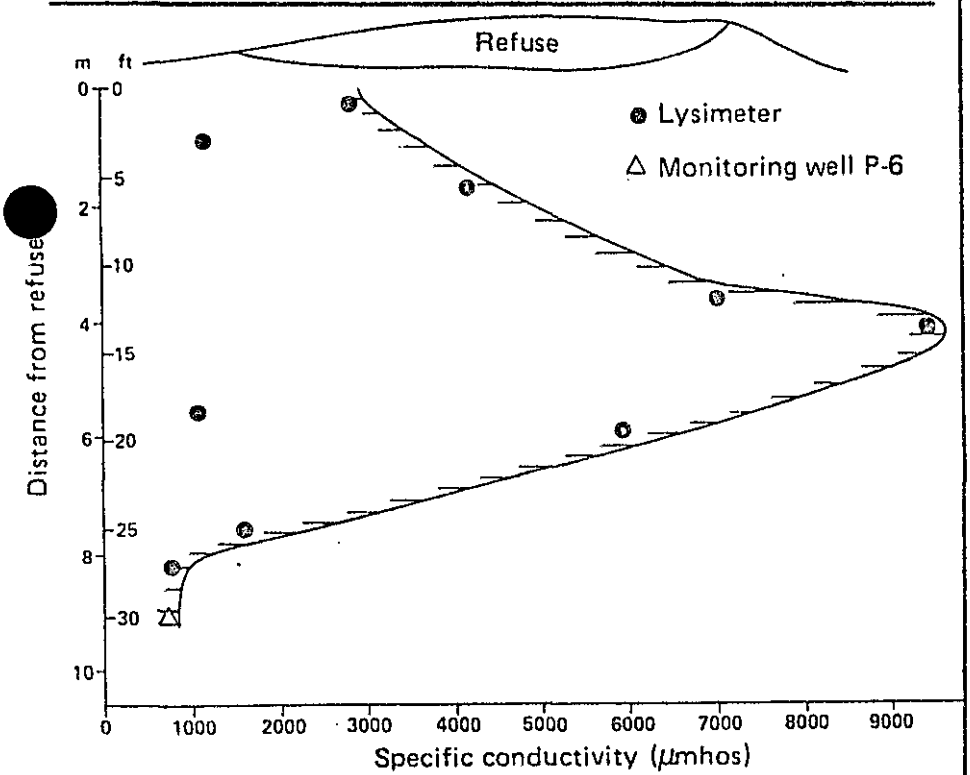


Figure 5. Specific conductivity of water beneath the Geneseo landfill, August 25, 1977.

Geneseo Landfill

The Geneseo site is situated in a massive sand dune (Figure 2). The site originally began operation as an open-burning dump in the early 1900s and operated as a sanitary landfill from 1967 to 1975. The site was closed in 1975 following the suspected contamination of shallow municipal wells several hundred meters away. This study has disclosed the presence of relatively thick deposits of fine-grained glacial till between the landfill and the underlying sand and gravel aquifer (Figure 4). Water levels range from 7 to 18 m (23 to 59 ft.) below the base of the refuse, and regional groundwater flow is toward the lowland to the north.

The average volume of each of the 56 samples obtained from the lysimeters at Geneseo was 316 ml. Highly contaminated soil moisture was collected beneath the landfill portion of the site. Less contaminated soil moisture was encountered beneath the remainder of the site. Sampling of monitoring wells and resampling of numerous municipal wells, however, has indicated virtually no leachate migration in the saturated zone.

Table 1 illustrates the range in quality of ground water and soil moisture at the site. Two processes apparently control the extent of contamination:

- the attenuation of leachate in the unsaturated zone
- an apparent decrease in the concentration of contaminants being released by the refuse. Many parameters, such as COD, were relatively stable over the two-year period encompassed by this study. Probably leachate has migrated through the unsaturated zone beneath the landfill at an average rate of 1 m/yr (3 ft/yr) since 1967. The actual rate of migration has probably been greater because much of the refuse was not emplaced until 1971 to 1975, and the sequence of materials beneath the site has caused highly variable rates in movement of soil moisture.

Soil-moisture samples from Geneseo indicated the expected effects of waste disposal in a permeable medium. The highly contaminated leachate migrating through the unsaturated zone beneath this site represents a significant threat to ground water. Maximum concentrations of most parameters, however, as illustrated by specific conductivity (Figure 5), are present at depths of 5 to 6 m (16 to 20 ft.) below the refuse. Below that depth, significant attenuation appears to have resulted from the presence of a layer of fine-grained glacial till that has restricted vertical migration and provided increased ion-exchange capacity. A significant amount of contaminated soil moisture probably flows laterally at the contact of the sand with the underlying glacial till, ultimately entering the groundwater system in the lowland to the north. However, no deterioration in water quality has yet been observed either in surface water or shallow ground water in the lowland north of the site. The pattern of leachate migration that was detected with the lysimeters also indicated that the suspected contamination of municipal wells was not due to leachate migration from the landfill.

Crystal Lake Landfill

The Crystal Lake landfill began operation in 1973 in an abandoned

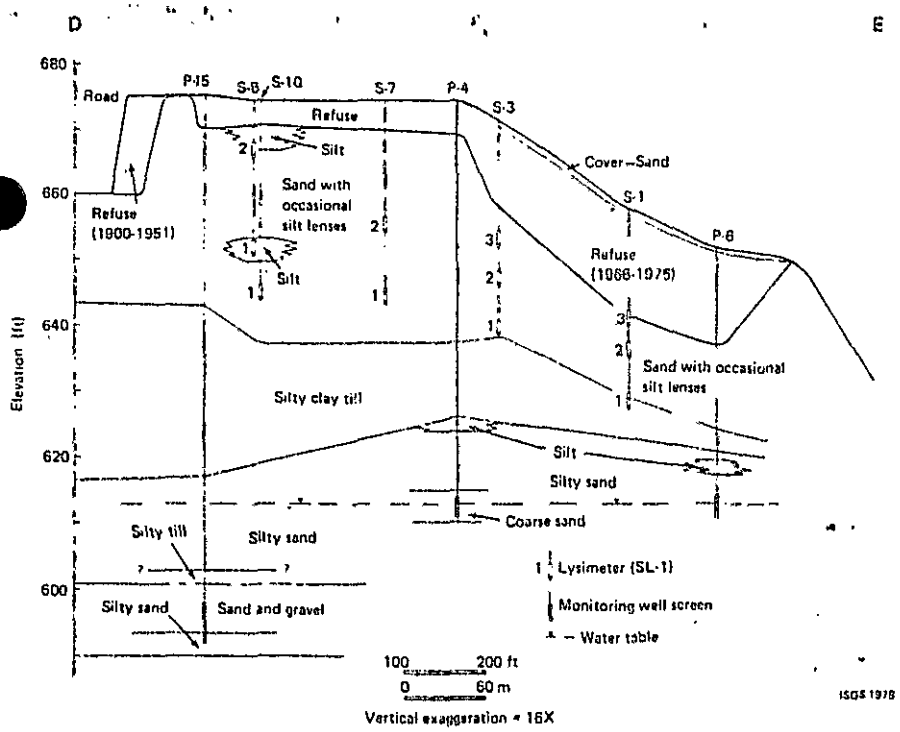


Figure 4. Cross section D-E of the Geneseo landfill and underlying materials showing a portion of the monitoring well-lysimeter network.

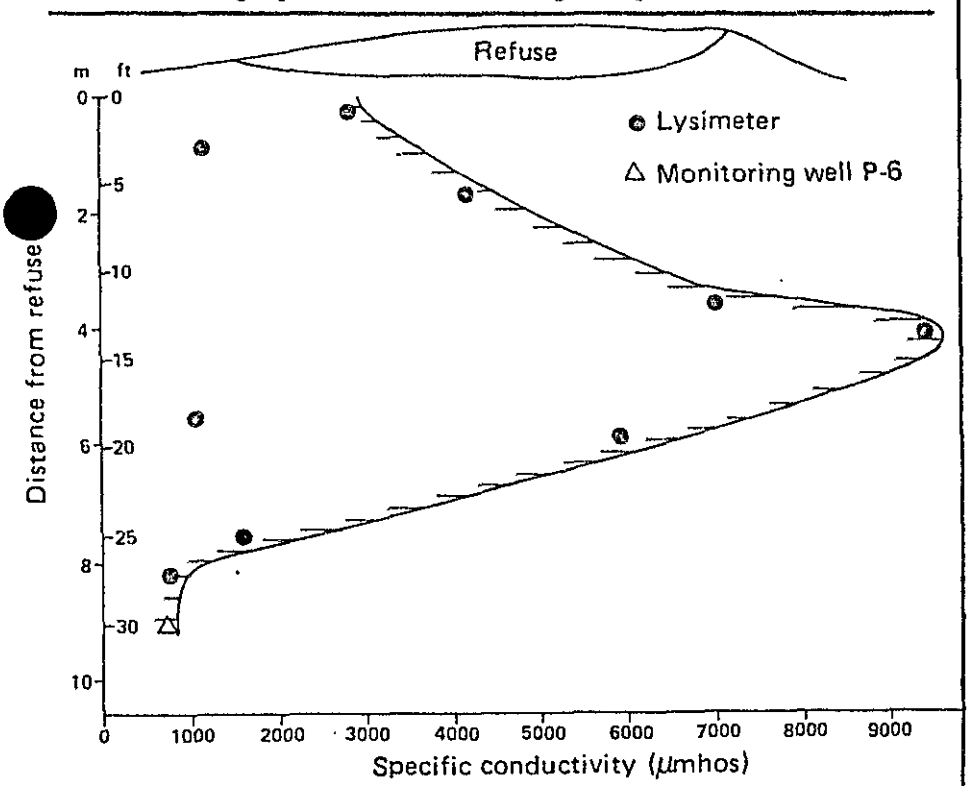


Figure 5. Specific conductivity of water beneath the Geneseo landfill, August 25, 1977.

Geneseo Landfill

The Geneseo site is situated in a massive sand dune (Figure 2). The site originally began operation as an open-burning dump in the early 1900s and operated as a sanitary landfill from 1967 to 1975. The site was closed in 1975 following the suspected contamination of shallow municipal wells several hundred meters away. This study has disclosed the presence of relatively thick deposits of fine-grained glacial till between the landfill and the underlying sand and gravel aquifer (Figure 4). Water levels range from 7 to 18 m (23 to 59 ft.) below the base of the refuse, and regional groundwater flow is toward the lowland to the north.

The average volume of each of the 56 samples obtained from the lysimeters at Geneseo was 316 ml. Highly contaminated soil moisture was collected beneath the landfill portion of the site. Less contaminated soil moisture was encountered beneath the remainder of the site. Sampling of monitoring wells and resampling of numerous municipal wells, however, has indicated virtually no leachate migration in the saturated zone.

Table 1 illustrates the range in quality of ground water and soil moisture at the site. Two processes apparently control the extent of contamination:

- the attenuation of leachate in the unsaturated zone
- an apparent decrease in the concentration of contaminants being released by the refuse. Many parameters, such as COD, were relatively stable over the two-year period encompassed by this study. Probably leachate has migrated through the unsaturated zone beneath the landfill at an average rate of 1 m/yr (3 ft/yr) since 1967. The actual rate of migration has probably been greater because much of the refuse was not emplaced until 1971 to 1975, and the sequence of materials beneath the site has caused highly variable rates in movement of soil moisture.

Soil-moisture samples from Geneseo indicated the expected effects of waste disposal in a permeable medium. The highly contaminated leachate migrating through the unsaturated zone beneath this site represents a significant threat to ground water. Maximum concentrations of most parameters, however, as illustrated by specific conductivity (Figure 5), are present at depths of 5 to 6 m (16 to 20 ft.) below the refuse. Below that depth, significant attenuation appears to have resulted from the presence of a layer of fine-grained glacial till that has restricted vertical migration and provided increased ion-exchange capacity. A significant amount of contaminated soil moisture probably flows laterally at the contact of the sand with the underlying glacial till, ultimately entering the groundwater system in the lowland to the north. However, no deterioration in water quality has yet been observed either in surface water or shallow ground water in the lowland north of the site. The pattern of leachate migration that was detected with the lysimeters also indicated that the suspected contamination of municipal wells was not due to leachate migration from the landfill.

Crystal Lake Landfill

The Crystal Lake landfill began operation in 1973 in an abandoned

TABLE 1. Comparison of soil moisture and ground water at the Crystal Lake landfill.

	Leachate-soil moisture (mg/L)[a]	Uncontaminated soil moisture (mg/L)	Ground water (mg/L)
Ca	3,760	53	54
Fe	240	0.6	0.8
[illegible]	<.2 ppb	<.2 ppb	<.2 ppb
K	17	0.4	1.7
Mg	120	18	59
Na	1,260	18	31
Pb	<.01	<.01	<.01
Zn	0.17	0.01	0.06
Alk ($CaCO_3$)[b]	9,410	210	352
Cl	3,583	31	56
COD	8,898	6	457
NH_4-N	11	0.0	–
NO_3-N	7	0.2	1.5
pH[b]	7.05	6.05	7.70
SC[b]	7,000	525	750
SO_4	<.01	35	12
TDS	10,186	537	480

[a]Except Hg (ppb), pH, and SC (μmhos).
[b]Field measurement.

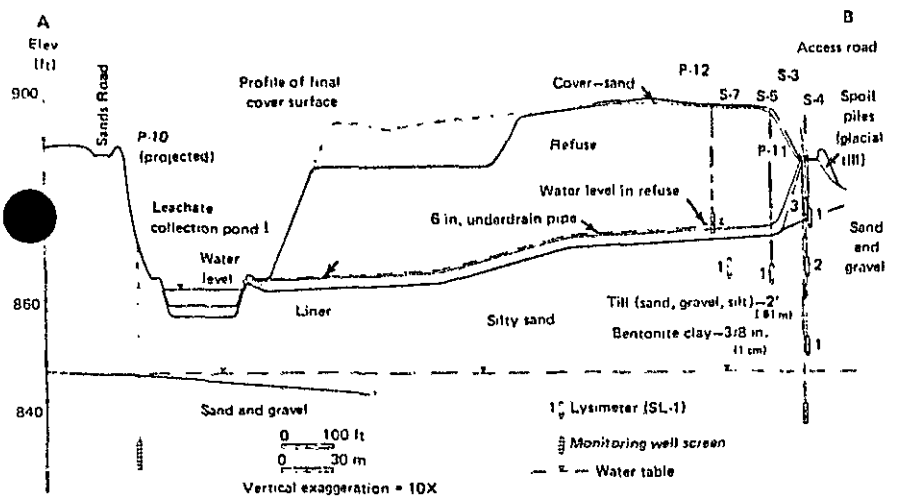


Figure 6. East-west cross section A-B of the Crystal Lake landfill showing the liner and relationships of monitoring devices to underlying materials. The base of the landfill slopes toward the west while the water table slopes gradually toward the east.

gravel pit (Figure 2). An artificial clay liner beneath the refuse consists of approximately 61 cm (2 ft.) of sandy glacial till from the adjacent spoil piles overlying a 1-cm (.5 in.) layer of bentonite clay spread over the underlying sand. Although the glacial till contained some silt and clay, it also contained much sand and many cobbles and boulders, which were not removed prior to installation of the liner. A leachate collection system consisting of underdrain pipe 15 cm (6 in.) in diameter was installed above the liner and led into a bentonite-lined lagoon at the west end of the fill area (Figure 6).

Water levels range from 7 to 10 m (23 to 33 ft.) below the refuse. The materials in this zone consist predominantly of very silty fine sand. The site is underlain by approximately 75 m (245 ft.) of glacial drift. Water-yielding sand and gravel units within the drift and the underlying Silurian dolomite are important aquifers in the area.

The liner and underdrain system were designed to collect leachate accumulating at the base of the refuse and divert it to the collection pond to be recovered and treated. However, during the eight years since refuse emplacement the drain pipe has yielded water only during heavy rainfalls. Although three to six years may generally be required for refuse to reach field capacity, a well at the base of the refuse indicated a saturated zone of leachate at least 1 m (3 ft.) thick overlying the liner. The rapid response of the underdrain to precipitation events indicates that water is able to enter and flow through the refuse. Although a portion of the infiltration is diverted into the leachate collection system, the remainder is absorbed by the refuse or percolates through the liner.

The effectiveness of the clay liner could be evaluated only by measuring the quality of soil moisture migrating out of the landfill, because samples collected from wells at the site show no indication of contamination. The lysimeters installed beneath the clay liner clearly indicate the presence of contamination; however, the extremely low volumes of samples indicate low contents of soil moisture compared to that in similar materials adjacent to the refuse. The average volume of all the lysimeter samples was 330 ml. Contaminated soil moisture was found below the liner; comparison with the quality of leachate above the liner indicates some attenuation of many constituents migrating through the liner and the underlying silty sand (Table 2).

Lysimeters installed adjacent to the refuse also indicated the presence of leachate migration. Concentrations of most parameters in soil moisture decreased with distance from the refuse to approximate background levels at a distance of 7.6 m (25 ft.). Infiltration and attenuation processes adjacent to the refuse probably limit the effects of the lateral migration of leachate; Cl concentrations have been reduced by 95 percent at a distance of 3 m (10 ft.) from the refuse. However, in soil moisture beneath the refuse at a depth of 1.5 m (5 ft.), Cl concentrations have been reduced by only 10 percent of that in the raw leachate.

Results of the Laboratory Study

There have been no detailed experiments to evaluate the validity of samples of highly contaminated leachate collected with pressure-vacuum lysimeters. This preliminary laboratory study was designed to determine any significant changes that may be caused in the concentrations of several major constituents

TABLE 2. Composition of leachate, soil moisture, and ground water at the Crystal Lake landfill.

	P-12 Leachate (mg/L)[a]	S-7 Contaminated soil moisture (mg/L)	Uncontaminated soil moisture (mg/L)	P-8 Ground water (P-8) (mg/L)
Ca	6,200	1,720	96	47
Fe	350	85	0.0	0.4
Hg	< .2 ppb	< .2 ppb	< .2 ppb	<0.2 ppb
K	650	46	0.5	0.5
Mg	1,660	93	19	19
Na	1,030	220	7	2
Pb	0.4	< .01	< .01	< .01
Zn	46.5	0.24	0.03	0.6
Alk ($CaCO_3$)[b]	11,800	960	200	240
Cl	1,602	750	16	6
COD	32,000	440	5	4
NH_4-N		13	0.0	-
NO_3-N	7.9	38	0.3	3.9
pH[b]	5.65	7.40	6.35	7.48
SC[b]	12,000	3,400	700	520
SO_4	992	250	73	40
TDS	22,900	3,664	619	400

[a]Except Hg (ppb), pH, and SC (μmhos).
[b]Field measurement.

in samples of landfill leachate by collection in pressure-vacuum lysimeters.

In the laboratory study, the intake rate and hence, volume collected from each lysimeter, decreased steadily with time. The decrease in intake rate, or cup conductivity, is illustrated in Figure 7 as volume collected per unit time per atmosphere of applied vacuum. During the first five days, the intake rate of each sampler decreased rapidly; subsequently, the decrease, although steady, was at a much lower rate.

The effects of acid treatment of the ceramic cup may be reflected by the consistently larger sample volumes and intake rate of the acid-cleaned lysimeter. This experiment indicated, however, that these effects appear to decrease with time when in contact with the raw leachate.

The decrease in yield of the samplers was probably the result of clogging of the small pores on the exterior of the ceramic cup by suspended particulates in the leachate. Microbial growth also may have contributed to clogging of pores. This decrease in yield, however, was not observed during field studies using identical lysimeters. Sample volume remained relatively constant from samplers at each of the three landfill sites. The suspended particulate matter primarily responsible for clogging of the ceramic cups is easily removed from leachate during

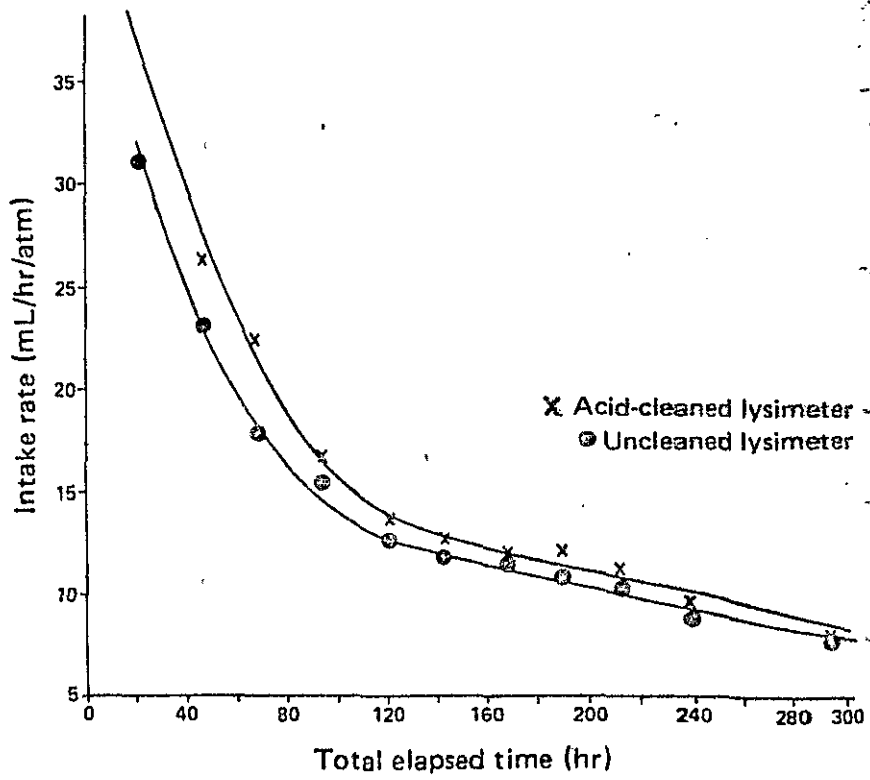
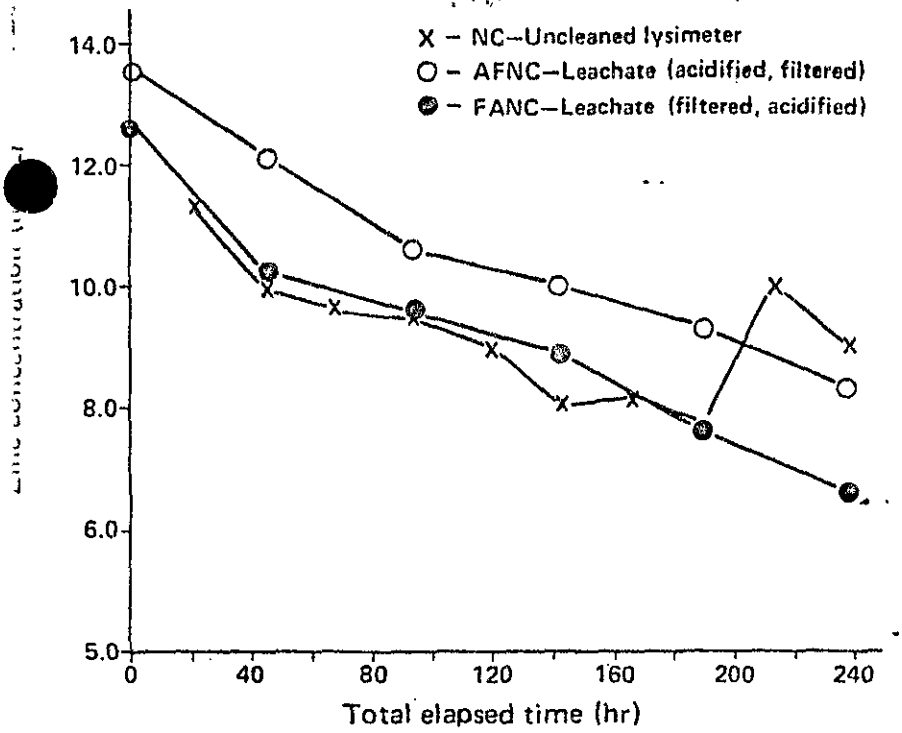


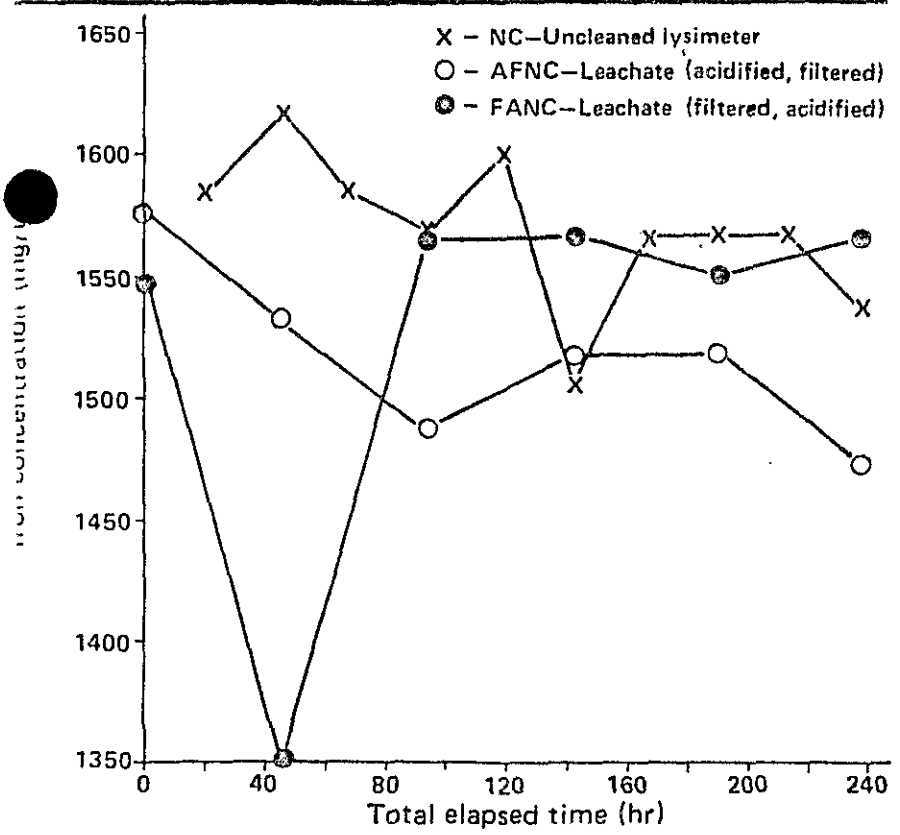
Figure 7. Intake rate (cup conductivity) of acid-cleaned and uncleaned lysimeters in landfill leachate versus elapsed time.

migration through sediments beneath a landfill. Although microbial growth and plugging by colloids may still occur following migration through soils, these did not markedly affect the field performance of lysimeters during this study.

Although each container of leachate initially contained at least 2.5 mg/l of Cu, Pb and Hg, no Cu or Hg was detected in any of the samples collected in the lysimeters. Pb was present in steadily decreasing amounts only in samples of raw leachate that were acidified prior to filtration. Apparently, these trace elements were adsorbed onto particulate matter in the leachate or precipi-



igure 8. Zinc concentration in samples obtained from an uncleaned lysimeter compared with samples of raw leachate during a 240-hour period.



igure 9. Iron concentration in samples obtained from an uncleaned lysimeter compared with samples of raw leachate during a 240-hour period.

ated and progressively settled out f the suspension. Filtration hrough a membrane filter or a mic cup effectively removed all icles containing adsorbed Pb.

Concentrations of Zn in samples f raw leachate decreased steadily ith time (Figure 8). For approximately the first 190 hours, samples rom the uncleaned lysimeter (NC) contained levels of Zn very similar to that of the samples of filtered-acidified leachate (FANC). The reason for the change after 190 hours is unknown. Although Zn concentrations appeared to decrease with time and exhibited marked fluctuations, results of statistical tests indicated that there were no signficant differences between the means or the variances of lysimeter samples and raw leachate from the same container. The steady decrease of Zn concentrations in leachate with time probably reflects the progressive settling out of particulate matter containing adsorbed Zn.

Total Fe concentrations were very high and fairly consistent in all samples (Figure 9). The iron was presumed to be virtually all in the ferrous (Fe^{+2}) state owing to the reducing conditions of the leachate. The results indicate that the levels and variation of Fe observed in NC lysimeter samples were in general similar to those of the raw leachate being sampled. Fe concentrations in samples from the cleaned lysimeter were quite variable; however, the mean concentration was nearly identical to that of FAC leachate. The variability of Fe observed in lysimeter samples may have resulted from the use of an air pump for sampling. The introduction of air to the samples may have resulted in partial oxidation and subsequent precipitation of the Fe from solution.

The remaining constituents observed in the leachates included Ca, Mg, Na, K and Cl. The concentrations of each of these constituents were generally very high, representative of leachate only a few years old. The variation of chloride from the NC lysimeter with time is shown in Figure 10. In general, the data indicate a great deal of similarity between the lysimeter and raw leachate samples. Mean concentrations and standard deviations for lysimeter samples closely approximated those of raw leachate samples. Although significant differences were found between the variances of NC and FANC concentrations of Ca, Na, K and Fe, no significant differences were observed between mean concentrations in NC lysimeter samples and FANC leachate samples. Differences in mean concentrations from the acid-cleaned lysimeter (C) and FAC leachate samples were in general not significant.

Although some degree of sorption and screening of ions undoubtedly occurred on the ceramic cup, the effects appeared to be negligible compared to the concentrations of several major ions in the leachate. No consistent, significant differences in concentrations were found between lysimeter and raw leachate samples that could be attributed to sorption or screening by the lysimeter. To reduce the possible effects of the ceramic cups on samples, it is generally recommended that new samples be rinsed first with at least

liter of approximately 8N HCl and then rinsed with distilled water (10 to 20 liters). Samples from lysimeters in this experiment were generally very representative of the surrounding leachate composition of several major ions; however, more detailed experiments are required to accurately determine the ability of ceramic-cup samplers to obtain representative concentrations of constituents in contaminated solutions.

Discussion of Waste Disposal in the Unsaturated Zone

The implications of waste disposal and leachate control in unsaturated materials have only recently become of concern to hydrogeologists. Whereas the factors that control saturated ground-water flow are reasonably well known to geologists and engineers, the laws governing unsaturated flow are commonly misunderstood and misapplied. The unsaturated component of the ground-water flow system is neglected in most hydrogeologic studies.

A frequently encountered hypothesis states that leachate will not form or migrate from solid waste emplaced above the zone of saturation. This study and others, however, have shown that infiltration will result in leachate migration through unsaturated materials beneath waste disposal sites in humid climates. Although this zone of partial saturation is generally a good buffer zone, the monitoring and control of leachate can be difficult. Whereas relatively simple techniques, such as wells, commonly can be used to remove and renovate contaminated ground water in saturated materials, such methods are generally not applicable to cases of extensive soil-moisture contamination indicative of imminent ground-water pollution. Where the underlying unsaturated materials are thick, the migration of the hazardous pollutant usually is detected later than at sites nearer or below the water table and correction can be more involved and costly. If the surrounding soils are sufficiently fine grained to provide adequate renovative capabilities, disposal above the water table would be of limited concern; however, those areas that have a well-defined, deep water table are generally underlain by coarse-grained materials that drain ground water and, potentially, leachate from the site.

Landfill liners and leachate collection systems are also generally designed for use in a saturated system where ground-water flow through fine-grained materials is restricted, and water easily flows into a gravel drain from which it can be pumped for treatment. In unsaturated soils, however, infiltration may actually bypass a leachate collection system, especially if the collection system consists of a narrow, coarse-gravel drain overlying a wide liner with a low hydraulic conductivity. In partially saturated soils, water is held under tension in progressively smaller pores; as water contents decrease, tension increases. Thus, the large pores of a gravel drain are the first to be drained with partial dewatering and the last to be filled upon rewetting. Hydraulic conductivity also decreases with a reduction in saturation to the point where it approaches zero in the absence of water-filled pores.

Infiltration through the surface of the landfill will raise the water content of the cover and refuse; however, saturation is not required for downward movement toward the water table. In partially saturated soils, soil moisture may move preferentially through fine-grained materials whose predominantly small pores remain filled with water. An adjacent gravel drain on the other hand, contains a few large pores that require nearly total saturation before soil moisture will enter. In unsaturated materials, therefore, a sump or gravel drain may be dry, but flow may be occurring, and leaching, although at limited rates, may be causing the migration of contaminants from the refuse toward the water table.

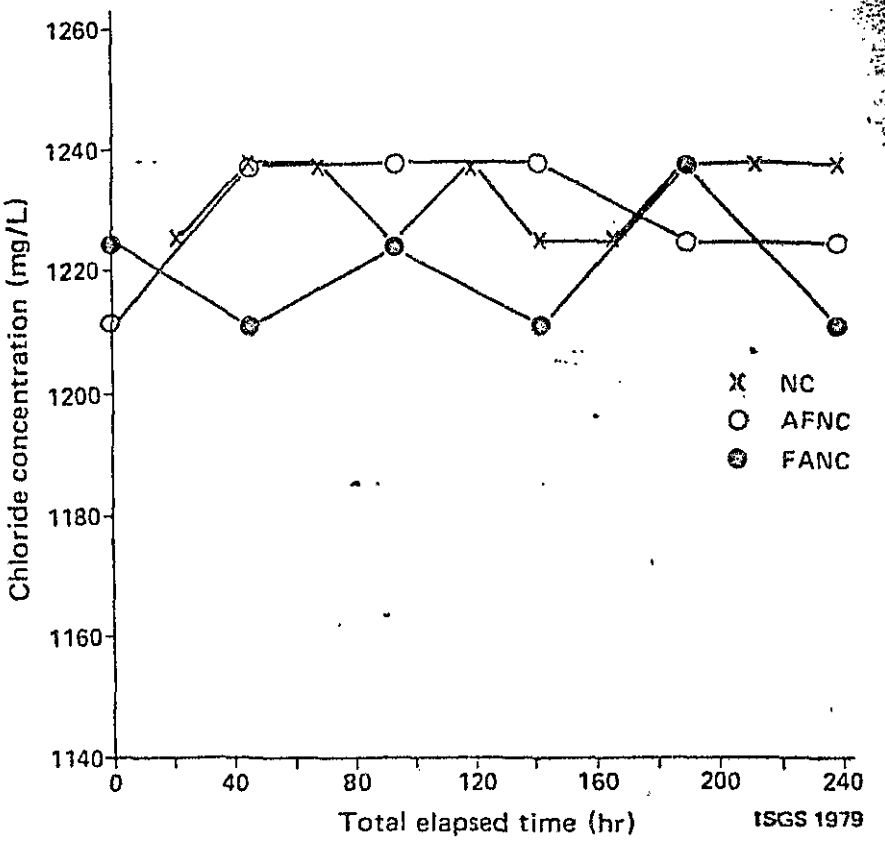


Figure 10. Chloride concentration in samples obtained from an uncleaned lysimeter compared with samples of raw leachate during a 240-hour period.

Summary

The chemical analyses of samples of soil moisture collected with pressure-vacuum lysimeters indicated the presence of leachate contamination beneath each landfill studied. The majority of the monitoring wells at these landfills have not been affected by leachate. Contamination by leachate was detected almost solely by samples of soil moisture. Given enough time and more careful placement of monitoring wells at these landfills, however, contamination of ground water probably will be observed. The importance of the early detection and delineation of zones of contamination beneath waste disposal sites in unsaturated materials necessitates monitoring of the unsaturated zone.

Soil samples collected for chemical analysis yielded little information

ubsequent boring would have been necessary to define changes in soil-water chemistry—an expensive and time-consuming process. The pressure-vacuum lysimeters used in this study have the advantage of providing soil-water samples continuously and repeatedly from unsaturated materials.

There are several limitations in the use of pressure-vacuum lysimeters. The relatively small sample volumes (500 ml or less) limit the selection of parameters for chemical analysis. The ceramic cup may alter the composition of samples and plugging of the ceramic cup pores may reduce the volume of the sample. In addition, sampler failure is, for all practical purposes, irreparable. Preliminary laboratory results indicate that lysimeters may be suitable for collecting representative samples of highly contaminated landfill leachate; however, no detailed experiments on validity of samples have been completed.

Regulations resulting in the increased use of the unsaturated zone for waste disposal should consider the implications of unsaturated flow through and beneath waste disposal sites where standard ground-water monitoring techniques are not applicable. The development of effective procedures to monitor the unsaturated zone will be necessary to implement an adequate monitoring program. Further research is also needed to evaluate the effectiveness of gravel drains and landfill liners as leachate collection systems in unsaturated materials.

**Mention of trade names in this article does not imply endorsement by the Ground Water Monitoring Review, Illinois State Geological Survey or sponsoring agencies.*

Biographical Sketches

***Thomas M. Johnson** is an assistant geologist with the Illinois State Geological Survey in Champaign, Illinois. He earned his M.S. in geology and M.S. in water resource management from the University of Wisconsin-Madison in 1975.*

***Keros Cartwright** is geologist and head of the hydrogeology and geophysics section of the Illinois State Geological Survey in Champaign, Illinois. He earned his Ph.D. in geology from the University of Illinois in 1973.*

assistant geochemist with the Illinois State Geological Survey in Champaign, Illinois. He earned his M.S. in geology from Wright State University in Dayton, Ohio, in 1976.

Acknowledgments

Funds for this investigation were provided by the Illinois Institute of Natural Resources under Contract No. 40.029. The authors gratefully acknowledge the cooperation and assistance of the landfill operators and the Illinois Environmental Protection Agency.

References

Apgar, M., and D. Langmuir. 1971. Ground-water pollution potential of a landfill above the water table. Ground Water, v. 9, no. 6, pp. 76-96.

Dazzo, F.B., and D.F. Rothwell. 1974. Evaluation of porcelain cup water samplers for bacteriological sampling. Applied Microbiology, v. 27, no. 6, pp. 1172-1174.

Gerhardt, R.A. 1977. Leachate attenuation in the unsaturated zone beneath three sanitary landfills in Wisconsin. Wisconsin Geological and Natural History Survey, Information Circular 35, 93 pp.

Grover, B.L., and R.E. Lamborn. 1970. Preparation of porous ceramic cups to be used for extraction of soil water having low solute concentrations. Soil Science Society of America Proceedings, v. 34, no. 4, pp. 706-708.

Hansen, E., and A. Harris. 1975. Validity of soil-water samples collected with porous ceramic cups. Soil Science Society of America Proceedings, v. 39, pp. 528-536.

Hughes, G.M., R.A. Landon, and R.N. Farvolden. 1971. Hydrogeology of solid waste disposal sites in northeastern Illinois. U.S. Environmental Protection Agency, Solid Waste Management Series, Report SW-12d, 154 pp.

Johnson, T.M., and K. Cartwright. 1980. Monitoring of leachate migration in the unsaturated zone in the vicinity of sanitary landfills. Illinois State Geological Survey Circular 514, 82 pp.

Levin, M.J., and D.R. Jackson. 1977. A comparison of in situ extractors for sampling soil water. Soil Science Society of America Journal, v. 41, pp. 535-536.

water sampling using pan and deep pressure vacuum lysimeters. Journal of Hydrology, v. IX, no. 1, pp. 1-21.

Wagner, G.H. 1962. Use of porous ceramic cups to sample soil water within the profile. Soil Science, v. 94, pp. 379-386.

Wolfe, R.G. 1967. Weathering of Woodstock Granite near Baltimore, Maryland. American Journal of Science, v. 265, pp. 106-117.

Wood, W.W. 1973. A technique using porous cups for water sampling at any depth in the unsaturated zone. Water Resources Research, v. 9, no. 2, pp. 486-488.

Wood, W. 1978. Use of laboratory data to predict sulfate sorption during artificial ground-water recharge. Ground Water, v. 16, no. 1, pp. 22-31.

44. Johnson, V.R. "Monitoring Ground Water at Cyanide Leach Mining Sites," Ground Water Monitoring Review, Winter 1983, pp. 144-147

2648

MONITORING GROUND WATER AT CYANIDE LEACH MINING SITES

Reviews available leach detection methods and describes the author's new *grid leach detection system.*

by Victor R. Johnson Jr.

Introduction

"I come before you today with the distressing news that one of this nation's most vast and vital resources (ground water) is in serious jeopardy," said Eckardt C. Beck, assistant administrator for the U.S. EPA on July 25, 1980, before the House of Representatives Environmental Energy and National Resources Subcommittee.

This congressional subcommittee, after studying ground-water contamination problems in the United States, concluded that "ground-water destruction will be one of the most serious environmental problems of the 1980s" and that "the destruction of our nation's ground water will continue unless we move immediately to locate all potential sources of ground-water contamination and take action to block the further flow of toxic substances into the ground." In the National Assessment of the Ground-Water Contamination Potential of Waste Impoundments, Silha & Brasier, (1980) found the following:

- More than 70 percent of the industrial impoundments (estimated 176,647 in the United States) are unlined, thereby potentially allowing contaminants to infiltrate unimpeded into the subsurface.
- Less than 20 percent of the sites have any ground-water monitoring, and only one-half of those with ground-water monitoring regularly are sampled. This means that nearly 95 percent of the sites are virtually unmonitored for ground-water contamination.

This article will provide a discussion of the technology currently available for monitoring the effectiveness of ground-water protection systems commonly being used at cyanide leach mining sites. Few mining projects are located where natural geologic hydrogeologic conditions are such that there is no possibility of ground-water contamination. Consequently, most cyanide leach mining sites need engineered ground-water protection systems such as natural and/or synthetic liners, as well as leachate detection, collection and treatment equipment.

One of the first elements of designing effective ground-water protection systems is a good understanding of the technical theories behind each potential system component.

Permeability

Permeability is a measurement of hydraulic conductivity and is used in the design of natural liners. The basic permeability theory (Darcy's Law) was developed for saturated soil conditions. For unsaturated soils, the theory is not totally applicable. For example, in the case of soil liners, when saturation drops below 100 percent (the usual field condition), the soil imbibes air and the pore water abandons larger pores in favor of smaller ones. Flow channels become constricted and more tortuous. As a result, hydraulic conductivity decreases with decreasing saturation. The U.S. EPA recognized the complexity of permeability testing and did not define how to perform permeability tests in the Resource Conservation and Recovery Act (RCRA). Currently, the minimum permeability test results for soil liners have been mandated by federal regulations, yet the test procedures have not been specified. Consequently, several testing procedures are used throughout the country with only moderate test-to-test correlation of results.

Permeability measurement is further complicated by several inherent factors which often lead to significant variations in test results. Such factors include:

- Alteration of clay chemistry may affect conductivity. Wilkinson (1969) found a 100-fold difference in hydraulic conductivity, depending upon whether the permanent fluid was distilled water or natural pore water
- Air in the sample can lead to reduced conductivities (Smith and Browning 1942)
- Micro-organisms may grow in the soil, plug the voids and reduce the conductivity (Allison 1947)
- Use of an excessive hydraulic gradient may lead to migration of individual grains of soil, and to modified conductivity (Gairon and Schwartzendruber 1975)
- The accuracy of conductivity results can vary if smear zones form when trimming samples or voids

occur in the sample during its preparation

- Conductivity is variable with regard to vertical and horizontal flow direction
- Correlation between in situ permeabilities and laboratory permeabilities normally vary significantly (Weber 1968)

Permeability measurement is a useful tool in the design of liners and ground-water protection systems, but the designer should understand that it is a test with significant inherent variables.

Ground-Water Monitoring Wells

Approximately thirty times as much ground water exists within half a mile of the earth's surface as is contained in all U.S. rivers and lakes. A common misconception about ground water is that it moves rapidly. Actually it moves at rates ranging from a few feet per day to a few feet per decade. Monitoring wells which intersect ground water under leach mining operations have traditionally been the primary indicators of any ground-water contamination. Unfortunately, monitoring well design and usage is not an absolute science. The following factors relating to monitoring wells should be considered: the extremely slow rate of subsurface liquid movement often results in a time lag of years from the initial time of leakage to interception by a monitoring well. This time lag results in significant subsurface soil volumes being contaminated before the monitoring well detects the pollutant. Recently, $325,000 was spent on removal and disposal of contaminated soil under a liner before RCRA EP Toxicity tests could even be started to determine the extent of contamination of the remaining soil; improper installation of monitoring wells can introduce minor amounts of pollutants into the ground water. Although these pollutants are not normally significant from a health standpoint, they may invalidate or confuse the interpretation of monitoring well results. For example:

- When monitoring wells are installed with rotary drilling fluids containing polymers, the polymer is often detected in water samples
- When glue is used to solvent-weld synthetic well casing joints together, the components of the glue often identified in the sampling
- When PVC well casing is sawed to make screens, shavings can provide a source for chlorinated compounds
- Hydraulic oil leaks from a drilling rig's hydraulic system as well as grease used for auger thread lubrication may also be detected in sampling;

the cost of the installation of a minimum of four high quality monitoring wells, one upgradient and three downgradient, for a surface impoundment or landfill under Section 265.91 of RCRA may be in the range of several thousand dollars per well. In addition to capital costs of monitoring well installation, there is the added cost of meeting RCRA Section 265.92 requirements for analytical testing, which includes:

- Testing for the 21 parameters characterizing the suitability of the ground water for drinking
- Testing for the six parameters establishing ground-water quality
- Testing for the four parameters used as indicators of ground-water contamination using four replicate measurements per parameter for each test.

Recent cost estimates for the first year's analytical costs for four monitoring wells run close to $10,000.

Furthermore, there are costs in collecting the samples. Today's highly sophisticated analytical techniques require sophisticated sample collection. Many pollutants can be inadvertantly masked, even in well-designed monitoring wells, through improper sampling techniques such as using unclean samplers, failing to stabilize samples if analytical work cannot commence quickly, etc.

Finally, there are costs incurred in developing the ground-water sampling and analysis plan mandated in RCRA Section 265.92, in developing the ground-water assessment plan mandated in RCRA Section 265.93, and in meeting the record keeping and reporting requirements in RCRA Section 265.94. Clearly, monitoring wells are an expensive ground-water evaluation system. This analysis of monitoring wells is intended to create an awareness of some of their potential deficiencies.

Lysimeters

Lysimeters are used for detecting liquids in the unsaturated or partially saturated zones of soil. Monitoring the unsaturated zone is desirable because it allows for earlier detection of leaks from an impoundment or landfill. Correction measures may then be implemented earlier and the amount of soil contamination may be minimized.

A lysimeter is a porous ceramic cup to which liquid migrates from the unsaturated or partially saturated soil zone when a vacuum is created in the cup. The lysimeter is subsequently pressurized and the liquid is forced to the surface for collection and analysis. Unfortunately, as with permeability testing and ground-water monitoring wells, lysimeters are not without some inherent drawbacks. Specifically, the following operational problems have been historically experienced:

- The porous cup has a high potential for plugging
- When the lysimeter is pressurized to force the sample to the surface, this same pressurization can force the liquid back out of the porus cup, thus reducing sample volumes
- Only relatively small volumes of liquid can be obtained from common size lysimeters, and thus some tests which require large sample sizes cannot be undertaken. In addition, the cost of sampling and analytical testing samples from lysimeters is very expensive
- The effectiveness of lysimeters which have mechanical check valves or other mechanical arrangements to stop the exfiltration during repressurization has been limited due to history of corrosion problems
- Lysimeters, as with monitoring wells, are not able to identify the exact location of the leak
- Some elements originally present in the ceramic cups may be dissolved by the ground water and constituents in the ground water may be absorbed or screened by the ceramic materials (Grover and Lamborn 1970).

Lysimeters serve an important role in ground-water protection, but as with permeability testing and monitoring wells, they have limitations.

Leachate Collection System

A leachate collection system is used as a leak detection system beneath impoundments and landfills. Some drawbacks to a leachate collection system are:

- They tend to plug with time
- They are unable to identify the location of a leak, and can identify only that a leak has occurred
- They are expensive to install and require daily inspection (RCRA Part 264.226)
- They require expensive sampling and analytical costs in order to differentiate between pollutant leaks and normal uncontaminated ground water which often is also present in the collection systems.

Leachate collection systems are valuable as a ground-water protection system, but their inherent drawbacks should be understood to make full use of the system.

Grid Leak Detection System (Patent Pending—Serial Number 201,841)

A new leak detection system has been recently developed by the author. When used selectively, such a system can be another valuable approach in the design of ground-water protection systems. The basic design assumption of the grid leak detection system is that when leakage migrates through a liner and into the soil's unsaturated zone, it is often corrosive to metal or will degrade certain organic compounds. For example, hydrocarbons may degrade natural rubber. The corrosive nature of the leakage is employed to activate a grid of coated and/or uncoated wire placed under the liner. The corrosion of the wires or wire coating causes accelerated changes in the electrical properties (resistivity, voltage, change, etc.) of the wires. These electrical property changes are detected through the use of a data logger which can send an electrical current through the wires and then measure any change in their electrical properties. In the case of large leaks of very corrosive materials, the grid wires would be totally corroded away, and an open circuit would occur. This effect can also be detected by the data logger. Due to the grid configuration of the wires, the data logger can detect the exact location of leak occurrence. This leak location ability is extremely important in the case of a synthetic liner covered with soil or ore, for example.

In the case of hydrocarbon leakage, the wire configuration is slightly different. The initial wire is coated with natural rubber or other organic compounds which would be rapidly degraded by hydrocarbons. A second wire is then coiled in a helix around the first wire so that when the hydrocarbon degrades the coating on the first wire it will, in effect, complete a circuit. The completed circuit will be detected when the data logger sends a current through the inner wire and receives it through the outer helix wire.

Soil chemistry and natural soil moisture conditions will have some effect on the electrical properties of the wires. Consequently, it is advisable in most cases to place a reference wire grid adjacent to the impoundment or landfill. This provides an indication of the degree of natural deterioration of the wires. Since the grid leak detection system is designed to identify significant changes in grid wire electrical properties, natural wire deterioration should not create a significant problem since the electrical reference baseline of the wires can be adjusted accordingly.

If highly corrosive leakage does occur regularly, it is obvious that the grid leak detection system cannot remain in use year after year without repair or partial replacement.

The grid wires can be adhered to woven or non-woven geotextiles and then the geotextiles can be layered over each other in a manner so that the wires will not come into contact with each other and give false readings. It has been found that there is no detectable heat buildup in geotextiles when 24.0 volt (8.8 amp) dry cells are used as energy sources. An alternative method of installing the wires without the use of geotextiles is to place the wires in a sand blanket with proper separation (4 to 6 inches).

Grid wire size normally varies from household size wire (12 to 16 gauge) to large (1/4 inch or more) size wire. The smaller wires adhere more easily to geotextiles, which simplifies field installation, but they have shorter initial system lives if highly corrosive leakage regularly occurs. Larger diameter wires are more difficult to install, but have significantly longer initial service lives.

Table 1 offers the results of laboratory analysis performed to determine the rates of corrosion of small-diameter wires (0.040 in. diameter) in 5 percent solutions of various chemicals.

These results indicate that different metallurgical composition of the wires in the grid can extend the flexibility of the detection system as required for impoundments which change chemical streams dramatically during their service life.

The grid leak detection system has other potential applications such as: vertical installation in bentonite slurry trench walls where "windows" in the slurry trench wall can be a source of horizontal pollutant migration; installation around pipelines since pipeline leaks often migrate through the pervious bedding material making identification of the leak location extremely difficult; installation under underground tank installations which have the same inherent leakage problems as pipelines; installation in the sand or gravel under aboveground storage tanks for leak detection and location identification for repair; and installation under lined mine-tailing impoundments from which any hazardous liquid leakage creates corrective problems due to the usually large depth of tailing waste over the liner. It should be noted that many of the new mining processes use cyanide as the method of leaching precious metals out of ore, and this practice has raised the degree of hazard in mine tailing waste.

The grid leak detection system's advantage of rapidly detecting leaks and their locations without the need for sample collection and chemical analysis makes it a valuable new ground-water protection system. As with the other systems reviewed, the grid leak detection system has its vulnerable aspects which should be taken into consideration during design.

Water Sampling for Cyanide

Water sample collection and analysis is usually performed to augment the previously described pollutant detection techniques: the analysis of a sample to precisely determine its level of cyanide is commonly performed. "Standard analytical methodologies for the determination of cyanide in water have been demonstrated both by inter- and intra-industry studies to be both inappropriate and imprecise. They are inappropriate because they do not distinguish between free and complexed cyanide thus leading to potential overestimates of the

Table 1.

	Chemical		
Diameter & Type of Wire	*NaOH*	*HCL*	*HNO_3*
0.040" Aluminum	8 hrs. to failure	3 hrs. to failure	No change in 36 days
0.040" Copper	40% dissolved in 36 days	4 days to failure	2 days to failure
0.040" Steel	No change in 31 days	2 hrs. to failure	1 day to failure

potential for free cyanide in water. They are imprecise because they do not give statistically reliable free cyanide estimates in the low $\mu g/l$ range. A number of promising alternative methodologies have been developed by industry some of which are currently used on a limited site specific basis. This is an important point since there is "sound scientific evidence that free cyanide and complex cyanides should be considered separately for the purposes of setting water quality criteria and standards and for regulating cyanide discharges." (Ecological Analysts Inc. 1979)

For purposes of discussion "free cyanide" is the summation of molecular HCN and the cyanide ion ($HCN+CN^-$) in aqueous solution. This term is used irrespective of the source of free cyanide in water except when used in descriptions of analytical techniques which must estimate the free cyanide potential of various sources. "Complex cyanide," on the other hand, refers to a cyanide compound which disassociates in water to a cation and an anion comprised of two or more different molecules, one of which is cyanide. The anion is termed a complex ion and is subject to further disassociation.

Recent research has been directed at determining safe levels of free cyanide, primarily as HCN in the aquatic environment (Ecological Analysts Inc. 1979). Data are available from laboratory bio-assays with aquatic organisms tested at continuous exposure levels of molecular HCN as low as 0.0052 mg/l (5.2 $\mu g/l$). Whereas Hermann (1975) calculated that the fatal dose of cyanide to humans was approximately 100 mg/l, a value of 0.0112 mg/l HCN was found to effect egg production in brook trout (Ecological Analysts Inc., 1979). Because the level of free cyanide which can cause aquatic damage is so very low, the methodology of the analytical test becomes extremely important.

The standard method approved for cyanide testing by the U.S. Environmental Protection Agency is described in Methods for Chemical Analysis of Water and Wastes, EPA 600-479-020 (March 1979). The EPA has several methods: 1. Method 335.1 is a test method for cyanides amenable to chlorination; 2. Method 335.2 is a total cyanide test method; and 3. Method 335.3 is another total cyanide test method. These three methods were issued in 1974, 1974 and 1978 respectively. Other present methods: ASTM (1976) and Standard Methods (1976) are also used for the determination of total cyanide and the estimation of free cyanide potential in industrial effluents.

Significant research has been done by the American iron and steel industry. With regard to the ASTM (1976) and Standard Methods (1976), the following has been found (Ecological Analysts Inc. 1979): the accuracy and precision of these standard methods are poor below 1 mg/l; these methods are highly susceptible to interference from other substances; because the prescribed analytical methods may be specific to different forms of cyanide and because the composition of the effluents being analyzed may vary, several methods may be needed and alternatives to the standard methods for estimating free cyanide potential in the effluent, such as the AISI or modified Roberts/Jackson procedures should be used where appropriate.

In summary, when dealing with regulatory officials on ground-water issues relating to cyanide, it is essential to determine the exact amount and form of cyanide before agreeing to standards. This may be more difficult than it would appear on the surface because of some of the inherent problems with the standard tests historically used. However, since relatively low levels of free cyanide cause toxic effects on aquatic life and can also affect humans, it is a pollutant which must be closely monitored.

References

Prepared Statement in Hearings, Environment, Energy and Natural Resources Subcommittee of the Committee on Government Operations. Toxic Chemical Contamination of Ground Water: Environmental Protection Agency Oversight. July 24 and 25, 1980, pp 1-10.

Beck, Eckhart and L.E. Allison. 1947. Effect of microorganisms on permeability of soil under prolonged submergence. Soil Science, v. 63, pp. 439-450.

Ecological Analysts Inc. June 1979. Cyanide—An Overview and Analysis of the Literature on Chemistry, Fate, Toxicity and Detection in Surface Water, pp. 1-2.

Gairon, S. and D. Schwartzendruber. 1975. Water flux and electrical potentials in water-saturated bentonites. Soil Sci. Soc. of Amer. Proc., v. 39, no. 5, pp. 811-817.

Grover and Lamborn. 1970. Discussion of their work referenced in "Monitoring and Leachate Migration in the Unsaturated Zone in the Vicinity of Sanitary Landfills" by Thomas M. Johnson and Keros Cartwright, published by the Illinois Institute of Natural Resources, State Geological Survey Division. Illinois State Geological Survey Circular No. 514 of 1980.

Silha, Lyle R. and Francoise M. Brasier. 1980. The National Assessment of the Ground-Water Contamination Potential of Waste Impoundments. Symposium on Surface-Water Impoundments. Minneapolis, MN.

Smith, R.M. and D.R. Browning. 1942. Persistent Water-Unsaturation of Natural Soils in Relation to Various Soil and Plant Factors. Soil Sci. Soc. Amer. Proc., v. 7, pp. 114-119.

Weber, W. G. 1968. In Situ Permeabilities for Determining Rates of Consolidation. Highway Research Record No. 243, pp. 49-61.

Wilkinson, W.B. 1969. Discussion of In Situ Investigation in Soils and Rocks, British Geot. Soc., Instn. of Civil Engrs. London, pp. 311-313.

Biographical Sketch

Victor R. Johnson Jr. is principal-in-charge of the HLA Waste Management Division, and has more than a decade of practical experience in designing and managing hazardous waste transportation, treatment, storage and disposal facilities. Johnson's work experience includes a total of nine years as a corporate officer for I.T. Corp. and of several subsidiaries of Chemical Waste Management Inc.—two of the nation's largest commercial hazardous waste firms. His activities have involved a close working relationship with local, state and federal regulatory agencies and their programs.

45. Josephson, Julian. "Restoration of Aquifers," Environmental Science & Technology, Vol. 17., No. 8, 1983, pp. 347A-350A.1

Eagle

2640
2647
2648

Restoration of aquifers

Methods for identifying, containing, and reclaiming contaminated groundwater are being developed and refined. But rehabilitation costs could remain high

Despite legislation aimed at protecting groundwater supplies, such as the Safe Drinking Water Act (SDWA) and the Resource Conservation and Recovery Act (RCRA) and related regulations, aquifers do become contaminated. When this occurs, there are three basic courses of action: Forbid use of the aquifer and obtain alternative water supplies, attempt to rehabilitate it, or continue to use the aquifer, but treat the water to remove the contaminants.

About 50% of the total of 3×10^{11} acre-ft (1 acre-ft = 325 900 gal) of groundwater estimated to be available in the U.S. is designated for drinking water. Presently, less than 1% of that total, or 3×10^{9} acre-ft, is believed to be contaminated. A national goal is to halt further groundwater contamination and, if and when feasible, to rehabilitate contaminated water supplies.

Abandoning a contaminated aquifer and procuring water supplies elsewhere might seem to be a more expedient way to solve the problem of contaminated groundwater. But this has disadvantages. Alternative supplies might be neither as cheap nor as abundant as one would hope. Moreover, if groundwater contamination ever threatened to become a national phenomenon, and more well systems were abandoned, alternative water supplies could become scarce, poorer in quality, and expensive. Kirk Brown of Texas A&M University told *ES&T* that once an aquifer used as a water supply is contaminated, 100% of its available groundwater must be considered contaminated. And rehabilitating groundwater is neither cheap nor easy.

Perceived limit of tolerance

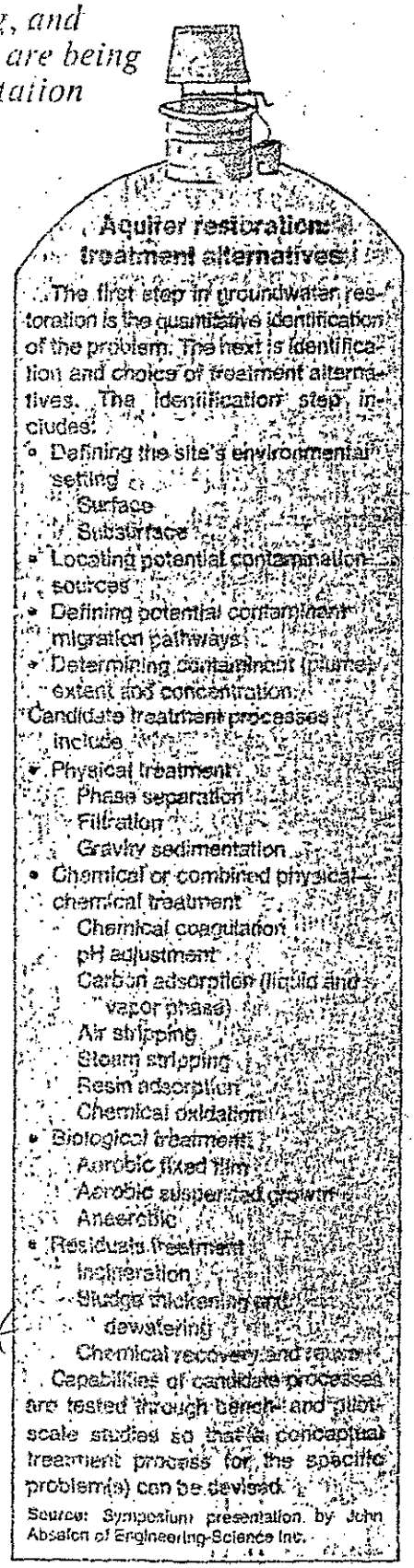
Although the total amount of contaminated groundwater nationwide comprises only a small portion of available groundwater, a problem is that contamination incidents tend to occur near populated areas that depend upon this water for potable supplies. Significant episodes, some of which forced well abandonment, have occurred in parts of Long Island, New Jersey, Massachusetts, Tennessee, Florida, and several other states.

Jay Lehr, executive director of the National Water Well Association (NWWA, Worthington, Ohio), believes that the pendulum will swing from well abandonment toward aquifer rehabilitation in response to contamination incidents. "People have reached their perceived limit of tolerance to groundwater contamination," Lehr told *ES&T*. "That's not because of health threats: people are not dying. But they want to clean up this water just as they clean their houses or yards when they see a mess there." He added that in his view, "the U.S. has the technology and know-how to clean up groundwater supplies; aquifer restoration will be a major American industry within the next several years." Lehr noted that at present, about 75 reclamation or containment projects are under way or planned.

Whether Lehr's optimistic predictions concerning the growth of an aquifer restoration industry will materialize remains to be seen. One thing is certain—such restoration work will *require major* scientific and technological efforts and outlays of funds. Contamination plumes must be identified, mapped, monitored, and contained. Then a treatment and use or recharge scheme must be designed, installed, and operated. Costs could run into millions or tens of millions of dollars for each aquifer rehabilitation project.

Plume identification

The first step toward groundwater restoration is knowing the extent, thickness, rate of spread, and contents of a contamination plume. Until re-



Aquifer restoration: treatment alternatives

The first step in groundwater restoration is the quantitative identification of the problem. The next is identification and choice of treatment alternatives. The identification step includes:

- Defining the site's environmental setting
  - Surface
  - Subsurface
- Locating potential contamination sources
- Defining potential contaminant migration pathways
- Determining contaminant (plume) extent and concentration

Candidate treatment processes include

- Physical treatment
  - Phase separation
  - Filtration
  - Gravity sedimentation
- Chemical or combined physical-chemical treatment
  - Chemical coagulation
  - pH adjustment
  - Carbon adsorption (liquid and vapor phase)
  - Air stripping
  - Steam stripping
  - Resin adsorption
  - Chemical oxidation
- Biological treatment
  - Aerobic fixed film
  - Aerobic suspended growth
  - Anaerobic
- Residuals treatment
  - Incineration
  - Sludge thickening and dewatering
  - Chemical recovery and reuse

Capabilities of candidate processes are tested through bench- and pilot-scale studies so that a conceptual treatment process for the specific problem(s) can be devised.

Source: Symposium presentation by John Absalon of Engineering-Science Inc.

0013-936X/83/0916-0347A$01.50/0 © 1983 American Chemical Society

cently, about the only way to map the plume was to drill *numerous monitoring wells around what is believed to be the plume's perimeter.* Moreover, the plume's thickness might not be as *great as that of the aquifer itself; so if* a monitoring well is not screened properly, its intake might miss the contaminant plume altogether since groundwater flow and contaminant transport can be extremely stratified. Conceivably, the zone of contamination could be both overlain and *underlain by clean water. That is why the* utmost care must be taken, when wells are screened, to account for the three-dimensional aspect of the plume when a monitoring well network is planned.

In fact, in a sense, plume identification involves *four* dimensions. The monitoring scheme must consider plume spread in two horizontal and one vertical direction *over time.*

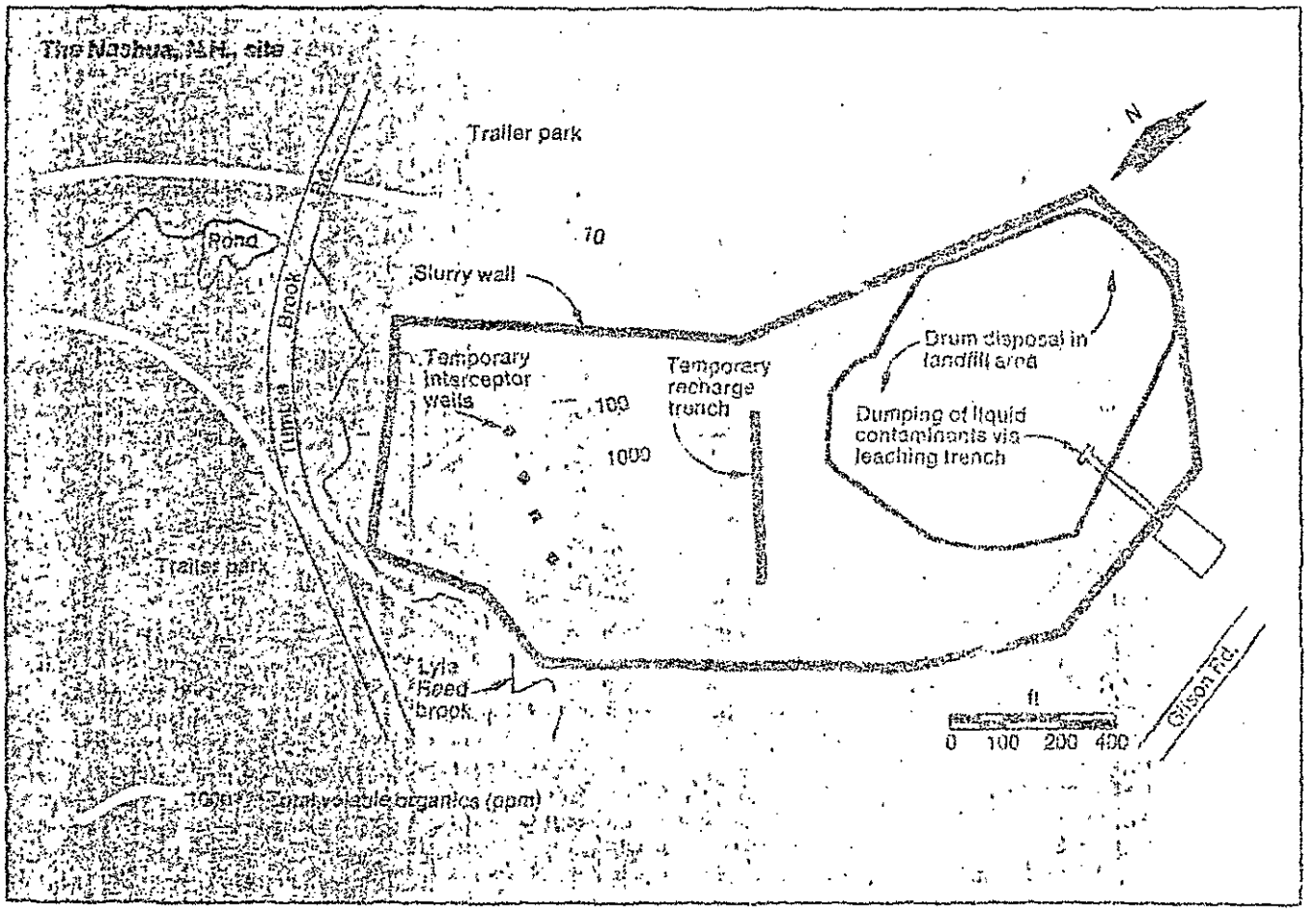
An example of a stratified contamination plume containing volatile organic solvents, in Nashua, N.H., was described at the Third National Symposium and Exposition on Aquifer Restoration and Groundwater Monitoring, held at Columbus, Ohio, in late May. Matthew Barvenik, a senior geotechnical engineer with Goldberg-Zoino & Associates, Inc., and a principal of Bar[illegible] Systems, Inc. (Mass.), spoke of [illegible] more than 450 m long, up to [illegible] deep, covering about 1.2×10^5 m^2 and moving at about 7×10^{-4} cm/s. It originated from the disposal of drums, chemical sludges, demolition debris, and domestic rubbish in an abandoned 24 000-m^2 sand and gravel pit. In addition, more than an estimated 4×10^6 L of liquid chemical wastes had been discharged next to the pit by "midnight dumpers." Site cleanup is being carried out under the first cooperative agreement signed pursuant to the federal "Superfund" law. Total construction costs, including change orders, are $2.4 million. Estimates of costs for the completed project come to $10 million. Work on the site has been under way since 1980.

To define the plume, more than 60 single-level and multilevel monitoring wells were installed. A properly installed well system *must monitor the* entire thickness of the aquifer, while taking into account the stratified nature of water movement and contaminant transport. *In this particular case,* monitoring would have to go as deep as 33 m.

Typically, the cost of such wells could *range from $400 to $3000 each.* Add to these figures the costs associated with sampling and analysis, which might come to $200–$1500/sample. In estimating costs, one should also include the expenses of hiring a consulting firm, Kirk Brown suggests.

While monitoring wells will always have to be used to delineate groundwater contamination, other, less expensive methods might be employed to obtain at least a rough idea of where the wells can be placed most effectively and what substances they should monitor. *In many situations,* geophysical techniques can perform these tasks and can also provide profiling and area mapping and knowledge of *the geological media through which* groundwater and its contaminants migrate.

Donald Bruehl of Normandeau Associates Inc. (Bedford, N.H.) lists electrical resistivity sounding, seismic refraction profiling, and precision gravity surveys as "methods with which we have had much success in groundwater studies." Other techniques he mentions include magnetic and electromagnetic methods, earth conductivity, borehole geophysics, and remote sensing. He has used these techniques in groundwater surveys "in geologic conditions typical of the formerly glaciated Northeast." These conditions usually entail aquifers



consisting of stratified, glacially deposited sand and gravel. These materials are very permeable. Other contamination incidents have involved aquifers of glacial till (mixed clay, sand, gravel, and boulders) and fractured bedrock (permeable through the fractures or cracks in the rock).

Resistivity measurements have been used as a preliminary method of defining the horizontal and vertical extent of leachate plumes stemming from suspected hazardous waste drum burial areas in EPA Region 4 (southeastern U.S.). On the other hand, magnetometry can be useful for detecting contamination "source areas" in the form of buried steel drums. A. Shane Hitchcock of EPA Region 4 (Atlanta, Ga.) explains that where such technologies can be used, they reduce equipment costs, provide data immediately, and, with sufficient background information, can be very reliable.

Plume containment

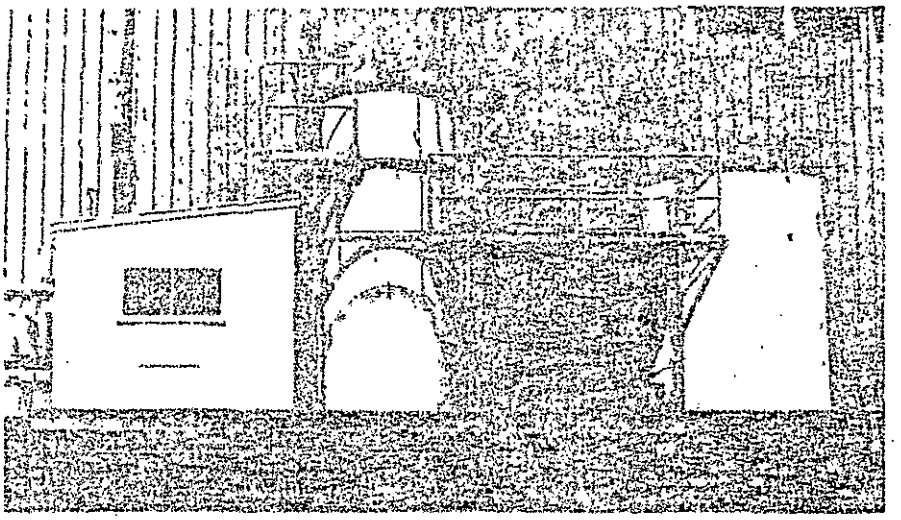
The strategy for containing the groundwater contaminants in Nashua, N.H., consisted of installing a 1-m-thick wall to surround them. The wall is a homogeneous soil-bentonite mixture constructed by a slurry technique; the material, keyed into bedrock at a maximum depth of 33 m is allowed to set. The wall is also keyed into a membrane surface cap.

After it has set, the wall's hydraulic conductivity is specified not to exceed 10^{-7} cm/s—the typical impermeability standard for hazardous waste sites—with leachate as permeant, Barvenik said. Moreover, since seepage under the wall through the rock was anticipated, a leachate collection and treatment plant has also been designed for the project; the design life of the containment system is 30 y.

But there are those who look askance at numbers indicating low hydraulic conductivity and permeability. Texas A&M's Kirk Brown maintains that under certain conditions, such as exposure to organic wastes, normally impermeable clays undergo structural changes and become more permeable, sometimes by several orders of magnitude (*ES&T*, September 1982, p. 503A). Perhaps this is one reason why EPA calls for synthetic impermeable materials in liners meant to protect groundwater from hazardous substances.

Treatment alternatives

Once a contamination plume is identified and mapped, a treatment scheme is needed. Treatment alternatives are considered, and then bench- and pilot-scale studies are conducted. Data from these studies help to establish design criteria for various treatment processes and to demonstrate performance capabilities of candidate processes, said John Absalon of Engineering-Science Inc. (Atlanta, Ga.). Treatability studies, in turn, can be used to develop a process aimed at specific problems, such as chlorinated solvents, hydrocarbons, heavy metals, and other contaminants.



Treatment: Mobile unit for groundwater and leachate treatment uses PAC.

The treatment of contaminated aquifer water could be carried out to prevent contamination spread (with purge wells) or to provide process water, or even potable water. Robert O'Brien of Calgon Carbon Corporation (Pittsburgh, Pa.) explains that granular activated carbon (GAC) is a frequently adopted treatment for contamination episodes involving organic chemicals. He says that his company installed GAC systems at 31 sites in the U.S. to treat contaminated groundwater flows of 5–2250 gallons per minute (gpm). In some cases, multimedia filtration was done before GAC treatment as a precaution; in others, air stripping was used to reduce the amount of volatile organics.

O'Brien says that for carbon tetrachloride (at four sites), influent concentrations of 130–10 000 μg/L were reduced to below 1 μg/L, and 5–10 000 μg/L of trichloroethylene (15 instances) were reduced to less than 1 μg/L. At one site, DDT, present at 4 μg/L, was curtailed to less than 0.05 μg/L. O'Brien notes that pre- and post-treatment analyses conformed to applicable EPA-published protocols for trace organics in water. He estimates that operating costs are \$0.22–\$2.52/1000 gal treated, depending upon the chemicals) and their concentrations.

Donald Hager of Rubel and Hager, Inc. (Tucson, Ariz.) says that aeration, catalyzed chemical oxidation, and GAC adsorption will be used in a pilot system for removing organic solvents, including chloroform, carbon tetrachloride, and other low-molecular-weight chlorinated hydrocarbons. Pressurized gas aeration followed by direct incineration will be evaluated as an alternative to air stripping, he adds. In this way, discharge of contaminants from water to air is avoided. A 20-gpm plant will test ways to clean water for aquifer recharge at the Rocky Mountain Arsenal, Colo. The GAC portion will use carbon made by Westvaco.

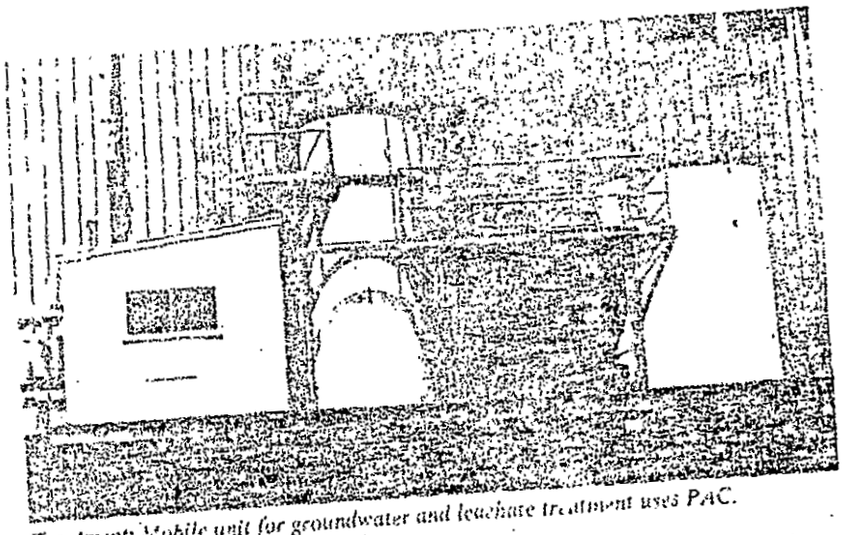
Many experts note that there are problems with using GAC for low-molecular-weight chlorinated hydrocarbon removal from water. Hager says that chemical oxidation using ultraviolet-peroxide systems will address the destruction of nonadsorbable or nonvolatile organic contaminants in the water.

Zimpro Inc. (Rothschild, Wis.) is simultaneously using microbes and an organics removal approach involving *powdered* activated carbon (PAC) with activated sludge. The PAC adsorbs contaminants that the microbes cannot assimilate, while the microbes handle organics that otherwise would need an additional carbon step. Zimpro says that its units, presently in use at 15 U.S. sites, can remove hydrocarbons, pesticides, and certain other organics from groundwater, wastewater, or leachates, with a 95–99% removal efficiency reported for COD, total nitrogen, and various organics. Known by the trade name "PACT," the system is being used in a groundwater recharge project in El Paso, Tex., and for groundwater treatment at a chemical plant site in Michigan.

But not all contaminants are or-

consisting of stratified, glacially deposited sand and gravel. These materials are very permeable. Other contamination incidents have involved aquifers of glacial till (mixed clay, sand, gravel, and boulders) and fractured bedrock (permeable through the fractures or cracks in the rock).

Resistivity measurements have been used as a preliminary method of defining the horizontal and vertical extent of leachate plumes stemming from suspected hazardous waste drum burial areas in EPA Region 4 (southeastern U.S.). On the other hand, magnetometry can be useful for detecting contamination "source areas" in the form of buried steel drums. A. Shane Hitchcock of EPA Region 4 (Atlanta, Ga.) explains that where such technologies can be used, they reduce equipment costs, provide data immediately, and, with sufficient background information, can be very reliable.



Treatment: Mobile unit for groundwater and leachate treatment uses PAC.

Plume containment

The strategy for containing the groundwater contaminants in Nashua, N.H., consisted of installing a 1-m-thick wall to surround them. The wall is a homogeneous soil-bentonite mixture constructed by a slurry technique; the material, keyed into bedrock at a maximum depth of 33 m is allowed to set. The wall is also keyed into a membrane surface cap.

After it has set, the wall's hydraulic conductivity is specified not to exceed 10^{-7} cm/s—the typical impermeability standard for hazardous waste sites—with leachate as permeant, Barvenik said. Moreover, since seepage under the wall through the rock was anticipated, a leachate collection and treatment plant has also been designed for the project; the design life of the containment system is 30 y.

But there are those who look askance at numbers indicating low hydraulic conductivity and permeability. Texas A&M's Kirk Brown maintains that under certain conditions, such as exposure to organic wastes, normally impermeable clays undergo structural changes and become more permeable, sometimes by several orders of magnitude (*ES&T*, September 1982, p. 503A). Perhaps this is one reason why EPA calls for synthetic impermeable materials in liners meant to protect groundwater from hazardous substances.

Treatment alternatives

Once a contamination plume is identified and mapped, a treatment scheme is needed. Treatment alternatives are considered, and then bench- and pilot-scale studies are conducted. Data from these studies help to establish design criteria for various treatment processes and to demonstrate performance capabilities of candidate processes, said John Absalon of Engineering-Science Inc. (Atlanta, Ga.). Treatability studies, in turn, can be used to develop a process aimed at specific problems, such as chlorinated solvents, hydrocarbons, heavy metals, and other contaminants.

The treatment of contaminated aquifer water could be carried out to prevent contamination spread (with purge wells) or to provide process water, or even potable water. Robert O'Brien of Calgon Carbon Corporation (Pittsburgh, Pa.) explains that granular activated carbon (GAC) is a frequently adopted treatment for contamination episodes involving organic chemicals. He says that his company installed GAC systems at 31 sites in the U.S. to treat contaminated groundwater flows of 5–2250 gallons per minute (gpm). In some cases, multimedia filtration was done before GAC treatment as a precaution; in others, air stripping was used to reduce the amount of volatile organics.

O'Brien says that for carbon tetrachloride (at four sites), influent concentrations of 130–10 000 μg/L were reduced to below 1 μg/L, and 5–10 000 μg/L of trichloroethylene (15 instances) were reduced to less than 1 μg/L. At one site, DDT, present at 4 μg/L, was curtailed to less than 0.05 μg/L. O'Brien notes that pre- and post-treatment analyses conformed to applicable EPA-published protocol: for trace organics in water. He estimates that operating costs are \$0.22–\$2.52/1000 gal treated, depending upon the chemical(s) and their concentrations.

Donald Hager of Rubel and Hager, Inc. (Tucson, Ariz.) says that aeration, catalyzed chemical oxidation, and GAC adsorption will be used in a pilot system for removing organic solvents, including chloroform, carbon tetrachloride, and other low-molecular-weight chlorinated hydrocarbons. Pressurized gas aeration followed by direct incineration will be evaluated as an alternative to air stripping, he adds. In this way, discharge of contaminants from water to air is avoided. A 20-gpm plant will test ways to clean water for aquifer recharge at the Rocky Mountain Arsenal, Colo. The GAC portion will use carbon made by Westvaco.

Many experts note that there are problems with using GAC for low-molecular-weight chlorinated hydrocarbon removal from water. Hager says that chemical oxidation using ultraviolet-peroxide systems will address the destruction of nonadsorbable or nonvolatile organic contaminants in the water.

Zimpro Inc. (Rothschild, Wis.) is simultaneously using microbes and an organics removal approach involving *powdered* activated carbon (PAC) with activated sludge. The PAC adsorbs contaminants that the microbes cannot assimilate, while the microbes handle organics that otherwise would need an additional carbon step. Zimpro says that its units, presently in use at 15 U.S. sites, can remove hydrocarbons, pesticides, and certain other organics from groundwater, wastewater, or leachates, with a 95–99% removal efficiency reported for COD, total nitrogen, and various organics. Known by the trade name "PACT," the system is being used in a groundwater recharge project in El Paso, Tex., and for groundwater treatment at a chemical plant site in Michigan.

But not all contaminants are or-

46. Kaufinann, R.F., et al. "Ground Water Monitoring Techniques for Arid Zone Hazardous Waste Disposal Sites," Ground Water Monitoring Review, Fall 1981, pp. 47-54

ROUND-WATER MONITOR-ING TECHNIQUES FOR ARID ZONE HAZARDOUS WASTE DISPOSAL SITES

2641
2646
2647
2648

Describes the monitoring rationale and monitoring techniques used at two very different waste disposal sites. Also looks at methods and results of water quality monitoring conducted at these sites.

' Robert F. Kaufmann, T. Alan eason, R. Brian Ellwood and erald P. Lindsey

Recent field studies conducted an existing solid and liquid hazdous waste disposal site in Calimia and at a wastewater treatment cility under construction in Ari-na necessitated use of a variety of onitoring techniques due to conists in hydrogeologic conditions, aste sources and pollutant transrt pathways. Also relevant is the at the California facility was and has been operating under ss stringent rules than would now revail, whereas the facility in Arina reflects state-of-the-art design nd construction. Discussion of sitepecific conditions and findings is eliberately avoided to ensure condentiality and to focus attention n the monitoring techniques. The iscussion which follows highlights oth water quality and ground-water ow system monitoring techniques.

Although not directly pertinent o the subject of this paper, the bjectives common to both investiations are provided to assist in rienting the reader:

- Define ground-water quality in he aquifers beneath and adjacent o the wastes.
- Delineate the present and/or rojected extent of subsurface conamination.
- Define the hydraulic conducivity of the materials beneath disosal areas.
- Define the elements of groundvater monitoring and protection s responsive to RCRA and state uirements.

Monitoring Rationale

Outlined in Table 1 are the major elements of the ground-water monitoring investigations undertaken at the California and Arizona sites. Those items with an asterisk are discussed in the sections to follow.

At both locations, the preliminary phases of investigation included a review of pertinent literature, a field reconnaissance study and an inventory of nearby active, inactive or abandoned water wells. This was followed by the application of numerous drilling, sampling and analytical techniques which are the focus of this article.

At the Arizona facility, a wastewater pond complex is present which consists of contiguous wastewater ponds equipped with double liners and a leachate collection system. The basic objective of the investigation for this facility was to design, install and test a groundwater protection system which was both technically and economically sound. Maximum use is made of an existing production well to monitor and intercept seepage from the wastewater ponds, should leakage ever advance farther than the double liners, the leachate collection system and over 300 feet of unsaturated fine-grained desert soils. Two monitoring wells installed downgradient of the ponds complete the well network. Soil resistivity data from depth profiling outside the facility perimeter and from buried electrodes beneath two of the four ponds establish baseline conditions against which any future changes can be compared. Periodic sampling provides additional protection against undetected long-term fluid release. The operational monitoring plan is integrated with normal ground-water pumping cycles to intercept contaminants which might occur at onsite locations.

Monitoring Techniques

Air and Hydraulic Rotary Drilling

Subsurface investigation at the California site involved both air and hydraulic rotary drilling to define stratigraphic variations with depth and water table position. Air rotary drilling proved to be very fast in the poorly cemented sandstone. Bed changes based largely on color variations between the sandstone and claystone units were readily detected. However, the boreholes below the water table were difficult to hold open for proper completion with screened or slotted casing, silica sand backfill, and either cement or bentonite seals installed with a tremie line. Borings made with air rotary equipment were most useful in the initial drilling program in obtaining water-table position and in emplacing suction lysimeters or percolation test holes.

Deeper borings at the California location penetrated to about 50 to 100 feet below the water table and were most successful when drilled with hydraulic rotary equipment and polymer mud. Although setup time for mud pits, pumps, etc., was longer than for air rotary drilling, borings drilled with mud remained fully open for geophysical logging, casing and completion. In particular, sand-pack materials could be readily installed in the screened/slotted intervals. Well development was by means of air and by bailing.

Rotary drilling techniques and polymer muds were used exclusively to install two 400-foot monitoring wells at the Arizona facility. Aside from the usual grab sampling, a wire-line piston sampler was very successfully used about every 40 feet to obtain in-situ samples to confirm cuttings data, to provide reference points for geophysical log

interpretation, and to develop accurate grain-size curves for use in screen and gravel-pack design. In order to sample, the drilling string was removed and the sampler was run in on the sand line. Most of the time spent in sampling was in tripping out and in with the drill string. Sample recovery was excellent.

Polymer muds are biodegradable through bacterial action and have variable but limited life, depending on temperature, presence of bacteria in the drilling water, and other factors such as pH. Residual chlorine levels must be maintained in the drilling fluid in accordance with manufacturers specifications. Useful life can be extended by the addition of formalin to retard bacterial action, and by temperature control through shading of the mud pit. Despite the extra degree of care and skill needed on the part of the contractor, use of such muds is warranted because of minimal formation damage. These muds are excellent for geophysical logging and sampling. Special precautions are needed to chlorinate the gravel pack and well water and to overpump the well to eliminate potentially unacceptable levels of coliform bacteria.

Piezometer and Sampling Well Installation

Piezometers and sampling wells were installed in rotary-drilled borings advanced by air and hydraulic rotary rigs, by hollow-stem auger, and by driven cylindrical piles. With few exceptions, installation involved a gravel or sand pack and either a bentonite or cement seal. Both pack and seal materials were installed via a tremie line. Pressure grouting was by means of a positive displacement pump. Figures 1 through 3 illustrate the principal construction details of the bored installations. Indication of acceptable sealing of piezometers at the California site is seen in the consistent head measurements decreasing with depth, confirming recharge gradients expected in the highland areas. Recharge is also indicated by development of a water-table mound in the wastes.

Casing materials used included

Table 1.
Principal Ground-Water Monitoring Elements

Existing Hazardous Waste Landfill

Definition of Site Geology
- Literature Review
- Geologic Mapping
- Trench Studies to Evaluate Fault Activity
- Refraction Survey
- Borehole Geophysical Logging

Ground-Water Flow System Delineation
- Piezometers*
- Sampling Wells*
- In-situ and Laboratory Permeability Measurements
- Water Level Measurements
- Water Well Inventory

Water Quality
- Source Term (Waste) Characterization
- Sampling of Wells, Springs, Seeps*
- Analysis of Pesticides, Metals, Volatile and Base Neutral Organics
- Characterization of Natural vs. Introduced Organics in Ground Water*

Development of Remedial Action Programs
- Water Saturation Control
- Digital Pollutant Transport Modeling
- Long-Term Monitoring Program

New Wastewater Pond Complex

Baseline Ground Water Conditions
- Literature Review
- Water Well Inventory
- Water Table Configuration

Ground-Water Monitoring
- Baseline Resistivity Surveys*
- Electrode Detection System*
- Ground-Water Monitoring Wells*
- Utilization of Existing Pumping Cones
- Water Sampling

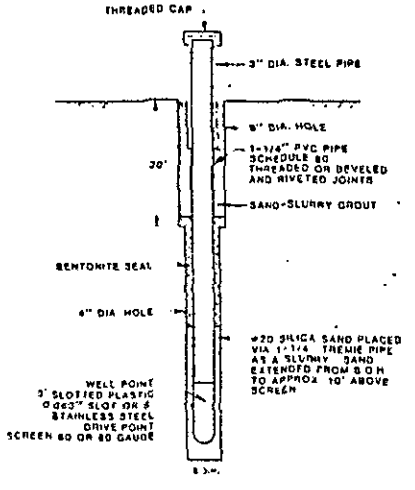


Figure 1. Construction of a typical piezometer.

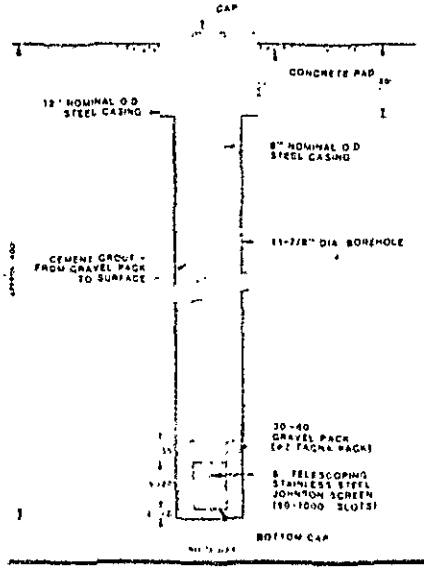


Figure 2. Construction details of a deep sampling well-steel casing.

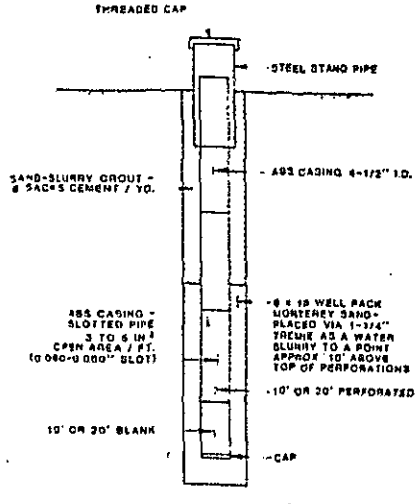


Figure 3. Construction details of a deep sampling well-plastic casing.

nch steel and PVC pipe, 5-inch pipe with flush screw joints both 5-inch and 6-inch steel ng with both threaded and ed connections. PVC and ABS was found to be economical ing rapid installation time to steel casing. ABS pipe is durable, but one failure of a ed section occurred from ex- e grout pressure and associated ated curing temperature. The r disadvantage of ABS and PVC tes to water quality (Scalf, et al., 1).

npling Methods

Soil, soil-moisture, and ground- er samples were collected from ings, suction lysimeters and ometers or sampling wells, re- ctively. The discussion which fol- s focuses on techniques which not routinely used, as these are sidered to be of more interest to reader.

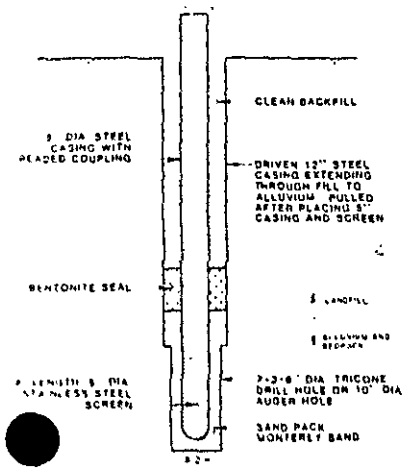
l Sampling

In addition to grab sampling and tings, sampling of soil at the ifornia location consisted of cor- and Pitcher barrel samplers. A e-line corer was used to facilitate id core recovery, but several ms developed from the mis- of equipment to subsurface ditions. Coring was done with for cuttings removal, but con- nsation around the core barrel d drill stem caused the clay soils expand, thereby restricting air w.

Subsequent soil sampling at the lifornia site was with a Pitcher rrel sampler in conjunction with ntonite and polymer drilling fluids recover consolidated samples immediately above and below the water table. The samples were used to confirm lithologic descriptions available from cuttings and also to perform subsequent analyses for contained organics. The decision to analyze for contaminants was largely based on water-quality data. Use of the Pitcher barrel was limited to relatively shallow rotary wash borings which were advanced with a tri-cone bit and bentonite or polymer drilling fluid.

At the Arizona site a split-spoon sampler in conjunction with a down-hole hammer on a wire line was used for soil sampling two monitoring well borings and a pilot hole for a high-capacity production well. The sampler consists of a hammer and drive corer lowered into a boring and operated by alternately raising and lowering the hammer.

Aside from some cross-mixing of cuttings in the immediate bottom of the boring, the resulting samples were fully representative of in-situ conditions. The samples were of considerable value for interpreting electrical and cuttings logs and for sizing of well screens used in one production well and two monitoring wells at the Arizona facility. In addition, the samples could be used for chemical analysis and for developing an improved understanding of the stratigraphic section in the unsaturated zone. In an arid setting, the unsaturated zone is typically rather thick and plays a significant role in the vertical and lateral pattern of contaminant migration. The data obtained are therefore of value in designing ground-water contamination assessment programs as specified in the RCRA regulations.



igure 4. Driven pile sampling and mping well completion.

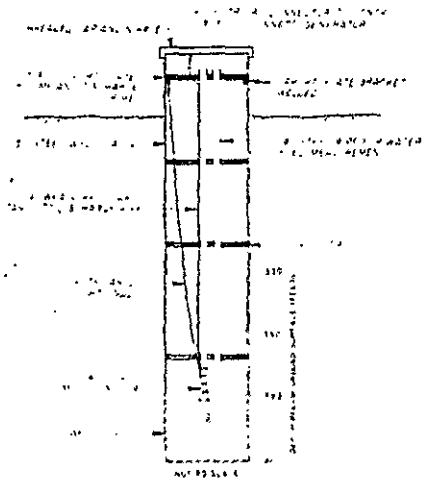


Figure 5. Generalized view of submersible pump installation in monitoring well.

Well Completion in Hazardous Waste

With regard to the California site, which received both liquid and solid hazardous wastes for over 10 years, initial piezometers and sampling wells were installed in bedrock materials adjacent to the wastes. Projection of static water levels from these wells laterally into the wastes indicated saturation of about a 25-foot thickness of wastes. An additional investigation made to confirm the thickness and saturation of the hazardous waste involved the use of four dual-purpose sampling and dewatering wells completed in the wastes or immediately beneath the wastes. The manner in which this was done necessarily had to consider safety in addition to technical and economic practicality. To our knowledge, this was the first drilling program in California to deliberately penetrate a hazardous waste landfill.

After considering hollow-stem auger, large-diameter auger (caisson rig), air and hydraulic rotary, cable tool and driven pile options, the latter was chosen as the best compromise under the given conditions. The method consisted of simultaneously driving two steel-cylinder piles, one inside the other, with a 54,000 foot-pound diesel hammer. The piles had inside diameters of 10 inches and 12 inches, wall thicknesses of 0.5 inches, and a combined weight of approximately 177 pounds per lineal foot. The inner pile was approximately six inches shorter than the outer pile, and was fitted with a reinforced flat tip.

After the pile assembly was driven to refusal, the inner pile was withdrawn, allowing completion of 5-inch diameter wells inside the 12-inch pile or, with additional drilling, completion below the piles. Both options were exercised, depending on location and hole conditions. Figure 4 illustrates basic construction features of the pile technique. Drilling below the piles was done at two locations with an air rotary rig, following installation of 8-inch diameter PVC pipe to increase the return of cuttings. Alternately, the boring was advanced with hollow-stem auger (6-inch inside diameter). In the latter instance, the final dual completion featured 1¼-inch steel pipe and screen, sand-packed and sealed in the underlying bedrock and, after withdrawal of the auger, a 5-inch screen and steel casing completion inside the pile.

After installation of the sampling well casing, screen, sand pack and seals, three of the 12-inch diameter

cylindrical piles were removed from depths of 34 to 64 feet using a vibratory hammer and truck-mounted crane. At a fourth location, the pile was left in place and the sampling well was completed at the waste-substrata interface which was also the top of the zone of saturation.

Several comments can be made concerning the use of driven piles for the purposes described:

- The method was considered extremely safe insofar as no waste or leachate was removed from the monitoring installation. Routine safety measures for explosive gases were followed when welding or cutting operations were underway.
- Wastes were readily penetrated for the full thickness of 25 to 60 feet at three locations. At the fourth location, metal objects caused pile refusal before the wastes were fully penetrated. Subsequent rotary drilling to penetrate to the base of the wastes was successful but difficult and time consuming.
- Yield of the 5-inch diameter wells, fitted with six feet of stainless well screen was less than 1 gpm in three of the four wells, and was considerably less than expected. Possible causes for this include low yield of the wastes, smearing of the borehole wall as the pile advanced, and/or compaction of the wastes by pile driving or removal.

The pile technique was considered acceptable for the purposes of this study insofar as static water levels in the waste, waste thickness, and leachate quality were confirmed with no adverse safety or environmental impacts.

Water-Quality Monitoring

Ground-Water Sampling Wells

For a variety of reasons, principal ground-water sampling wells constructed at both of the sites investigated were a minimum of five inches in diameter. Small-diameter wells were not practical in terms of time needed for well development or sampling and cost effectiveness considering the high cost of labor and chemical analyses. Where possible within budgetary limits, ¼ to ¾ horsepower pumps were permanently installed, as shown in Figure 5, in six locations distributed between the two study sites. With a small portable generator, a technician can prepare the wells for sampling and do the sampling in about two hours per well.

Between sampling, the wells are sealed with a screw-on cap. There is no cross-contamination between wells and the volume of water removed before sampling enhances sample representativeness. Considering the RCRA requirements for quarterly sampling, or more frequent sampling if a ground-water assessment program is mandated (40 CFR part 265, Federal Register, May 19, 1980, vol. 45, no. 98, pp. 33239-33242), the use of submersible pumps becomes increasingly cost-effective with time.

Initial sampling wells at the California site were constructed with threaded joint ABS casing, with PVC bottom plates bonded to the PVC with two-part epoxy cement. ABS pipe was chosen to facilitate rapid completion of the air rotary borings. The common presence of certain organic constituents in the wastes and in the plastic pipe or epoxy cement precluded further use of these materials. Steel casing and screen was used exclusively in subsequent phases of the California study and throughout the work at the Arizona site.

Decontamination of steel casing and stainless steel screens was accomplished by cleaning with steam, acetone and methyl alcohol to remove solvents and oils. The lacquer coating on steel pipe is essentially impossible to remove. Thus, it is recommended that pipe be ordered which is either uncoated or which has been allowed to develop a coat-

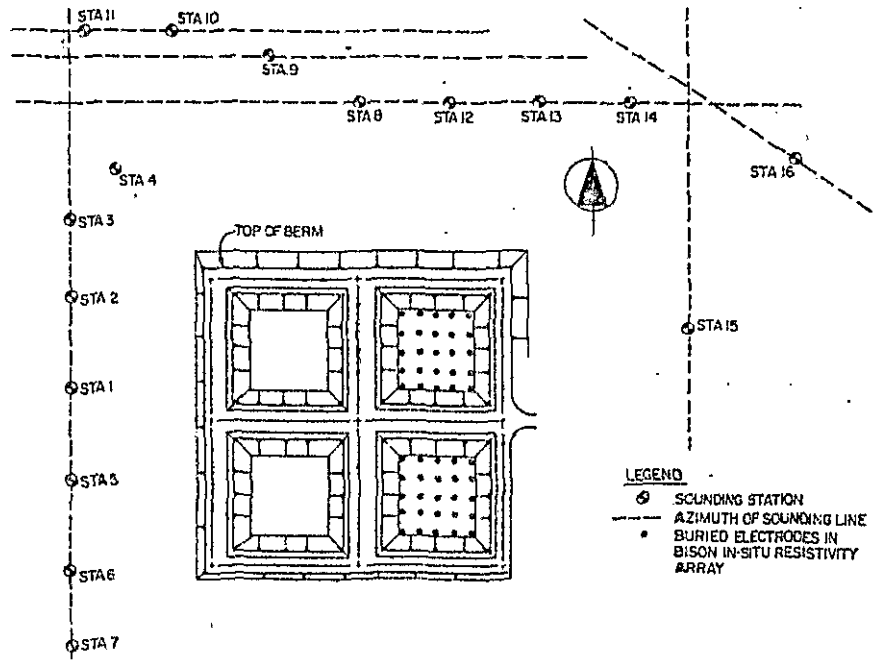


Figure 6. Surface resistivity sounding survey.

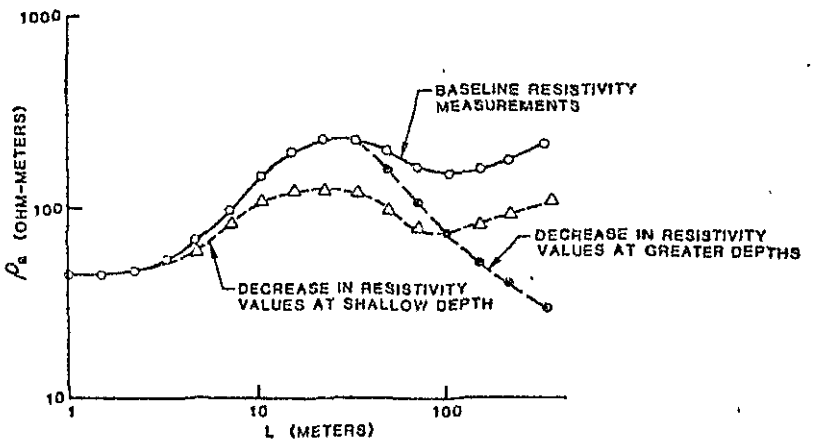


Figure 7. Changes in baseline resistivity measurements due to migration of waste fluids.

of surface rust.

rth Resistivity Soundings

Numerous investigations incor-ate electrical resistivity surveys a means of detecting shallow d-water contamination (e.g. and Roux, 1975; Cartwright d McComas, 1968; Warner, 1969). wever, not much use has been ıde of such surveys to establish seline conditions. At the Arizona e, 16 earth resistivity survey sta-ıns were established peripheral to wastewater pond complex (Fig-e 6) to define baseline resistivity. ıture readings will be taken at ese stations. Should earth resis-ity significantly decrease, other tions such as test drilling or sup-ementary readings would be taken confirm the presence or extent of leachate problem.

At each station the survey lines ere oriented parallel to the pond eriphery. The method used was the chlumberger electrode array which widely used in electrical prospect-ıg (Dobrin, 1960; Zohdy, 1969). It onsists of four electrodes which re systematically extended outward long a straight line from a central oint. The (L) spacings used for the utside A and B current electrodes ged from 1 meter to 215 meters the central point for a total pread length of 430 meters. The nside or M and N potential elec-rodes were placed from 0.3 meter to 0 meters. At each spacing the vol-age measured was recorded. The ıpparent potential, ρa, is calculated ıs $\rho a = K(V/I)$ where K is a constant or each particular electrode spac-ıng, V is the measured voltage re-corded on the receiver, and I is the current input level. The current is generally constant for distances less than 100 meters. This is known as the vertical electrical sounding (VES) method, because the increasing spread of the electrodes results in a deeper penetration of the field of current.

The equipment used, a Bison Instruments Inc. Model 2390 signal enhancement earth resistivity sys-tem, was the same as that used for the electrode detection system under the waste ponds. The transmitter containing a 12-volt battery has a current output ranging up to 100 milliamperes at frequencies up to 5 Hz. The receiver, with two six-volt teries, records the voltage up to 1999 millivolts.

The electrical resistivity method of exploration is generally suitable for delineating areas with favorable aquifer conditions when used in conjunction with exploratory bor-ings to provide control. Without cor-relation with test borings, interpre-tations of hydrogeologic conditions such as depth, thickness, saturation and physical properties of various layers are unreliable (Stollar and Roux, 1975). Many variable condi-tions affect the measurement of the various layers, including density, porosity, mineralization, moisture content, formation thickness and the characteristics of overlying and underlying layers. Figure 7 is a schematic showing baseline versus subsequent contaminated condi-tions as reflected by earth resistivity measurement. Note that the curves are depth-sensitive and can indicate which layer(s) are likely to be af-fected. For monitoring purposes, deviations from baseline conditions are most relevant and detailed inter-pretation of subsurface conditions is not necessary. Should contami-nation be detected, however, borings to establish subsurface control and possibly to provide for water sam-pling are likely to be necessary. At that point, detailed resistivity inter-pretation should be possible.

Electrical Leak Detection Systems

Two evaporation ponds at the Arizona site have an electrode de-tection system (patent applied for) installed beneath the lower liner. The system (in-situ resistivity array) is designed and constructed to measure the apparent resistivities of soils beneath the ponds. As in the use of surface electrical resistivity surveys, decrease in the apparent resistivity indicates the presence of contaminants—in this case, the leakage of conductive fluids through the lower line.

As shown in Figure 8, the system for each pond consists of 25 elec-trodes placed in a five-by-five square grid pattern with adjacent electrodes 45 feet apart. The grid pattern forms multiple Wenner arrays. The elec-trodes are galvanized steel rods ⅝-inch in diameter and two feet long. They are connected to a junction box by 16 gauge single conductor shielded, coaxial cable. The cables are shielded to minimize electro-magnetic interference. Connections between the electrodes and the cable are covered with grease to minimize corrosion, and then protected by heat-shrink tubing.

Prior to installation, preliminary tests were performed to assess the extent of electromagnetic coupling (and the resulting interference with readings) between cables bunched together in narrow trenches as com-pared with cables spread out, using trenches with a 3' x 3' cross section and as much cable separation as possible.

There were no significant differ-ences observed in apparent resistiv-ity values measured with bunched cables versus those spread out.

The electrodes and cable were installed horizontally in shallower trenches 18 inches deep and 8 inches wide. After installation, the trenches were backfilled and com-pacted. Figure 9 shows the arrange-ment and details of the system. All cables terminate at a junction box placed in a protected housing lo-cated near a corner of the pond, a maximum slope distance of 75 feet from the nearest electrode.

Operation of the system consists of directing an electric current to one set of electrodes and measuring the potential drop across adjacent electrodes. The potential drop is a measure of the conductivity of the soil and interstitial water between the electrodes. Surveys of all the possible Wenner arrays in the grid system are performed quickly by connecting an earth resistivity me-ter to the junction box in any one of 28 configurations (see Figure 8). Any leakage of wastes through the lower liner will be detected by a decrease in resistivity values with respect to the baseline readings. The location and rate of leakage migration can be established based on resistivity changes from one date to the next.

Figure 10 shows average resis-tivity readings from the electrode system beneath the wastewater ponds in Arizona. The readings were taken prior to installation of the liner and reflect ponding of rain-fall in the west central sector of the pond, where resistivity is lowest. The contours simply reflect average soil moisture conditions. The spread in values is rather small and on the

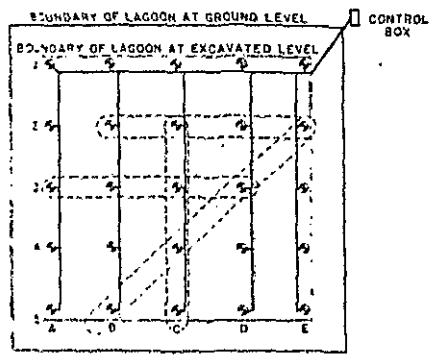


Figure 8. Layout of in-situ resistivity array/electrode detection system.

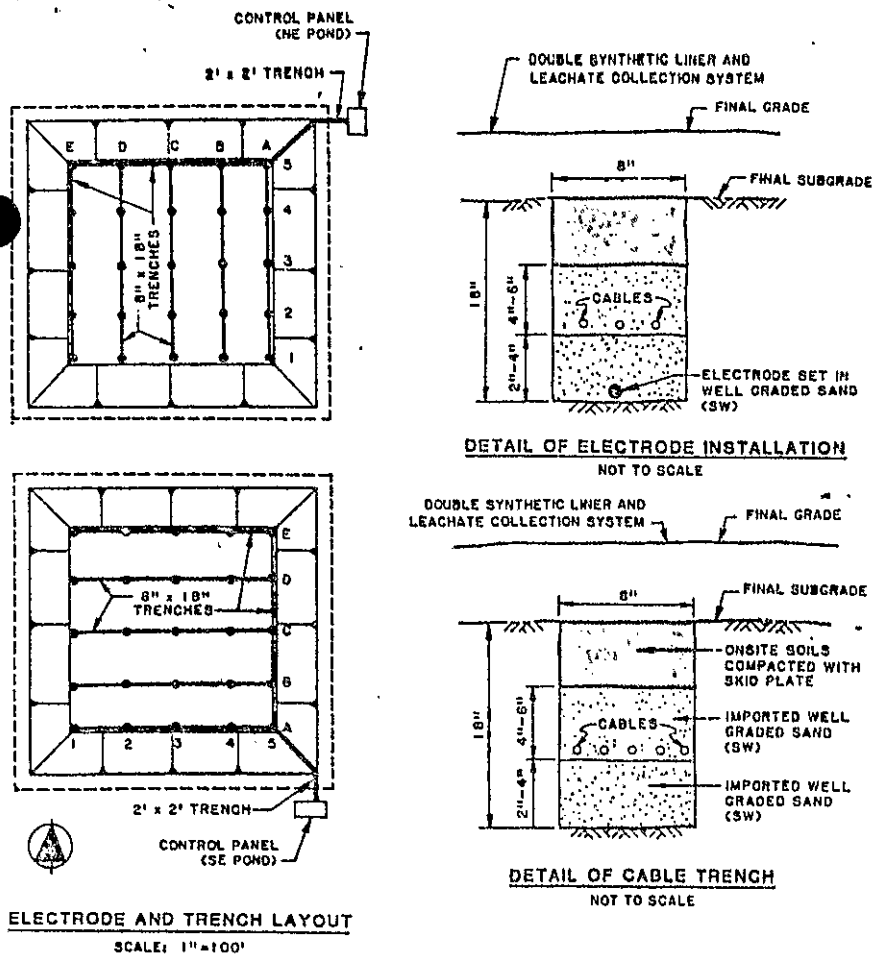


Figure 9. Electrode detection system (patent applied for).

order of 11 ohmmeters. Should a leak develop, the resistivity would be drastically lowered, presumably at a few node points at the onset of leakage.

Water Sampling

Field procedures for sampling wells varied to some degree with the method of construction of the well or piezometer and whether a submersible pump had been permanently installed. For those wells fitted with a pump, sampling was preceded by two to three minutes of pumping. Wells were previously fully evacuated or the water volume in the casing was exchanged five times before sampling. Large-diameter wells without pumps were first evacuated and then sampled using a separate PVC bailer for each installation. The small-diameter wells were sampled using a one-inch outside diameter copper or steel bailer fitted with a foot valve. These wells were sampled after specific conductance values stabilized, an indication that formation water was entering the borehole and casing. In general, conductivity initially rose sharply and then stabilized as formation water displaced the potable water used for drilling.

Between sampling points, the bailers were thoroughly cleaned to avoid cross contamination. This initial procedure was judged to be too time consuming. Subsequent sampling at the California site and all sampling at the Arizona site involved no filtering or sample preservation in the field, minimal reuse of bailers, and more stringent decontamination where needed. The samples were iced immediately after collection and stored in a styrofoam chest for delivery to the laboratory later that day. A preservative (nitric acid) was added to the metal samples on delivery to the laboratory.

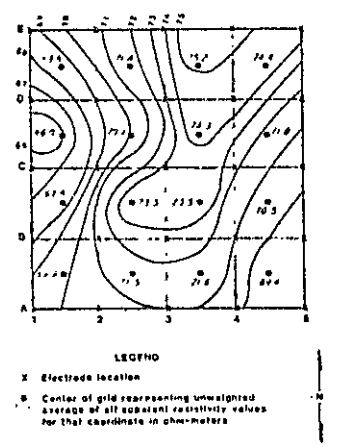


Figure 10. Base line data of in-situ resistivity array.

Characterization of Natural vs. Introduced Organics in Ground Water

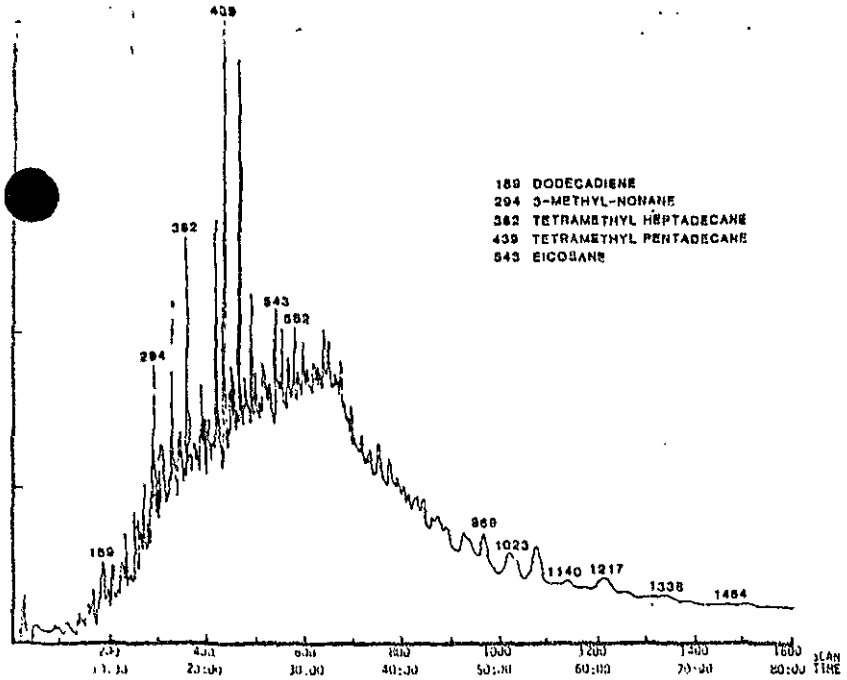
Naturally occurring organics in the form of crude oil and gas were present beneath and adjacent to the California site. In addition, the following organics were disposed over an 11-year period:

	Gallons	Tons
Alcohols/Solvents	335,000	—
EDC (ethylene dichloride)	—	1,400
Grease	—	430
Polychlorinated biphenyls (PCB)	—	1
Pesticides	35,000	—
Pesticide containers	—	2,300
Petrochemical waste (including refining waste and petroleum distillates)	270,000	—
	640,000	4,131

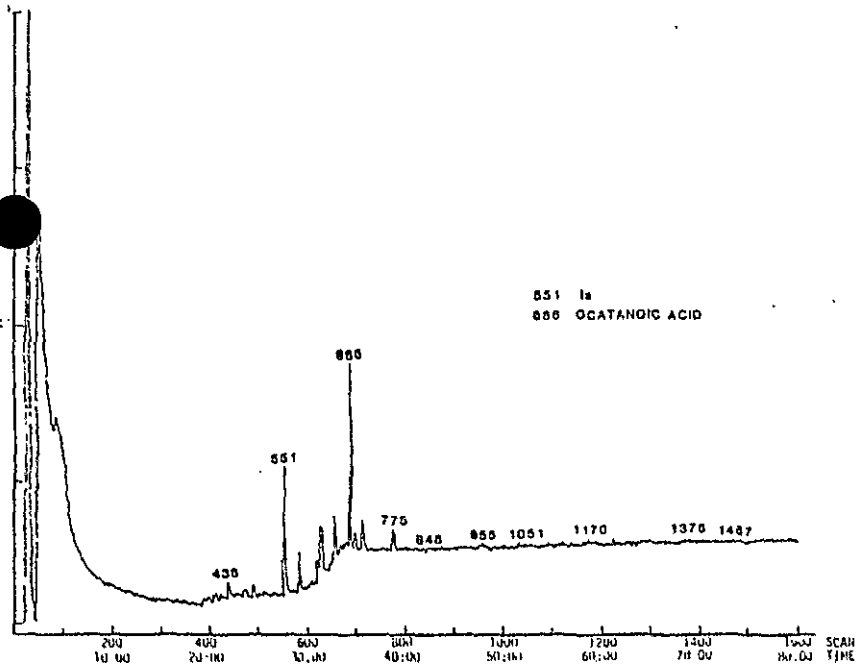
Interpretation of the groundwater quality data considered differences in spectra resulting from natural vs. waste-related organics. After generation of gas chromatograph mass spectrometer spectra data, examples of which are shown in Figures 11 and 12, the spectra were analyzed to determine the nature and source of the compounds detected.

Organics found in ground water at the California site originate from one or more of the following: natural crude oil, waste materials, drilling fluids, casing screen and decontamination fluids. The presence of natural crude oil compounds showed up in several deep well water samples as a hydrocarbon envelope (see Figure 11) in the base neutral organics fraction. The hydrocarbon spectra usually consisted of clusters of up to two hundred peaks that easily mask the presence of other waste-related compounds. Most waste-related constituents showed up in the volatile organics fraction and included compounds such as trichloroethylene, trichlorethane, dichloroethane or other halogenated organics.

Compounds considered to be derived from the wastes were primarily methyl benzene, ethyl benzene and toluene. Compounds which where considered to originate with either wastes or well construction included volatiles such as acetone



ure 11. Chromatogram of base neutral organics in a ground-water sample ıtaining natural hydrocarbons.



igure 12. Chromatogram of base neutral organics in a ground-water sample ee of natural hydrocarbons.

·trahydrofuran and methyl ethyl etone. Some water samples con-ıined elements and compounds ·hich were not consistently found ·ith repeated sampling or contained ubstances in very low amounts ıne to several parts per billion). hese results are generally incon-lusive and indicate the need for e data to establish a pattern ch can be related to ground-vater conditions.

It is assumed that ground-water low in the waste site is laminar and hat flow paths and sources, or sinks, ıre generally constant. Pronounced changes in concentration with time are believed attributable to other than waste or natural factors and may include sampling and decon-tamination procedures, for example.

The primary natural factor affect-ing hydrocarbon concentrations would presumably be flushing ac-tion associated with seasonal chang-es in water level, a phenomenon which is noticed more in some wells than in others.

General conclusions reached are that when natural hydrocarbons are abundantly present, they are readily recognizable but they may mask certain waste-related constituents. Compounds introduced by the wastes or by the well installation either appear outside the natural hydrocarbon envelope or appear in the absence of such an envelope (Figure 12), as do many organics derived from wastes (e.g. benzene, ethyl benzene, toluene, TCE). Wells yielding generally inconclusive re-sults require additional monitoring with respect to seasonal water-level changes and additional sampling.

Summary

Selected ground-water monitor-ing techniques are presented for use in waste disposal facility inves-tigations in arid zone settings of the Southwest. Although local site con-ditions in terms of geology, hydrol-ogy and waste disposal practices largely dictate a given monitoring program and, in turn, the mechanics of instrumenting a site, the following is offered for consideration:

- Completion of wells in poorly consolidated bedrock and in allu-vium is greatly facilitated by the use of polymer drilling fluids to stabilize the boring. Air rotary and hollow-stem auger techniques proved dis-appointing except for very shallow completions.
- Of the PVC, ABS and steel casing and screen materials used, the plastic materials were easiest to install, but presented a possible source of trace organic contami-nants in the water samples. Where water sampling for trace organic contaminants is of primary concern, wells should be cased with steel. While galvanized casing was used in wells installed at the sites described, perhaps stainless steel would be even more appropriate, though cost then becomes a significant factor. If plastic is used, blanks should be run to determine the influence of the casing on water quality. Addi-tional quantitative data are needed concerning the full suite of organics and the concentrations that might be expected in water samples from PVC and ABS pipe and associated cements.
- Use of wire-line coring and drive-sampling equipment is recom-mended considering the relative speed with which representative samples can be obtained. Pitcher barrel samplers proved superior to NX coring in the soft sandstone strata penetrated.
- Penetration of hazardous wastes using driven cylindrical piles was safe and practical for confirm-ing waste thickness and saturation. Water sampling wells could be com-

pleted within and below the wastes, but well yields were disappointingly low.

- For purposes of baseline definition and early warning of contaminant release from wastewater ponds, earth resistivity and buried electrode detection systems are excellent methods for inexpensively generating areally distributed, time-series data.
- Although not completely diagnostic, differences in the overall pattern of chromatograms representative of natural hazardous waste-related hydrocarbons are useful in defining contamination.
- In arid zone settings with deep water tables, maximum use should be made of the aforementioned techniques integrated with existing pumping wells in developing least cost monitoring systems to meet the intent of state and RCRA regulations.

Biographical Sketches

The authors are professionals in the firm of Converse Ward Davis Dixon consulting geologists and engineers.

Dr. Robert F. Kaufmann is a principal geologist with 13 years of ground-water experience consisting of university research, the U.S. Environmental Protection Agency and private consulting in the central and western portions of the country. His recent projects [illegible] municipal water supplies, ground-water quality, hazardous waste disposal and the influence of mining and milling on ground water.

T. Alan Gleason is a principal in the firm. He specializes in contamination investigations and compliance evaluations for a variety of industrial clients. Mr. Gleason's experience centers around solid (hazardous) waste management facilities, facility siting investigations and environmental assessments and permitting assistance.

Dr. R. Brian Ellwood, vice president, has specialized in ground-water resource evaluations for over 20 years in both the United States and abroad. Projects in recent years have involved investigations of industrial waste treatment-storage facilities and their interaction with local ground-water regime, compliance evaluations of waste facilities in terms of RCRA criteria and consultations in connection with hazardous waste cleanup programs.

Gerald P. Lindsey is a project geologist with formal training and 18 years of experience in engineering geology. He has been involved with numerous siting investigations including dams, LNG facilities and major commercial buildings.

References

Cartwright, K. and M. R. McCann. 1968. Geophysical surveys in the vicinity of sanitary landfills in northeastern Illinois: Ground Water, v. 6, no. 5, pp. 23-30.

Dobrin, M. B. 1960. Introduction to geophysical prospecting. McGraw-Hill Book Co., New York, N.Y., 446 pp.

Federal Register. May 19, 1980. 40 CFR Part 265—Interim status standards for owners and operators of hazardous waste treatment, storage and disposal facilities: Subpart F—ground-water monitoring. Federal Register, v. 45, no. 98, pp. 33239-33242.

Scalf, M. R., J. F. McNabb, W. J. Dunlap, R. L. Cosby, and J. S. Fryberger. 1981. Manual of ground-water quality sampling procedures. NWWA/EPA series. National Water Well Association, Worthington, Ohio. 19 pp.

Stollar, R. L., and P. Roux. 1975. Earth resistivity surveys—A method for defining ground-water contamination. Ground Water, v. 13, no. 2, pp. 145-150.

Warner, D. L. 1969. Preliminary field studies using earth resistivity measurements for delineating zones of contaminated ground water. Ground Water, v. 7, no. 1, pp. 9-16.

Zohdy, A. A. R. 1969. The use of Schlumberger and equatorial soundings in ground water investigations near El Paso, Texas. Geophysics, v. 34, no. 5, pp. 713-718.

47. Keely, J.F. "Optimizing Pumping Strategies for Contaminant Studies and Remedial Actions", Ground Water Monitoring Review, Summer 1984, pp. 63-74

2648

Optimizing Pumping Strategies for Contaminant Studies and Remedial Actions

by Joseph F. Keely

Abstract

One of the more common techniques for controlling the migration of contaminant plumes is the use of pumping wells to produce desired changes in local flow rates and hydraulic gradients. When seeking to optimize an array of pumping well locations and discharge rates, it is important to consider the effects that non-ideal aquifer conditions, well construction and demographic constraints produce. Heterogeneous and anisotropic aquifer conditions seriously complicate siting and discharge rate requirements for pumping wells because of the distorted cones of depression that result from withdrawing water in such settings. Proper screen selection, gravel pack emplacement and well development are crucial factors affecting the operational characteristics and economics of pumping wells; these factors are generally recognized, though often undervalued. The impacts that well depth and diameter, and screen length and position have on the effectiveness of pumping efforts are also often undervalued, with detrimental consequences. Perhaps the most difficult problems to overcome in designing pumping schemes, however, are posed by demographic constraints. Denial of property access, vandalism and the unpredictability of nearby water supply and irrigation pumpage tend to wreak havoc with the best of pumping strategies.

Introduction

Safe storage and disposal of hazardous wastes have become major social issues because of the discovery that many sites lack proper precautions for the prevention of soil and water contamination. Ground water contamination has received the major share of society's attention to these issues, primarily because the route of human exposure by this pathway is direct. In practical terms, this means that the level of cleanup of the damage done by contamination incidents is often dictated by social concerns (e.g. health risk). Plume stabilization by interception and control with perimeter wells, injection and recovery loops, and other pumping schemes may be chosen as the "remedial action" appropriate for a particular plume. The affected plume may be held in place and treated, it may be held and allowed to move on after alternate public supplies have been located for downgradient water systems, it may be held in place to allow biodegradation of particular constituents, or it may be held until better treatment procedures can be devised.

Factors Affecting Pumping Strategies

Hydrodynamic control and recovery strategies vary considerably in their efficiencies. Besides the obvious need to choose the well locations and flow rates carefully, a number of other considerations demand attention (Figure 1). Non-ideal aquifer conditions are a reality for virtually all real-life situations; heterogeneity is the rule rather than the exception. Three-dimensional anisotropy, as expresed by the vertical vs. horizontal hydraulic conductivity ratio, is a near certainty for most strata. Less visibly pronounced, yet almost as prevalent, is an expressed anisotropy in the horizontal plane of many strata. These commonplace non-ideal aquifer conditions complicate our perception of where a given plume can go (Fetter 1981) under both natural flow conditions and remedial action pumping schemes. The preferential flow paths that are created by buried lake beds, glacial outwash gravels, streambeds, coastal deposits and the like cannot be delineated without expensive and time-consuming field tests. Likewise, it is nearly impossible to accurately predict the magnitudes of distortion in the cones of depression created by wells pumping from heterogeneous, anisotropic aquifers.

Variations in the properties of the fluid in an aquifer, particularly the solution density, also can significantly affect the behavior of contaminant plumes (Jorgenson et al. 1982). Immiscible plumes with lower density than that of the native ground water will float at the surface of the saturated zone, traveling along the same general gradient, but traveling

at a different rate than the underlying ground water. Immiscible plumes with greater density than that of the native ground water will sink through the ground water, losing small but significant amounts of low solubility constituents as they move. Miscible plumes of any density, by definition, mix intimately with native ground water. The duration of time required to achieve a specific dilution by this mixing changes markedly, however, and is generally inversely related to the density. For most situations, the greater the density, the shorter the mixing period. The exception to this general rule would be the case of a large volume of highly dense, miscible fluid penetrating a shallow aquifer quickly enough to reach bedrock in a relatively undisturbed form.

Considerations

Non-Ideal Aquifer Conditions:
- Heterogeneity
- Anisotropism
- Variable density

Well Construction Effects:
- Partial penetration
- Partial screening
- Incomplete development

Anthropogenic Influences:
- Property access
- Vandalism
- Unknown pumpage/injection

Other Factors:
- Physiochemical attenuation
- Biological transformations
- Operational failures

Figure 1. General considerations for optimizing pumping strategies

These complexities work against us if we are ignorant of them. Working up an appropriate recovery system for a contaminant plume can be compared to designing an oil production system. What you get out depends directly on what you put in—up to a point. Where that break-even point comes is hard to say, given unknowns like the source strength and timing, and immeasurables like the dollar value of additional cancer victims. What is abundantly clear, however, is that there is a substantial minimum for serious play. One does not blithely draw up plans to pump and treat a plume until considerable manpower and funds are expended to obtain information on the natural flow direction, gradient and velocity. The question is usually one of how much to spend to reach some desired level of detail; the level of detail is set by social concerns.

This seems to be logical application of technology for social need, but the logic may be shortsighted. If social concerns (based on preliminary evaluation of a contaminant incident) are minimal, there is no guarantee that such social concerns are appropriate. Additional studies, which could delineate preferential flow paths and quantify factors affecting contaminant behavior, might well generate findings that would justify considerably greater or lesser social concern. Quite often data from preliminary investigations are limited to samples from shallow on-site wells, which may fail to signify the potential impact of dense plumes or seasonally-occurring leachate plumes that have moved off-site. Additionally, the preliminary investigation wells are not normally installed to a sufficient depth for appreciation of the local stratigraphic and lithologic characteristics of the aquifer.

In addition to a better understanding of where contaminants might go with the natural flow, a second powerful argument to avoid "penny-wise and pound-foolish" investigations concerns the need to provide the best information possible for targeting well locations and pumping strengths in remedial actions. The occurrence of specific heterogeneities can be used to advantage by locating wells near low permeability clay units to generate greater drawdown for a given pumping rate. Likewise, knowledge of the direction of the principal horizontal axis in anisotropic strata can help to maximize the arrangement of the "troughs of depression" for wells to be located in such settings; knowledge of the magnitude of vertical anisotropy can help determine the amount of water pumped from strata containing contaminants vs. the amount of "clean" water from the other strata open to the well.

This latter factor, vertical anisotropy, leads to examination of some of the more controllable items to be considered in optimizing pumping strategies—well construction effects. For example, the impact that partial penetration of a fully screened pumping well can have on the estimate of potential for contamination of a water supply or on the effectiveness of a remedial action scheme is tremendous (Saines 1981). The effect is to cause exaggerated drawdowns near the well. The magnitude of the effect is inversely dependent on the degree of penetration of the well into the aquifer, being greatest for slight penetration. Naturally, partial screening of a fully penetrating well results in the same effect—greater drawdown for a given pumping rate as compared with a fully screened, fully penetrating well.

Again, knowledge of these factors can be used to enhance a pumping scheme that is, for example, designed to maintain hydrodynamic control of a plume at the lowest possible level of pumpage. Lack of appreciation of these well construction effects can result in poor estimates of potential contaminant impacts on supply wells and in poorly designed remedial action schemes. Another effect worthy of mention is that generated by well development practices. If a well is properly developed, the drawdown measurable inside the well will agree with the level projected by close observation wells. More often, however, a well is not perfectly efficient because the well development procedures were not adequate to remove drilling fluid fines and locally disturbed aquifer material resulting from the drilling process. These materials lower the permeability of the gravel pack and formation immediately adjacent to the well. The greater the degree of well inefficiency caused by lack of proper development, the greater the amount of non-productive drawdown inside the well; this means that the well may never be able to pump at design capacity without risk of running dry, and it means increased operating expense due to the additional pump lift required. What it may also portend, for seriously inefficient wells, is that certain strata penetrated by the well may be effectively sealed by drilling mud or by natural clays that were smeared over the borehole face by the actions of the drilling operation. Such "sealed off" strata may carry the bulk of the contaminants, resulting in poor recovery of the plume.

Some of the most significant, though less controllable, factors that should be considered when optimiz-

ing pumping strategies concern direct anthropogenic influences: denial of property access, vandalism and unknown pumpage all tend to wreak havoc with the best laid plans. Bedient et al. (1984) describe efforts to delineate a plume of contaminants migrating under a residential area from an abandoned wood creosoting plant in Conroe, Texas:

> "Several wells exist in the general flow direction, but not directly downgradient from the waste pit locations. Access was not granted for installing monitoring wells . . . Approximately 50 percent of the chloride plume has been defined since the monitoring well network is incomplete at this time . . . Completion of the monitoring well network is needed to capture the center of the contaminant plume. This will require more wells downgradient on land that has not previously been accessible for investigation."

The granting of property access during investigations of ground water contamination incidents in populated areas is no trivial matter. One typically finds it necessary to contact not only homeowners and landlords for private property access, but also to negotiate with company engineers, vice presidents and attorneys for commercial property access. It is quite normal for such negotiations to be involved and protracted as city councils, educational boards, corporate headquarters and other bureaucratic entities are asked to concur in signing access agreements containing provisions deemed necessary to ensure against incurred liability and potential damage.

The role played by unknown pumping and/or injection wells operating near a remedial action pumping system is subtle but far-reaching. Such unknown stresses can significantly distort the flow field and render remedial actions ineffective. Projections on plume movement made during an investigation of a ground water contamination incident would also be in error if unknown wells are causing distortion in the flow field; both the direction and the speed of the plume could be dramatically altered. The reason for the subtlety of the effects of many such wells is that their cyclic, seasonal or on-demand pumping schedules allow them to be detected only by continuous recording of water level changes at numerous points around the zone of interest. Since aquifer responses at a given observation point are somewhat non-unique, merely detecting extraneous sources of drawdown does not automatically result in identification of the sources.

There are a few other important factors to consider that also affect pumping strategies. The physiochemical properties of the contaminant itself can result in a need to pump several pore volumes from each unit volume of aquifer to be decontaminated. Sorption, ion exchange and speciation changes can result in retarded movement of contaminants relative to the average velocity of the water with which they are initially associated. Biotransformation of contaminants may result in reaction products (daughter products) that are of greater or lesser toxicity, mobility and persistence—in other words, uncertain contaminant behavior. Unlike the aquifer properties of storage coefficient, saturated thickness and hydraulic conductivity, which can be readily determined, the current state-of-the-science with regard to determining the potentials for physiochemical attenuation and biotransformation is not up to the level of routinely providing reliable answers on a site-specific basis.

Finally, an obvious but often overlooked consideration involved in optimizing pumping strategies is the need to develop adequate contingencies for operational failures. This means some intentional overdesign for reserve capacity, total redundancy of key wells and electronic controls, backup power systems and so on. It also means bonding or insurance against unforeseen catastrophies so that as little downtime is expended as possible. It may also mean that an escrow account or trust fund must be established to provide the necessary capital for replacement of burned-out or inadequate pumps, deepening or abandonment of existing wells, or drilling of additional wells.

Capture Zones vs. Zones of Pressure Influences

Keely and Tsang (1983) introduced the term "capture zone" to describe that portion of the aquifer affected by pumping which actually yields water to the well. They have shown that the capture zone is generally much smaller than the zone of pressure influence because a balance is achieved, under steady-state conditions, between the pull of water back toward the well from its downgradient side and the tendency of the natural flow system to move on further downgradient. Figure 2 is a series of four idealized illustrations that present conceptualizations of how the size of the capture zone changes, relative to the zone of pressure influence/cone of depression, as the local gradient is increased. In Figure 2A the well is pumping from a stagnant aquifer, indicated by the flat pre-pumping surface, overlaid on the theoretical cone of depression that would occur during pumpage. For stagnant aquifer conditions, the capture zone is everywhere identical to the zone of pressure influence and flow is radial into the well. As the successive diagrams indicate, however, non-stagnant aquifer conditions lead to smaller capture zones (Figures 2B to 2D).

The slopes of the pre-pumping surfaces are overlaid on the theoretical drawdown cones in each frame of Figure 2 to emphasize the interaction of the natural flow system with the pumping stress to yield a capture zone smaller than the zone of pressure influence. There is no intention to show the net surface resulting from pumpage by subtracting theoretical drawdown values from pre-pumping water elevations. These sketches do have the cosmetic drawback of showing crossing water level lines/curves, but the point is to illustrate the individual components of the net surface (cross-sectional view) and how they interact to yield a capture zone (three-dimensional view).

The flow lines generated by pumping a well from an idealized aquifer (homogeneous, isotropic, constant density, etc.) under different natural flow conditions are shown in Figure 3. In Figure 3 a well pumping 1,000m^3/day from a 10m thick aquifer having a porosity of 0.10 and a hydraulic conductivity of 100m/day has uniform radial flow under stagnant aquifer conditions (e.g. natural flow velocity equal to zero). When a mild hydraulic gradient (0.0001) is imposed on the same system (Figure 3B), the resulting natural flow velocity (0.1m/day) is insufficient to significantly affect the flow lines, and uniform radial flow is nearly maintained. With a more moderate hydraulic gradient (0.001), the resulting natural flow velocity (1.0m/day) is sufficient to sweep away many of the flow lines and the capture zone is clearly evident (Figure 3C). Where a steep gradient (0.01) is present, the capture zone diminishes to a small fraction of the zone of pressure

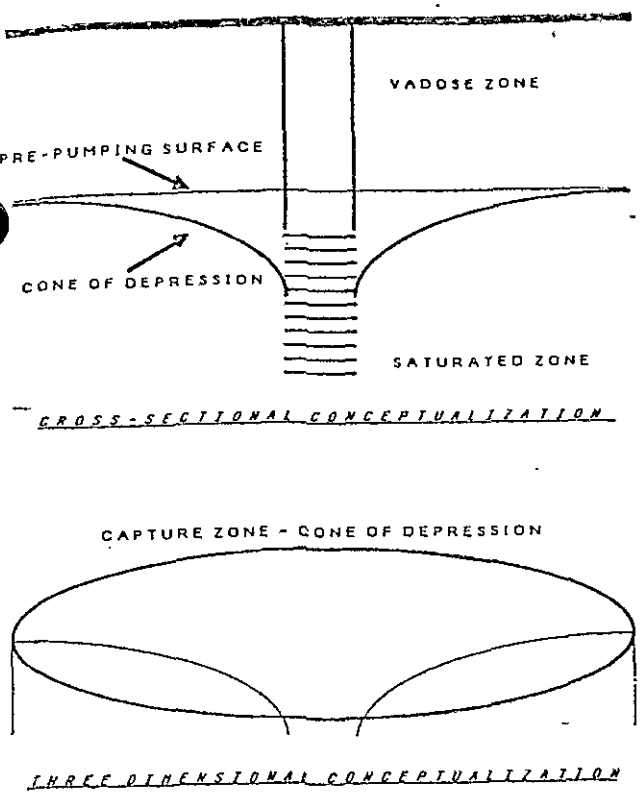


Figure 2A. Stagnant aquifer conditions

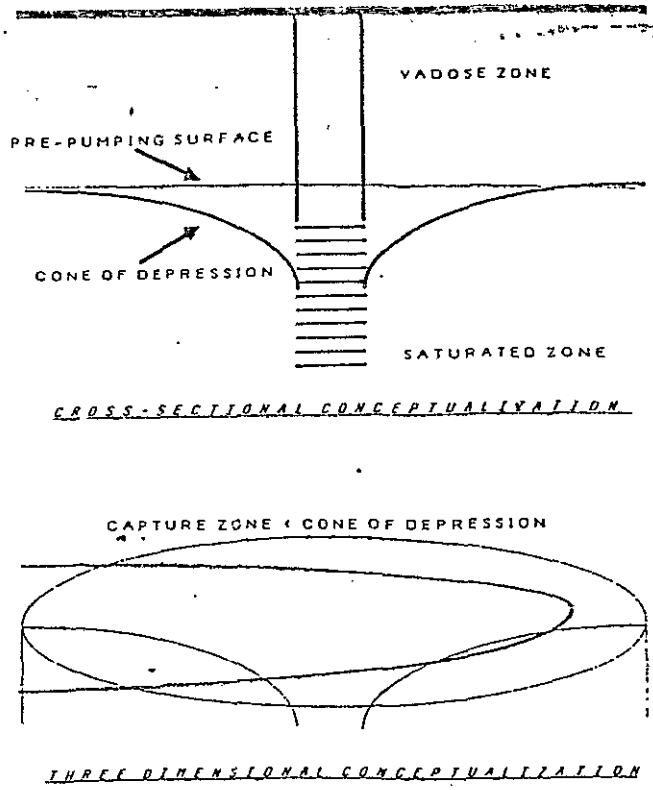


Figure 2B. Mild natural gradient

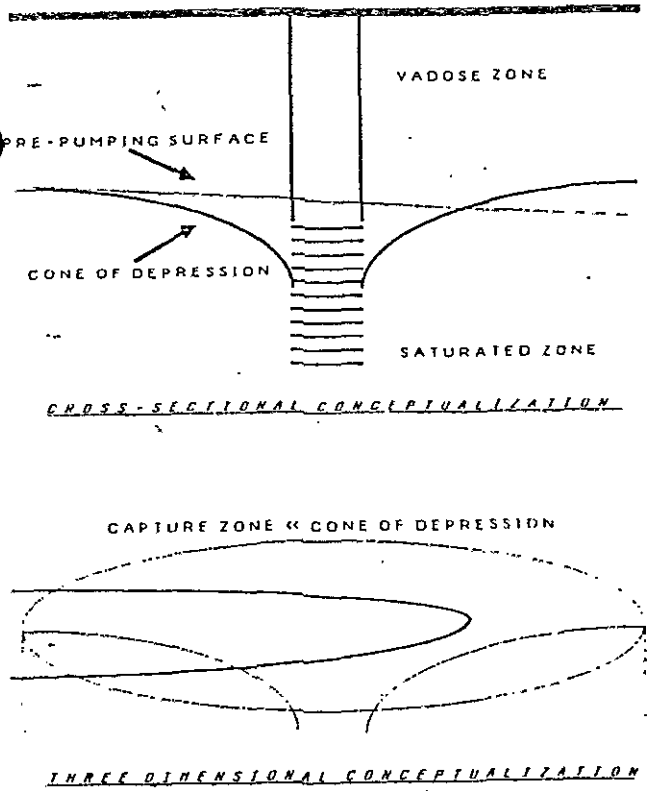


Figure 2C. Moderate natural gradient

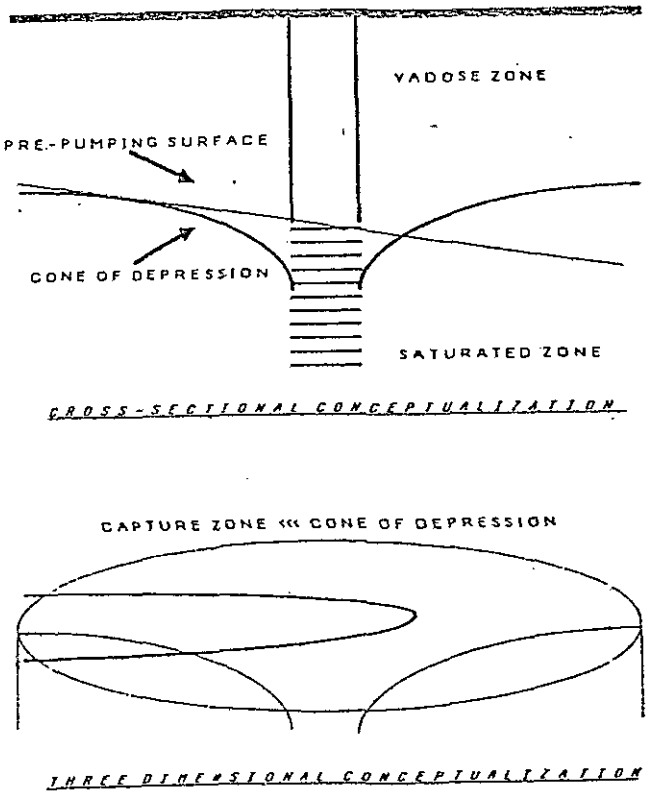


Figure 2D. Steep natural gradient

Figure 2. Cross-sectional and three-dimensional conceptualizations of capture zone vs. cone of depression

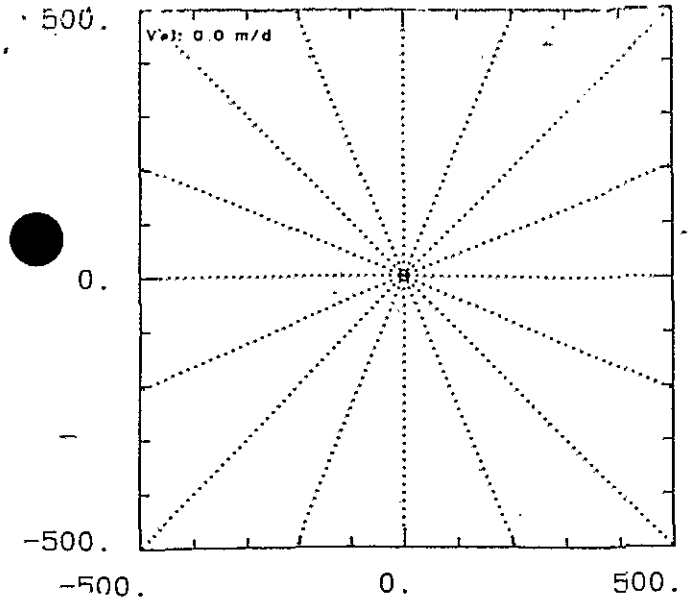


Figure 3A. Stagnant aquifer conditions

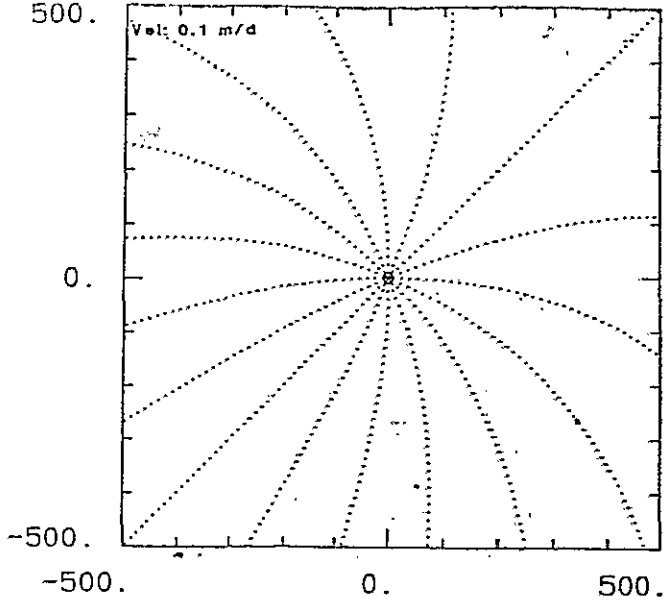


Figure 3B. Mild hydraulic gradient (0.0001)

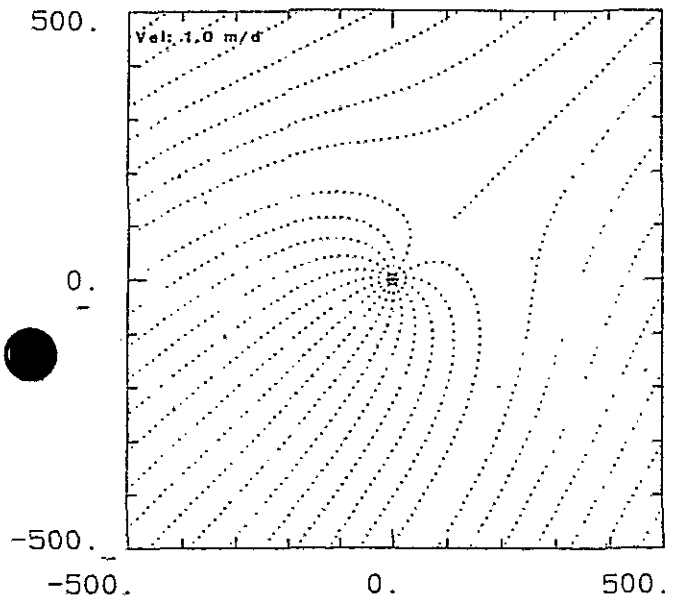


Figure 3C. Moderate hydraulic gradient (0.001)

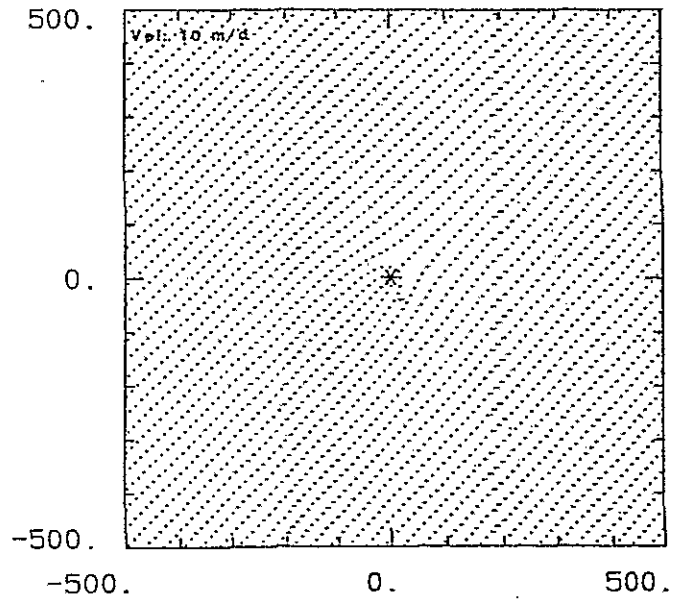


Figure 3D. Steep hydraulic gradient (0.01)

Figure 3. Flow line plots for a single well discharging 1,000m³/day from an aquifer with 10m saturated thickness, 100m/day hydraulic conductivity and 0.10 porosity

NOTE: Scale is in meters and natural flow proceeds from lower left-hand corner to upper right-hand corner of each plot at the velocity indicated.

influence (Figure 3D).

Comparing Pumping Strategies

A typical use of pumping schemes is to effect hydrodynamic control over a plume, either for long-term stabilization or for withdrawal and treatment. Consider extending the example illustrated by Figure 3. First, assume a line of five wells lying perpendicular to the direction of natural flow (Figure 4). Each of the five wells pumps 200m³/day, so that the total pumpage of the five wells is the same as that of the single well in Figure 3. Under stagnant aquifer conditions to low natural flow velocities (Figures 4A and 4B) there does not seem to be any difference in the effectiveness of the pumpage from the five wells as compared with the single well case (Figures 3A and 3B). The situation changes markedly if moderate to high natural flow velocities are present, however, as depicted in Figures 4C and 4D. As the natural flow velocity increases, the capture zone of each of the five wells diminishes to a point where adjacent capture zones no longer overlap and natural flow lines run on through the line of wells. By contrast, the capture zone of the single well pumping 1,000m³/day does not develop holes, but does diminish in size to well below the perceived size of the leaky collective capture zone of the line of five wells.

In actuality, there is no difference between the true collective size of the capture zones generated by the five wells and that generated by the single, high-flow

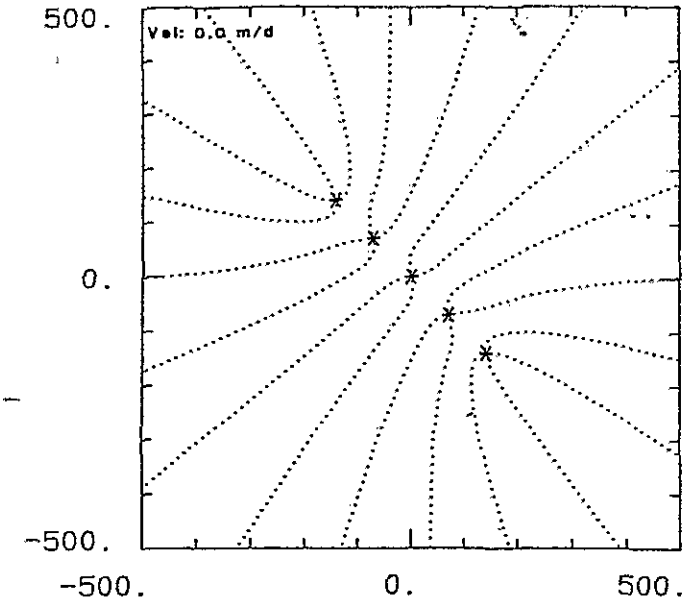


Figure 4A. Stagnant aquifer conditions

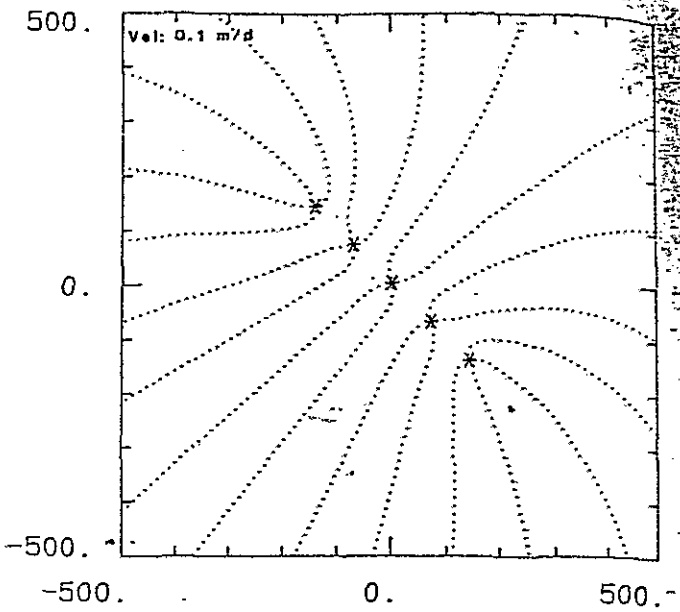


Figure 4B. Mild hydraulic gradient (0.0001)

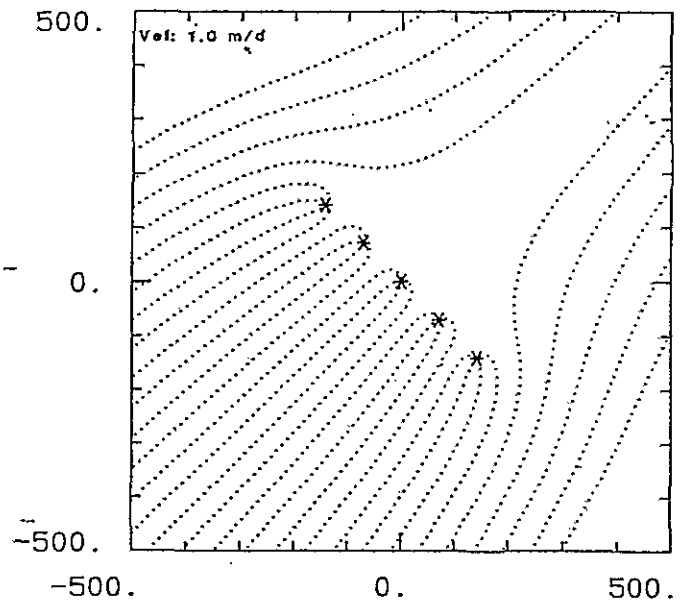


Figure 4C. Moderate hydraulic gradient (0.001)

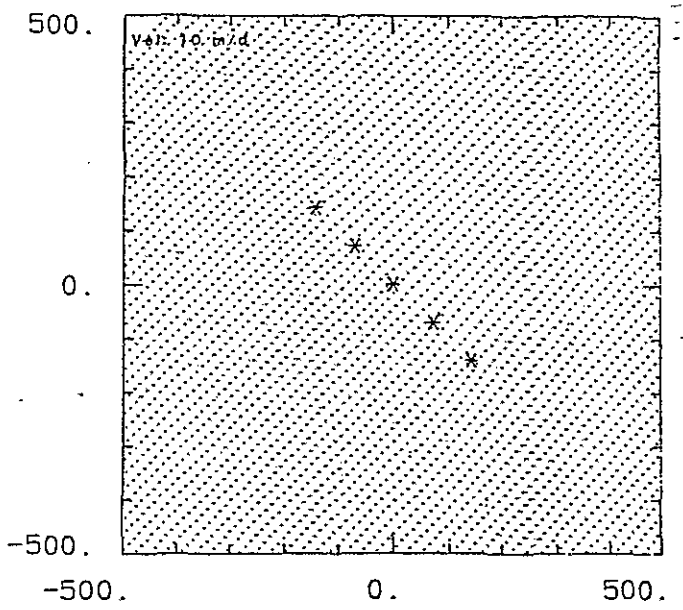


Figure 4D. Steep hydraulic gradient (0.01)

Figure 4. Flow line plots for a line of five wells, each discharging 200m³/day from an aquifer with 10m saturated thickness, 100m/day hydraulic conductivity and 0.10 porosity

NOTE: Scale is in meters and natural flow proceeds from lower left-hand corner to upper right-hand corner of each plot at the velocity indicated.

rate well. By rearranging some of the expressions for capture zone dimensions given by Keely and Tsang (1983), it is possible to define the maximum width of the capture zone upgradient of the well as: $W_{max} = Q \div (h\phi_e V_{nat})$. Using this relationship, it is apparent that the maximum width (W_{max}) of the capture zone of a well is directly and linearly related to its flow rate (Q), and is inversely related to the natural flow velocity (V_{nat}).

For the example discussed here regarding a single well pumping 1,000m³/day, the maximum width of the capture zone is 1,000m when the natural flow velocity is 1.0m/day, and is 100m when the natural flow velocity is 10m/day. Each of the five wells in the second example discussed pumps at a flow rate equal to one-fifth the flow rate of the well in the first example (200m³/day), and each, therefore, has a capture zone the maximum width of which is one-fifth that of the single well (200m). Hence, by comparing Figure 3 with Figure 4, it is seen that the way in which the total pumpage is distributed does directly affect the distribution of the capture zone(s), but does not affect the magnitude or total area of the capture zone(s). Also to be seen in Figures 3 and 4 is that increasing the natural flow velocity estimate can have a dramatic impact on the effectiveness of the pumping strategy. Given the order-of-magnitude uncertainty so often associated with hydraulic conductivity estimates, it is not surprising that many seemingly acceptable remedial action schemes are doomed to fail miserably.

A more complicated example provides further illustration of these points. Assume that we have the same

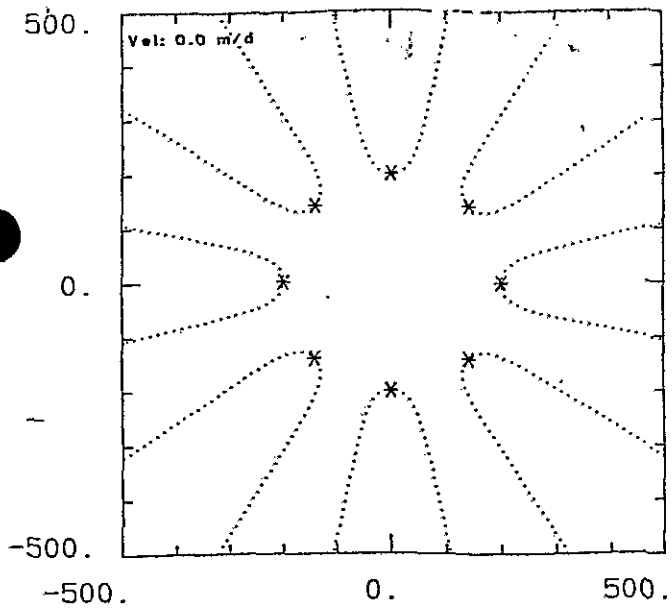


Figure 5A. Stagnant aquifer conditions

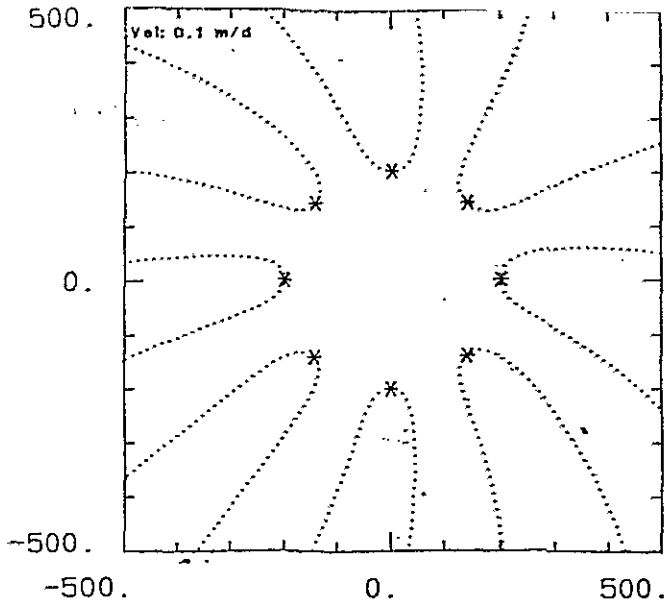


Figure 5B. Mild hydraulic gradient (0.0001)

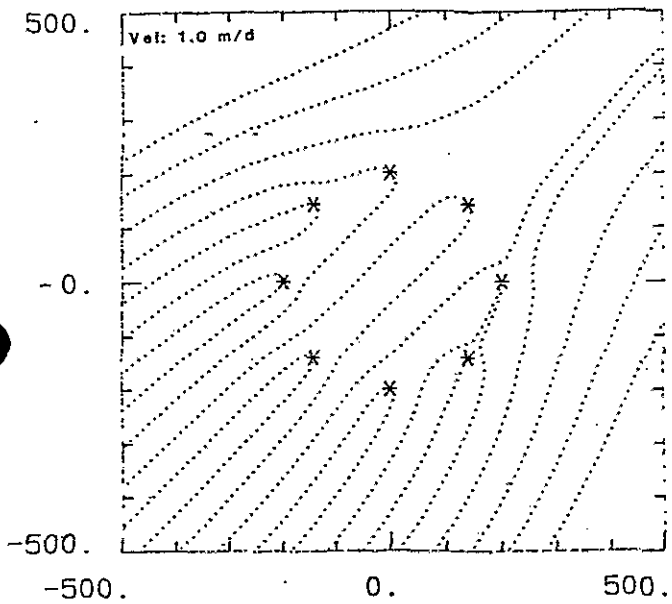


Figure 5C. Moderate hydraulic gradient (0.001)

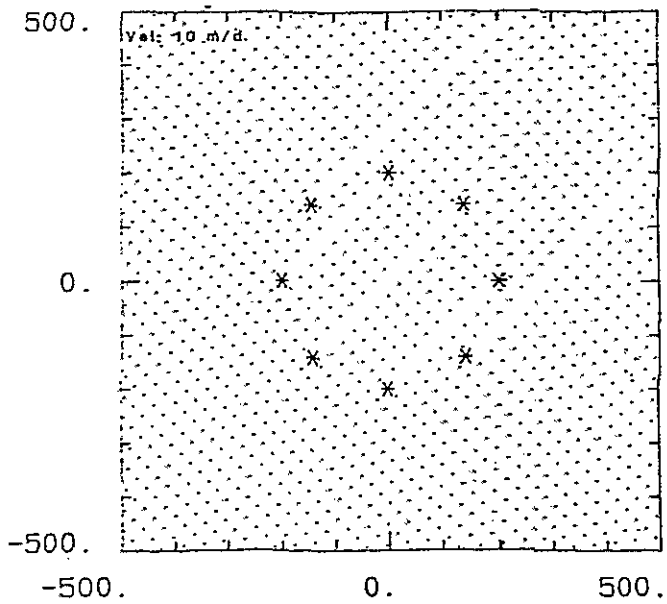


Figure 5D. Steep hydraulic gradient (0.01)

Figure 5. Flow line plots for a circle of eight wells, each discharging 125m³/day from an aquifer with 10m saturated thickness, 100m/day hydraulic conductivity and 0.10 porosity

NOTE: Scale is in meters and natural flow proceeds from lower left-hand corner to upper right-hand corner of each plot at the velocity indicated.

aquifer conditions and total pumpage limitation (1,000m³/day) as the preceding examples. We will distribute the pumpage uniformly by pumping each of eight wells at 125m³/day. The eight wells are evenly spaced around a circle of 200m radius. We are trying to hold a plume within the circle. With stagnant aquifer conditions to low natural flow velocities, the plume appears to be stable; no flow lines pass through the circle (Figures 5A and 5B). At moderate to high natural flow velocities, however, the situation is quite different; flow lines readily pass through the circle, indicating that the plume stabilization attempt has failed (Figures 5C and 5D).

A pump and treat scenario can be examined by modifying the example shown in Figure 5 to change the operation of the eight wells from pumping to injecting and by adding a major pumping well in the center of the circle. The single pumping well will withdraw 1,000m³/day from the plume. The withdrawn water will be treated and re-injected into the eight injections wells at 125m³/day each. At zero to low flow velocities, the injected water flows radially toward the central pumping well, forming a closed loop for recovery and treatment of the plume (Figures 6A and 6B). At moderate to high natural flow velocities, the recovery loop is broken and an increasing amount of the injected water and the plume are swept away by the regional flow (Figures 6C and 6D). It must be emphasized that the cones of impression or depression of the wells overlap significantly for all of the multiwell examples discussed so far. Despite those overlaps, the net surface resulting from the natural gradient and the

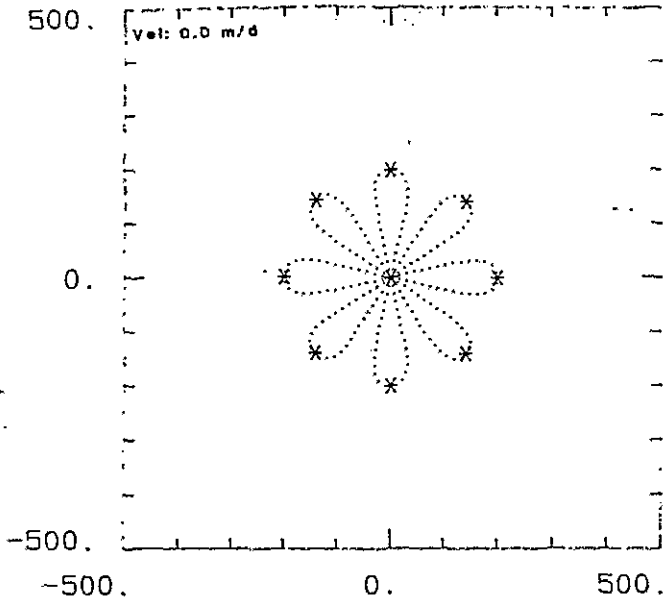


Figure 6A. Stagnant aquifer conditions

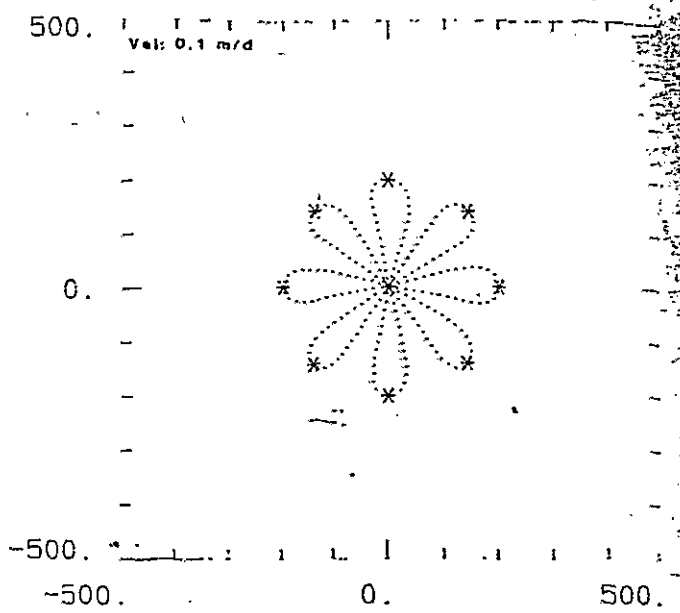


Figure 6B. Mild hydraulic gradient (0.0001)

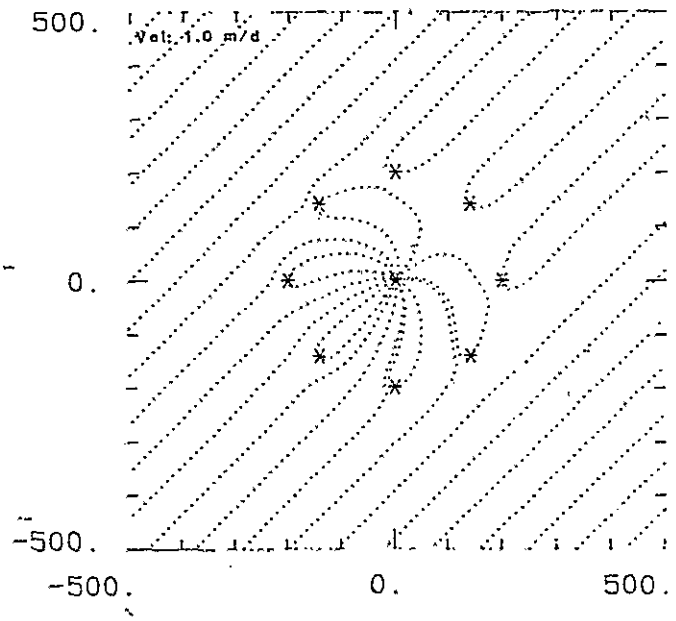


Figure 6C. Moderate hydraulic gradient (0.001)

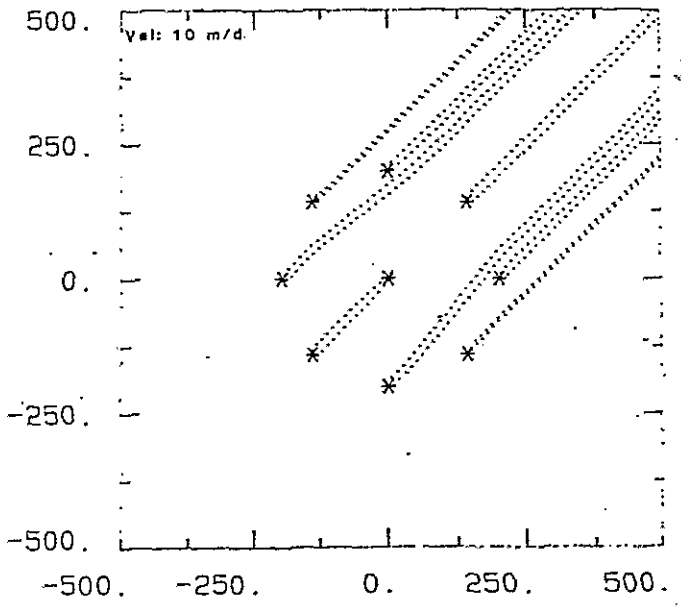


Figure 6D. Steep hydraulic gradient (0.01)

Figure 6. Flow line plots for a single well discharging 1,000m³/day, encircled by eight wells injecting 125m³/day into an aquifer with 10m saturated thickness, 100m/day hydraulic conductivity and 0.10 porosity

NOTE: Scale is in meters and natural flow proceeds from lower left-hand corner to upper right-hand corner of each plot at the velocity indicated.

water level changes due to pumpage and/or injection is shaped such that the streamlines are truly as presented here. For further discussion of capture zones and velocity distribution plots, see Keely and Tsang (1983). The detailed theoretical development and source code listings for the models that were used to generate the stream line plots shown here are given in Javandel et al. (1984).

A Little More Detail

It was quite clear in each of the preceding examples that the pumping strategy began to fail as the natural flow velocities became appreciable. The tendency to fail is generally becoming evident at a natural flow velocity of 1.0m/day and is beyond question at a natural flow velocity of 10m/day. Figure 7 shows that failure of each design is certain at 5.0m/day as well: the point at which the flow lines break through must be at much lower natural flow velocities.

In Figure 8 the natural flow velocity has been reduced to 0.5 and 0.4m/day for the last two examples only. Breakthrough of the streamlines (failure of the pumping strategy) occurs somewhere between the 0.4 and 0.5m/day natural flow velocities. Similar comparisons for the first two examples are not presented because flow line breakthrough does not apply to the first example (a single production well) and the flow line did not indicate breakthrough at 1.0m/day for the second example (a line of five wells).

The presence of an unknown well is being studied in Figure 9. A major pumping well (1,000m³/day) has been arbitrarily located downgradient of the same line

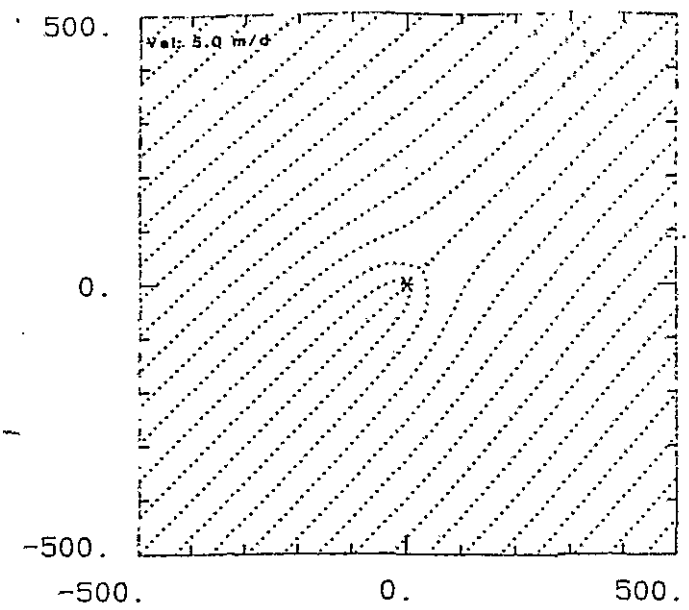


Figure 7A. Single well discharging 1,000m³/day

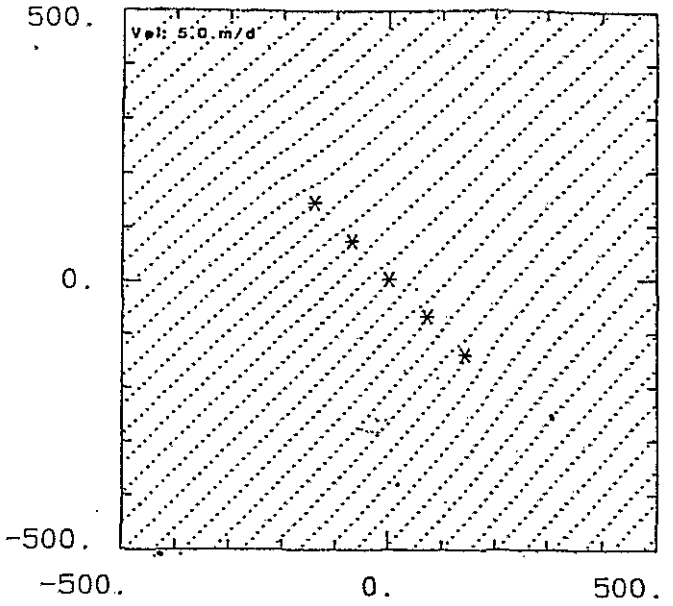


Figure 7B. Line of five wells, each discharging 200m³/day

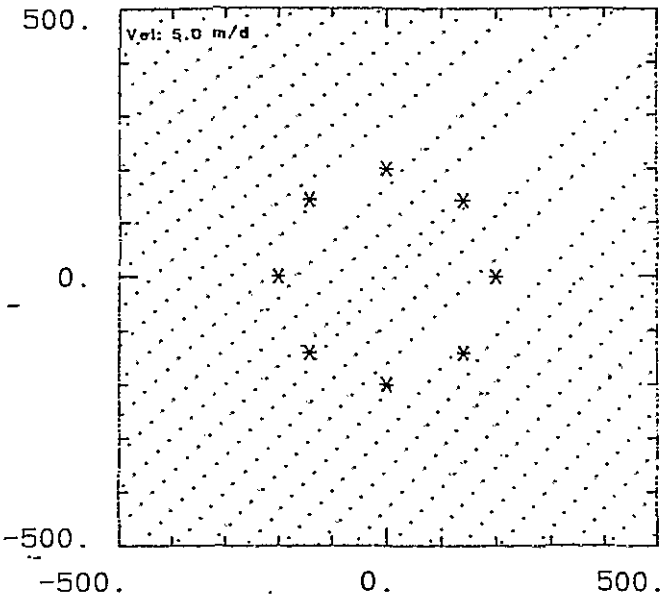


Figure 7C. Circle of eight wells, each discharging 125m³/day

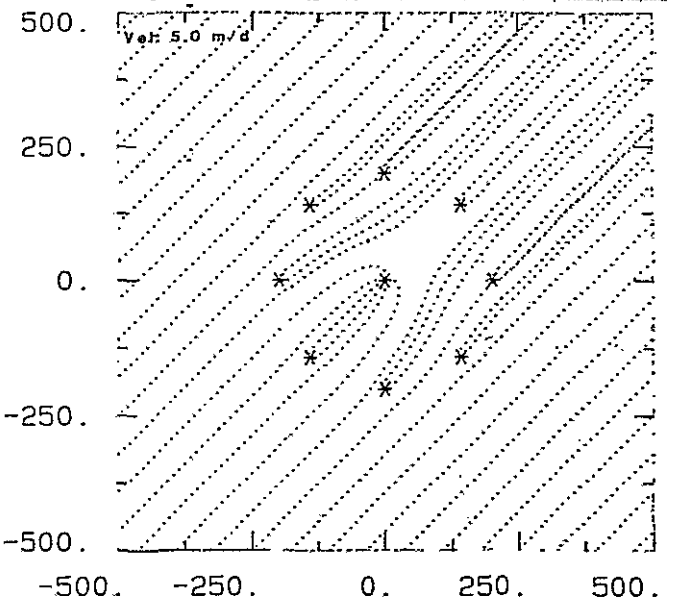


Figure 7D. Single well discharging 1,000m³/day, encircled by eight wells injecting 125m³/day each.

Figure 7. Comparison of pumping arrays in an aquifer with 10m saturated thickness, 100m/day hydraulic conductivity, 0.10 porosity and 0.005 hydraulic gradient

NOTE: Scale is in meters and natural flow proceeds from lower left-hand corner to upper right-hand corner of each plot at the velocity indicated.

of five wells discussed in the second example. Naturally, under stagnant aquifer conditions, the unknown well creates a hydraulic divide by distorting the flow field, but it does not cause breakthrough of the flow line from across the line of five wells (Figure 9A). With a natural flow velocity of 0.5m/day, however, flow lines do begin to break through the line of five pumping wells (Figure 9B). Substantial failure of the pumping scheme occurs at 1.0m/day natural flow velocity (Figure 9C). Contrast the onset of breakthrough due to unknown pumpage (Figure 9B) with the same situation in the absence of the unknown pumpage (Figure 9D). The impact of the unknown well is staggering, not only because flow line breakthroughs are occurring, but the collective size of the capture zones of the five pumping wells is being substantially reduced.

Another illustration of the impact of an unknown well on the effectiveness of a pumping scheme is shown in Figure 10, which is the same example as discussed earlier (Figure 6) for a closed-loop aquifer rehabilitation system. Under stagnant aquifer conditions, the unknown well diverts flow away from two of the injection wells (Figure 10A). At 1.0m/day natural flow velocity, the unknown well diverts flow from five of the eight injection wells (Figure 10B). It also allows flow to break away from the well field entirely, as indicated by the streamline leaving the uppermost injection well and heading downgradient in Figure 10B. The regional flow lines were omitted from Figure 10 and some of the diagrams in previous figures because inclusion of those flow lines would create confusion due to the excessive number of plotted points.

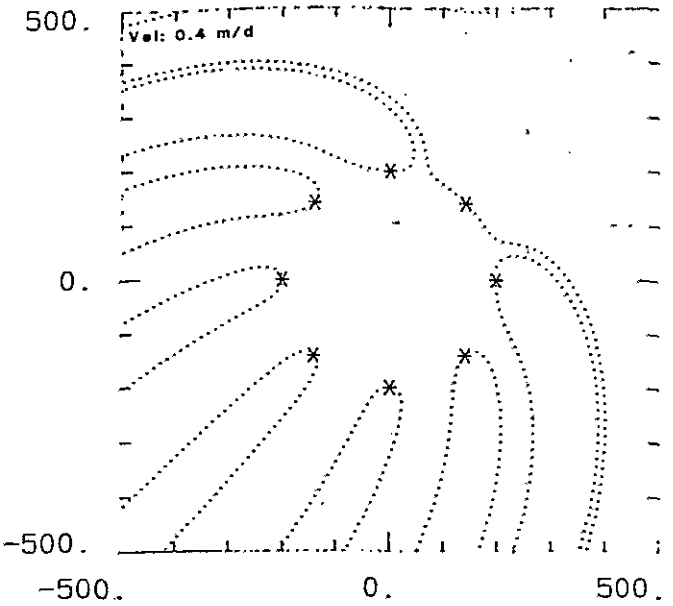


Figure 8A. Circle of eight wells, each discharging 125m³/day with 0.0004 hydraulic gradient

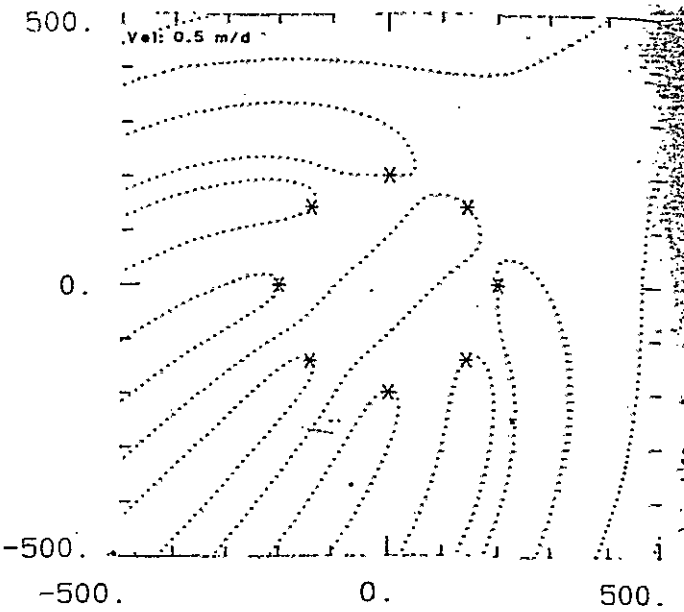


Figure 8B. Circle of eight wells, each discharging 125m³/day, with 0.0005 hydraulic gradient

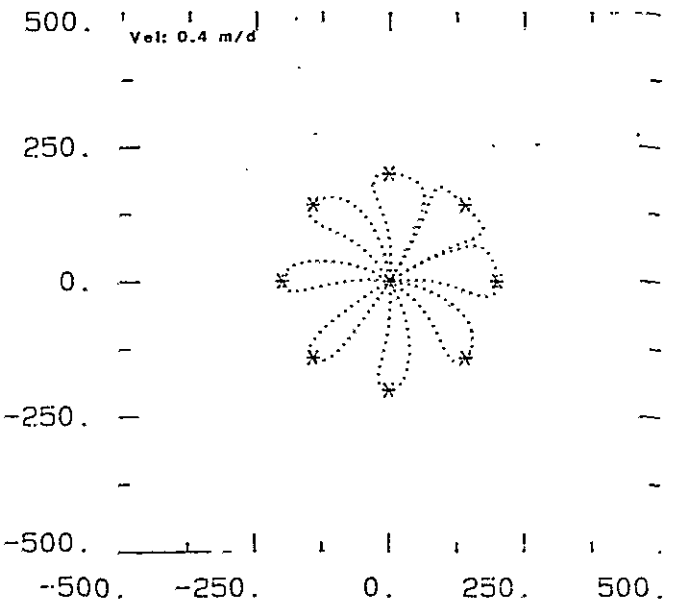


Figure 8C. Single well discharging 1,000m³/day, encircled by eight wells injecting 125m³/day each, with 0.0004 hydraulic gradient

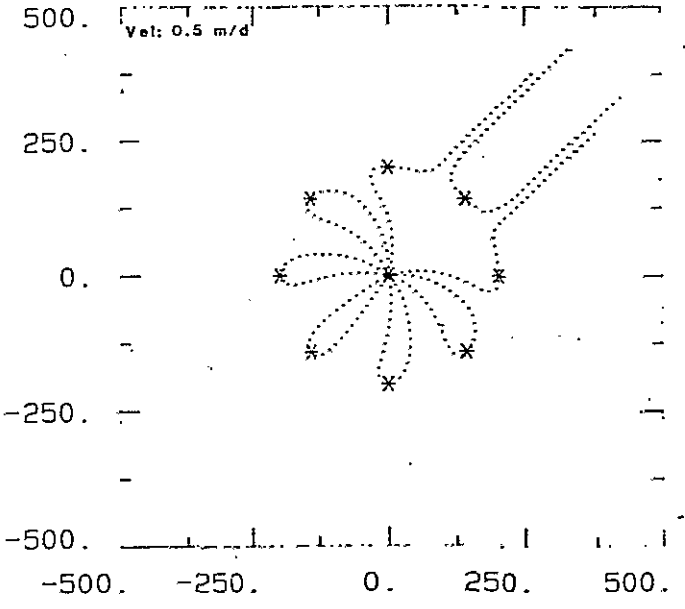


Figure 8D. Single well discharging 1,000m³/day, encircled by eight wells injecting 125m³/day each, with 0.0005 hydraulic gradient

Figure 8. Detailed views of the onset of flow line breakthroughs for two plume control strategies in an aquifer with 10m saturated thickness, 100m/day hydraulic conductivity and 0.10 porosity

NOTE: Scale is in meters and natural flow proceeds from lower left-hand corner to upper right-hand corner of each plot at the velocity indicated.

Conclusions

Heterogeneity, anisotropy, partial penetration and so on distort drawdown patterns and associated velocity distributions. If known, such influences can be used to enhance recovery efficiencies for remedial actions. If unknown, such influences may cause recovery efficiencies to be substantially lowered. Similarly, predictions of plume migration in non-ideal aquifers under non-pumping/natural flow conditions will be strengthened by specific knowledge regarding the occurrences, extent and magnitude of the non-ideal condition(s). Such predictions may be seriously in error if non-ideal conditions are not evaluated properly.

Denial of property access, loss by vandalism and unpredictable operation of nearby wells are also major sources of uncertainty in predicting contaminant migration and in designing remedial actions. Though commonly perceived to be less of an impact on optimizing pumping strategies than non-ideal aquifer conditions, these factors may indeed be the most uncontrollable and the most detrimental to operational success. Other factors that have major impacts are the physiochemical attenuation and biotransformation potentials of the individual contaminant; it is not yet economically feasible to conduct adequately detailed studies of these potentials on a routine site-specific basis. Finally, a factor often overlooked that greatly impacts optimization efforts is the risk of

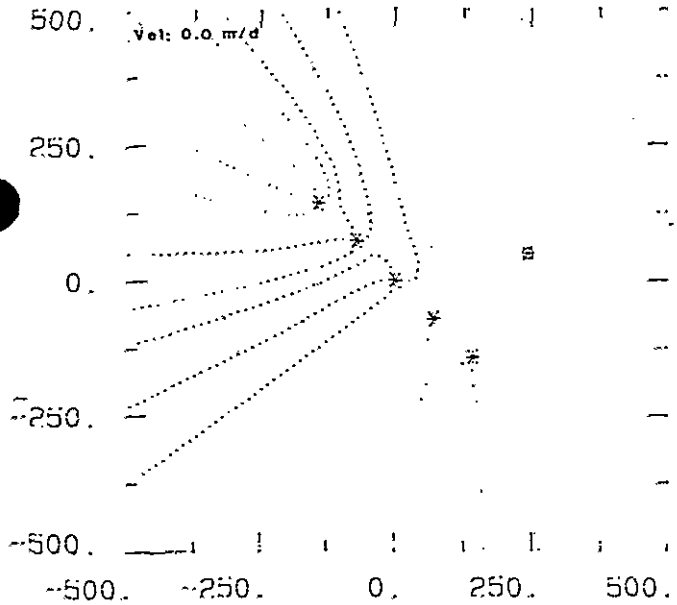


Figure 9A. Stagnant aquifer conditions

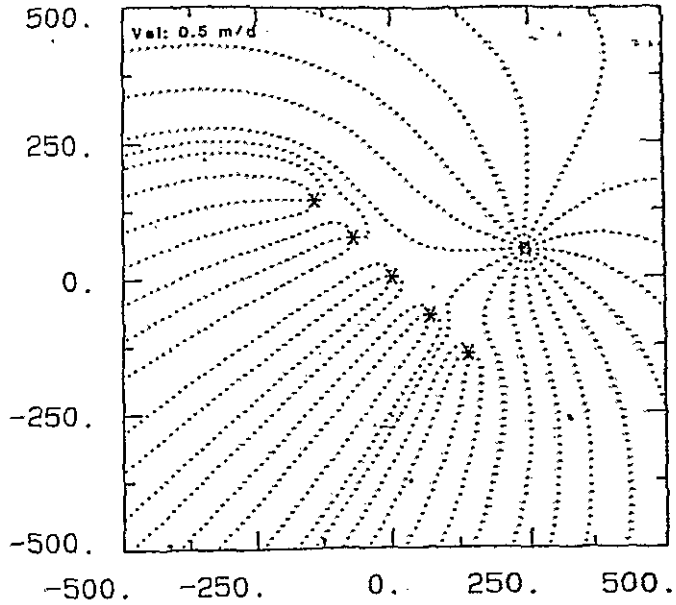


Figure 9B. Hydraulic gradient of 0.0005

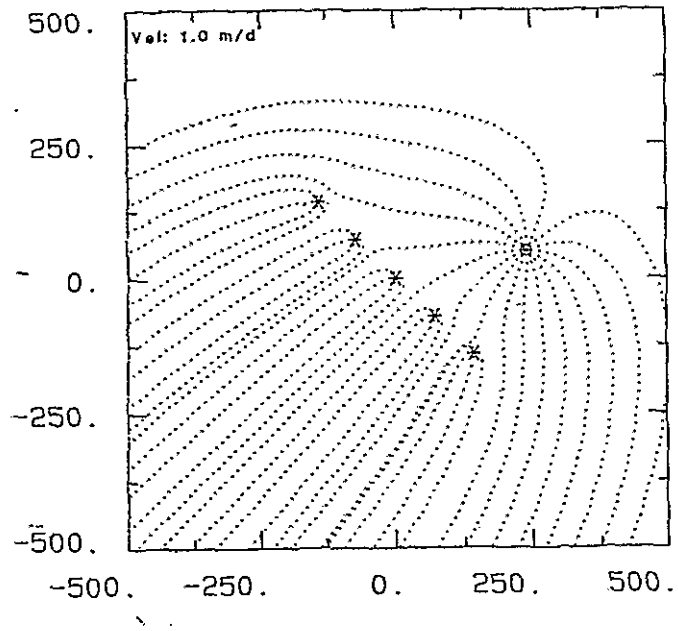


Figure 9C. Hydraulic gradient of 0.001

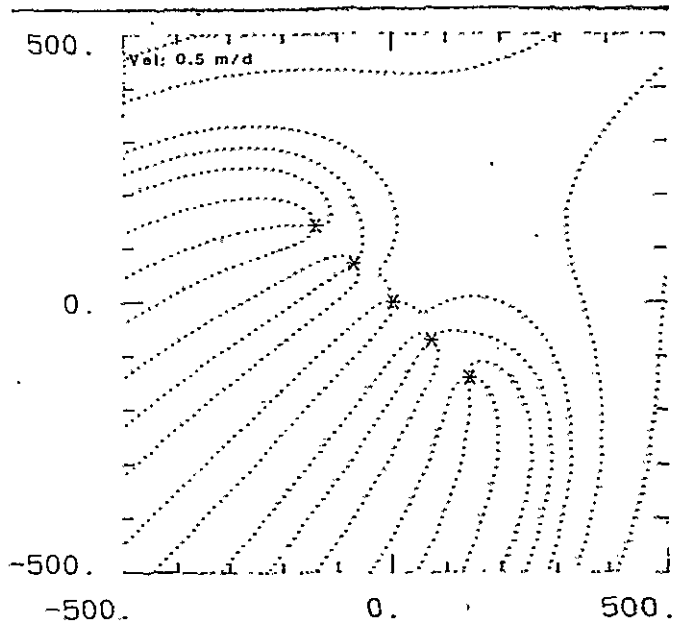


Figure 9D. Hydraulic gradient of 0.0005—without the unknown well

Figure 9. Influence of an unknown well discharging 1,000m³/day on flow line breakthroughs for a line of five wells discharging 200m³/day each from an aquifer with 10m saturated thickness, 100m/day hydraulic conductivity and 0.10 porosity

NOTE: Scale is in meters and natural flow proceeds from lower left-hand corner to upper right-hand corner of each plot at the velocity indicated.

mechanical and electrical operational failure; adequate contingency plans must provide certain minimal levels of excess/reserve capacity and redundancy of key system components.

The capture zones of wells do not equal their associated zones of pressure influence (cones of depression), except for stagnant aquifer conditions. Velocity distribution plots must be constructed to define potentials of contaminant migration. In particular, plotting the streamlines for various scenarios involving pumping and/or injection wells subject to a specific natural flow velocity can greatly assist the ground water professional in selection of an optimal pumping strategy.

Acknowledgments

Thanks go to Rosemary Keely and Christine Doughty for (computer) drafting the illustrations. Thanks also go to Renae Daniels for typing this manuscript.

Disclaimer

Although this article was produced by an employee of the United States Environmental Protection Agency, it has not been subjected to Agency review and therefore does not necessarily reflect the views of the Agency; no official endorsement should be inferred.

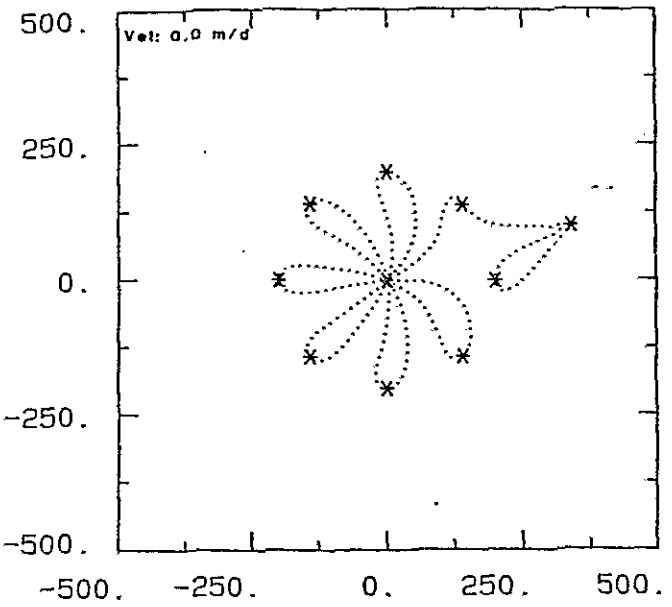


Figure 10A. Stagnant aquifer conditions

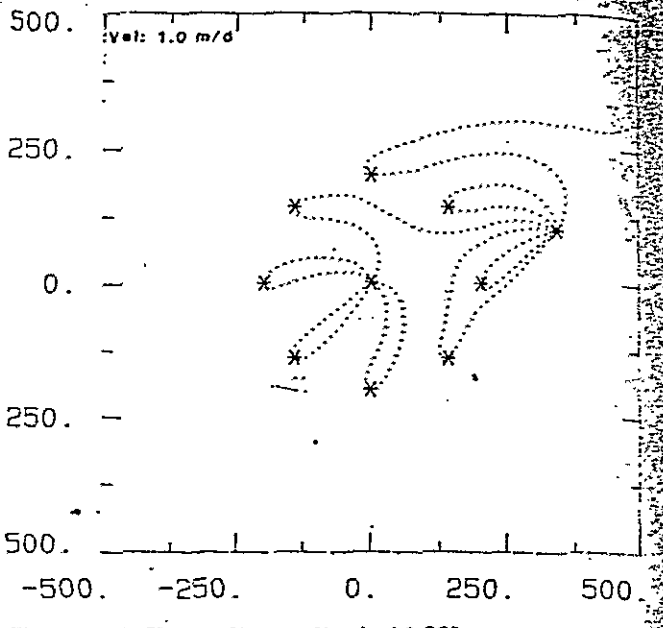


Figure 10B. Hydraulic gradient of 0.001

Figure 10. Influence of an unknown well discharging 1,000m³/day on flowline breakthroughs for a single well discharging 1,000m³/day that is encircled by eight wells injecting 125m³/day into an aquifer with 10m saturated thickness, 100m/day hydraulic conductivity and 0.10 porosity.

NOTE: Scale is in meters and natural flow proceeds from lower left-hand corner to upper right-hand corner of each plot at the velocity indicated.

References

Bedient, P.B., A.C. Rodgers, T.C. Bouvette, M.B. Tomson and T.H. Wang. 1984. Ground water quality at a creosote waste site. Ground Water, v. 22, no. 3, pp. 318-329.

Fetter, C.W. 1981. Determination of the direction of ground water flow. Ground Water Monitoring Review, v. 1, no. 3, pp. 28-31.

Javandel, I., C. Doughty and C.F. Tsang. 1984. Ground water transport: handbook of mathematical models. American Geophysical Union, Water Resources Monograph 10.

Jorgensen, D.G., T. Gogel and D.C. Signor. 1982. Determination of flow in aquifers containing variable-density water. Ground Water Monitoring Review, v. 2, no. 2, pp. 40-45.

Keely, J.F. and C.F. Tsang. 1983. Velocity plots and capture zones of pumping centers for ground water investigations. Ground Water, v. 21, no. 6, pp. 701-714.

Saines, M. 1981. Errors in interpretation of ground water level data. Ground Water Monitoring Review, v. 1, no. 1, pp. 56-61.

Biographical Sketch

Joseph F. Keely (Robert S. Kerr Environmental Research Laboratory, U.S. EPA, P.O. Box 1198, Ada, OK 74820) received his B.S. in professional chemistry and M.S. in hydrology from the University of Idaho (Moscow). He is employed as a hydrologist at EPA's Robert S. Kerr Environmental Research Laboratory, where his efforts are directed toward geohydraulic and hydrogeochemical investigations of ground water contamination incidents, coordination of ground water modeling research and instructional assistance. He sits on the Policy Board of the International Ground Water Modeling Center and serves as expert witness to the U.S. Department of Justice for Superfund cases.

48. Kmet, Peter, et al. "Use of Collection Lysimeters in Monitoring Sanitary Landfill Performance presented at the National Water Well Association Conference on the Characterization and Monitoring of the Vadose (Unsaturated) Zone, Las Vegas, Nevada, December 8-10, 1983

2648

Use of Collection Lysimeters in Monitoring Sanitary Landfill Performance

Eagle

by

Peter Kmet and David E. Lindorff[1]

ABSTRACT

Monitoring of the unsaturated zone beneath a landfill can provide an important early warning system for assessing site performance. Pressure-vacuum lysimeters have been used for this purpose at numerous landfills in Wisconsin over the last decade. Unsatisfactory experiences with several of these installations led to the use of the collection basin or collection lysimeter as a monitoring tool. A collection lysimeter is a lined structure placed beneath a portion of the base of a landfill to collect leakage from the site. A pipe extends from the lysimeter to an access point outside of the limits of fill where collected liquid can be extracted. They are best suited for monitoring the unsaturated zone beneath lined landfills. Collection lysimeters have been installed at seven landfills in Wisconsin. The lysimeter design and performance data for the Marathon County and Nekoosa Papers Combined Treatment Landfills is summarized. Available data demonstrate the effectiveness of collection lysimeters in monitoring landfill performance.

Collection lysimeters have the advantage of providing a method of monitoring the quantity as well as the quality of leakage from a landfill. In addition, sampling is easier than with pressure - vacuum lysimeters. The major disadvantages are cost of installation and inability to nest collection lysimeters. Recommendations are made for design and construction of collection lysimeters, including lysimeter location, number and size of lysimeters, sample storage, construction materials, construction techniques, and sampling. Although there is insufficient data to fully evaluate their use, the collection lysimeter holds promise as part of a total monitoring program in providing an early indication of landfill performance.

1 Environmental Engineer and Hydrogeologist, Bureau of Solid Waste Management, Wisconsin Department of Natural Resources, Madison, WI.

Presented at the National Water Well Association Conference on the Characterization and Monitoring of the Vadose (Unsaturated) Zone Las Vegas, Nevada. December 8 - 10, 1983.

In this case, as at the Nekoosa Papers Landfill, the collection lysimeters appear to be functioning well as a monitoring tool in assessing landfill performance. At the Marathon County site, the lysimeters indicate no significant leakage through the clay liner to date and this correlates well with the results from the monitoring wells.

Collection Lysimeters - Advantages and Disadvantages

Both pressure-vacuum lysimeters and collection lysimeters can be used to monitor the unsaturated zone beneath a landfill and provide an early indication of landfill performance. Each has its own advantages and disadvantages.

The major advantage of a collection lysimeter is that it provides a method of monitoring the quantity as well as the quality of leakage from the base of a landfill. If one assumes that the leakage reaching the lysimeter is representative of leakage over the entire base of the site, it is possible to calculate the volume of leakage from the entire landfill and thus assess the effectiveness of the liner in attenuating the leachate and in limiting the rate of leachate movement.

Also, collection lysimeters do not require the special equipment or the care that is necessary to properly sample pressure-vacuum lysimeters. Samples can be taken from a manhole or riser using a bailer rather than a vacuum pump. In addition, collection lysimeters do not require that a vacuum be placed on the system at least several days prior to sampling, as is the case with pressure-vacuum lysimeters. When the monitoring results from a landfill indicate that one or more pressure-vacuum lysimeters are dry, one is never sure whether there was insufficient soil moisture or whether improper sampling techniques were used. With collection lysimeters, one is reasonably certain that if liquid is present in the subsurface, it will be collected. Collection lysimeters also eliminate the problem of frozen lines in cold weather which can occur with pressure-vacuum lysimeters.

Research (Apgar and Langmuir, 1971; Johnson and Cartwright, 1980; and others), has suggested that some chemical constituents may be filtered out by the porous membrane of the pressure-vacuum lysimeter, thereby producing inaccurate water quality data. This is not a concern with collection lysimeters since there is no membrane present.

The major disadvantage of a collection lysimeter in comparison with a pressure-vacuum lysimeter is the lower cost and shorter time required for pressure-vacuum lysimeter installation. Whereas a pressure-vacuum lysimeter is installed in bored hole, construction of a collection lysimeter necessitates excavation of sufficient area to appropriate grade to install the basin, collection pipe, and manhole. A substantial number of pressure-vacuum lysimeters could be installed in the time and for the cost of one collection lysimeter construction. A pressure-vacuum lysimeter can be installed for less than $100 plus drilling costs. Although data is limited, the cost of collection lysimeter installation, including excavation, materials, and construction costs, is expected to be several thousand dollars and can approach $10,000 for the larger lysimeters.

Another disadvantage is that only one collection lysimeter can be installed at a given location. Therefore, data is generated for only one depth in the unsaturated zone, typically just below the clay liner. In contrast, pressure-vacuum lysimeters are frequently installed in a nest at different depths to monitor changes in water quality with depth.

Recommendations

After a close examination of the collection lysimeter designs of the various sites in Wisconsin, the following design recommendations are made:

1. Location: The collection lysimeter should be located well above the water table. A minimum separation distance of 10 feet is recommended to avoid the possibility that a rise in the water table could interfere with lysimeter construction or result in groundwater infiltration into the lysimeter leading to erroneous monitoring results.

   The basin should be placed directly below and parallel to the liner. A one to two foot separation distance between the upper edge of the lysimeter and the clay liner is recommended so that the lysimeter will not be damaged during liner construction.

   The leachate head, liner thickness and consequently the amount of leakage will vary throughout the base of a landfill. Thus, a collection lysimeter cannot give a precise measurement of the total amount of leakage that will occur. There are two approaches to siting a collection lysimeter. If worst case monitoring is desired, the lysimeter should be located in an area where leachate is likely to flow to and build up such as at the low end of the site. If a more representative monitoring of total site leakage is desired, then the lysimeter or a series of lysimeters should be located so that a representative sample or samples of the whole site are obtained.

   The basin and sampling riser/manhole should be located so that its installation and subsequent monitoring will not interfere with the construction and operation of the site and so that the sampling riser/manhole will not have to be constructed to great depth.

2. Number of basins: Where possible, more than one collection lysimeter should be installed in different phases to provide a comparison of the performance of the different phases. Installation of multiple lysimeters also allows monitoring of the landfill performance even if one of the lysimeters fails. It is recommended that at least one collection lysimeter be installed beneath the first phase of filling to provide an early indication of the effectiveness of the clay liner.

3. Size: The collection lysimeter should be sufficiently sized to ensure collection of an adequate amount of sample to do the necessary analytical work yet not so large as to create a maintenance problem by needing frequent pumping of the collected liquid. The collection lysimeters installed to date range in size from 25 to 7,400 square feet;

with the exception of Nekoosa, most collection lysimeters have been at least 1,000 square feet in size (see Table III). However, insufficient data exists on the performance of the lysimeters at these sites to determine the appropriate size. Until such data is available, it is recommended that collection lysimeters continue to be sized conservatively large. For clay lined sites it would appear a lysimeter size of 1,000 ft^2 to 5,000 ft^2 in area should be adequate.

TABLE III - Summary of Information on Collection Lysimeters Installed at Landfills in Wisconsin

Landfill (License No.)	Date Installed	Liner Material	Liner Thickness	Lysimeter Size
Nekoosa Papers (#2613)	1976 1980	PVC PVC	40 mil *	100 $ft.^2$ 25 ft^2
Marathon Co. (#2892)	1980	PVC	20 mil	760-1000 ft^2
Portage Co. (#2966)	1982	PVC	30 mil	7400 ft^2
Sauk Co. (#2978)	1982	PVC	30 mil	900 ft^2
Rhinelander Papers (#2965)	1982	PVC	20 mil	3300 ft^2
Green Co. (#2990)	1983	CSPE	36 mil	5600 ft^2
Barrett (#1940)	1983	PE	30 mil	1000 ft^2

* SDR 35 pipe, minimum thickness .437 inches

4. Sample storage: Due to the uncertainty in the amount of liquid expected to be collected, sample storage facilities should be sized to allow considerable flexibility in storage capacity. If possible, for safety and convenience, samples should be retrievable without requiring a person to climb into a manhole to obtain the sample. The use of a narrow diameter sampling riser as the primary method of sample retrieval plus a manhole for overflow storage and transfer line access appears to be a workable yet simple approach to meeting these requirements. Figure 2 is an example of how such a system could be designed.

5. Materials: There are a wide variety of materials that can be used to construct a collection lysimeter. In selecting materials, durability is a prime concern since the lysimeter cannot be replaced once it is installed.

   a. The basin itself should be lined with a material that is less permeable than the overlying clay liner and is chemically compatible with the underlying soils and the expected liquid. In Wisconsin, reinforced polyethelene (PE) and chlorosulfonated polyethelene (CSPE)

were each used as liner material at one site. At the other five sites, the collection basins were constructed of PVC (see Table III). Although chemical compatibility of the lysimeter liner with the site leachate is a major consideration in material selection, it is not felt that compatibility testing is warranted at this time because the lysimeter will be collecting a liquid of likely lesser strength than raw leachate since it will have passed through the clay liner. However, if there is any doubt as to the ability of the liner material to contain the collected liquid, then compatibility testing should be done or another type of liner material selected.

As shown in Table III, liner thickness has varied considerably but is generally about 30 mils. If flexible membranes are used, a minimum 30 mil thickness is recommended.

b. The transfer pipe should have a perforated section extending a substantial length of the lysimeter to provide good hydraulic connection and minimize the possibility of clogging. The transfer pipe should be constructed of schedule 80 pipe to protect against possible crushing since bedding of the pipe will be difficult. A minimum diameter of 6 inches is recommended to allow for clean out should the need arise.

6. Construction: Careful construction of a collection lysimeter is a must. Uncontaminated materials should be used in construction to insure collected liquid quality is not influenced. If a flexible membrane is used then standard construction procedures should be used to insure proper installation. The subgrade beneath the liner should be carefully inspected to remove all roots, stones or other sharp objects. In some cases, over excavation and replacement with select soils may be necessary to provide the proper bedding. As with any flexible membrane, seaming is particularly important. Where possible, the number of field seams should be kept to a minimum. This can be done by using a single factory prefabricated sheet wherever possible. A specially fabricated boot should be used to insure a leak proof connection is made between the liner and the transfer pipe. Also, the use of a similar material for the liner and transfer pipe is recommended to facilitate bonding between the two.

The basin should be backfilled with a clean (less than 5% P200), highly permeable granular material to insure it will be free draining. This material should be sized appropriately to insure the membrane will not be punctured and that the drain pipe will have adequate support. The potential for piping of backfill material into the transfer pipe should also be considered when sizing the backfill. This is particularly important because, should significant piping occur, it could undermine the liner and affect its integrity. Given these concerns with the backfill it may be necessary to use specially graded backfill materials and/or geotextiles to meet all of these requirements. It is also of utmost importance that the soils utilized are uncontaminated so that the

quality of collected liquid will not be adversely affected. On-site soils may be acceptable since these lysimeters are typically specified at sites with permeable soils. These soils may also provide for a more accurate flow measurement since soils of a similar texture would be located within and external to the lysimeter. However, if on-site soils contain considerable fines their use may not be desirable as they may restrict drainage.

Once installed, the lysimeter should be tested by spraying with clean water and drained to insure it works. This will also help consolidate the backfilled soils above the lysimeter. The initial layers of clay compacted over the lysimeter should be carefully placed so not to damage it or the transfer pipe.

7. As-built documentation: The exact location and elevation of the collection lysimeter, transfer pipe and sampling manhole as installed in the field should be recorded on the engineering plans. All materials utilized in construction and construction procedures used should be carefully documented. Photographs of collection basin construction are highly recommended.

8. Sample retrieval: The quantity and quality of liquid collected by the basin should be determined on a routine basis. A monthly schedule is preferred while the site is actively operating.

It is also important to note that the collection lysimeter should be considered as only one part of the monitoring system for a landfill. A complete monitoring program would also include wells to monitor groundwater quality and leachate wells to monitor leachate head levels and leachate quality within the landfill. Records should also be kept of the quantity and quality of leachate removed from the collection system. A combination of pressure-vacuum lysimeters and collection lysimeters or other monitoring devices could be used to provide more complete monitoring of the unsaturated zone.

Summary

Monitoring of the unsaturated zone beneath landfills is desirable to provide an early indication of site performance. The pressure-vacuum lysimeter is one device for vadose zone monitoring but has met with limited success in Wisconsin. As a result, the use of collection lysimeters (or collection

basins) has evolved as an alternative technique for monitoring the unsaturated zone beneath clay lined sites. Collection lysimeters have been installed at seven landfills in Wisconsin to date. Based on a review of the design and performance data for two of these sites, some design recommendations have been provided. Collection lysimeters have the advantage of increased reliability and offer the ability to monitor the quantity as well as the quality of leakage from a landfill. The major disadvantages are cost and inability to nest collection lysimeters.

It should be noted that collection lysimeters are still in the developmental stage and that further refinements in their design will likely occur as a broader experience with their installation and use is gained. In the interim, the recommendations provided in this paper can be used as general guidance for designing these lysimeters but should not be considered the final word in their design.

Although there is insufficient data to fully evaluate their use, the collection lysimeter holds promise as part of a total monitoring program in providing an early indication of landfill performance.

State of Wisconsin DEPARTMENT OF NATURAL RESOURCES
Carroll D. Besadny
Secretary
BOX 7921
MADISON, WISCONSIN 53707

January 19, 1984

File Ref: 3200-1

Mr. David M. Nielsen
Symposium Coordinator
National Water Well Association
500 West Wilson Bridge Road
Worthington, OH 43085

Dear Mr. Nielsen:

Here, as requested, are responses to the questions for the paper I presented in Las Vegas.

Q. Does the Wisconsin DNR routinely require the use of collection lysimeters or other vadose zone monitoring devices beneath landfills? (Mr. Evans)

A. Vadose zone monitoring for new landfills is a site specific decision. In general, vadose zone monitoring is required when liners are utilized (to check for liner leakage) or at unlined "natural attenuation" sites where there is a substantial separation distance to groundwater. To date, 15 landfills have been required to install pressure-vacuum lysimeters and 7 landfills to install collection lysimeters.

Q. What problems have been experienced with the use of suction lysimeters at Wisconsin landfills? To what are these problems attributed? (Mr. Seigrist and Mr. Welby)

A. The main problem experienced with suction lysimeters has been the inability to obtain samples consistently. Because experience in the literature has shown these devices to work effectively this problem is probably not due to a failure of the technology. Rather, it is probably attributable to improper installation and/or sampling techniques.

Q. The recommended method for draining the collection lysimeter by penetrating the membrane appears to be inviting leakage at this point. Wouldn't it be better to create a sump and riser at the low end of the device to pump it out? (Mr. Newell)

A. The use of a properly sealed, prefabricated boot at the membrane-transfer pipe connection should minimize leakage at this point. The use of a sump and riser may be a viable alternative provided the riser does not have to penetrate the landfill liner. To do this would require the use of an angular riser making sample retrieval more difficult.

49. Kuhns v. Santa Cruz County Board of Supervisors. 181 Cal. Rptr., 128 Cal. App. 3d 369

128 Cal.App.3d 369

Earl Stanley KUHNS, Plaintiff, Appellant and Respondent,

v.

SANTA CRUZ COUNTY BOARD OF SUPERVISORS, Defendant, Respondent, and Appellant.

Civ. 26397.

Court of Appeal, Fourth District, Division 1.

Feb. 1, 1982.

As Modified on Denial of Rehearing Feb. 24, 1982.

Applicant for a planned development permit to operate general bookstore appealed judgment of Superior Court, Santa Cruz County, John J. Hauck, Assigned Judge, attaching conditions to writ of mandate, and Board of Supervisors cross-appealed. The Court of Appeal, Gerald Brown, P. J., held that: (1) neither applicant's conviction for distributing obscene materials nor fact that he had been involved in three civil suits to compel county to permit him to operate an adult bookstore at the same location worked a forfeiture of First Amendment rights; (2) phrase "distinguished or characterized by an emphasis on matter depicting [certain sexual acts or anatomical areas]" was subject to a narrowing interpretation; (3) phrase "substantial or significant portion of its stock in trade" meant over one half of the stock and trial court's choice of 20 percent figure was invalid; (4) applicant, who operated two other adult bookstores under name "Frenchy's," could not be barred from using the same name for store at issue; and (5) no legitimate purpose was served by requiring submission of sales receipts of regular and "adult" sales.

Modified and affirmed.

1. Constitutional Law ⇐90(1, 3)

Bookstores are entitled to First Amendment protection but are not exempt from reasonable regulation. U.S.C.A.Const. Amend. 1.

2. Constitutional Law ⇐48(8), 82(1)

Denial of a permit to engage in a constitutionally protected activity is a total prior restraint and as such comes to a court bearing a heavy presumption against its constitutional validity. U.S.C.A.Const. Amend. 1.

3. Constitutional Law ⇐82(3)

Refusal to issue a permit to conduct a First Amendment related business on the basis of prior misconduct on part of the applicant can only be sustained if there is a clear and present danger that serious substantive evil would result from granting the license. U.S.C.A.Const.Amend. 1.

4. Constitutional Law ⇐90.1(4)

Applicant's conviction for distributing obscene material was not a proper basis for denying a permit to operate a general bookstore and, also, fact that applicant had been involved in three civil proceedings to compel county to permit it to operate an adult bookstore at the same location did not work a forfeiture of First Amendment rights and denial of permit on basis of the conviction and civil suits was unconstitutional prior restraint of free speech. U.S.C.A.Const. Amend. 1.

5. Constitutional Law ⇐90.1(8)

Provision of zoning ordinance that less than a substantial or significant portion of an adult bookstore's stock in trade consist of books, magazines or other publications or devices distinguished or characterized by their emphasis on their matter depicting, describing or relating to specified sexual activities or specified anatomical areas is not a prior restraint on free speech based on content. U.S.C.A.Const.Amend. 1.

6. Obscenity ⇐2.5

Phrase "distinguished or characterized by an emphasis on matter depicting [certain sexual acts or anatomical areas]" in county zoning ordinance was not qualitatively vague in view of the narrow interpretation of such phrase as adopted in *Pringle*. U.S.C.A.Const.Amend. 1.

7. Zoning and Planning ⇐382.1

Condition of planned development permit to operate general bookstore that operator stock not more than 20 percent adult items could only be justified if it furthered legitimate governmental interest for which the ordinance was enacted. U.S.C.A.Const. Amend. 1.

8. Zoning and Planning ⇐76

Where zoning ordinance precluded a significant or substantial portion of general bookstore's trade items as adult items the trial court's choice of a 20 percent figure was admittedly arbitrary, was an invasion of legislative body's province and was invalid and although phrase "substantial or significant portion" lacked clarity, if over half of the stock was "adult" such portion was both "substantial" and "significant" and it was for the legislature to quantify the phrase if it intended to allow a lesser portion.

See publication Words and Phrases for other judicial constructions and definitions.

9. Municipal Corporations ⇐111(1)

An ordinance will not be held void for uncertainty if any reasonable or practicable construction can be given as language.

10. Zoning and Planning ⇐278

Where no more than a "substantial or significant portion" of books, etc. sold in bookstore could be "adult" items, substantiality was most reasonably measured in terms of titles on display for sale with nonidentical materials with the same "title" considered separate.

See publication Words and Phrases for other judicial constructions and definitions.

11. Constitutional Law ⇐90.1(1)

An on-premise business sign is protected both as a property right and as a limited First Amendment free speech right. U.S.C.A.Const.Amend. 1.

12. Zoning and Planning ⇐81

Size, location and other physical attributes of on-premises business signs may be regulated in the interest of public safety and aesthetics, although there is no authority which allows prohibition of a nonoffensive name simply because the name may attract undesirable clientele.

13. Zoning and Planning ⇐382

Although applicant for a permit to operate general bookstore under name "Frenchy's" owned two adult bookstores in the same area under the same name, conditioning permit on use of sign which did not include name "Frenchy's" was inconsistent with applicant's rights. U.S.C.A.Const. Amend. 1.

14. Theaters and Shows ⇐2

Use of police power to limit location of adult movie and mini theaters to protect character of neighborhoods is constitutional, but prohibiting use of motion picture machines goes beyond police power purposes because it precludes the presentation of nonadult motion pictures. U.S.C.A.Const. Amend. 1.

15. Theaters and Shows ⇐2

Prohibiting all motion picture machines at general bookstore was overbroad and was to be limited to prohibiting presentation of adult motion pictures to the extent required by zoning ordinance. U.S.C.A. Const.Amend. 1.

16. Zoning and Planning ⇐382

Although general bookstore was limited in quantity of adult materials it could offer for sale, it was unreasonable and unnecessary to require sales receipts to conform to a strict percentage requirement and conditioning permit on submission of sales receipts of regular and "adult" items was void as not in furtherance of police power purpose. U.S.C.A.Const.Amend. 1.

Joseph Rhine, Hollywood, for plaintiff, appellant and respondent.

Clair A. Carlson, County Counsel, and James M. Ritchey, Asst. County Counsel, Santa Cruz, for defendant, respondent and appellant.

GERALD BROWN, Presiding Justice.

Earl Stanley Kuhns, plaintiff, appeals conditions attached to a writ of mandate ordering the Santa Cruz Board of Supervisors, defendant, to issue him a planned development permit to operate a general bookstore. The Board of Supervisors cross-appeals claiming the court erred in granting the writ.

Kuhns is the owner of property in Santa Cruz. He applied for a planned development permit to operate "Frenchy's" an adult bookstore. His application was rejected because such a store would violate a Santa Cruz County zoning ordinance.[1] A year later Kuhns reapplied for a permit, this time to operate a general bookstore with the same name at the same location. This application was also rejected. Kuhns refiled his general bookstore application, insisting he did not intend to operate an "adult" bookstore. The Santa Cruz Zoning Administrator approved the permit subject to certain conditions:

(1) A new sign should be built which does not include the name "Frenchy's";

(2) The property should be used as a bookstore and not as an "adult" bookstore;

(3) The store must comply with the zoning ordinance by not including "as a substantial or significant portion of its stock in trade" books, magazines or other publications or devices which are "distinguished or characterized by their emphasis on matter depicting, describing, or relating to specified sexual activities or specified anatomical areas";

(4) No motion pictures shall be permitted;

(5) Sales records are to be kept in two categories of regular and "adult" sales and are to be submitted for review on a bimonthly basis.

The Santa Cruz County Board of Supervisors then requested a public hearing to reconsider Kuhns' application. The Board considered Kuhns' background: he owned two other adult bookstores in the area (also named "Frenchy's"); he was convicted of distributing obscene materials in Santa Cruz County; he has been involved in three civil proceedings seeking to compel the County to permit him to operate an adult bookstore at the same location; and he operated an adult bookstore at this location without the required permits until enjoined from so doing.

The Board concluded it was unlikely Kuhns would comply with the law and refrain from operating an adult bookstore if granted the permit. It further concluded operation of any type of bookstore by Kuhns would generate law enforcement problems requiring substantial costs in time and money to monitor and enforce compliance with the permit conditions.

The superior court granted Kuhns a peremptory writ of mandate setting aside the Board of Supervisors' decision and ordering the Board to issue a permit subject to the conditions imposed by the zoning administrator. The court found the Board's denial of the permit to be a prior restraint of free speech and thus an abuse of discretion. The court later clarified the phrase "substantial or significant portion of ... stock in trade" to mean not more than 20 percent of the store's stock in trade for sale to the public.

The Board of Supervisors claims the court erred in granting the writ because the denial of the permit was properly based on Kuhns' past behavior.

[1-3] Although bookstores are not exempt from reasonable regulation, they are entitled to First Amendment protection (*Smith v. California*, 361 U.S. 147, 150, 80 S.Ct. 215, 217, 4 L.Ed.2d 205). The denial

1. The property is located in a Commercial-2 Planned Development Zone. The County Code allows unrestricted operation of adult bookstores in Commercial-1 Districts. However, in Commercial-2 Districts the code requires such establishments to be dispersed. Specifically, an adult establishment may not be located within 1,000 feet of another adult establishment, within 500 feet of a school or public playground, or within 400 feet of a residential area.

of a permit to engage in a constitutionally protected activity is a total prior restraint, and as such comes to a court bearing a heavy presumption against its constitutional validity (*EWAP, Inc. v. City of Los Angeles*, 97 Cal.App.3d 179, 185, 158 Cal.Rptr. 579). A refusal to issue a permit to conduct a First Amendment related business based on the applicant's prior misconduct can only be sustained if there is a clear and present danger that serious substantive evil would result from granting the license (*Id.* at p. 185, 158 Cal.Rptr. 579). *Perrine v. Municipal Court*, 5 Cal.3d 656, 97 Cal.Rptr. 320, 488 P.2d 648, held an applicant's prior criminal conviction for selling and distributing obscene material does not indicate such a danger, and the denial of a permit to operate a bookstore based on such a conviction is unconstitutional (*id.* at p. 665, 97 Cal.Rptr. 320, 488 P.2d 648).

[4] Accordingly, Kuhns' past conviction for distributing obscene materials is not a proper basis for denying a permit. Moreover, it is absurd to find Kuhns has forfeited his First Amendment rights because he attempted to assert those same rights in three civil suits. Hence, the Board's denial of Kuhns' permit was an unconstitutional prior restraint of free speech and was properly set aside by the writ of mandate.

Kuhns appeals the constitutionality of the ordinance and the conditions attached to his permit. He contends: (1) the zoning ordinance is unconstitutional because it is a prior restraint of free speech and is vague; (2) the condition prohibiting the use of the name "Frenchy's" on the store's sign violates his right to free commercial speech; (3) the condition prohibiting all motion pictures is unconstitutionally overbroad; and (4) the condition requiring the submission of sales receipts is a prior restraint of free speech.

[5] Kuhns argues the ordinance is a prior restraint on free speech based upon content. This argument was rejected in *Young v. American Mini Theatres*, 427 U.S. 50, 96 S.Ct. 2440, 49 L.Ed.2d 310, which involved an ordinance nearly identical to the Santa Cruz ordinance here (accord, *Walnut Properties, Inc. v. City Council*, 100 Cal.App.3d 1018, 161 Cal.Rptr. 411).

[6–9] Kuhns claims the phrase "distinguished or characterized by an emphasis on matter depicting [certain sexual acts or anatomical areas]" is qualitatively vague. However, we see no reason not to accept the narrowing interpretation of this phrase adopted in *Pringle v. City of Covina*, 115 Cal.App.3d 151, 171 Cal.Rptr. 251. He also argues the phrase "substantial or significant portion of its stock in trade" is quantitatively vague even in light of the court's clarification of the terms "substantial or significant portion" to mean 20 percent. Kuhns says the court's 20 percent figure is arbitrary and the ordinance is unclear as to what "stock in trade for sale to the public" refers to.

The 20 percent figure can only be justified if it furthers the legitimate governmental interest for which the ordinance was enacted (*United States v. O'Brien*, 391 U.S. 367, 377, 88 S.Ct. 1673, 1679, 20 L.Ed.2d 672; *Young v. American Mini Theatres, supra*, 427 U.S. 50, 79–80, 96 S.Ct. 2440, 2456–2457, 49 L.Ed.2d 310). The ordinance must be "rationally tailored to support its asserted purpose." (*Young v. American Mini Theatres, supra*, 427 U.S. 50, 83, 96 S.Ct. 2440, 2458, 49 L.Ed.2d 310, conc. opn. of Powell, J.) The trial court's choice of 20 percent was admittedly arbitrary, was an invasion of the legislative body's province and is invalid. While an ordinance will not be held void for uncertainty if any reasonable or practical construction can be given its language (*American Civil Liberties Union v. Board of Education*, 59 Cal.2d 203, 218, 28 Cal.Rptr. 700, 379 P.2d 4), the phrase "substantial or significant portion" lacks clarity. However, if over half of a bookstore's stock is "adult," the adult portion is both substantial and significant. If the Board of Supervisors intended to allow a lesser portion it behooves them to quantify the phrase and make findings showing their figure is consonant with the governmental interest being protected. Until such time, a preponderance of the store's stock in trade must be "adult" (as defined in the ordinance) in

order for the store to be deemed an "adult book store" within the ambit of the zoning ordinance as written. (See *Pringle v. City of Covina*, 115 Cal.App.3d 151, 162, 71 Cal. Rptr. 251.)

[10] There is nothing cryptic in the phrase "stock in trade for sale to the public." No more than a "substantial or significant portion" of the books, magazines or other materials sold in the store may be adult as defined in the ordinance. This is most reasonably measured in terms of titles on display for sale (with nonidentical materials with the same "title" considered separate).

[11–13] Kuhns contends he has a constitutional right to use the name "Frenchy's" on his sign. An on-premise business sign is protected both as a property right (*Serve Yourself Gas etc. Assn. v. Brock*, 39 Cal.2d 813, 819, 249 P.2d 545) and as a limited First Amendment free speech right (*Carlin v. City of Palm Springs*, 14 Cal.App.3d 706, 713, 92 Cal.Rptr. 535). The size, location, and other physical attributes of signs may be regulated in the interest of public safety and aesthetics (*id.* at p. 712, 92 Cal.Rptr. 535). However, there is no authority which allows the prohibition of a nonoffensive name such as "Frenchy's" simply because the name may attract undesirable clientele. Such a condition is inconsistent with Kuhns' rights and cannot be imposed.

[14, 15] Kuhns argues the prohibition of all motion picture machines at the bookstore is unconstitutionally overbroad. The use of the police power to limit the location of adult movie and mini theaters for the purpose of protecting the character of neighborhoods is constitutional (*Young v. American Mini Theatres, supra*, 427 U.S. 50, 71–72, 96 S.Ct. 2440, 2452–2453, 49 L.Ed.2d 310). However, prohibiting the use of motion picture machines goes beyond the police power purpose (see *Welton v. City of Los Angeles*, 18 Cal.3d 497, 504, 134 Cal. Rptr. 668, 556 P.2d 1119) because it precludes the presentation of nonadult motion pictures. As such the condition is overbroad. The condition should instead prohibit presentation of adult motion pictures to the extent required by the ordinance.

[16] Kuhns contends the condition requiring the submission of sales receipts is unconstitutional. No legitimate purpose is served by requiring the submission of such records. The store is limited in the quantity of adult materials it may offer for sale to the public. It is unreasonable and unnecessary to require the sales receipts also conform to a strict percentage requirement. The condition is void as it is not in the furtherance of the police power purpose.

The integrity of the judicial process relates to the trial court's ability to enforce its orders. A practical method to assure compliance with the ordinance as interpreted is essential. This control should be exercised without impinging on Kuhns' First Amendment rights and without unduly interfering with his business interests. The manner of control remains an appropriate area of inquiry and solution for the trial court upon presentation of relevant evidence.

A permit for operating a general bookstore should be issued in accordance with this opinion.

The superior court shall modify the judgment to harmonize with this opinion. As modified, the judgment is affirmed.

WIENER and MILKES,* JJ., concur.

WEST KEYNUMBER SYSTEM

* Assigned by the Chairperson of the Judicial Council.

50. Letey, J. and W. Farmer. "Movement of Pesticides in Soil", Soil Science Society of America, reprinted from Pesticides in Soil and Water, 1974, pp. 67-97

Eagle

2645

Reprinted from: *Pesticides in Soil and Water*
Copyright © 1974, Soil Science Society of America, Inc.
677 South Segoe Road, Madison, Wis. 53711 U.S.A.

Movement of Pesticides in Soil

4

J. LETEY and W. J. FARMER

University of California, Riverside, Calif.

I. INTRODUCTION

Knowledge on the distribution of a pesticide in soil is often desirable for predicting the probable effectiveness of the pesticide or possible negative effects such as water or air pollution. Movement of a pesticide through soil can occur by two processes—diffusion and mass flow. Diffusion is the process by which matter is transported as a result of random molecular motion caused by the molecule's thermal energy. The random molecular motions gradually cause the molecules to become uniformly distributed in the system. There is therefore net movement from positions of higher concentration to positions of lower concentration. Mass flow occurs as a result of external forces. The pesticide will be considered to be either dissolved or suspended in water, present in the vapor phase, or adsorbed on solid mineral or organic components of the soil. Mass flow of the pesticide therefore will result from the mass flow of water and/or soil particles with which the pesticide molecule is associated. Mass flow due to air movement in soil will be considered negligible. Total rate of movement is the summation of diffusion and mass flow.

Pesticide movement by diffusion will be discussed first, followed by a discussion on mass flow. Each subject will be considered in the sequence of theoretical considerations, published results, and conclusions. For convenience, a list of symbols used and their definitions is included as Appendix A. The chemical names of all pesticides cited in this chapter are listed in Appendix B.

The reader is referred to Hamaker (1972) for another treatment of diffusion of organic chemicals in the soil system.

II. DIFFUSION

A. Theoretical Considerations

The mathematical theory of diffusion in an isotropic system is based on the hypothesis that the rate of transfer of a diffusing substance through unit area of a section is proportional to the concentration gradient measured normal to that section. The coefficient of proportionality is commonly referred to as the diffusion coefficient. The equation of steady-state linear diffusion (known as Fick's first law) is

$$q = -D\partial C/\partial x \qquad [1]$$

where q is the quantity of transfer per unit cross sectional area per unit time, D is the diffusion coefficient, C is concentration, and x the space coordinate measured normal to the section. The general equation describing nonsteady-state diffusion is obtained by combining Fick's first law with the continuity equation. For a "simple" system such as diffusion through water, the result is

$$\partial C/\partial t = D\ \partial^2 C/\partial x^2 \qquad [2]$$

which is commonly referred to as Fick's second law of diffusion.

In principle, diffusion is analyzed by solving Eq. [2] for the appropriate boundary conditions of the system in question. Several books (Carslaw & Jaeger, 1947; Crank, 1956; Jost, 1965) treat the mathematics of diffusion for a number of coordinate and boundary conditions. Most of the solutions presented are based on the independence of the diffusion coefficient relative to concentration—a factor which must be experimentally established before their equations can be used with confidence.

The soil system provides several complexities to diffusion analysis. Some of these are: (i) the diffusion coefficient cannot be assumed to be independent of concentration, (ii) diffusion is confined to certain segments of the system, i.e. a molecule will not diffuse through a solid soil particle, (iii) sorption of the diffusing substance by soil particles often occurs, and (iv) the diffusion coefficient is dependent upon a number of soil properties such as mineral composition, organic matter content, bulk density, water content, and temperature. Diffusion of organic pesticides through a soil system may have an additional complexity of being partially volatile so that diffusion can occur both in the vapor and the "nonvapor" phases.

Two general approaches to diffusion analysis through soil systems have been followed by soil scientists. One approach is merely to measure a diffusion coefficient for a variety of soil-water parameters. Diffusion coefficients measured in this manner are usually referred to as "apparent diffusion coefficients." This approach is reasonable and quite useful but has the limitation that the measured diffusion coefficient is only applicable to systems identical to the one measured. The second approach to diffusion analysis in the soil system has been to incorporate soil variables such as bulk density and water content into the equations so that the diffusion coefficient measured can be extrapolated to other soil conditions.

Shearer et al. (1973) followed the second approach and presented a detailed mathematical development for pesticide diffusion through soils. They assumed that the pesticide was volatile so that diffusion occurs both in the vapor and "nonvapor" phases. Diffusion in the "nonvapor" phase was further assumed to occur in solution and at the solution-solid and solution-air interfaces. Their resultant general diffusion equation is

$$\partial c/\partial t = D_{vs}\partial^2 c/\partial x^2 \qquad [3]$$

where

$$D_{vs} = [D_v P^{7/3}/P_T^2(R+1)] + [R/(1+R)]\,[(D_S + D_A K'\beta + \beta D_I R')/(\beta K' + \theta + \beta R')]. \quad [4]$$

In these equations

c = total concentration of pesticide in soil (g g^{-1} of soil);
D_v = pesticide vapor diffusion coefficient in air ($cm^2 sec^{-1}$);
P and P_T = air-filled and total porosity of the soil ($cm^3 cm^{-3}$), respectively;
R = equilibrium coefficient of proportionality between vapor density and c;
D_S = apparent solution phase diffusion coefficient ($cm^2 sec^{-1}$);
D_A = apparent diffusion coefficient of molecules adsorbed at the solution-solid interface ($cm^2 sec^{-1}$);
K' = coefficient of proportionality between solution concentration and concentration adsorbed at the solution-solid interface (cm^3 water g^{-1} soil);
β = soil bulk density (g cm^{-3});
D_I = apparent diffusion coefficient of molecules adsorbed at the solution-air interface ($cm^2 sec^{-1}$);
R' = coefficient of proportionality between solution concentration at the air-solution interface (cm^3 water g^{-1} soil); and
θ = volumetric water content ($cm^3 cm^{-3}$).

As shown by Shearer et al. (1973), the relationship between D_S and the free solution diffusion coefficient D_O can be approximated by

$$D_S = (\theta/P_T)^2 \theta^{4/3} D_O. \quad [5]$$

Thus far no theoretical analysis has been made to further describe D_A and D_I.

Note that c has units of g g^{-1} of soil as used in this treatment. The magnitude of diffusion is influenced by a number of soil and pesticide characteristics. Some of these properties can be measured whereas others cannot. Although quantitative predictions on diffusion of a given pesticide through a given soil system may not always be possible from the theory presently available, the relationships developed do help in making qualitative assessments of diffusion.

Equations [3] and [4] were developed in terms of "nonvapor" concentrations. These equations would be useful for pesticides with moderate to low vapor pressure which are not applied as fumigants. Diffusion of fumigants is better described in terms of vapor density, ρ, because it is the measured variable. In Shearer et al. (1973) development of equations, ρ was eliminated. Following identical procedures, c could be eliminated and ρ retained in the equations. When this is done, identical equations are achieved except where c now appears in the equation, ρ would appear. For example Eq. [3] would be written

$$\partial\rho/\partial t = D_{vs}\partial^2 \rho/\partial x^2. \quad [6]$$

These general diffusion equations must then be solved for specific boundary and initial conditions of a given problem.

B. Published Results

As noted in Eq. [3] and [4], the factors influencing diffusion in soils are diffusion coefficient, adsorption, bulk density, porosity, and soil water content. Soil water content can in certain situations serve as a factor controlling adsorption. The diffusion of inorganic ions and molecules has been extensively studied and there are reviews available on the subject (Olsen & Kemper, 1968; Gardner, 1965). However, information regarding the influence of soil properties on the diffusion of organic pesticides in soils is still sparse. Goring (1962) presented a development on the theory of fumigation processes in soils. Hartley (1960, 1964) discussed the diffusion of herbicides in soils. This review will consider the influence of various soil and environmental factors on the diffusion of pesticides in soils.

1. SOIL WATER CONTENT

Several researchers have measured diffusion of pesticides through soil at various soil water contents (pesticides applied primarily as soil fumigants will not be considered in this section of the chapter, but will be discussed later).

Shearer et al. (1973) made a detailed investigation of the diffusion of lindane through Gila silt loam soil. They measured the vapor and "nonvapor" diffusion components as a function of soil water content. Furthermore, they estimated the amount of diffusion occurring at the water-solid interface, water-air interface and through solution. The results of their study are presented in Figure 1. Essentially no diffusion occurred in dry soil but increased rapidly with increasing water content reaching a maximum at approximately 4% water content. Increasing soil water content above 4% caused a decline in total diffusion until 30% water content when an increase in diffusion occurred with increasing water. Vapor diffusion decreased slightly as water content increased from 4 to 20% and then decreased rapidly at water contents above 20%.

The "nonvapor" diffusion was maximum at about 4% water and decreased with increasing water content to about 16% water after which the diffusion increased again with increasing water content. It was estimated that diffusion at the air-water interface was highest under the lower water contents and then declined with increasing water because of decreased water-air surface area. On the other hand, diffusion in solution was very low at the low water contents and increased as water content increased. Diffusion at the water-solid interface was relatively constant over the whole water content range. As pointed out by Shearer et al. (1973) quantitative relationships between concentration in solution and concentration at the air-water interface are needed to properly evaluate the diffusion components at the two inter-

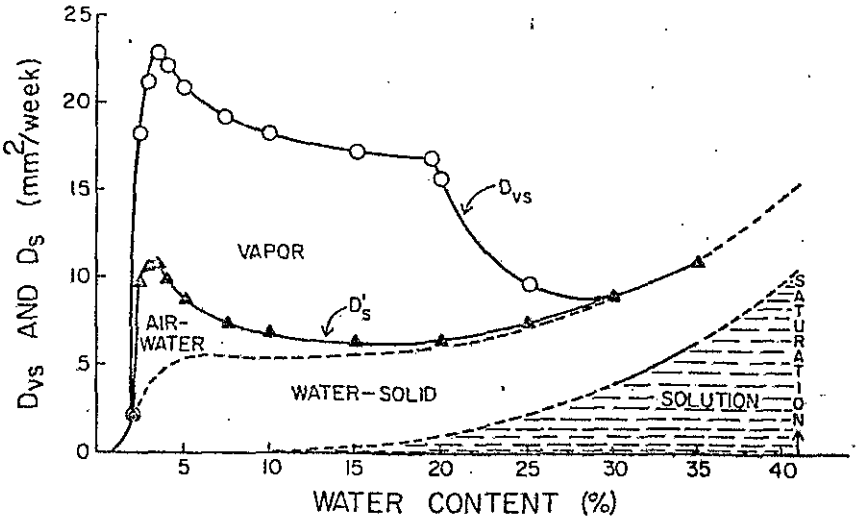


Figure 1. Contributions of various transfer paths for lindane diffusion in Gila silt loam (Reprinted from Shearer et al., 1973).

faces at the lower water contents. Since these data are not available, the calculations presented tend to overestimate the water-solid contribution to diffusion at the lower water contents.

Ehlers et al. (1969b) also measured lindane diffusion through Gila silt loam at different water contents. They also measured the highest diffusion coefficient at approximately 4% water content. The shape of their curve differs somewhat from that of Shearer et al. (1973), possibly because diffusion at concentrations of 100 ppm (Ehlers et al., 1969b) would be concentration dependent. Ehlers and his co-workers determined the ratio of diffusion occurring in the vapor and "nonvapor" phases at two water contents. They found that approximately half of the lindane diffused in the vapor phase at 10% soil water content, total diffusion was in the "nonvapor" phase at near saturation. These findings are in reasonable agreement with the findings of Shearer et al. (1973) who conducted a more detailed study on this aspect.

Graham-Bryce (1969) measured the diffusion of disulfoton and dimethoate in a Broadbalk silt loam soil as a function of soil-water content. He found a rather rapid increase in the diffusion coefficient of dimethoate as the soil water content increased. The range of values was 3.31×10^{-8} cm^2sec^{-1} at 10% volumetric water content to 1.41×10^{-6} cm^2sec^{-1} at 43% water content. On the other hand, the disulfoton diffusion coefficient remained relatively constant over the entire soil water content range used.

The results were explained on the basis that disulfoton diffused both in the vapor and nonvapor phases and that the decrease in vapor phase diffusion would be balanced by an increase in solution phase diffusion as soil water content increased. On the other hand, essentially no dimethoate vapor

Table 1. Calculation of D_O for dimethoate from data of Graham-Bryce (1969)

$D_{VS} \times 10^7$ cm² sec⁻¹	θ	$(\theta/P_T)^2\theta^{4/3}$	Calculated $D_o \times 10^7$ cm² sec⁻¹
0.34	0.104	0.00196	68.9
1.16	0.174	0.0109	49.4
2.18	0.234	0.0290	39.4
4.69	0.316	0.0793	35.8
5.64	0.328	0.0899	38.8
9.23	0.356	0.115	51.8
14.1	0.429	0.220	46.1

diffusion occurred. Furthermore, it appears that dimethoate diffuses primarily in solution with very little occurring at the interfaces (at least at the water-air interface).

Table 1 presents the results of calculations for the free solution diffusion coefficient D_O using measured diffusion coefficients of Graham-Bryce and Eq. [4], assuming that D_v, D_A, and D_I equal zero. It was further assumed that any change in the apparent diffusion coefficient with water content can be described by Eq. [5]. Based on calculations reported by Graham-Bryce (1969), K' was assumed to equal 0.29.

The calculated values of D_O are reasonably constant indicating that changes in diffusion with changes in soil water content could largely be accounted for by changes in geometry of the system. The highest calculated value of D_O occurred at the lowest soil water content. This may suggest that another component of diffusion was becoming effective at the low water content. Shearer et al. (1973) found significant air-water interface diffusion occurring at water contents below approximately 10% (Fig. 1). Thus the possibility of this diffusion component for dimethoate at the low soil water contents cannot be completely ruled out. Nevertheless over most of the soil water content range, it appears that dimethoate can be well described by solution diffusion.

For comparison, the molecular weight of dimethoate is 229 whereas the molecular weights of glucose and sucrose are 180 and 342, respectively. The diffusion coefficient of dimethoate is expected to be intermediate between the diffusion coefficients of glucose and sucrose. Solution diffusion coefficients for glucose and sucrose reported in the *Handbook of Chemistry and Physics* (1973) are 67.3 and 52.1 X 10^{-7} cm²sec⁻¹, respectively. Thus, the calculated diffusion coefficients of dimethoate are in reasonable agreement with these compounds, being only slightly lower on the average.

Quite obviously, disulfoton diffusion was occurring in the vapor phase and possibly at the various interfaces. Graham-Bryce (1969) did make an evaluation of the solution diffusion coefficient for disulfoton at various soil water contents and presented these analyses in his Fig. 7. Further fractionation of the diffusion coefficient into the various components is not possible.

Lavy (1970) measured the diffusion coefficient of three *s*-triazines in six soils at two soil water contents. The two soil water contents were listed

as field capacity and one-half field capacity. The pooled average diffusion coefficients were reported as 0.26 and 1.83 X 10^{-8} cm^2sec^{-1} at one-half field capacity and field capacity, respectively. Detailed results for individual pesticides and soils were not reported. Furthermore, the volumetric water contents were not reported. Thus, it can only be concluded that on the average, the diffusion coefficients for atrazine, propazine, and simazine tend to increase with increased soil water content.

Diffusion of several herbicides through Lanton silty clay loam at different soil water contents was measured by Scott and Phillips (1972). Measurements were made at three (sometimes two) water contents. The diffusion coefficient for prometone, atrazine, simazine, prometryne, diphenamid, and chloropropham all increased as the soil water increased. On the other hand the measured diffusion coefficient for trifluralin was not greatly affected by soil water content. Trifluralin is considered to be the most volatile of the herbicides tested and the diffusion results are explained on the basis of vapor phase diffusion.

Free solution diffusion coefficients D_O were calculated from the data of Scott and Phillips assuming that diffusion was entirely in the solution phase. Results of these calculations are tabulated in Table 2. Note that the calculated value of D_O for prometone, simazine, and diphenamid all tend to increase as the soil water content decreases. Diffusion either at the interfaces and/or in vapor could account for the increased calculated D_O with decreasing water content. There is evidence therefore that diffusion of these three herbicides occurs in other phases in addition to the solution phase.

On the other hand, the calculated value of D_O for atrazine was the same at the two water contents. These limited data suggest that atrazine is diffusing strictly in solution. Furthermore, the calculated diffusion coefficient is comparable to those reported for similar size organic molecules.

Table 2. Calculation of D_O for several herbicides from data of Scott and Phillips (1972)

	Measured			Calculated
	$D \times 10^7$ cm^2 sec^{-1}	θ	$K'\beta+\theta$	$D_o \times 10^7$ cm^2 sec^{-1}
Prometone	1.2	0.221	3.107	143
	3.65	0.325	3.211	125
	8.9	0.494	3.267	76
Atrazine	1.1	0.325	3.640	42.6
	4.25	0.494	3.809	42.5
Simazine	0.5	0.221	3.510	67.5
	1.25	0.325	3.614	48.0
	3.8	0.494	3.783	37.7
Prometryne	0.55	0.325	4.030	23.6
	4.15	0.404	4.199	45.7
Chloropropham	0.8	0.221	17.550	540
	1.0	0.325	17.654	188
	7.15	0.494	17.823	334
Diphenamid	2.1	0.325	3.692	82.5
	2.55	0.390	3.757	55.4
	3.1	0.494	3.861	31.4

The calculated values for prometryne cannot logically be explained. In this case a higher D_O is calculated at the higher soil water content than at the lower. Measurements were made only at two water contents so the information is somewhat limited.

Chloropropham exhibited a somewhat peculiar behavior. The highest value of D_O was calculated at the lowest water content but the trend was not consistent. All of the diffusion coefficients calculated are well above reported diffusion coefficients for comparable molecules suggesting that diffusion of chloropropham through the soil occurred by a mechanism other than simple solution diffusion. This herbicide also has a relatively high vapor pressure so vapor phase diffusion could be expected.

In general the results of Scott and Phillips (1972) agree with those of Lavy (1970) in that the apparent diffusion coefficient of most herbicides tends to increase with increased soil water content.

The effect of water content on diffusion of pesticides under very dry conditions has been investigated. The strong adsorption of pesticides in relatively dry soils and its influence on diffusion has been shown for a number of organochlorine insecticides (Farmer & Jensen, 1970; Barlow & Hadaway, 1955, 1958). Farmer and Jensen (1970) showed an increase in dieldrin diffusion in three soils as the equilibrium relative humidity increased from 53 to 94%. The apparent diffusion coefficients ranged from 0.30 to 0.36 mm^2/week at 53% relative humidity and from 3.8 to 9.7 mm^2/week at 94% relative humidity. These studies were conducted at 20°C.

Barlow and Hadaway (1955, 1958a, 1958b) reported on the influence of relative humidity on the diffusion of three organochlorine insecticides into dry mud blocks of a Uganda "red" soil. Barlow and Hadaway did not present their results as diffusion coefficients. However, their results have been analyzed (C. R. Jensen, W. J. Farmer, and J. Letey. University of California, Riverside. Unpublished results.) and values were obtained for the apparent diffusion coefficient. At 25°C and as the air relative humidity increased from 10 to 90%, the apparent diffusion coefficient increased from 0.05 ± 0.06 to 13.9 ± 1.7 mm^2week^{-1} for lindane, from 0.07 ± 0.06 to 7.9 ± 0.7 mm^2week^{-1} for dieldrin, and from 0.04 ± 0.03 to 5.5 ± 0.7 mm^2week^{-1} for DDT.

2. ADSORPTION

A number of researchers have evaluated the effect of adsorption on diffusion. Lindstrom, Boersma, and Gardiner (1968) measured the diffusion of 2,4-D in a number of soils. They conducted their experiments under water-saturated conditions so that vapor phase and water-air interface movement were eliminated. The adsorption coefficient for the nine soil materials they studied ranged from 0.4 to 23.0. The measured apparent diffusion coefficient ranged from 0.06 to 4.3 $\times 10^{-6}$ cm^2sec^{-1} (approximately 70-fold difference). The range in diffusion coefficients for the nine soils after correction for adsorption was from 1.24 to 7.05 $\times 10^{-6}$ cm^2sec^{-1} (less than a six-fold difference). Thus the results of Lindstrom et al. (1968) provide evidence

that the effective diffusion coefficient is reduced by adsorption of the chemical by soil. Furthermore, the effect of adsorption can be reasonably well calculated by Eq. [4].

Walker and Crawford (1970) measured the diffusion coefficients for two triazine herbicides (propazine and prometryne) in six soils having a wide range of properties. Specifically there was an approximate 20-fold difference in the adsorption coefficients between the soil and herbicide. Measurements were made to determine the effect of adsorption on the measured diffusion coefficient. Unfortunately, bulk density and water content for the different soils were not held constant. Thus, variables other than adsorption were introduced into the results. Nevertheless, there was an obvious inverse relationship between the measured diffusion coefficient and adsorption. The diffusion coefficient for prometryne was lower than for propazine in each soil. The measured adsorption coefficient on the other hand was always higher for prometryne as compared to propazine. Thus, the results of Walker and Crawford provide further evidence for the inverse relationship between diffusion and adsorption.

The data of Scott and Phillips (1972) have been discussed previously relative to the effect of water content on diffusion. However, the chemicals they studied did not all have the same adsorption coefficient with the soil used in the study. When trifluralin, benefin, and chloropropham (herbicides which are somewhat volatile and could move in the vapor phase) were eliminated from consideration, a correlation coefficient of $r = 0.85^{**}$ was found between diffusion coefficients and adsorption.

Diffusion of atrazine, propazine, and simazine in eight different soils as measured by Lavy (1970) provided the general result that an increase in total surface area and organic matter content tended to increase the measured diffusion rate. These results appear to be in conflict with other reports because *an increase in total surface area and organic matter usually causes an increased adsorption coefficient.* Thus, on the basis of adsorption, one would expect the diffusion coefficient to decrease as surface area and organic matter content increase. This conclusion would apply under conditions of no diffusion at the interfaces. Lavy did not measure adsorption coefficients so any conclusions on the effect of adsorption on his measured diffusion coefficients are based on indirect and incomplete information. Furthermore, measurements were made in the presence of a number of soil variables which could have overriding effects. For example, the highest average diffusion coefficients were obtained for a muck. The water content in the muck was probably much higher than in the other soil samples since all soils were wetted to 80% of field moisture capacity. Since muck would be expected to retain larger quantities of water, it probably had a higher water content during the course of measurements. Increase in water content could also cause increase in diffusion coefficient.

Farmer and Jensen (1970) found the diffusion of dieldrin in relatively dry soils (approximately 1 monolayer of water) to increase from 3.8 mm^2 $week^{-1}$ in a very fine sandy loam to 9.77 $mm^2 week^{-1}$ in a clay soil. At low

water contents most of the diffusion would be occurring on the surface. Increasing surface area might be expected to cause an increase in effective diffusion coefficient when diffusion is at the interface.

Lavy (1970) did find a decrease in diffusion coefficient with decreased soil pH which could be associated with adsorption since lowering pH increases adsorption of the pesticides he was studying (Bailey & White, 1970).

3. BULK DENSITY

Note in Eq. [4] that bulk density either directly or indirectly influences the diffusion of a pesticide through soil. The indirect effect of bulk density would be to alter the porosity and interface properties. The general overall effect of increasing soil bulk density is to decrease the diffusion coefficient. This would be particularly true for compounds which have a significant amount of diffusion in the vapor phase as increasing bulk density would decrease the air-filled porosity of the soil.

Ehlers et al. (1969a) reported a decrease in the apparent diffusion coefficient of lindane from 16.5 to 7.5 mm^2week^{-1} as the bulk density of the Gila silt loam studied was increased from 1.00 to 1.55 g cm^{-2}. The water content (weight basis) was maintained at 10% so that the air-filled porosity decreased from 51.5 to 26.3% as the bulk density increased.

Farmer, Igue, and Spencer (1973) determined the influence of bulk density on diffusion and volatilization of dieldrin from soil. They found volatilization of dieldrin tended to decrease as bulk density increased. The principal effect of bulk density was that of limiting the vapor phase movement of dieldrin to the soil surface, a necessary prerequisite to volatilization.

Call (1957a) varied the bulk density of a loamy sand soil from 1.39 to 1.62 g cm^{-3} while maintaining the weight percent water content constant. The air-filled porosity decreased from 0.302 to 0.189 as the bulk density was increased. An increase in the bulk density resulted in a decrease from 4.49 $\times 10^{-4}$ to 2.67 $\times 10^{-4}$ cm^2sec^{-1} for the measured apparent diffusion coefficient of EDB.

4. TEMPERATURE

Temperature does not appear directly in any of the diffusion equations presented. Nevertheless, temperature has a very significant effect on the rate of diffusion. Several of the equation variables are temperature dependent. For example, diffusion coefficients tend to increase with increased temperature. Vapor density increases significantly as temperature increases. The general overall effect of increasing temperature is an increase in diffusion.

The influence of temperature on lindane diffusion in soil was illustrated by Ehlers et al. (1969a) who reported an exponential increase in the apparent diffusion coefficient for lindane with increasing temperature. The overall diffusion coefficient increased 10-fold as the temperature increased from 20 to 40°C. The increase in the diffusion coefficient was predicted from

theoretical considerations utilizing either the temperature effects on components of the diffusion equation or the activation energies of diffusion processes.

Lavy (1970) reported a decrease in the diffusion coefficient for the *s*-triazine herbicides (atrazine, propazine, and simazine) when the temperature in several soils was lowered from 25 to 5°C.

A decrease in the diffusion coefficient of EDB as temperature decreased was measured by Call (1957b).

5. FUMIGATION

Chemicals applied as soil fumigants have relatively high vapor pressures and one is usually concerned with the distribution of pesticide in the vapor phase. Analysis of vapor phase concentration as a function of position and time can be calculated by the same equations presented in the theory section by substituting the vapor density ρ for the nonvapor concentration c. Compared with other pesticides, fumigants are characterized by their relatively higher vapor phase concentrations. A fumigant would have a much lower adsorption coefficient R. Note from our definition of the total apparent diffusion coefficient D_{vs} that decrease of R causes the total diffusion coefficient to be shifted toward vapor phase diffusion as compared to the "nonvapor" diffusion.

Theoretically, one would expect the distribution of a fumigant to be more rapid at lower soil water contents. Under these conditions the apparent vapor phase diffusion coefficient would increase for two reasons. First, the air-filled porosity is higher and secondly, R would be lower. The latter consideration is confirmed by the data of Call (1957c) who determined that the amount of EDB in the "nonvapor" phase at equilibrium with a given vapor concentration was higher at higher water contents.

Diffusion in the "nonvapor" phase may also be dependent upon water content. However, the data of Shearer et al. (1973) indicate that the "nonvapor" phase diffusion coefficient for lindane was not greatly influenced by water content. Thus, one would expect the distribution of a fumigant to be greatly reduced at higher soil water contents.

Leistra (1972) presented a comprehensive discussion of fumigation including such factors as diffusion, decomposition, temperature effects, mortality, and practical fumigation practices. He concluded that soil water content is one of the most important factors in soil fumigation. Diffusion rate is usually high in dry soils so that low values of the concentration-time integral are obtained. In wet soils the movement is so slow that the concentration in most of the soil is continuously low. Soil temperature also affects diffusion of a fumigant by modifying the diffusion coefficients and the adsorption characteristics. However, Leistra (1972) considered temperature to be less important than soil water content. In other words, the influence on diffusion by temperature-dependent variables is not as great as changes due to soil water content.

theoretical considerations utilizing either the temperature effects on components of the diffusion equation or the activation energies of diffusion processes.

Lavy (1970) reported a decrease in the diffusion coefficient for the *s*-triazine herbicides (atrazine, propazine, and simazine) when the temperature in several soils was lowered from 25 to 5°C.

A decrease in the diffusion coefficient of EDB as temperature decreased was measured by Call (1957b).

5. FUMIGATION

Chemicals applied as soil fumigants have relatively high vapor pressures and one is usually concerned with the distribution of pesticide in the vapor phase. Analysis of vapor phase concentration as a function of position and time can be calculated by the same equations presented in the theory section by substituting the vapor density ρ for the nonvapor concentration c. Compared with other pesticides, fumigants are characterized by their relatively higher vapor phase concentrations. A fumigant would have a much lower adsorption coefficient R. Note from our definition of the total apparent diffusion coefficient D_{vs} that decrease of R causes the total diffusion coefficient to be shifted toward vapor phase diffusion as compared to the "nonvapor" diffusion.

Theoretically, one would expect the distribution of a fumigant to be more rapid at lower soil water contents. Under these conditions the apparent vapor phase diffusion coefficient would increase for two reasons. First, the air-filled porosity is higher and secondly, R would be lower. The latter consideration is confirmed by the data of Call (1957c) who determined that the amount of EDB in the "nonvapor" phase at equilibrium with a given vapor concentration was higher at higher water contents.

Diffusion in the "nonvapor" phase may also be dependent upon water content. However, the data of Shearer et al. (1973) indicate that the "nonvapor" phase diffusion coefficient for lindane was not greatly influenced by water content. Thus, one would expect the distribution of a fumigant to be greatly reduced at higher soil water contents.

Leistra (1972) presented a comprehensive discussion of fumigation including such factors as diffusion, decomposition, temperature effects, mortality, and practical fumigation practices. He concluded that soil water content is one of the most important factors in soil fumigation. Diffusion rate is usually high in dry soils so that low values of the concentration-time integral are obtained. In wet soils the movement is so slow that the concentration in most of the soil is continuously low. Soil temperature also affects diffusion of a fumigant by modifying the diffusion coefficients and the adsorption characteristics. However, Leistra (1972) considered temperature to be less important than soil water content. In other words, the influence on diffusion by temperature-dependent variables is not as great as changes due to soil water content.

Hemwall (1959, 1960) developed an equation describing vapor diffusion through soil. His development allowed for pesticide reaction with the soil, but neglected diffusion in the "nonvapor" phase. The equation was written in finite difference form and solved with the aid of a computer for a number of soil conditions.

Call (1957b) measured transient-state diffusion coefficients of EDB in a number of soils. For one soil he varied the bulk density and consequently the air-filled porosity. As expected, the measured diffusion coefficient increased as the air-filled porosity increased. His observed diffusion coefficients were quite close to those calculated using a diffusion equation he presented. Basically his diffusion equation assumed that the "nonvapor" diffusion was negligible.

McKenry examined the vapor phase movement of dichloropropene and EDB in soils in both laboratory and field situations (M. V. McKenry, 1972. The behavior of pesticides containing 1,3-dichloropropene and 1,2-dibromoethane in soils. Ph.D. Diss., Univ. of California, Riverside.). He found a large decrease in movement of these pesticides with increasing soil water content which was attributed to a decrease in continuous air space and a decrease in vapor concentration due to increased dissolution in the liquid phase. Qualitatively these observations are consistent with predicted behavior based on diffusion analysis. McKenry made no calculations of diffusion coefficients for the two fumigants.

C. General Conclusions

Diffusion of pesticides through soils depends on a number of soil properties including water content, bulk density, air-filled porosity and temperature, and on certain chemical properties of the pesticide such as solubility, vapor density, and the diffusion coefficient. Adsorptive interactions between the chemical and soil are important and are dependent on both soil and chemical properties. Diffusion can occur both in the vapor and in the "nonvapor" phases. Furthermore, the "nonvapor" phase diffusion can occur in solution or at the air-water or air-solid interfaces. Diffusion in each phase is quite dependent upon soil-water content.

The importance of vapor diffusion as compared to "nonvapor" diffusion is dependent largely on the ratio of the vapor density to the "nonvapor" concentration. A large value of R decreases the relative effect of vapor diffusion and increases the relative effect of "nonvapor" diffusion. Because the vapor phase diffusion coefficient is so much larger (approximately 10^4) than the solution diffusion coefficient, vapor phase diffusion can be important even for pesticides, which have relatively low vapor pressures. Goring (1962) suggested that compounds with water-air ratios (weight/volume basis) under 10^4

will diffuse primarily in air while those over 3×10^4 will diffuse mainly in water. Helling, Kearney, and Alexander (1971) using Goring's prerequisites suggested that chloroneb, DDT, EPTC, lindane, CDEC, trifluralin, and the common fumigants would diffuse mainly in soil air and the *s*-triazines, monuron, diuron, and PMA would tend to diffuse in a "nonvapor" phase. This classification is considered approximate. The measured components of lindane diffusion in soil were dependent upon soil water content (Ehlers et al., 1969b; Shearer et al., 1973). Diffusion of lindane in both the vapor and "nonvapor" phases was approximately equal over a wide range of soil water contents.

While few diffusion coefficients for pesticides have been measured in soils, they tend to agree with the theoretical development presented. An obvious factor is the wide range of chemical properties in the pesticide field, some which diffuse almost exclusively in the vapor phase and others in the "nonvapor" phase. Each pesticide must be individually analyzed under each soil condition.

Diffusion processes are involved either directly or indirectly in the fate and behavior of pesticides in soils. Dispersion of a treatment band is the intent of many pesticide applications and will often occur through diffusion. Even when broadcast applications are made, diffusion becomes a mechanism for more complete distribution of the pesticide in soils. While water may serve as a principal carrier for moving some pesticides into the soil profile, distribution into smaller pores, aggregates, and blocked pores is dependent on diffusion. Fumigation is a special case where volatile fumigants, because of their relatively high vapor pressure, diffuse rapidly through a porous media except at high soil water contents.

Recently, volatilization losses from soil have been found to be one of the important pathways for the disappearance of pesticides (Cliath & Spencer, 1971; Guenzi & Beard, 1970; Farmer et al., 1972; Willis et al., 1972). Diffusion is a primary process controlling volatilization of soil-incorporated pesticides. As soon as loss occurs at the soil surface, a concentration gradient is established causing pesticide diffusion to the surface replacing that lost by vaporization.

Stikler, Knake, and Hinesly (1969) found that herbicide effectivnesss was dependent upon soil water content. Some herbicides became more effective as water content increased, whereas others either were not affected or decreased in effectiveness as water content increased. The authors attributed the results to the relative effect of water content on diffusion. In general, those chemicals which were more effective at high water contents were those which diffuse primarily in the solution phase and would have a higher diffusion coefficient. On the other hand, those chemicals which diffuse primarily in the vapor phase were either not affected by water content or decreased in effectiveness at high water contents. An increase in soil water content would decrease their movement.

III. MASS FLOW

A. Theoretical Considerations

As previously stated, mass flow of pesticide will result from the flow of water and/or soil particles with which the pesticide molecules are associated. Information on the movement of water and soil particles and the distribution of pesticide in the soil-water system is required to describe the mass transport of pesticide.

Soil particle movement in the soil profile results from mechanical tillage of the soil or transport of fine particles by water. (Surface erosion resulting from overland water flow will not be considered in this chapter.) Particle movement and deposition in the profile have been factors in profile development in soils. However, this process occurred over long periods of time and is not considered to be extremely important over the relatively short time span we are considering.

Mechanical tillage is obviously an effective method of redistributing a pesticide in the soil. Many pesticides are incorporated into the soil by disking. Pesticide movement is strictly a function of soil movement by the tillage instrument and will not be considered further in this chapter. The reader is referred to Gill and Vandenberg (1967) on the relationship between soil movement and various tillage instruments and practices.

Mass transport by water flowing through a soil profile is dependent upon the direction and rate of water flow and the sorption characteristics of the pesticide with soil. Analytical description of water flow through soil can be quite complex. Models which have been proposed to predict the mass transport of chemicals such as a pesticide have therefore dealt with rather simple water flow systems.

The general equation for chemical movement through porous media under steady state soil-water flow conditions is

$$\beta \partial S/\theta \partial t + \partial c'/\partial t = D' \, \partial^2 c'/\partial x^2 - v_o \partial c'/\partial x \qquad [7]$$

where D' is the dispersion coefficient (cm^2/sec), v_o is the average pore-water velocity (cm/sec), and other terms are as previously defined.

Exact analytical solutions to Eq. [7] have been presented for cases when assumptions are made concerning the mechanisms of adsorption or diffusion and dispersion (Hashimoto, Deshpande, & Thomas, 1964; Lapidus & Amundson, 1952; Lindstrom et al., 1967; Oddson et al., 1970). Each case assumed a single-valued (no hysteresis) linear relationship between adsorbed and solution concentration. Lapidus and Amundson (1952) presented solutions of Eq. [7] for equilibrium adsorption between solution and adsorbed phases and also for a first-order rate equation for adsorption. They assumed diffusion and dispersion processes were negligible. Oddson et al. (1970) assumed a first-order rate equation for adsorption and that diffusion

and dispersion processes were negligible. Hashimoto et al. (1964) obtained a solution for equilibrium adsorption but included the longitudinal mixing process. The analysis of Lindstrom et al. (1967) included a diffusion term. All models assume constant water flow velocity. This condition is achieved either by saturated water flow or by applying water at the soil surface at a constant rate lower than the saturated hydraulic conductivity of the soil. The latter condition can be achieved through sprinkler irrigation.

The assumptions used in solving Eq. [7] may not always be applicable. Kay and Elrick (1967) and Davidson and Chang (1972) showed deviation between the mathematical model requiring equilibrium adsorption and experimental data at high water flow velocities. On the other hand, Huggenberger, Letey, and Farmer (1972) presented data which indicate that the rate of adsorption of lindane and three soils is not a first-order reaction. Hornsby and Davidson (1974) reported that equilibrium adsorption exists at low water flow velocities, but that the dispersion coefficient is necessary under these conditions if the shape of the pesticide distribution is desired. Biggar (1970) discussed dispersion and its relationship to pesticide movement through soil.

Most models assume that $1/n$ of the Freundlich equation ($S = K'c^{1/n}$) equals 1. Based upon a number of reports on adsorption of pesticides by soils, this assumption appears reasonable provided the range of concentrations of significance is not too great. Harris (1966) studied the adsorption of several herbicides by three different soils. He found that $1/n$ varied from 0.70 to 0.99 while Geissbuhler, Haselbach, and Aavi (1963) obtained values from 0.89 to 0.98. Huggenberger et al. (1972) found that $1/n$ for lindane and three different soils was 0.88. Scott and Phillips (1972) measured the adsorption isotherm for ten herbicides and one soil. They did not calculate $1/n$; however, a plot of adsorbed herbicide as a function of amount of herbicide in solution phase was linear for seven herbicides. Three of the herbicides had a slightly curvilinear relationship between amount absorbed and solution concentration. Davidson, Mansell, and Baker (1973) calculated that the pesticide would penetrate deeper for $1/n$ equal 0.7 as compared to unity.

One of the major shortcomings of the analytical solution of Eq. [7] is its inability to handle the nonsingular adsorption-desorption process. Kay and Elrick (1967), van Genuchten, Davidson, and Wierenga (1974), and Hornsby and Davidson (1973) presented data illustrating great hysteresis in the adsorption-desorption behavior.

Lindstrom et al. (1971), van Genuchten et al. (1974), Hornsby and Davidson (1973), and Davidson et al. (1973) presented approaches to incorporating nonsingular sorption relationships in the analysis of pesticide transport. They developed numerical solutions for Eq. [7] which allow greater flexibility than the exact analytical solutions.

Figures 2 through 4 show calculated results using the model of Oddson et al. (1970) for a variety of soil and pesticide properties. The calculations assume a linear single-value adsorption isotherm and dispersion and diffusion neglible. Rate of adsorption is assumed to be a first-order reaction and is

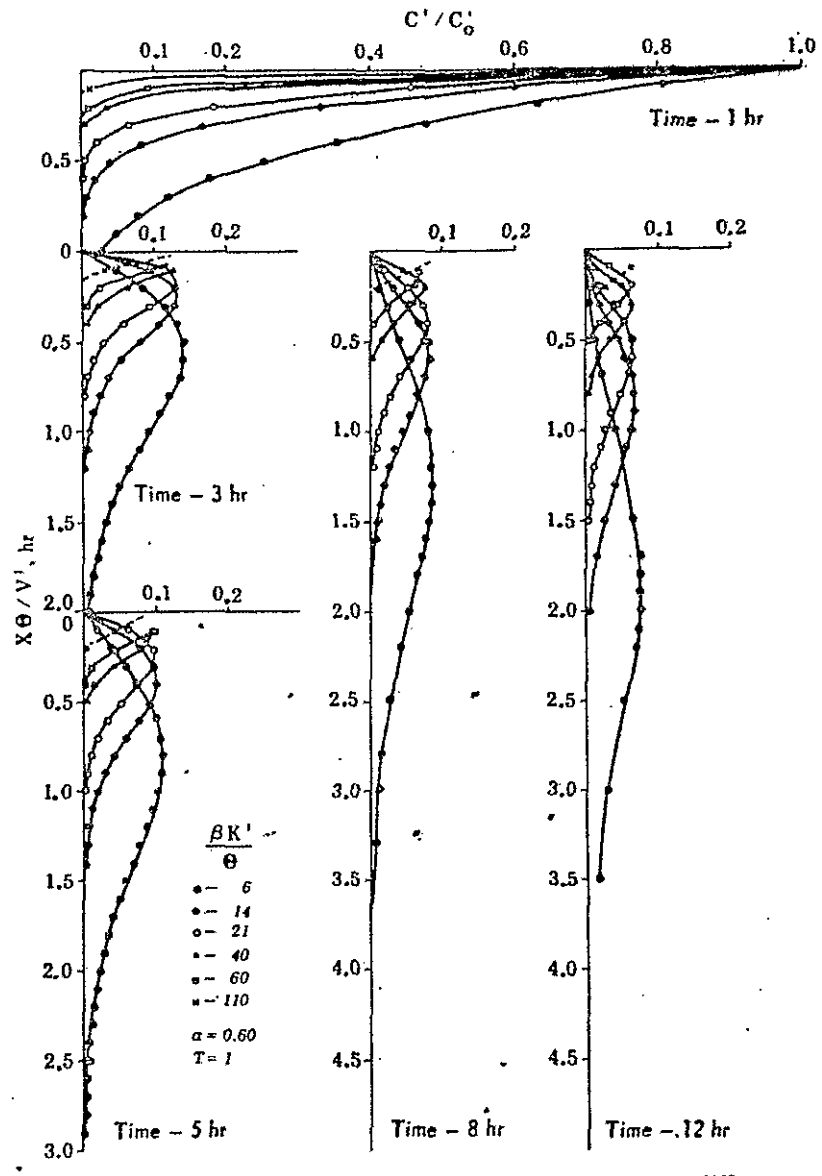


Figure 2. The distribution of organic chemical in solution at different times of water application for various values of K when $a = 0.60$ and pesticide solution is applied for 1 hour (Reprinted from Oddson et al., 1970).

mathematically stated as $\partial S/\partial t = a(K'c'-S)$. The boundary conditions were zero initial pesticide concentration in the soil and pesticide solution with concentration C_O applied at the surface for time T followed by water application.

Figure 2 shows the distribution of solution concentration (g cm^{-3} solution), relative to the solution concentration entering the soil surface, for

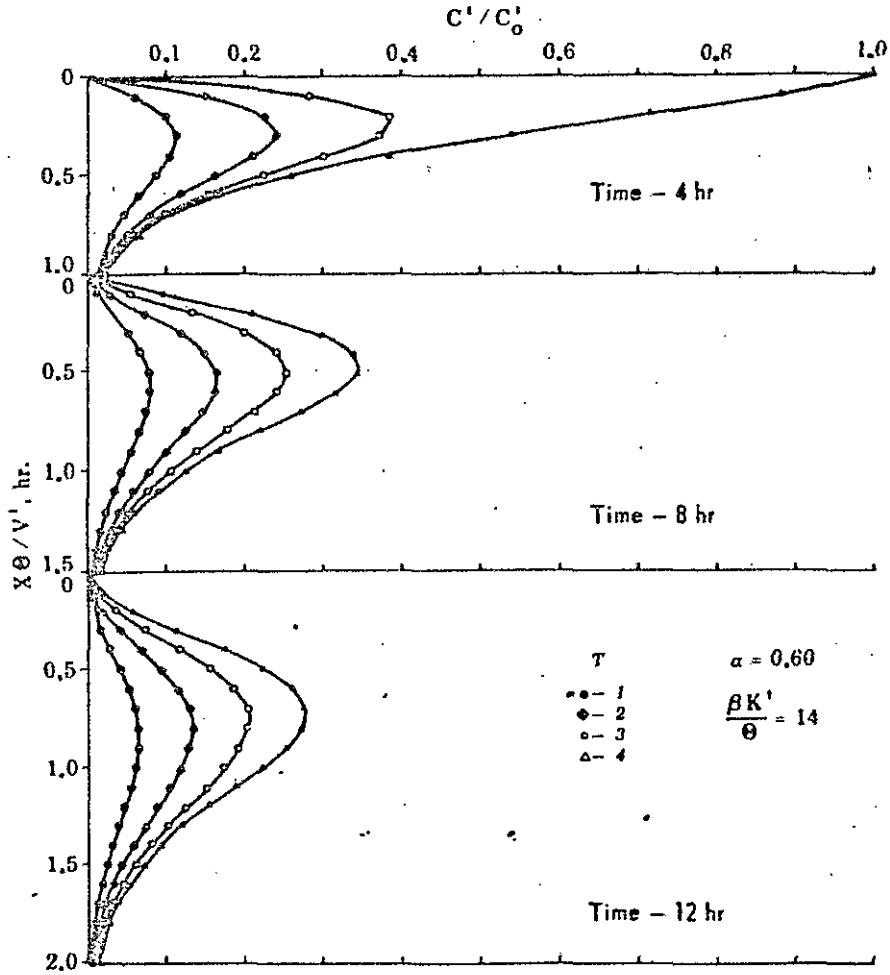


Figure 3. The effect of applying different amounts of organic chemicals and their distribution in solution after different times of water application when $\alpha = 0.60$ and $K = 14$ (Reprinted from Oddson et al., 1970).

different times and soil adsorptive characteristics. The ordinate can be considered to be a scaled depth factor which is dependent upon the water flow velocity and the volumetric water content. The conditions illustrated are for application of a pesticide for 1 hour followed by leaching with water for the times indicated.

The following are noteworthy observations. The depth of movement for the pesticide is dependent upon $K(K = \beta K'/\theta)$. The higher K, the less the movement. After the surface is free of pesticide, the chemical is carried through the profile as a symetrical wave. The lower K is, the broader the wave. The position of maximum concentration is equal to the depth of water penetration divided by K. For example, after 12 hours the wetting

front would have reached a value of 12 on the scale presented. For $K = 6$, maximum concentration is at about 2 which is 1/6 of 12. This behavior is consistent for all times and for all values of K evaluated. Therefore, if K for a particular pesticide and soil is known, the depth of water penetration necessary to get maximum concentration of the pesticide to a certain depth can be estimated for linear adsorption isotherm cases and when the flow velocity doesn't differ greatly between pores.

As previously stated, this model assumed that diffusion and hydrodynamic dispersion processes are negligible. Both of these processes would cause the concentration profile to be "spread out" more than indicated. The depth of maximum concentration should not, however, be greatly affected by hydrodynamic dispersion or diffusion. Lindstrom and Boersma (1971) calculated that increasing pore size numbers causes a broader distribution of the chemical through the profile.

The effect of applying different amounts of pesticide at the soil surface is illustrated in Figure 3. The time necessary to remove all of the pesticide from the soil surface varies from 1 to 4 hours. The depth of movement appears to be independent of the amount added to the soil surface (assuming that solubility of the pesticide is independent of the amount applied). Concentration at a given position in the soil profile is approximately proportional to the increase in amount of pesticide added. Therefore, the addition of different amounts of pesticide does not appear to influence the depth of movement but does influence the concentration in solution. The higher the amount added, the greater the concentration.

The concentrations plotted in Figures 2 and 3 are relative to the initial concentration c'_0 for pesticides applied to the surface in a "dry" form. Results presented in Figure 3 indicate that the solution concentration in the profile may be independent of pesticide solubility as long as the same amount is applied and there is sufficient water for dissolution and transport of the pesticide. For example, assume pesticide A is four times more soluble than pesticide B, thus c'_0 for A is four times larger than c'_0 for B. However, the time required to dissolve and carry pesticide B into the soil is four times greater than A. According to Figure 3, c'/c'_0 for pesticide B is four times c'/c'_0 for A. Since c'_0 for A is four times greater than c'_0 for B, the result is that c' is the same for both A and B. This analysis is valid for pesticides sufficiently soluble for transport into the profile.

The effect of a (the factor which influences rate of equilibrium) is shown in Figure 4. During the first hour (time during which the pesticide is maintained at the soil surface) the depth of movement is greatly decreased by increasing a. Over this period the effect of increasing a is similar to the effect of increasing K. After the pesticide has been removed from the soil surface, the pesticide moves through the profile as a wave. The depth of maximum concentration is independent for a for $a = 0.10$ or greater. A sharper peak and higher concentration occurs for high a as compared to lower a.

Lindstrom, Boersma, and Stockard (1971) analyzed the effect of three

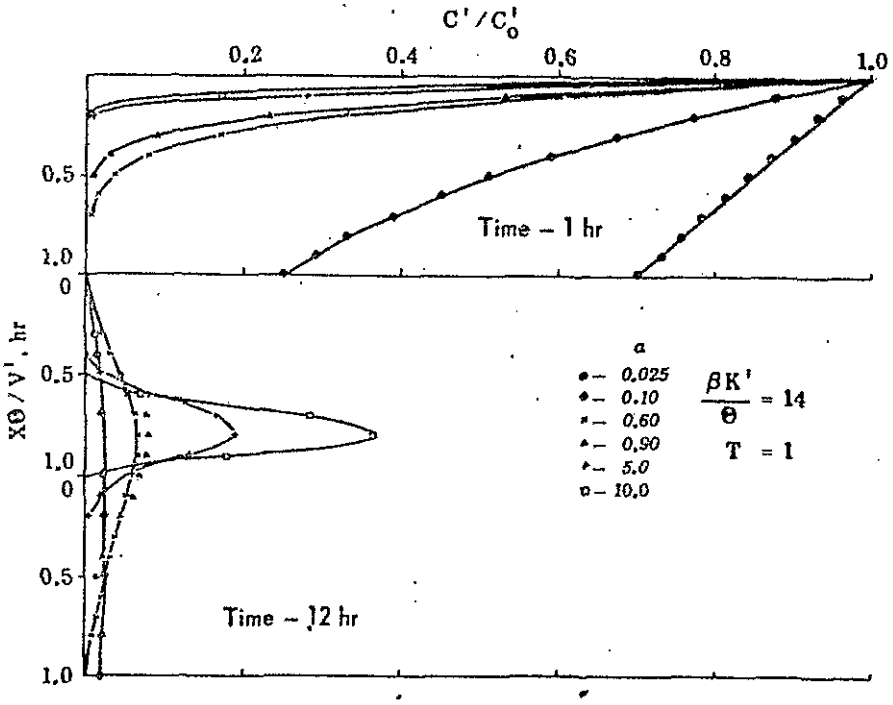


Figure 4. The effect of the rate of equilibrium between adsorbed and solution chemical on the distribution in solution after 1 and 12 hours of water application (Reprinted from Oddson et al., 1970).

sorption models on mass transport of chemicals through porous media. Model 1 assumed a linear relationship between adsorbed and solution concentrations with instantaneous equilibrium between the two phases. Model 2 assumed that equilibrium between the adsorbed and solution phases was not instantaneous, and closely represents the sorption characteristics used to calculate data for Figure 4. Model 3 took into account the quantum mechanical features of changing potentials or energies of activation with changing surface coverage. In Model 3 the kinetic rate coefficient is dependent upon concentration.

Lindstrom et al. (1971) calculated distribution curves for the three models. Their initial condition was pesticide uniformly distributed and at equilibrium in the top centimeter of soil. Results calculated for Model 2 by Lindstrom et al. agree with those presented in Figure 4. Decreasing the value of a (λ in their manuscript) caused a spreading of the chemical distribution through the profile.

The calculated results of Model 3 produced a nonsymmetric concentration wave in the soil. When the backward rate coefficient was less than the forward rate coefficient (rate of desorption lower than the rate of adsorption) the chemical was retained towards the upper part of the soil column as compared with equal rates of adsorption and desorption.

Davidson et al. (1973) calculated the distribution of pesticide for cases of nonsingularity between adsorption and desorption. (Higher equilibrium adsorbed concentration for a given solution concentration occurred during desorption as compared to that for the adsorption process.) The calculated distribution curves were not symetrical and resulted in higher residual concentrations toward the surface. The calculated maximum concentration in the profile was less for a nonsingle-valued adsorption-desorption relationship as compared to the single-valued relationship. Thus both maximum concentrations and the shape of the concentration distribution in soil are significantly altered by the nonsingularity of the adsorption and desorption relationships.

The reader is referred to Leistra (1973) for a good review on computation models for the transport of pesticides in soil. (Leistra's review was published after this chapter had been written and could not be referred to in detail).

B. Published Results

Published results which can be used to check the usefulness of theory in predicting distribution of pesticides through a soil profile will be reviewed first. Since some studies were not conducted specifically to test theory, one or more parameters required for the proposed models were not measured. Thus, meaningful comparisons between measured and theoretical results are not always possible.

Hornsby and Davidson (1973) measured the distribution of fluometuron in a soil column in the laboratory for three displacement periods and two water flow velocities. The measured distribution was compared to distribution calculated by a numerical solution of Eq. [7]. Adsorption and desorption curves were previously measured and these data were used in the numerical solution. Thus the nonsingle-valued sorption case was treated by these investigators.

The agreement between experimental and calculated values was good for the slower water flow velocity. The calculated and experimental distribution waves were not symetrical, indicating the importance of the desorption data. Agreement between the calculated and measured values for the tailing edge was good indicating that the authors' approach to the problem was valid.

Agreement between experimental and calculated values when the average water velocity was increased tenfold was not as good as for the slower water flow rate. Nevertheless, the agreement was reasonable and sufficiently accurate for most practical purposes. Equilibrium adsorption did not exist at any location in the soil column at the higher water velocity. Kinetics of the adsorption-desorption process must be known for accurate calculations. Both measured and calculated maximum solution concentration was deeper in the column than the maximum adsorbed concentration peak. (A consequence of nonequilibrium adsorption.) Also the relative solution and ad-

sorbed concentration distributions are flatter and more spread out for the high flow velocity as compared to the lower flow velocity.

The measured distribution was slightly deeper in the column than the calculated distribution for the higher water flow rates. One explanation is that the surface area contacted by the pesticide during fast displacement may be a function of the average pore-water velocity and the pore-size distribution. Measured adsorption characteristics are for the entire surface area being contacted and thus overestimate adsorption if the total surface area is not contacted during the flow process. van Genuchten et al. (1974) also observed this phenomenon and attempted a correction by determining the fraction of the pesticide near equilibrium. The calculated fraction near equilibrium decreased as the water velocity increased. The calculated pesticide effluent distribution was close to measured distribution when the fraction near equilibrium was used in the analysis for the various flow velocities.

van Genuchten et al. (1974) reported results of studies on picloram movement through laboratory soil columns. They measured adsorption and desorption curves and found them to be nonsingle-valued. Good agreement was found between measured and calculated results for low water flow velocities. The measured and calculated agreement was not good at the higher water flow velocities until adjustments were made to account for the fraction of the pesticide near equilibrium as previously stated. Calculations made assuming single-valued adsorption-desorption behavior did not agree with measured results, and illustrate the importance of the desorption data. Ignoring desorption behavior resulted in an overestimate of the maximum concentration and did not predict the tailing effect.

Huggenberger et al. (1972) designed experiments to check the validity of the theory proposed by Oddson et al. (1970). They ran experiments on three soils having different adsorptive capacities for lindane and checked the effect of applying lindane to the surface for different amounts of time. Adsorption (but no desorption) isotherms were measured for lindane and each of the three soils.

The experimental and calculated distributions of lindane for Pachappa sandy loam for different times of water application are illustrated in Figure 5. While the depth of maximum concentration is reasonably well predicted by theory, the shape of the concentration distribution is not. A higher concentration peak and narrower spreading was predicted than was observed. The predicted curves were symetrical whereas the measured curves had a tailing toward the soil surface. The difference between the observed and calculated curves can largely be explained by the use of a single-valued adsorption-desorption curve in the theory. The results presented in Figure 5 agree with predicted curves presented by van Genuchten et al. (1974) for single-valued and nonsingle-valued adsorption phenomena.

Comparison of experimental and calculated distribution of lindane in Pachappa sandy loam when the pesticide solution was applied for two periods of time is illustrated in Figure 6. Theory predicted that the concentration increase at a given depth would be proportional to the pesticide application

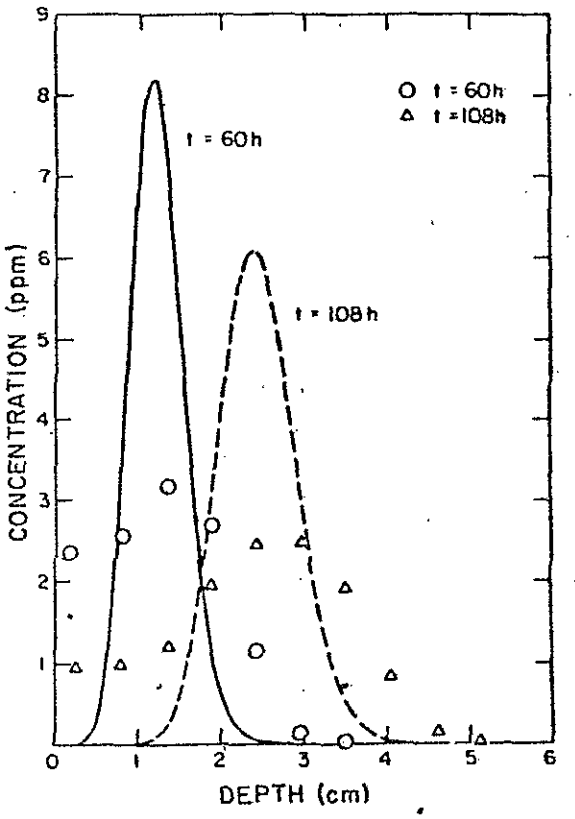


Figure 5. Experimental and calculated distribution of lindane for Pachappa sandy loam and different times of water application, pesticide solution applied for 12 hours, $v' = 0.2$ cm/hour, $K' = 5.514$, and $a = 0.542$ (Reprinted from Huggenberger et al., 1972).

time but the distribution shape would be unaffected. The observed distribution agreed closely with this premise. The concentration of lindane in the soil profile at each depth was approximately twice as high when the application was for 6 hours compared to 3 hours. Again, the shape of the predicted deviated from the observed curve.

Table 3 summarizes the results of Huggenberger et al. (1972). The observed depth of maximum concentration was always slightly greater than the calculated depth. However, except for one case, the difference was less than 1 cm. Use of a simple relationship that the depth of maximum concentration can be estimated by dividing the depth of water penetration by the adsorption coefficient indicated that the predicted depth was within 0.6 cm or less of the measured depth. From a practical point of view, the theory would give a sufficiently accurate prediction for the depth of maximum concentration.

Using miscible displacement techniques, Davidson and Chang (1972)

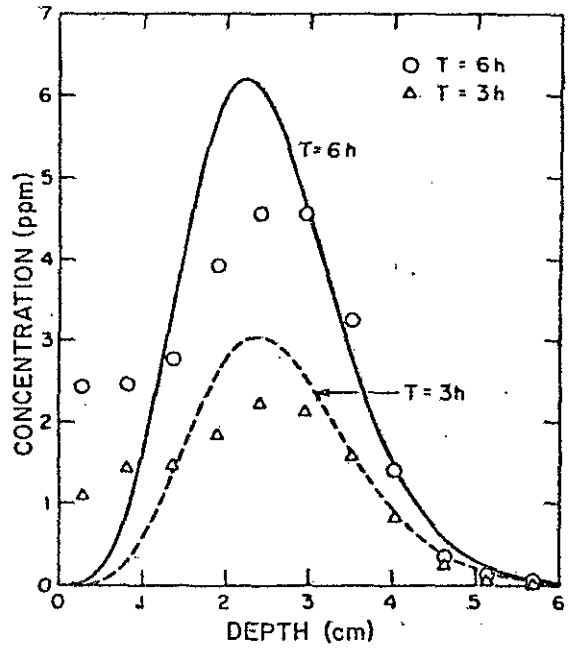


Figure 6. Experimental and calculated distribution of lindane for Pachappa sandy loam and different amounts of lindane added, $t = 27$ hours, and $v' = 0.8$ cm/hr (Reprinted from Huggenberger et al., 1972).

studied the effect of water flow rate, soil bulk density, and aggregate size on transport of picloram through soil columns. Picloram mobility was reduced significantly by decreasing the average water velocity from about 5.8 to about 0.59 cm hour^{-1}. Picloram concentrations in the effluent were closer to pre-

Table 3. Observed and calculated depth of maximum concentration of lindane for various application conditions (Huggenberger et al., 1972).

Soil		Depth of maximum concentration		Depth of water penetration	Depth of water penetration divided by K
		Observed	Calculated		
		cm			
Gila	t = 36h	1.7	1.0	21.5	2.0
Gila	t = 84h	4.8	3.1	40.2	4.2
Pachappa	t = 60h	1.4	1.2	41.8	1.4
Pachappa	t = 108h	2.7	2.4	72.7	2.6
Kentwood	t = 84h	1.3	0.9	53.5	1.0
Kentwood	t = 132h	1.9	1.5	86.9	1.6
Pachappa	T = 3h	2.6	2.4	66.1	2.7
Pachappa	T = 6h	2.7	2.2	66.7	2.7
Kentwood	V^1 = 2.1 cm/h	1.4	0.8	68.8	1.3
Kentwood	V^1 = 0.2 cm/h	1.1	1.1	52.8	1.3

dicted values at the lower water flow velocity as compared to the higher velocity. Apparent picloram adsorption was greater for the soil sieved through a finer mesh screen as compared with a coarser one.

Results of Davidson and Chang (1972) and Davidson, Rieck, and Santelmann (1968) are consistent with the concept that the measured adsorption coefficient obtained by thoroughly mixing a pesticide solution with soil and allowing sufficient time for equilibrium may differ from the effective adsorption coefficient for solution flowing through a soil column. If a soil has large aggregates, adsorption may occur only on the outer parts of the aggregate as the solution flows by. This would cause the pesticide to be carried deeper than predicted. Likewise, the pesticide would probably be carried deeper when flow rate was rapid because of greater flow through the larger pores, with smaller pores contributing little to adsorption.

Several investigators have measured the mass transfer of pesticides through laboratory soil columns but did not measure all of the parameters required to calculate the distribution. Some of these reports will now be reviewed and estimates of the maximum concentration position will be calculated by dividing depth of water penetration by K.

Geissbuhler et al. (1963) studied the distribution of products listed as C-1983 and a reference compound in three soil materials after leaching with water. Adsorption coefficients were reported, but bulk density, depth of water penetration, and volumetric water content were not reported. For comparison between measured and predicted results, reasonable estimates of these parameters will be made. It is assumed that $\beta = 1.2$ g cm^{-3}, $\theta = 0.33$, and therefore depth of water penetration = 60 cm. The K' values reported are 14, 40, and 110 for C-1983 and a sandy loam, clay soil, and humus, respectively, and 6.3, 21, and 60 for the reference compound. Dividing the depth of water penetration by K, both compounds were calculated to be concentrated at less than 1 cm for the clay soil and humus, and this was the observed result. The highest concentration of C-1983 and the reference compound was calculated at about 1 cm and 3 cm, respectively, in sandy loam soil. About 80% of C-1983 was in the first centimeter and not quite as deep as predicted. The reference compound was concentrated in the 5- to 7-cm layer which is deeper than predicted. Inasmuch as some assumptions were necessary to complete the calculations, the agreement between measured and calculated is reasonable.

The distribution of surface-applied diuron in a soil profile after leaching with 40 cm of water was measured and reported by Hilton and Yuen (1966). It is assumed that $\beta = 1.2$, $\theta = 0.33$, and depth of water penetration equals 120 cm since these values were not reported by the authors. Maximum concentration of diuron was predicted at about the 2.5-cm depth, which agrees with their measurements.

Although many factors contribute to mass transport of pesticides through soil by water, the most important factor appears to be adsorption between the pesticide and soil. Several investigators have reported this general relationship. Ashton (1961) measured the adsorption and relative

distance moved of several pesticides. He found the relative distance moved in the order fenuron > monuron > diuron > neburon, and the adsorption coefficient in the order neburon > diuron > monuron > fenuron. The inverse order between movement and adsorption is expected. Hamaker, Goring, and Youngson (1966) also reported an inverse relationship between adsorption and leaching. Harris (1966, 1967) found that the adsorption coefficient and mobility of atrazine, simazine, monuron, and propazine were similar in different soils. Prometryne had a much higher adsorption coefficient and lower mobility compared to the other four pesticides.

There is further indirect evidence for the inverse relationship between adsorption and movement of pesticides by water through soil. Increasing organic matter content of soils decreases depth of leaching (Upchurch & Pierce, 1958; Ogle & Warren, 1954; Hill et al., 1955; Eshel & Warren, 1967; Gray & Weierich, 1968; Lichtenstein, 1958; Rodgers, 1962; Rauser & Switzer, 1962; Bowman, Scheehter, & Carter, 1965; Hernandez & Warren, 1950). An increase in soil organic matter content causes an increase in adsorption coefficient for pesticides which accounts for the decreased depth of leaching. Similarly, an increase in clay content of soil has been reported to both increase the adsorption coefficient and decrease mobility of pesticides.

Guenzi and Beard (1967) measured the movement of lindane and DDT in four different soils after applying two amounts of water. No adsorption coefficients between the two insecticides and the soils were reported. They found lindane to be carried deeper than DDT which was retained essentially in the top 3 cm of the soil column which was attributed to the very low water solubility of DDT. Movement was found to be greater in the soils higher in sand content.

Harris (1969) reported on relative mobilities of several insecticides and herbicides in soil systems. The chlorinated hydrocarbons (aldrin, *o,p'*-DDT, *p,p'*-DDT, DDE, dieldrin, endrin, and heptachlor) were immobile by his standards. Phorate and disulfoton were very slightly mobile, while diazinon and especially thionazin exhibited greater mobilities. Among the herbicides, chloropropham and toluene herbicides (benefin, nitralin, trifluralin, dipropalin) had very low mobility. A group of herbicides having somewhat higher mobility included monuron, buturon, linuron, diuron, atrazine, simazine, propazine, prometryne, EPTC, pebulate, vernolate, and diphenamid. A group having even higher mobility included dinoseb, pyriclor, norea, and cycluron. The acid herbicides (dicamba, tricamba, 2,3,6-TBA, amiben, fenac) had the highest mobility.

Helling (1971a, 1971b, 1971c) presented a thorough discussion of using thin-layer chromatography techniques to measure pesticide mobility through soils. Forty pesticides were grouped into five relative mobility categories using these techniques. He also measured the effect of several soil properties on mobility of pesticides. He found that mobility of nonionic compounds was inversely related to adsorption. Acidic compound mobility was directly correlated with soil pH. Increasing water flux tended to cause increased mobility.

No attempt has been made to make reference to every published report on pesticide distribution in a soil profile following leaching. Helling (1970) presented a complete review on *s*-traizine mobility data prior to 1969. Helling et al. (1971) classified 82 pesticides into five different mobility classes based upon data from a number of references.

C. Conclusions

Models have been developed to describe mass transfer of organic chemicals through the soil profile by water. All have dealt with rather simple water flow systems assuming unidirectional constant water flow velocity. Best agreement between measured and calculated pesticide distribution had been for numerical solutions of Eq. [7] which allow for nonsingle-valued absorption-desorption characteristics.

The most important parameter appears to be the adsorption coefficient between the pesticide and soil. Pesticides which have high adsorption coefficients will be relatively immobile in the soil.

The depth of maximum pesticide concentration can for practical purposes be estimated by dividing the depth of water penetration by the adsorption coefficient K. Greatest deviations from this behavior will be for high water flow velocities and well aggregated soils where some pores are bypassed by water. Information presented in other chapters dealing with adsorption coefficients is very pertinent to understanding the mass transfer of a given pesticide through a given soil.

IV. APPENDIX A

List of Symbols

C = concentration, g cm^{-3} total volume
c = "nonvapor" concentration, g g^{-1} soil
c' = pesticide concentration in solution, g cm^{-3} solution
c_S = pesticide concentration in solution, g g^{-1} soil
D = diffusion coefficient, cm^{2}sec^{-1}
D' = dispersion coefficient, cm^{2}sec^{-1}
D'_A = diffusion coefficient of molecules adsorbed at water-soil interface, cm^{2}sec^{-1}
D_I = diffusion coefficient of molecules adsorbed at water-air interface, cm^{2}sec^{-1}
D_S = apparent solution phase diffusion coefficient, cm^{2}sec^{-1}
D_V = vapor phase diffusion coefficient, cm^{2}sec^{-1}
D'_S = apparent "nonvapor" phase diffusion coefficient, cm^{2}sec^{-1} (includes factor for exchange with vapor phase)
K' = coefficient of proportionality between solution concentration and concentration adsorbed at soil-water interface, $K' = S/c'$, cm^3 water g^{-1} soil

K = dimensionless coefficient of proportionality between solution concentration and concentration adsorbed at soil-water interface, $K = \beta K'/\theta$
P = air-filled porosity, $cm^3 cm^{-3}$
P_T = total porosity, $cm^3 cm^{-3}$
q = flux, quantity per unit cross sectional area per unit time, g cm^{-2} sec^{-1}
R' = coefficient of proportionality between solution concentration and concentration at the air-water interface, $R' = I/c'$, cm^3 water g^{-1} soil
R = coefficient of proportionality between vapor density and "non-vapor" concentration ($R = c\beta/P\rho$), dimensionless
S = pesticide concentration adsorbed at soil-water interface, g g^{-1} soil
T = time that pesticide solution is applied, hours
v_o = average pore-water velocity cm sec^{-1}
α = coefficient related to rate of adsorption
β = soil bulk density, g cm^{-3}
ρ = vapor density, g cm^{-3}
θ = volumetric water content, $cm^3 cm^{-3}$.

V. APPENDIX B

Chemical Designations of Pesticides Mentioned in Text

Common Name	*Chemical Name*
Aldrin	1,2,3,4,10,10-hexachloro-1,4,4a,5,8,8a-hexahydro-1,4-*endo, exo*-5,8-dimethanonaphthalene
Amiben	3-amino-2,5-dichlorobenzoic acid
Atrazine	2-chloro-4-(ethylamino)-6-(isopropylamino)-*s*-triazine
Benefin	*N*-butyl-*N*-ethyl-*α,α,α*-trifluoro-2,6-dinitro-*p*-toluidine
Buturon	3-(*p*-chlorophenyl)-1-methyl-1-(1-methyl-2-propynyl) urea
CDEC	2-chloroallyl diethyldithiocarbamate
Chloroneb	1,4-dichloro-2,5-dimethoxybenzene
Chlorpropham	isopropyl *m*-chlorocarbanilate
CIPC	See chlorpropham
Cycluron	*N'*-cyclo-octyl-N-N-dimethylurea
2,4-D	(2,4-dichlorophenoxy)acetic acid
DDE	1,1-dichloro-2,2-bis(*p*-chlorophenyl)ethylene
DDT	1,1,1-trichloro-2,2-bis(*p*-chlorophenyl)ethane(*p,p'*-isomer)
Diazinon	*O,O*-diethyl *O*-(2-isopropyl-6-methyl-4-pyrimidinyl) phosphorothioate
Dicamba	3,6-dichloro-*o*-anisic acid
Dichloropropene	1,3-dichloropropene
Dieldrin	1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-oxtahydro-1,4-*endo,exo*-5,8-dimethanonaphthalene

Dimethoate	*O,O*-dimethyl *S*-(*N*-methylcarbamoylmethyl) phosphorodithioate
Dinoseb	2-*sec*-butyl-4,6-dinitrophenol
Diphenamid	*N,N*-dimethyl-2,2-diphenylacetamide
Dipropalin	N,N-di-*n*-propyl-2,6-dinitro-4-methylaniline
Disulfoton	*O,O*-diethyl *S*-[2(ethylthio)ethyl] phosphorodithioate
Diuron	3-(3,4-dichlorophenyl)-1,1-dimethylurea
EDB	1,2-dibromoethane
Endrin	1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-1,4-*endo,endo*-5,8-dimethanonaphthalene
EPTC	*S*-ethyl dipropylthiocarbamate
Fenac	(2,3,6-trichlorophenyl)acetic acid
Fenuron	1,1-dimethyl-3-phenylurea
Fluometuron	1,1-dimethyl-3-(*a,a,a*-trifluoro-*m*-tolyl)urea
Heptachlor	1,4,5,6,7,8,8-heptachloro-3a,4,7,7a-tetrahydro-4,7-methanoindene
Lindane	γ-1,2,3,4,5,6-hexachlorocyclohexane
Linuron	3-(3,4-dichlorophenyl)-1-methoxy-1-methylurea
Monuron	3-(*p*-chlorophenyl)-1,1-dimethylurea
Neburon	1-*n*-butyl-3-(3,4-dichlorophenyl)-1-methylurea
Nitralin	4-(methylsulfonyl)-2,6-dinitro-*N,N*-dipropylaniline
Norea	3-(hexahydro-4,7-methanoindan-5-yl)-1,1-dimethylurea
Pebulate	*S*-propyl butylethylthiocarbamate
Phorate	*O,O*-diethyl *S*-[(ethylthio)methyl] phosphorodithioate
Picloram	4-amino-3,5,6-trichloropicolinic acid
PMA	phenylmercuric acetate
Prometryne	2,4-bis(isopropylamino)-6-methylthio-*s*-triazine
Propazine	2-chloro-4,6-bis(isopropylamino)-*s*-triazine
Pyriclor	2,3,5-trichloro-4-pyridinol
Simazine	2-chloro-4,6-bis(ethylamino)-*s*-triazine
2,3,6-TBA	2,3,6-trichlorobenzoic acid
Thionazin	*O,O*-diethyl *O*-2-pyrazinyl phosphorothioate
Tricamba	3,5,6-trichloro-*o*-anisic acid
Trifluralin	*a,a,a*-trifluoro-2,6-dinitro-*N,N*-dipropyl-*p*-toluidine
Vernolate	*S*-propyl dipropylthiocarbamate

LITERATURE CITED

Ashton, Floyd M. 1961. Movement of herbicides in soil with simulated furrow irrigation. Weeds 9:612–619.

Bailey, G. W., and J. L. White. 1970. Factors influencing the adsorption, desorption and movement of pesticides in soil. Residue Rev. 32:29–92.

Barlow, F., and A. B. Hadaway. 1955. Studies on aqueous suspensions of insecticides. V. The adsorption of insecticides by soil. Bull. Entomol. Res. 46:547–559.

Barlow, F., and A. B. Hadaway. 1958a. Studies on aqueous suspensions of insecticides. VI. Further notes on the sorption of insecticides by soils. Bull. Entomol. Res. 49: 315–331.

Barlow, F., and A. B. Hadaway. 1958b. Studies on aqueous suspensions of insecticides. VII. The influence of relative humidity upon the adsorption of insecticides by soils. Bull. Entomol. Res. 49:333–354.

Biggar, J. W. 1970. Pesticide movement in soil water. *In* Pesticides in the soil: Ecology, degradation and movement. Int. Symposium on Pesticides in Soils, Feb. 25–27, 1970. Michigan State University, East Lansing.

Bowman, M. C., M. S. Schechter, and R. L. Carter. 1965. Behavior of chlorinated insecticides in a broad spectrum of soil types. J. Agr. Food Chem. 13:360–365.

Call, F. 1957a. The diffusion of ethylene dibromide vapor in air. J. Sci. Food Agr. 8: 86–89.

Call, F. 1957b. Soil fumigation. V. Diffusion of ethylene dibromide through soils. J. Sci. Food Agr. 8:143–150.

Call, F. 1957c. The mechanism of sorption of ethylene dibromide on moist soils. J. Sci. Food Agr. 8:630–639.

Carslaw, H. S., and J. C. Jaeger. 1947. Conduction of heat in solids. Oxford Press, London.

Cliath, M. M., and W. F. Spencer. 1971. Movement and persistence of dieldrin and lindane in soil as influenced by placement and irrigation. Soil Sci. Soc. Amer. Proc. 35:791–795.

Crank, J. 1956. The mathematics of diffusion. Oxford Press, London.

Davidson, J. M., and R. K. Chang. 1972. Transport of picloram in relation to soil physical conditions and pore-water velocity. Soil Sci. Soc. Amer. Proc. 36:257–261.

Davidson, J. M., R. S. Mansell, and D. R. Baker. 1973. Herbicide distributions within a soil profile and their dependence upon adsorption-desorption. Soil Crop Sci. Soc. Fla. Proc. 32:36–41.

Davidson, J. M., C. E. Rieck, and P. W. Santelmann. 1968. Influence of water flux and porous material on the movement of selected herbicides. Soil Sci. Soc. Amer. Proc. 32:629–633.

Ehlers, Wilfried, W. J. Farmer, W. F. Spencer, and J. Letey. 1969a. Lindane diffusion in soils: II. Water content, bulk density, and temperature effects. Soil Sci. Soc. Amer. Proc. 33:505–508.

Ehlers, Wilfried, J. Letey, W. F. Spencer, and W. J. Farmer. 1969b. Lindane diffusion in soils: I. Theoretical considerations and mechanism of movement. Soil Sci. Soc. Amer. Proc. 33:501–504.

Eshel, Y., and G. F. Warren. 1967. A simplified method for determining phytotoxicity, leaching and adsorption of herbicides in soils. Weeds 15:115–118.

Farmer, W. J., K. Igue, and W. F. Spencer. 1973. Effect of bulk density on the diffusion and volatilization of dieldrin from soil. J. Environ. Qual. 2:107–109.

Farmer, W. J., K. Igue, W. F. Spencer, and J. P. Martin. 1972. Volatility of organochlorine insecticides from soils. I. Effect of concentration, temperature, air flow rate, and vapor pressure. Soil Sci. Soc. Amer. Proc. 36:443–447.

Farmer, W. J., and C. R. Jensen. 1970. Diffusion and analysis of carbon-14 labeled dieldrin in soils. Soil Sci. Soc. Amer. Proc. 34:28–31.

Gardner, W. R. 1965. Movement of nitrogen in soil. *In* W. V. Bartholomew and F. E. Clark (ed.) Agronomy 10:550–572. Amer. Soc. Agron., Madison, Wis.

Geissbuhler, H., C. Haselbach, and H. Aavi. 1963. The fate of N′-(4-chlorophenoxyphenyl)-N,N-dimethylurea (c-1983) in soils and plants. I. Adsorption and leaching in different soils. Weed Res. 3:140–153.

Gill, William R., and Glen E. Vandenberg. 1967. Soil dynamics in tillage and traction. Agricultural Handbook no. 316. U. S. Gov. Printing Office, Washington, D. C. 20102.

Goring, C. A. I. 1962. Theory and principles of soil fumigation. *In* R. L. Metcalf (ed.) Advan. Pest Control Res. 5:47–84. Interscience Publishers, New York.

Graham-Bryce, I. J. 1969. Diffusion of organophosphorus insecticides in soils. J. Sci. Food Agr. 20:489–494.

Gray, Reed A., and Andre J. Weierich. 1968. Leaching of five thiocarbamate herbicides in soils. Weed Sci. 16:77–79.

Guenzi, W. D., and W. E. Beard. 1967. Movement and persistence of DDT and lindane in soil columns. Soil Sci. Soc. Amer. Proc. 31:664–647.

Guenzi, W. D., and W. E. Beard. 1970. Volatilization of lindane and DDT from soil. Soil Sci. Soc. Amer. Proc. 34:443–447.

Hamaker, J. W., C. A. I. Goring, and C. R. Youngson. 1966. Sorption and leaching of 4-amino-3,5,6-trichloropicolinic acid in soils. *In* R. F. Gould (ed.) Organic pesticides in the environment. Advan. Chem. Ser. 60:23–37.

Hamaker, J. W. 1972. Diffusion and volatilization. p. 341-397. *In* C. A. I. Goring and J. W. Hamaker (ed.) Organic chemicals in the soil environment. Vol. 1. Marcel Dekker, Inc., New York.

Handbook of Chemistry and Physics. 1973. R. C. Weast, editor. 53rd ed. CRC Press, Inc., Cleveland, Ohio.

Harris, C. I. 1966. Adsorption, movement and phytotoxicity of monuron and *s*-triazine herbicides in soil. Weeds 14:6-10.

Harris, C. I. 1967. Movement of herbicides in soils. Weeds 15:214-216.

Harris, C. I. 1969. Movement of pesticides in soil. J. Agr. Food Chem. 17:80-82.

Hartley, G. S. 1960. Physico-chemical aspects of the availability of herbicides in soils. p. 63-78. *In* E. K. Woodford and G. R. Sager (ed.) Herbicides and the soil. Blackwell Scientific Publications, Oxford, England.

Hartley, G. S. 1964. *Herbicide behavior in the soil.* I. Physical factors and action through the soil. p. 111-161. *In* L. J. Audus (ed.) The physiology and biochemistry of herbicides. Academic Press, London and New York.

Hashimoto, I., K. B. Deshpande, and H. C. Thomas. 1964. Peclet numbers and retardation factors for ion exchange columns. Ind. Eng. Chem. Fundam. 3:213-218.

Helling, C. S. 1970. Movement of *s*-triazine herbicides in soils. Residue Rev. 32:175-210.

Helling, Charles S. 1971a. Pesticide mobility in soils: I. Parameters of thin-layer chromatography. Soil Sci. Soc. Amer. Proc. 35:732-737.

Helling, Charles S. 1971b. Pesticide mobility in soils: II. Applications of soil thin-layer chromatography. Soil Sci. Soc. Amer. Proc. 35:737-743.

Helling, Charles S. 1971c. Pesticide mobility of soils: III. Influence of soil properties. Soil Sci. Soc. Amer. Proc. 35:743-748.

Helling, C. S., P. C. Kearney, and M. Alexander. 1971. Behavior of pesticides in soils. Advan. Agron. 23:147-240.

Hemwall, John B. 1959. A mathematical theory of soil fumigation. Soil Sci. 88:184-190.

Hemwall, John B. 1960. Theoretical considerations of several factors influencing the effectivity of soil fumigants under field conditions. Soil Sci. 90:157-168.

Hernandez, T. P., and G. F. Warren. 1950. Some factors affecting the rate of inactivation and leaching of 2,4-D in different soils. Amer. Soc. Hort. Sci. 56:287-293.

Hill, G. D., J. W. McGahen, H. M. Baker, D. W. Finnerty, and C. W. Bingeman. 1955. The fate of substituted urea herbicides in agricultural soils. Agron. J. 47:93-104.

Hilton, H. W., and Q. H. Yuen. 1966. Adsorption and leaching of herbicides in Hawaiian sugarcane soils. J. Agr. Food Chem. 14:86-90.

Hornsby, A. G., and J. M. Davidson. 1973. Solution and adsorbed fluometuron concentration distribution in a water-saturated soil: experimental and predicted evaluation. Soil Sci. Soc. Amer. Proc. 37:823-828.

Huggenberger, F., J. Letey, and W. J. Farmer. 1972. Observed and calculated distribution of lindane in soil columns as influenced by water movement. Soil Sci. Soc. Amer. Proc. 36:544-548.

Jost, W. 1965. Diffusion in solids, liquids, gases. Academic Press, Inc., New York.

Kay, B. D., and D. E. Elrick. 1967. Adsorption and movement of lindane in soils. Soil Sci. 104:314-322.

Lapidus, L., and N. R. Amundson. 1952. Mathematics of adsorption in beds. VI. The effect of longitudinal diffusion in ion exchange and chromatographic columns. J. Phys. Chem. 56:984-988.

Lavy, T. L. 1970. Diffusion of three chloro *s*-triazines in soil. Weed Sci. 18:53-56.

Leistra, M. 1972. Diffusion and adsorption of the nematocide 1,3-dichloropropene in soil. Agr. Res. Reports 769. 105 pp. Center for Agricultural Publishing & Documentation, Wageningen.

Leistra, Minze. 1973. Computation models for the transport of pesticides in soil. Residue Rev. 49:87-130.

Lichtenstein, E. P. 1958. Movement of insecticides in soil under leaching and nonleaching conditions. J. Econ. Entomol. 51:380-383.

Lindstrom, F. T., and L. Boersma. 1971. A theory on the mass transport of previously distributed chemicals in a water saturated sorbing porous media. Soil Sci. 111: 192-199.

Lindstrom, F. T., L. Boersma, and H. Gardiner. 1968. 2,4-D diffusion in saturated soils: a mathematical theory. Soil Sci. 106:107–113.

Lindstrom, F. T., L. Boersma, and D. Stockard. 1971. A theory on the mass transport of previously distributed chemicals in a water saturated sorbing porous media: Isothermal cases. Soil Sci. 112:291–300.

Lindstrom, Fredrick T., Rizwanul Haque, Virgil H. Freed, and Larry Boersma. 1967. Theory on the movement of some herbicides in soils: Linear diffusion and convection of chemicals in soils. Environ. Sci. Tech. 1:561–565.

Oddson, J. K., J. Letey, and L. V. Weeks. 1970. Predicted distribution of organic chemicals in solution and adsorbed as a function of position and time for various chemical and soil properties. Soil Sci. Soc. Amer. Proc. 34:412–417.

Ogle, R. E., and G. F. Warren. 1954. Fate and activity of herbicides in soils. Weeds 3: 257–273.

Olsen, S. R., and W. D. Kemper. 1968. Movement of nutrients to plant roots. Advan. Agron. 20:99–151.

Rauser, W. F., and C. M. Switzer. 1962. Factors contributing to the loss of amiben phytotoxicity in soils. Weeds 10:62–64.

Rodgers, E. G. 1962. Leaching of four triazines in three soils as influenced by varying frequencies and rates of simulated rainfall. Proc. S. Weed Contr. Conf. 15:268.

Scott, H. Don, and R. E. Phillips. 1972. Diffusion of selected herbicides in soil. Soil Sci. Soc. Amer. Proc. 36:714–719.

Shearer, R. C., J. Letey, W. J. Farmer, and A. Klute. 1973. Lindane diffusion in soil. Soil Sci. Soc. Amer. Proc. 37:189–193.

Stikler, R. L., E. L. Knake, and T. D. Hinesly. 1969. Soil moisture and effectiveness of preemergence. Weed Sci. 17:257–279.

Upchurch, R. P., and W. C. Pierce. 1958. The leaching of monuron from Lakeland sand soil. II. The effect of soil temperature, organic matter, soil moisture and amount of herbicide. Weeds 6:24–33.

van Genuchten, M. Th., J. M. Davidson, and P. J. Wierenga. 1974. An evaluation of kinetic and equilibrium equations for the prediction of pesticide movement through porous media. Soil Sci. Soc. Amer. Proc. 38:29–35.

Walker, A., and D. V. Crawford. 1970. Diffusion coefficients for two triazine herbicides in six soils. Weeds Res. 10:126–132.

Willis, G. H., J. F. Parr, S. Smith, and B. R. Carroll. 1972. Volatilization of dieldrin from fallow soil as affected by different soil water regimes. J. Environ. Qual. 1:193–196.

51. Lewis, Norma. "Attenuation of Polybrominated Biphenyls and hexachlorobenzene by Earth Materials," Project Summary EPA, 1981

United States
Environmental Protection
Agency

Municipal Environmental Research
Laboratory
Cincinnati OH 45268

Research and Development

EPA-600/S2-81-191 Dec. 1981

2645
2647

Project Summary

Attenuation of Polybrominated Biphenyls and Hexachlorobenzene by Earth Materials

Norma M. Lewis

This laboratory study of the aqueous solubility, adsorption, mobility, and microbial degradation of polybrominated byphenyls (PBB's) and hexachlorobenzene (HCB) was undertaken to provide information of their behavoir in the environment, particularly on the potential for their movement through soil at land disposal facilities for hazardous wastes. Studies indicated that PBB's were more than 200 times and HCB more than 2.5 times more soluble in landfill leachate than in distilled water. Also, the solubilities of PBB's and HCB were higher in creekwater and landfill leachates than in purified waters; this was correlated with a level of dissolved organics in the waters.

HCB showed a greater tendency for adsorption than did PBB's. There was a high direct correlation between the total organic carbon (TOC) content of soils and the amount adsorbed. PBB's and HCB were strongly adsorbed by the Ambersorb XE-348 but not so by organic solvents.

PBB's and HCB remained immobile when leached with water or landfill leachate but were highly mobile when leached with organic solvents. PBB's and HCB were found to be resistant to microbial degradation.

This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The purposes of the study summarized here were: to produce a literature review on attentuation of PBB's and HCB in soil materials; to measure quantitatively the aqueous solubilities of PBB's and HCB to determine the effect of measuring concentrations of dissolved organic matter on the solubilities; to measure the adsorption capacity of selected earth and carbonaceous materials for PBB's and HCB from aqueous and organic solvents; to evaluate the effects of time, organic carbon content, adsorbent structure, and solvent on attenuation and mobility of PBB's and HCB; to measure the persistence of PBB's and HCB to microbial degradation, both in soluble cultures and soils; and to use these data to develop a mathematical model that will allow prediction of PBB's and HCB adsorption and mobility in earth material.

Polybrominated Biphenyls

The major uses of PBB's were for the production of flame retardant resins of acrylonitrile, bertadiene, and styrene for business machines, electrical housings,

textiles, and other materials. All of these uses were discontinued in late 1974 as a result of the contamination incident in Michigan. At present, no PBB's are being imported in commercial quantities.

A serious problem was created in 1973 when PBB's were accidentally added to livestock feed in place of magnesium oxide. In Michigan, thousands of farm animals had to be disposed, and approximately 300 persons became contaminated through their food source. Studies in Michigan have shown that PBB's can cause liver, kidney, and brain damage in animals, and liver damage and personality changes in humans.

PBB's have the hydrophobic characteristic of being strongly adsorbed from aqueous solution onto soils, depending on the soil's texture and organic carbon content. A linear correlation was found between adsorption capacity and total organic carbon content of soil. Low-clay and low organic matter soil resulted in higher PBB's in root crops, but much of the contamination could be removed by peeling.

Little information exists on the disposal of PBB's, except for that concerning the Gratiot County landfill near St. Louis, Michigan, and the disposal site in Kalkaska County, Michigan, where the PBB contaminated animals were buried.

Incineration is the safest method for disposal of PBB's; however, costs are high, they do not burn readily, and conditions must be controlled because these compounds will reenter the environment in the form of stack gases. Less expensive alternatives are land burial or landfilling, which is more accessible and energy efficient.

PBB's are very sensitive to UV-light, and lower brominated biphenyls are found when PBB's are irradiated. Degradation of the hexabromobiphenyl was more rapid than hexachloro analog; less than 10 percent of the initial compound persisted 9 minutes of illumination. At present, there is no information to indicate that biological degradation of PBB's occurs in animals.

Hexachlorobenzene

A problem became evident with HCB when contamination in cattle occurred in December 1972, near Darrow, Louisiana. Quarantine restrictions involved approximately 120 square miles and about 20,000 cattle. By 1974, the U.S.D.A. had identified HCB in domestic meat and poultry supplies in at least 14 states. HCB residues in livestock were found above the acceptable 0.5 ppm level.

It was estimated in 1975 that approximately 240 metric tons were being used annually in the manufacturing of tires and as a fungicide for treatment of seed grain. An additional 2,850 metric tons were being produced annually as a byproduct waste of various chlorinated solvents and as an impurity or byproduct in the production of several pesticides.

The cost for disposal by incineration is desirable but more costly than land disposal. Current methods of disposal include land disposal (sanitary and industrial landfill, deep well injection, and dry pond), incineration, open pit burning, resource recovery, municipal sewage treatment plants, and emission to the atmosphere.

The nature of the soil and the organic matter content are factors affecting adsorption. The half life of HCB in soil under controlled conditions was approximately 4 years. Also, HCB was not lost in soil under aerobic (sterile and nonsterile) and anaerobic nonsterile conditions for 1 year. Photo degradation was observed when HCB was irradiated by UV-light.

In the complete report, studies of the aqueous solubility, adsorption, mobility, and microbial degradation of PBB's and HCB are detailed. The following will discuss some of the various methods, techniques, types, and conclusions of these studies.

Materials and Methods

PPB and HCB Materials

The PBB material, known as fireMaster PB-6,* was supplied by the Michigan Chemical Corporation (lot #6244A); it was used without further purification.

^{14}C-PBB (lot #872-244) was synthesized and purified by New England Nuclear Corporation, Boston, Massachusetts.

HCB was purchased from Aldrich Chemical Company, Inc., Milwaukee, Wisconsin. The product was recrystallized from glass-distilled hexane. This process was repeated several times until the purity reached nearly 100 percent.

^{14}C-HCB (lot #852-058) was purchased from New England Nuclear Corporation, Boston, Massachusetts. The specific activity was 35.5 m Ci/m mole (0.125 m Ci/mg). No other components were detected by gas chromatography.

*Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Waters and Leachates

Distilled water, deionized water, Sugar Creek water, and leachate from two landfills (Blackwell and Du Page) were selected for use in the solubility study. Leachates were centrifuged in a continuous flow centrifugation apparatus at approximately 17,000 rpm before passing through a 0.22-μm pore size membrane before use.

The total organic content (TOC) and chemical analyses of the waters and leachates are shown in Table 1.

Solubility of PBB's and HCB in Waters and Leachates

Isomer Identification

The PBB material fireMaster PB-6 is a mixture of more than 30 isomers (Figure 1). The six major isomers are 2,2',4,5,5'-penta-; 2,3',4,4',5'-penta-; 2,2',4,4',5,5'-hexa-; 2,2',3,4,4',5'-hexa-; 2,3',4,4',5,5'-hexa-; and 2,2',3,4,4',5,5'-hepta brominated biphenyl.

The remainder of the 30 isomers were not identified completely; the mass spectrometer analysis (Figure 2) shows the number of bromine atoms for these remaining isomers.

Solubility in Pure Water

The compositions of penta- (peaks 1-3), hexa- (peaks 4-8), and hepta- (peaks 9 and 10) isomers in the hexane-water-soluble fractions of fireMaster BP-6 are compared in Table 2. In general, the water-soluble fractions of the PBB mixtures were richer in the lower brominated isomers than the original (hexane-soluble) PBB mixtures—this should be considered when attempting to predict PBB migration in aqueous solution.

The solubility of the major isomers of PBB's and solubilities of HCB in deionized water as a function of filter media at room temperature showed that filter pore size was a major factor in measuring the aqueous solubility of PBB's and HCB. A finite pore size may allow particles smaller than the pore to pass through; this consequently affects the measurement of solubility. Recognizing that the definition of solubility in this case is an operational one, a 0.22-μm cellulose acetate membrane was chosen for future studies of solubility

and adsorption measurements. This was done because it is believed that the smaller pore size yielded filtrates that were more representative of the "true" solubility than the larger pore size, and because the hydrophilic cellulose acetate membranes were operationally easier to use and less costly than Teflon, while yielding comparable solubility values.

Solubility in Waters and Leachates

The solubilities of PBB's and HCB in waters and leachates as a function of time are shown in Tables 3 and 4. The results show that the solubilities of both PBB's and HCB were very low and that there was no significant change in the measurements after 2 days, 6 months, or even 1 year. It was concluded, therefore, that equilibrium was completed within 2 days.

The average solubilities of PBB's in distilled water, deionized water, creek water, Du Page leachate, and Blackwell leachate were 0.057 μg/L, 0.317 μg/L, 0.497 μg/L, 8.889 μg/L, and 16.892 μg/L, respectively, and the average solubilities of HCB in the same waters and leachates were 1.75 μg/L, 1.78

Table 1. *Total Organic Carbon (TOC) and Major Elements Analyses of Waters Used in PBB's and HCB Solubility Study*

Waters	*TOC (ppb)*	*B (mg/L)*	*Ca (mg/L)*	*Cr (mg/L)*	*Fe (mg/L)*	*Mg (mg/L)*	*Mn (mg/L)*	*Zn (mg/L)*	*Na (mg/L)*	*K (mg/L)*
Distilled water	*335*	*BDL**	*BDL*	*BDL*	*BDL*	*BDL*	*BDL*	*BDL*	*BDL*	*BDL*
Deionized water	*336*	*BDL*	*BDL*	*BDL*	*BDL*	*BDL*	*BDL*	*BDL*	*BDL*	*BDL*
Sugar Creek	*1,841*	*0.083*	*80.4*	*0.013*	*0.014*	*28.3*	*BDL*	*0.087*	*10.1*	*1.8*
Blackwell leachate	*63,030*	*0.915*	*48.3*	*0.133*	*0.135*	*191.0*	*0.045*	*0.087*	*291.0*	*232.0*
Du Page leachate	*83,690*	*2.690*	*33.6*	*0.092*	*0.091*	*140.0*	*BDL*	*0.271*	*321.0*	*281.0*

**BDL = Below detection limit.*

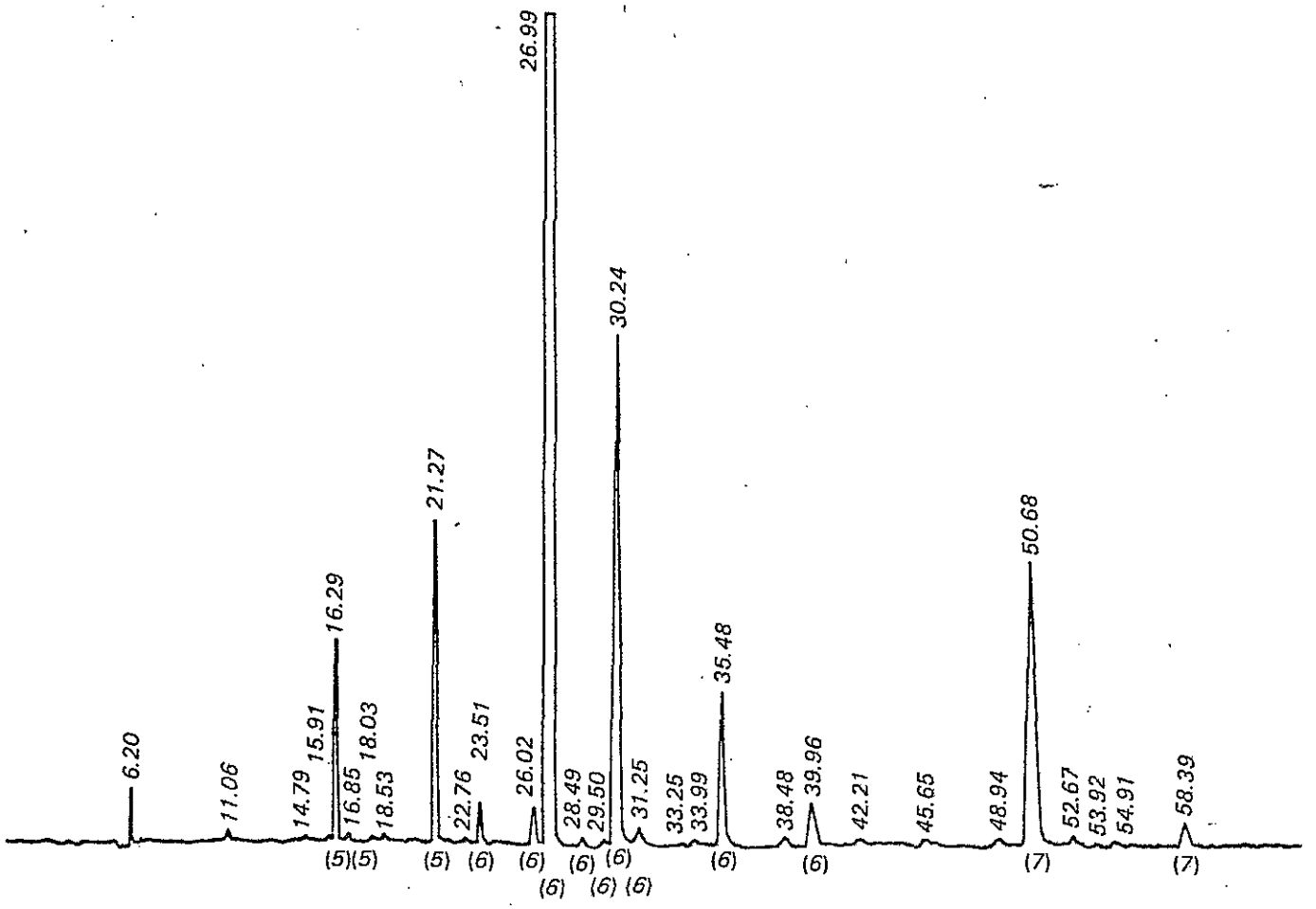


Figure 1. *Gas chromatogram of PBB isomers on SE-30 WCOT glass capillary column, using Ni electron capture detector. The numbers on each peak are the retention times in minutes; the numbers along the baseline are the numbers of Br atoms present in the particular isomer as identified by mass-spectral analysis.*

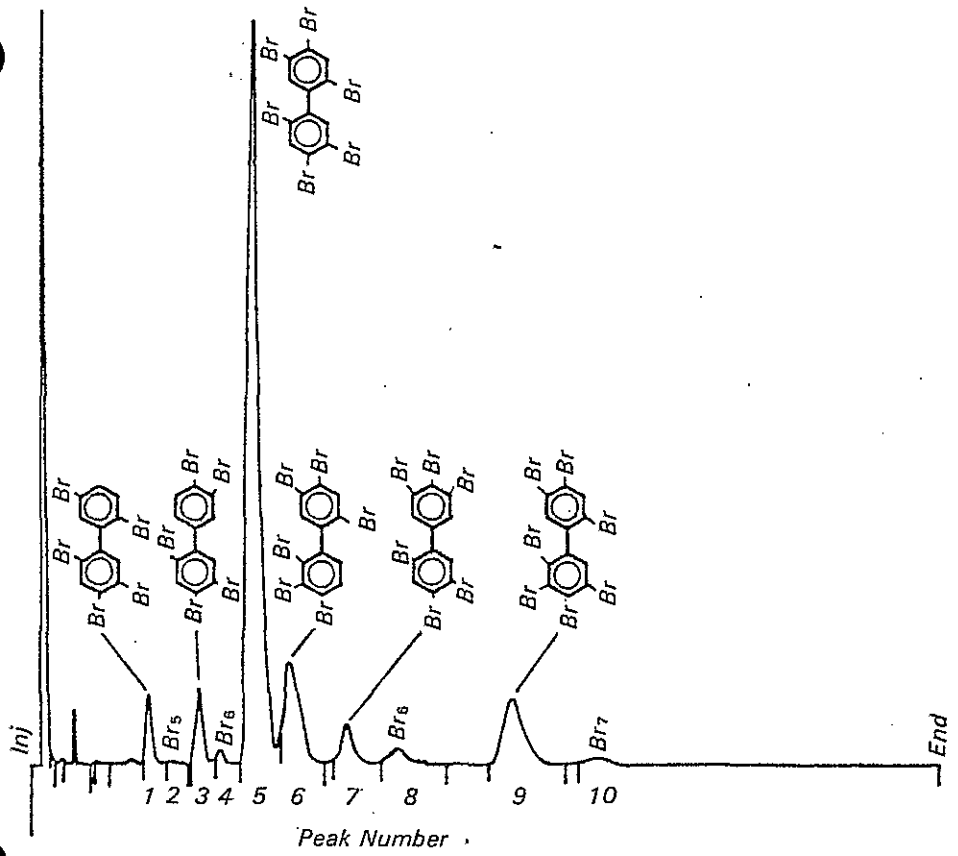


Figure 2. *Gas chromatogram of the PBB mixture fireMaster BP-6 on 6-ft glass column packed with 3 percent SE-30 on 80/100 mesh Chromosorb WHP.*

Table 2. *Distribution of PBB Isomers in Hexane- and Water-Soluble Fractions of fireMaster BP-6, Based on Total Area**

Isomer (#Br)	Hexane-soluble (%)	Water-soluble† A (%)	Water-soluble† B (%)
1 (5 Br)	3.84	18.30	16.49
2 (5 Br)	0.31	6.06	6.31
3 (5 Br)	5.02	17.09	15.50
4 (6 Br)	1.21	3.48	4.73
5 (6 Br)	60.44	27.32	31.61
6 (6 Br)	10.42	14.92	12.00
7 (6 Br)	4.42	4.12	5.50
8 (6 Br)	1.39	1.50	1.08
9 (7 Br)	11.92	6.51	5.69
10 (7 Br)	0.91	0.70	1.10
TOTAL	99.88	100.00	100.01

**Using electron capture detector.*
†PBB-saturated water filtered through glass wool (A) and glass microfiber filter (B).

μg/L, 2.22μg/L, 4.14 μg/L, and 4.47 μg/L, respectively. The higher solubilities of both compounds in creek water and leachates were directly correlated with the level of dissolved organics in the waters, as shown by the TOC values for the waters given in Table 1. These results indicate that PBB's were more than 200 times and HCB more than 2.5 times more soluble in landfill leachates than in pure waters. The type of dissolved organic matter is also apparently important in determining how soluble the compound will be in a given water. These factors must be considered when predicting the migration of these compounds from waste disposal sites.

Adsorption by Soil Materials and Ambersorb® Carbonaceous Adsorbent

All data were fitted by linear regression to the log form of the empirical Freundlich adsorption equation:

$$\log \frac{x}{m} = \log K + 1/n \log C_f$$

where x = μg or ng of compound adsorbed; m = weight of adsorbent (g); C_f = equilibrim concentration of the solution (μg/mL or ng/mL); and K and 1/n are constants.

The intercept of the linear plot of the Freundlich equation is equal to the value of K when $C_f = 1$ (log $C_f = 0$). The K value can be used to compare the adsorption of different components on various earth materials at unit concentrations. The K values reported in this study are in units of μg/g at unit concentration of 1 μg/mL and are in units of ng/g at unit concentration of ng/mL. The slope of the line gives 1/n and provides a rough estimate of the intensity of the adsorption; it also varies in a regular manner with the temperature of the system and the nature of the adsorbate.

Adsorption by Soils

The measurements of PBB adsorption on three soils from Blackwell leachate and HCB adsorption from deionized water were plotted according to the Freundlich isotherms. The data for both compounds yielded linear and nearly parallel lines for each soil type tested. All the regression lines generated had coefficients (r^2) of at least 0.98; this indicates an excellent fit of the data to the Freundlich equation. The data also show that HCB had a greater tendency for adsorption on these adsorbents than did PBB's under these experimental conditions. The adsorption of PBB's and HCB on these three soils followed the series: muck>Catlin>Ava. This suggests a relationship between the organic carbon content of these soils and their adsorption capacity for PBB's and HCB.

Effect of Organic Solvents on Adsorption by Soils

The adsorption of hexane-ethanol-soluble ^{14}C-PBB's and ^{14}C-HCB by Catlin

Table 3. Solubility of PBB's in Waters and Leachates (μg/L) filtered Through Presaturated Millipore Membrane (0.22 μm) as a Function of Equilibration Time*

	Distilled water			Deionized water			
Peaks	2 days	4 days	7 days	2 days	4 days	7 days	6 months
1	BDL†	BDL	BDL	0.030	0.029	0.035	0.037
2	BDL	BDL	BDL	BDL	BDL	BDL	BDL
3	BDL	BDL	BDL	0.040	0.038	0.045	0.055
4	0.001	0.002	0.001	BDL	BDL	BDL	0.013
5	0.035	0.032	0.038	0.136	0.142	0.125	0.100
6	0.004	0.003	0.004	0.059	0.050	0.064	0.062
7	BDL	BDL	BDL	0.017	0.016	0.015	0.014
8	BDL	BDL	BDL	0.009	0.008	0.015	0.012
9	0.017	0.019	0.016	0.028	0.025	0.026	0.023
10	BDL	BDL	BDL	BDL	BDL	BDL	BDL
TOTAL	0.057	0.056	0.059	0.319	0.308	0.325	0.316

	Sugar Creek			Du Page			Blackwell		
Peaks	2 days	4 days	7 days	2 days	4 days	7 days	2 days	4 days	7 days
1	0.038	0.034	0.043‡	0.461	0.501	0.448‡	0.610	0.660	0.721‡
2	BDL	BDL	BDL	0.242	0.240	0.244	0.490	0.498	0.520
3	0.040	0.039	0.044	0.901	1.005	0.760	1.415	1.373	1.467
4	0.005	0.004	0.006	0.178	0.210	0.163	0.306	0.314	0.333
5	0.175	0.161	0.190	2.605	2.686	2.417	5.615	5.097	6.141
6	0.067	0.087	0.089	1.673	1.979	1.457	3.000	2.979	3.149
7	0.039	0.037	0.042	0.910	0.923	0.788	1.857	1.709	1.901
8	0.037	0.039	0.038	0.510	0.490	0.469	0.773	0.756	0.711
9	0.080	0.074	0.084	1.050	1.203	0.930	1.925	1.908	2.136
10	BDL	BDL	BDL	0.430	0.427	0.368	0.790	0.725	0.798
TOTAL	0.481	0.475	0.536	8.960	9.664	8.044	16.781	16.019	17.877

**Each value is a mean of two replications.*
†Below detection limit.
‡Each value is a mean of four replications (two separate sets).

Table 4. Solubility of HCB in Waters and Leachates (μg/L) Filtered Through Presaturated Millipore Membrane (0.22 μm) as a Function of Equilibration Time

	Concentration (μg/L)*			
Waters and Leachates	2 days	7 days	30 days	1 yr
Distilled water	1.77	1.71	1.75	ND+
Deionized water	1.83	1.67	1.78	1.89
Sugar Creek water	2.43	2.35	2.22	ND
Du Page leachate	4.17	4.04	4.14	ND
Blackwell leachate	4.58	4.29	4.47	ND

**Each value is a mean of two replications.*
+Not determined.

and muck soil was investigated. Little or no adsorption of either PBB's or HCB from these two organic solvents was observed. Representative data for hexane-soluble ^{14}C-PBB's and ^{14}C-HCB remaining in hexane solution after equilibrium with Catlin silt loam soil are presented in Table 5.

As indicated by these results, it may not be feasible to dispose of PBB's or HCB dissolved in organic solvents on soils. A migration of PBB's and HCB from the soil surface or from a landfill environment could occur if PBB or HCB wastes and organic solvents were disposed of at the same location.

Adsorption by Ambersorb XE-348 from Organic Solvents

The adsorption of PBB's and HCB by carbonaceous adsorbents was investigated to learn if activated carbons or similar materials could be used to adsorb these two compounds from organic solvents.

The measurements of PBB and HCB adsorption from several organic solvents by Ambersorb XE-348 were plotted according to the Freundlich adsorption isotherm. In contrast to the results obtained with soils, these data indicate that large quantities of PBB's and HCB were adsorbed by the Ambersorb from the organic solvents. There were also large differences in the amounts adsorbed among the solvents. HCB was consistently absorbed in greater amounts than PBB's from a given solvent; this was also true for adsorption by soils from aqueous solutions. The fact that a high melting point indicates that the adsorption of PBB's from a solvent is lower, and that the higher intermolecular forces for nonionic compounds must be overcome for melting to occur, shows that inter-molecular forces between solvent-solvent mole-

cules and solvent-solute molecules are important factors in determining the amount of PBB's and HCB adsorbed from organic solvents.

Results indicate that the various PBB isomers have different affinities for a given adsorbent from a given solvent. These facts may be important when predicting PBB migration through soils or carbonaceous liners if the isomer distribution is markedly different than that found in fireMaster BP-6, or if various solvents are involved.

Effect of Soil TOC on Adsorption

There was a high direct correlation between the TOC content of the soil and the amount adsorbed.

The PBB adsorption constant (K) was plotted as a function of TOC. A high correlation was found with a linear regression relation of:

$$K = 64.92 + 17.57\ TOC$$
$$r^2 = 0.999$$

For HCB, results were silimar:

$$\log K = 2.01 + 0.10\ TOC$$
$$r^2 = 0.999$$

These results indicate that the adsorption properties of soil materials for PBB's and HCB can be predicted accurately when TOC content of the soil is known. This information should be used with caution, however, because only three soils were used to develop the equations. The large values of the intercept indicates substantial adsorption should take place when the TOC content of the soil is zero. This implies that the mineral fraction of the soil contributed to the adsorption capacity; therefore, the relationship may be incorrect for soil materials with low TOC content.

Mobility of PBB's and HCB in Soil Materials

Effect of Leachate Solvent and Soil TOC

Table 6 shows the mobilities of PBB's and HCB, expressed as Rf values, in several earth materials as determined by soil thin-layer chromatography (TLC). The data show that PBB's and HCB remained immobile in the earth materials when leached with water and Du Page leachate, but were highly mobile when leached with organic solvents.

PBB's and HCB are nonpolar in nature and have low solubility in water; however, they have high solubility in organic solvents such as dioxane, carbon tetrachloride, acetone, methanol, etc. The mobilities of PBBs and HCB in earth materials were dramatically reduced when they were leached with the acetone/water mixture.

Column Leaching Studies

Column leachate studies showed that no PBB's or HCB were retained in columns when ethanol containing ^{14}C-PBB's or ^{14}C-HCB was percolated through the soil columns. Also, nearly 100 percent of ^{14}C-PBB's or ^{14}C-HCB were recovered from soil columns percolated with organic solvent.

These facts are significant for the diposal of PBB's and HCB wastes. To prevent migration of PBB's and HCB from a landfill, PBB and HCB wastes and organic solvents should not be disposed of in the same landfill area, and neither compound should be allowed to come in contact with leaching organic solvents in soils. The results from the adsorption studies indicate that carbonaceous liners may restrict the migration by removing PBB's or HCB dissolved in organic solvents.

Degradation of PBB's and HCB in Soils

Extraction of PBB's and HCB from Soil

The studies indicate that a polar organic solvent is important in the extraction of PBB's and HCB from soil. This suggests that acetone or methanol acts as a bridge between the water film on the soil particles and allows transfer of the compound being extracted into the nonpolor solvent, thus yielding higher extraction efficiencies from the dual solvent system than when either solvent is used alone.

Soil Incubation Studies

Data in the incubation studies show that PBB's and HCB persisted for 6 months in the soil, with no significant decreases in concentration resulting from to microbial degradation.

Since PBB's are not degraded, are not leached by water, are not taken up by plants, and are not readily volatilized, we expect PBB's to be a permanent component of contaminated soils. HCB also is not degraded or leached by water and is probably not taken up by plants; however, HCB has a moderate vapor pressure and its most likely path for redistribution or migration in soils is by vapor transport.

Recommendations

The results show that organic solvents increase the mobility of PBB's and HCB and that carbonaceous adsorbents such as Ambersorb XE-348 are capable of adsorbing PBB's and HCB from organic solvents. These findings led to the recommendation that disposal of PBB or HCB wastes dissolved in organic solvents or co-disposal of PBB or HCB materials with organic solvents be avoided at land disposal sites unless a carbonaceous liner material is used.

Because it was shown that adsorption of PBB's and HCB by soils was essentially zero in organic solvents, the problem of predicting PBB and HCB migration shifted from adsorption to fluid conductivity. Prediction of migration depends on a knowledge of what the fluid conductivity of the soil material is to the organic solvent. Unfortunately, information on this subject is sparse. To

Table 5. ^{14}C-PBB's and ^{14}C-HCB Remaining in Hexane Solution After Equilibrium with Catlin Silt Loam Soil at 22° ± 1°C

Amount of soil (g)	Concentration (ppm)* ^{14}C-PBB's	^{14}C-HCB
0	0.325	0.227
1	0.330	0.229
2	0.324	0.227
3	0.327	0.224
4	0.320	0.224
5	0.322	0.225
6	0.323	0.223
8	0.320	0.223
10	0.322	0.225

**Each value is a mean of two replications. The original concentration of PPB's and HCB were 0.326 ppm and 0.228 ppm, respectively.*

Table 6. *Mobility, Expressed as Rf Values,* of PBB's and HCB in Several Soil Materials Leached with Various Solvents, Measured by Soil TLC*

Soil Materials	Rf Values*											
	Water		Du Page Leachate		Acetone/water (1:1, v/v)		Methanol		Acetone		Dioxane	
	PBB	HCB	PBB	HCB	PBB	HCB	PBB	HCB	PBB	HCB	PBB	HCB
Catlin silt loam	0.00	0.00	0.00	0.00	0.01	0.00	0.40	0.40	0.69	0.45	1.00	0.99
Flanagan silty clay loam	ND†	ND	0.00	0.00	ND	ND	0.60	0.44	ND	ND	1.00	1.00
Ava silty clay loam	0.00	0.00	0.00	0.00	0.02	0.01	0.61	0.48	0.76	0.80	1.00	1.00
Bloomfield loamy sand	ND	ND	0.00	0.00	ND	ND	0.86	0.72	ND	ND	1.00	1.00
Ottawa sand	0.00	0.00	0.00	0.00	0.17	0.02	1.00	0.99	0.99	1.00	1.00	1.00

**Computed from statistical peak analysis of data by using values of first moment for grouped data.*
†ND = Not determined.

predict migration, more information is needed to determine the effects of soil properties, soil moisture conditions, and organic solvent interactions on the migration rate of the solvent through soil materials in a landfill environment.

The results and conclusions formulated from this study deal specifically with attenuation and mobility of PBB's and HCB in the liquid phase. Vapor phase transport through soil pores was ignored; however, for compounds with a moderate or high vapor pressure, such as HCB, this means of migration may be a significant mechanism for redistribution. More information is needed to assess the magnitude of this means of migration for organic wastes.

The full report was submitted as an amendment to Grant No. R-804684-01 by the Illinois State Geological Survey, Urbana, IL, under the sponsorship of the U.S. Environmental Protection Agency.

The EPA author of this Project Summary is ***Norma M. Lewis*** *of the Municipal Environmental Research Laboratory, Cincinnati, OH 45268.*
Richard A. Carnes *was the EPA Project Officer (see contact below).*
The complete report, entitled "Attenuation of Polybrominated Biphenyls and Hexachlorobenzene by Earth Materials," was authored by R. A. Griffin and S. F. J. Chou of the Illinois State Geological Survey, University of Illinois, Urbana, IL 61801 (Order No. PB 82-107 558; Cost: $8.00, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
For information contact ***Mike H. Roulier*** *at:*
Municipal Environmental Research Laboratory
U.S. Environmental Protection Agency
Cincinnati, OH 45268

United States
Environmental Protection
Agency

Center for Environmental Research
Information
Cincinnati OH 45268

Postage and
Fees Paid
Environmental
Protection
Agency
EPA 335

Official Business
Penalty for Private Use $300

RETURN POSTAGE GUARANTEED

Third-Class
Bulk Rate

☆U.S. GOVERNMENT PRINTING OFFICE:1981--359-092/3334

52. Mackay, D.M., et al. "A Field Experiment on Ground Water Transport of Halogenated Organic Solutes," Preprint Extended Abstract, American Chemical Society, 1983

"PREPRINT EXTENDED ABSTRACT"
Presented Before the Division of Environmental Chemistry
American Chemical Society
Washington, D.C. September 1983

Eagle

2647

A FIELD EXPERIMENT ON GROUND WATER TRANSPORT OF HALOGENATED ORGANIC SOLUTES

Douglas M. Mackay, David L. Freyberg, Mark N. Goltz,
Gary D. Hopkins, and Paul V. Roberts

Department of Civil Engineering
Stanford University
Stanford, California 94305

To assess whether understanding gained from theory and laboratory experiments can be used to interpret and predict the transport of halogenated organic solutes in ground water under natural field conditions, a group of investigators from Stanford University and the University of Waterloo have initiated a large-scale natural gradient field experiment. In August 1982, a known mass of selected solutes was injected as a broad pulse into an uncontaminated portion of an unconfined, glaciofluvial sand aquifer at Canadian Forces Base Borden in Ontario, Canada.

Experimental

The total volume injected was $12m^3$. The solutes and their injected concentrations were: chloride (892 mg/l), bromide (324 mg/l), carbon tetrachloride (31 μg/l), bromoform (35 μg/l), tetrachloroethylene (30 μg/l), o-dichlorobenzene (337 μg/l) and hexachloroethane (20 μg/l). The injection concentrations were chosen to allow detection of the solute plumes for a relatively long period of time (over 1 year) using rapid, reliable ion and gas chromatographic techniques.

The solute plumes are being monitored using a dense network of multilevel sampling wells, with horizontal spacings of 0.5-3.0m and vertical spacings of 0.2-0.3m. The network extends approximately 40m in the direction of the natural gradient (x-axis), is 15-20m wide, and covers a vertical interval of 1.5-6.0m below ground surface. As of March 1983, over 4000 samples had been collected using devices specially designed to ensure that the samples were representative and properly logged. The majority of samples were taken in seven sessions, at intervals of 1-3 weeks, to yield detailed three-dimensional "snapshots" of solute distribution. The results of intensive examination of the snapshot data have been reported elsewhere (1). The goal of that effort was the quantitative characterization of the size, shape and location of the solute plumes, including the estimation of total dissolved mass, location of the center of mass, and the second moment of mass about the center of mass of each solute plume. From that information, quantitative descriptions of the advective and dispersive characteristics of the plumes have been developed.

More frequent sampling (3-5 times/week) is being conducted at three points within the well-field near the injection zone to provide more detailed time series concentration information (breakthrough curves). An example of the breakthrough curves for one of the points is shown in Figure 1, in which normalized concentrations (measured values divided by the injected concentrations) are plotted versus time after injection. The chromatographic separation of the solutes graphically illustrates their varied mobility under natural gradient conditions. Similar plots were obtained for the other two points sampled frequently. For solutes whose breakthrough was complete, the plots permit some preliminary quantitative analysis as follows.

Results and Discussion

The time which bisects the area under each breakthrough curve is taken as the time, t_i, for the center of mass of solute i to travel from its injected location to the sampling point. Assuming uniform injection of the various solutes (i.e., identical location of center of mass of each solute after injection), the retardation factor, R_i, for transport of organic solute i is given by (t_i/t_o), where t_o is the travel time for the conservative tracers. The travel times and retardation factors thus determined are shown in Table 1 for the three sampling points, along with the coordinates of the points.

Examination of Table 1 reveals that the estimated retardation factors for carbon tetrachloride and bromoform are similar and the variation of values for a given solute at the three sampling points is 15% or less. If these differences are significant, they may reflect spatial variability in sorptive characteristics of the aquifer, as the solutes travel different paths to the sampling points. Further work is necessary to define the confidence limits of these estimates before a firm conclusion regarding such spatial variability can be made.

It is instructive to compare the field estimates of retardation factors with calculations based on theory and empirical correlations. If mass transfer of solute to sorption site is rapid (i.e., local equilibrium is attained) and the sorption equilibrium relationship is linear, the retardation factor for ideal flow transport of the sorbing but non-reacting solute is given by

$$R = [1 + (\rho_b K_d/n)]$$

where K_d = the distribution coefficient (m^3/g), ρ_b = the bulk density of the aquifer material (g/m^3), and n = the aquifer porosity (void fraction). Karickhoff et al. (2) found that the value of K_d for a given soil-solute system is well-estimated by

$$K_d = 6.3\text{x}10^{-7} f_{oc} K_{ow}$$

where f_{oc} = fraction of organic carbon in the soil (g/g) and K_{ow} = octanol:water partition coefficient (molar concentration basis). In similar experiments by Schwarzenbach and Westall (3), K_d was best estimated by

$$\log K_d = 0.72 \log K_{ow} + \log f_{oc} - 5.51$$

where definitions and units are as before.

Table 2 lists the comparison of our field estimates of retardation factors with values calculated using the equations above. The assumed values of K_{ow} are taken from Hansch and Leo (4) and are listed in the table. Bulk density was taken as $1.76\text{x}10^6$ g/m^3 and porosity as 0.38 (5). The organic carbon content of the aquifer solids has been estimated as 0.075-0.2% in preliminary analyses at Stanford and Waterloo. Consequently, Table 2 lists a range of calculated retardation factors corresponding to that range of organic carbon contents.

Although further work is required to improve our estimation of field retardation and aquifer characteristics (especially f_{oc} and n), Table 2 indicates that the calculated values of R for bromoform agree well with the field results. Agreement is not as good for carbon tetrachloride. Comparison for the other solutes is not possible at the time of writing, as breakthrough is incomplete. Continued sampling and analysis will allow more complete comparison in the future.

Acknowledgements

This work was supported by the Robert S. Kerr Environmental Research Laboratory of the U.S. Environmental Protection Agency under CR-808851. The authors gratefully acknowledge the invaluable participation of numerous researchers at the Department of Earth Sciences, University of Waterloo, and the Department of Civil Engineering, Stanford University.

References

1. Freyberg, D.L. et al. A Large Scale Natural Gradient Field Experiment for Assessing Models of Solute Transport in Groundwater. Presented at 1983 Hydraulics Division Specialty Conference Special Session on Groundwater Quality Modeling, ASCE, held at M.I.T. on 9-12 August 1983.

2. Karickhoff, S.W., D.S. Brown and T.A. Scott. Sorption of Hydrophobic Pollutants on Natural Sediments. Water Res. 13:241-248, 1979.

3. Schwarzenbach, R. and J. Westall. Transport of Nonpolar Organic Compounds from Surface Water to Groundwater. Laboratory Sorption Studies. Environ. Sci. Technol. 15(11):1360-1367, 1981.

4. Hansch, C. and A. Leo. Substituent Constants for Correlation Analysis in Chemistry and Biology. Wiley and Sons, Inc., N.Y., 1979.

5. Waterloo Research Insitute. CFB Borden Landfill Study. Vol. 1. Hydrogeological Studies of a Sandy Aquifer at an Abandoned Landfill. Final Report under Contract No. OSU78-00195 for the Dept. of Supply and Services, Dec. 1980.

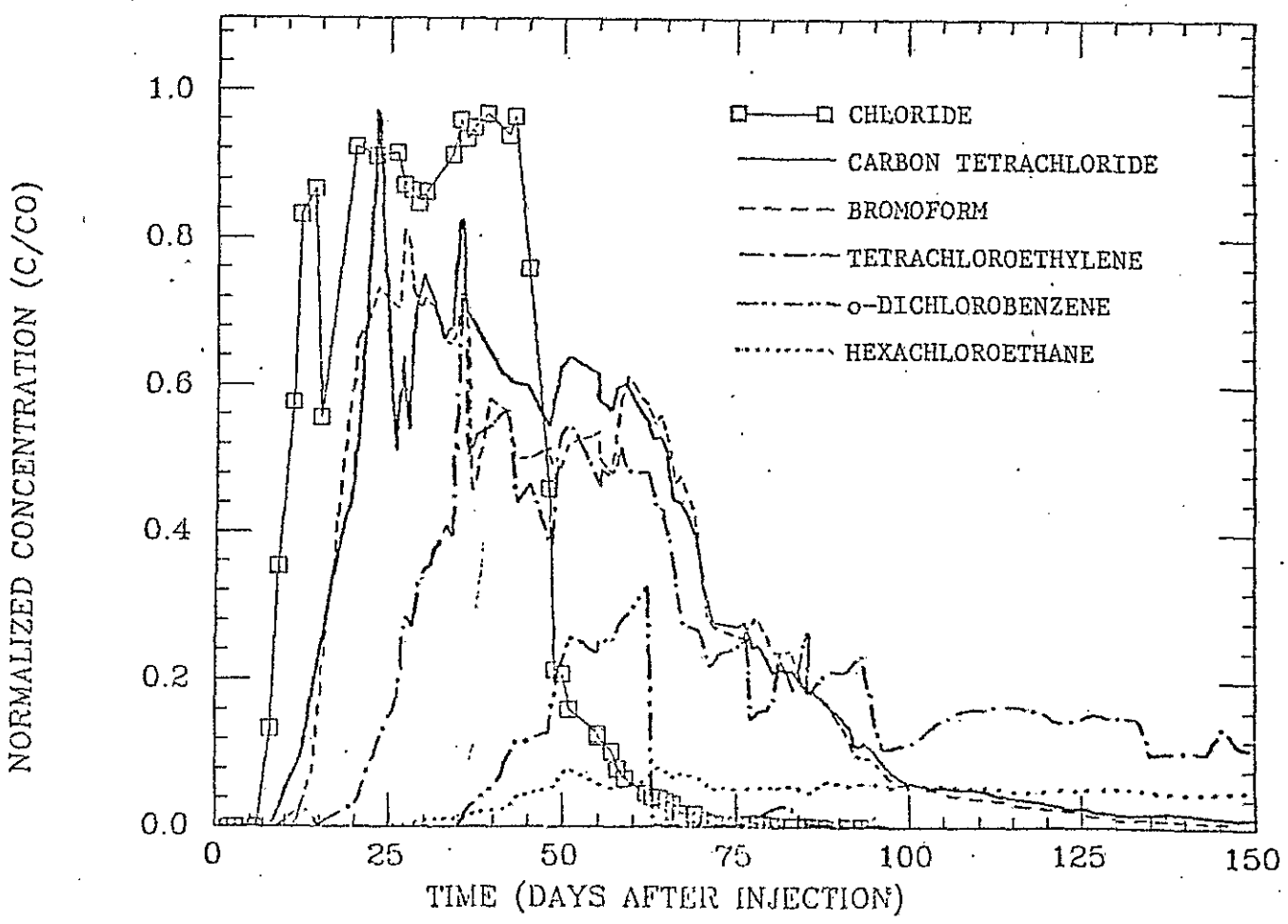


Figure 1. Breakthrough plot for well (2,1) tube 9. Normalized concentration (measured/injected) versus time. Coordinates of sampling point are given in Table 1.

TABLE 1: RESULTS OF BREAKTHROUGH SAMPLING

Sampling Location	Solute	Average Travel Time (days)	Retardation Factor
Well (2,1) tube 9			
x = 2.5m	Chloride	32	1.00
y = 1.25m	Carbon Tetrachloride	46	1.44
z = 3.4m	Bromoform	48	1.50
Well (2,0) tube 7			
x = 2.5m	Chloride	40	1.00
y = 0	Carbon Tetrachloride	66	1.65
z = 3.0m	Bromoform	68	1.70
Well (4,0) tube 7			
x = 5.0m	Chloride	67	1.00
y = 0	Carbon Tetrachloride	115	1.72
z = 3.0m	Bromoform	120	1.79

TABLE 2: COMPARISON OF RETARDATION FACTOR ESTIMATES

Solute	log K_{ow}*	Retardation Factor (R)		
		Calculated according to		Field Results
		Ref. 2**	Ref. 3**	
Carbon Tetrachloride	2.72	2.2 - 4.1	2.0 - 3.6	1.4 - 1.7
Bromoform	2.38	1.5 - 2.4	1.6 - 2.5	1.5 - 1.8
Tetrachloroethylene	2.60	1.9 - 3.3	1.8 - 3.1	***
o-Dichlorobenzene	3.38	6.3 - 15	3.9 - 8.8	***
Hexachloroethane	4.62	92 - 244	24 - 62	***

* octanol-water partition coefficients from Hansch and Leo (4)
** see text for discussion of calculations
*** insufficient field data for evaluation of R at time of writing

53. Matrecon, Inc., Lining of Waste Impoundment and Disposal Facilities, Office of Research and Development, U. S. Environmental Protection Agency, Cincinnati, Ohio, September 1980, pp. 54-80, 107-140

United States
Environmental Protection
Agency

Office of Water and
Waste Management
Washington DC 20460

SW-870
September 1980

EPA

Lining of Waste Impoundment and Disposal Facilities

LINING OF WASTE IMPOUNDMENT AND DISPOSAL FACILITIES

by

Matrecon, Inc.
Oakland, California 94623

Project Officer

Robert Landreth
Solid and Hazardous Waste Research Division
Municipal Environmental Research Laboratory
Cincinnati, Ohio 45268

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

ACKNOWLEDGMENTS

This document was prepared by Matrecon, Inc., Oakland, California, under a contract with the Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, Ohio. Henry E. Haxo, Jr., was Principal Investigator on this project.

The following personnel made contributions to the text.

Matrecon, Inc.:

Suren Dakessian

Michael A. Fong

Richard M. White

Emcon Associates, San Jose, California:

John G. Pacey

Southwest Research Institute, San Antonio, Texas:

David W. Shultz

Texas A and M University, College Station, Texas:

Kirk W. Brown

Also, Paul D. Haxo contributed in editing.

Prefabricated asphalt panels have been used as liners for water reservoirs. These panels typically consist of a core layer of blown asphalt blended with mineral fillers and reinforcing fibers. The asphalt mix is molded under heat and pressure, then placed between fabric sheets with a protective coating of hot applied asphalt. The fabric sheets are usually asphalt impregnated felt, plastics, or flexible glass fabrics. Panels are one-eighth to one-half inch thick, three to four feet wide, and 10 to 20 feet long (Asphalt Institute, 1976, p. 21). The panels are rugged and flexible. They are flexible enough to conform to and mold around irregularities in the subgrade, although bends with a radius of less than 12 inches should be avoided. They are tough enough to withstand abuse from pocket knives, razor blades, animal traffic, burrowing and digging rodents, light vehicular traffic, and the erosive forces of wind and waves. When properly installed and seamed, the panels form a relatively smooth watertight seal exhibiting the resistance characteristic of asphalt as described previously. Some problems occur with aging in hot dry climates; volatile fractions are lost, causing the panels to become somewhat brittle and to shrink. Thermal expansion and contraction of exposed panels may cause "neck down" at joints, resulting in cracks and possible leaks. These problems may be partially overcome by covering the portions exposed to direct sunlight (Asphalt Institute, 1976). The panels may be joined by lapping joints or butting together and seaming by use of batten strips. Hot asphalt, cold asphalt mastic, or heat welding may be used in seaming.

3.3.3 Soil Cement

Soil cement is a compacted mixture of portland cement, water, and selected in-place soils. The result is a low strength portland cement concrete with greater stability than natural soil. The permeability of this mixture varies with the type of soil; a more granular soil produces a more permeable soil cement. A fine-grained soil produces a soil cement with a permeability coefficient of about 10^{-6} cm s^{-1} (Stewart, 1978). To date, there have been few studies performed to design a soil cement with very low permeabilities (less than 10^{-8} cm s^{-1}), as opposed to mixes designed for high compressive strength. To reduce permeability of soil cement, coatings such as epoxy asphalt and epoxy coal-tar have been used.

Any soil, except organic soil, with less than 50% silt and clay is suitable for soil cement. However, a well-graded soil with a maximum size of 0.75 inch and a maximum silt and clay content of 35% is preferable (Bureau of Reclamation, 1963). A high clay content impairs the ability to form a homogeneous cemented material thus reducing the efficiency of producing an impermeable layer. Three criteria must be considered for soil cement liners: cement content, moisture content, and the degree of compaction. The optimum moisture and cement contents are determined by laboratory testing. The optimum moisture is that which results in maximum density of the compacted soil cement. Laboratory samples should be tested in wet-dry and freeze-thaw cycle tests (ASTM D559 and ASTM D560) to determine the optimum cement content.

The aging and weathering characteristics of soil cements are good, especially those associated with wet-dry, freeze-thaw cycles. Some degradation has been noted when this substance is exposed to highly acidic environments (Stewart, 1978), but soil cements can resist moderate amounts of alkali, organic matter,

and inorganic salts. One of the main deficiencies of soil cement as a liner material is its tendency to crack and shrink on drying.

3.3.4 Soil Asphalt

Soil asphalt is a mixture of available on-site soil, usually low plasticity, and liquid asphalt. A silty, gravelly soil with 10-25% silty fines is the preferred soil type. The permeability of soil asphalt after compaction varies with the percent compaction and the percent asphalt. A high void content (3-10%) soil asphalt has a measurable permeability. Soil asphalts containing cutback asphalt are not recommended as lining materials. Soil asphalt made with asphalt emulsion is not sufficiently impermeable and requires a waterproof seal such as a hydrocarbon resistant or bituminous seal (Asphalt Institute, 1976).

3.4 Flexible Polymeric Membranes

3.4.1 Introduction

Prefabricated liners based upon sheeting of polymeric materials are of particular interest for the lining of waste storage and disposal impoundments. As a group, these materials exhibit extremely low permeability. They have found substantial use in water impoundments in reservoirs and are being used in the lining of sanitary landfills and various waste disposal facilities.

Liner technology is relatively new and a wide variety of liner materials are being manufactured and marketed. These materials vary considerably in physical and chemical properties, methods of installation, costs and interaction with various wastes. Not only are there variations in the polymers used, but also there is considerable variation in the lining materials of a given polymer type due to compounding, construction, and manufacturing differences among the producers.

In this section, the lining industry, the various polymeric materials, and the liner construction and methods of manufacture are described and discussed.

3.4.2 Description of the Polymeric Liner Industry

Although it is only a small part of the plastic and synthetic rubber industry, the polymer liner industry has a unique hierarchy which needs to be examined carefully (Figure 3-4). Basically, the industry breaks down into four major segments:

- Raw materials producers
- Manufacturers of sheeting or roll goods
- Fabricators of prefabricated panels
- Installers or construction contractors.

A given company in the industry can perform two or more of these functions, e.g. a sheeting manufacturer might also fabricate and install; however, that is not the usual case. Another important factor is that of the design of the disposal site and the selection of the lining. This function is usually

FLEXIBLE MEMBRANE LINER INDUSTRY

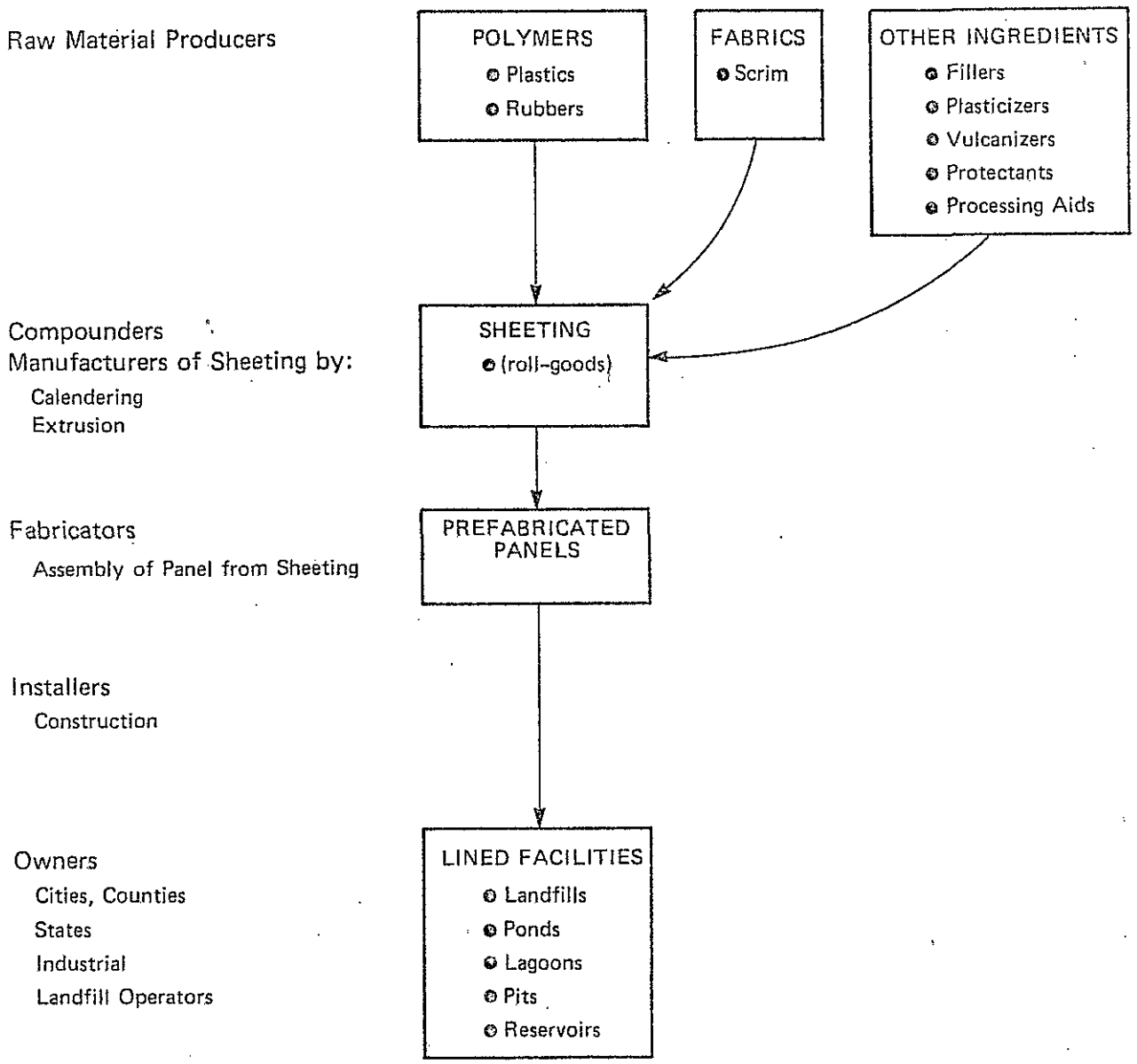


Figure 3-4. Basic structure of the polymeric membrane liner industry from raw material manufacturers to liner installers. A representative list of organizations and personnel in the individual segments of the industry is presented in Appendix II.

performed by engineering and consulting firms and at times by fabricators and installers.

Current representative lists of polymer producers, liner manufacturers, fabricators, and installers are included in Appendix II. The various segments of the industry are discussed in the following sections.

3.4.2.1 Raw Materials Production

The membrane or finished sheeting is made from raw polymer combined with a variety of compounding ingredients, such as carbon black, pigments, fillers, plasticizers, processing aids, crosslinking chemicals, antidegradants and biocides. Table 3-5 presents such a list of polymer producers giving trade names or other common identification and respective suppliers of the polymer.

The polymer producers normally supply technical service to reputable sheeting manufacturers, presenting recommended formulations and manufacturing procedures. Some of the polymer producers conduct random monitoring of the sheet manufacturers to protect their polymer, but such quality control is growing more difficult to achieve because of the rapid growth of the industry. The individual polymers are discussed in Section 3.4.3.

3.4.2.2 Preparation of Liner Compounds and Manufacture of Sheeting and Roll Goods

The final selection of compounding ingredients for each of the polymers is the responsibility of the sheeting manufacturer. The expertise employed in formulating, mixing, and forming sheets will control the properties of the finished liner. The polymer and its required compounding ingredients are often mixed on a mill or in an internal mixer, such as a banbury. The mixed compound is then converted continuously into rolls of sheeting 48 to 96 inches wide by hundreds of feet in length by calendering or extrusion. A description of the manufacturing process is presented in Section 3.4.4. A representative list of sheeting manufacturers is presented in Appendix II.

3.4.2.3 Fabrication

After calendering or extrusion, the sheeting is ready for fabrication into panels. In this step the sheets or roll goods are joined (seamed) together to form panels (up to 100 feet x 200 feet). The size of the panels is limited by weight and the ability of a crew to place it in the field. Various seaming techniques can be employed including, but not limited to: heat seaming, dielectric seaming, adhesive systems, and solvent welds. The method used should be fully specified including the type of quality control to be used. Factory seams are usually more reliable than field seams, since they are made under carefully controlled conditions. If the area to be lined is small enough, the entire finished liner may be prefabricated in one piece, eliminating field seaming altogether; this is called a drop-in liner.

TABLE 3-5. POLYMER PRODUCERS AND SUPPLIERS

Polymer	Trade Name	Company
Butyl rubber	-	Exxon Columbian Carbon Polysar
Chlorinated polyethylene (CPE)	CPE[a]	Dow Chemical
Chlorosulfonated polyethylene (CSPE)	Hypalon	Du Pont
Elasticized polyolefin	3111	Du Pont
Epichlorohydrin rubbers	Herclor Hydrin	Hercules B. F. Goodrich
Ethylene propylene rubber (EPDM)	Epcar Epsyn Nordel Royalene Vistalon	B. F. Goodrich Copolymer DuPont Uniroyal Exxon
Fluorocarbon polymers	Viton/Teflon	Du Pont
Neoprene (chloroprene rubber)	Neoprene[a]	Du Pont Denka
Nitrile rubber (NBR)	Chemigum Hycar Krynac NYsyn Paracril	Goodyear B. F. Goodrich Polysar Copolymer Uniroyal
Polybutylene (PB)	-	Shell Chemical
Polyester	Hytrel	Du Pont
Polyethylene - HDPE - LDPE	- -	Many Many
Polyvinyl chloride	PVC[a]	Borden General Tire B.F. Goodrich Firestone Pantasote Stauffer Tenneco Union Carbide
Thermoplastic elastomer	Santoprene TPR	Monsanto Uniroyal
Urethane	-	Many

[a] Generic name

3.4.2.4 Installation

After the raw materials are produced, compounded, converted into roll-goods and fabricated into panels, the installation is the final step in completing the liner project. The installation should be performed by an experienced liner installer or by a qualified specialty contractor whose experience is in liner installation, the associated earthwork, and piping installation. The installation is not complete until all field seams have been inspected to the satisfaction of the end user or his representative. Air lancing and ultrasonic methods have been used in the field to make 100% inspection of seams.

3.4.2.5. Engineering and Design Services

Another important segment of the liner industry is the engineering and design services that are furnished by various engineering and consulting firms. Such services can supply the designs of disposal sites and participate in the selection of the liner systems to be used. They also can supply quality control services during the installation of the liners.

3.4.2.6. Integration in the Liner Industry

Some companies perform two or more functions within the industry. For example, some manufacturers of sheeting will also fabricate. Some installers fabricate, other installers will design and supply engineering services.

3.4.3 Polymers Used in Liner Manufacture

Polymers used in the manufacture of lining materials are listed in Table 3-6. They include rubbers and plastics differing in polarity, chemical resistance, basic composition, etc. They can be classified into four types:

- Rubbers (elastomers) which are generally vulcanized.
- Plastics which are generally unvulcanized, such as PVC.
- Plastics which have a relatively high crystalline content, such as the polyolefins.
- Thermoplastic elastomers which do not need to be vulcanized.

Table 3-6 lists the various types of polymers that are used and indicates whether they are used in the vulcanized or nonvulcanized form and whether they are reinforced with fabric. The polymeric materials most frequently used in liners are polyvinyl chloride (PVC), chlorosulfonated polyethylene (CSPE), chlorinated polyethylene (CPE), butyl rubber, ethylene propylene rubber (EPDM), neoprene, high-density polyethylene (HDPE), and low-density polyethylene (LDPE). The thickness of polymeric membrane for liners range from 20 to 120 mils, with most in the 20-60 mil range.

Most of the lining materials are based on individual polymers; however, plastics and rubber technology has been developing blends or rubber-plastic alloys for improved properties. Consequently, it is difficult to make generic classifications based on individual polymers of the liners though one polymer may predominate in the compound. Blending of polymers introduces the long range possibility of performance specifications being needed. However,

Table 3-6 POLYMERIC MATERIALS USED IN LINERS

Polymer	Use in liners		Fabric reinforcement	
	Thermo-plastic	Vulcanized	With	W/O
Butyl rubber	No	Yes	Yes	Yes
Chorinated polyethylene	Yes	Yes	Yes	Yes
Chlorosulfonated polyethylene	Yes	Yes	Yes	Yes
Elasticized polyolefin	Yes	---	No	Yes
Elasticized polyvinyl chloride	Yes	---	Yes	No
Epichlorohydrin rubber	Yes	Yes	Yes	Yes
Ethylene propylene rubber	Yes	Yes	Yes	Yes
Neoprene (chloroprene rubber)	No	Yes	Yes	Yes
Nitrile rubber	Yes	---	Yes	---
Polyethylene	Yes	No	No	Yes
Polyvinyl chloride	Yes	No	Yes	Yes

liner performance in the field cannot, at the present time, be defined by laboratory tests.

Most of the membrane liners currently manufactured are based on unvulcanized or uncrosslinked polymeric compounds which are thus thermoplastic. Even if the polymer in the vulcanized form is more chemically resistant, such as CPE and CSPE, it is generally supplied unvulcanized because it is easier to obtain reliable seams and to make repairs in the field. Thermoplastic polymers can be heat sealed or can be seamed with solvent or bodied solvent (a solvent containing dissolved polymer to increase the viscosity and reduce the rate of evaporation). Information on individual polymers and liners is presented in subsequent subsections. Subjects covered on each polymer are: composition, general properties and characteristics, general use, and specific use in liners.

3.4.3.1 Butyl Rubber

Liners of butyl rubber were among the first synthetic liners to be used for potable water impoundment and have been in this type of service for about 30 years (Smith, 1980).

Butyl rubber is a copolymer of isobutylene (97%) with small amounts of isoprene introduced to furnish sites for vulcanization (Morton, 1973, pp. 249-59). The important properties of butyl rubber to its use as a liner are:

a. low gas and water vapor permeability
b. thermal stability
c. ozone and weathering resistance
d. chemical and moisture resistance
e. resistance to animal and vegetable oils and fats.

It is generally compounded with fillers and some oil and vulcanized with sulfur. Butyl vulcanizates are highly swollen by hydrocarbon solvents and petroleum oils, but are only slightly affected by oxygenated solvents and other polar liquids. Butyl also has a high resistance to mineral acids. After 13 weeks of immersion in 70% sulfuric acid, a butyl compound showed little loss in tensile strength or elongation (Morton, 1973, pp. 249-59). Butyl rubber has a high tolerance for extremes in temperature and retains its flexibility throughout its service life. It has good tensile strength and desirable elongation qualities.

Butyl rubber liners are manufactured in both reinforced and in unreinforced versions. They are difficult to seam and to repair. They require special room temperature vulcanizing adhesives (Kumar and Jedlicka, 1973; Lee, 1974).

3.4.3.2 Chlorinated Polyethylene

Chlorinated polyethylene (CPE) is produced by a chemical reaction between chlorine and high-density polyethylene. Presently available polymers contain 25-45% chlorine and 0-25% crystallinity. CPE is compounded and used in thermoplastic and crosslinked compositions.

Since CPE is a completely saturated polymer (no double bonds) it is not susceptible to ozone attack and weathers well. The polymer also has good tensile and elongation strength. Chlorinated polyethylene is characterized by resistance to deterioration by many corrosive and toxic chemicals. Because they contain little or no plasticizer, CPE liners have good resistance to growth of mold, mildew, fungus, and bacteria. Membranes of CPE can also be formulated to withstand intermittent contact with aliphatic hydrocarbons and oils. CPE will swell in the presence of high concentrations of aromatic hydrocarbons and oils but regains some of its original properties when removed from that environment. Continuous exposure to aromatics will shorten the service life of the liner. In most cases CPE liners are not recommended for containment of aromatic liquids (Dow, 1977).

CPE can be compounded with other polymers, making it a feasible base material for a broad spectrum of liners. CPE can be alloyed with PVC, PE and numerous synthetic rubbers. Nevertheless, at least half the polymer content of CPE

liners is CPE resin. CPE is widely used to improve the stress crack resistance and softness of ethylene polymers and to improve the cold crack resistance of flexible polyvinyl chloride. CPE membranes are available in varied thicknesses in unreinforced or fabric reinforced versions (Bureau of Reclamation, 1963, p. 23). Membranes of CPE are generally unvulcanized and thus can be seamed by bodied-solvent adhesives, solvent welding or dielectric heat sealing (Stewart, 1978).

3.4.3.3 Chlorosulfonated Polyethylene (CSPE)

Chlorosulfonated polyethylene is a family of polymers prepared by reacting polyethylene in solution with chlorine and with sulfur dioxide. Presently available polymers contain from 25-43% chlorine and from 1.0-1.4% sulfur. They can be used in both thermoplastic (uncrosslinked) and in vulcanized (crosslinked) compositions. Uncured CSPE is more thermoplastic than other commonly used elastomers. It is generally tougher at room temperature, but softens more rapidly as temperatures are increased (Morton, 1973, pp. 337-8).

Chlorosulfonated polyethylene (CSPE) is characterized by ozone resistance, light stability, heat resistance, good weatherability, and resistance to deterioration by corrosive chemicals, e.g. acid and alkalies. It has good resistance to growth of mold, mildew, fungus, and bacteria. Membranes of this material are available in both vulcanized and thermoplastic forms, but primarily in the latter. Usually, they are reinforced with a polyester or nylon scrim and generally contain at least 45% of CSPE polymer. The fabric reinforcement gives needed tear strength to the sheeting for use on slopes, and reduces the distortion resulting from shrinkage when placed on the base and when exposed to the heat of the sun.

CSPE can be seamed by heat sealing, dielectric heat sealing, solvent welding, or by using "bodied" solvent adhesive. Membranes of this polymer do not crack or fail at extremes of temperatures or from weathering. Disadvantages of CSPE membranes are low tensile strength, a tendency to shrink from exposure to sunlight (Clark and Moyer, 1974, p. 20), and relatively poor resistance to oils. Also, some CSPE tends to harden on aging, due to crosslinking by moisture, ultraviolet radiation, and heat.

Membranes of CSPE are also available in colors other than black, without appreciable loss of other desirable characteristics (Du Pont, 1979).

3.4.3.4 Elasticized Polyolefins

Elasticized polyolefin is a blend of rubbery and crystalline polyolefins. This polymeric material was introduced in 1975 as a black unvulcanized, thermoplastic liner, which readily and easily heat sealed with a specially designed heat welder in the field or at the factory. It has a low density (0.92) and is highly resistant to weathering, alkalis, and acids (Haxo and White, 1977). This membrane is unsupported and is manufactured by blow extrusion and supplied in sheets 20 mil thick, 20 feet wide, and up to 200 feet long (Du Pont, 1979) which are shipped to site for assembly in the field.

Some difficulties have been encountered with elasticized polyolefin in low temperature and high winds, in oily environments, and in adhesion to structures.

3.4.3.5 Epichlorohydrin Rubbers (CO and ECO)

Included in this classification are two epichlorohydrin-based elastomers which are saturated, high molecular weight, aliphatic polyethers with chloromethyl side chains. The two types include a homopolymer and a copolymer of epichlorohydrin and ethylene oxide. These materials are vulcanized with a variety of reagents that react difunctionally with the chloromethyl group, including diamines, urea, thioureas, 2-mercaptoimidazoline, and ammonium salts.

Epichlorohydrin elastomer vulcanizates exhibit the following characteristics:

a. resistance to hydrocarbon solvents, fuels and oils.
b. ozone and weathering resistance.
c. low rate of gas/vapor permeability.
d. thermal stability.
e. good tensile and tear strength.

Epichlorohydrin rubber has a high tolerance for temperature extremes and retains its flexibility at extreme temperatures throughout its service life. The homopolymer has a performance range of 0 to 325°F. The copolymer shows improved low temperature flexibility and is recommended for service from -40 to 300°F.

Epichlorohydrin elastomers can be seamed with room temperature-vulcanizing adhesives.

3.4.3.6 Ethylene Propylene Rubber (EPDM)

Ethylene propylene rubbers are a family of terpolymers of ethylene, propylene, and a minor amount of nonconjugated diene hydrocarbon. The diene supplies double bonds to the saturated polymer chain to be chemically active sites for vulcanization, usually with sulfur. These rubbers vary in ethylene:propylene ratio, in the type and amount of the third monomer, and in molecular weight. Although EPDM liners are generally based on vulcanized compounds, thermoplastic EPDM liners are also available. Both versions are manufactured as fabric reinforced and unsupported sheeting.

Liners based on vulcanized EPDM compounds have excellent resistance to weather and ultraviolet exposure and, when compounded properly, resist abrasion and tear. Because of its excellent ozone resistance, minor amounts of EPDM are sometimes added to butyl to improve the weather resistance of the latter. EPDM liners tolerate extremes of temperature, and maintain their flexibility at low temperatures. They are resistant to dilute concentrations (10% by weight) of acids, alkalis, silicates, phosphates, and brine, but are not recommended for petroleum solvents (hydrocarbons) or for aromatic or halogenated solvents.

Vulcanized EPDM membranes require the use of special cements and careful application to assure satisfactory field seaming. The proposed seam construction should be tested in the use environment to assure serviceability. Thermoplastic EPDM liners are seamed by thermal methods.

3.4.3.7 Neoprene

Neoprene is the generic name of synthetic rubbers based upon chloroprene. These rubbers are vulcanizable, usually with metal oxides, but also with sulfur. They closely parallel natural rubber in mechanical properties, e.g. flexibility and strength. However, neoprene is superior to natural rubber in its resistance to oils, weathering, ozone, and ultraviolet radiation. Neoprene is resistant to puncture, abrasion, and mechanical damage. Neoprene membranes have been used primarily for the containment of wastewater and other liquids containing traces of hydrocarbons. They also give satisfactory service with certain combinations of oils and acids for which other materials do not provide long-term performance (Kumar and Jedlicka, 1973; Lee, 1974).

Neoprene sheeting for liners is vulcanized, thus vulcanizing cements and adhesives must be used for seaming.

3.4.3.8 Polyethylene

Polyethylene is a thermoplastic polymer based upon ethylene. It is made in two major types: (1) low-density polyethylene, and (2) high-density polyethylene. The properties of a polyethylene are largely dependent upon its crystallinity and density. High-density polyethylene polymers exhibit superior resistance to oils, solvents, and permeation by water vapor and gases. Unprotected clear polyethylene degrades readily on outdoor exposure, but the addition of 2-3% carbon black can produce improved ultraviolet light protection. Polyethylenes, for the most part, are free of additives such as plasticizers and fillers.

Both types of polyethylene have been used as liners. Membranes of low-density polyethylene have been used unsupported for 15 to 20 years (Hickey, 1969) in lining canals and ponds. Recently, high-density polyethylene in heavy sheeting has been introduced. The low-density polyethylene (LDPE) available in thin sheeting tends to be difficult to handle and to field seam. Also, it is punctured easily under impact such as when rocks are dropped on the lining; however, it has good service puncture resistance as a buried membrane lining. Linings of high-density polyethylene (HDPE) recently introduced are available in thick sheets up to 125 mil; special seaming equipment has been developed for making seams both in the factory and in the field. This type of liner is very stiff compared to most of the other membranes described.

3.4.3.9 Polyvinyl Chloride

Polyvinyl chloride is produced by any of several polymerization processes from vinyl chloride monomer (VCM). It is a versatile thermoplastic polymer which is compounded with plasticizers and other modifiers to produce a wide range of physical properties.

PVC liners are produced in roll form in various widths and thicknesses. Most liners are used as unsupported sheeting, but fabric reinforcement can be incorporated. PVC compounds contain 25% to 35% of one or more plasticizers to make the sheeting flexible and rubber-like. They also contain 1% to 5% of a chemical stabilizer and various amounts of other additives. The PVC compound should not contain any water soluble ingredients. There is a wide choice of plasticizers that can be used in PVC sheeting, depending upon the application and service conditions under which the PVC compound will be used. Plasticizer loss during service is a source of PVC degradation. There are three basic mechanisms for plasticizer loss: volatilization, extraction, and microbiological attack. The use of the proper plasticizers and an effective biocide can virtually eliminate microbiological attack and minimize volatility and extraction. The PVC polymer, itself, is not affected by these conditions. It is affected, however, by ultraviolet exposure.

The principal reason for loss of plasticizer is by volatilization in the heat of the sun rather than solution in the waste fluid. Carbon black prevents ultraviolet attack but does cause the absorption of solar energy raising the temperature to a high level to cause vaporization of plasticizer. A soil or other suitable cover material used to bury the liner protects it from ultraviolet exposure and reduces the rate of plasticizer loss. PVC sheeting is not recommended for exposure to weathering and ultraviolet light conditions during its service life.

Plasticized PVC sheeting has good tensile, elongation, and puncture and abrasion resistance properties. It is readily seamed by solvent welding, adhesives, and heat and dielectric methods.

PVC membranes are the most widely used of all polymeric membranes for waste impoundments. They show good chemical resistance to many inorganic chemicals (Chan et. al. 1978, p. 19); however, they are attacked by many organic chemicals, particularly hydrocarbons, solvents, and oils. Special compounds of PVC are available, designated as Oil-Resistant PVC (PVCOR), that possesses high resistance to oil attack. These "oil-resistant" grades of sheeting must be made with "specialty" plasticizers; the PVC polymer is inherently resistant to the effects of oils.

Polymers such as nitrile rubber, CPE and EVA may be used to replace the liquid plasticizers so that the PVC liner is not affected by the waste fluid.

3.4.3.10 Thermoplastic Elastomers (TPE)

Thermoplastic elastomers are a relatively new class of rubbery materials (Walker, 1979). They include a wide variety of polymeric compositions from highly polar materials, such as the polyester elastomers, to the nonpolar materials, such as ethylene-propylene block polymers. These polymers are thermoplastic and nonvulcanized. They are processed and shaped at relatively high temperatures at which they are plastic; when they are cooled to normal ambient temperatures, they behave like vulcanized rubbers. Products made of these polymers have a limited upper temperature service range, which, however, is substantially above the temperatures encountered in waste disposal sites.

Of particular potential interest for use in liners are the polyolefin thermoplastic elastomers such as thermoplastic EPDM, which are probably related to the elasticized polyolefins, and nitrile rubber/PVC blends for oil resistant liners. Such liner materials are now under development and test.

Nitrile/PVC thermoplastic elastomer blends have excellent oil, fuel, and water resistance with high tensile strength and excellent resistance to ozone and weathering. Blends tend to stiffen at low temperatures but remain serviceable.

As with liners of other thermoplastic polymers, liners of thermoplastic elastomers can be heat sealed to make seams and should be easy to repair; however, their durability in various chemical environments remains to be tested.

3.4.4 Membrane Manufacture

The two basic methods used in the manufacture of polymeric sheeting are calendering and extrusion. Calendering is used in forming both unsupported and fabric reinforced sheeting, whereas extrusion is only used in making unsupported sheeting.

Calendering is the more common method of forming the sheeting. In this process, heated rubber or elastic compounds are passed between the heated rolls of a calender to form a sheet of predetermined thickness. A calender usually consists of three to four rolls, as shown in Figure 3-5. The arrangement for preparing a single-ply sheeting on a 3-roll calender is shown in Figure 3-6. Unsupported sheeting is usually a single-ply construction; however, some manufacturers have resorted to multiple plying of unsupported liners to eliminate the formation of pinholes through the sheet. By manufacturing sheeting in this manner, the probability of a pinhole in one ply coinciding with a pinhole in another is remote.

Some manufacturers set up special straining operations to clean out all grit that may be in the compound. This operation immediately precedes the calendering. In this step, grit and other coarse particles are screened out to yield a clean compound for the calender.

Reinforcing fabric can be placed between the plies of the polymeric compound to produce a supported liner. In this case, sufficient material must be placed on both sides of the fabric in order that pinholes are not generated between the fabric and the outside of the sheeting. Also, there should be sufficient compound present to strike through the open weave of the fabric and achieve direct contact of the rubber on both sides of the fabric. Fabric reinforcement is usually achieved through the use of open fabrics or scrim of nylon, polyester, polypropylene, or glass fiber. The thread count or ends per inch usually range from 6 x 6 to 10 x 10 per inch, but some have run to 20 x 20. Figure 3-7 shows several types of scrim. A coating is applied to the finished scrim after weaving in order to tack the yarns in place so that the finished scrim construction pattern will not lose its shape. Different coating formulations are used, depending on the end use. Scrims or fabrics to be used with vulcanized elastomeric lining materials are usually treated with

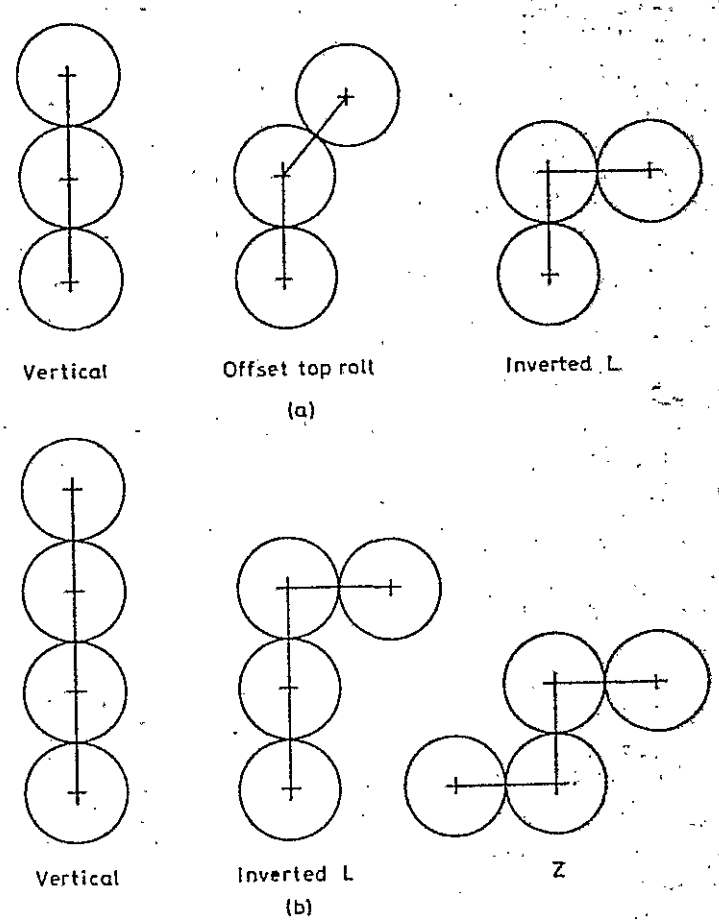


Figure 3-5. Roll configuration of calenders: (a) three-roll calenders, and (b) four-roll calenders (Blow, 1971).

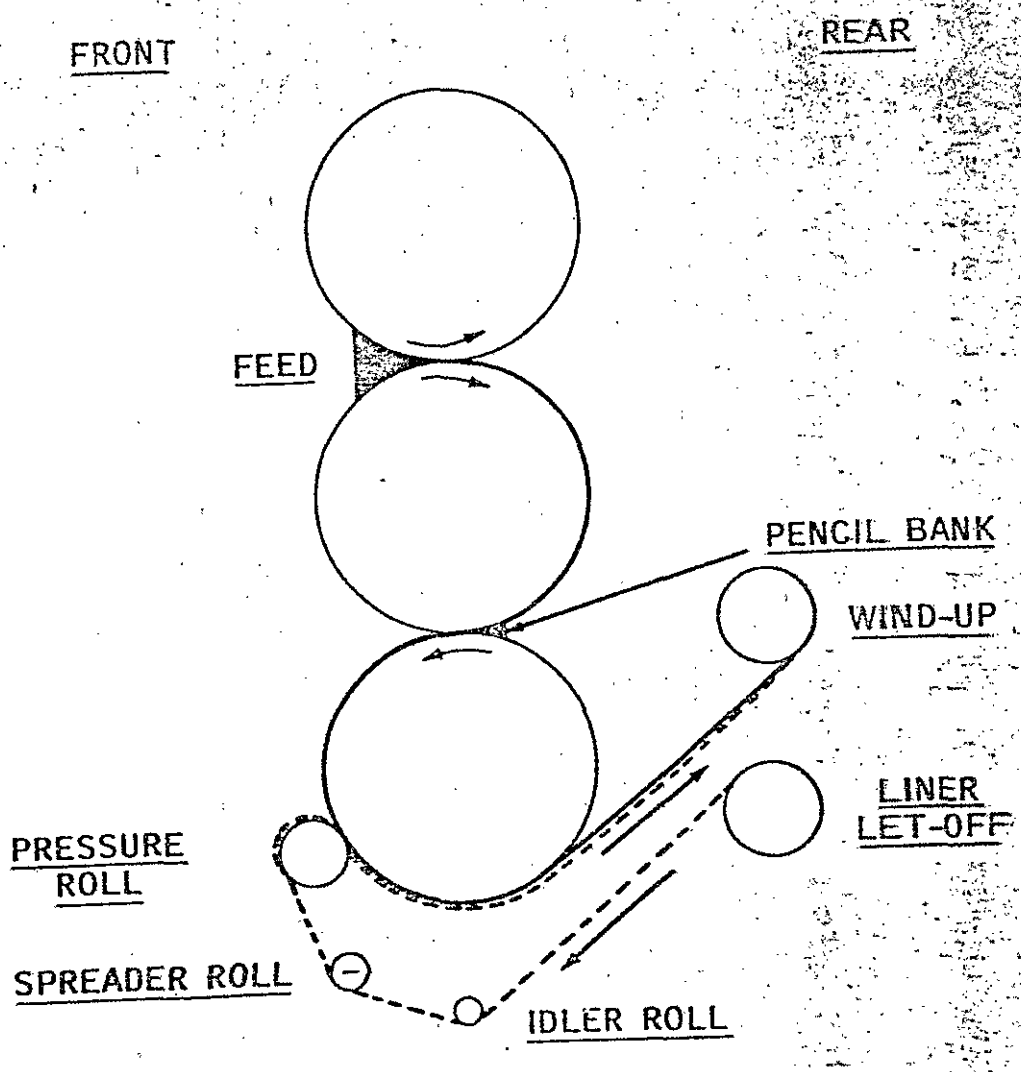
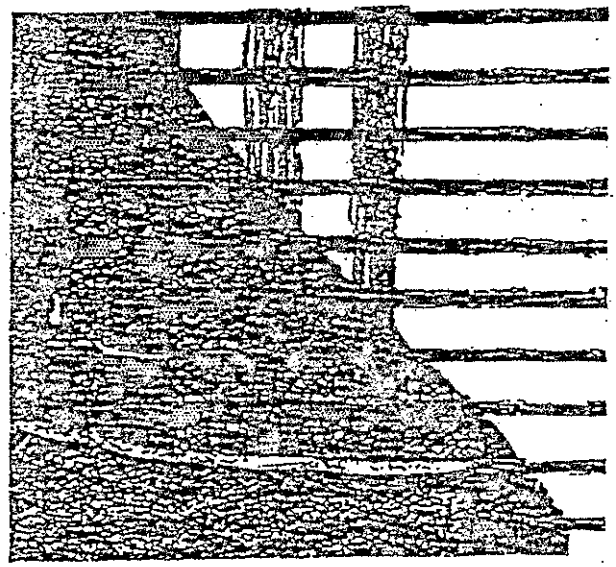
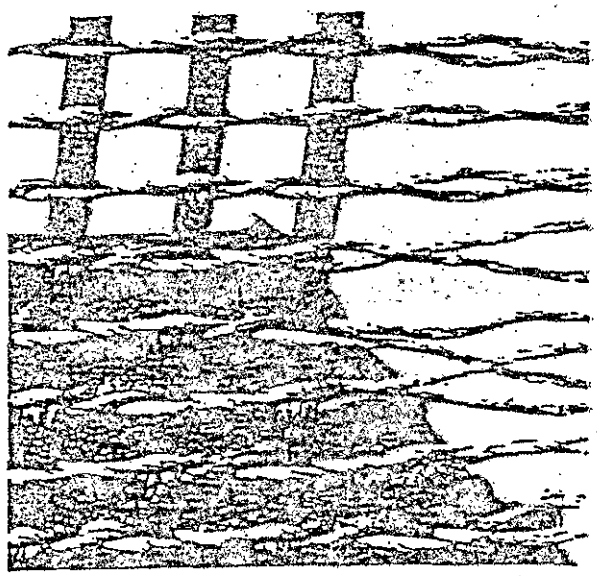


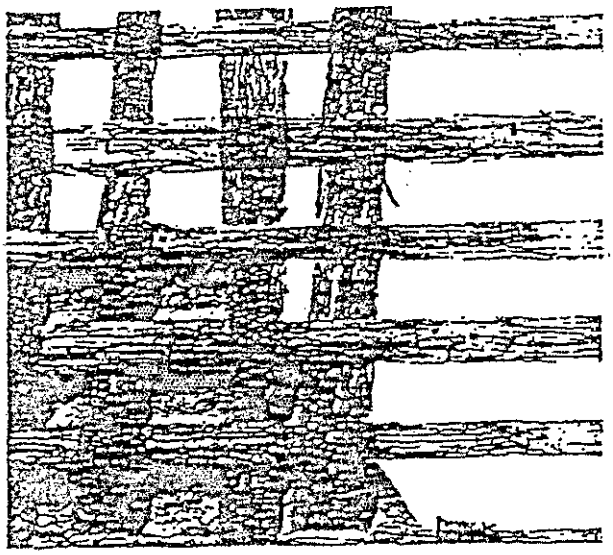
Figure 3-6. Calender arrangement - sheeting, one-pass or ply-up with pencil bank (Banks, 1966).



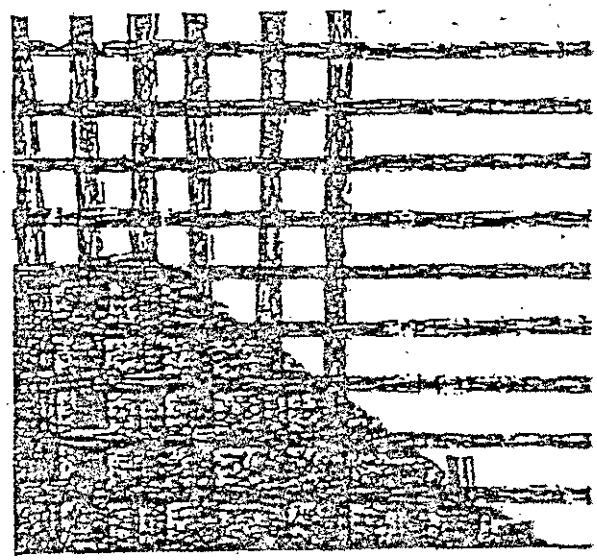
Manufacturer F. 30 mils (0.76 mm), B-5602. Photo P222-D-65685



Manufacturer A. 60 mils (1.52 mm), B-4606. Photo PX-D-68886



Manufacturer G. 30 mils (0.76 mm), B-5540. Photo PX-D-68887



Manufacturer H. 30 mils (0.76 mm), B-5560. Photo PX-D-68888

Figure 3-7. Nylon-reinforced, butyl lining samples showing different weaves and weights of nylon used by four manufacturers (6x magnification). From Hickey, 1971.

an adhesive coating which chemically reacts with the membrane material during the curing cycle to produce adhesion to the polymer compound.

The extrusion technique is used primarily with polyolefins, such as polyethylene, and with elasticized polyolefin. For thinner films, a tube of film is produced and slit to form a sheet. For the thicker gauge polyethylenes, thick sheets are extruded directly.

3.5 Sprayed-on Linings

3.5.1 Introduction

Liners for disposal impoundments can potentially be formed in the field by spraying onto a prepared surface a liquid which then solidifies to form a continuous membrane. Such liners have been used in water control and impoundment, e.g. for canals, small reservoirs, and ponds. Most of the experience with this type of liner has been with air blown asphalt; however, a variety of new materials are becoming available which have been used in small water control installations. Sprayed-on liners are seam-free, but preparing them pinhole-free in the field poses serious difficulties. Furthermore, most of the spray-on materials that have been considered are thermoplastic and are of low molecular weight, e.g. asphalt, and may interact adversely with many wastes. Some of the new materials that are being introduced are of high molecular weight or contain polymeric additives which improve their durability.

In this section, the following materials are discussed; airblown asphalt, emulsified asphalt, urethane modified asphalt, and rubber and plastics, in either liquid or latex form.

3.5.2 Air-blown Asphalt

Membranes of catalytically-blown asphalt are the most commonly used sprayed-on linings. The asphalts used in making these membrane linings have high softening points and are manufactured by blowing air through the molten asphalt at temperatures in excess of 500°F in the presence of a catalyst such as phosphorous pentoxide or ferric chloride. To prepare the membrane, the asphalt is sprayed on a prepared soil surface at a temperature of 400°F, at a pressure of 50 psi through a slot-type nozzle, and at a rate of 1.5 gal yd^{-2} (Bureau of Reclamation, 1963, p. 80). The finished liner is usually 0.25 inch thick (Bureau of Reclamation, 1963, p. 79), formed by two or more passes of the spray device and overlapping sections by one or two feet (Clark and Moyer, 1974). It can be placed during cold or wet weather, in large quantities, by mobile equipment (Bureau of Reclamation, 1963, p. 10). Sprayed-on membranes retain their tough flexible qualities indefinitely when properly covered and protected from mechanical damage (Asphalt Institute, 1976). The actual placing of the earth covers on a sprayed-on membrane may cause some damage to its integrity.

Studies have shown the addition of 3-5% rubber improves the properties of the asphalt by inducing greater resistance to flow, increased elasticity and

toughness, decreased brittleness at low temperatures, and greater resistance to aging (Chan et al., 1978, p. 17).

Bituminous seals are used on asphalt concrete, portland cement concrete, soil asphalt, or soil cement linings to close pores, thus improving waterproofing or when there may be a reaction between the stored liquid and the lining. The two types of seals usually applied are:

a. An asphalt cement sprayed over the surface about one qt yd^{-2} to form a membrane about 0.04 in. thick.

b. An asphalt mastic containing 25 - 50% asphalt cement, the rest being a mineral filler, squeegeed on at 5 - 10 lb yd^{-2}.

Installation of sprayed-on asphaltic membranes is usually done on a subgrade which has been dragged and rolled to obtain a smooth surface. If there is an excessive number of irregular rocks and angular pieces, a fine sand or soil "padding" is necessary for good membrane support (Bureau of Reclamation, 1963, p. 81). Covering protects the membrane from most mechanical damage.

A special deep penetration formula of liquid cutback asphalt was applied over natural-on-site soil at a rate of two gal yd^{-2}. The seepage rate, in this case, was reduced from 15.9 to 6.14 ft^3 ft^{-2} yr^{-1} (Day, 1970, p. 20). Another formulation of cationic asphalt, incorporating white gasoline and water, penetrated 3/16 to 3/8 inch into the soil. This proved to be inadequate for complete sealing (Bureau of Reclamation, 1963, p. 115). A special cationic asphalt emulsion forms a highly impermeable seal at the soil interface through the attraction of the positively charged asphalt droplets to the negatively charged soil particles as the emulsion penetrates the substrate. As little as 15 fluid oz ft^{-2} results in almost zero seepage. This product has been used mainly in reservoirs and ponds (Wren, 1972).

Field data on a hot asphalt membrane lining in a canal lateral was obtained after 11 years of service. The seepage rate at this time was 0.08 $ft^3/ft^2/$ day. The seepage rate prior to placement of the liner was 9.9 $ft^3/ft^2/$ day. Ninety percent of the aging occurred during the first four years of membrane service. A poor correlation was found between the 14-day laboratory aging test at (60°C) and actual field aging. Geier (1964, p. 3) concluded that, if properly applied and covered, a buried hot applied asphalt membrane canal lining should last beyond 12 years.

Styron and Fry (1977) used an AC-40 grade asphalt cement as a lining material in tests with two flue gas desulfurization (FGD) sludges. A base of silty sand was compacted to six inches depth and cured at 78°F and 50% humidity for two to three days. The asphalt liner was then sprayed on the base at a rate of 0.75 gal yd^{-2}. After one year, under a pressure head of five feet of water, no liquid had passed through the liner. Specifications for AC-40 require a viscosity of 4000±800 poises at 140°F (60°C) and a minimum penetration of 20. This asphalt requires temperatures of 300 - 400°F for spraying (Klym and Dodd, 1974).

Except for resistance to hydrocarbon solvents, oils, and fats, the chemical resistance of asphaltic liners is, in general, good. Asphaltic membranes are resistant to methyl and ethyl alcohols, glycols, mineral acids other than nitric acid (at moderate temperatures and concentrations), mineral salts, alkalis to about 30% concentration, and corrosive gases such as H_2S and SO_2. Asphaltic liners exhibit variable to poor performance when exposed to hydrogen halide vapors, but are essentially impermeable to water (Anonymous, 1966). Preparing pinhole-free membranes on large areas by spraying techniques, particularly when hot materials must be sprayed, poses a variety of problems which are discussed in Section 5.5.

3.5.3 Membranes of Emulsified Asphalt

Emulsions of asphalt in water can be sprayed at ambient temperatures (above freezing), to form continuous membranes of asphalt after breaking of the emulsion and evaporation of the water. The membranes are less tough and have lower softening points than membranes of hot applied catalytically-blown asphalt. Toughness and dimensional stability can be achieved by spraying asphalt emulsions onto a supporting fabric. Fabrics of woven jute, woven or nonwoven glass fiber, and nonwoven synthetic fibers have been used with various anionic or cationic asphalt emulsions to form linings for ponds and canals and as reinforcing patches under asphalt concrete overlays to prevent "reflection" of cracks in the old pavement beneath. Seams in the supporting fabric are often sewn with portable sewing machines after the fabric is placed (Phillips Petroleum, 1972).

3.5.4 Urethane Modified Asphalt

A urethane modified asphalt liner system is being marketed. It is generally spray applied, but may be squeegeed onto a prepared surface. A premix is combined with the activator, and sprayed on at a rate of two gallons per minute, covering about eight square yards per minute. The final membrane is generally recommended to have a thickness of 50 mil, usually obtained by applying one coat of 0.28 gal yd^{-2} on horizontal surfaces or two coats on vertical surfaces. The second coat may be applied about 15 minutes after the first coat. The membrane must cure for 24 hours before being put into service. This system has good UV stability and low temperature ductility, eliminating the need for a soil cover in most cases. The liner system is limited to a maximum of 140°F continuous exposure and is not recommended for prolonged exposure to hydrocarbon or organic solvents. It should be applied only to properly prepared surfaces. The surface must be clean and dry. Porous surfaces should be filled. Generally, a primer and a bonding agent are applied prior to the application of the actual membrane. The procedures for several base surfaces and the necessary precautions are provided by the manufacturer (Chevron, 1980).

3.5.5 Rubber and Plastic Latexes

Rubber and resin latexes have also been studied as spray-on liners. Gulf South Research Institute studied two synthetic latexes. The first was an experimental styrene polymer, which had a 50% solids content with a high concentration of wetting agents. The spray was allowed to soak into the

soil and dry. The result was a fairly resilient film with good soil sealing capabilities. The second latex was an off-grade polyvinylidene chloride. It also had a 50% solids content and was used as a vapor barrier on air strips. It formed a film on the soil surface and was reported to provide a good seal at high pressures (Wren, 1972, pp. 30-40).

3.6 Soil Sealants

The permeability of some soils can be significantly reduced by the application of various chemicals or latexes. They may be waterborne, mixed in place, spray applied, or injected below the soil surface (Bureau of Reclamation, 1973, p. 13). Water borne or spray-on polymer soil sealants can reduce permeability of earth lined impoundments. However, the sealing effect is confined to the upper few centimeters and can be significantly diminished by the effects of wet-dry and/or freeze thaw cycles. Types of sealants include resinous polymer-diesel fuel mixtures, petroleum based emulsions, powdered polymers which form gels, and monovalent cationic salts (Bureau of Reclamation, 1963, p. 115). See Table 3-7 for a list of representative soil sealants.

Soil sealants utilizing monovalent cations, mainly sodium salts, chemically reduce the effective porosity of the soil for flow by replacing the multivalent cations in the clay structure. This exchange renders the clustered soil particles more easily dispersed (Morrison, 1965, p. 1). Sodium carbonate applied at a rate of two lb yd^{-2} provided a seepage reduction of greater than 90% in Bureau of Reclamation tests. The seepage reduction was still 80% after removal of the top six inches of soil. Sodium pyrophosphate and sodium silicate are also potential soil sealants. Soil treated with sodium silicate and sulfuric acid prior to compaction showed a significant seepage reduction and is compatible with sulfuric acid bearing wastes (Clark and Moyer, 1974, p. 13).

Some powdered polymers can form gelatinous masses which tend to fill the soil voids, thus effecting a surface seal. Some early studies showed that this surface seal is easily damaged by a water spray, indicating that durability tests should be made when considering this type of liner (Morrison, 1965, p. 2). A powdered mixture of carboxymethyl cellulose and alum (0.25 CMC + 0.05% alum by wt of dry soil) was mixed with the soil and compacted to a six-inch thickness in one project. The seepage was reduced only slightly from 16 to 14 ft^3 ft^{-2} yr^{-1} (Day, 1970, p. 21). Soil sealants based on polymers are generally mixtures of swellable linear and crosslinked polymers of approximately the same molecular weight. The linear portion sorbs to the soil, forming a flexible network. The crosslinked polymer particles can flow, and thus can conform to and permeate the soil pores. The formulation depends on the application. The polymer is usually mixed in a low pH water/acid solution and sprayed onto an unfilled site as a low viscosity slurry. The low pH allows the slurry to penetrate the surface and form a deeper seal.

Polymeric soil sealants may be applied as a dry blend which is mixed into the soil and compacted, sprayed on as a slurry, or dusted on as a powder. Highway construction equipment may be used for dry blending. Water hauling trucks

TABLE 3-7. REPRESENTATIVE SOIL SEALANTS[a]

Sealant	Application	Remarks
Cationic asphalt emulsion	Farm ponds	Requires approximately 19,000L/4,047 m^2 (5,000 gal/acre) dispersed in water.
Oil soluble polymers in diesel fuel	Fresh water	Injected beneath surface of water where seepage was occurring.
Sodium tetraphosphate	Sulfite liquor storage	Dispersant distributed in 15.2-cm (6-in.) layer of soil at 2.3 kg/9 m^2 (5 lb/100 ft^2). Careful compaction rendered soil impervious.
Sodium carbonate	Canals	Wet-dry cycles disrupt water barrier. Used 183 g (0.4 lb) of reagent/0.84 m^2 (yd^2) of soil.
Lignin derivatives gelled alum	Desalination byproduct brine	1% lignin. Cost $3,400/4,047 m^2 (acre).
Carboxymethyl cellulose with alum	Desalination byproduct brine	0.2% CMC. Cost $2,250/4,047 m^2 (acre).
Petroleum emulsions	Desalination byproduct brine	4% additive. Cost $4,400/4,047 m^2 (acre).
Attapulgite clay	Desalination byproduct	2% Zeogel. Cost $1,000/4,047 m^2 (acre).
Liquid elastomeric polymer	Fresh water	Patent discloses several compositions, including polyurethane elastomers.

[a] Parks and Rosene, 1971.

equipped with centrifugal pumps, hoses, and adjustable fire nozzles have been successfully used to spray-apply polymer slurries. Any equipment suitable for dispersing a powder may be used for dusting with a polymer powder.

Dry blending forms the most effective seal and adds some structural strength to the impoundment. Other factors influencing the effectiveness of the seal are the degree of soil compaction and the composition of the impounded fluid. The limitations of the polymer seals are: the polymer itself does not supply strength, the site must be compacted; exposure to salts, acids, and multivalent cations causes the polymers to shrink, increasing the permeability and decreasing the effectiveness of the seal (Parks and Rosene, 1971).

Uniroyal (1972) conducted a study to test the feasibility of using latex as a soil sealant to prevent seepage into subterranean abandoned mines. In general, the field tests confirmed laboratory findings that latex does reduce the permeability of the soil to water, but the latex is subject to damage by microbiological attack, frost, and vegetation.

3.7 Chemical Absorptive Liners

The use of chemical absorptive liners is a new and promising concept in the lining of waste disposal facilities. This type of liner functions primarily by removing pollutants from the liquid waste as it passes through the liner mass. Chan et al. (1978) tested several clays and minerals, acidic and basic fly ash, bottom ash, activated alumina, and activated charcoal as potential chemical liners for calcium fluoride, metal finishing, and petroleum sludges. The tests were done under flow through conditions, mixing the sorbent with sand when necessary to achieve the required permeability. None of the substances alone adequately removed the hazardous or polluting compounds. However, combinations of sorbents, in a predetermined sequence, do satisfactorily remove contaminants. The type, sequence, and behavior of the sorbents varies with pH and the nature of the waste to be treated. For example, some materials remove certain metals or organics more effectively than others. The same sorbent, such as fly ash, may release ions in one pH range and absorb ions in another. Flow and nonflowing conditions also affect the absorption capacities of a material. This concept shows promise, but further testing is necessary under nonflow conditions with specific wastes to evaluate the effectiveness of various sorbents in applied situations (Chan et al.,1978).

REFERENCES

Chapter 3 - Lining Materials and Lining Technology

Aitchison, G. D., and C. C. Wood. 1965. Some Interactions of Compaction, Permeability, and Post-Construction Deflocculation Affecting the Probability of Pipe Failure in Small Dams. In: Proc. 5th. Int. Conf. on Soil Mech. and Foundation Engineering. 2:422-446.

Anonymous. 1966. Chemical Resistance of Asphalt Coatings. Materials Protection. 5: 81-83.

The Asphalt Institute. 1966. Asphalt Linings for Waste Ponds. (IS-136). College Park, Maryland. 10 pp.

The Asphalt Institute. 1974. Specifications for Paving and Industrial Asphalt. (SS-22). College Park, Maryland.

The Asphalt Institute. 1976. Asphalt in Hydraulics. (MS-12). College Park, Maryland. 65 pp.

Banks, S. A. 1966. Butyl Sheeting - Technology Review. EPL 6604 339. Enjay Polymer Laboratories. 22 pp.

Blackmore, A.V., and T. J. Marshall. 1965. Water Movement Through a Swelling Material. Australian J. Soil Res. 3:11-21.

Blow, C. M., ed. 1971. Rubber Technology and Manufacture. Butterworths, London. 527 pp.

Boyes, R. G. H. 1972. Uses of Bentonite in Civil Engineering. In: Proceedings of the Instn. Civil Engineers. 52:25-37.

Brown, K.W. and D. Anderson. 1980. Effect of Organic Chemicals on Clay Liner Permeability. In: Proceedings of 6th Annual Research Symposium. EPA-600/9-80-010. U.S. Environmental Protection Agency, Cincinnnati, Ohio. pp 123-134. PB 80-175086.

Bureau of Reclamation. 1963. Linings for Irrigation Canals, Including a Progress Report on the Lower Cost Canal Lining Program. U. S. Department of the Interior, Washington, D. C. 149 pp.

Burmister, D. M. 1964. Environmental Factors in Soil Compaction. In: ASTM Symposium, Compaction of Soils. ASTM STP 377. pp. 47-66.

Chan, P., et al. 1978. Sorbents for Fluoride, Metal Finishing and Petroleum Sludge Leachate Contaminant Control. EPA-600/2-78-024. U. S. Environmental Protection Agency, Cincinnati, Ohio. 83 pp. PB 280-696/AS.

Cheremisonoff, N., P. Cheremisonoff, F. Ellerbush, and A. Perna. 1979. Industrial and Hazardous Wastes Impoundment. Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan. pp. 192-208.

Chevron USA, Inc. 1980. Chevron Industrial Membrane System Manual. Asphalt Division, Chevron USA, Inc. 56 pp.

Clark, D. A., and J. E. Moyer. 1974. An Evaluation of Tailings Pond Sealants. EPA-660/2-74-065. U. S. Environmental Protection Agency, Corvallis, Oregon. 29 pp. PB 235-929/7BA.

Daniels, F., and R. A. Alberty. 1963. Physical Chemistry. 2nd ed. John Wiley and Sons, Inc., New York. 744 pp.

Day, M. E. 1970. Brine Pond Disposal Manual. Office of Solid Waste Contract No. 14-001-1306. Bureau of Reclamation, U. S. Dept. of the Interior, Denver, Colorado. 134 pp.

Day, P. R. 1955. Effect of Shear on Water Tension in Saturated Clay. Annual Report, I and II, Western Regional Research Project W-30. University of California, Berkeley, CA.

Dow Chemical Co. 1977. CPE Resin Flexible Liner Brochure.

Du Pont. 1975. Flexible Membranes for Pond and Reservoir Liners and Covers. Brochure E-23335.

Geier, F. H. 1964. Evaluation of Field Aging on the Physical Characteristics of Buried Hot-Applied Asphaltic Membrane Canal Lining - Lower Cost Canal Lining Program. Report No. B-34. Bureau of Reclamation, U. S. Department of the Interior, Denver, Colorado. 75 pp.

Goodyear Tire and Rubber Co. 1973. Pond and Pit Liner Materials. 1004-1/73.

Hardcastle, J. H., and J. K. Mitchell. 1974. Electrolyte Concentration-Permeability Relationships in Sodium Illite-Silt Mixtures. Clays and Clay Minerals. 22(2):143-154.

Haxo, H., and R. White. 1976. Evaluation of Liner Materials Exposed to Leachate - Second Interim Report. EPA-600/2-76-255. U. S. Environmental Protection Agency, Cincinnati, Ohio. 53 pp. PB 259-913/AS.

Haxo, H., R. Haxo, and R. White. 1977. Liner Materials Exposed to Hazardous and Toxic Sludges - First Interim Report. EPA-600/2-77-081. U. S. Environmental Protection Agency, Cincinnati, Ohio. 63 pp. PB 271-013/AS.

Hickey, M. E. 1969. Investigation of Plastic Films for Canal Linings. Research Report No. 19. Bureau of Reclamation, U. S. Dept. of the Interior, Washington, D. C. 35 pp.

Hickey, M. E. 1971. Synthetic Rubber Canal Linings. REC-ERC-71-22. Bureau of Reclamation, U. S. Dept. of the Interior, Denver, Colorado. 34 pp.

Hinkle, Dale. 1976. Impermeable Asphalt Concrete Pond Liner. (IS-166). Reprinted from *Civil Engineering - ASCE*. Asphalt Institute, College Park, MD. 4 pp.

Holtz, W. G., and M. J. Gibbs. 1956. Engineering Properties of Expansive Clays. In: ASCE Transactions. 121:641-677.

Holtz, W. G. 1964. Panel Discussion. In: ASTM Symposium, Compaction of Soils. ASTM STP 377. pp. 80-135.

Kays, W. B. 1977. Construction of Linings for Reservoirs, Tanks, and Pollution Control Facilities. Wiley Interscience - John Wiley and Sons, New York. 379 pp.

Klym, T., and D. Dodd. 1974. Landfill Disposal of Scrubber Sludge. Presented at ASCE Conference, Kansas City, MO. 44 pp.

Kumar, L., and J. A. Jedicka. 1973. Selecting and Installing Pond Linings. Chem. Eng. 80(3):67-70.

Lambe, T. W. 1958. The Structure of Compacted Clay. J. of the Soil Mechanics and Foundations Division, ASCE. 84(SM2):34.

Lambe, T. W. and R. V. Whitman. 1979. Soil Mechanics, SI Version. John Wiley and Sons, New York. 553 pp.

Lee, J. 1974. Selecting Membrane Pond Liners. Pollution Engineering. 6(1):33-40.

Lowell, Philip S. 1975. In reference Radian Corp. 1975.

Lutz, J. F., and W. D. Kemper. 1959. Intrinsic Permeability of Clay as Affected by Clay-Water Interaction. Soil Science. 88:83-90.

McDowell, C. 1946. Progress Report on Development and Use of Strength Tests for Subgrade Soils and Flexible Base Materials. In: Proc. the Highway Research Board. 26:484-511.

McNeal, B. L., and N. T. Coleman. 1966. Effect of Solution Composition on Soil Hydraulic Conductivity. SSSAP. 30:308-312.

Meade, R. H. 1964. Removal of Water and Rearrangement of Particles During the Compaction of Clayey Sediments - Review. U. S. Geological Survey Professional Paper 497-B. U. S. Government Printing Office.

Mielenz, R. C., and M. E. King. 1955. Physical-Chemical Properties and Engineering Performance of Clays. Bull. No. 169. California Division of Mines. pp. 196-254.

Middlebrooks, E. J., C. Perman, and I. Dunn. 1978. Wastewater Stabilization Pond Linings. Special Report 78-28. Cold Regions Research and Engineering Laboratory, U. S. Army Corps of Engineers, Hanover, New Hampshire. 116 pp.

Miller, R. J. and P. E. Low. 1963. Threshold Gradient for Water Flow in Clay Systems. SSSAP. 27:605-609.

Mitchell, J. K. 1956. The Fabric of Natural Clays and its Relation to Engineering Properties. In: Proceedings of the Highway Research Board. 35:693-713.

Mitchell, J. K. 1964. Panel Discussion. In: ASTM Symposium, Compaction of Soils. ASTM STP 377.

Mitchell, J. K. 1976. Fundamentals of Soil Behavior. John Wiley and Sons, Inc., New York. 422 pp.

Mitchell, J. K., D. R. Hooper, and R. G. Campanella. 1965. Permeability of Compacted Clay. J. of the Soil Mechanics and Foundations Division, ASCE. 91(SM4):41-65.

Morrison, W. R. 1965. Preliminary Evaluation of Three Types of Materials Proposed for Use as Chemical Soil Sealants - Lower Cost Canal Lining Program. Report No. ChE-32. Bureau of Reclamation, U. S. Department of the Interior, Denver, Colorado. 8 pp.

Morton, Maurice, ed. 1973. Rubber Technology. 2nd ed. Van Nostrand Reinhold Company, New York. 603 pp.

Nayak, N. V., and R. W. Christensen. 1971. Swelling Characteristics of Compacted Expansive Soils. Clays and Clay Minerals. 19:251-261.

Parks, C. F., and R. B. Rosene. 1971. Preventing Losses of Industrial and Fresh Water from Pits, Ponds, Lakes, and Canals. AIME Environmental Quality Conf. Preprint, No. EQC-64. pp. 351-358.

Perkins, Philip H. 1976. Concrete Structures: Repair, Waterproofing and Protection. Applied Science Publishers, London. 302 pp.

Porter, O. J. 1946. The Use of Heavy Equipment for Obtaining Maximum Compaction of Soils. Technical Bull. No. 109. ARBA.

Phillips Petroleum Co. 1973. Asphalt Sealed Membranes for Pond Liners and Erosion Control. Handbook and Installation Guide for Petromat Fabric, Hydraulic Grade.

Quirk, J. P. 1965. Deflocculation of Soil Colloids. Ph.D. Thesis. University of London, London.

Quirk, J. P., and R. K. Schofield. 1955. The Effect of Electrolyte Concentration on Soil Permeability. J. Soil Sci. 6:163-178.

Radian Corp. 1975. Environmental Effects of Trace Elements from Ponded Ash and Scrubber Sludge. EPRI-202. Electric Power Research Institute, Palo Alto, California.

Seed, H. B., and C. K. Chan. 1959. Structure and Strength Characteristics of Compacted Clays. J. of the Soil Mechanics and Foundations Division, ASCE. 85(SM5):87-128.

Seed, H. B., J. K. Mitchell, and C. K. Chan. 1960. The Strength of Compacted Cohesive Soils. In: Proceedings of Research Conference on Shear Strength of Cohesive Soils. Soil Mechanics and Foundations Division, ASCE, Univ. of Colorado, Boulder, Colorado. 877 pp.

Seed, H. B., J. K. Mitchell, and C. K. Chan. 1962. Swell and Swell Pressure Characteristics of Compacted Clays. Highway Research Board Bull. 313: 12-39.

Shainberg, I., E. Bresler, and Y. Klausner. 1971. Studies on Na/Ca Montmorillonite Systems I. The Swelling Pressure. Soil Science. III(4): 214-219.

Skempton, A. W. 1953. The Colloidal Activity of Clays. In: Proc. 3rd Int. Conf. Soil Mechanics and Foundation Engng. 1:57-61.

Smith, W. S. 1980. Butyl - The Original Water Saver Elastomer. Presented at H. C. Remsberg Memorial Education Symposium, "The Role of Rubber in Water Conservation and Pollution Control" during 117th Meeting of Rubber Division, ACS., Las Vegas, Nevada.

Sowers, G. F., and J. G. Gulliver. 1955. Effect of Varying Tamping-Foot Width on Compaction of Cohesive Soil. In: Proc. the Highway Research Board. 34:538-601.

Stewart, W. S. 1978. State-of-the-Art Study of Land Impoundment Techniques. EPA 600/2-78-196, U. S. Environmental Protection Agency, Cincinnati, Ohio. 76 pp. PB 291-881.

Styron, C. R. III, and Z. B. Fry. 1979. Flue Gas Cleaning Sludge Leachate/ Liner Compatibility Investigation - Interim Report. EPA-600/2-79-136, U. S. Environmental Protection Agency, Cincinnati, Ohio. 78 pp. PB 80-100480.

Theng, B. K. G. 1979. Formation and Properties of Clay - Polymer Complexes Developments in Soil Science. Elsevier Scientific Publishing Company, New York. pp. 22-31.

Turnbull, W. 1964. Panel Discussion. In: ASTM Symposium, Compaction of Soils. ASTM STP 377. pp. 80-135.

Uniroyal, Inc. 1972. *Use of Latex as a Soil Sealant to Control Acid Mine Drainage.* Water Pollution Control Research Series 14010EFK 06/72, U. S. Environmental Protection Agency.

Vallerga, B. A., and R. G. Hicks. 1968. Water Permeability of Asphalt Concrete Specimens Using Back Pressure Saturation. J. of Materials. 3(1):73-86.

Walker, B. M., ed. 1979. Handbook of Thermoplastic Elastomers. Van Nostrand Reinhold Co., New York. 345 pp.

Wren, E. J. 1973. Preventing Landfill Leachate Contamination of Water. EPA 670/2-73-021. U. S. Environmental Protection Agency, Cincinnati, Ohio. 109 pp. PB 222-468.

Yong, R. N., and B. P. Warkentin. 1975. Soil Properties and Behavior. Geotechnical Engineering 5. Elsevier Scientific Pub. Co., New York. 449 pp.

Typical of the results which have been obtained on the exposure to leachate are those shown in Figures 4-3 through 4-5 regarding absorption of leachate, tensile strength retention, and relationship of retention of tensile strength and leachate absorption for various membrane lining materials that were immersed in leachate for 8 and 19 months. The effects of 8 month and 19 months of immersion in leachate upon the S-200 modulus of the membranes are shown in Table 4-10.

In Figure 4-3 the specific membranes are numbered on the bars. The length of the bars show the range of absorption values obtained for a liner material of a given polymer type. For example, one neoprene liner at 8 months swelled approximately 2% and another approximately 20%; at 19 months the spread had become 3% and 32%, respectively. Similar effects were observed for the values of modulus and of tensile strength (Figure 4-4).

In Figure 4-5 the retention of tensile is plotted against the leachate absorption for all pairs of data points measured at 8 and 19 months. These data show a general downward trend of tensile strength with increasing leachate absorption. Much of the loss in tensile strength can be attributed to swelling per se and the reduced amount of rubber in the cross-section of the tensile test specimen.

4.4.3 Exposure of Membrane Liners to Hazardous Wastes

The second contract was concerned with the laboratory evaluation of a wide range of liner materials, including membranes, on exposure to a variety of hazardous wastes. Our basic approach was to expose specimens of the various commercial lining materials under conditions which simulated real service, using actual wastes, to measure seepage through the specimens, and to measure effects of exposure by following changes in important physical properties of the respective lining materials.

In this study, various membrane lining materials were subjected to seven types of exposure testing:

- Bench screening tests; small specimens immersed in wastes.
- Primary exposure cells; one-side exposure to waste.
- Weather test; roof exposure.
- Weather test; small tubs lined with membranes and containing wastes.
- Water absorption at room temperature and 70°C.
- Membrane bags containing wastes in deionized water; one-side exposure.

The above exposure conditions are discussed and tests presented:

1. Primary exposure tests.
2. Immersion tests of membranes.
3. Pouch test of membranes.

TABLE 4-10. RETENTION OF MODULUS[a] OF POLYMERIC MEMBRANE LINER MATERIALS ON IMMERSION IN LANDFILL LEACHATE

Polymer	Liner no.	S-200, psi			Retention % of original value	
		Unexposed	8 mo.	19 mo.	8 mo.	19 mo.
Butyl rubber	44	685	590	620	86	90
Chlorinated polyethylene	12	1330	1130	1190	85	89
	38	1205	1070	1090	89	90
	86	810	790	860	98	106
Chlorosulfonated polyethylene	3	735	395	335	54	46
	6[b]	1550	1775	2070	114	134
	85	1770	1360	1920	77	108
Elasticized polyolefin	36	970	1005	1050	104	109
Ethylene propylene rubber	8	690	870	860	126	124
	18	760	840	830	110	109
	83[b]	845	905	900	107	107
	91	855	775	790	91	92
	41	1040	1035	1030	100	99
Neoprene	9	1235	975	950	79	77
	37	1635	1630	1640	100	100
	42[b]	–	–	–	–	–
	90	1190	1245	1350	105	114
Polybutylene	98	3120	3160	3150	101	101
Polyester elastomer	75	2735	2790	2670	102	98
Polyethylene	21	1260	1340	1285	106	102
Polyvinyl chloride	11	2120	1845	1805	87	85
	17	1965	1570	1640	80	84
	19	1740	1545	1645	89	94
	40	1720	1560	1570	91	91
	67	1700	1570	1780	92	105
	88	2400	1900	2105	79	88
	89	2455	2370	2330	96	95
Polyvinyl chloride + pitch[c]	52	1020	870	880	85	86

[a]Average of stress at 200% elongation (S-200) measured in machine and transverse directions.
[b]Fabric reinforced.
[c]S-100 values given; original and subsequent exposed specimens failed at less than 200% elongation.

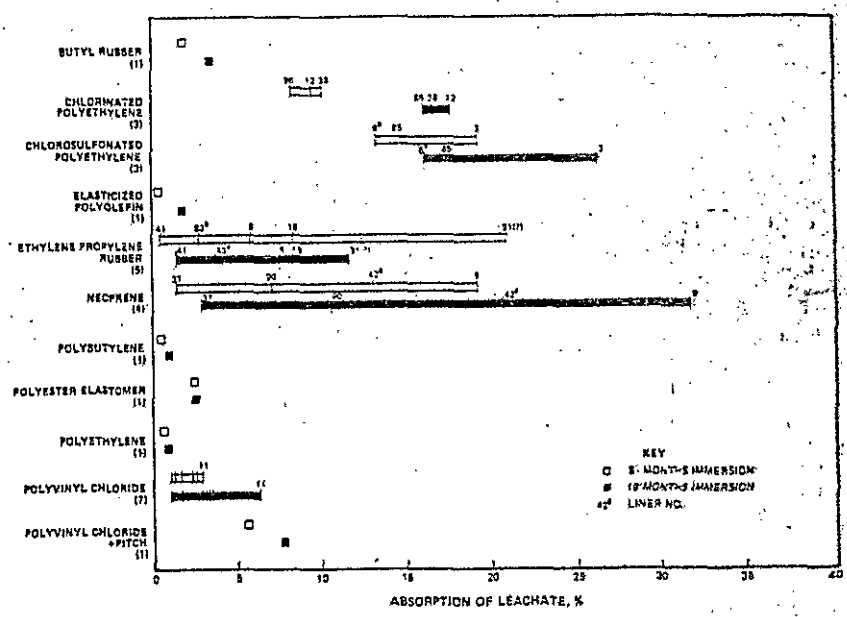


Figure 4-3 Swelling of membrane liners during immersion in leachate for 8 and 19 months. The number of different liners of a given polymer that are included in the test is shown in parentheses.

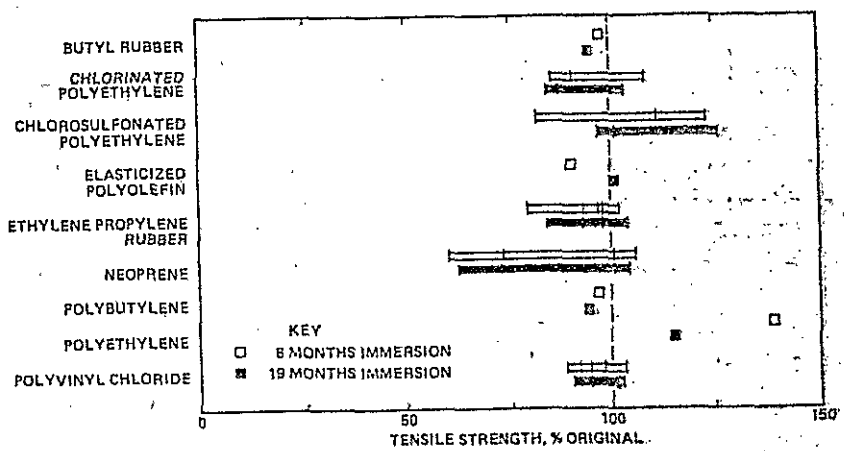


Figure 4-4 Retention of tensile strength of polymeric membrane liners on immersion in landfill leachate after 8 and 19 months. Tensile strength data were obtained by averaging the tests in machine and transverse directions.

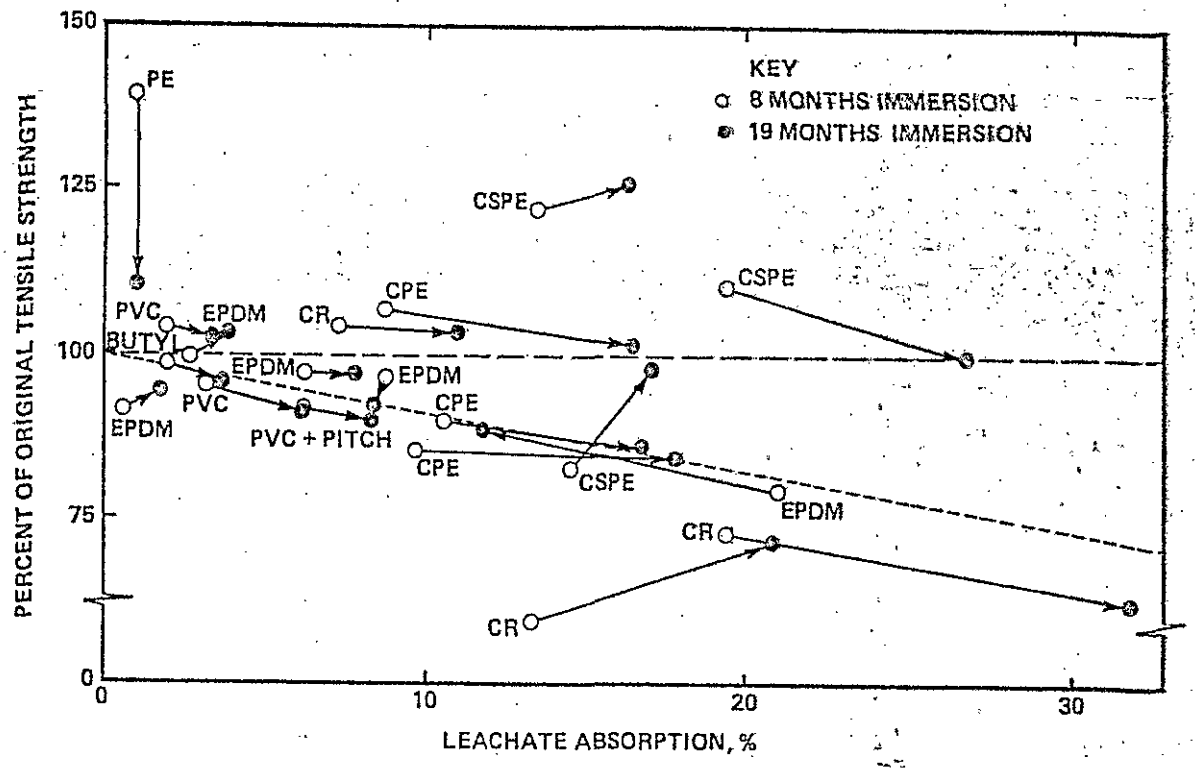


Figure 4-5 Retention of average tensile strength of membrane liner materials during immersion in landfill leachate as a function of swelling by the leachate.

Details regarding the other exposures are available in EPA reports. (Haxo, 1978 and 1980).

4.4.3.1 Exposure of Primary Liner Specimens

In this part of the study, specimens of one square foot of eight different polymeric membrane liners were exposed below one foot of waste in cells which simulated ponds. The wastes included two strong acid wastes, a strong alkali waste, an oil refinery tank bottom waste, a lead waste from gasoline, saturated and unsaturated hydrocarbon wastes, and a pesticide waste. Characteristics of these wastes are presented in Tables 4-11 and 4-12.

The exposure cell for the primary specimens is shown schematically in Figure 4-6. A similar type of exposure cell has been used for the thick admix and soil liners (Figure 4-7). Each membrane specimen was prepared with a field-type seam across the center made according to the recommended practice of the supplier of the membrane. Two specimens of each liner material were placed in two sets of cells which were loaded with portions of the same waste. The cells were dismantled at two exposure times and the liner specimens were recovered, analyzed, and their physical properties measured.

TABLE 4-11. WASTES IN EXPOSURE TESTS
Phases

Type of Waste	Name	Organic Phase I	Water Phase II	Solids Phase III
Acidic	"HFL"[a]	0	100	0
	"HNO_3, HF, HOAC"[b]	0	100	0
Alkaline	"Slopwater"[a]	0	100	0
	"Spent caustic"[b]	0	95.1	4.9
Lead	"Low lead gas washing")Blend[b]	10.4	86.2	3.4
	"Gasoline washwater")	1.5?	89.1?	–
Oily	"Aromatic oil"[b]	100	0	0
	"Oil Pond 104"[b]	89.0	0	11.0
	"Weed oil"[a]	20.6	78.4	–
Pesticide	"Weed killer"[b]	0	99.5	0.5

[a]In immersion tests only.
[b]In both primary exposure and immersion tests.

TABLE 4-12. WASTES IN EXPOSURE TESTS
pH, Solids, and Lead

Type of waste	Name	pH Water phase	Solids, % Total	Solids, % Volatile	Lead, ppm
Acidic	"HFL"	4.8	2.48	0.9	–
	"HNO_3, HF, HOAC"	1.5	0.77	0.12	–
Alkaline	"Slopwater"	12.0	22.43	5.09	–
	"Spent caustic"	11.3	22.07	1.61	–
Lead	"Low lead gas washing"	7.2	1.52	0.53	34
	"Gasoline washwater"	7.9	0.32	0.17	11
Oil	"Aromatic oil"	–	–	–	–
	"Oil Pond 104"	–	ca. 36	ca. 31	–
	"Weed oil"	7.5	1.81	1.00	–
Pesticide	"Weed killer"	2.7	0.78	0.46	–

Source: Haxo, 1980a.

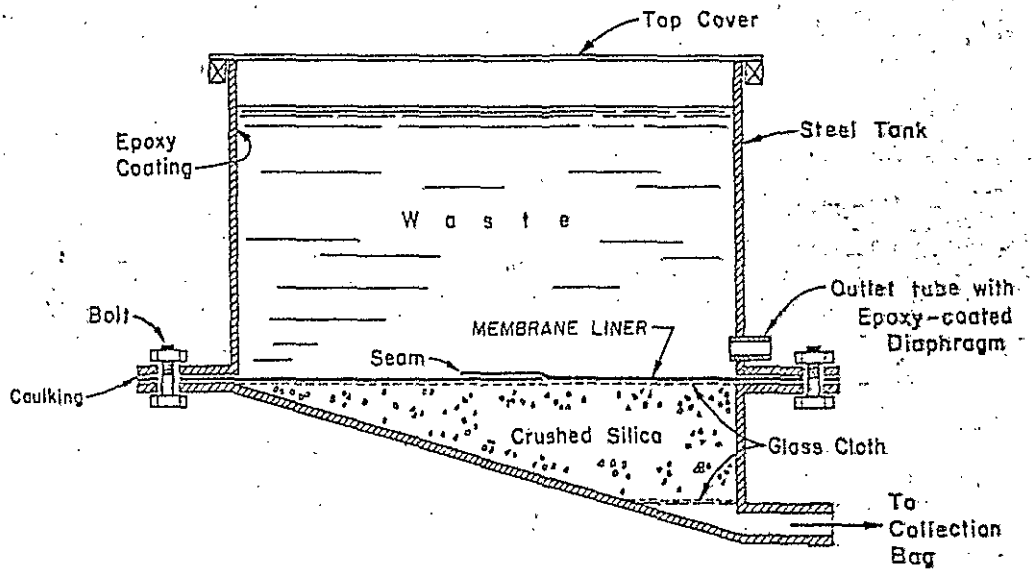


Figure 4-6. Exposure cells for membrane liners. Dimensions of the steel tank are 10 x 15 x 13 inches in width, length, and height.

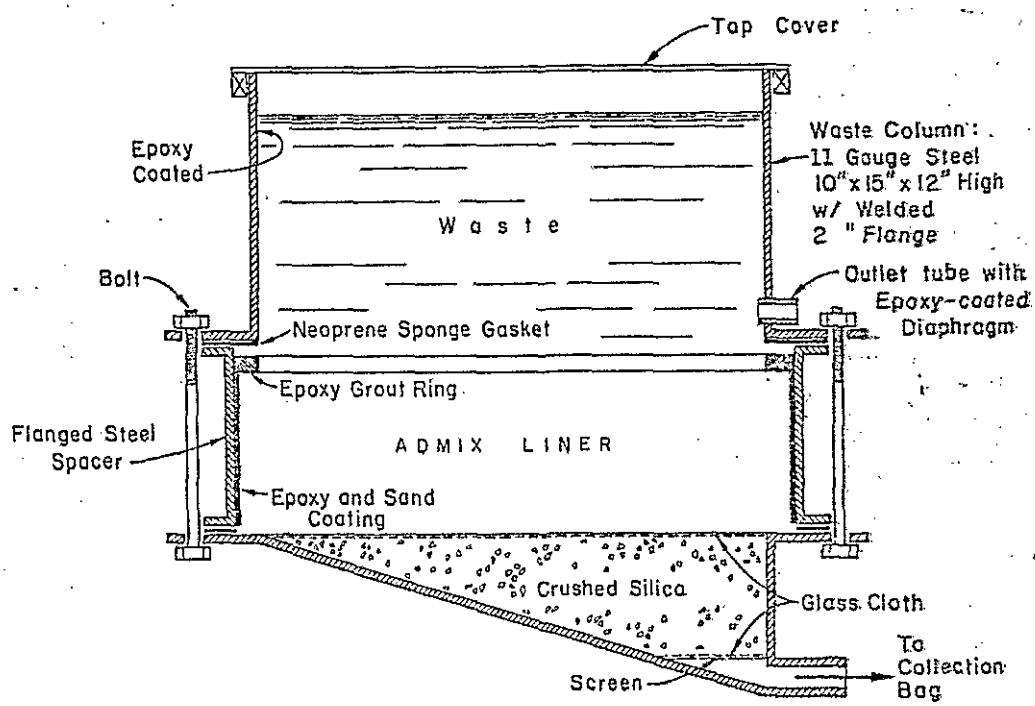


Figure 4-7. Exposure cell for thick liners.

The first set of primary specimens was removed after one year of exposure and the second set after approximately 3.5 years of exposure to the wastes. Selected data on the second set after 3.5 years of exposure are presented in Tables 4-13 and 4-14. Table 4-13 presents the results of tests for volatiles and extractables of the eight membrane liners exposed in four different wastes. The volatiles were determined on a sample of the liner immediately after removal from the waste and the extractables were determined on the specimen which had been devolatilized. Results show the variation in the volatiles and extractables both with respect to the polymer type and the waste. There are indications that, in some cases, the plasticizer which was in the original compound was removed during the exposure period. In other cases, the extractables were higher, indicating the absorption of nonvolatile constituents in the waste.

Table 4-14 presents the effects of one and three years of exposure upon ultimate elongation and S-100 modulus of the same liner materials in the same wastes.

The effects of 3.5 years of exposure to the wastes varies considerably with the liner material and the waste. Only one material, a polyester elastomer, completely lost its elongation and that was in exposure to a strongly acidic waste. The CSPE, neoprene, and EPDM liners lost significant elongation in the caustic, lead, and nitric acid wastes, respectively. The CSPE and PVC liners stiffened during exposure to the wastes and the neoprene liner softened. The CSPE crosslinked during exposure and the PVC probably lost plasticizer.

4.4.3.2 Immersion Tests

Concurrent with the exposure of the primary liners in the bases of the cells, supplemental membrane liner specimens were hung in the wastes. The effects of exposure were measured by determining the increase in weight, analyzing the exposed specimens and measuring selected physical properties. Details of the procedure followed in conducting the immersion tests are presented in Appendix III-A. The effects of the immersion tests on absorption of the wastes are shown in Table 4-15; the effects upon the elongation of the same materials are shown in Table 4-16.

In these tables, data are presented for 12 membranes based on eight different polymers immersed in eight different wastes from 2 to 2.2 years. Among these membrane specimens were two CSPE membranes, two EPDM membranes, and three PVC membranes. The oily type wastes, which included the lead waste, Oil 104, aromatic oil, and weed oil, represented a range in aromaticity and molecular weight. The weed oil, which is the most aggressive of the oils toward lining materials, is a light aromatic oil. It particularly swelled the CPE and CSPE liners. Oil 104 is a naphthenic and relatively heavy type of oil. It had its most pronounced effect upon the butyl rubber liner. In all cases, there was a variation between the two liners based upon the same polymer. The differences between the two CSPE specimens was the smallest. There were significant differences among the three PVC specimens. The effects of swelling carried into the elongation of the swollen material resulting, in some cases, in drastic reductions in this property.

TABLE 4-13. VOLATILES[a] AND EXTRACTABLES[b] OF PRIMARY POLYMERIC MEMBRANE LINER SPECIMENS AFTER EXPOSURE TO SELECTED WASTES

Liner data		Compound data		Volatiles, % Waste and exposure time in days (d)					Extractables, % Waste and exposure time in days (d)			
Polymer	No.[c]	Type[d]	Extractables, %	Unexposed	Pesticide 1260 d	HNO_3 1220 d	Caustic 1250 d	Lead 1340 d	Pesticide 1260 d	HNO_3 1220 d	Caustic 1250 d	Lead 1340 d
Butyl	57R	VZ	6.4	0.29	4.8	11.5	1.4	3.5	7.6	8.7	7.9	7.9
CPE	77	TP	9.1	0.00	7.9	13.2	2.8	19.2	9.4	10.6	9.1	7.2
CSPE	6R	TP	3.8	0.29	9.7	7.2	5.8	11.4	5.4	4.6	3.8	6.0
ELPO[e]	36	TP	5.5	0.15	...[f]	5.3	...[f]	1.5	...[f]	7.1	...[f]	8.1
EPDM	26	VZ	18.2	0.50	6.3	12.0[g]	1.3	5.3	25.2	22.8[g]	24.0	26.0
Neoprene	43	VZ	13.9	0.45	13.6	...	5.7	17.5	16.1	...	13.7	12.2
Polyester	75	TP	2.7	0.26	2.9	7.4[h]	0.9	1.7	5.8	13.5[h]	3.3	5.4
PVC	59	TP	35.9	0.26	3.6	...[f]	1.8	4.4	33.4	...[f]	35.6	22.5

[a]Percent weight loss after 2h @ 105°C.
[b]After devolatization in air oven for 2h @ 105°C.
[c]No. = Serial number of liner set by Matrecon; R = Reinforced with a fabric.
[d]Type = Vulcanized (VZ) or thermoplastic (TP).
[e]ELPO = Elasticized polyolefin.
[f]Specimens still under exposure to waste.
[g]Exposure time = 1150 days.
[h]Exposure time = 509 days.

Source: Haxo, 1980a.

TABLE 4-14. RETENTION OF ULTIMATE ELONGATION[a] AND S-100 MODULUS[b] OF PRIMARY POLYMERIC MEMBRANE LINER SPECIMENS ON EXPOSURE TO SELECTED WASTES

Liner data		Compound data			Ultimate elongation, % retention Waste and exposure time in days					S-100 modulus, % retention Waste and exposure time in days			
Polymer	No.[c]	Type[d]	Extractables, %	Original elongation[e], %	Pesticide 1260 d	HNO_3 1220 d	Caustic 1250 d	Lead 1340 d	Original S-100[f], psi	Pesticide 1260 d	HNO_3 1220 d	Caustic 1250 d	Lead 1340 d
Butyl	57R	VZ	6.4	70	77	419	142	108	...	...	...	...	...
CPE	77	TP	9.1	405	90	88	115	84	900	114	84	132	72
CSPE	6R	TP	3.8	235	88	83	68	81	645	118	112	199	118
ELPO[g]	36	TP	5.5	665	...[h]	96	...[h]	106	875	...[h]	103	...[h]	110
EPDM	26	VZ	18.2	450	103	79[i]	95	106	360	88	70[i]	109	80
Neoprene	43	VZ	13.9	320	84	...	95	75	460	54	...	96	62
Polyester	75	TP	2.7	575	87	<1[e]	87	90	2585	96	...	110	88
PVC	59	TP	35.9	385	93	...[h]	95	106	960	144	...[h]	170	107

[a]Ultimate elongation = The average of the values in both machine and transverse directions.
[b]S-100 modulus = The average of the values in both machine and transverse directions of the stress at 100% elongation.
[c]No. = The serial number of liner set by Matrecon.
[d]Type = Vulcanized (VZ) or thermoplastic (TP).
[e]Original elongation = Ultimate elongation of unexposed material.
[f]Original S-100 = S-100 modulus of unexposed material.
[g]ELPO = Elasticized polyolefin.
[h]Specimens still under exposure to waste.
[i]Exposure time = 1150 days.
[j]Exposure time = 509 days.

Source: Haxo, 1980a.

TABLE 4-15. ABSORPTION OF WASTE BY POLYMERIC MEMBRANE ON IMMERSION IN SELECTED WASTES
(Data in Weight Percent)

Polymer	No.[a]	Data on liner compound: Type[b]	Data on liner compound: Extractables, %	Waste and immersion time in days (d): Pesticide 807 d	HNO_3 751 d	HF 761 d	Spent caustic 780 d	Lead 786 d	Oil 104 752 d	Aromatic oil 761 d	Weed oil 809 d
Butyl	44	VZ	11.8	1.6	3.8	3.7	0.8	28.7	103.9	31.2	64.2
CPE	77	TP	9.1	12.7	19.9	12.9	1.1	118.9	36.9	226.4	ND[c]
CSPE	6R[d]	TP	3.8	17.3	10.0	9.0	4.3	120.7	49.5	105.2	368.4
CSPE	55	TP	4.1	15.7	10.9	7.7	3.3	116.2	55.0	110.5	347.5
ELPO[e]	36	TP	5.5	0.5	7.6	1.1	0.6	17.0	28.9	29.4	38.1
EPDM	83R[d]	TP	18.2	4.5	4.2	3.1	1.6	24.8	26.5	19.8	84.4
EPDM	91	VZ	23.6	20.4	50.9	23.9	1.3	34.7	84.7	34.2	76.2
Neoprene	90	VZ	21.5	11.4	17.4	12.0	1.5	59.1	26.3	142.6	89.3
Polyester	75	TP	2.7	4.2	6.4	2.0	1.5	7.4	8.5	16.6	14.7
PVC	11	TP	33.9	5.1	22.1	18.1	0.4	-1.5	-10.4	18.5	15.3
PVC	59	TP	35.9	1.0	-6.1	0.9	-0.9	7.4	-0.5	28.9	24.7
PVC	88	TP	33.9	1.6	28.2	14.3	1.1	-5.2	-9.8	14.1	25.2

[a]No. = the serial number of liner set by Matrecon.
[b]Type = vulcanized (VZ) or thermoplastic (TP).
[c]ND specimen was lost; some indication that it dissolved in the waste.
[d]R = fabric reinforced.
[e]ELPO = elasticized polyolefin.

TABLE 4-16. VOLATILES[a] CONTENT OF FLEXIBLE POLYMERIC LINERS ON IMMERSION IN SELECTED WASTES
(Data in percent loss of weight)

Polymer	No.[b]	Data on liner compound: Type[c]	Extractables, %	Volatiles (unexposed)[d], %	Waste and immersion time in days (d): Pesticide 807 d	HNO_3 751 d	HF 761 d	Spent caustic 780 d	Lead 786 d	Oil 104 752 d	Aromatic oil 761 d	Weed oil 809 d
Butyl	44	VZ	11.8	0.28	3.0	3.8	2.9	6.9	15.3	9.8	3.3	19.2
CPE	77	TP	9.1	0.00	8.6	20.4	8.1	1.6	42.2	5.2	ND[e]	ND[f]
CSPE	6R[g]	TP	3.8	0.29	10.8	10.4	7.6	4.2	3.3	20.2	6.1	50.7
CSPE	55	TP	4.1	0.42	7.9	9.1	7.1	3.6	1.1	10.0	4.8	39.7
ELPO[h]	36	TP	5.5	0.15	0.45	7.2	1.3	0.6	9.5	3.1	1.5	16.4
EPDM	83R[g]	TP	18.2	0.31	4.89	3.1	2.8	2.2	13.9	8.5	4.4	24.1
EPDM	91	VZ	23.6	0.34	15.6	22.6	23.6	1.2	18.5	11.8	4.2	33.4
Neoprene	90	VZ	21.5	0.27	7.26	13.7	10.5	2.9	23.6	6.3	3.9	28.9
Polyester	75	TP	2.7	0.26	1.75	28.0	3.8	1.3	6.1	2.1	3.4	9.5
PVC	11	TP	33.9	0.15	30.9	22.6	18.3	0.6	16.1	2.7	3.6	17.1
PVC	59	TP	35.9	0.26	40.1	10.6	3.0	1.5	12.7	3.3	4.6	16.1
PVC	88	TP	33.9	0.17	3.51	23.2	13.1	1.2	11.5	4.3	3.5	24.1

[a] "Volatiles" content is the loss in weight of a specimen of liner (unexposed or exposed) on air-oven heating for 2 hours at 105°C.
[b] No. is the serial number of liner assigned by Matrecon for identification.
[c] Type of compounds: vulcanized (VZ) or thermoplastic (TP).
[d] Volatiles content of unexposed specimens of liners.
[e] ND = no data obtained because the sample was too badly deteriorated to test.
[f] Immersion sample was lost. Some indication that it dissolved in the waste.
[g] R = fabric reinforced.
[h] ELPO = elasticized polyolefin.

4.3.3.3 Pouch Test

A new test, which was devised during work on the two EPA research contracts, appears to be a promising method for assessing the permeability and durability of membrane liner materials in contact with wastes.

In this test, small pouches are fabricated of the membranes to be tested. They are filled with wastes or other test fluids such as salt water, sealed and immersed in deionized water. The permeabilities of the membranes to water and to pollutants are determined by observing, respectively, the change in weights of the bags and the measurements of pH and electrical conductivity of the deionized water. Due to osmosis, water should enter the pouch and ions and dissolved constituents should leave the bag. Details of the test procedure are presented in Appendix III-B. A schematic representation of the pouch test showing the movement of the various constituents in shown in Figure 4-8.

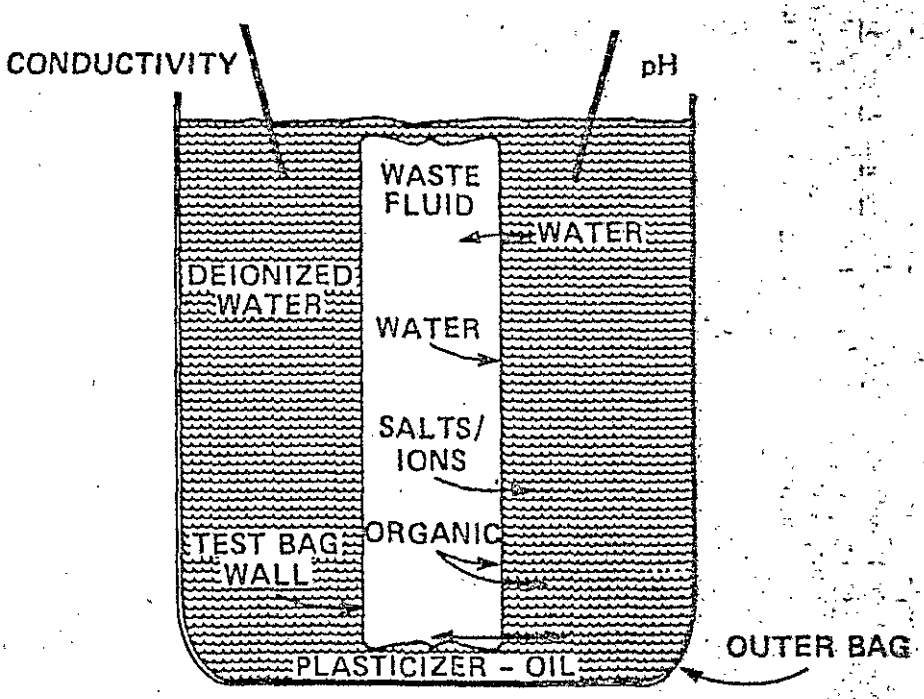


Figure 4-8. Schematic representation of the movements of the mobile constituents in the pouch (bag) test of membrane liner materials.

The initial tests were made with thermoplastic materials because they could be fabricated into pouches with relative ease by heat sealing. Some of these pouches have now been exposed more than 1000 days.

Bags containing the wastes actually increased in weight, indicating the flow of water into the bags through osmosis, as shown in Table 4-17. The long-term tests now show that some ionic material is diffusing through the liners into the deionized water.

TABLE 4-17. RELATIVE PERMEABILITIES OF POLYMERIC MEMBRANE LINING MATERIALS IN POUCH TEST WITH THREE WASTES[a]

Average flux into the pouch in grams per square meter per day x 10^{-2}

Polymer	Liner no[b]	Nominal thickness, mils	HNO_3 waste	Spent caustic	Slopwater
CPE	86	22	78.2	26.3	190.7[c]
CSPE	85	33	67.8	36.3	49.2
ELPO[d]	36	23	2.5	3.8	18.4[e]
PB[f]	98	7.5	3.0	7.9	13.6
PVC	19	22	32.4	78.8	325.0
PVC	88	20	64.2	65.9	118.8[g]

[a]Exposure time is 552 days unless otherwise noted.
[b]Matrecon identification number
[c]Pouch failed at 450 days.
[d]Elasticized polyolefin.
[e]Pouch failed at 300 days
[f]PB - polybutylene
[g]Pouch failed at 40 days

Table 4-18 presents the interpolated or estimated times to reach an electrical conductivity of 1000 μmho for slopwater and nitric acid, both of which are concentrated wastes. The data show the greater permeability of the PVC lining materials as compared to CPE, CSPE, elasticized polyolefin, and polybutylene; the latter two are partially crystalline materials.

TABLE 4-18. PERMEABILITY OF THERMOPLASTIC POLYMERIC MATERIALS IN OSMOTIC POUCH TEST

Time in days for electrical conductivity of water in outer pouch to reach 100 μmho

	Wall of inner bag			Waste in inner bag	
Polymer	Liner no[a]	thickness mils	Extractables, %	NHO_3 waste	Slopwater
CPE	86	20	...	200	420
CSPE	85	33	...	500	510
ELPO[b]	36	22	5.5	300	>1000
PB[c]	98	7	...	600	>1000
PVC	19	20	38.9	70	200
PVC	88	20	33.9	110	160

[a]Matrecon identification number

[b]Elasticized polyolefin.

[c]PB = polybutylene.

Table 4-19 presents the results of the thermoplastic membranes tested with 5% sodium chloride solution. The data again show the greater permeability of the PVC with respect to the CSPE and the elasticized polyolefin, which is the most impermeable of the three. These pouches have now been taken out of the test and physical properties of the pouch wall materials have been measured. The results show that, within the 1150 days of exposure, there was some loss in elongation and an increase in the stiffness of the membranes.

TABLE 4-19. POUCH TEST OF THERMOPLASTIC MEMBRANES[a]
Pouches filled with 5% NaCl solution

Polymer	CSPE	ELPO	PVC
Liner number[c]	6	36	59
Thickness, mils.	32	23	33
Volatiles content of exposed pouch wall, %	8.7	0.38	0.90
Change in weight of pouch plus waste, %	+2.6	+0.71	+0.38
Change in weight of fluid in pouch during exposure, %	+0.95	+0.76	+0.38
Conductivity of water in outer pouch, μmho	585	34	4500
Retention of physical properties, %:			
Elongation	95	100	94
S-100	106	119	120

[a]Exposure time 1150 days (164 weeks).

[b]Elasticized polyolefin.

[c]Matrecon identification number.

4.4.4 General Discussion of Results

The types of polymeric compounds that have been studied in the above two projects were described in Section 3.4.3. They are based upon the following four types of polymers:

- Vulcanized elastomers, e.g. butyl rubber, neoprene, EPDM, CSPE, CPE, ECO, nitrile rubber, blends.
- Thermoplastic elastomers (TPE), e.g. CSPE, CPE, polyolefins, blends.
- Thermoplastics, e.g. plasticized PVC, PVC blends with selected elastomers.
- Crystalline polymers (thermoplastic), e.g. LDPE AND HDPE.

Note: CSM is the identification used in the liner industry for chlorosulfonated polyethylene

Some of the polymers used in both crosslinked and thermoplastic versions. For example lining materials of CSPE and EPDM have been manufactured in both crosslinked and thermoplastic versions.

On exposure to fluids, most polymeric materials, whether they are crosslinked or not, will tend to swell and change in some properties. The major factors involved in the swelling of polymeric materials are:

- Solubility parameter.
- Crosslinking of polymer.
- Crystallinity of polymer.
- Chemical stability.
- Soluble constituents in compound.

The solubility parameter is used by polymer scientists to measure the similarity in chemical characteristics of the polymer such as is in the lining material, with a fluid with which it is in contact (Hilderbrand and Scott, 1950). For example, a hydrocarbon rubber like natural rubber will swell and dissolve in a hydrocarbon such as gasoline. On the other hand, a highly polar polymer, such as polyvinyl chloride or nitrile rubber, will not dissolve in gasoline.

Crosslinking a polymer or a rubber reduces its ability to swell in a solvent. Polymer scientists use the swelling of a crosslinked rubber as a measure of the degree of crosslinking: the greater the crosslinking, the less the swelling. This effect is pronounced in such rubbers as CSPE and CPE, liners of which are available in both vulcanized and unvulcanized forms.

Crystallinity of a polymer acts much like crosslinking to reduce the ability of a polymer to dissolve. Highly crystalline polymers, such as high-density polyethylene, will not dissolve in gasoline, even though they are basically similar in chemical composition. Such high density polymers are finding considerable use in containers for a wide range of solvents and chamicals.

Chemical stability means that the polymer does not degrade on aging which would result principally in reducing its molecular weight causing swelling and dissolving.

The soluble constituents of a rubber compound have a strong bearing on the ability of that material to swell. Most polymers contain minor amounts of solubles, e.g. salt, which are used in the manufacture of the raw rubber and of the compound. The swelling is a result of the diffusion of water into the compound. Soluble constituents can also arise from the compounding ingredients which are present in the compounding.

The effects that the first three factors have on the swelling of liner materials is illustrated in Figure 4-9. The swelling of the thermoplastic type of material in a fluid with which it is somewhat compatible is represented in Curve A, which indicates that the material will continue to swell with time and that no real plateau is reached.

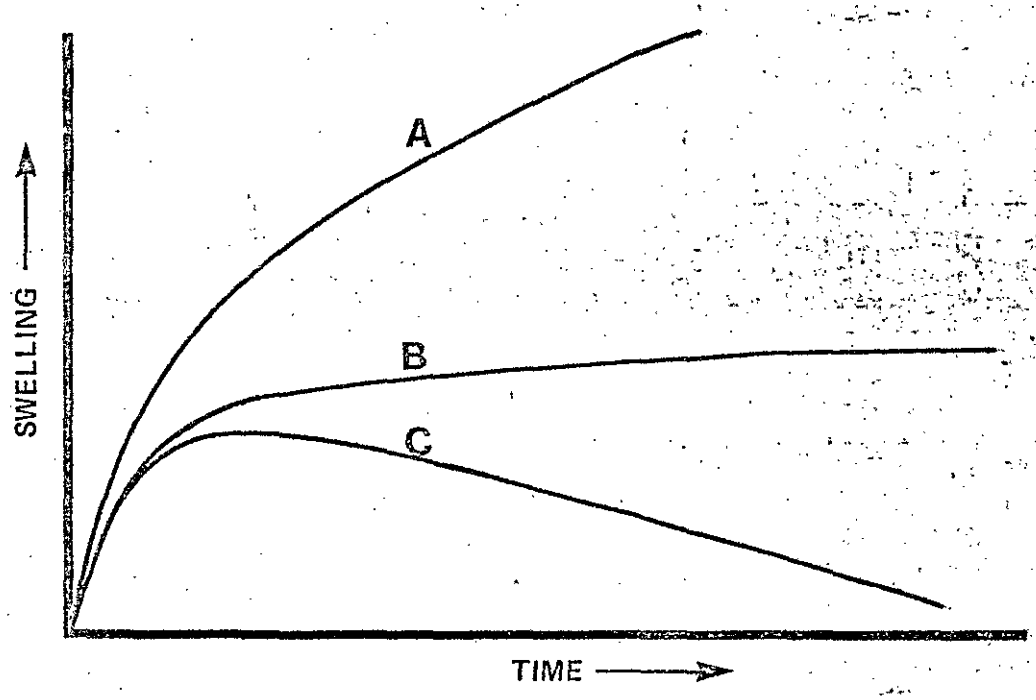


Figure 4-9. Types of swelling of polymeric membranes.

The swelling of crosslinked material is represented in Curve B, in which the swelling reaches a plateau and changes only slightly with time. The level of the plateau is determined by the degree of crosslinking and by the solubility parameter of the waste fluid and the polymer.

Curve C represents a plasticized thermoplastic or a oil-extended rubber in which the plasticizer is leached from the polymer. In this case, there is an initial swelling and reduction in swelling. In some cases, there can be a shrinkage of the liner due to the loss of plasticizer or oil. The effects on the physical properties of these exposures have been indicated in the above sections. The swelling will result principally in the softening of the material, possibly in its dissolving, and in increased permeability.

In selecting polymer and rubber compounds for service in a liquid medium, a designer generally selects materials which have low or negligible swell. Swelling of a compound usually has adverse effects which will make the product unserviceable. Some of the major effects of swelling generally are:

- Softening.
- Loss or tensile and mechanical strength.
- Loss of elongation.

- Increased permeability.
- Increased potential of creep.
- Greater susceptibility to polymer degradation.

All of these effects are adverse with respect to liner performance. Swelling, therefore, is a valuable indicator of the compatibility of a liner to a waste.

Shrinkage can also be a measure of compatibility for liner compositions that are highly plasticized. For example, in the case of highly plasticized PVC compounds, the plasticizer can leach and diffuse out of the polymer leaving the compound stiff and brittle.

4.5 Effect of Waste Fluids on Admix and Other Liner Materials

As a part of the two liner research programs described in the above section, a variety of soils and admix liner materials were exposed to the same waste fluids. The results of these tests, after limited exposure, are described in the next two subsectons.

4.5.1. Exposure to Municipal Solid Waste Leachate

After one year of exposure to leachate, the asphalt concrete and soil asphalt liners lost drastically in their compressive strengths; however, they maintained their impermeability to leachate. The asphalt binder, which normally hardens on aging in air, became softer indicating possible absorption of organic components from the leachate.

The soil cement liner lost some of its compressive strength; however, it hardened considerably during the exposure period and cored like a portland coment concrete. It became more impermeable during the exposure.

Inhomogeneities in the admix materials, which probably caused the leakage in the paving asphalt and soil asphalt liners, indicate the need for considerably thicker materials in practice. Thicknesses of two to four inches were selected for this experiment to give an accelerated test and were designed with an appropriately-sized aggregate. The same compositions in the second set of 12 liners did not leak after 27 months of exposure.

The asphalt membranes withstood the leachate for one year, although they did swell slightly. There was no indication of disintegration or dissolving of the asphalt.

4.5.2 Exposure to Hazardous Wastes

Five types of admix materials are being studied in this ongoing project:

- Compacted fine-grain native soil.
- Soil cement.

- Modified bentonite in sand.
- Hydraulic asphalt concrete.
- Membrane based on emulsified asphalt on a nonwoven fabric.

Because of the incompatibility of some of the wastes with particular admix materials, several combinations were deleted. The only liner material that was placed below the acid waste was the hydraulic asphalt concrete. Neither of the two oily wastes was placed on the asphaltic liners; however, the lead waste, which contained a light, oily fraction, was placed on these liners. The performance of the individual admix liners is discussed below:

Compacted fine-grain soil - All of the wastes, except the nitric acid waste, were placed above the compacted fine-grain soil liner. Seepage below all of the liners took place. The amount of seepage was measured and the respective pH, conductivity, and percent total solids were determined. The following observations are made with respect to the seepages through the soil liners:

a. The rate of seepage is 10^{-8} to 10^{-7} cm sec^{-1} which compares favorably with the permeability of the soil measured in the laboratory permeameter. There is some variation in the amount of seepage collected below the liner which may reflect permeability differences, perhaps due to density of the soil.

b. The fluids being collected after more than three years of exposure still continue to be essentially neutral and to have high solids content (mostly salt) and electrical conductivity.

c. There is a downward trend in solids content of the seepages collected under the pesticide and lead wastes, but the seepage under the spent caustic waste continues to be 23% solids.

One set of the soil liners was removed and tested. The permeability of a specimen taken from the cell containing the soil and the aromatic oil waste was determined using a "back-pressure" permeameter (Vallerga and Hicks, 1968). The sample was collected from a depth of seven to ten inches below the surface of the soil, i.e. from that part of the soil which was not penetrated by the oil. The three consecutive values obtained were: 1.83×10^{-8}, 2.43×10^{-8}, and 2.60×10^{-8} cm sec^{-1}. These figures indicate the low permeability of the soil, which had a bulk density of 1.318 g cm^{-3} and a saturation degree of 101%.

Analyses for trace metals were made of the soils which were below the lead waste, Oil 104, and the aromatic oil. The testing included determination of pH and heavy metal content (cadmium, chromium, copper, magnesium, nickel, and lead) on samples collected at different depths in the cells.

With the exception of the liner exposed to spent caustic, the pH of the soil liner was not significantly altered by the wastes. The pH of these samples

was in the range of 7.0 to 7.6; the ratio, soil:solution, was 1:2 with 0.01 N $CaCl_2$ being the equilibration solution.

In the case of the spent caustic, the pH values were around 9.0 for samples collected in the first two to three centimeters, which concurs with our previous findings that, over the exposure period of 30 months, the wetting front of the wastes penetrated the soil to a depth of only three to five centimeters.

The heavy metals distribution, as indicated by the analysis, shows, in the case of the lead, only a shallow contamination of the soil. Similar results were obtained on all six heavy metals in the case of the soil below the Oil 104 waste.

Soil cement - All of the wastes except the acid waste were placed on the soil cement liner. No seepage occurred through the liner during the 30 months of exposure.

One set of the soil cement lining materials was recovered after 625 days of exposure to the various wastes and the individual linings were cored and tested for compressive strength. In all cases, compressive strength of the exposed soil cement was greater than that of the unexposed material. There was some blistering of the epoxy asphalt coating which was applied to one-half the surface of each specimen.

Modified Bentonite and Sand - Two types of modified bentonites were used as liners in ten cells. One type allowed somewhat less seepage than the other. There was measurable seepage in seven of the ten cells and one failed allowing the waste (Oil 104) to come through the liner.

Irrespective of the type of waste above the liner, the quality of the seepage was not greatly different among the samples collected. The seepages collected below the pesticide waste on both types of modified bentonite liners were similar.

When the spacers containing the bentonite-sand were sampled, it was found that there had been considerable channeling of the wastes into these liners. There was no channeling at the walls of the spacers.

This type of liner is probably not satisfactory for these types of waste. The use of a soil cover on the bentonite layer to produce an overburden would probably reduce the channeling effect.

Hydraulic Asphalt Concrete - Liner specimens of hydraulic asphalt concrete were placed under four of the wastes. Excluded were the oily wastes.

This lining material functioned satisfactorily under the pesticide and spent caustic wastes, but failed beneath the nitric acid waste. However, the failure arose primarily from the failure of the aggregate which contained calcium carbonate; also, the asphalt was hardened considerably.

In the case of the lead waste, the asphalt absorbed much of the oily constituents of the waste and became "mushy". There was some staining of the gravel below the asphalt liner.

Duplicate cells containing the hydraulic asphalt concrete and the lead waste are still functioning without seepage.

Membrane Based on Emulsified Asphalt and Nonwoven Fabric - This membrane was placed under only three of the six wastes: pesticide, spent caustic, and lead. The acid waste was excluded because of the severe hardening it caused the asphalt, and the oil wastes were excluded because of the high mutual solubility of the asphalt and the wastes.

The asphalt membrane functioned satisfactorily with the pesticide and spent caustic wastes; however, when the cell containing the lead waste was dismantled, the gravel below the liner was wet and stained brown. This result indicates that some seepage took place.

4.6 Compatibility of Liner Materials in Waste Fluids

4.6.1 Introduction

In Chapter 2 various wastes which must be contained are discussed with particular reference to their aggressiveness to various lining materials. In Chapter 3, various liner materials which are candidates for the lining of waste disposal facilities are described and discussed with respect to their composition and characteristics.

The compatibility of a liner with specific waste is on of the first considerations that a designer has in planning a specific landfill site. The designer of a lined waste disposal site must decide which liner material of those he has available can effectively contain the particular waste over the needed length of time. In some cases, the requirement will be for extended lengths of time, such as would be encountered in landfills. The designer must determine what liner materials are compatible with the wastes that must be contained.

It is the objective of this section to summarize some of the information on the wastes and the liners presented in Chapters 2 and 3 and to describe the approach and methodology of determining the compatibility of liners with given wastes.

4.6.2 Screening of Liner Materials Based upon the State-of-the-art Knowledge

Although the direct experience of compatibility of liners and wastes based upon actual experience is limited, there is a vast amount of information available from the chemical and petroleum industries, soils science, materials science, polymer science and technology, containers industry, coatings industry, etc., from which the engineer and designer can draw to assess compatibility of given materials with wastes. The technology involving the use of materials for the lining of waste disposal facilities is relatively new. It

must depend on the experience of other technologies while it is developing and obtaining experience.

In this section the initial screening of liners based upon the available knowledge is described.

4.6.2.1 Characterizing the Waste

As has been indicated in Chapter 2, the waste fluids that are in the waste or are leached from the waste can be highly complex materials usually containing water and a wide range of inorganic and organic dissolved constituents. Individually, most of the constituents are well characterized. The difficulty with waste fluids is that they are complex blends containing components that can be toxic and also affect lining materials in a variety of ways. Also, the waste fluid can be highly concentrated and relatively simple, such as would occur in a spill. The analytical capabilities have developed greatly in recent years, therefore, an accurate compositional analysis can generally be made of a waste fluid. The designer must characterize the waste by obtaining an analysis to determine its major constituents. With these data he can make a first estimate of the kind of a liner which must be avoided. For example, oily wastes generally degrade asphalts and many polymeric materials. Soils, though very effective with water, may interact with ionic components such as calcium or, in some cases, some of the organic solvents.

The characterization of the waste should focus on those waste properties which are potentially damaging to liners described in this study. The following is a partial listing of waste constituents which can adversely affect one or more of the liners:

- High pH, greater than 10.
- Low pH, lower than 3.5.
- Oily wastes.
- High temperature.
- Presence of exchangeable ions, e.g. calcium.
- Organic fluids and acids.
- Organic compounds, in general.

4.6.2.2 Characterizing the Liner Materials Available

As discussed in Chapter 3, the range of materials which could be used to line disposal sites is large and covers a wide range of types, from soils and admixes to membranes of many kinds. As the soil at the site would probably be a candidate liner, it should be thoroughly investigated with respect to its character, not only as to permeability, but also to compatibility with the waste that might be placed on it.

The effects of various salts and chemicals upon soils are known from the agricultural science and, to some extent, from chemical science. From the polymer industry there is considerable information available on the use

of polymeric materials for the lining of many pipes, reactors, gaskets, etc. which function in non aqueous media, acids, bases, etc. Generally, these fluids are simple, that is the number of constituents are few. However, there is wide experience with handling these various materials. Many of these plastics and rubbers are used in outdoor applications and much information is available on their durability and weatherability. Considering the available liner materials, it is quite possible that some can be eliminated when considering the waste that must be contained.

4.6.2.3 Matrix of Liner Materials-Waste Compatibilities

Out of experience to date, matrixes of wastes and liners can be considered to indicate the general compatibility of some of the materials. An example of this is in Table 4-20 which shows the range of types of liner materials and a variety of industrial and hazardous wastes. In all cases, neither the types of liner materials nor the types of wastes are specific. Each has a range of compositions and characteristics. A rating of "good" indicates that the combination is probably satisfactory; "fair" indicates the combination should be tested, and "poor" indicates the combination should be avoided. This table functions only as an initial guide and, in many cases, specific combinations of liner materials and wastes must be tested before selecting acceptable liner materials. This is the subject of the next section.

4.6.3. Testing of Specific Combinations of Liners and Wastes

As indicated in the previous section, knowledge of the wastes to be contained and the lining materials available can be used to make an initial screening of specific lining materials which might be suitable for containing the wastes. In some cases this knowledge may be sufficient to make a choice, particularly if the waste does not contain components aggressive toward liners. Generally, a compatibility test should be performed before a specific liner is selected.

4.6.3.1 Sampling and Analyses of Wastes for Compatibility Tests

In order to run accurate compatibility tests of lining materials, a representative sample of the waste must be obtained. In as much as wastes are generally highly complex and heterogeneous, there is a major problem in obtaining representative samples. In some cases samples of the specific waste may not be available and similar types of wastes must be used. Furthermore, consideration must be given to the fact that over the period of time that an impoundment may be operating, there may be a change in the composition of the wastes.

4.6.3.2 Compatibility Testing of Soils

In Section 4.2 some of the testing of the soils which is necessary to determine the chemical sensitivity of the soil is described. The use of Atterberg limits using the wastes as the fluid, when compared with the use of water, will give an indication of the sensitivity of that soil. Also, the effect of the waste upon permeability of soils is described in Section 4.2 and Appendix III-D.

TABLE 4-20. LINER-INDUSTRIAL WASTE COMPATIBILITIES[a]

Liner material	Caustic petroleum sludge	Acidic steel-pickling waste	Electro-plating sludge	Toxic pesticide formula-tions	Oil refinery sludge	Toxic pharma-ceutical waste	Rubber and plastic
Soils:							
Compacted clayey soils	P	P	P	G	G	G	G
Soil-bentonite	P	P	P	G	G	G	G
Admixes:							
Asphalt-concrete	F	F	F	F	P	F	G
Asphalt-membrane	F	F	F	F	P	F	G
Soil asphalt	F	P	P	F	P	F	G
Soil cement	F	P	P	G	G	G	G
Polymeric membranes:							
Butyl rubber	G	G	G	F	P	F	G
Chlorinated polyethylene	G	F	F	F	P	F	G
Chlorosulfonated poly-ethylene	G	G	G	F	P	F	G
Ethylene propylene rubber	G	G	G	F	P	F	G
Polyethylene (low den-sity)	G	F	F	G	F	G	G
Polyvinyl chloride	G	F	F	G	G	G	G

[a]Stewart, 1978. G = Good, F = Fair, P = Poor.

4.6.3.3 Polymeric Materials

Three individual types of tests have been found useful in assessing the effects of the wastes upon lining materials. These are:

- Immersion Test
- Pouch Test
- Tub Test

Each of these tests is described in detail in Appendix III-A, III-B, and III-C, respectively.

Immersion Test - In this test samples of the specific membrane liners are immersed in the waste and the effects of the immersion upon the weight and dimensions of the liner specimens and a selected number of physical properties are measured as a function of immersion time. By immersing the samples totally in the waste fluid, a somewhat accelerated test is generated. Further acceleration can be effected by increasing the temperature somewhat. However, the closer the temperature and exposure conditions are to actual service, the more reliable the results will be. Also, the longer the test can be run, the more reliable it will be. These types of tests should be initiated early in the design phase of the waste facility. An exposure period of twelve months is desirable. Samples can be withdrawn at one, two, four, etc., months to assess the effect as a function of time.

Pouch Test - This test was designed to measure the permeability of polymeric membrane liner materials to water and to dissolved constituents of the wastes. A sample of the waste is sealed in a small pouch fabricated of the liner material under test which is then placed in distilled or deionized water. Measurements are taken periodically to determine the extent of movement of water into the membrane and/or leakage of waste into the water. A concentration gradient is created by the deionized water on one side of the membrane and the waste on the other side. This test environment results in the movement by osmosis of water and ions and other dissolved constituents through the membrane due to the differences in concentrations on either side of the membrane. Changes in liner materials are observed and later physical properties are tested.

Tub Test - The purpose of this test is to evaluate flexible membrane liner materials under conditions which simulate those that occur in actual service. The effects of exposure to the sun, temperature changes, ozone, and other weather factors can be evaluated as well as the effect of a given waste on a specific liner. The fluctuation of the level of the waste is particularly significant in that a horizontal section of the liner is subjected to the effects of both the waste and weather. This alternating of conditions is especially harsh on liner materials and is usually encountered in the field.

4.7 Failure Mechanisms and Estimating Service Lives

An important factor in selecting liner material for a given disposal facility is to match the required life of the waste impoundment with the estimated service life that can be anticipated for a given liner in the particular exposure condition. It is recognized that there can be a range in the lives that are needed. For ultimate disposal of a waste, very long times are required during which a liner must maintain its integrity and function as designed. On the other hand, for temporary holding ponds, much shorter lives are satisfactory. Furthermore, the life of a liner will depend upon the waste which it contains.

In order to make estimates of the service lives, it is necessary to know how the liner system might fail. In Section 4.3 the various failure mechanisms relating to clayey soil liners are described and discussed. The effects of a variety of wastes on soils are described with particular reference to their loss in permeability and in strength resulting from the effects of chemical species on the soils.

The effects of various wastes on polymeric membrane and admix limer materials are described in Sections 4.4 and 4.5 respectively. Some of the effects appear to be severe enough to cause a liner to fail if the exposure is sufficiently long.

The experience in the field with membrane type liners and liners in general has been primarily for reservoirs and other water containment facilities. The failure type mechanisms that have been encountered are described by Kays (1977). An amplification of the subject of failure mechanisms and estimating service life will be forthcoming in revisions of this Manual.

This section describes and discusses the categories and characteristics of the failures of liners in the service environment. The objective of this section is to enable the user of this manual to understand and identify liner failures and the events leading to failure. The three major categories of liner failure that will be discussed in this subsection are physical, biological, and chemical. Table 4-21 is a listing of the principal failure mechanisims in liners.

Failure of liners include problems in the subgrade, the lining material itself, forces of weather and aging, and problems imposed by operating procedures on condition. The problems in subgrades are related to compaction, differential settling, slope sloughing, built-up hydrostatic and gas pressures. Failures may be induced by chemical and/or physical circumstances. Chemical compatibility failures are a function of the waste-liner combination, while physical failures are more often subgrade related.

4.7.1 Physical Failures

There are several modes of liner failure due to physical processes and stresses, each of which is described in the following paragraphs. Each particular failure mode may or may not apply to every type of liner. However, notable examples will be presented where warranted.

TABLE 4-21. FAILURE CATEGORIES

Physical	Biological	Chemical
Puncture	Microbial attack	Ultraviolet attack
Tear		Ozone attack
Creep		Hydrolysis
Freeze-thaw cracking		Ionic species attack
Wet-dry cracking		Extraction
Differential settling		Ionic species incompatibility
Thermal stress		Solvents
Hydrostatic pressure		
Abrasion		

4.7.1.1 Puncture

Puncture failure would most commonly occur in membrane liners; however, such failure can occur in the other types of liners under specific circumstances. Puncture failure of membrane liners due to sharp angular rocks in the subgrade that have become exposed to the liner because soil fines migrated downward over time is a major concern. Puncture from operations, man or vehicular, is of concern but can largely be mitigated through good operation procedures. Burrowing animals and amnimals seeking water can also cause puncture.

4.7.1.2 Tear

Tear failure is similar to puncture failure in its occurrence. Because of a membrane's relative thinness compared to soils, clays, asphalts and other liners, its resistance to failure in that dimension is correspondingly reduced. Localized structural tear failure can result from several stress-relaxation-stress cycles in which the liner is losing strength or it stretched with each cycle. Tear, like puncture, can occur due to operations or animals.

4.7.1.3 Creep

Creep is the common term used to describe increasing deformation of a material under sustained load. The main factors which influence creep failure are material microstructure, stress level and temperature. The significance of this type of failure is that it is difficult to detect and control. Creep can occur with any liner material.

4.7.1.4 Freeze-thaw Cracking

Cycles of freezing and thawing cause material cracking which leads to failure by volume expansion of liquids in pore spaces during freezing. This expansion increases pore space volume and the accessibility of liquids to the pore space

volumes. In addition, the freeze-thaw cycle will not be a localized failure at a facility, but will occur throughout. Proper planning and design is essential to mitigate this type of failure in areas where freezing is a major concern.

4.7.1.5 Wet-dry Cracking

This mode of failure is most commmonly found when clay liners are used. The wet-dry cycles cause alternate expansion and shrinkage of clay liners which decrease the strength of the liner and increase its overall effective permeability. Because soil materials have poor tensile strength, the shrinkage caused by drying is highly disruptive to the cohesive structure of clays. Other liners are adversely affected by wet-dry cracking, but to a lesser extent.

4.7.1.6 Differential Settling

Differential settling can damage all liners. This problem is best mitigated with a thorough geologic analysis prior to site selection and careful subgrade design and construction. Differential settling is a localized structural stress phenomenon and the greater the thickness and elasticity of the liner, the greater the tolerance range for differential settlement.

4.7.1.7 Thermal Stress

Thermal stress results from differential temperatures through a material or when temperature change is sufficent to cause a phase change in a material. This temperature change (especially in polymeric membranes) can cause volume changes by thermal expansion (or contraction) as the case may be, or by phase changes. Thermal stress may also become significant in light of the different reaction rates produced by individual components of a composite material. Phase changes in solid materials caused by heat, generally cause stress because different phases usually have different volumes per unit weight. Thermal stress can be controlled or tolerated by allowing for expansion or contraction in design, stress relief, or an acceptable range of variation. However, if the stress is great enough, cracks will occur. All asphalt liners are highly susceptible to temperature. Polymeric membrane liners are also temperature sensitive, but to a lesser degree.

4.7.1.8 Hydrostatic Pressure

Hydrostatic pressure is of concern when the structural support of a subgrade or base material is lost by piping, sinkholes, oxidation of organic material, settlement, etc. The effect of hydrostatic pressure exerted beneath a liner, which is due to inadequate drainage below the liner, is discussed in Chapter 5.

4.7.1.9 Abrasion

The continuous or near continuous action of abrasion on a liner has a significant wearing effect over time. Windborne abrasion is a serious consideration. In arid regions, sand particles carried by the wind have a

sandblasting effect on the liner. Liners with high abrasion resistance must be specified, or a protective cover must be placed on the exposed berms. Runoff entering the pond from the surrounding topography may contain sticks, branches, rocks, and other debris which could abrade, tear, or even puncture the liner. Construction of a diversion channel to handle runoff will avoid the potential problems.

4.7.2 Biological Failures

The major emphasis on biologically induced failure is microbial attack in which the microbes "eat" the material and damage or destroy its structural integrity and low seepage characteristics. Particularly susceptible to biological attack are the plasticizers that are used in some polymer compounds. Bactericides are sometimes used to counteract this type of failure.

4.7.3 Chemical Failure

Because organic and inorganic chemicals constitute a great majority of the hazardous wastes to be contained in lined waste impoundment facilities, chemical failures are of great importance and significance. The following paragraphs describe the various types of chemical failure.

4.7.3.1 Swelling

The most serious chemical effect to polymeric liners at waste disposal facilities is that of swelling which is discussed in detail in Section 4.4.4. Potentially, sufficient swelling can cause loss in strength, elongation, creep and flow, and loss in puncture resistance. Failures of these types are most apparent when the liner is in direct contact with the wastes.

4.7.3.2 Extraction

Liner materials such as polyvinyl chloride which contain large amounts of monomeric plasticizer are highly susceptible to extraction of the plasticizer. Such extraction can result in embrittlement and shrinkage and possibly breakage of the liner. This effect is also discussed in Section 4.4.4.

4.7.3.3 Outdoor Exposure

Exposed polymeric linings can be subject to failure from heat and infrared, ultraviolet light, oxygen, ozone, and moisture. The factors generally operate in combination, with the presence of oxygen and moisture being the major contributing factors. Failure of the liner generally occcurs from embrittlement, shrinkage and breakage. Ozone can cause cracking of many polymers, particularly those which contain some unsaturation. Failures of this type occur in areas where the rubber sheeting is stretched.

Considerable information is available on the durability and service lives of exposed lining materials in which the principal environmental conditions are ultraviolet light, oxygen, ozone, heat, and wind (Strong, 1980).

REFERENCES

Chapter 4. Lining Materials in Service Environments

Adams, N.K. 1941. The Physics and Chemistry of Surfaces. Oxford University Press, London.

Aitchison, G.D., and C.C. Wood. 1965. Some Interactions of Compaction, Permeability and Post-Construction Deflocculation Affecting the Probability of Piping Failure in Small Dams. In: Proc. 5th Int. Conf. on Soil Mech. and Foundation Eng. 2:442-446.

Anonymous. 1966. Chemical Resistance of Asphalt Coatings. Materials Protection. 5:81-83.

Anonymous. 1977. Groundwater Manual: A Water Resources Technical Publication. Bureau of Reclamation, U.S. Dept. of Interior, Denver, Colorado. pp. 457-460.

Barrier, R.M. 1978. Zeolites and Clay Minerals as Sorbents and Molecular Sieves. Academic Press, New York. 497 pp.

Barshad, I. 1952. Factors Affecting the Interlayer Expansion of Vermiculite and Montmorillonite With Organic Substances. SSSAP. 16: 176-182.

Baver, L.D., W.H. Gardner, and W.R. Gardner. 1972. Soil Physics. John Wiley and Sons, Inc., New York. 498 pp.

Bennett, J.P. 1966. Permeability of Soils at Elevated Permeant Pressures. Master's Thesis. Colorado State University, Fort Collins, Colorado.

Blevins, R.L., and L.P. Wilding. 1968. Hoytville Soils: Their Properties, Description, Management, and Use. Research Bul. 1006. Ohio Agricultural Research and Development Center, Wooster, Ohio.

Bowles, J.E. 1968. Coefficient of Permeability - Falling Head Method. In: Engineering Properties of Soils and their Measurement. McGraw Hill Book Co., New York. pp. 105-110.

Bowles, J.E. 1979. Physical and Geotechnical Properties of Soil. McGraw-Hill Book Co., New York. 478 pp.

Brant, G.J. 1968. Water Movement in Hydrophobic Soils. In: Proceedings of Water Repellent Soils Symposium. Univ. of California, Riverside, CA. pp. 91-115.

Cedergren, H.R. 1977. Seepage, Drainage and Flow Nets. 2nd ed. John Wiley & Sons, Inc., New York. 534 pp.

Cheremisonoff, N.P., P.N. Cheremisonoff, F. Ellerbusch, and A.J. Perna. 1979. Industrial and Hazardous Wastes Impoundment. Ann Arbor Sci. Publ., Inc., Ann Arbor, MI. 475 pp.

Christiansen, J.E., M. Fireman, and L.E. Allison. 1946. Displacement of Soil-air by CO_2 for Permeability Tests. Soil Science. 61: 355-365.

Clementz, D.M. 1976. Interaction of Petroleum Heavy Ends with Montmorillonite. Clays and Clay Minerals. 24:312-319.

Crouch, R.J. 1978. Variation in Structural Stability of Soil in a Tunnel Erroding Area. In: Modification of Soil Structure. John Wiley & Sons, Inc., New York. pp. 267-274.

Davidson, F.E., and J.B. Page. 1956. Factors Affecting Swell and Shrinking in Soil. SSSAP. 20:320-324.

EPA-OSWMP. 1974. Report to Congress: Disposal of Hazardous Waste. SW-115. U.S. Environmental Protection Agency, Washington, DC. 110 pp.

Ewald, G.W. 1973. Stretching the Life Span of Synthetic Pond Linings. Chemical Engineering. 80(22):67-70.

Gieseking, J.E. 1939. Mechanism of Cation Exchange in the Montmorillonite-Beidellite-Nontronite Type of Clay Materials. Soil Science. 47:1-14.

Glaeser, R. 1949. On the Mechanism of Formation of Montmorillonite-acetone Complexes. Clay Minerals Bulletin. 3:89-90.

Goring, C.A.I., and J. W. Hamaker. 1972. Organic Chemicals in the Soil Environment. Vols. I and II. Marcel Dekker, Inc., New York.

Greene-Kelly, R. 1955a. Unusual Montmorillonite Complex. Clay Minerals Bulletin. 2(13):225-232.

Greene-Kelly, R. 1955b. Sorption of Aromatic Organic Compounds by Montmorillonite, Part I, Orientation Studies. Trans. Faraday Soc. 51:412-424.

Grim, R.E. 1953. Clay Mineralogy. 2nd ed. McGraw-Hill Book Co., Inc., New York. 296 pp.

Grim, R.E. 1968. Clay Mineralogy. McGraw-Hill Book Co., Inc., New York. pp. 434-436.

Grim, R.E., and F.L. Cuthbert. 1945. The Bonding Action of Clays I: Clays in Green Molding Sands. Report of Investigation No. 102. Illinois State Geologic Survey.

Grubbs, D.M., C.D. Haynes, T.H. Hughes, and S.H. Stow. 1972. Compatibility of Subsurface Reservoirs with Injected Liquid Wastes. Report No. 721. Nat. Resources Center, Univ. of Alabama.

Grubbs, D. M., C. D. Haynes, and G. P. Whittle. 1973. Permeability Restoration in Underground Disposal Reservoirs. Report No. 773. Nat. Resources Center, Univ. of Alabama.

Hardcastle, J.H., and J.K. Mitchell. 1974. Electrolyte Concentration — Permeability Relations in Sodlium Illite-Silt Mixtures. Clays and Clay Minerals. 22(2): 143-154,

Haxo, H.E. 1977. Compatibility of Liners With Leachate. In: Management of Gas and Leachate in Landfills, Proceedings of the Third Annual Municipal Solid Waste Research Synposium. EPA-600/9-77-026. U.S. Environmental Protection Agency, Cincinnati, Ohio. (PB-272-595).

Haxo, H.E. 1978. Interaction of Selected Lining Materials with Various Hazardous Wastes. In: Proceedings of the Fourth Annual Research Symposium. EPA-600/9-78-016. U.S. Environmental Protection Agency, Cincinnati, Ohio. PB 286-956.

Haxo, H.E. 1980a. Interaction of Selected Liner Materials with Various Hazardous Wastes. In: Disposal of Hazardous Wastes, Proceedings of the Sixth Annual Research Symposium. EPA-600/9-80-010. U.S. Environmental Protection Agency, Cincinnati, Ohio. pp. 160-180. PB 80-175086.

Haxo, H.E. 1980b. Laboratory Evaluation of Flexible Membrane Liners for Waste Disposal Sites. Presented at the 117th Meeting of the Rubber Division, American Chemical Society, Las Vegas, Nevada, May 22, 1980.

Haxo, H.E., and R.M. White. 1974. Evaluation of Liner Materials Exposed to Leachate, First Interim Report. EPA Contract 68-03-2134, unpublished.

Haxo, H.E., and R. M White. 1976. Evaluation of Liner Materials Exposed to Leachate, Second Interim Report. EPA-600/2-76-255. U.S. Environmental Protection Agency, Cincinnati, Ohio. 53 pp. PB 259-913/AS.

Haxo, H.E., R. S. Haxo, and T. F. Kellogg. 1979. Liner Materials Exposed to Municipal Solid Waste Leachate, Third Interim Report. EPA-600/2-79-038. U. S. Environmental Protection Agency, Cincinnati, Ohio. PB 293-335.

Haxo, H.E., R.S. Haxo, and R.M. White. 1977. Liner Materials Exposed to Hazardous and Toxic Sludges, First Interim Report. EPA-600/2-77-081. U. S. Environmental Protection Acency, Cincinnati, Ohio. 63 pp. PB 271-013/AS.

Holtz, W. G., and H. G. Gibbs. 1956. Engineering Properties of Expansive Clays. Trans of the ASCE. 121:641-677.

Hughes, J. 1975. Use of Bentonite as a Soil Sealant for Leachate Control in Sanitary Landfills. Soil Lab. Eng. Report Data 280-E. American Colloid Co., Skokie, IL.

Hurst, R.E. 1970. Chemicals Find Growing Use in Oil Fields, Chem. & Eng. News. 48: March 9, p.10.

Johansen, R.T., J.P. Powell, and H.N. Dunning. 1951. The Use of Non-Ionic Detergent and Citric Acid for Improving Cleanout Procedures of Water-Input Wells in Secondary Oil-Recovery Projects. Information Circular No. 7797. Bureau of Mines, U. S. Dept. of the Interior, Denver, Colorado.

Jones, C.W. 1960. Permeability Tests With the Permeant Water Under Pressure. Earth Laboratory Report # EM-559. Division of Engineering-Laboratories Commissioner's Office. Denver, Colorado.

Jones, J.A.A. 1978. Soil Pipe Networks: Distribution and Discharge. Cambria. 5:1-21.

Kays, William B. 1977. Construction of Linings for Reservoirs, Tanks, and Pollution Control Facilities. Wiley-Interscience, John Wiley and Sons, Inc., New York. 379 pp.

Lambe, T.W. 1958. The Structure of Compacted Clays. J. of Soil Mechanics and Foundations Div., ASCE. 84 (SM2): 34.

Landau, H.C., and A.G. Altschaeffl. 1977. Conditions Causing Piping in Compacted Clay. In: Dispersive Clays, Related Piping, and Erosion in Geotechnical Projects. ASTM STP 623. pp. 240-259.

Letey, J., J.F. Osborn, and R.E. Pelishek. 1962. Measurement of Liquid Solid Contact Angles in Soil and Sand. Soil Science. 93:144-153.

Low, P.F. 1979. Nature and Properties of Water in Montmorillonite-Water Systems. SSSAJ. 43:651-658.

Mansur, C.I., and R.I. Kauffman. 1956. Underseepage, Mississippi River Levees, St. Louis District. Proceedings Paper 864. American Society of Civil Engineers.

Mielenz, R.C., and M.E. King. 1955. Physical-Chemical Properties and Engineering Performance of Clays. Bulletin 169. California Division of Mines. pp. 196-254.

Miller, W.W., N. Valoras, and J. Letey. 1975. Movement of Two Non-Ionic Surfactants in Wettable and Water Repellent Soils. SSSAP. 39:11-16.

Mitchell, J.K. 1976. Fundamentals of Soil Behavior (Series in Soil Engineering). John Wiley and Sons, Inc. New York. 422 pp.

Moriwaki, Y., and J.K. Mitchell. 1977. The Role of Dispersion in the Slaking of Intact Clay. In: Dispersive Clays, Related Piping, and Erosion in Geotechnical Projects. ASTM STP 623.

Nutting, P.E. 1943. The Action of Some Aqueous Solution in Clays of the Montmorillonite Group. Prof. Paper 197F. U.S. Geological Survey. pp. 219-235.

Pask, J.A, and B. Davis. 1945. Thermal Analysis of Clays and Acid Extraction of Alumina from Clays. Technical Paper 644. U.S. Bureau of Mines, U. S. Dept. of the Interior, Denver, Colorado. pp. 56-58.

Perkins, P.H. 1976. Concrete Structures: Repair, Waterproofing and Protection. Applied Science Publishers, London. 302 pp.

Ravina, I., and P.F. Low. 1972. Relation Between Swelling, Water Properties and b-Dimension in Montmorillonite-Water Systems. Clays and Clay Minerals 20:109-123.

Raza, S.H., L.E. Trieiber, and D.L. Archer. 1968. Wettability of Reservoir Rocks and Its Evaluation. Producers Monthly. 32(4):2-7.

Rosenbaum, M.S. 1976. Effect of Compaction on the Pore Fluid Chemistry of Montmorillonite. Clays and Clay Minerals. 24:118-121.

Schecter, R.S., and J.L. Gidley. 1969. The Change in Pore Size Distribution from Surface Reactions in Porous Media. AICHE Journal. 15(3):339-350.

Seed, H.B., R.J. Woodward, and R. Lundgren. 1964. Clay Mineralogical Aspects of "The Atterberg Limits". J. of Soil Mechanics and Foundations Division, ASCE. 90(SM4):107-131.

Sherard, J.L., and R.S. Decker. 1977. Summary-Evaluation of Symposium in Dispersive Clays. In: Dispersive Clays, Related Piping, and Erosion in Geotechnical Projects. ASTM STP 623. pp.467-479.

Sinex, H.E. 1970. Dissolution of a Porous Matrix by Slowly Reacting Flowing Acids. Master's Thesis. University of Texas, Austin, Texas.

Soil Conservation Service. 1976. Soil Survey Laboratory Data and Description for Some Soils of Texas. Soil Service Investigations Report 30. U.S. Department of Agriculture.

Stewart, W. S. 1978. State-of-the-art Study of Land Impoundment Techniques. EPA-600/2-78-196. U. S. Environmental Protection Agency, Cincinnati, Ohio. 76 pp. PB 291-881.

Strong, A.G. 1980. The Deterioration of Rubber and Plastic Linings on Outdoor Exposure - Factors Influencing their Longevity. Presented at 117th Meeting of Rubber Division of the American Chemical Society. Las Vegas, Nevada.

Styron, C. R. III, and Z. B. Fry. 1979. Flue Gas Cleaning Sludge Leachate/Liner Compatibility Investigation - Interim Report. EPA-600/2-79-136. U. S. Environmental Protection Agency, Cincinnati, Ohio. 78 pp. PB 80-100480.

Theng, B.K.G. 1974. The Chemistry of Clay Organic Reactions. Wiley-Interscience, John Wiley and Sons, Inc., New York. 343 pp.

Vallerga, B.A., and R.G. Hicks. 1968. Water Permeability of Asphalt Concrete Specimens Using Back-Pressure Saturation. J. Materials 3(1): 73-86.

Van Olphen, H. 1963. An Introduction to Clay Colloid Chemistry. Wiley-Interscience, John Wiley and Sons, Inc. New York. 301 pp.

Watson, C.L. 1968. Hydraulic Conductivity of Soil as Influenced by Surfactants. In: Proceedings of Water Repellent Soils Symposium. University of California, Riverside, CA. pp. 163-169.

Weiss, A. 1963. Organic Derivatives of Mica-Type Layer Silicates. Angew. Chem. 2:134-143.

Wolstenholme, R.M. 1977. Disposal of Solvent Waste. In: Second Solvent Symposium. University of Manchester, Institute of Science and Technology.

Yong, R.N., and B.P. Warkentin. 1975. Soil Properties and Behavior. Geotechnical Engineering 5. Elsevier Scientific Pub. Co., New York. 449 pp.

54. McWhortes, David and John Nelson. "Unsaturated Flow Beneath Tailings Impoundment's," Journal of the Geotechnical Engineering Division, 1979, pp. 131F-1334

The Tran[illegible]ns of the 12th International Congress on Large Dams, Vol. 2, International Commission on Large Dams, Paris, France, 1976, pp. 527–540.
12. Cutchin, D. L., "Problems Relating to the Measurement of Near Surface Drift Currents and a Possible Solution—the Tethered Drogue Current Meter," *Water Resources Instrumentation, Vol. 1, Measuring and Sensing Methods*, R. J. Krizek and E. I. Mosonyi, eds., Ann Arbor Science Publishers, Inc., Ann Arbor, Mich., 1975, pp. 68–82.
13. Dobrin, M. B., *Introduction to Geophysical Prospecting*, 3rd ed., McGraw-Hill Book Co., Inc., New York, N.Y., 1976.
14. Dolphin, L. T., Bollen, R. L., and Oetzel, G. N., "An Underground Electromagnetic Sounder Experiment," *Geophysics*, Vol. 39, No. 1, Feb., 1974, pp. 49–55.
15. Dvoracek, J., Hulla, J., Parizek, and Skuthan, B., "Methods Used for the Determination of Origin and Interconnections of Seepage on Dams in Czechoslovakia," *The Transactions of the 12th International Congress on Large Dams*, Vol. 2, International Commission on Large Dams, Paris, France, 1976, pp. 711–719.
16. Ellerbruch, D. A., and Adams, J. W., "Microwave Measurement of Coal Layer Thickness," *Final Report NBSIR 74-387*, National Bureau of Standards, Boulder, Colo., Sept., 1974.
17. El-Said, M. A. H., "Geophysical Prospecting of Underground Water in the Desert by Means of Electromagnetic Interference Fringes," *Proceedings of the IRE*, Jan., 1956, pp. 24–50.
18. Koerner, R. M., Lord, A. E., Jr., and McCabe, W. M., "Acoustic Emission (Microseismic) Monitoring of Earth Dams," *The Evaluation of Dam Safety*, ASCE, 1976, pp. 274–291.
19. Koerner, R. M., Lord, A. E., Jr., and McCabe, W. M., "Acoustic Emission Monitoring of Soil Stability," *Journal of the Geotechnical Engineering Division*, ASCE, Vol. 104, No. GT5, Proc. Paper 13753, May, 1978, pp. 571–582.
20. Koerner, R. M., Lord, A. E., Jr., Okrasinski, T. A., and Reif, J. S., "Detection of Seepage and Subsurface Flow of Liquids by Microwave Interference Methods," presented at the April 10–14, 1978, National Conference on Control of Hazardous Materials Spills, held at Miami Beach, Fla.
21. Lord, A. E., Jr., "Acoustic Emission—A Review," *Physical Acoustics*, Vol. 11, W. P. Mason and R. N. Thurston, eds., Academic Press, New York, N.Y., 1975, pp. 289–353.
22. Lundien, J. R., "Terrain Analysis by Electromagnetic Means—Laboratory Measurement of Electromagnetic Propagation Constants in the 1.0 to 1.5 GHz Microwave Spectral Region," *Technical Report 3-693*, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss., 1971.
23. Moffatt, D. L., and Puskar, R. J., "A Subsurface Electromagnetic Pulse Radar," *Geophysics*, Vol. 41, No. 3, June, 1976, pp. 506–518.
24. Ogilvy, A., Ayed, M., and Bogoslovsky, V., "Geophysical Studies of Water Leakages from Reservoirs," *Geophysical Prospecting*, Vol. 17, No. 1, 1969, pp. 36–61.
25. Okrasinski, T. A., Lord, A. E., Jr., and Koerner, R. M., "Microwave Interference Detection of Subsurface Water," *Journal of the Geotechnical Engineering Division*, ASCE, Vol. 104, No. GT1, Proc. Paper 13453, Jan., 1978, pp. 119–124.
26. "Product Information," Geophysical Survey Systems, Inc., Hudson, N.H., 1978.
27. "Radar See Through Concrete and Soil Surface," (Calspan Notice), *IEEE Spectrum*, Nov., 1973.
28. Rubin, L. A., Griffin, J. N., and Still, W. L., "Subsurface Site Investigation by Electromagnetic Radar—Phase I Report—Feasibility," ENSCO, Inc., Springfield, Va., Mar., 31, 1976.
29. Unterberger, R. R., "Locating Discontinuities in Geologic Environments by Radar and Sonar Probing Techniques," presented at the June 18–21, 1979, Rapid Excavating and Tunneling Conference, held at Atlanta, Ga.

JOURNAL OF THE GEOTECHNICAL ENGINEERING DIVISION

Unsaturated Flow Beneath Tailings Impoundments

By David B. McWhorter[1] and John D. Nelson,[2] M. ASCE

Introduction

Tailings impoundments are frequently constructed utilizing liners to minimize seepage losses, particularly if the tailings contain toxic or hazardous materials. This paper is directed primarily towards seepage from uranium mill tailings impoundments, although the results can be directly applied to other materials.

Reliable estimates of seepage losses from tailings impoundments are required to assess environmental impacts and to provide input for water balance computations. The effects that seepage may have on ground-water conditions and location of the phreatic surface are also of interest.

In many areas of the world tailings impoundments are located on or in natural soils or formations several meters above the ground-water level. The foundation material between the impoundment and the phreatic surface in the aquifer is unsaturated in such cases and conventional methods of analysis for saturated flow through porous media do not apply. Technology from related fields for analysis of flow through partially saturated porous media has been utilized herein to develop methods for the estimation of seepage from tailings impoundments.

The purpose of this paper is to provide reasonably simple, engineering procedures for the estimation of seepage rates from tailings impoundments when the floor of the impoundments is several meters above the phreatic surface in an underlying aquifer. The value of this paper is the presentation of engineering solutions that do not require impractical quantities of data or the use of numerical methods and computer applications. To achieve that only those aspects of the flow phenomena that have first order effects on seepage rates have been accounted for in the analyses. Several potentially important aspects have necessarily been

Note.—Discussion open until April 1, 1980. To extend the closing date one month, a written request must be filed with the Editor of Technical Publications, ASCE. This paper is part of the copyrighted Journal of the Geotechnical Engineering Division, Proceedings of the American Society of Civil Engineers, Vol. 105, No. GT11, November, 1979. Manuscript was submitted for review for possible publication on September 1, 1979.

[1]Prof., Dept. of Agricultural and Chemical Engrg., Colorado State Univ., Fort Collins, Colo.
[2]Prof., Dept. of Civ. Engrg., Colorado State Univ., Fort Collins, Colo.

neglect due to space limitations. These include the potential for the hydraulic conduc of earthen liners to change with time and chemical composition of the percolate, the effects of pre-impoundment gradients in the aquifer, and lateral variation of aquifer hydraulic conductivity.

Description of Problem

The purpose of this paper is to provide reasonably simple procedures for estimating vertical seepage rates from tailings impoundments when the elevation of the floor of the impoundment is a few meters or more above the initial phreatic surface in the underlying aquifer. The general subsoil profile and water

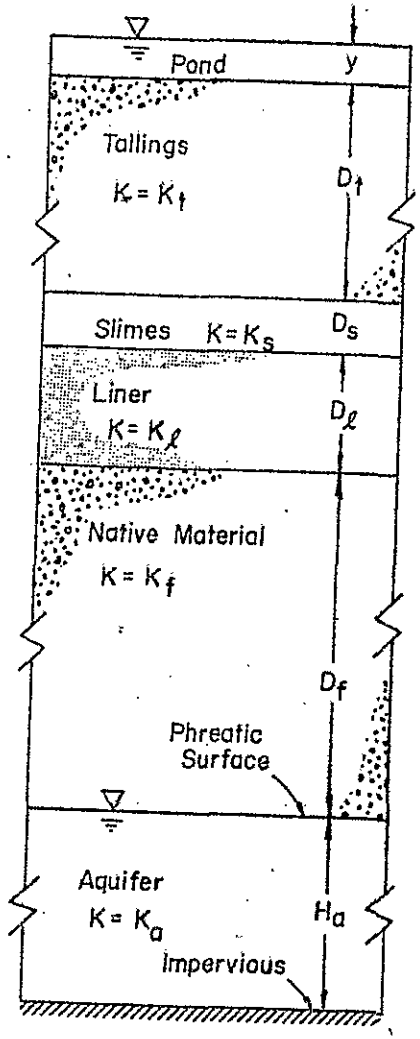


FIG. 1.—Definition Sketch of Flow System

els in the tailings and aquifer are idealized as shown in Fig. 1. The th ss of each layer is denoted by the symbol D with the subscripts t, s, l, and f designating coarse tailings, slimes, liner, and foundation material, respectively. If the pond depth, y, is zero, D_t would represent the height to the phreatic line in the tailings. The saturated thickness of the underlying aquifer is H_a. The symbol K denotes the hydraulic conductivity at saturation. Again the subscripts designate particular strata. The strata are assumed to be uniform and isotropic.

Seepage from beneath the impoundment is conveniently reviewed as taking place in three distinct stages designated as Stages I, II, and III. It is implicit in the following analysis that seepage is not limited by a supply of water. If the supply is depleted prior to full development of all three stages, the computation

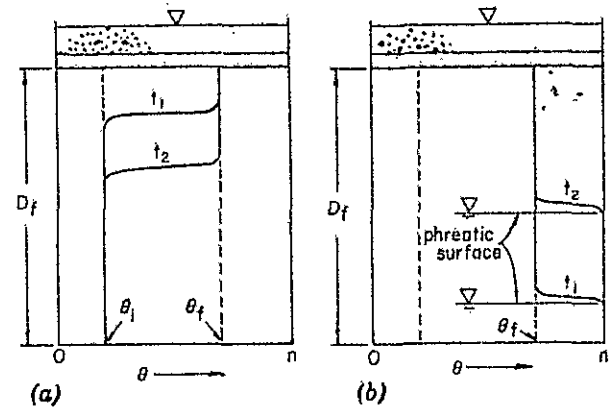


FIG. 2.—Schematic Distribution of Volumetric Water Content during: (a) Stage I; (b) Stage II

may be applied up to that time. The three stages are defined as follows:

Stage I. During this stage a wetting front advances downward through the partially saturated underlying foundation material. Above the wetting front the material may or may not be saturated.

Stage II. When the wetting front contacts either an impermeable stratum or the phreatic surface of an aquifer, a ground-water mound will develop and rise toward the impoundment. Stage II represents the stage during which the mound is developing.

Stage III. If the ground-water mound establishes contact with the impoundment, saturated seepage occurs through a mound whose height is defined by the impoundment.

The foundation material below the disposal site is assumed to be partially saturated at the beginning of disposal operations with volumetric water content equal to θ_i. The volumetric water content, θ, is defined as the volume of water per unit total volume of soil. It is related to the degree of saturation, S, by $\theta = Sn$ and is equal to the porosity, n, when the material is completely saturated. Infiltration of water from the disposal site into the underlying foundation material

produces a [illegible]tting front" which moves downward as depicted schematically in Fig. 2(*a*). [illegible]e wetting front is the transition zone in which the volumetric water content increases from θ_i below the front to θ_f above the front. The value of θ_f depends upon the rate at which water can be supplied through the overlying strata. It will be close to the residual water content when the overlying strata greatly restrict the rate of supply and is equal to n when the supply rate is greater than K_f. The period of time during which the wetting front is moving downward is referred to as Stage I in this paper.

Stage I ends and Stage II begins when the downward moving wetting front encounters either a phreatic surface or an impervious stratum. During Stage II, a phreatic surface moves upward filling the remaining available pore space as shown schematically in Fig. 2(*b*). The rate of rise of the phreatic surface during Stage II depends upon the tendency for water to spread laterally in the saturated zone below the phreatic surface and the difference between n and θ_f. Both restricted lateral spreading in the saturated zone and small values of $(n - \theta_f)$ promote a rapid rise of the phreatic surface and, therefore, a short duration of Stage II. Stage II ends when the phreatic surface has risen to the bottom of the impoundment.

Stage III is initiated when the rising ground-water mound encounters the floor of the impoundment. The entire flow region during Stage III is saturated.

Summary of Principles and Background

Historically, the motivation for studies of multifluid phenomena in porous materials has largely stemmed from problems in petroleum production, soil physics, hydrology, irrigation, and drainage; disciplines where multifluid phenomena are common. In this section the pertinent tenets of flow in porous media are reviewed briefly.

Conservation of Mass and Darcy's Law.—Balance of water mass in a nondeforming control volume of porous medium leads to

$$\operatorname{div}(\bar{q}) = -\frac{\partial \theta}{\partial t} \quad \text{(1)}$$

assuming that water is incompressible. In Eq. 1, div = divergence operator; $\bar{q}$ = volume flux of water; θ = volumetric water content; and t = time. The relationship between volume flux of water and the driving forces in a homogeneous and isotropic medium is

$$\bar{q} = -K_e \operatorname{grad}(h + z) \quad \text{(2)}$$

in which K_e = the effective hydraulic conductivity; h = pore-water pressure head; z = elevation head; and grad = the gradient operator. Eq. 2 is Darcy's law and is assumed valid for flow in both saturated and partially saturated porous media. In the case of saturated homogeneous media, K_e is a constant, but in partially saturated materials, K_e is a function of the pore-water pressure head, h.

Combining Eqs. 1 and 2 yields

$$\operatorname{div}[K_e \operatorname{grad}(h + z)] = \frac{\partial \theta}{\partial t} \quad \text{(3)}$$

[illegible] is a nonlinear partial differential equation known as the Richards' equa[illegible]. [illegible], K_e, h, and θ are all dependent variables in Eq. 3. Two consti[illegible]e equations are required in addition to boundary and initial conditions to make solution possible. The equations $K_e = K_e(h)$ and $\theta = \theta(h)$, permit Eq. 3 to be written with either h or θ as the sole dependent variable. The relations $K_e(h)$ and $\theta(h)$ are the hydraulic properties of the soil or rock and are considered subsequently in some detail.

In saturated, homogeneous materials, both K_e and θ are constant and Eq. 3 simplifies to the Laplace equation

$$\nabla^2(h + z) = 0 \quad \text{(4)}$$

Solutions of Eq. 4 in saturated flow regions bounded in part by a phreatic surface have proven to be extremely difficult to derive due to the nonlinear condition that must be satisfied on the phreatic surface. Therefore, the Dupuit hydraulic approach is more widely used as a starting place for the analysis of saturated flow bounded in part by a phreatic surface (2,6,8,15). Conservation of mass, coupled with the Dupuit approximations, results in the Boussinesq equation (2,15):

$$\frac{\partial}{\partial x}\left(H\frac{\partial H}{\partial x}\right) + \frac{\partial}{\partial y}\left(H\frac{\partial H}{\partial y}\right) = \frac{S_{ya}}{K}\frac{\partial H}{\partial t} \quad \text{(5)}$$

in which H = the elevation of the phreatic surface measured relative to a horizontal impermeable base of the aquifer; x and y are space coordinates; S_{ya} = apparent specific yield; and other symbols are as defined previously. The apparent specific yield is a term that defines the volume of stored or released water associated with a change in phreatic surface. It is defined as the ratio of the volume of water released (or stored) to the change in volume of aquifer below the phreatic surface (15).

Approximate solutions to Eq. 5 subsequently will be used to estimate lateral spreading in the saturated zone during Stage II.

Desaturation of Porous Materials.—The pore fluid may consist of any mixture of liquid and gas. However, in applications to tailings disposal, water and air are of primary importance. Further consideration, therefore, is limited to these fluids.

Pore fluid pressures are measured relative to the ambient atmospheric pressure. It is assumed that the pressure of air contained in the pores is equal to the ambient atmospheric pressure, and is taken as being zero throughout the paper. Pore-water pressures less than atmospheric pressure are negative.

The variation of capillary head with changes in water content or degree of saturation is considered in detail in many textbooks (7,13,15). Some typical data are presented herein for illustration and considered as it applies to the analysis that is developed.

As the soil drains, the largest pores are desaturated first because the capillary forces are smaller in the larger pores. In most porous materials the pore-water pressure must become more negative than a threshold pressure before air will become continuous in the material. This threshold pressure is called the displacement pressure and, when expressed as a pressure head, is given the symbol h_d. Very little desaturation occurs until the pore-water pressure head becomes

more negative than h_d (4,7). The displacement pressure head is smaller (more negative) for fine-grained materials than for coarser media.

Fig. 3 shows typical relationships between pore-water pressure head, h, and volumetric water content, θ. As h becomes increasingly negative, θ approaches a constant value. This value is termed residual water content and is given the symbol θ_r. It is very difficult to reduce the volumetric water content below θ_r by purely mechanical means. The residual water content is a property of the soil and is roughly equivalent to field capacity in agriculture literature or to specific retention in ground-water hydrology.

Brooks and Corey (4) have shown that the functional relationship between pore-water pressure head and volumetric water content can be expressed

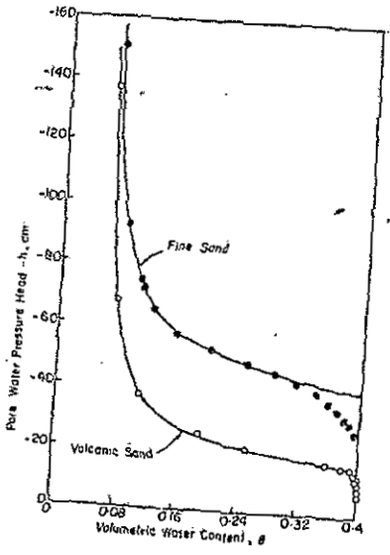


FIG. 3.—Typical Relationship between Capillary-Pressure Head and Saturation

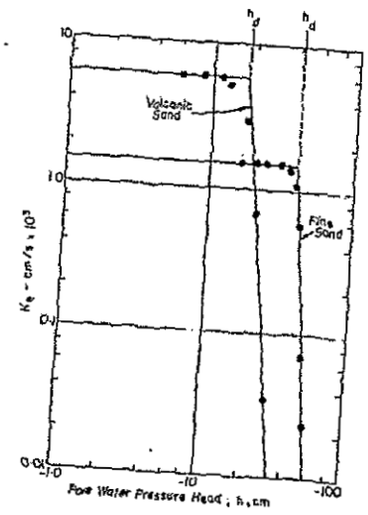


FIG. 4.—Typical Relationship between Hydraulic Conductivity (K_e) and Pore-Water Pressure Head

conveniently by the following empirical formulas

$$\theta = n, \quad h \geq h_d; \quad \theta = (n - \theta_r)\left(\frac{h}{h_d}\right)^{-\lambda} + \theta_r, \quad h \leq h_d \quad \ldots\ldots (6)$$

in which n = porosity; λ = pore size distribution index; and other symbols are as previously defined.

Analysis of flow in partially saturated porous media is made more complex by the fact that the function $\theta(h)$ is not unique but depends upon the wetting and drying history. The representation of $\theta(h)$ by Eqs. 6 was developed for the case where the porous medium is draining (i.e., θ is decreasing) but Eqs. 6 have also been used when the volumetric water content is increasing (1,11).

$K_e(h)$ Relationship.—Fig. 4 shows the measured relationship between K_e and h for the same materials to which Fig. 3 applies. The data shows that K_e

is approximately constant and equal to the saturated hydraulic conductivity until the pore-water pressure becomes more negative than h_d, after which K_e decreases rapidly. The reduction of K_e with increasingly negative h is primarily a consequence of a reduction in cross-sectional area, a change of hydraulic radius and an increased tortuosity of water flow channels as the material desaturates (7). A satisfactory parametric representation of the function $K_e(h)$ is

$$K_e = K, \quad h \geq h_d; \quad K_e = K\left(\frac{h}{h_d}\right)^{-(2+3\lambda)}, \quad h \leq h_d \quad \ldots\ldots (7)$$

in which K = saturated hydraulic conductivity, and other symbols are as previously defined.

As for the case of the function $\theta(h)$, the relation $K_e(h)$ is hysteretic in that it depends upon whether h is increasing or decreasing. Eqs. 7 were developed for the case in which h becomes increasingly more negative (i.e., drying), but again it is assumed that they can be used for the wetting processes as well. Combining Eqs. 6 and 7 yields, for $h \leq h_d$

$$K_e = K\left(\frac{\theta - \theta_r}{n - \theta_r}\right)^{(2+3\lambda)/\lambda} \quad \ldots\ldots (8)$$

which represents the dependence of K_e upon θ. In spite of the fact that both functions $\theta(h)$ and $K_e(h)$ are hysteretic, it has been observed that the function $K_e(\theta)$ is quite insensitive to whether θ is increasing or decreasing. This is fortunate, because Eq. 8 will be seen to play the more important role in subsequent calculations.

Analysis of Flow during Stage I

Calculation of the seepage rates during Stage I, when the wetting front is advancing downward, requires the simultaneous solution of Eqs. 3 and 4 written for one-dimensional vertical flow. Eq. 4 applies in the saturated strata above the bottom of the lined impoundment and Eq. 3 applies in the foundation material in the interval D_f of Fig. 1.

Vertical Seepage in Saturated Tailings and Liner.—Flow through a sequence of saturated strata oriented normal to the direction of flow is well known (2,15):

$$q = \frac{\Delta(h + z)}{\sum_{i=1}^{k} \frac{D_i}{K_i}} \quad \ldots\ldots (9)$$

in which D_i = thickness of layer i; K_i = saturated hydraulic conductivity of layer i; $\Delta(h + z)$ = the total change in piezometric head across the sequence; and k = the number of layers in the series.

Applying Eq. 9 to the sequence of strata above the foundation material in Fig. 1 yields

$$q = \frac{(y + D_t + D_s + D_l) - h_f}{\frac{D_t}{K_t} + \frac{D_s}{K_s} + \frac{D_l}{K_l}} \quad \ldots\ldots (10)$$

in which h_f = pore-water pressure head at the interface between the foundation material and the liner. Eq. 10 can be modified easily to accommodate fewer or more distinct strata present in a particular application.

It is worth noting at this point that both the piezometric head in the tailings and the resistance to flow increases as D_t increases. However, the resistance to flow in the tailings, as represented by D_t/K_t, is usually small compared to the resistance offered by the liner. Consequently the effect of the increase in piezometric head overshadows the effect of increased resistance to flow.

Vertical Seepage Beneath Disposal Site.—The flux q at the interface between the liner and the underlying material is regarded as a constant at this point. The effect of time varying q will be addressed subsequently. Thus, Stage I seepage into the foundation material is idealized as one-dimensional infiltration with a constant flux boundary condition. McWhorter (14) analyzed this problem and included the complicating effects of air displacement. Parlange (17) provides an approximate solution to Eq. 3 that applies when the effects of air displacement are negligible.

Immediately prior to penetration of water into the underlying foundation material, the pore-water pressure head therein is very negative and is that value corresponding to the initial water content, θ_i. Infiltration causes the pressure head to become less negative as the water content increases. Parlange's (17) solution for the time variation of the volumetric water content θ_f at the top of the foundation material is given in implicit form by:

$$t = \int_{\theta_i}^{\theta_f(t)} \left[\frac{K_e \dfrac{dh}{d\theta}}{q(q - K_e)} \right] d\theta \quad \text{(11)}$$

If q and the hydraulic properties $h(\theta)$ and $K_e(\theta)$ are known, $\theta_f(t)$ can be computed from Eq. 11. Fortunately, the results pertinent to the present application can be deduced without carrying out the indicated computations.

Because the interval of integration in Eq. 11 is finite, Eq. 11 can be satisfied for large values of t only if the integrand becomes very large. For $\theta_f < n$ this will be true only when $(q - K_e)$ approaches zero. This condition corresponds to a unit hydraulic gradient, for which pressure gradients are zero and gravity is the sole driving force. The function $K_e(\theta)$ has a maximum value equal to K_f, the permeability of the foundation material at saturation. Therefore, Eq. 11 applies for all time only when $q \leq K_f$. At large time for this case

$$K_e(\theta_f) \approx q \quad \text{(12)}$$

and in view of Eq. 8

$$\theta_f = (n - \theta_r)\left(\frac{q}{K_f}\right)^{\lambda/(2+3\lambda)} + \theta_r; \quad q \leq K_f \quad \text{(13)}$$

The value of θ_f computed from Eq. 13 is that value of water content indicated in Fig. 2(a) and 2(b). The question then arises as to how much time must elapse following the initiation of seepage before Eq. 13 applies. Fortunately, "large" time in the context of the foregoing analysis is on the order of a few hours to several days. This is a negligibly short time period compared to the

duration of Stage I which can be on the order of several years. Therefore for practical purposes, Eq. 13 can be assumed to apply throughout Stage I.

For cases in which $q > K_f$ at the beginning of infiltration, Eq. 11 applies up to the time for which $\theta_f = n$ (i.e., saturation occurs). This represents the time at which the hydraulic gradient in the foundation soil is no longer sufficient to accept flow at rate q. The result is an increase of pore-water pressure, h_f, at the interface which tends to reduce the flux, q, through the overlying materials (see Eq. 10). Again the time period required for θ_f to adjust from θ_r to n is small compared to the duration of Stage I and can be neglected. Thus, the material above the wetting front is assumed to be saturated throughout Stage I if the overlying materials can supply water at a rate greater than K_f. This condition will most often occur when the underlying materials are relatively fine-grained or in the absence of a liner.

Criterion for Saturation versus Partial Saturation above Wetting Front.—It is apparent from the foregoing analysis that estimation of seepage rates will require different procedures, depending upon whether θ_f is less than or equal to n. Before proceeding with estimation of seepage rates, a criterion is established that permits the selection of the appropriate method. It has been shown that saturation will exist above the wetting front if $q \geq K_f$. The value of h_f that corresponds to $q = K_f$ may be computed from Eq. 10. As indicated by Eq. 6, if the computed value is less (more negative) than h_d for the foundation material below the liner, then θ_f is less than n. Otherwise, a saturated zone will exist above the wetting front. Explicitly:

$$y + D_t + D_s + D_l - K_f\left(\frac{D_t}{K_t} + \frac{D_s}{K_s} + \frac{D_l}{K_l}\right) < h_d, \text{ unsaturated;}$$

$$y + D_t + D_s + D_l - K_f\left(\frac{D_t}{K_t} + \frac{D_s}{K_s} + \frac{D_l}{K_l}\right) \geq h_d, \text{ saturated} \quad \text{(14)}$$

Estimation of Seepage Rate for $h_f < h_d$.—In view of Eqs. 7 and 12

$$h_f = h_d\left(\frac{q}{K_f}\right)^{-1/(2+3\lambda)} \quad \text{(15)}$$

which can be substituted into the right side of Eq. 10 to yield

$$q = \frac{(y + D_t + D_s + D_l) - h_d\left(\dfrac{q}{K_f}\right)^{-1/(2+3\lambda)}}{\dfrac{D_t}{K_t} + \dfrac{D_s}{K_s} + \dfrac{D_l}{K_l}} \quad \text{(16)}$$

A trial and error procedure may be used to find the precise value for q for which Eq. 16 is satisfied. A first approximation to the correct value of q may be computed from

$$q = \frac{(y + D_t + D_s + D_l) - h_d}{\dfrac{D_t}{K_t} + \dfrac{D_s}{K_s} + \dfrac{D_l}{K_l}} \quad \text{(17)}$$

It was pointed out earlier that the quantities y, D_t, and D_s are increasing functions of time due to continued placement of tailings in the disposal site. Up to this point, the effect of increasing the depth of saturated tailings has been neglected. In fact, both Eqs. 13 and 15 were derived under the explicit assumption that q was constant. However, for typical ranges of λ ($1 < \lambda < 3$) both h_f and θ_f prove to be relatively insensitive to changes of q. Therefore, it is a reasonable approximation to regard θ_f as constant and compute its value from Eq. 13 using a mean value of q. The mean value of q is obtained after computing q as a function of time from Eq. 17 using y, D_t and D_s as functions of time as determined by the planned rate of tailings placement.

It is worth pointing out that the seepage rates predicted by Eqs. 16 or 17 are almost independent of the hydraulic characteristics of the foundation material. It is emphasized that this condition prevails only when the liner or other overlying strata restrict the flow sufficiently to cause q to be less than K_f. This result was noted by Kisch (12).

Estimation of Seepage Rate for $h_f \geq h_d$.—Unlike the previous case in which seepage rates were largely controlled by the average permeability of the coarse tailings, slimes, and liner, the seepage rates in this case are substantially influenced by the hydraulic properties of the foundation material. Furthermore, a time variation of q exists that cannot be reasonably ignored, even if the saturated thickness of the tailings are constant.

To compute the seepage rates, the Green-Ampt (7,9) infiltration equation is generalized to account for the retarding effect of the overlying tailings, slime, and liner. The wetting front is idealized as a discontinuity, above which the volumetric water content is n and below which $\theta = \theta_i$. The flux is determined by Darcy's law applied to the saturated zone above the wetting front. Thus

$$q = K_f \frac{(h_f + L - h_c)}{L} \qquad (18)$$

in which $L(t)$ = the time varying depth of penetration of the wetting front; and h_c = the constant, effective capillary drive defined by (3,19)

$$h_c = \frac{1}{K_f}\int_0^{-\infty} K_e dh = h_d\left(\frac{2+3\lambda}{1+3\lambda}\right) \qquad (19)$$

The second equality follows from use of Eq. 7 to evaluate the integral.

The flux is also given by Eq. 10 which is written as

$$q = \frac{A - h_f}{B} \qquad (20)$$

for simplicity in notation. The value A represents the first term in the numerator and B represents the entire denominator in Eq. 10. A third equation is provided by the conservation condition

$$q = (n - \theta_i)\frac{dL}{dt} \qquad (21)$$

Elimination of h_f between Eqs. 18 and 20 yields

$$q = K_f\left(\frac{L + A - h_c}{L + K_f B}\right) \qquad (22)$$

and from Eqs. 21 and 22

$$(n - \theta_i)\frac{dL}{dt} = K_f\left(\frac{L + A - h_c}{L + K_f B}\right) \qquad (23)$$

Because the thickness of the saturated tailings is time dependent, the quantities A and B are functions of time. However in many practical problems A and B can be regarded as constants. Eq. 23 is integrated to yield

$$\frac{n - \theta_i}{K_f}\left[L + (K_f B - A + h_c)\ln\left(\frac{L + A - h_c}{A - h_c}\right)\right] = t \qquad (24)$$

The computation procedure is to select various values of L and compute the corresponding values of seepage rate and time from Eqs. 22 and 24, respectively. Thus, the function $q(t)$ is obtained. Mean values of A and B can be used.

Duration of Stage I.—Recall that Stage I terminates when the wetting front encounters either an impervious stratum or an underlying saturated zone. The duration of Stage I is, therefore, the time required for the wetting front to traverse the interval D_f as shown in Fig. 1. For the case in which $\theta_f = n$, the duration of Stage I is given by Eq. 24 with $L = D_f$. The estimate of the duration of Stage I is improved somewhat by putting $L = D_f + h_d$ for the case in which an aquifer exists because this accounts for the fact that the capillary fringe of height $(-h_d)$ shortens the distance the wetting front must travel before the phreatic surface is affected. It should be recalled that h_d is a negative number.

For the case $\theta_f < n$, the mean quantity of water required to fill the volume $D_f(\theta_f - \theta_i)$ is given by

$$q_m T = D_f(\theta_f - \theta_i) \qquad (25)$$

in which q_m = mean seepage rate; and T = the time required for the wetting front to traverse distance D_f. Substituting for θ_f with Eq. 13 and solving for T results in

$$T = \frac{D_f}{q_m}\left[(n - \theta_r)\left(\frac{q_m}{K_f}\right)^{\lambda/(2+3\lambda)} + (\theta_r - \theta_i)\right] \qquad (26)$$

Since the time interval over which q_m is to be computed is not known at the outset, the procedure is to estimate a value for q_m, compute T, and recompute q_m over this time interval. The computation is repeated as required. Again, D_f should be replaced by $D_f + h_d$ in the case of an existing phreatic surface at depth D_f because this accounts for the existence of the capillary fringe.

Analysis of Flow during Stage II

Stage II is characterized by a rising phreatic surface in the underlying aquifer in response to the seepage from the disposal site. The rate of rise of the phreatic surface depends upon the seepage rate, the fraction of the pore space in the

transmission zone that remains available for water storage (i.e., $n - \theta_f$), and the tendency of the ground water to spread laterally as the phreatic surface rises. It is convenient to analyze the seepage and rise of the phreatic surface for the case when $\theta_f < n$, separately for the case when $\theta_f = n$.

Seepage and Mound Height When $\theta_f < n$.—When the transmission zone between the impoundment and the underlying phreatic surface is partially saturated, the seepage rates during Stage II are independent of the depth to the phreatic surface

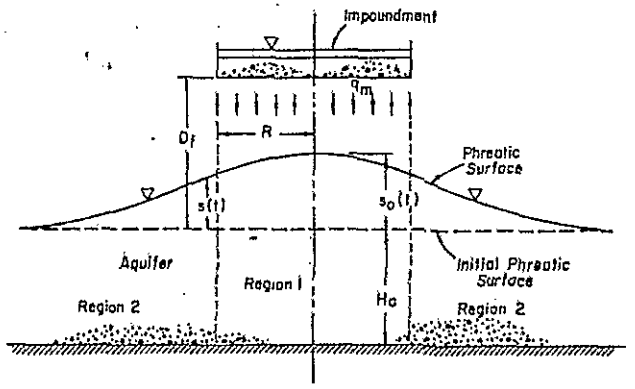


FIG. 5.—Section View of Ground-Water Mound

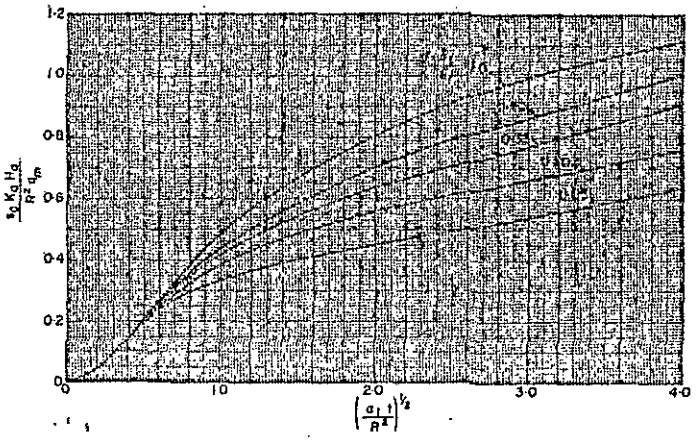


FIG. 6.—Graphical Representation of Eq. 29

and can be calculated from Eq. 17 as for Stage I. This conclusion is in agreement with Kisch (12) who also found seepage to be practically independent of depth to the phreatic surface when the intervening interval was partially saturated. The main purpose of this section, then, is to develop a means of estimating the time required for the phreatic surface to rise to the bottom of the impoundment.

Based upon the Dupuit approximation, the differential equation for the height of the phreatic surface above a horizontal impervious stratum is the nonlinear

Eq. The saturated height H is written as $H_a + s$, in which s is the build-up of the phreatic surface above its initial level as indicated in Fig. 5. Provided that s is everywhere small relative to H_a, Eq. 5 can be linearized and analytic solutions obtained. The problem is further simplified by idealizing the impoundment area as a circle (plan view) of radius R with an area equivalent to the actual area of the impoundment.

The foregoing simplifications permit Eq. 5 to be written as

$$\frac{\partial^2 s_1}{\partial r^2} + \frac{1}{r}\frac{\partial s_1}{\partial r} = \frac{1}{\alpha_1}\frac{\partial s_1}{\partial t} \quad \text{(27)}$$

for the region $r \leq R$ in Fig. 5, and

$$\frac{\partial^2 s_2}{\partial r^2} + \frac{1}{r}\frac{\partial s_2}{\partial r} = \frac{1}{\alpha_2}\frac{\partial s_2}{\partial t} \quad \text{(28)}$$

for the region $r > R$, in which $\alpha_1 = K_a H_a/(n - \theta_f)$; $\alpha_2 = K_a H_a/(n - \theta_i)$; K_a = the horizontal hydraulic conductivity of the aquifer; H_a = initial saturated thickness; r = radial coordinate; t = time; and the subscripts 1 and 2 denote regions one and two in Fig. 5.

A solution is sought under the conditions that the mean seepage rate is constant and uniform in the region $r \leq R$ and zero elsewhere. The initial condition is $s(r,0) = 0$ and the boundary condition at infinity is $s(\infty, t) = 0$. In addition the solution must yield $s_1 = s_2$ at $r = R$ and $(\partial s_1/\partial r)_R = (\partial s_2/\partial r)_R$. The problem thus formulated has a direct analog in the theory of heat conduction and the appropriate solution is borrowed from Carslaw and Jaeger (5). Because the build-up of the phreatic surface is a maximum beneath the center of the impoundment, the solution is written only for the point $r = 0$:

$$s_o(t) = \frac{4 q_m R^2}{\pi^2 K_a H_a} \int_0^\infty \left[1 - \exp\left(-\frac{\alpha_1}{R^2} x^2 t\right)\right] \frac{J_1(x)\,dx}{x^4(\Phi^2 + \Psi^2)} \quad \text{(29)}$$

in which $\Phi = J_1(x)\,Y_o(\beta x) - \beta J_o(x)\,Y_1(\beta x)$

$\Psi = J_1(x)\,J_o(\beta x) - \beta J_o(x)\,J_1(\beta x)$

$$\beta = \left[\frac{(n - \theta_i)}{(n - \theta_f)}\right]^{1/2}$$

where J_o and J_1 are the Bessel functions of the first kind; Y_o and Y_1 are the Bessel functions of the second kind; x is an integration variable; and s_o is the build-up at $r = 0$. Numerical results from Eq. 29 in the form of reduced variables are provided in Fig. 6. The form of the reduced variables in Fig. 6 makes it possible to display the solution (Eq. 29) conveniently on one graph but obscures several important features of the solution. Calculations will show, however, that $s_o(t)$ increases without bound as t becomes very large, that $s_o(t)$ increases rapidly as $n - \theta_f$ decreases, and that $s_o(t)$ increases as the size of the disposal area increases.

Fig. 6 can be used to estimate the duration of Stage II by determining the time at which $s_o = D_f + h_d$. There are a number of shortcomings in the foregoing analysis of the growth of the ground-water mound. In some situations, the

constraint that remain small relative to H_a may not be satisfied, in which cases, the calculations yield estimates of mound growth more rapid than will actually occur. Comparison of the solution for the nonlinear steady-state case with the corresponding solution for the linear case suggests that replacement of H_a by the average saturated flow depth equal to $H_a + (D_f + h_d)/2$ will substantially improve the estimate for the duration of Stage II.

A second deficiency is that not all disposal areas can be satisfactorily approximated by a circle and a third deficiency is the assumption of an infinite aquifer. If flow boundaries restrict the spread of the mound, the rate of growth of the mound will be more rapid than the foregoing analysis indicates. On the other hand, the existence of a discharge boundary, such as a stream or a natural ground-water gradient could permit the mound to reach an equilibrium condition not predicted by the preceding solution. Several computer solutions have been developed for mound growth that are not nearly so restricted as regards the geometry and boundary conditions that can be handled (e.g., 16). An analytic solution for rectangular geometries has also been completed and is being prepared for publication.

Seepage and Mound Height When $\theta_f = n$.—The seepage rate depends upon the height of the phreatic surface beneath the impoundment for this case in contrast to the situation in the foregoing section. Let ξ_o be the distance between the bottom of the impoundment and the underlying phreatic surface at the center (i.e., at $r = 0$). The seepage rate beneath the center of the impoundment is

$$q = \frac{A + \xi_o(t)}{B + \dfrac{\xi_o}{K_f}} \qquad (30)$$

which is Eq. 9 applied to the entire saturated zone. The parameters A and B are the same as in Eq. 20. The value of ξ_o varies from D_f at the beginning of Stage II to zero at the end of Stage II. Rigorous calculations of q require that Eq. 30 be solved simultaneously with the differential equation describing the mound growth. While in principle such a computation is possible, it represents a complicated refinement probably unwarranted in view of the other simplifying assumptions already invoked, accuracy required in field applications, and the reliability of input data in many cases. Therefore, for the purpose of estimating the duration of Stage II, a constant mean seepage rate given by

$$q_m = \frac{1}{2}\left(\frac{A}{B} + \frac{A + D_f}{B + \dfrac{D_f}{K_f}}\right) \qquad (31)$$

is assumed to apply for the case in which $\theta_f = n$.

The next step is to compute the height of the phreatic surface beneath the impoundment so that the duration of Stage II can be estimated. The height depends upon both the vertical seepage rate above the phreatic surface and the rate of lateral spreading below the phreatic surface as is described by the solution to the following boundary value problem

$$\frac{\partial^2 s_1}{\partial r^2} + \frac{1}{r}\frac{\partial s_1}{\partial r} - \frac{q_m}{K_a H_a} = 0, \quad r \le R; \quad s_1(R,t) = s_2(R,t) \qquad (32)$$

and

$$\frac{\partial^2 s_2}{\partial r^2} + \frac{1}{r}\frac{\partial s_2}{\partial r} = \frac{1}{\alpha_2}\frac{\partial s_2}{\partial t}, \quad r \le R; \quad s_2(\infty,t) = 0; \quad s_2(r,0) = 0;$$

$$-2\pi K_a H_a R \frac{\partial s_2(R,t)}{\partial r} = \pi R^2 q_m \qquad (33)$$

Eqs. 32 are readily solved by direct integration to give

$$s_o = s_2(R,t) + \frac{q_m R^2}{4 H_a K_a} \qquad (34)$$

in which s_o = the mound build-up beneath the center of the region of seepage as previously defined. The quantity $s_2(R,t)$ is provided by the solution to Eqs. 33. Fortunately, the boundary value problem as described by Eqs. 33 is mathematically identical to that for flow to a large diameter well treated in

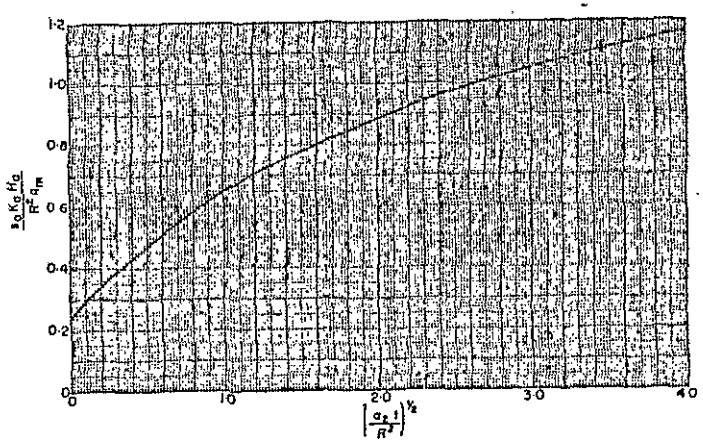


FIG. 7.—Graphical Representation of Simultaneous Solution of Eqs. 32 and 33

detail by Hantush (10). In Table VI of Hantush (10) values of $s_2(R,t)$ are tabulated in dimensionless form. These numerical values were used in Eq. 34 and the results are shown graphically in Fig. 7.

The results in Fig. 7 imply an instantaneous change in dimensionless mound height from 0 to 0.25 at $t = 0$. This instantaneous change is consistent with the fact that the region $r \le R$ is saturated and, therefore, has no storage capacity under the assumption of incompressible fluids and porous media. The instantaneous build-up is required to develop the gradients necessary to cause lateral flow in the aquifer beneath the impoundment assuming that there is no natural ground-water gradient.

Fig. 7 can be used to compute the time at which $s_o = D_f + h_d$ and, therefore, the duration of Stage II when $\theta_f = n$. The results are subject to the same limitations as described previously for Fig. 6. Again, an average value of saturated thickness equal to $H_a + (D_f + h_d)/2$ should be used in place of H_a to partially account for the variable saturated thickness that was neglected in order to obtain linear differential equations.

ANALYSIS OF FLOW DURING STAGE III

Seepage during Stages I and II is largely controlled by vertical gradients and the hydraulic conductivity of the liner and tailings; the seepage rates being relatively insensitive to the position of the phreatic surface in the underlying aquifer and the resistance to lateral spreading of the ground-water mound. If the phreatic surface in the aquifer rises to the elevation of the impoundment (Stage III begins at this point) the resistance to lateral flow in the aquifer has a very significant influence upon subsequent seepage rates. The resistance to lateral spreading in the aquifer during Stage III causes the pore-water pressure to increase on the interface between the impoundment and the foundation material, reducing the vertical gradients in the tailings and liner and, therefore, the seepage rates. Thus, the maximum seepage rate during Stage III occurs at the beginning of Stage III and is equal to the terminal rate in Stage II. After a sufficient period of Stage III seepage the seepage rates are controlled entirely by the resistance to flow in the aquifer and are practically independent of the hydraulic properties of the liner and tailings.

Rigorous analysis of flow in Stage III is complex mathematically, and the purpose of this section is to provide an upper bound estimate of the seepage rates. This is accomplished by assuming that the resistance to lateral flow in the aquifer, exterior to the impoundment, controls the seepage rates. To insure that the seepage rates so computed constitute a reasonable upper bound, the initial rate for Stage III is forced to equal the terminal Stage II rate.

Succession of Steady States.—At any instant in time, the phreatic surface, exterior to the impoundment, is assumed to be of the shape given by the steady-state equation

$$s = -\frac{R^2 q_m}{2K_a H_a} \ln \frac{r}{r_e}; \quad r \geq R \qquad (35)$$

in which r_e = the radius at which the mound height is zero. Both the seepage rate q_m and r_e are regarded as functions of time.

The cumulative volume of seepage at any time is given by

$$\text{Volume} = 2\pi S_{y2} \int_R^{r_e} (rs)\,dr = -\frac{\pi R^2 q_m S_{y2}}{K_a H_a} \int_R^{r_e} \left(r \ln \frac{r}{r_e} \right) dr \qquad (36)$$

Eq. 36 yields

$$\text{Volume} = \frac{\pi S_{y2} R^4 q_m}{4K_a H_a} \left[\exp\left(\frac{4K_a H_a s_R}{R^2 q_m} \right) - 1 \right] - \pi S_{y2} R^2 s_R \qquad (37)$$

in which s_R = the mound height at $r = R$ and is assumed constant and equal to D_f. The volume of seepage is also given by

$$\text{Volume} = \pi R^2 \int_0^t q_m\,dt \qquad (38)$$

Substitution of Eq. 38 into Eq. 37 and differentiating with respect to time yields the following ordinary differential equation for $q_m(t)$:

$$q_m = \frac{S_{y2} R^2}{H_a K_a} \frac{d}{dt} \left\{ q_m \left[\exp\left(\frac{4K_a H_a D_f}{R^2 q_m} \right) - 1 \right] \right\} \qquad (39)$$

Integration of Eq. 39 subject to $q_m(0) = q_{mo}$, where q_{mo} is the terminal Stage II rate yields

$$\frac{4K_a H_a t}{S_{y2} R^2} = \exp(w) - \exp(w_o) - \frac{(w - w_o)}{1 \cdot 1!} - \frac{w^2 - w_o^2}{2 \cdot 2!} - \frac{w^3 - w_o^3}{3 \cdot 3!} - \ldots \qquad (40)$$

in which $w = (4K_a H_a D_f)/R^2 q_m$; and $w_o = (4K_a H_a D_f)/R^2 q_{mo}$. As in the previous cases, estimates are improved by replacing H_a by the quantity $H_a + (D_f + h_a)/2$. The seepage rates, q_m, during State III can be computed from Eq. 40.

CONCLUSIONS

A method for computing seepage rates into the partially saturated zone beneath a tailings impoundment has been presented. This method of computation was based primarily on existing technology in other fields that has been developed for flow through partially saturated porous media. Some simplifying assumptions had to be made in order to allow a reasonably simple method to be developed that could be used to arrive at an engineering solution to the problem. However, the accuracy of the method is believed to be well within the accuracy with which the input parameters may be determined.

Seepage rates may vary considerably depending on the boundary conditions of the particular problem being analyzed. The method of analysis presented herein may be used to estimate seepage under a variety of conditions and must be utilized in a manner consistent with the timewise variation of conditions at the site. It is shown, however, that when the foundation material between the impoundment and the aquifer is not saturated the seepage rates may vary in a complex manner and will bear little relation to rates computed assuming saturated conditions.

APPENDIX.—REFERENCES

1. Ahuja, L. R., "A One-Step Wetting Procedure for Determining Both Water Characteristic and Hydraulic Conductivity of a Soil Core," *Soil Science Society of America Proceedings*, Vol. 39, 1975, pp. 418–423.
2. Bear, J., *Dynamics of Fluids in Porous Media*, American Elsevier, New York, N.Y., 1972, 764 p.
3. Bouwer, H., "Unsaturated Flow in Groundwater Hydraulics, *Journal of the Hydraulics Division*, ASCE, Vol. 90, No. HY5, Proc. Paper 4057, Sept., 1964, pp. 121–144.
4. Brooks, R. H., and Corey, A. T., "Properties of Porous Media Affecting Fluid Flow," *Journal of the Irrigation and Drainage Division*, ASCE, Vol. 92, No. IR2, Proc. Paper 4855, June, 1966, pp. 61–80.
5. Carslaw, H. S., and Jaeger, J. C., *Conduction of Heat in Solids*, Oxford University Press, London, England, 1959.
6. Casagrande, A., "Seepage Through Dams," *Contributions to Soil Mechanics*, Boston Society of Civil Engineers, 1925–1940, 1937.
7. Corey, A. T., *Mechanics of Heterogeneous Fluids in Porous Media*, Water Resources Publications, Fort Collins, Colo., 1977, 259 p.
8. DeWiest, R. J. M., *Geohydrology*, John Wiley & Sons, New York, N.Y., 1965, 366 p.

9. Green W. H., and Ampt, C. A., "Studies on Soil Physics I. Flow of Air and Water Through Soils," *Journal of Agricultural Science*, Vol. 4, May, 1911, pp. 1–24.
10. Hantush, M. S., "Hydraulics of Wells," *Advances in Hydroscience*, Vol. 1, Academic Press, New York, N.Y., 1964.
11. Jeppson, R. W., Rawls, W. J., Hamon, W. R., and Schreiber, P. L., "Use of Axisymmetric Infiltration Model and Field Data to Determine Hydraulic Properties of Soil," *Water Resources Research*, Vol. 11, No. 1, 1975, pp. 127–138.
12. Kisch, M., "The Theory of Seepage from Clay-Blanketed Reservoirs," *Geotechnique*, London, England, Vol. IX, 1959, pp. 22–28.
13. Lambe, T. W., and Whitman, R. V., *Soil Mechanics*, Chapter 16, John Wiley & Sons, Inc., New York, N.Y., 1968.
14. McWhorter, D. B., "Vertical Flow of Air and Water With a Flux Boundary Condition," *Transactions of the American Society of Agricultural Engineers*, Vol. 19, No. 2, 1976.
15. McWhorter, D. B., and Sunada, D. K., *Ground-Water Hydrology and Hydraulics*, Water Resources Publications, Fort Collins, Colo. 1977, 290 p.
16. Ortiz, N. V., Duke, H. R., Sunada, D. K., and McWhorter, D. B., "Artificial Ground-Water Recharge with Capillarity," *Journal of the Irrigation and Drainage Division*, ASCE, Vol. 104, No. IR1, Proc. Paper 13627, Mar., 1978, pp. 79–93.
17. Parlange, J. Y., "Theory of Water Movement in Soils: 8. One-Dimensional Infiltration With Constant Flux at the Surface," *Soil Science*, Vol. 114, No. 1, 1972, pp. 1–4.
18. Philip, J. R., "Theory of Infiltration," *Advances in Hydroscience*, Vol. 5, Academic Press, New York, N.Y., 1969, pp. 215–296.
19. Raats, P. A. C., and Gardner, W. R., "Movement of Water in the Unsaturated Zone Near a Water Table," *Drainage for Agriculture*, J. van Schilfgaarde, ed., American Society of Agronomy, 1974, 700 p.

JOURNAL OF THE GEOTECHNICAL ENGINEERING DIVISION

TECHNICAL NOTES

Note.—Discussion open until April 1, 1980. To extend the closing date one month, a written request must be filed with the Editor of Technical Publications, ASCE. This paper is part of the copyrighted Journal of the Geotechnical Engineering Division, Proceedings of the American Society of Civil Engineers, Vol. 105, No. GT11, November, 1979.

55. Miller G.D., et al. "Uptake and Release of Lead, Chromium, and Trace Level Volatile Organics Exposed to Synthetic Well Casings", Ground Water Monitoring Symposium, Columbus, Ohio, May 1982

GW MONITORING SYMP
COLUMBUS, OHIO
MAY 26-28, 1982

2648

UPTAKE AND RELEASE OF LEAD, CHROMIUM AND TRACE LEVEL VOLATILE ORGANICS EXPOSED TO SYNTHETIC WELL-CASINGS

G.D. Miller, University of Oklahoma
Department of Civil Engineering and Environmental Science
National Center for Ground Water Research
Norman, Oklahoma

The pollution of ground water by organic and inorganic chemicals is being given increased attention by researchers, environmental regulators and the general public. Highly sensitive research tools are being applied to the detection and identification of trace levels of these chemicals. Detection of organic chemicals and metal pollutants at concentrations in the low parts per billion (ppb) and less range is now possible. However, at these very low detection limits sampling and measurement inaccuracies may result from the adsorption (or uptake) of some chemicals and the leaching (or release) of others from monitoring well-casing materials, sampling apparatus and analytical equipment.

Relatively small amounts of adsorption or leaching can greatly affect sensitive analytical results when measuring trace levels in the low parts per billion range. The amount of adsorption and leaching that occurs in ground water quality monitoring wells has not been determined under controlled conditions for the metals and toxic organic chemicals for which the U.S. EPA has established or proposed test procedures. Other investigators have studied the sorption and leaching characteristics of many metals and some organics with laboratory plastic and glass containers. This laboratory study examines sorption and leaching interferences associated with three types of synthetic well-casing materials and selected metal and volatile organic pollutants under static conditions. The objectives of this study include identification of chemicals that may leach from well-casing material when exposed to selected pollutants, quantification of adsorption of selected pollutants on various well-casing materials, and to guide materials selection and data interpretation during ground water monitoring.

Background

Studies have been conducted on the adsorption of metals in various types of containers during storage or preservation of water samples. Robertson (1968a, 1968b) investigated the adsorption of trace amounts of 11 elements from sea water on various containers. He indicated that certain trace elements (especially iron, indium, scandium and silver) are significantly adsorbed on container surfaces when stored in glass and polyethylene. This adsorption can be prevented by adjusting the pH to 1.5 with hydrochloric acid. Smith's (1973) results were in agreement that a pH of 1.5 is necessary to ensure metals remain in solution. Shendrikar, et al. (1976) studied the adsorption characteristics of

barium, beryllium, cadmium, manganese, lead, and zinc on Pyrex, flint glass and polyethylene. Eichnolz, Nagel and Hughes (1965) found borosilicate glassware is preferable over polypropylene for the storage of most metals. Robertson (1968a) noted that significant amounts of zinc, iron, antimony, and copper may be contained in polyvinyl chloride (PVC) well-casing and that polyethylene contains antimony. These metals potentially may leach from these materials and pollute contacting water.

Factors commonly associated with the adsorption of metals at low concentrations on container walls include: 1) concentration, 2) pH, 3) contact time, 4) container composition, 5) composition of dissolved salts, and 6) complexing agents (Massee, Maessen and DeGoeij, 1980). Dissolved organic carbon may also increase the adsorption of metals on container walls.

The adsorption and leaching of organic pollutants with various container and potential well-casing materials has been studied to a much lesser extent than have metals. One study of the interaction of m-cresol with two types of plastic tubing has been reported (U.S. EPA, 1980). Industrial grade PVC tubing and bev-a-line VHT tubing were exposed to the m-cresol solution for varying lengths of time up to two hours. The m-cresol was progressively lost to the PVC tubing in amounts proportional to the increasing contact time, while no measurable loss of m-cresol to the VHT tubing occurred.

Junk, et al. (1974) determined that organic contamination ranging from 1 ppb to 5000 ppb by weight was detected in "organic free" water which had flowed through tubes of polyethylene, polypropylene, black latex, six different formulations of PVC and a plastic garden hose. Among the contaminants found from PVC were o-cresol, napthalene, butyloctylfumarate, and butylchloroacetate. The amount of plasticizers in PVC tubing is approximately 40% by weight and represents an essentially inexhaustable supply of contamination. Should this supply of plasticizers eventually be depleted the contamination will decrease but the tubing will have lost its flexibility and will therefore need to be replaced. However, in the case of relatively rigid polyethylene and polypropylene tubes, Junk, et al. (1974) found that they may eventually become noncontaminating.

Curran and Tomson of Rice University (1982) passed "organic free" water through five different types of plastic tubing. These included polypropylene, polyethylene, Teflon, Tygon, PVC (with glue), and PVC (nonglued). Their results indicate low levels of leachates from all the tubing tested except no leachate were found with Teflon. Between one and five contaminants were found leached into the water from nonglued PVC, polyethylene and polypropylene at less than 0.5 ppb. Numerous contaminants were found leached from glued PVC and Tygon. Two organic chemical spikes, naphthalene and para-dichlorobenzene, were not retained (sorbed) significantly by any of the tubing except Tygon.

Leaching of organic and organotin compounds from PVC and chlorinated PVC (CPVC) pipe has been studied by Boettner, et al. (1981) at the University of Michigan. They found that alkyltin species and organic pipe cement solvent components can leach into potable water (pH 5 at 37°C). For example, they found from 10 ppm to 10 ppb of methylethylketone (MEK), tetahydrofuran (THF), and cyclohexanone from the solvent leached into the water in a miniature pipe loop exposed for 14 days. From the PVC pipe dimethyltin (as dichloride) was found to be leached at a concentration of 45 ppb after one day of exposure at 37°C. During 21 additional days of exposure the concentration of dimethyltin decreased, in a diphasic manner, from 3.0 to 0.25 ppb per day. Lesser levels of dibutyltin were leached from CPVC.

A recent field and laboratory study by Sosebee, et al. (1982) included assessment of the potential for contamination of ground water samples by six different PVC primers and one PVC adhesive. THF, MEK, methylisobutylketone (MIBK), and cyclohexanone were found to be leached into the water surrounding bonded joints. Even though a well was developed after installation and bailed prior to sampling, they found detectable levels of these compounds in well water several months after installation. After immersion of freshly cemented PVC pipe for five days up to 110 mg/l of MEK was found. After five washings and a 24-hour equilibrium the concentration of MEK was reduced to about 0.54 mg/l. Similar trends were noted for the other three pollutants studied although the presence of each constituent and their relative concentrations varied significantly between solvent brands and manufacturers. All four compounds could be introduced into monitor wells by one or more of the brands of adhesive. Concentrations of contaminants declined significantly with successive washes with deionized water, from a mean total concentration of 77,800 ug/l after 5 days of soaking to a mean total of 591 ug/l after being washed four more times with deionized water and soaked for an additional 24 hours.

Field sampling with a PVC bailer constructed several weeks before resulted in samples with low levels of THF and MEK. With a PVC bailer constructed 30 minutes prior to sampling Sosebee, et al. found 16,000 ppb cyclohexanone, 3,800 ppb MEK and 1,400 ppb THF in a ground water sample. Contaminants in PVC solvents can mask the presence of other volatile priority pollutants that elute from the chromatograph at similar retention times. For example, MEK and 1,2-dichloroethane, cyclohexanone and bromoform, and THF and 1,1-dichloroethane all coelute with the EPA analytical protocol. All these problems can most simply be circumvented by using well-casings and bailers constructed with threaded PVC or with other materials (Sosebee, et al., 1982).

While PVC is the most common type of synthetic well casing material in use other materials have been used or could be used including, for example, acrylonitrile butadiene styrene (ABS), styrene-rubber (SR), polyethylene, polypropylene, Teflon and Kynar. Pettyjohn, et al. (1981) indicated in a recent article that when sampling for organic contaminants the preferred order of choice of well-casing and sampling

materials includes glass, Teflon, stainless steel, polypropylene, polyethylene, other plastics and metals, and rubber. But they indicated detailed experimental data on materials selection are simply not available.

Experimental Methods

Three types of well-casing materials were selected for testing including schedule 40 PVC 1120, low density polyethylene, and polypropylene. All materials were purchased from Almac Plastics of Illinois, Inc. Polyethylene and polypropylene were selected because of their potential usage and relatively low cost (compared to Teflon and stainless steel).

Three general experiments were conducted with the well-casing materials and selected metal and volatile organic pollutants. These are listed along with the concentrations used in Table 1. Each of the six organic chemicals used is an EPA listed priority pollutant and a purgeable aliphatic halocarbon. Drinking water standards have been estblished for the two metals studied.

Water free of interferences, "organic free", was prepared with a Barnstead Nanopure unit followed by an Organicpure unit. It was also necessary to briefly boil the water to remove all purgeables. The pH of the water was about 7.2. All experiments were conducted at about 23° C and in the dark.

In the first experiment the adsorption (uptake) of these pollutants was measured weekly for six weeks versus controls for each of the casing materials. Borosilicate glass exposure chambers with 40 milliter capacity and Teflon lined caps were used for this experiment. The experimental set-up is shown in Table 2. The same set-up was used in the second experiment. This second experiment included an initial four week exposure of the pollutants to each of the well-casings followed by replacement with "organic free" water. The release or leaching of adsorbed pollutants was then measured weekly for four weeks. Duplicate exposure chambers were used to measure variability and the chambers were sacrificed since no head space could be allowed. Each of the well-casing materials used for these two experiments was cut to a 3 inch length. The surface areas exposed were 60.09 square centimeters for PVC, 57.17 square centimeters for polyethylene, and 57.73 square centimeters for polypropylene.

The objective of the third experiment was to determine the leaching of solvent extractable leachates such as plasticizers or other additives from each of the well-casing materials after exposure to the metal and organic pollutants. The well-casing material was cut into 6 inch lengths and exposed in 1 liter borosilicate glass chambers for three and six week periods. The set-up for this experiment is shown in Table 3.

The well-casing material was cut on a table saw and rinsed in "organic free" water to remove fines prior to placement in the exposure chambers. Glassware was cleaned by rinsing with 1:1 nitric acid, "organic free" water, 1:1 hydrochloric acid, "organic free" water, methylene chloride, and "organic free" water. All chemicals used were reagent grade or better.

The sample analyses for lead and chromium were completed with an Instrumentation Laboratory Inc. 551 Atomic Absorption/Emission Spectrophotometer. Samples were preserved after organics analysis and removal of the well-casing material by the addition of 4-5 drops of nitric acid. Output was the mean of thirty one-second readings.

For purgeable organics analysis was performed with Hewlett-packard 5750 gas chromatograph and a nickel-63 electron capture detector (ECD). Results were recorded with a Hewlett-Packard 3380A integrator and samples were concentrated with a Hewlett-Packard model 7675A purge and trap unit. The column packing used was 1% (w/w) SP-1000 on 60/80 mesh Carbopack B (Supelco, 1-1815). The 10 milliliter samples were purged with 40 milliliters per minute helium carrier gas for 10 minutes and desorbed at 250° C. Auxiliary gas was 5% methane in argon at 110 milliliters per minute. The ECD temperature was 320° C. The temperature program was 45° C for 3 minutes and increasing at 8° C per minute to a final temperature of 195° C for 8 minutes. An internal standard, 1-chloro-2-bromopropane, was used for calibration and interpretation of results.

For the analysis of extractables in the third experiment a Hewlett-Packard 5880A gas chromatograph with a flame ionization detector (FID) was used. Results were recorded with a Hewlett-Packard 3388A reporting/integrator. Sample preparation included extraction of 1 liter with methylene chloride using separatory funnel techniques. The extract was then dried and concentrated in a Kuderna-Danish flask to 1 milliliter. An intection (splitless) of about 1 microliter was then made of this concentrated sample onto a 15 meter J & W DB-5 (Durabond) fused silica capillary column and detected by flame ionization (FID). The temperature program was initially 40° C and increasing at 8° C per minute to a final temperature of 250° C. Nitrogen was the carrier gas. Mass spectroscopy was performed on selected samples with a Finnigan 3200 GC-MS system and 6100 Interaction data system.

Quality assurance requirements followed those generally given by EPA for metals (U.S. EPA, 1979b) and those given for organics analysis (U.S. EA, 1979a). For metals analysis calibration standards were prepared and the sensitivity limit, linear range and analytical precision for each metal was determined. The analytical technique was demonstrated to be interference free and calibration standards were analyzed daily. For the analysis of volatile organics the sensitivity limit and linear range of the purge and trap - gas chromatography system were first determined for each compound. The entire system was demonstrated to be interference free on a daily basis by the analysis of

an "organic free" water blank. The system was also calibrated daily with a midrange concentration level of the internal standard. The accuracy and precision of the analytical system was determined by the analysis of replicate and fortified samples (U.S. EPA, 1979a). Results of this analysis is shown in Table 4. The mean percent recoveries and the associated standard deviations are within acceptable limits.

Results and Discussion

The results of the adsorption experiment and the adsorption/leaching experiment are descriptively summarized in Tables 5 through 7 for organics. Tables 8 and 9 descriptively summarize the results for the chromium (VI) and lead adsorption and leaching experiments. The terms slight, moderate and mostly in these tables are used in the following way. Slight adsorption means that about 25 percent of the chemical is adsorbed compared to the controls. Slight leaching means about 25 percent of that chemical leached compared to the amount adsorbed. Moderate adsorption is defined as about 50 percent adsorption versus the controls. About 50 percent leaching compared to the amount adsorbed is defined as moderate leaching. A chemical is described as mostly adsorbed when 75 percent or more is adsorbed on the well-casing compared to controls and moderate leaching means at least 75 percent is leached compared to the amount adsorbed.

During the first (adsorption) and second (adsorption/leaching) experiments it was found that the PVC well-casing material did not adsorb or leach (release) five of the six organics tested. Only tetrachloroethylene was adsorbed to a slight to moderate extent (25 to 50 percent retained on the well-casing versus controls). This is shown in Figure 1. The maximum adsorption of tetrachloroethylene found was about 0.6 nanograms per square centimeter of well-casing material. Slight leaching of tetrachloroethylene (less than 0.08 nanograms per square centimeter) was observed in the second experiment as shown in Figure 2.

All six of the organic chemicals tested adsorbed to a moderate or greater extent to polyethylene. Tetrachloroethylene was completely adsorbed while half or more of each of the other five chemicals was adsorbed onto the well-casing. For example, the adsorption of trichloroethylene to each of the well-casing materials tested is shown in Figure 3. About 1.05 nanograms per square centimeter was absorbed to the polyethylene after seven days of exposure. While trichloroethylene did not leach or was not released to a great extent from any of the well-casing materials about 1.7 nanograms per square centimeter of bromoform was adsorbed to polyethylene and about 1.2 nanograms per square centimeter leached or was released. This was about the same whether exposed only to the six organics or when exposed to the solution containing the six organics and the two metals. A similar adsorption pattern was found for 1,1,2-Trichloroethane on polyethylene as shown in Figure 4. About 4.8 nanograms per square centimeter were adsorbed and about 1.3 nanograms per square centimeter leached.

As noted in Table 6 and shown in Figure 5 the release of bromoform was delayed. The experiment was not designed to determine the release mechanism but one possibility that has been suggested is that some microbiological activity may be the predominant influence. Tetrachloroethylene was completely adsorbed by the first week on polyethylene and did not leach. Two of the other chemicals, 1,1,2-Trichloroethane and 1,1,1-Trichloroethane, were released to a slight extent (about a quarter of the amount adsorbed was released). Lesser leaching was found with the other two pollutants. All six organic pollutants tested adsorbed to polyethylene to an equal or greater extent than to either PVC or polypropylene.

Four of the organics tested adsorbed to a moderate extent (50 percent) or greater to polypropylene well-casing. The adsorption of trichloroethylene to polypropylene is shown in Figure 3. The adsorption of 1,1,1-Trichloroethane is shown in Figure 6. As can be seen adsorption to polypropylene was intermediate in extent between PVC and polyethylene and the rate of adsorption was delayed compared to polyethylene. No additional leaching was found after about three weeks of exposure. This was generally the trend for all of the organic pollutants except tetrachloroethylene which was completely adsorbed by the first week. About 0.8 nanograms per square centimeter of 1,1,1-Trichloroethane were adsorbed and about 0.14 nanograms per square centimeter were released or leached with polypropylene. Bromoform leached or was released, as shown in Figure 5, from polypropylene. About 1 nanogram per square centimeter of bromoform adsorped on polypropylene and all of that was released although delayed by about three weeks. For two other pollutants, 1,1,1-trichloroethane and trichloroethylene, about 25 percent of the amount adsorbed was released. As with polyethylene, all of the tetrachloroethylene was adsorbed and none of it was released from the polypropylene well-casing material.

As shown in Table 8 chromium (VI) did not adsorb to any of the well-casing materials to any significant extent when in the solution with lead. When in solution with lead and the six other organics slight (25 percent) adsorption (about 125 nanograms per square centimeter) of chromium was observed. No significant leaching of chromium was found from any of the well-casing materials with any of the treatments.

Lead was found to adsorb to the greatest extent (about 75 percent) to PVC and about 50 percent to polyethylene and polypropylene. An example of the adsorption of lead to PVC is shown in figure 7. In this experiment about 400 nanograms of lead were adsorbed. An example of the delayed adsorption of lead to polyethylene is shown in Figure 8. About 170 nanograms per square centimeter were adsorbed.

No significant leaching or release of lead from any of the well-casing materials was observed when in solution with chromium only. When the metals and organics were exposed to the well-casing material about half of the lead adsorbed was released. A slow and nearly constant rate of release of lead was observed from PVC and polyethylene during the

four week experiment as shown in Figures 9 and 10. Lead was more rapidly released from polypropylene as shown in Figure 11.

No identifiable leachates were found in the third experiment from any of the well-casing materials examined. There were no differences between exposure of the well-casing materials to only the two metals, only the six organics or to a solution containing the metals and organics. Some leachates may have been present which were below the detection limit of the analytical technique used. No interference with flame ionization detection was found after liquid/liquid extraction and approximately a thousand fold concentration. Leaching of plasticizers or other additives might be greater when exposed to other pollutants and under flowing water conditions.

Conclusions and Future Directions

This research examined three types of well-casing materials exposed under static (batch) conditions to two metal pollutants and six volatile organic pollutants. It was generally found that schedule 40 PVC causes less monitoring interferences with volatile organics than polyethylene or polypropylene under the conditions of this experiment. However, some variation by chemical was found and tetrachloroethylene was adsorbed by each well-casing material with little or no subsequent release observed. Adsorption and leaching (release) of the organic pollutants examined were more rapid with polyethylene than polypropylene and were slowest with PVC well-casing.

Lead reached a maximum level of adsorption in about 2 weeks with PVC, from 2 to 5 weeks with polyethylene, and in 1 to 4 weeks with polypropylene depending on the treatment. The release of lead after an exposure period also varied by treatment ranging from 1 to 6 weeks with polyethylene and polypropylene, and 4 to 6 weeks with PVC. The adsorption and release of lead was more rapid when in a solution with chromium and the six other volatile organics examined than when in a solution with only chromium. Chromium (VI) did not adsorb or leach with any of the well-casing materials examined. Also, no extractable pollutants were leached from the well-casing materials under any treatment and the conditions of this study.

Organic pollutants were adsorbed and released at a relatively slow rate with PVC well-casing. The most rapid adsorption occurred with polyethylene where no additional adsorption was observed after 1 week. The release rates of these adsorbed organics from polyethylene varied greatly. For example, no additional release of trichlorofluoromethane, 1,1,1-Trichloroethane, and 1,1,2-Trichloroethane was observed after one week. Increasing amounts of Tetrachloroethylene were found to be released throughout the four weeks of the observations.

The results of the experiments to date suggest several and interesting questions for future research. During the next year additional sources of PVC well-casing and other well-casing materials including ABS will be examined. Similar experiments to those reported here will be conducted on those materials with higher concentrations of additional pollutants such as selected phenols, phthalates, and polynuclear aromatic hydrocarbons. Emphasis will be on pollutants likely to be found in ground water, less volatile and more polar than those exmained to date. It is thought that more hydrophilic pollutants may be more readily adsorbed.

Experimental conditions similar to those encountered in the field will be used. This includes the examination of a range of pH conditions, exposure at a lower temperature, and the addition of pollutants to an organic-interference-free ground water. The well-casing material will be exposed to the pollutants for longer periods of time (about six months) followed by an examination of how rapidly and at what concentration levels the pollutants are released. This should provide a better indication of the potential for the well-casing to interfere with ground water monitoring efforts. The well-casing will also be examined microbiologically to determine if microorganisms are influencing the uptake and release of any of the pollutants.

REFERENCES

Boettner, E.A. 1981. Organic and Organotin Compounds Leached from PVC and CPVC Pipe. U.S. Environmental Protection Agency Report Number EPA-600/1-81-062 (NTIS PB82-108333) Washington, D.C.

Curran, C.M. and M.B. Tomson. 1982. Leaching of Trace Organics into Water from Five Common Plastics. Personnal Communication. Rice University. Houston, Texas.

Eichholz, G.G., A.E. Nagel, and R.B. Hughes. 1965. Adsorption of Ions in Dilute Aqueous Solutions on Glass and Plastic Surfaces, Analytical Chemistry, v. 37, no. 7, pp. 863-868.

Junk, G.A., et al. 1974. Contamination of Water by Synthetic Polymer Tubes. Environmental Science and Technology, v. 8, no. 13, pp. 1100-1106.

Massee, R., F.J.M.J. Maessen and J.J.M. DeGoeij. 1981. Losses of Silver, Arsenic, Cadmium, Selenium and Zinc Traces from Distilled Water and Artificial Sea-Water by Sorption on Various Container Surfaces. Analytica Chimica Acta, v. 127, pp. 181-193.

Pettyjohn, W.A., et al. 1981. Sampling Ground Water for Organic Contaminants. Ground Water, v. 19, no. 2, pp. 180-189.

Robertson, D.E. 1968a. Role of Contamination in Trace Element Analysis of Sea Water. Analytical Chemistry, v. 40, no. 7, pp. 1067-1072.

Robertson, D.E. 1968b. The Adsorption of Trace Elements in Sea Water on Various Container Surfaces. Analytica Chimica Acta, v. 42, pp. 533-536.

Shendrikar, A.D. 1976. Adsorption Characteristics of Traces of Barium, Beryllium, Cadmium, Manganese, Lead and Zinc on Selected Surfaces. Analytica Chimica Acta, v. 84, pp. 409-417.

Smith, A.E. 1973. Study of the Variation with pH of the Solubility and Stability of Some Metal Ions at Low Concentrations in Aqueous Solution. Part I. Analyst, v. 98, pp. 65-68.

Sosebee, J.B., Jr. 1982. Contamination of Groundwater Samples with PVC Adhesives and PVC Primer from Monitor Wells. Environmental Science and Engineering, Inc., Gainesville, Florida.

U.S. Environmental Protection Agency. 1979a. Guidelines Establishing Test Procedures for the Analysis of Pollutants; Proposed Regulations. Federal Register, Part III, v. 44, no. 233, pp. 69463-69575.

U.S. Environmental Protection Agency. 1979b. Handbook for Analytical Quality Control in Water and Wastewater Laboratories. Office of Research and Development, Cincinnati, Ohio.

U.S. Environmental Protection Agency. 1980. Publications on the Analysis of Spilled Hazardous and Toxic Chemicals and Petroleum Oils. Industrial Environmental Research Laboratory, Cincinnati, Ohio.

Table 1: Metal and Organic Pollutants Studied and Concentrations Used

	INITIAL CONCENTRATION
Metals	
Chromium (VI)	0.5 ppm
Lead	0.5 ppm
Organics	
Bromoform	4 ppb
Tetrachloroethylene	2 ppb
Trichloroethylene	3 ppb
Trichlorofluoromethane	2 ppb
1,1,1-Trichloroethane	2 ppb
1,1,2-Trichloroethane	14 ppb

Table 2: Set-up for Adsorption and Adsorption/Leaching Experiments.

Well-Casing Material	Numbers of Chambers in Treatment			
	Blank	Metals	Organics	Metals and Organics
None	2	1	1	1
PVC	2	2	2	2
Polyethylene	2	2	2	2
Polypropylene	2	2	2	2

Table 3: Set-up for Leaching of Extractables Experiment

Well-Casing Material	Numbers of Chambers in Treatment			
	Blank	Metals	Organics	Metals and Organics
None	1	1	1	1
PVC	1	1	1	1
Polyethylene	1	1	1	1
Polypropylene	1	1	1	1

Table 4: Precision and Accuracy of Analytical Method

PARAMETER	MEAN PERCENT RECOVERY	STANDARD DEVIATION OF THE MEAN PERCENT RECOVERY
Trichlorofluoromethane	98.64	1.123
1,1,1-Trichloroethane	105.37	1.323
Trichloroethylene	92.18	0.906
1,1,2-Trichloroethane	100.12	0.750
Bromoform	104.68	1.148
Tetrachloroethylene	96.59	0.922

Table 5: Trends of Organic Pollutants Exposed to PVC Well-Casing (Compared to Controls)

Pollutant	Adsorption		Adsorption/Leaching	
	Organics Only	Organics & Metals	Organics Only	Organics & Metals
Trichlorofluoromethane	No Adsorption	No Adsorption	No Leaching	No Leaching
1,1,1-Trichloroethane	No Adsorption	No Adsorption	No Leaching	No Leaching
Trichloroethylene	No Adsorption	Slight (25%) Adsorption	No Leaching	No Leaching
1,1,2-Trichloroethane	No Adsorption	No Adsorption	No Leaching	No Leaching
Bromoform	No Adsorption	No Adsorption	No Leaching	No Leaching
Tetrachloroethylene	Moderate (50%) Adsorption	Slight (25%) Adsorption	Slight (25%) Leaching - Readsorption?	Slight (25%) Leaching - Readsorption?

Table 6: Trends of Organic Pollutants Exposed to Polyethylene Well-Casing (Compared to Controls)

Pollutant	Adsorption		Adsorption/Leaching	
	Organics Only	Organics & Metals	Organics Only	Organics & Metals
Trichlorofluoromethane	Mostly (75%) Adsorbed	Mostly (75%) Adsorbed	Slight (25%) Leaching	No Leaching
1,1,1-Trichloroethane	Mostly (75%) Adsorbed	Mostly (75%) Adsorbed	Slight (25%) Leaching	Slight (25%) Leaching
Trichloroethylene	Mostly (75%) Adsorbed	Mostly (75%) Adsorbed	No Leaching	Slight (25%) Leaching
1,1,2-Trichloroethane	Moderate (50%) Adsorption	Moderate (50%) Adsorption	Slight (25%) Leaching	Slight (25%) Leaching
Bromoform	Moderate (50%) Adsorption	Mostly (75%) Adsorbed	Moderate (50%) Leaching (Delayed)	Moderate (50%) Leaching
Tetrachloroethylene	Adsorbed (100%)	Adsorbed (100%)	No Leaching	No Leaching

Table 7: Trends of Organic Pollutants Exposed to Polypropylene Well-Casing (Compared to Controls)

Pollutant	Adsorption		Adsorption/Leaching	
	Organics Only	Organics & Metals	Organics Only	Organics & Metals
Trichlorofluoromethane	Moderate (50%) Adsorption	Mostly (75%) Adsorbed	Slight (25%) Leaching	No Leaching
1,1,1-Trichloroethane	Moderate (50%) Adsorption	Moderate (50%) Adsorption	Slight (25%) Leaching	Slight (25%) Leaching
Trichloroethylene	Mostly (75%) Adsorbed	Mostly (75%) Adsorbed	Slight (25%) Leaching	Slight (25%) Leaching
1,1,2-Trichloroethane	Slight (25%) Adsorption	Slight (25%) Adsorption	Slight (25%) Leaching (Delayed)	No Leaching
Bromoform	Slight (25%) Adsorption	Slight (25%) Adsorption	All (100%) Leached (Delayed)	All (100%) Leached (Delayed)
Tetrachloroethylene	Adsorbed (100%)	Adsorbed (100%)	No Leaching	No Leaching

Table 8: Trends of Chromium (VI) Exposed to Synthetic Well-Casing Materials (Compared to Controls)

Casing Material	Adsorption		Adsorption/Leaching	
	Metals Only	Metals & Organics	Metals Only	Metals & Organics
PVC	No Adsorption	Slight (25%) Adsorption	No Leaching	No Leaching
Polyethylene	No Adsorption	Slight (25%) Adsorption	No Leaching	No Leaching
Polypropylene	No Adsorption	Slight (25%) Adsorption	No Leaching	No Leaching

Table 9: Trends of Lead Exposed to Synthetic Well-Casing Materials (Compared to Controls)

Casing Material	Adsorption		Adsorption/Leaching	
	Metals Only	Metals & Organics	Metals Only	Metals & Organics
PVC	Mostly (75%) Adsorbed	Mostly (75%) Adsorbed	No Leaching	Mostly (75%) Leached
Polyethylene	Moderate (50%) Adsorption (Delayed)	Moderate (50%) Adsorption	No Leaching	Mostly (75%) Leached
Polypropylene	Moderate (50%) Adsorption (Delayed)	Moderate (50%) Adsorption	No Leaching	Mostly (75%) Leached

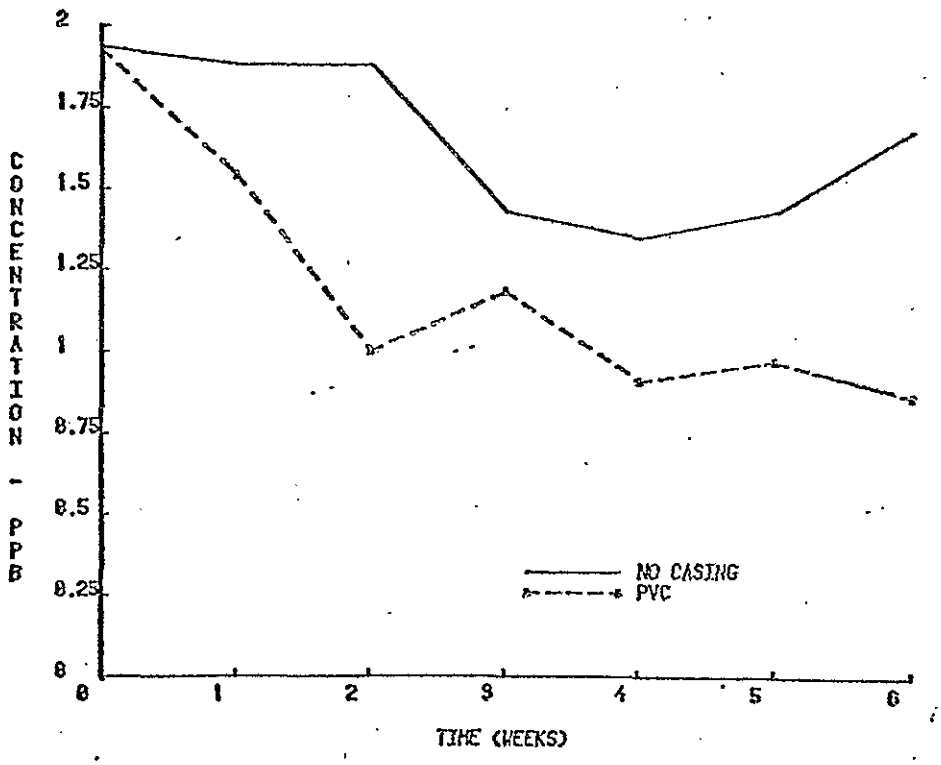


FIGURE 1:TETRACHLOROETHYLENE ADSORPTION EXPOSED TO ORGANICS (AVERAGE)

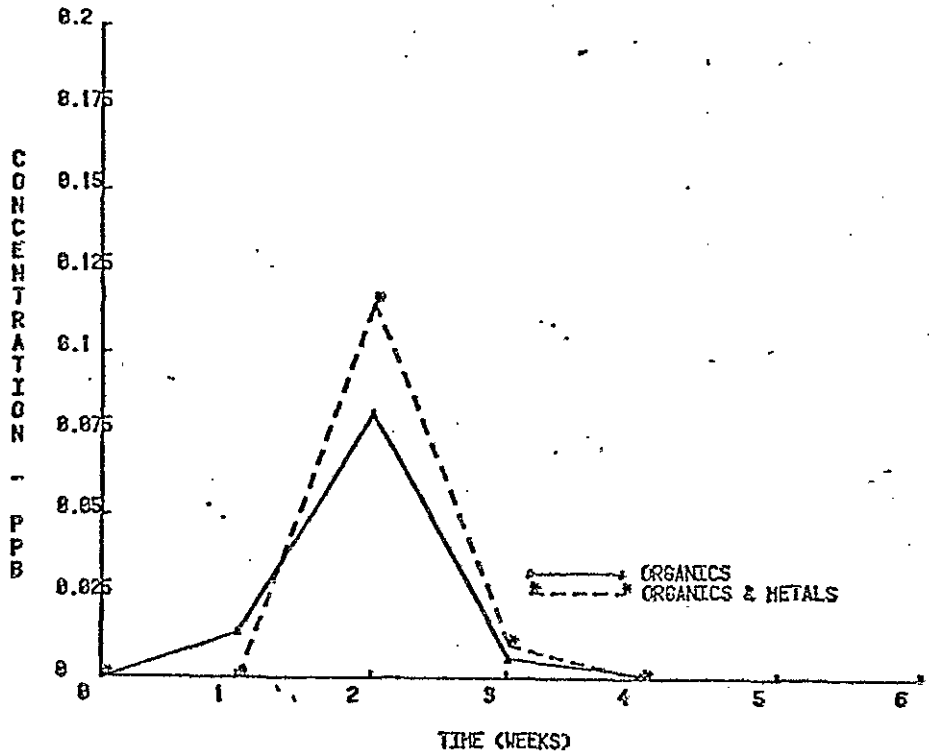


FIGURE 2: LEACHING OF TETRACHLOROETHYLENE FROM PVC (ORG & METALS)

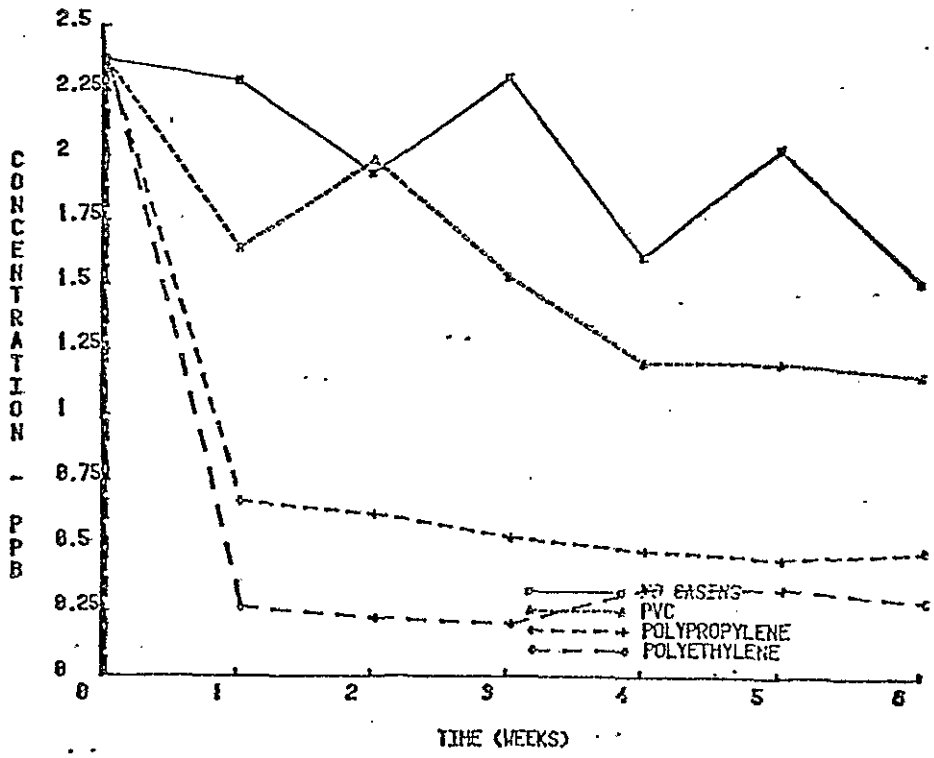


FIGURE 3: TRICHLOROETHYLENE ADSORPTION EXPOSED TO ORGANICS & METALS (AV)

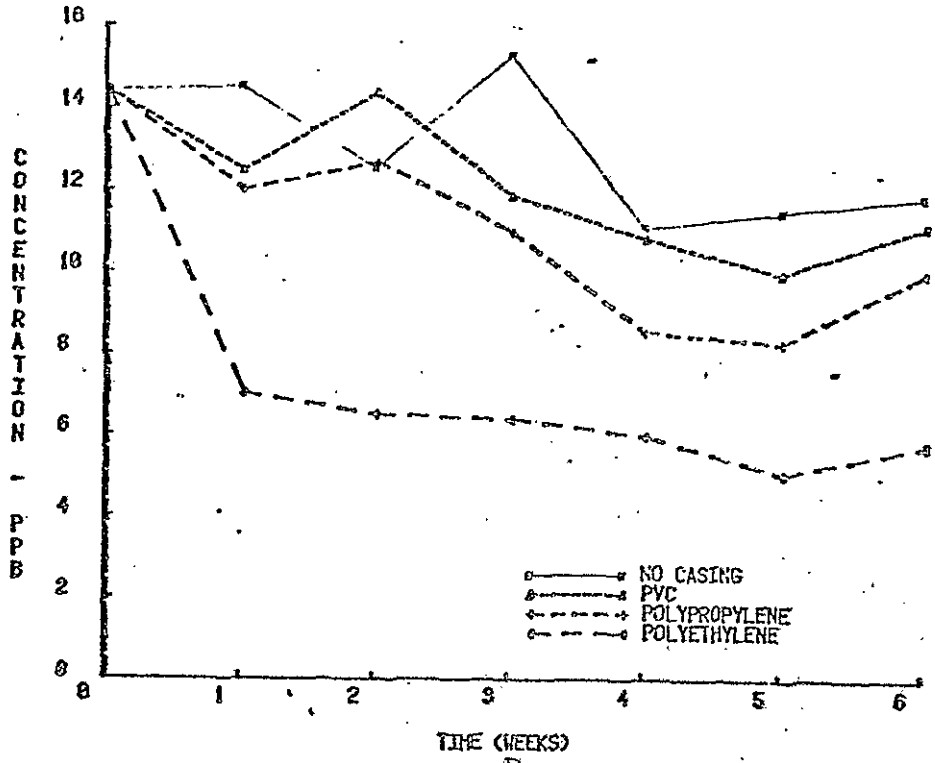


FIGURE 4: 1,1,2-TRICHLOROETHANE ADSORPTION EXPOSED TO ORGANICS & METALS

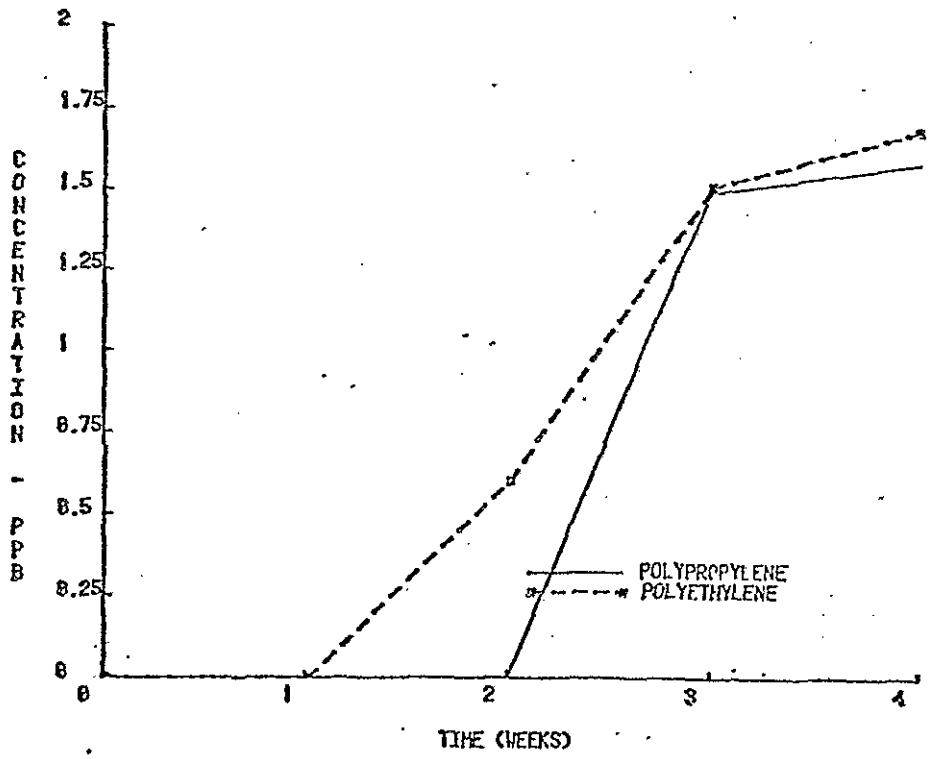


FIGURE 5: BROMOFORM ADSORPTION/LEACHING EXPOSED TO ORGANICS (AVG)

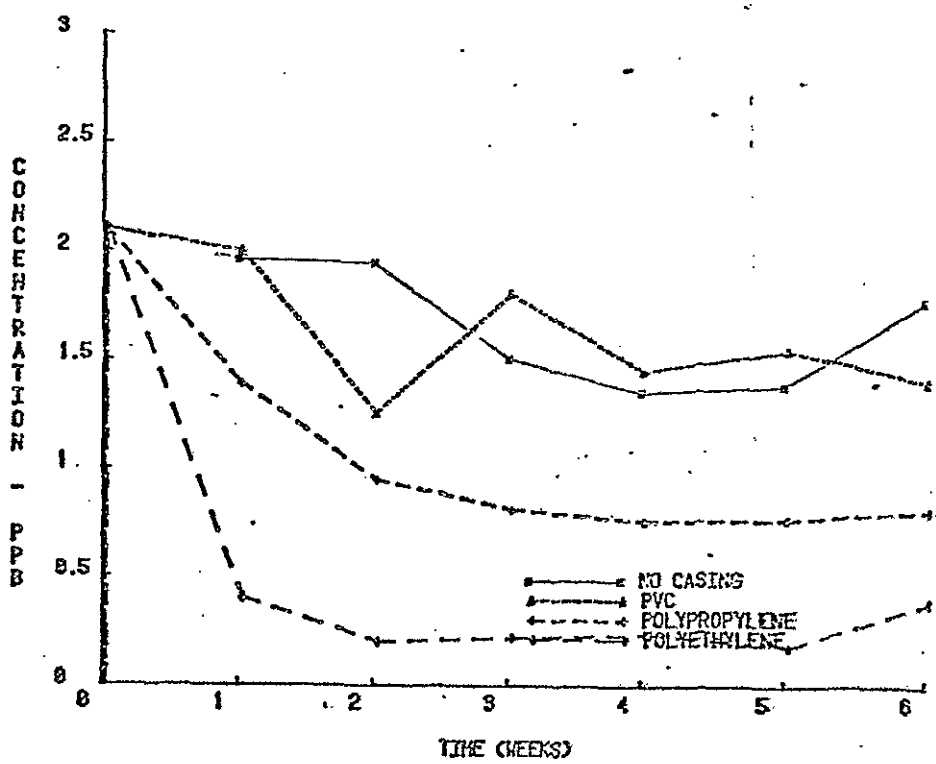


FIGURE 6: 1,1,1-TRICHLOROETHANE ADSORPTION EXPOSED TO ORGANICS (AVG)

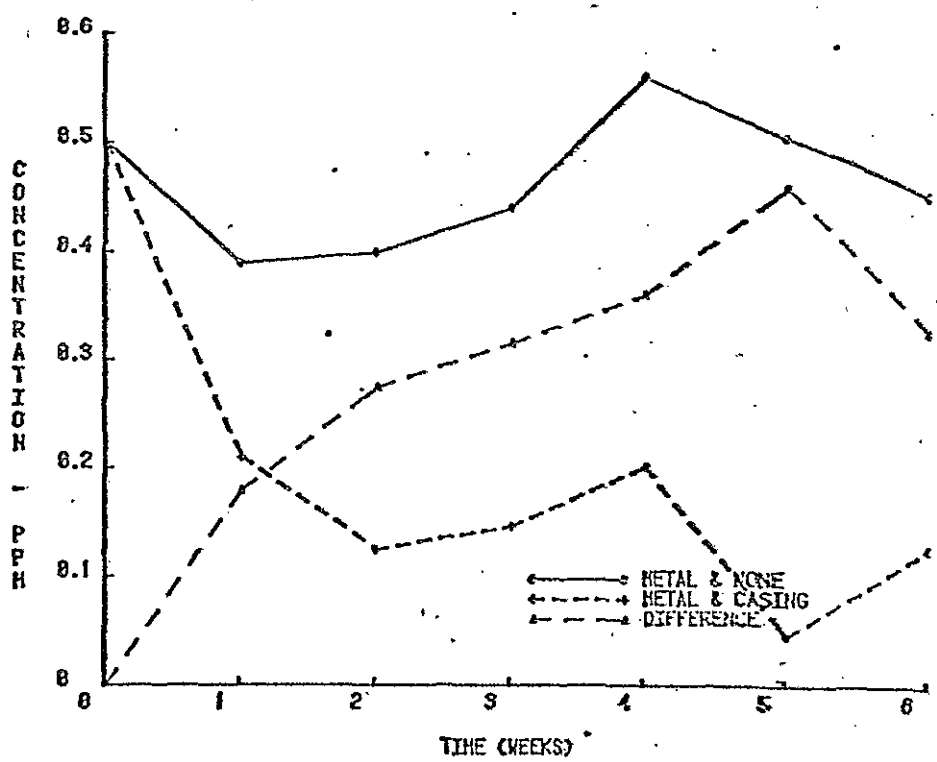


FIGURE 7: LEAD ADSORPTION TO PVC EXPOSED TO METALS (AVERAGE)

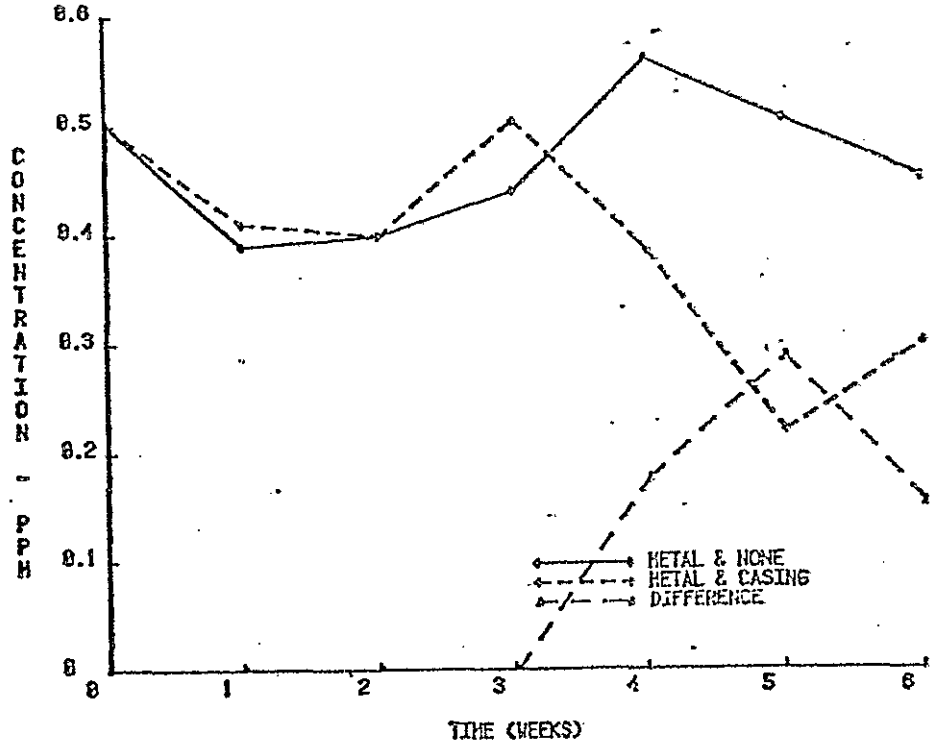


FIGURE 8: LEAD ADSORPTION TO POLYETHYLENE EXPOSED TO METALS (AVG)

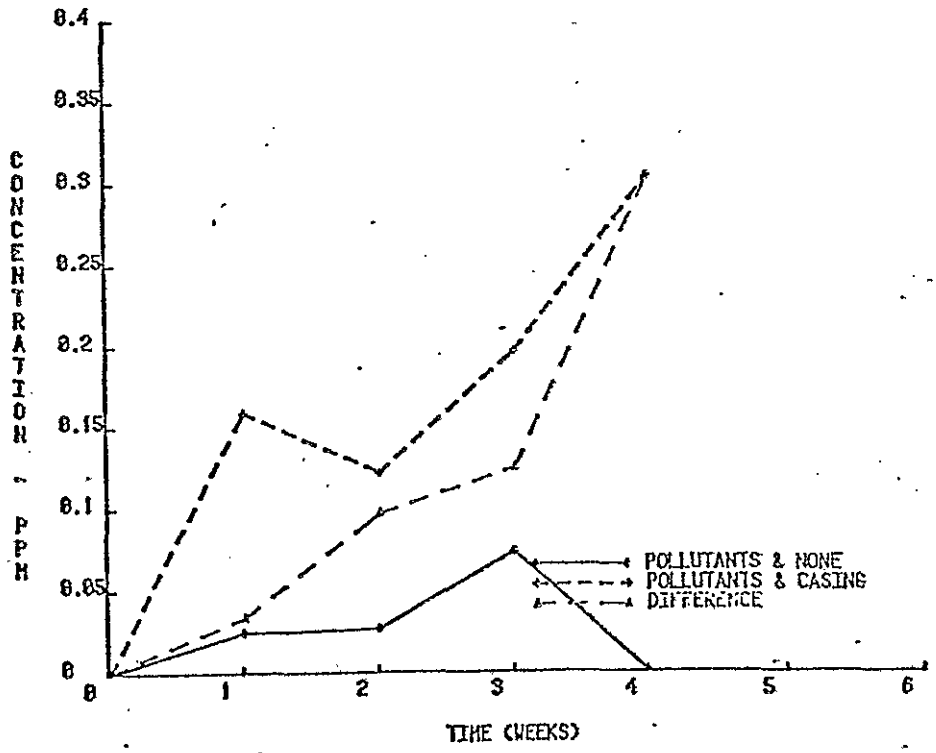


FIGURE 9: LEAD RELEASED FROM PVC EXPOSED TO METALS & ORGANICS (AVG)

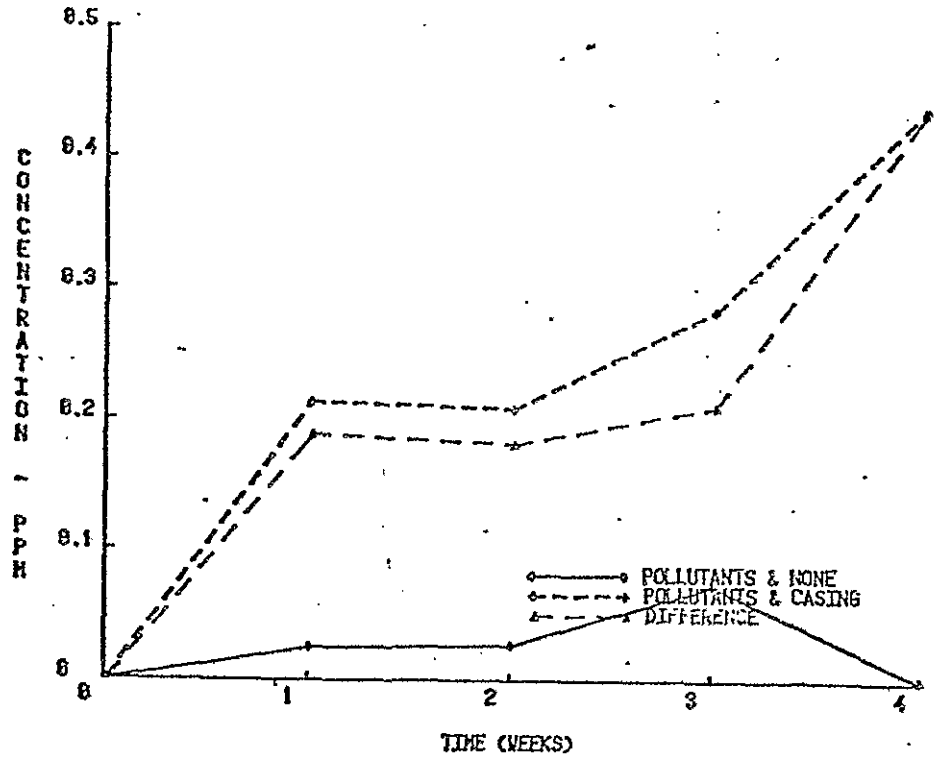


FIGURE 10: LEAD RELEASED FROM POLYETHYLENE EXPOSED TO ORG & METALS (AVG)

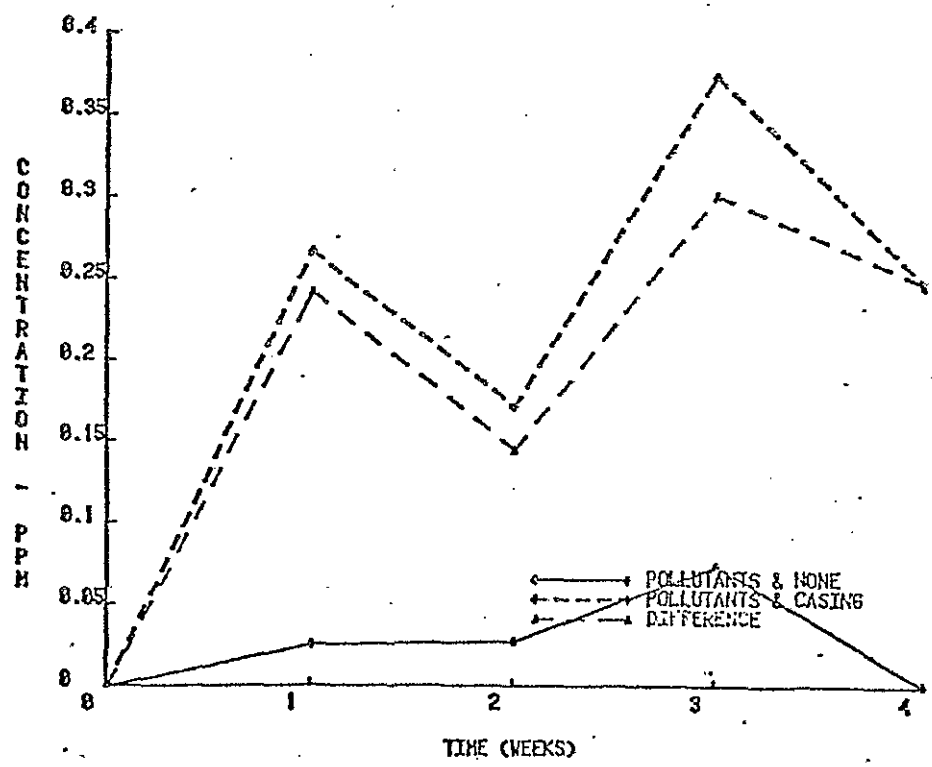


FIGURE 11: LEAD RELEASED FROM POLYPROPYLENE EXPOSED TO METALS & ORGANICS

56. Morrison, R.D., et al. "Vadose Zone Monitoring at a Hazardous Waste Disposal Facility", presented at the National Water Well Association Conference on the Characterization and Monitoring of the Vadose (Unsaturated) Zone, Las Vegas, Nevada, December 8-10, 1983

Characterization and Monitoring of the Vadose (Unsaturated) Zone

December 8-10, 1983
Riviera Hotel
Las Vegas, Nevada

national water well association

National Water Well Association
500 West Wilson Bridge Road
Worthington, OH 43085

Proceedings of the NWWA/U.S. EPA Conference on Characterization and Monitoring of the Vadose (Unsaturated) Zone

December 8-10, 1983
The Riviera Hotel
Las Vegas, Nevada

Edited by

David M. Nielsen, Director of Research
Mary Curl, Research Associate
National Water Well Association
Worthington, Ohio

Sponsors

National Water Well Association
U.S. Environmental Protection Agency

Published by

National Water Well Association
500 W. Wilson Bridge Road
Worthington, Ohio 43085

Produced by

Water Well Journal Publishing Company
500 W. Wilson Bridge Road
Worthington, Ohio 43085

Table of Contents

	Page
Symposium Coordinating Committee	i
Acknowledgments	i
Abstract	ii

Section I
Water Movement and Storage in the Vadose Zone

Vadose Moisture Migration in Semi-Arid and Arid Environments —Atef Elzeftawy and Martin D. Mifflin	1
Vadose Water Storage and Movement at an Upland Southern Piedmont Site —J.T. Ligon and T.V. Wilson	37
Influence of Entrapped Air on Field Determinations of Hydraulic Properties in the Vadose Zone —Daniel B. Stephens	57
Effects of Stones on Hydraulic Properties of Vadose Zones —Herman Bouwer and R.C. Rice	77

Section II
Modeling Water Movement and Storage in the Vadose Zone

Modeling Water Movement in a Sandstone Matrix —Dan B. Jaynes and Robert C. Rice	96
Numerical Considerations in Modeling Unsaturated Vertical Ground Water Flow —Carol J. Miller and Steven J. Wright	116
Use of a Computer Model to Select Monitoring Locations in the Vadose Zone —C.R. McKee, J.T. Laman, R.D. Santoro, T.L. Deshler, R.H. Jacobson and A.C. Bumb	133

Section III
Attenuation Mechanisms in the Vadose Zone

Retardation of Adsorbed Chemicals in Variably Saturated Flow —David B. McWhorter and Victor A. Nazareth	168
Calculation of Dispersion Coefficients in the Vadose Zone Using Soil Water Characteristics Curves —Donald L. Reddell and Allen G. Smajstria	178
Field Scale Transport of Nonadsorbing and Adsorbing Chemicals Applied to the Soil Surface —William A. Jury and Hesham Al Abd	203
Vadose Zone Aeration Status and Its Effect on Pollutant Attenuation Beneath Large Subsurface Waste Water Adsorption Systems —Robert L. Siegrist, David L. Hargett and Damann L. Anderson	223

Section IV
The Vadose Zone in Land Treatment

The Vadose Zone as a Waste Water Treatment System —Herman Bouwer, R.C. Rice and E.J. Bouwer	248
The Effect of Fluctuating High Water Tables on the Treatment of Waste Water in the Vadose Zone —Craig G. Cogger and Lisa M. Hajjar	263
Multi-Dimensional Spline Smoothing as a Tool in Monitoring the Performance of Land Treatment Systems —Damann L. Anderson, Robert L. Siegrist and Roberta J. Fine	288
Water Quality Changes After a Decade of Waste Water Application —Joseph A. Magner and Bradley R. Sielaff	318

Section V
Monitoring Water Movement in the Vadose Zone

Monitoring Water Flow Pathways in Unsaturated/Saturated Field Soils
—James R. Hoover 337
Tracer Techniques in Monitoring Vadose Zone Flow
—Robert S. Bowman 364
Monitoring the Movement and Chemical Quality of Water in the Unsaturated Zone on Long Island, New York
—Brian J. Schneider, James Oliva, Henry F. Ku and Edward T. Oakesford 383

Section VI
Monitoring Water Quality Changes in the Vadose Zone

Vadose Zone Monitoring at Sites Used for Land Treatment of Oily Residues
—Leale E. Streebin, James M. Robertson and Alistaire B. Callender 412
Unsaturated Zone Monitoring Protocols for Hazardous Waste Land Treatment Units
—L.G. Everett, L.G. Wilson and L.G. McMillion 439
Measurement of Contaminant Distribution, Migration and Attenuation Within the Vadose Zone Below Disposal Lagoons
—Matthew J. Barvenik, Donald Schulze and Charles A. Lindberg 461
Vadose Zone Monitoring for Evaluating the Integrity of Hazardous Waste Pond Liners
—D.C. Baier, F.K. Aljibury, J.K. Meyer and A.K. Wolfenden 476
Landfill Leachate Attenuation in the Unsaturated Zone: Instrumentation and Monitoring of a Site in Southern England
—John L. Lucas and Howard D. Robinson 492
Vadose Zone Monitoring at a Class I Landfill
—Robert Morrison, K. Lepic and J. Baker 517
A Monitoring and Removal Plan for Leaked Propane in the Vadose Zone
—Thomas Lobasso Jr. and Andrew J. Barber 530

Section VII
Instruments Used in Studying the Vadose Zone

The Utilization of Pressure-Vacuum Lysimeters for Unsaturated Zone Monitoring
—Todd Giddings 545
The Use of Collection Lysimeters in Monitoring Sanitary Landfill Performance
—Peter Kmet and David E. Lindorff 554
Nuclear Logging and Electrical Earth Resistivity Techniques in the Vadose Zone in Glaciated Earth Materials
—P.E. Reed, P.B. DuMontelle, M.L. Sargent and M.M. Killey 580
An Automatic Instrument for Recording the Count Rate of a Moving Neutron Moisture Probe
—David G. Scholl and William E. Honey 602

Section VIII
Vadose Zone Sampling Techniques

Continuous Soil Sampling in the Vadose Zone
—Charles Riggs 611
Sampling and Analysis of Soil for Volatile Organic Compounds
—Jill P. Slater, Frederick R. McLaren 623
Detection of Ground Water Contamination by Shallow Gas Sampling in the Vadose Zone
—Eric G. Lappala and Glenn M. Thompson 659

Section IX
Field Studies/Case Histories

Performance of Layered Soil Covers Using the Wick Effect to Minimize Infiltration at Waste Disposal Sites
—T.M. Johnson, T.J. Larson, B.L. Herzog, K. Cartwright and C.J. Stohr 682
Water Balance at a Compacted Fly Ash Fill
—James E. Villaume, Lynn E. Lang and John J. Ripp 719
Multi-Level Lysimeter Monitoring of a Municipal Sludge Spreading Site
—Kathryn S. Makeig and Douglas J. Riddle 758
Unsaturated Zone Water Chemistry from Undisturbed and Surface-Mined Areas of North Dakota
—Bernd W. Rehm and Gerald H. Groenewold 782
Estimating Ground Water Recharge from Distribution of Environmental Chloride in the Vadose Zone
—M.L. Sharma 799
Study of the Vadose Zone at a Low-Level Radioactive Waste Disposal Site
—R.W. Healy, C.A. Peters, M.P. DeVries, P.C. Mills and D.L. Moffett 820
Characteristics of a Shallow Water Table on the Illinoian Till Plain of Southwestern Ohio
—Neil E. Smeck and M.D. Ransom 832
Fluctuations of Apparent Water Tables in Soils in Central New York State
—Gerald W. Olson 862
Measurement of Unsaturated Flow Below the Root Zone at an Arid Site
—R.R. Kirkham and G.W. Gee 917
Fate of Aldicarb in Florida Citrus Soils: 1) Field and Laboratory Studies
—A.G. Hornsby, P.S.C. Rao, P. Nkedi-Kizza, W.G. Wheeler and R.G. Jones 936
Fate of Aldicarb in Florida Citrus Soils: 2) Model Evaluation
—R.B. Jones, P.S.C. Rao and A.G. Hornsby 959

Vadose Zone Monitoring At A Hazardous Waste Disposal Facility

by Robert D. Morrison, Kenneth A. Lepic and John A. Baker

Introduction

A vadose zone monitoring system was designed for a Class I hazardous waste disposal facility located south of Arlington, Oregon. The purpose of the monitoring network is to provide an early warning detection system for the transport of any contaminants from existing and proposed waste impoundments and to provide a mechanism for soil pore water collection. An approach which integrated the existing network of lysimeters with additional devices to detect changes in moisture content and provide soil pore water sampling was examined. Field testing of the existing ceramic cup lysimeters and laboratory testing of various prototypes resulted in the development of a dual purpose unit. The dual purpose device functions as a tensiometer and if the matric potential reaches a value near saturation, the liquid within the unit is withdrawn. The unit is then evacuated and allowed to function as a lysimeter. A similar procedure can be used for the existing lysimeters to function as tensiometers.

Instrumentation selected for tensiometer measurements consisted of both an automatic Scanivalve system and manually read Bourdon gauge. The use of the Scanivalve system is to be employed for one pond under which 22 units are to be installed. Installation of the Scanivalve commenced on the first week of December 1983. The instrumentation consisted of a 24 point fluid switch wafer, a pressure transducer and digital read out. Bourdon gauges were used in cases where the distance between the tensiometer/lysimeter was not conductive to a centralized recording system.

A sampling grid was designed by calculating the distribution of possible point and line source leaks from a waste impoundment. The results from these calculations, in addition to determination of the maximum radii of influence for a tensiometer and lysimeter, provided the information necessary for determining sampler depths and density.

Physiographic Setting

The Arlington facility is located approximately 140 miles east of Portland, Oregon, 7 miles south of the Columbia River and 15 miles from the town of Arlington. The 320-acre site is operated by Chem-Security Systems which is a subsidiary of Waste Management Inc., of Oak Brook, Illinois. The facility is situated on a plateau at an elevation ranging between 900 and 980 feet in a semi-arid region. The average yearly precipitation is about 9 inches with an annual potential evaporation of about 60 inches.

The site is located within the Dalles-Umatilla syncline which is a major regional geologic structure produced during the Cascadian Orogeny. The formations in the vicinity of the site are primarily volcanic in origin and consist of four basic groups. These deposits

from the youngest to the oldest are: (1) Holocene deposits, (2) Dalles formation, (3) Yakima basalt and Ellensburg Formation, and (4) the Yakima basalt and Columbia River group. The first two groups are encountered within the upper 150 feet of the surface and represent the major unsaturated zone sediments. The Holocene deposits consist of a series of loess, talus and alluvium to depths of about 50 feet. The Dalles formation underlies this group and includes deposits of volcanic ash, breccia, alluvial gravels, sands and silts.

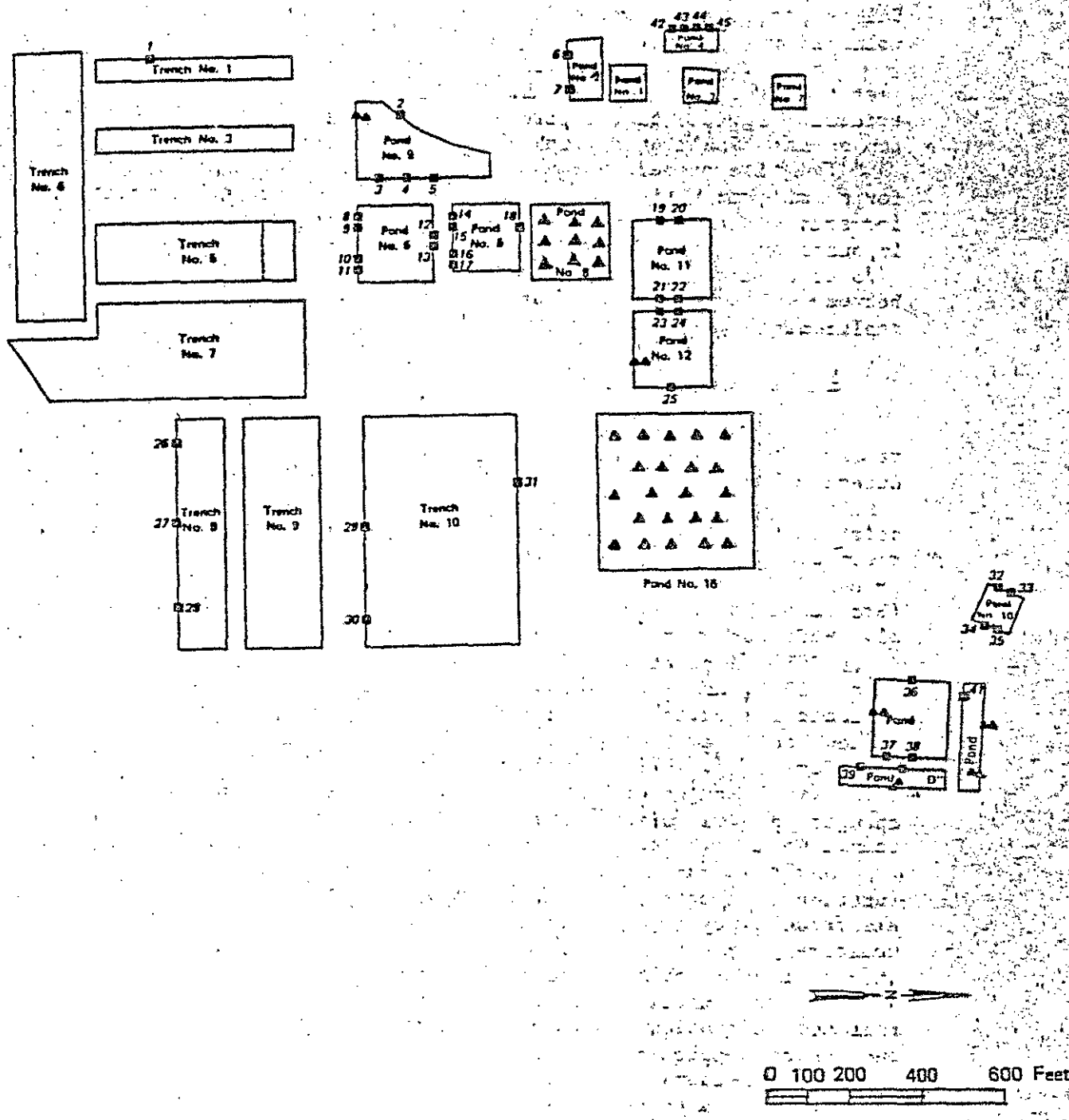
The only documented aquifer occurs at a depth in excess of 560 feet below the site and within the Yakima basalt. Preliminary evidence suggests that a perched water table condition occurs at the top of the basalt at a depth about 200 feet below the site.

The site presently consists of a series of 16 lined impoundments for solar evaporation and treatment of liquid wastes, eight trenches for solids disposal and a land treatment operation (Figure 1). The impoundments range in size from 0.25 to 4 acres and the trenches from 0.75 to 6 acres. Average pond depth is 7-9 feet; most trenches are between 40-50 feet deep. Future site plans will result in the replacement of several of the smaller impoundments with larger units.

Monitoring Systems

A variety of active and passive monitoring techniques were reviewed to assess their applicability for providing an early warning detection system. This review included the examination of such passive techniques as tensiometers (Long 1982; Savvides et al. 1977), moisture blocks (Williams 1980), capacitance sensors (Kuraz 1981), thermocouple psychrometers (Hoffman et al. 1972), electrothermal probes (Wechsler et al. 1965; Sophocleous 1978) neutron thermalization (Brakensiek et al. 1979; Holmes et al. 1959) soil salinity (Enfield et al. 1969; Yadav et al. 1979), electrical techniques (Nadler 1981; Van Hoorn 1980; Topp et al. 1982) and penetrometer instruments (O'Sullivan et al. 1982, Anderson et al. 1980). Pore water sampling approaches included extraction of soil cores, lysimeters (Morrison 1982), vacuum plates and tubes (Haines et al. 1982), membrane filter samplers (Shaffer et al. 1979) and absorbent methods (Tadros et al. 1976). This review suggested that an in situ device(s) which would rely upon changes in soil moisture content and which would also be able to sample would provide an optimum combination of instrument functions.

A monitoring network which relied upon a single unit which functioned as both a tensiometer/lysimeter and an in situ four electrode array appeared to be most suited at the site. This system would rely upon the tensiometer and geophysical array for detecting changes in soil moisture content. The tensiometer could then be evacuated to function as a lysimeter for leak verification via radioactive tracers introduced into the impoundment. While the geophysical approach was well documented and straightforward (Shea et al. 1961), a commercially available tensiometer/lysimeter was unavailable. A prototype was therefore constructed and field tested to assess the feasibility of such a unit.



LEGEND

Existing Ceramic Cup Lysimeter

Tensiometer/Lysimeter Units

Figure 1. SITE MAP

Tensiometer/Lysimeter

The prototype illustrated in Figure 2 was fabricated to evaluate the feasibility of using it in the capacity of a tensiometer/lysimeter. The dual purpose unit consisted of a seven inch long 7/8 inch diameter O.D. ceramic cup tensiometer with a one bar entry value. The cap was fitted with linear polyethelene tubing capable of withstanding pressures of 600 psi. All fittings were brass with an inner support tube, which provides a leakproof and high strength system for field applications. Linear polyethylene tubing was selected since it has a low gas diffusion rate. A 5/15 inch O.D. tubing was used for most installations, although 1/4 inch O.D., tubing was also tested.

A number of inner diameter tubing and lengths were tested to assess the influence of the inner diameter and length upon unit sensitivity to moisture changes when used as a tensiometer. Distances with lengths of tubing up to 510 feet long between the unit and pressure monitoring instrumentation were found to maintain a high sensitivity to changes in moisture content (tensiometer). Pore water samples could also be collected at these distances when the unit was converted to function as a lysimeter.

Two types of tensiometer instrumentation were field tested and included an automatic Scanivalve system (Figure 3) and a Bourdon gauge. The Scanivalve arrangement consisted of a 24-point fluid switch wafer, a pressure transducer and digitial readout and automatic pressure monitoring system in the form of a 24-port water switch and pressure transducer (Williams 1978; Anderson and Burt 1977).

Twenty-two tensiometers/lysimeters were routed to the Scanivalve. The system continuously monitors one of the 22 tensiometer/lysimeters and the timed 24 port wafer switch automatically changes depending upon which unit is being recorded. Matric potentials from all 22 tensiometers can be recorded within one hour. The entire Scanivalve system is powered by 12-volt batteries enclosed in a separate housing.

The Bourdon gauge was used in cases where distances between units did not warrant a centralized recording system. Surface protective housing consists of a 1.5 feet diameter 6 feet long steel casing in which the Bourdon gauge and valves were attached.

Geophysical Array

In cases where the monitoring system could be installed prior to liner installation, an in situ geophysical array was installed. The primary emphasis of the array is for shallow leak detection and horizontal moisture content profiling.

Geophysical arrays were installed for two impoundments (8 and 16). Impoundment pond 8, which is 200 x 200 feet, has a 12 probe array installed in the form of 8 equally spaced probes surrounded by 4 central probes. A Schlumberger array is therefore available which can be used in several directions. Additional probes can be installed outside the impoundment boundaries if deeper profiling is considered necessary. The geophysical array under Pond 16 (400 x 400 feet)

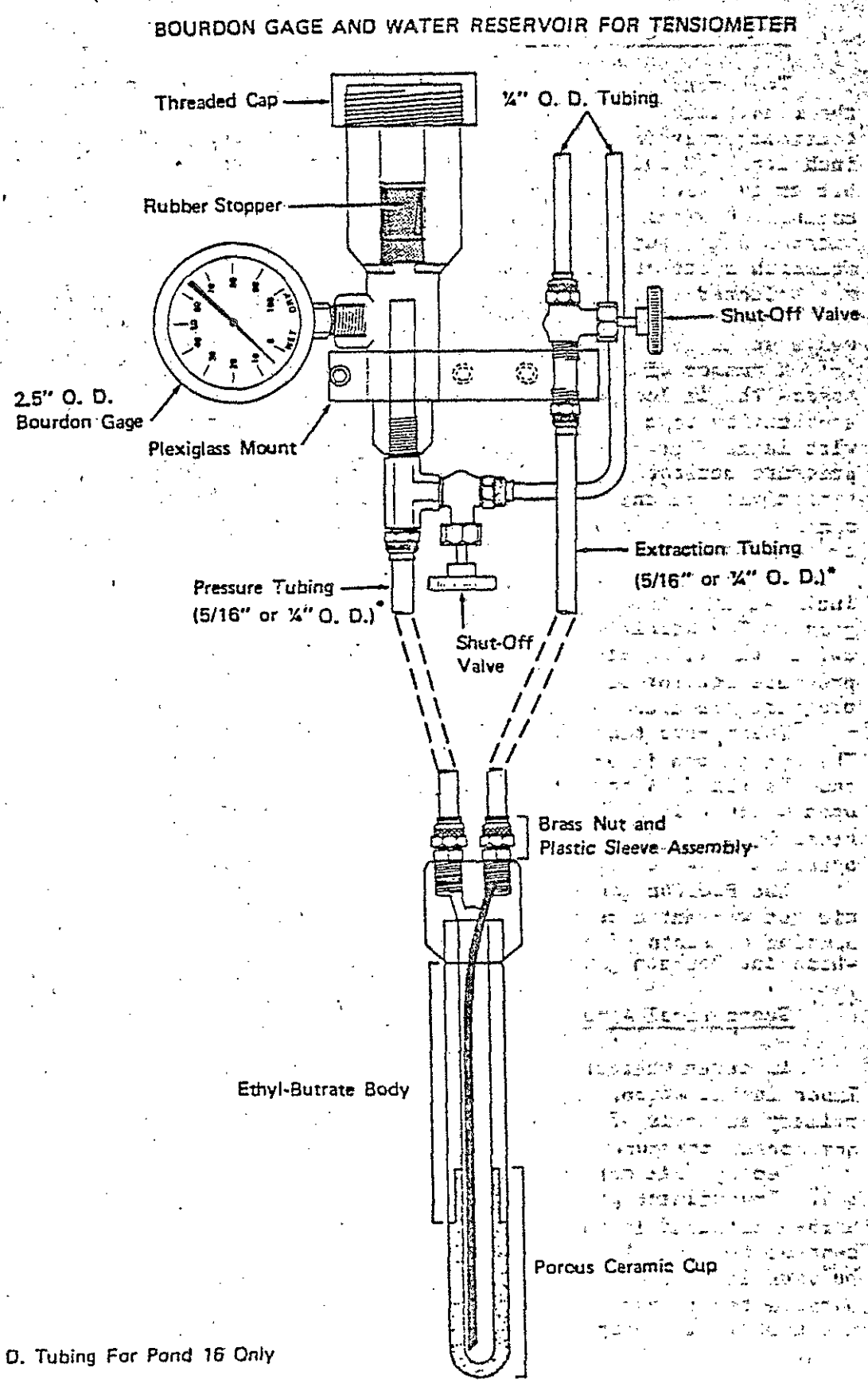


Figure 2: BOURDON GAGE AND WATER RESERVOIR FOR TENSIOMETER/LYSIMETER UNITS

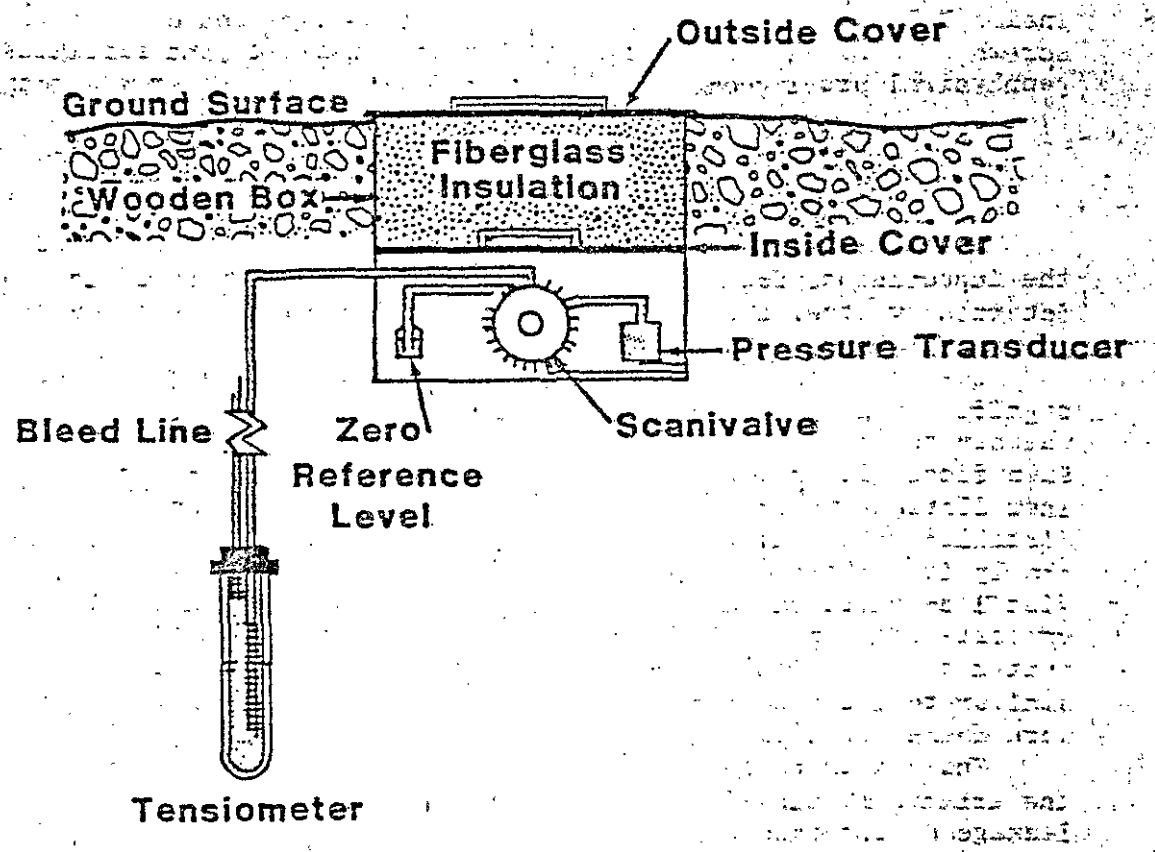


Figure 3. PROPOSED SCANIVALVE INSTRUMENTATION FOR POND 16

consists of 25 equally spaced probes (5 x 5 feet) with an additional 4 probes around the center (Figure 4). This configuration allows a variety of profiling including Schlumberger, Wenner and Dipole-Dipole arrays. Since the actual resistivity is unimportant for leak detection purposes, apparent resistivity contour maps can be prepared and compared over time. The geophysical array provides complete coverage under the impoundment although a leak must be large enough to change the resistance between potential probes.

The geophysical probes consist of a 1 foot square by 1/32 inch lead sheet connected to 3000 volt, 12 gauge wire which is routed inside PVC tubing to a central panel. Wires were connected to brass screws on a Lexan plastic board which is a model of the impoundment's geophysical probe geometry. This facilitates the proper connection for various profiling arrays.

Conversion of Existing Lysimeter Network

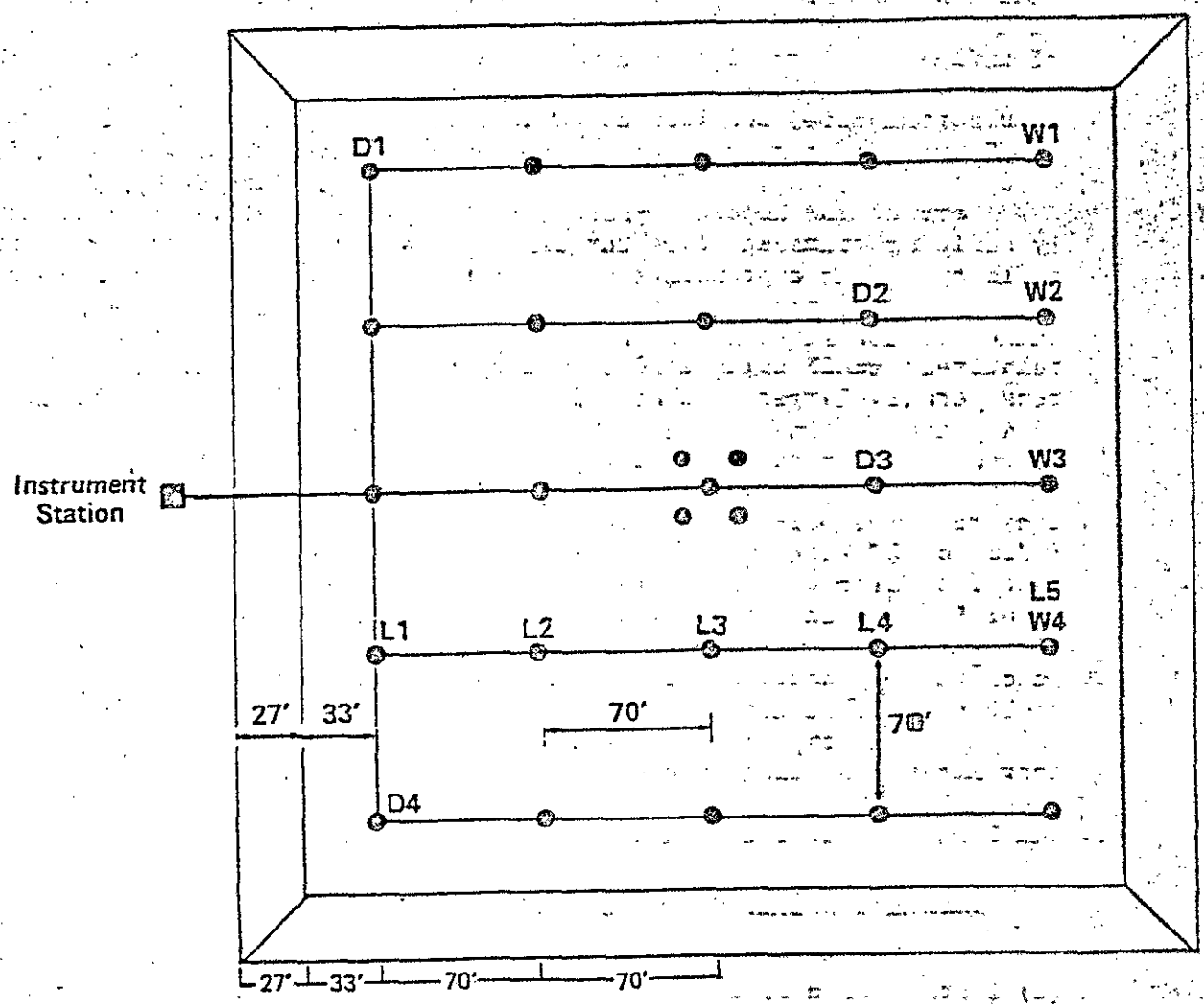
An existing network of ceramic cup lysimeters was in place under the impoundments and trenches. Field tests were performed to determine whether these units could also be used in the capacity of a tensiometer/lysimeter.

The existing lysimeters were tested to determine (1) if any significant leaks existed in the unit and tubing, and (2) to determine whether the unit could be used as a tensiometer. Lysimeters in which significant leaks were observed were abandoned. Lysimeter installations which indicated a close system were flushed with distilled water until no air bubbles were observed in the discharge of the lysimeter pressure or vacuum tubes. The system was filled with distilled water and one end connected to a Bourdon gauge. The opposite end tube was stoppered. A 24-hour period was allowed for the system to reach equilibrium. Units whose matric potential values were similar to background tensiometer values in similar soils and depths were deemed functional as lysimeters.

While this testing demonstrated the viability of the approach, the effects of slow leakage via diffusion through the tubing or leakage at the connection areas could not be delineated over the 24-hour testing period. The operation of the system over time may therefore require that the units be replaced or frequently deaired. A total of 23 existing lysimeters were converted into tensiometer/lysimeter units along with the installation of shut off valves, Bourdon gauges and surface housing.

Tensiometer/Lysimeter Unit Density Under Impoundments

The horizontal and vertical spacing of the tensiometer/lysimeters were important for several reasons. Complimenting the installed ceramic cup lysimeters required that the new units be placed so as to form a reliable detection grid. The vertical spacing was also critical since the installation of the units in fine-textured soils would optimize unit performance. The radius of influence of the units as a lysimeter and tensiometer was required in order to determine either point or line source leaks.



Example of a Wenner Electrode Array Probes W1, W2, W3, W4

Example of a Lee-Partitioning Electrode Array: Probes D1. D2. D3, D4

Example of a Dipole-Dipole Electrode Array: Probes L1, L2, L3, L4, L5,

Figure 4. GEOPHYSICAL PROBE LOCATION FOR POND 16

The radius of influence of a lysimeter has been primarily estimated for agricultural infiltration purposes. Laboratory experiments and numerical modeling of the radial flow equation and unsaturated hydraulic conductivity function lead to solutions of the hydraulic head distribution around a lysimeter. Finite difference models are available which calculate head distributions over time, which indicate that after 20 days of continuous extraction, the radius of influence of the lysimeter is about 4 inches for a loess soil (van der Ploeg and Beese 1977). The radius of influence of a line source (horizontal pipe) has been calculated at about 9 inches for clay loam and 8 inches for sandy loam (Thomas et al. 1976). Line source radius of influence should be similar to that of a point source.

Warrick and Amoozegar-Fard (1977) employed a different approach by defining transient flow through a ceramic disc for time approaching infinity, which approximates steady-state conditions. This approach results in the radius of influence for the 7/8 inch OD lysimeters of 4 inches in coarse soils to about 18 inches for the finest soils. This relatively small calculated diameter of influence is actually considerably larger when considering the effect of lateral spreading of a point or line source leak. Infiltration from a buried point source to a buried sink (tensiometer) was estimated for steady-state conditions (Warrick et al. 1980). A 30 cbar soil matric potential line from the point or disc source was shown to extend laterally in a radius of 10 feet at a depth of 11.5 feet. Other researchers report that flow from a point source in the vadose zone is likely to have lateral spreading approximately equal to 1 to 3 times the lateral infiltration (Raats 1971; Ben-Asher et al. 1978). A unit 10 feet below the impoundment will most likely detect a leak from a distance of 10 to 30 feet laterally.

A second type of leak resulting from a lining tear can be approximated by line source infiltration. Lateral spreading is also approximated at 1 to 3 times the vertical distance traveled (Zackman and Thomas 1973; Gilley and Allred 1974; Warrick and Lomen 1977).

Monitoring System Installation

Two types of installation procedures were required for the site: (1) installation of additional tensiometer/lysimeters to compliment ceramic cup lysimeters at existing impoundments, and (2) installations of tensiometer/lysimeters and geophysical arrays in new impoundments.

Additional tensiometer/lysimeter units will soon be installed via slant drilling techniques for existing impoundments. An Aardvark 125 drill rig with Odex casing was used for this purpose. A 200-mesh silica flour slurry was used for backfill to optimize the pore water sampling radius. Tubing from the device was routed to the surface where it was attached to a Bourdon gauge and associated housing.

Traditional vertical drilling techniques were employed for tensiometer/lysimeter placement for the new and relined impoundments. Unit tubing was routed to the sides of the pond in PVC which was placed in a 3-feet deep trench. All units were filled with a tensiometer fluid which consisted of a mixture of 48 percent ethylene

glycol, 2 percent surfactant and 50 percent deaired, deionized water. Ethylene glycol was selected to both inhibit fungal growth and to eliminate solution freezing in the line. The use of the ethylene glycol in the tensiometer should also enhance the movement of any waste constituents into the tensiometer and decrease the osmotic flow of tensiometer fluid outward, thereby making it a more effective detector.

In order to calibrate the Scanivalve/Bourdon gauge measurements to actual in-site soil matric values, several corrections were required. The gauge readings were converted into the actual soil matric potential by the following equation which corrects for the depth of porous cup, altitude and capillary forces in the tubes:

Matric Soil Potential = P(gauge value) + (depth) (2.99 cbar/ft) + 3.23 cbar.

The P gauge and soil matric potential are negative numbers since they represent pressures less than atmospheric pressure. A gauge rading of -62 cbar at 20 feet, for example, corresponds to a soil matric potential of 0 cbar (saturated soil). A gauge reading of -100 cbar corresponds to a soil matric potential of -38 cbar only for a tensiometer at a depth of 20 feet. The theoretical maximum depth that a surface gauge mounted tensiometer can operate is 33 feet based upon empirical calculations, although field testing suggests that 25 feet should be considered maximum.

Summary and Conclusions

The vadose zone monitoring system at the Chem-Security Systems Inc., Arlington Hazardous Waste Facility integrates lysimeters, dual purpose tensiometer/lysimeter units and geophysical arrays to provide an early warning leak detection and sampling system. Numerical analysis of the radius of influence of tensiometers and analysis of point and line source flow provided the basis for optimum tensiometer/lysimeter unit placement and density. Bench testing of a unit at a depth of 15 feet deep and with 510 feet of horizontal tubing between the tensiometer and instrumentation was successful in terms of tensiometer response and lysimeter sampling. Additional field monitoring and performance verification is necessary over the next few years to fully ascertain the effectiveness and longevity of the designed system.

References

Anderson, G., Oidgeon, J., Spencer, H., and Parks, R., 1980. A new hand-held recording penetrometer for soil studies. Journal of Soil Science. 31:279-296.

Anderson, H. G., and Burt, T. P., 1977, Automatic monitoring of soil moisture conditions in a hillslope spur and hallow. Journal of Hydrology, v. 33, p. 27-36.

Ban-Asher, J., Lomen, D. O., and Warrick, A. W., 1978, Linear and non-linear models of infiltration from a point source. Journal of Soil Science Society of America, v. 42, p. 3-6.

Brakensiek, D., Osborn, H., and Rawls, W., 1979. Field manual for research in agricultural hydrology. Sciences and Education Administration. U.S. Department of Agriculture. Agricultural Handbook. 224:505-548.

Enfield C., and Evans, D., 1969. Conductivity instrumentation for in-site measurement of soil salinity. Soil Science of America Proceedings. 33:787-789.

Gilley, J. R., and Allred, E. R., 1974. Infiltration and root extraction from subsurface irrigation laterals: Transactions, ASAE, v. 17, No. 5, p. 927-933.

Haines, B., Waide, J., and Todd, R., 1982. Soil solution nutrient concentrations sampled with tension and zero tension lysimeters: reports of discrepancies. Soil Science Society of America Journal. 46:658-661.

Hoffman, G., Oster, J., and Merrill, S., 1972. Automated measurement of water potential and its components using thermocouple psychrometers. R. Brown and B. Van Haveren (Eds). Psychrometry in Water Relations Research Utah Agricultural Experiment Station, Utah State University, Logan, Utah. p. 123-130.

Holmes, J., and Jenkinson, A., 1959. Techniques for using the neutron moisture meter. Journal of Agricultural Engineering Research. 4:100-109.

Kuray, V., 1981. Testing of a field dielectric soil moisture meter. ASTM Geotechnical Testing Journal. 4:111-116

Long, F., 1982. A new solid-state device for reading tensiometers. Soil Science. 133:131-132.

Morrison, R., 1983. Ground water monitoring technology. Procedures, equipment, and applications. Timco Manufacturing Co., Prairie du Sac, Wisconsin. p. 113.

Nadler, A., 1981. Field application of the four-electrode techniques for determining soil solution conductivity. Soil Science Society of America Journal. 45:30-34.

O'Sullivan, M., Henshall, Anderson, G., and Dickson, J., 1982. The use of a solid-state data collector interfaced to a "bush" digital, recording soil penetrometer. Scottish Institute of Agricultural Engineering. Department Note Sin/348 p. 12.

Raats, P. A. C., 1971. Steady infiltration from point sources cavities, and basins. Soil Science of America, Proceedings, v. 35, p. 689-694.

Savvides, L., Ayers, R., and Ashkar, 1977. A modified mercury tensiometer. Soil Science of America Journal. 41:660-661.

Shaffer, K., Fritton, D., and Baker, D., 1979. Drainage water sampling in a wet, dual-pore soil system. Journal of Environmental Quality. 8:241-246.

Shea, R., and Luthim, J., 1961. An investigation of the use of the four-electrode probe for measuring soil salinity in situ. Soil Science. 92:331-339.

Sophocleous, M., 1978. Analysis of heat and water transport in unsaturated/saturated porous media. Ph.D. Thesis. University of Alberta. Edmonton, Alberta, Canada. p. 271.

Tadros, V., and McGarity, J., 1976. A method for collecting soil percolate and soil solution in the field. Plant and Soil. 44:655-667.

Thomas, A., Duke, H., Zackman, D., and Kruse, G., 1976. Comparisons of calculated and measured capillary potentials for line sources. Journal of the Soil Science Society of America. 40:10-14.

Topp, G., Davis, J., and Annan, A., 1982. Electromagnetic determination of soil water using TDR:II. Evaluation of installation and configuration of parallel transmission lines. Soil Science Society of America Journal. 46:678-684.

van der Ploeg, R. R., and Beese, F., 1977. Model calculations for the extraction of soil water by ceramic discs and plates: Journal of the Soil Science Society of America, v. 41, p. 466-470.

van Hoorn, J., 1980. The calibration of four-electrode soil conductivity measurements for determining soil salinity. D. Bhumbla and J. Yadav (Eds). International Symposium on Salt Affect Soils. Karnal, India. p. 148-156.

Warrick, A. W., and Lomen, D., 1977. Flow from a line source above a shallow water table. Journal of the Soil Science Society of America. 41:849-852.

Warrick, A. W., and Amoozegar-Fard, A., 1977. Soil water regimes near porous cup water samplers: Water Resources Research, v. 13, No. 1, p. 203-207.

Warrick, A., Lomen, D., and Amoozegar-Fard, A., 1980. Linearized moisture flow with root extraction for three dimensional, steady conditions: Journal of the Soil Science Society of America, v. 44, p. 911-914.

Welchsler, A., Glaser, P., and McConnell, R., 1965. Methods of laboratory and field measurements of thermal conductivity of soils. Cold Regions Research and Engineering Laboratory. Hanover, New Hampshire. Special Report 82, p. 31.

Williams, T., 1978. An automatic scanning and recording tensiometer system: Journal of Hydrology 39:175-183.

Williams, T., 1980. An automatic electrical resistance soil-moisture measuring system. Journal of Hydrology. 46-385-390.

Yadav, B., Rao, N., Raliwal, K., and Sarma P., 1979. Comparison of different methods for measuring soil salinity under field conditions. Soil Science 127:335-339.

Zackman, D., and Thomas, A., 1973. A mathematic investigation of steady infiltration from line sources: Soil Science Society of America, Proceedings, v. 37, p. 495-500.

Biographical Sketches

Kenneth A. Lepic is Manager of Regulatory Affairs for Chem-Security Systems Inc. (CSSI), which is a major hazardous waste treatment/disposal firm serving the Pacific Northwest, Canada and Alaska. In this capacity, Lepic is responsible for all environmental safeguards which includes permitting and the monitoring and design of waste treatment/disposal systems. Prior to joining CSSI, Lepic worked for the EPA for eight years where he received EPA's Bronze Medal for commendable service for a major environmental problem regarding lead discharge into the environment. Before the EPA, Lepic managed a chemical processing facility which handled radioactive and hazardous waste. Lepic has degrees in chemistry and chemical engineering from the University of Washington and is a Registered Professional Engineer in the State of Washington.

Robert D. Morrison is a Senior Project Hydrogeologist with Woodward-Clyde Consultants. In this capacity Morrison is involved in projects primarily related to the transport and contamination of ground water resources. Vadose zone monitoring is an area of special interest especially in terms of instrumentation. Morrison has designed and installed vadose zone systems for over 30 individual sites throughout the United States with some still operational after 12 years. Morrison has degrees in geology, hydrology and environmental engineering.

John A. Baker is Manager of Environmental Monitoring for Waste Management Inc. (WMI). Baker is involved in new site development, engineering, regulatory compliance and the closure and post-closure activities for the 65 sanitary and chemical waste landfills operated by WMI in the United States. All corporate compliance and permitting activities related to the US-EPA Hazardous Waste Regulations developed under RCRA are managed by Baker. He is on the Board of Directors of the Illinois Association of Environmental Professionals and a member of the Water Pollution Control Federation. Baker has degrees in biology and environmental engineering from the University of Illinois at Urbana.

57. Nacht, S.J. "Ground Water Monitoring System Considerations," Ground Water Monitoring Review, Spring 1983, pp. 33-39

2645
2646
2647

GROUND-WATER MONITORING SYSTEM CONSIDERATIONS

Discusses factors that should be considered when designing a system for the collection and analysis of water quality data.

by Steve J. Nacht

Introduction

This article discusses a number of generic factors that should be considered in the design of a ground-water monitoring program for the collection and analysis of water quality data. It serves to bring together a number of factors common to most ground-water monitoring programs, such as the definition of objectives, number of samplers required, selection of the analytical laboratory, etc., which, if ignored, can lead to the improper interpretation of data.

In the past few years, considerable attention has been given to the monitoring of ground-water quality. This is the result of legal requirements, the availability of analytical equipment which can detect very low levels of contaminants and the realization that aquifers can be easily contaminated. Ground-water monitoring is required under several federal laws, including the Resource Conservation and Recovery Act (RCRA). RCRA requires ground-water monitoring for many facilities as part of their permit to operate. Under the Comprehensive Environmental Response Compensation and Liability Act of 1980 (Superfund), a hazardous waste generator is held liable for waste produced. This liability continues even when the material has been properly transferred to a transporter or to a treatment, storage or disposal site. In the event leachate is generated and moves to the ground water, he remains liable for these wastes even though the generator may have followed the letter and spirit of the law.

Monitoring organic compounds has been made possible by recent refinements in analytical chemistry in detecting organic compounds in the parts-per-billion range. Within the past few years, ground water in a number of industrialized areas of the country has been identified as contaminated. Even low levels of certain contaminants may result in health problems for persons utilizing water from contaminated aquifers, as some of the contaminants found may be carcinogenic or lack a minimum dosage under which no adverse health effect occurs. The U.S. EPA is devising a ground-water strategy to protect ground water from pollution sources.

The developer of a ground-water monitoring program for regulatory, health or environmental purposes has several options to consider. When properly devised, the monitoring program should be cost-effective and capable of detecting contaminants suspected of occurring and defining the extent of contaminant plumes.

Monitoring system factors outlined here are generalizations concerning the considerations that should be given to a monitoring program for either regulated or unregulated activities. Although some state and federal regulations may specify monitoring requirements, a technically sound monitoring program should be tailored to the site under study. For example, while RCRA requires that three wells be installed downgradient from monitored hazardous waste sites, additional wells may be necessary to properly identify complex ground-water conditions. Many site-specific factors must be considered in a monitoring program to adequately define site conditions. Due to the wide range of conditions encountered in nature, only a few recommendations can be provided in this article.

Figure 1 is a flow chart depicting a typical monitoring program. Of the activities that comprise design and implementation of a ground-water monitoring program, emphasis is placed on defining monitoring objectives, the constituents which should be considered for monitoring, criteria for selecting the analytical laboratory and other considerations on which a monitoring team must make decisions in order to collect representative data once well design, drilling methods and aspects of well development (Figure 1) have been determined. Scalf et al. (1981), Campbell and Lehr (1973), and Johnson Division (1966) provide through discussions on well drilling and related topics and should be referred to prior to developing the portions of the monitoring program identified here. Figure 1 should be viewed only as a general method for conducting a monitoring program. The order of activities may change due to objectives, site conditions, etc. In addition, research programs, political conditions and client needs can change or reorder the need for some activities.

Table 1 summarizes the cultural and field-related factors which can be used to determine which monitoring components should be incor-

clearly determine what the monitoring program is to accomplish. Typical objectives might be, but are not limited to:

- Meeting regulatory requirements
- Determining site baseline ground-water quality and hydrologic conditions
- Determining why ground-water quality problems are occurring in the area
- Determining the effect of a facility discharging to the ground water, a special situation being as an early warning system to determine when pollution has begun or has changed in character or location
- Determining the effect of a particular activity on the environment
- Determining regional ground-water trends and background ground-water quality.

It is important to realize that objectives most likely will be closely related to environmental, political or socioeconomic conditions, history of the problem and hydrologic conditions at the site and that several of these objectives may be applicable to the solution of a defined problem. Objectives may also change with time due to environmental, regulatory, political or economic factors, a change in site ownership or in project management. Whenever objectives are chosen, they should be clearly defined and recorded in writing to document monitoring rationale for future management. This should also be done when the objectives or the program are changed. Documentation should include program objectives, parameters sampled, number of wells drilled, construction details etc., as decisions are made. This will ensure that the initial rationale is not lost and that the monitoring program is not conducted only for data collection which may have little relationship to objectives or future site conditions.

The definition of ground-water objectives is a major element that is undertaken during the initial phases of the program. To be successful, a monitoring team must keep the agreed-upon objectives in mind throughout the full course of the project, which may cover a period of many years. A critical review of objectives should be scheduled after data become available for analysis to determine if monitoring objectives are being met. A similar review should be conducted whenever objectives are changed. The purposes of the review are to keep the monitoring effort in line with objectives and to reduce costs. This review process should be conducted by the ground-water monitoring team, management and the client and may also include input from regulatory agencies. It is not unusual to refine the monitoring program once information on the site becomes available by adding or deleting wells and chemical parameters, or by changing the objectives of the monitoring program.

Table 1
Matrix of Ground-Water Monitoring Components to Factors to Consider in Designing a Monitoring Program

Included are some of the major factors affecting monitoring program design. The ▲ indicates that a factor may have applicability in monitoring, although the degree of applicability may vary. Not all factors or components are shown due to the diversity in ground-water conditions nationwide.

Factor \ Monitoring Component	When to Monitor	Pollutants Monitored	Number of Wells Over Aquifer Thickness	Number of Wells Areally	Vadose Zone Monitoring	Sampling Protocol	Sampling Frequency	Well Diameter	Type of Sampler/Pump and Composition	Use of Models	Safety Considerations	Chain of Custody
Aquifer Is a Drinking Water or Irrigation Source	▲	▲	▲	▲	▲		▲			▲		▲
Facility Handles Hazardous Materials	▲	▲	▲	▲	▲		▲			▲	▲	▲
Heavily Used Aquifer	▲	▲	▲	▲	▲		▲			▲		▲
Legal Proceedings	▲	▲	▲	▲	▲		▲			▲	▲	▲
Required by Regulations	▲	▲	▲	▲	▲		▲	▲	▲	▲	▲	▲
Adequate Sample Volume					▲			▲	▲			
Attenuation of Pollutants		▲	▲	▲	▲		▲		▲	▲		
Background Concentrations		▲	▲	▲	▲		▲		▲			
Casing/Sampler Composition		▲			▲			▲	▲			
Complex Geology		▲	▲	▲	▲		▲			▲		
Depth Sample Taken in Well		▲	▲	▲				▲	▲			
Ground-Water Velocity		▲	▲	▲	▲		▲		▲			
Highly Variable Conditions		▲	▲	▲	▲		▲			▲		
Permeability		▲	▲	▲	▲		▲	▲	▲			
Plume Density		▲	▲	▲			▲			▲		
Rapid Water Level Changes	▲	▲	▲	▲	▲		▲		▲	▲		
Rapid Water Chemistry Changes	▲	▲	▲	▲	▲		▲		▲	▲		
Sample Representativeness		▲	▲	▲	▲		▲	▲	▲			▲
Vadose Zone Thickness			▲	▲	▲							

Which Constituents Require Monitoring?

Chemical constituents to be monitored are dependent on the type of materials handled by the facility, background water-quality considerations, health and environmental regulatory requirements, aquifer uses and site geology (Table 1). Facilities handling highly hazardous materials or materials that are a nuisance (conventional pollutants such as iron or total dissolved solids)

should be considered for inclusion in the monitoring program. This requires knowledge of the facility's effluent. For a manufacturing plant, this data may be available from the NPDES or RCRA permit. For facilities lacking this data, it might be necessary to sample the effluent or runoff over time and analyze for suspected constituents based on process chemistry or compounds typical of those being released by the industry.

Another approach is to use the phased approach developed by EPA for analysis of complex energy facility waste streams (Dorsey et al. 1977; Harris et al. 1979). This approach may be useful for complex waste streams or when a thorough analysis of waste constituents is desired. It has three levels of effort. The first level (Level 1) provides preliminary analytical data that produces results with an accuracy and precision of ±2 or 3, which is sufficient to determine the presence or absence of a material or category of material. While not providing data on specific materials in all situations, a Level 1 analysis will provide data for initial priority ranking of what should be sampled. Level 2 identifies, quantifies and confirms specific components identified in Level 1 and provides statistically representative data as well as confirmation of Level 1 information. A Level 3 assessment uses sampling and analytical methods with precision and accuracy sufficient to permit quantification of specific pollutants identified under previous levels.

Background water-quality should also be determined. High levels of naturally occurring constituents may overshadow levels of contaminants resulting from human activity. For example, in many areas in the West, ground water has high levels of natural fluoride, lead or other trace metals which may be above drinking water standards or other use limitations. Knowledge of background concentrations will help to define changes taking place in the system.

While an enormous number of compounds can be suggested for monitoring, the following general groups of parameters, some of which overlap, will most likely make up most of the parameters sampled:

- Drinking water quality parameters
- Constituents required under a surface-water discharge permit (NPDES)
- Constituents for ground-water monitoring programs as required by RCRA
- Health effects constituents for unregulated drinking water contaminants (Suggested No Adverse Response Levels [SNARLS])
- Constituents identified by state and local requirements
- Constituents identified from a manufacturing plant's waste streams which may be toxic or cause a severe nuisance
- Constituents of local significance, such as naturally occurring radioactive isotopes in Florida's phosphate region
- Pollutants known to exist in the area, such as trichloroethylene (TCE) founding in a neighboring well
- Parameters which may help explain the ground-water chemistry, such as dissolved gases, pH etc.

The number of parameters in a sampling program may vary over time. Therefore, the large number of parameters initially analyzed in many programs may be reduced once site conditions are fully understood. When properly conducted, the high initial sampling costs for a long-term program can frequently be reduced to an economical program which provides the most information for the funds available.

Which Analytical Laboratory?

The question refers not to finding a laboratory, but to determining which ones will produce results that are accurate and precise and can meet project objectives. Excluding cost and locality, a few questions to ask when looking for a laboratory are:

- Does the laboratory have a quality control/quality assurance program? These programs are designed to minimize systematic and random variables in the measurement and data collection process, provide prompt detection and correction of conditions leading to production of poor-quality data, collect and supply information to describe data quality and evaluate overall adequacy of the data gathering process as it affects data quality. Two good information sources to begin with are The Handbook for Analytical Quality Control for Water and Wastewater Laboratories (U.S. EPA 1979) and NEIC Policies and Procedures Manual (U.S. EPA 1978).
- Is the quality control/quality assurance program in writing? This document should be up-to-date and available to all analysts for reference. The program should also provide a feedback mechanism to inform the analyst of problems.
- Are unknown, blanks and spiked samples frequently used? These tools are helpful in early detection of analytical problems.
- Is the lab clean when you visit it? Equipment that is covered at the end of use and kept clean by the analyst generally has a better history of operation than unkept equipment. Clean labs and equipment promote a good environment to conduct analysis and also reduce sample contamination.
- Does the lab participate in round robin or other testing programs? This is a good tool to determine how a lab compares to other labs under similar conditions. For instance, the state of Ohio requires that some self-monitoring data obtained by regulated entities be analyzed at certified laboratories.
- Is the lab certified by the state EPA (or equivalent regulatory authority) for drinking water or other regulated activities? Certification provides some indication that the lab is capable of properly analyzing samples.
- Are analysts certified by state agencies and also provided ongoing training by the lab to refresh and expand their expertise? This provides some indication that management and analysts are concerned about discharging their duties in a professional manner.
- What are the levels of detection for the various parameters analyzed by the laboratory? Some labs may have unnecessarily high detection limits for the parameters of interest. Under these conditions, a laboratory may report that the constituent was not detected and provide incorrect information for decision making.
- Is turnaround rapid? Will you be able to get results in a reasonable time? To manage this problem, large labs are now using data processing systems that interface with major analytical equipment, reducing errors and turnaround time.
- Are sample splitting and preparation areas removed from analytical areas to reduce contamination? Also, are areas and equipment dedicated for trace analysis of materials? These problems are becoming a major concern in the analysis of trace levels of materials to reduce contamination from dust and other minor contaminants. As equipment becomes more sensitive and the number of samples increases, clean

rooms are also becoming the norm.

• Can confidentiality be provided regarding laboratory results, especially if a computer is used to store data and write laboratory reports? Access to the computer by laboratory personnel should be through a unique code that ensures that data will be kept confidential.

These questions should provide an indication of what to look for in an analytical laboratory. Smaller labs may not be capable of providing all of the above, but may still produce very good results. If no other criteria are used during your visit to the lab, the observation of pride in the analyst's work and desire to do a good job are signs that the lab's management and personnel will most likely meet your needs.

Should One Well or Clusters Be Used?

Location of a plume of contaminated water can be a hit-or-miss proposition, due to the density of the plume with respect to ground water, variations in permeability, heterogeneity of aquifer materials and other aquifer conditions. While odor may be used to detect some compounds, this simple test to detect pollutants may not be helpful when low levels of pollutants are involved, which may be further diluted in concentration if the well is open throughout the full aquifer thickness. Detection of trace qualities of compounds in the parts-per-billion range can be subject to sample contamination and sample noise, indicating that aquifer contamination may or may not exist. Under these conditions, consideration should be given to installing clusters of wells at various depths to sample smaller vertical segments of the aquifer. Fenn et al. (1977) suggested the use of three cluster arrangements when contamination from a landfill is suspected:

• At the top and bottom of the aquifer

• Adding a third well to the above in the middle of the aquifer

• At preselected intervals (such as every 3m [10 ft]).

This technique can also be used if several aquifers underlie the site. If hazardous materials are suspected of occurring at the site, care should be taken not to spread contamination by installing clusters of wells (or piezometers) in a single borehole that will interconnect the aquifers. If clusters are used in this situation, all wells in a cluster should be dedicated to a specific aquifer.

Several factors which may affect the number of wells necessary include pollutant attenuation (if known), background concentrations for the constituents under study and other hydrologic parameters which will influence contaminant movement. A number of these factors are identified in Table 1.

Under certain conditions where the aquifer is thin (i.e., on the order of several meters), the geology simple, the density of the plume about equal to water and the velocities low, one well open over the entire thickness may be used to detect contaminants.

Although installation of wells is expensive, the analysis of trace organic compounds (for example the 129 priority pollutants—mostly organics), can easily cost $1,000 or more per sample. By specifying clusters, it may be possible to reduce or at least not greatly increase sampling and analytical costs while allowing for a more representative sampling over the aquifer's thickness and increasing chances for plume detection. Still, contaminants may not be detected.

Number of Wells Necessary to Determine Areal Extent of Pollution

Considerations are similar to those in the previous section. As a plume cannot be readily observed without wells or other devices, some exploratory wells may need to be installed to provide preliminary information prior to a commitment for a full monitoring program. In many instances, conductivity, surface resistivity or temperature surveys can be used to define a plume, as plumes are usually more conductive or may be warmer than native ground water. When pollution is significant, all three methods can usually produce an obvious demarcation. Knowledge of site soils and geology, specifically composition and variability, relative permeability and geologic structures, are needed to determine general plume geometry.

As is the situation with most aspects of ground-water monitoring, professional experience is required to determine the appropriate number of sampling points. An absolute minimum of three wells or piezometers are required to determine the slope of the water table or piezometric surface, which can be helpful in determining monitoring well configuration. Most situations will require many more wells or piezometers to define hydrogeologic site conditions or the three-dimensional form of a plume. However, the expense of this large number of wells and piezometers is often prohibitive for owners of small landfills and other facilities, making site selection of the few wells and piezometers used even more important.

When Should Models Be Used to Predict Aquifer Hydraulics or Plume Movement?

There is a definite place for use of sophisticated computer models in a ground-water monitoring study. When used properly, models can assist in the analysis of data (Figure 1) and provide management with information or decision making. Models are useful where geology is very complex or where numerous waste sources or complex pumping patterns exist (Table 1). Another situation in which models may be useful is in the evaluation of aquifers in which water withdrawals are significant and information on the effect of additional pumping or input of pollutants to the aquifer may be critical, and in which the prediction of ground-water conditions at some point in the future is desired.

For example, location of a waste disposal site in fractured or in highly heterogeneous glaciated terrains poses problems to the monitoring team, which must predict the direction of travel and areal extent of a leachate plume. In fractured-rock terrain, lack of information on the location of fractures complicates prediction of the flow path of contaminated ground water. Models capable of handling this situation are not yet able to adequately solve this problem. However, there are models available which are capable of providing some insight into the transport of solutes in the subsurface. These can be used, with some modifications, to predict flow in fractured media.

Models applied in areas of complex geology, such as in highly heterogeneous glacial terrain, are also useful. Here, materials and hydrologic characteristics can also be expected to vary rapidly both laterally and vertically. As in fractured-rock terrain, the ground-water specialist must identify the areal and vertical geologic and hydrologic changes and understand the processes which created and are presently affecting site geology prior

to modeling or monitoring. Once this and applicable information is available, modeling can proceed.

In situations where aquifers are mined for water or heavily used, any additional withdrawal (or addition of leachate) can be modeled to determine its effects on the system. Models can be utilized to predict the effects of flow in an aquifer, complex pumping patterns, boundary conditions and other factors. Several other points on modeling are:

- Models need not be used unless a definite advantage results from their use over standard field and analytical procedures.
- If results are to be considered valid, all models will require significant input data to run and verify for the site under analysis. Models cannot be used in place of initial data collection and monitoring; rather they are an extension of monitoring.
- The field geologist or hydrologist and the modeler should become more familiar with the problems and objectives and their respective duties, to better complement one another.
- Only the skilled geologist or hydrologist, modeler and decision maker can decide what is correct for the problem under analysis. This implies that model outputs may be used in several ways to provide different results depending on the socioeconomic, political and other technical conditions as viewed by the technician and decision maker. Stating that the model provided the solution to a problem is only partially correct, as it furnishes the basis for a decision and management and operations activities.

Should the Vadose Zone Be Monitored?

Until recently, few ground-water specialists monitored the vadose zone, believing that monitoring of the saturated zone was sufficient for protection of ground-water resources. Unfortunately, aquifer rehabilitation methods in the saturated zone are expensive and may not be entirely suitable once large-scale contamination has occurred.

The objectives of a vadose zone monitoring system are to reduce saturated zone monitoring costs and to allow for the early recognition of problems while pollution is in the vadose zone. Under these conditions, ground-water rehabilitation may be less costly and the source of the problem may be easily corrected. Vacuum lysimeters can be used to collect water samples from beneath landfills, ponds or other discharging facilities where pollution can be expected to move from the vadose zone to the saturated zone. Monitoring is generally suitable where the vadose zone is thick, perhaps greater than 10m (33 ft). It is particularly applicable in arid regions where the vadose zone can be more than 100m (330 ft) thick. Use of vacuum lysimeters to sample the vadose zone will reduce but not eliminate the need for saturated zone monitoring.

Present technology has numerous problems which make routine use of lysimeters difficult. Problems include the small water sample volume available, the potential for clogging and the possibility of equipment failure. Also because only a small volume of soil surrounding the lysimeter is sampled (point sample), vacuum lysimeters must be installed through the waste or around the perimeter of the waste. This may provide a path through a damaged lysimeter or through the annular space for wastes to migrate and further pollute the vadose zone and/or pollution movement from beneath a facility.

Determining the number of sampling points required areally and with depth poses problems similar to those mentioned earlier for saturated zone monitoring. Factors to consider for vadose zone monitoring include the thickness and permeability of the vadose zone, the attenuation capacity of soils and geologic materials and the degree of hazard the leachate being sampled poses. Salk and Decicco (1978) developed recommendations based on vadose zone thickness which may be useful for initial determination of the number of sampling points required. Under conditions where permeability is high, attenuation is minimal and hazardous materials are involved, it should be prudent to use well clusters and increase the density of vacuum lysimeters installed surrounding and beneath the site.

Because of the many problems involved with vacuum lysimeters, site investigators may find soil samples helpful. These samples can provide information on contaminants sorbed onto soil particles that either are not released back to the water or released only when chemical or physical conditions change. In addition, other devices can be used to trace (but not sample) water flux through the vadose zone such as soil moisture blocks, pschrometers and tensiometers.

When Should Safety Precautions Be Taken?

All drillers and many hydrogeologists are familiar with the Occupational Safety and Health Administration (OSHA) and the rules promulgated to promote on-the-job safety. In working with hazardous waste, additional precautions may be required to protect the driller and the hydrogeologist. Safety devices may be required when hazardous materials are suspected. Precautions take the form of protective devices, clothing and hazardous materials management. These include breathing devices, self-contained suites, gloves, decontamination of drill rig, sampler and surrounding area and safe handling of samples including the preservation of unstable materials to reduce generation of heat or toxic gases and packaging following EPA and DOT rules, if shipped over public rights of way.

As the monitoring team may not know what to expect at a site, a review of production, waste analysis or disposal data and available chemical sampling and analysis data of water and soils will provide an idea of the situation's hazardousness. Using safety precautions it might be advantageous for monitoring personnel to secure a sample from leachate springs, contaminated wells or through installation of shallow well points. By analyzing for suspected hazardous materials before bringing in additional personnel and equipment, the associated high medical and decontamination costs might be reduced. Most importantly, costs to human health will be averted.

Concern over personnel safety should continue beyond the initial phases of the monitoring program. As identified in Figure 1, it is important that proper safety precautions are taken if hazardous materials are suspected or are found at the site. These precautions should be taken throughout the life of the monitoring program from the initial site visit, sampling phase and the handling of samples in the laboratory.

As this is a new area of concern, the hydrogeologist should contact a local industrial hygienist or public health specialist when a problem is suspected. A medical university or hospital can also be contacted for assistance. If a client has a staff

industrial hygienist, it is critical that a close working relationship be established prior to site work. The objective of this is to reduce human contamination from drilling and sampling operations through proper protective gear, hygiene and appropriate health screening tests.

Conclusions

This article should not be considered as the final statement on what is required for a monitoring program. It is an initial compilation of a number of the more significant generic factors which should be considered in the design and operation of a ground-water quality monitoring system. The great diversity of conditions nationwide may never allow for a comprehensive listing of factors. Each site must require a separate evaluation of the factors briefly discussed. Monitoring system decisions by the hydrogeologist on a particular site may vary dramatically from those outlined here. Additional effort is required in developing computer models that can more accurately predict ground-water flow and solute transport in complex terrain, health and safety education, determining the effect of pollutants on the ground-water system, contamination of unpolluted aquifers during drilling and other factors.

References

Campbell, M. and J. Lehr. 1973. Water well technology. McGraw-Hill. New York.

Dorsey, J., L. Johnson, R. Statnick and C. Lockmuller. 1977. Environmental assessment sampling and analysis: phased approach and techniques for Level 1. U.S. EPA. EPA-600/2-77-115. Research Triangle Park, North Carolina.

Fenn, D., E. Cocozza, J. Isbiter, O. Braids, B. Yare and P. Roux. 1977. Procedures manual for ground-water monitoring at solid waste disposal facilities. U.S. EPA. EPA/530/SW-611. Cincinnati, Ohio.

Harris, J., M. Hayes, P. Levins and D. Lindsay. 1973. EPA/IERL-RTP procedures manual for Level 2 sampling and analysis of organic materials. U.S. EPA. EPA-600/7-79-033. Research Triangle Park, North Carolina.

Johnson Division. 1966. Ground water and wells. St. Paul, Minnesota.

Nacht, S. 1983. Ground-water monitoring sampling protocol considerations. In press.

Salk, M. and S. DeCicco, editors. 1978. Environmental monitoring handbook for coal conversion facilities. Oak Ridge National Laboratory. ORNL-5319, special. Oak Ridge, Tennessee.

Scalf, M., J. McNabb, W. Dunlap, R. Cosby and J. Fryberger. 1981. Manual of ground-water sampling procedures. U.S. EPA. Robert Kerr Environmental Research Laboratory. Ada, Oklahoma.

U.S. EPA. 1978. NEIC policies and procedures manual. National Enforcement Investigations Center. EPA-330/9-78-001. Denver, Colorado.

U.S. EPA. 1979. Handbook for analytical quality control in water and wastewater laboratories. EPA-600/4-79-019. Cincinnati, Ohio.

Wickersham, G. and L. Canter. 1980. Summary of state ground-water laws. Report No. NCGWR 80-19. National Center for Ground Water Research. Ada, Oklahoma.

Biographical Sketch

Steve Nacht is a certified professional geologist with Lockheed Engineering and Management Services Co. He earned his M.S. in geology from Kent State University in Kent, Ohio in 1973 and an M.S. in environmental sciences in 1979 from Cleveland State University. Nacht developed ground-water monitoring guidelines from commerical scale coal gasification, liquefaction and oil shale facilities for the U.S. EPA, Las Vegas Laboratories and has been involved in assisting industry with hazardous waste management and ground-water monitoring system design and implementation to comply with the Resource Conservation and Recovery Act.

58. NACE Standard TM-01-69 (1976 revision), "Test Method, Laboratory Corrosion Testing of Metals for the Process Industries," 1969

technical practices committees

NATIONAL ASSOCIATION OF CORROSION ENGINEERS

NACE Standard TM-01-69
(1976 Revision)

Test Method

Laboratory Corrosion Testing of Metals for the Process Industries

This National Association of Corrosion Engineers Standard implies a consensus of those individual members substantially concerned with this document, its scope, and provisions. This Standard is intended to aid the manufacturer, the consumer, and the general public. Its acceptance does not in any respect preclude anyone, whether he has adopted the Standard or not, from manufacturing, marketing, purchasing, or using products, processes, or procedures not in conformance with this Standard. NACE Standards are subject to periodic review, and the user is cautioned to obtain the latest edition.

CAUTIONARY NOTICE: This NACE Standard may be revised or withdrawn at any time without prior notice. NACE requires that action be taken to reaffirm, revise, or withdraw this Standard no later than two years from the date of initial publication. Purchasers of NACE Standards may receive current information on all Standards by writing to NACE Publications Department, 1440 South Creek, Houston, Texas 77084.

Approved March, 1969
Revised 1972
Revised 1976
National Association of Corrosion Engineers
1440 South Creek Dr.
Houston, Texas 77084
Phone: (713) 492-0535

Copyright 1969, National Association of Corrosion Engineers

The National Association of Corrosion Engineers issues this Standard in conformity to the best current technology regarding the specific subject. This Standard represents minimum requirements and should in no way be interpreted as a restriction on the use of better procedures or materials. Neither is this Standard intended to apply in any and all cases relating to the subject. Numerous external factors may negate the usefulness of this Standard in specific instances.

This Standard may be used in whole or in part by any party without prejudice if recognition of the source is included.

The National Association of Corrosion Engineers assumes no responsibility for the interpretation or use of this Standard.

Nothing contained in this Standard of the National Association of Corrosion Engineers is to be construed as granting any right, by implication or otherwise, for manufacture, sale, or use in connection with any method, apparatus, or product covered by Letters Patent, nor as indemnifying or protecting anyone against liability for infringement of Letters Patent.

Foreword

Unit Committee T-5A ("Corrosion in Chemical Processes") of the National Association of Corrosion Engineers issues this Standard with a dual purpose.

The first purpose is to standardize, as much as possible, simple immersion corrosion studies. In this sense, this Standard is reasonable and effective without imposing inflexible requirements as to apparatus, conditions, or techniques. The actual conditions of test will be determined by the problem at hand and limited only by the ingenuity of the individual investigator.

The second purpose of this Standard is to present to the user a consensus on the best current technology in this field of laboratory corrosion testing. As such, this Standard enumerates and discusses the many factors which must be considered, controlled, and reported in order to aid in correlation or reproducibility of such studies.

The techniques described permit the investigator to reproduce to a considerable extent in the laboratory, through judicious experimental design, the process conditions which govern corrosion mechanisms. The tests are not to be construed as "accelerated" tests, which are generally unreliable. The methods described are also applicable to materials qualification tests for quality control. However, the latter require more rigid definition of apparatus, conditions, and technique.

The ultimate purpose is better correlation of results in the future and the reduction of conflicting reports through a more detailed recording of meaningful factors and conditions.

TEST METHOD

Laboratory Corrosion Testing of Metals for the Process Industries

CONTENTS

1. General 2
2. Specimen Preparation 2
3. Equipment and Apparatus 3
4. Test Conditions 4
5. Methods of Cleaning Specimens After the Test 7
6. Evaluation of Results 8
7. Calculating Corrosion Rates 9
8. Reporting the Data 10

References 10

1. General

1.1 This Standard describes the factors which influence laboratory tests. These factors include specimen preparation, apparatus, test conditions (solution composition, temperature, velocity, aeration, volume, method of supporting specimens, duration of test), methods of cleaning specimens, evaluation of results, and calculation of corrosion rates. This Standard also emphasizes the importance of recording all pertinent data and provides a check list for reporting test data.

1.2 Experience has shown that all metals and alloys do not respond alike to the many factors that control corrosion and that "accelerated" corrosion tests give indicative results only. Consequently, it is impractical to propose an inflexible standard laboratory corrosion testing procedure for general use except for material qualification tests, where standardization is obviously required.

1.3 In designing any corrosion test, consideration must be given to the various factors discussed in this test method because these factors have been found to affect greatly the results obtained.

2. Specimen Preparation

2.1 In laboratory tests, corrosion rates of duplicate specimens are usually within ± 10% under the same test conditions. Occasional exceptions, in which a large difference is observed, can occur under conditions of borderline passivity of metals or alloys that depend on a passive film for their resistance to corrosion. Therefore, at least duplicate specimens should be exposed in each test.

2.2 If the effects of corrosion are to be determined by changes in mechanical properties, untested duplicate specimens should be preserved in a non-corrosive environment for comparison with the corroded specimens. The mechanical property commonly used for comparison is the tensile strength. The procedure for determining this value is shown in detail in ASTM Standard E-8- latest edition.

2.3 The size and the shape of specimens will vary with the purpose of the test, nature of the materials, and apparatus used. A large surface-to-mass ratio and a small ratio of edge area to total area are desirable. These ratios can be achieved through the use of rectangular or circular specimens of minimum thickness. Circular specimens should be cut preferably from sheet and not bar stock to minimize the exposed end grain.

2.3.1 A circular specimen of about 1 1/2-inch (38 mm) diameter is a convenient shape for laboratory corrosion tests. With a thickness of approximately 1/8 inch (3 mm) and a 5/16 or 7/16-inch (10 mm) diameter hole for mounting, these specimens will readily pass through a 45/50 ground glass joint of a distillation kettle. The total surface area of a circular specimen is given by the following equation:

$$A = \frac{\pi}{4}(D^2 - d^2) + t\pi D + t\pi d$$

where t = thickness, D = diameter of the specimen, and d = diameter of the mounting hole. If the hole is completely covered by the mounting support, the last term ($t\pi d$) in the equation is omitted.

2.3.2 Strip coupons [of about 4 square inches (25 cm^2)] may be preferred as corrosion specimens, particularly if interface or liquid line effects are to be studied by the laboratory test, but such effects are beyond the scope of this Standard.

2.3.3 All specimens should be measured carefully to permit accurate calculation of the exposed areas. An area calculation accurate to plus or minus 1% is usually adequate.

2.4 More uniform results may be expected if a substantial layer of metal is removed from the specimens to eliminate variations in condition of the original metallic surface. This can be done either by chemical treatment (pickling), electrolytic removal, or by grinding with a coarse abrasive paper or cloth, such as No. 50, using care not to work harden the surface (see Section 2.7). At least 0.0001 inch (3 μm) or 10 to 15 milligrams per square inch (0.03 milligrams/mm^2) should be removed. If clad alloy specimens are to be used, special attention must be given to insure that excessive metal is not removed. After final preparation of the specimen surface, the specimens should be stored in a desiccator until exposure if they are not used immediately.

2.5 Exposure of sheared edges should be avoided unless the purpose of the test is to study effects of the shearing operation. It may be desirable to test a surface representative of the material and metallurgical condition used in practice.

2.6 The specimen can be stamped with an appropriate identifying mark.

2.6.1 The stamp, besides identifying the specimen, introduces stresses and cold work in the specimen, that could be responsible for localized corrosion and/or stress corrosion cracking.

2.6.2 Stress corrosion cracking at the identifying mark is a positive indication of susceptibility to such

corrosion; however, the absence of cracking should not be interpreted as indicating resistance. Additional tests should be run to study specifically the effects of stress.

2.7 Final surface treatment of the specimens should include finishing with new No. 120 abrasive paper or cloth, or the equivalent, unless the surface is to be used in the mill-finished condition. This resurfacing may cause some surface work-hardening to an extent which will be determined by the vigor of the surfacing operation but is not ordinarily significant.

2.7.1 Coupons of different alloy compositions should never be ground on the same cloth.

2.7.2 Wet grinding should be used on alloys which work harden quickly, such as the austenitic stainless steels.

2.8 The specimens should be finally degreased by scrubbing with bleach-free scouring powder, followed by thorough rinsing in water and in a suitable solvent (such as acetone, methanol, or a mixture of 50% methanol and 50% ether) and air dried. For relatively soft metals such as aluminum, magnesium, and copper, scrubbing with abrasive powder is not always needed and can mar the surface of the specimen. The use of towels for drying may introduce an error through contamination of the specimens with grease or lint.

2.9 The dried specimens should be weighed on an analytical balance to an accuracy of plus or minus 0.5 milligram.

2.10 The method of specimen preparation should be described when reporting tests results to facilitate interpretation of data by other persons.

2.10.1 Reports should include trade name or composition of specimens in the following order of preference: (a) chemical composition determined by analysis, (b) approximate or nominal chemical composition, and (c) trade name or grade and specification (if bought to MIL, ASTM, etc.)

2.10.2 Metallurgical condition of the specimens including the degree of hot or cold working and heat treatment, should be described as completely as possible.

2.11 The use of welded specimens is often desirable because some welds may be cathodic or anodic to the base metal and may affect the corrosion.

2.11.1 The heat-affected zone is also of importance but should be studied separately because welds on coupons do not faithfully reproduce heat input or size effects of full-size vessels.

2.11.2 Corrosion of a welded coupon is best reported by description and thickness measurements rather than a mils-per-year rate because the attack is normally localized and not representative of the entire surface.

2.11.3 A complete discussion of corrosion testing of welded coupons or the effect of heat treatment on the corrosion resistance of a metal is not within the scope of this Standard.

3. Equipment and Apparatus

3.1 A versatile and convenient apparatus should be used, consisting of a kettle or flask of suitable size (usually 500 to 5000 milliliters), a reflux condenser with atmospheric seal, a sparger for controlling atmosphere or aeration, a thermowell and temperature regulating device, a heating device (mantle, hot plate, or bath), and a specimen support system. If agitation is required, the apparatus can be modified to accept a suitable stirring mechanism such as a magnetic stirrer. A typical resin flask set up for this type test is shown in Figure 1.

3.2 These suggested components can be modified, simplified, or made more sophisticated to fit the needs of a particular investigation. The suggested apparatus is basic, and the apparatus is limited only by the judgment and ingenuity of the investigator.

3.2.1 A glass reaction kettle can be used where configuration and size of specimens will permit entry through the narrow kettle neck.

3.2.2 In some cases, a wide mouth jar with a suitable closure is sufficient when simple immersion tests at ambient temperatures are to be investigated.

3.2.3 Open beaker tests should not be used because of evaporation and contamination.

3.2.4 In more complex tests, provisions might be needed for continuous flow or replenishment of the corrosive liquid while simultaneously maintaining a controlled atmosphere.

4.1 Selection of the conditions for a laboratory corrosion test will be determined by the purpose of the test.

4.1.1 If the test is to be a guide for the selection of a material for a particular purpose, the limits of controlling factors in service must be determined. These factors include oxygen concentration, temperature, rate of flow, pH value, and other important characteristics of the solution.

4.2 An effort should be made to duplicate all service conditions in the corrosion test.

4.3 It is important that test conditions be controlled throughout the test in order to ensure reproducible results.

4.4 The spread in corrosion rate values for duplicate specimens in a given test should not exceed ± 10% of the average when the attack is uniform.

4.5 Composition of solution.

4.5.1 Test solutions should be prepared accurately from chemicals conforming to the Standards of the Committee on Analytical Reagents of the American Chemical Society,[1] and distilled water, except in those cases where naturally occurring solutions or those taken directly from some plant process are used.

4.5.2 The composition of the test solution should be controlled to the fullest extent possible and should be described as completely and as accurately as possible when the results are reported.

4.5.2.1 Minor constituents should not be overlooked because they often affect corrosion rates.

4.5.2.2 Chemical content should be reported as percentage by weight of the solution. Molarity and normality are also helpful in defining the concentration of chemicals in the test solution.

4.5.3 The composition of the test solution should be checked by analysis at the end of the test to determine the extent of change in composition, such as might result from evaporation.

4.5.4 Evaporation losses should be controlled by a constant level device or by frequent additions of evaporating liquid to maintain the original volume within ± 1%.

4.5.5 In some cases, composition of the test solution may change as a result of catalytic decomposition or by reaction with the test coupon. These changes should be determined if possible. Where required, the exhausted constituents should be added or a fresh solution provided, during the course of the test.

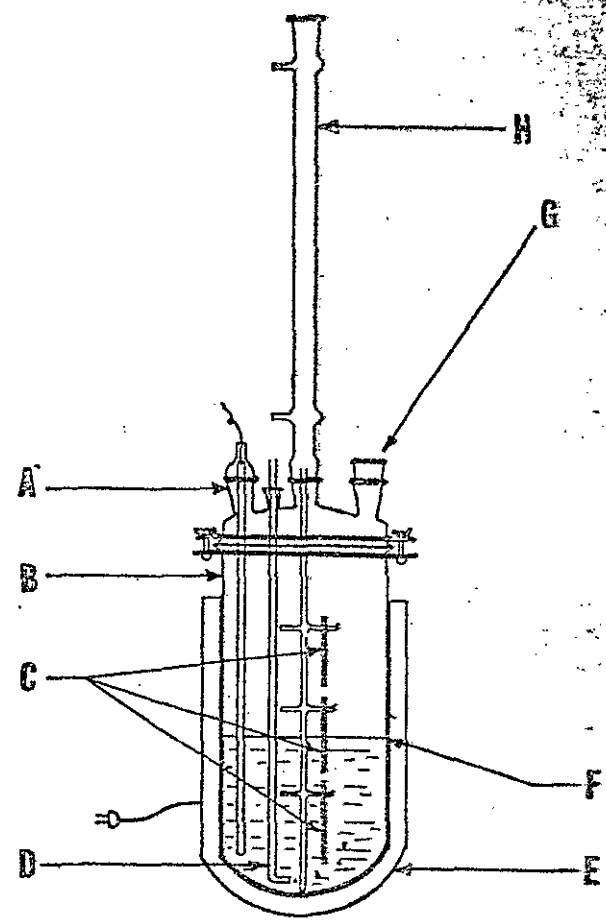


Figure 1 — Typical resin flask that can be used as a versatile and convenient apparatus to conduct simple immersion tests. Configuration of the flask top is such that more sophisticated apparatus can be added as required by the specific test being conducted. A = thermowell, B = resin flask, C = specimens hung on supporting device, D = gas inlet, E = heating mantle, F = liquid interface, G = opening in flask for additional apparatus that may be required, and H = reflux condenser.

4.5.6 When possible, only one type of metal should be exposed in a given test. If several different metals are exposed in the same solution, the corrosion products from one metal may affect the rate of attack on another metal. For example, copper corrosion products can reduce corrosion of stainless steel and titanium but can accelerate corrosion of aluminum.

4.6 Temperature of solution.

4.6.1 Temperature of the corroding solution should be controlled within ± 1 C (± 1.8 F) and must be stated in the report of test results.

4.6.2 If no specific temperature, such as boiling, is required or if a temperature range is to be investigated, the selected temperatures used in the test must be reported.

4.6.3 For tests at ambient temperatures, the tests should be conducted at the highest temperature anticipated for stagnant storage in summer months. This temperature may be as high as 40 to 45 C (104 to 113 F) in some areas. The variation in temperature should be reported also (e.g., 40 C ± 2 C).

4.7 Aeration of solution.

4.7.1 Unless specified, the solution should not be aerated. Most tests related to process equipment should be run with the natural atmosphere inherent in the process, such as the vapors of the boiling liquid.

4.7.2 If aeration is used, the specimens should not be located in the direct air stream from the sparger. Extraneous effects can be encountered if the air stream impinges on the specimens.

4.7.3 If complete exclusion of dissolved oxygen is necessary, specific techniques are required such as prior heating of the solution and sparging with an inert gas (usually nitrogen). A liquid atmospheric seal is required on the test vessel to prevent further contamination.

4.7.4 If oxygen saturation of the test solution is desired, this can best be achieved by sparging. For other degrees of aeration, the solution should be sparged with synthetic mixtures of air or oxygen with an inert gas.

4.8 Solution velocity.

4.8.1 The effect of velocity is not usually determined in normal laboratory tests although specific tests have been designed for this purpose. However, for the sake of reproducibility, some velocity control is desirable.

4.8.2 Tests at the boiling point should be conducted with minimum possible heat input, and boiling chips should be used to avoid excessive turbulence and bubble impingement.

4.8.3 In tests conducted below the boiling point, thermal convection generally is the only source of liquid velocity.

4.8.4 In test solutions with high viscosities, supplemental controlled stirring is recommended.

4.9 Volume of test solution.

4.9.1 The volume of the test solution should be large enough to avoid any appreciable change in its corrosiveness either through exhaustion of corrosive constituents or accumulation of corrosion products that might affect further corrosion.

4.9.2 The preferred minimum volume-to-area ratio is 250 milliliters of solution per square inch (0.4 ml/mm^2) of specimen surface as stipulated in ASTM Standard A-279-63 on "Total Immersion Corrosion Test of Stainless Steels."

4.9.3 When the test objective is to determine the effect of a metal or alloy on the characteristics of the test solution (for example, to determine the effects of metals on dyes), it is desirable to reproduce the ratio of solution volume to exposed metal surface that exists in practice. The actual time of contact of the metal with the solution also must be taken into account. Any necessary distortion of the test conditions must be considered when interpreting the results.

4.10 Method of supporting specimens.

4.10.1 The supporting device and container should not be affected by or cause contamination of the test solution.

4.10.2 The method of supporting specimens will vary with the apparatus used for conducting the test but should be designed to insulate the specimens from each other physically and electrically and to insulate the specimens from any metallic container or supporting device used with the apparatus.

4.10.3 Shape and form of the specimen support should assure free contact of the specimen with the corroding solution, the liquid line, or the vapor phase as shown in Figure 1. If clad alloys are exposed, special procedures will be required to insure that only the cladding is exposed unless the purpose is to test the ability of the cladding to protect cut edges in the test solution.

4.10.4 Some common supports are glass or ceramic rods, glass saddles, glass hooks, fluorocarbon plastic strings, and various insulated or coated metallic supports.

4.11 Duration of test.

4.11.1 Although duration of any test will be determined by the nature and purpose of the test, an

excellent procedure for evaluating the effect of time on corrosion of the metal and also on the corrosiveness of the environment in laboratory tests has been presented by Wachter and Treseder.[2] This technique is called the "Planned Interval Test," and the procedure and evaluation of results are given in Table 1. Other procedures that require the removal of solid corrosion products between exposure periods will not measure accurately the normal changes of corrosion with time.

4.11.2 Materials which experience severe corrosion generally do not need lengthy tests to obtain accurate corrosion rates. Although this assumption is valid in many cases, there are cases where it is not valid. For example, lead exposed to sulfuric acid corrodes at an extremely high rate at first while building a protective film, then the rates decrease considerably so that further corrosion is negligible. The phenomenon of forming a protective film is observed with many corrosion resistant materials, and therefore short tests on such materials would indicate a high corrosion rate and would be completely misleading.

4.11.3 Short time tests also can give misleading results on alloys that form passive films, such as stainless steels. With borderline conditions, a prolonged test may be needed to permit breakdown of the passive film and subsequently more rapid attack. Consequently, tests run for long periods are considerably more realistic than those conducted for short durations. This statement must be qualified by stating that corrosion should not proceed to the point where the original specimen size or the exposed area is drastically reduced or where the metal is perforated.

4.11.4 If anticipated corrosion rates are moderate or low, the following equation[2] gives a suggested test duration:

$$\textit{Duration of test (hr)} = \frac{2000}{\text{corrosion rate (mpy)}}$$

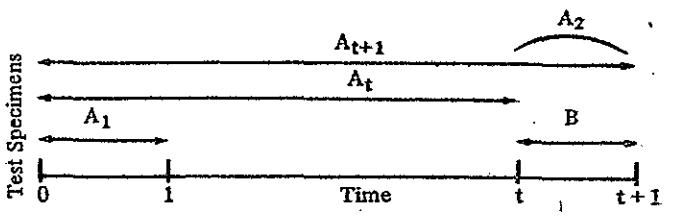
Examples: Where the corrosion rate is 10 mpy, the test should run for at least 200 hours. If the rate is 1 mpy, the duration should be at least 2000 hours.

> 4.11.4.1 This method of estimating test duration is useful only as an aid in deciding, after a test has been made, whether or not it is desirable to repeat the test for a longer period. The most common testing periods are 48 to 168 hours (2 to 7 days).

4.11.5 In some cases, it may be necessary to know the degree of contamination caused by the products of corrosion; this can be accomplished by analysis of

TABLE 1 – Planned Interval Test[2]

(Reprinted by permission from "Chemical Engineering Progress," June, 1947.)



Identical specimens-all placed in the same corrosive fluid. Imposed conditions of the test kept constant for entire time t + 1. Letters, A_1, A_t, A_{t+1}, B, represent corrosion damage experienced by each test specimen. A_2 is calculated by subtracting A_t from A_{t+1}.

Occurrences During Corrosion Test		Criteria
Liquid corrosiveness	unchanged	$A_1 = B$
	decreased	$B < A_1$
	increased	$A_1 < B$
Metal corrodibility	unchanged	$A_2 = B$
	decreased	$A_2 < B$
	increased	$B < A_2$

Combinations of Situations

Liquid Corrosiveness	Metal Corrodibility	Criteria
1. unchanged	unchanged	$A_1 = A_2 = B$
2. unchanged	decreased	$A_2 < A_1 = B$
3. unchanged	increased	$A_1 = B < A_2$
4. decreased	unchanged	$A_2 = B < A_1$
5. decreased	decreased	$A_2 < B < A_1$
6. decreased	increased	$A_1 > B < A_2$
7. increased	unchanged	$A_1 < A_2 = B$
8. increased	decreased	$A_1 < B > A_2$
9. increased	increased	$A_1 < B < A_2$

Example of Planned Interval Corrosion Test

Conditions: Duplicate strips of low-carbon steel, each 3/4 by 3 inches (20 x 75 mm) immersed in 200 ml of 10% $AlCl_3$ - 90% $SbCl_3$ mixture through which dried HCl gas was slowly bubbled at atm. pressure. Temperature 90 C.

	Interval, days	Wt. Loss, mg	Penetration, mils	Apparent Corrosion Rate, mils/yr	mmpy
A_1 . .	0-1	1080	1.69	620	15.7
A_t . .	0-3	1430	2.24	270	6.9
A_{t+1} .	0-4	1460	2.29	210	5.3
B . . .	3-4	70	0.11	40	1.0
A_2 . .	calc. 3-4	30	0.05	18	0.5

$A_2 < B < A_1$
$0.05 < 0.11 < 1.69$

Therefore, liquid markedly decreased in corrosiveness during test and formation of partially protective scale on the steel was indicated.

the solution after corrosion has occurred. The corrosion rate can be calculated from the concentration of the matrix metal found in the solution, and it can be compared to that determined from the weight loss of the specimens. However, some of the corrosion products usually adhere to the specimen as a scale, and the corrosion rate calculated from the metal content in the solution is not always correct.

5. Methods of Cleaning Specimens After the Test

5.1 Before specimens are cleaned, their appearance should be observed and recorded. Location of deposits, variations in types of deposits, or variations in corrosion products are extremely important in evaluating localized corrosion, such as pitting and concentration cell attack.

5.2 Cleaning specimens after the test is a vital step in the corrosion test procedure and, if not done properly, can cause misleading results.

5.2.1 Generally, the cleaning procedure should

TABLE 2 — Methods for Chemical Cleaning of Corrosion Test Specimens After Exposure[1]

Material	Chemical	Time	Temperature	Remarks
Aluminum and Aluminum Alloys	70% HNO_3	2-3 min	Room	Follow by light scrub.
	or			
	2% CrO_3, 5% H_3PO_4, Soln.	10 min	175-185 F (79-85 C)	Used when oxide film resists HNO_3 treatment. Follow by 70% HNO_3 treatment previously described.
Copper and Copper Alloys	15-20% HCl	2-3 min	Room	Follow by light scrub.
	or			
	5-10% H_2SO_4	2-3 min	Room	Follow by light scrub.
Lead and Lead Alloys	1% acetic acid	10 min	Boiling	Follow by light scrub. Removes PbO.
	or			
	5% ammonium acetate	5 min	Hot	Follow by light scrub. Removes PbO and/or $PbSO_4$.
	or			
	80 g/l NaOH, 50 g/l mannitol, 0.62 g/l hydrazine sulfate	30 min, or until clean	Boiling	Follow by light scrub.
Iron and Steel	20% NaOH, 200 g/l zinc dust[2]	5 min	Boiling	---
	or			
	conc. HCl, 50 g/l $SnCl_2$ + 20 g/l $SbCl_3$	Until clean	Cold	---
Magnesium and Magnesium Alloys	15% CrO_3, 1% $AgCrO_4$ Soln.	15 min	Boiling	---
Nickel and Nickel Alloys	15-20% HCl	Until clean	Room	---
	or			
	10% H_2SO_4	Until clean	Room	---
Stainless Steel	10% HNO_3	Until clean	140 F (60 C)	Avoid contamination with chlorides
Tin and Tin Alloys	15% Na_3PO_4	10 min	Boiling	Follow by scrubbing.
Zinc	10% NH_4Cl followed by	5 min	Room	Follow by light scrubbing.
	5% CrO_3, 1% $AgNO_3$ Soln.	20 sec	Boiling	---
	or			
	Saturated ammonium acetate	Until clean	Room	Follow by light scrub.
	or			
	100 g/l NaCN	15 min	Room	---

(1) For a list of other effective chemicals see *Materials Protection*, July, 1967.

(2) It is possible for zinc dust as well as the cleaning residue (containing zinc dust) to ignite spontaneously on exposure to air. Proper precautions should be taken in handling and disposing of these materials.

remove all corrosion products from specimens with a minimum removal of sound metal.

5.2.2 Set rules cannot be applied to specimen cleaning because procedures will vary depending on the type of metal being cleaned and on the degree of adherence of corrosion products.

5.3 Cleaning methods can be divided into three general categories: mechanical, chemical, and electrolytic.

5.3.1 Mechanical cleaning includes scrubbing, scraping, brushing, mechanical shocking, and ultrasonic procedures. Scrubbing with a bristle brush and mild abrasive is the most popular of these methods; the others are used principally as a supplement to remove heavily encrusted corrosion products before scrubbing. Care should be used to avoid the removal of sound metal.

5.3.2 Chemical cleaning implies the removal of material from the surface of the specimen by dissolution in an appropriate chemical solution. Solvents such as acetone, carbon tetrachloride, and alcohol, are used to remove oil, grease, or resin and are usually applied prior to other methods of cleaning. Chemicals are chosen for application to a specific material. Some of these treatments in general use are outlined in Table 2.

5.3.3 Electrolytic cleaning should be preceded by scrubbing to remove loosely adhering corrosion products. One method of electrolytic cleaning that has been found to be useful for many metals and alloys is as follows:

Solution	5% (by weight) H_2SO_4
Anode	Carbon or lead
Cathode	Test specimen
Cathode C.D.	20 amp/dm^2 (129 amp/sq in)
Inhibitor	2 cc organic inhibitor per liter
Temperature	74 C (165 F)
Exposure period	3 minutes (longer times may be required)

5.3.3.1 Precautions must be taken to insure good electrical contact with the specimen, to avoid contamination of the solution with easily reducible metal ions, and to insure that inhibitor decomposition has not occurred; Instead of using 2 milliliters of any proprietary inhibitor, 0.5 gram per liter of inhibitors such as diorthotolyl thiourea or quinoline ethiodide can be used.

5.4 Whatever treatment is used to clean specimens after a corrosion test, its effect in removing metal should be determined, and the weight loss should be corrected accordingly. A "blank" specimen should be weighed before and after exposure to the cleaning procedure to establish this weight loss.

5.4.1 Following removal of all scale, the specimen should be treated as discussed in Section 2.8.

5.4.2 A description of the cleaning method should be included with the data reported.

6. Evaluation of Results

6.1 After corroded specimens have been cleaned, they should be reweighed with an accuracy corresponding to that of the original weighing. The weight loss during the test period can be used as the principal measure of corrosion. Sometimes all corrosion products cannot be removed. In this case, the weight should be reported but the observation made that some corrosion products were not removed.

6.2 After the specimens have been reweighed, they should be examined carefully for the presence of pits. If there are pits, the average and maximum depths of pits are determined after measurement with a pit gauge or a calibrated microscope which can be focused first on the edge and then on the bottom of the pit. An excellent discussion of pitting corrosion has been published.[3]

6.2.1 Pit depths should be reported in millimeters or thousandths of an inch for the test period and not interpolated or extrapolated to millimeters per year or thousandths of an inch per year or any other arbitrary period because rarely, if ever, is the rate of initiation or propagation of pits uniform.

6.2.2 The size, shape, and distribution of pits should be noted. A distinction should be made between those occurring underneath the supporting devices (concentration cells) and those on surfaces that were freely exposed to the test solution.

6.3 If the material being tested is suspected of being subject to dealloying forms of corrosion such as dezincification, or to intergranular attack, a cross section of the specimen should be microscopically examined to determine the type and depth of such attack.

6.4 The specimen may be subjected to simple bending tests to determine whether any embrittlement has occurred.

6.5 It may be desirable to make quantitative mechanical tests to compare the exposed specimens with uncorroded specimens reserved for the purpose, as described in Section 2.2.

7. Calculating Corrosion Rates

7.1 The calculation of corrosion rates requires several pieces of information and several assumptions.

7.1.1 The use of corrosion rates implies that all weight loss has been due to general corrosion and not to localized corrosion, such as pitting or sensitized areas on welded coupons. Localized corrosion is reported separately.

7.1.2 The use of corrosion rates also implies that the material has not been internally attacked as by dezincification or intergranular corrosion.

7.1.3 Internal attack can be expressed as a corrosion rate if desired. However, the calculations must not be based on weight loss, which is usually small, but on microsections which show depth of attack.

7.2 Assuming that localized or internal corrosion is not present or are recorded separately in the report, the corrosion rate expressed as mils penetration per year (mpy) or millimeters per year (mmpy) can be calculated by the equations:

$$\text{mpy} = \frac{\text{wt loss} \times 534}{(\text{area})\,(\text{time})\,(\text{metal density})}$$

where weight loss is in milligrams, area is square inches of metal surface exposed, and time is hours exposed.

$$\text{mmpy} = \frac{\text{wt loss} \times 87.6}{(\text{area})\,(\text{time})\,(\text{metal density})}$$

where weight loss is in milligrams, area in cm^2 of metal surface exposed, and time is hour exposed. Metal density of many common alloys (expressed in grams per cubic centimeter) is listed in Table 3. The density for new or unlisted alloys can be obtained from the producer or from various metal handbooks.

TABLE 3 — Density of Common Metals for Use in Corrosion Rate Calculations[9]

Alloy	Density, gm/cm^3
Aluminum	
99.0 + Al	2.71
Al, 1.2 Mn	2.73
Al, 1.0 Mg, 0.6 Si, 0.25 Cr	2.70
Brass	
85 Cu, 15 Zn	8.75
71 Cu, 28 Zn, 1 Sn	8.53
65 Cu, 35 Zn	8.47
60 Cu, 39.25 Zn, 0.75 Sn	8.41
Bronze	
95 Cu, 5 Sn	8.86
90 Cu, 10 Sn	8.78
85 Cu, 5 Sn, 5 Zn, 5 Pb	8.80
94.8 Cu, 3 Si	8.53
95 Cu, 5 Al	8.17
85-90 Cu, 10 Al	7.58
Copper	
99.90 Cu, 0.01 P	8.91
Cupro-Nickel	
90 Cu, 10 Ni	8.93
70 Cu, 30 Ni	8.94
Iron	
94 Fe, 3.5 C, 2.5 Si	7.00
96 Fe, 3.0 C	7.60
99.94 Fe, 0.025 S, 0.017 Mn, 0.012 C, 0.005 P	7.86
84.3 Fe, 14.5 Si, 0.35 Mn, 0.85 C	7.00
Lead	
99.90 + Pb	11.34
Nickel	
99.4 Ni + Co	8.89
67 Ni, 30 Cu	8.84
62 Ni, 30 Mo, 5 Fe	9.24
58 Ni, 17 Mo, 15 Cr, 5 W, 5 Fe	8.94
80 Ni, 14 Cr, 6 Fe	8.51
Steel	
0.20 C, Mn, P, S	7.85
Stainless Steel	
11.50-13.50 Cr, 0.15 C	7.75
14.00-18.00 Cr, 0.12 C	7.70
18.00-20.00 Cr, 8.00-12.00 Ni, 0.08 C	7.93
16.00-18.00 Cr, 10.00-14.00 Ni, 2.00-3.00 Mo, 0.08 C	7.98
17.00-19.00 Cr, 9.00-12.00 Ni, 0.08 C, Ti	8.02
17.00-19.00 Cr, 9.00-12.00 Ni, 0.08 C, Cb	8.02
19.00-21.00 Cr, 24.00-30.00 Ni, 2.00-3.00 Mo, 3.00-4.00 Cu	8.02
Tantalum	16.60
Tin	7.30
Titanium	4.54
Zirconium	6.53

8. Reporting the Data

8.1 The importance of reporting all data as completely as possible cannot be overemphasized.

8.2 Expansion of the testing program in the future or correlating the results with tests of other investigators will be possible only if all pertinent information is properly recorded.

8.3 The following checklist is a recommended guide for reporting all important information and data:

8.3.1 Corrosive media and concentration (changes during test).

8.3.2 Volume of test solution.

8.3.3 Temperature (maximum, minimum, average).

8.3.4 Aeration (describe conditions or technique).

8.3.5 Agitation (describe conditions or technique).

8.3.6 Type of apparatus used for test.

8.3.7 Duration of each test.

8.3.8 Chemical composition or trade name of metals tested.

8.3.9 Form and metallurgical conditions of specimens.

8.3.10 Exact size, shape, and area of specimens.

8.3.11 Treatment used to prepare specimens for test.

8.3.12 Number of specimens of each material tested, and whether specimens were tested separately or which specimens were tested in the same container.

8.3.13 Method used to clean specimens after exposure and the extent of any error expected by this treatment.

8.3.14 Actual weight losses for each specimen.

8.3.15 Evaluation of attack if other than general, such as crevice corrosion under support rod, pit depth and distribution, and results of microscopic examination or bend tests.

8.3.16 Corrosion rates for each specimen expressed as mils per year.

8.4 Minor occurrences or deviations from the proposed test program often can have significant effects and should be reported if known.

8.5 Statistics can be a valuable tool for analyzing the results from test programs designed to generate adequate data and should be used wherever possible. Excellent references for the use of statistics in corrosion studies include References 4 through 8.

References

1. Joseph Rosin. Reagent Chemicals and Standards, Fifth Edition. D. Van Nostrand Co., Inc., 120 Alexander St., Princeton, N. J., 1966.
2. A. Wachter and R. S. Treseder. Corrosion Testing Evaluation of Metals for Process Equipment. *Chemical Engineering Progress*, 43, 315-326 (1947) June.
3. N. D. Greene and M. G. Fontana. A Critical Analysis of Pitting Corrosion. *Corrosion*, 15, 25t (1959) January.
4. Harold S. Mickley, Thomas K. Sherwood, and Charles E. Reed (editors). Applied Mathematics in Chemical Engineering, (second edition). McGraw-Hill, New York, N. Y., 1957.
5. D. M. Douglas. Are You Using or Abusing Data? Paper presented at the Northeast-North Central Region Conference, National Association of Corrosion Engineers, October 4-6, 1965, Pittsburgh, Pa.
6. W. J. Youden. Experimentation and Measurement. National Science Teachers Association, Washington, D. C., 1962.
7. F. F. Booth and G. E. G. Tucker. Statistical Distribution of Endurance in Electrochemical Stress-Corrosion Tests. *Corrosion*, 21, 173 (1965) May.
8. Compilation of Examples of Applying Statistics to Corrosion Problems. ASTM Standard G-16, ASTM, 1916 Race St., Philadelphia, Pa.
9. Metals Handbook, American Society for Metals, Metals Park, Novelty, Ohio, 8th Edition, Volume 1, 1961.

59. NACE Standard TM-02-70, "Test Method; Method of Conducting Controlled Velocity Laboratory Corrosion Tests", National Association of Corrosion Engineers, 1970

DWR Corrosion Engineering

technical practices committees

NATIONAL ASSOCIATION OF CORROSION ENGINEERS

NACE Standard TM-02-70

Test Method

Method of Conducting Controlled Velocity Laboratory Corrosion Tests

This National Association of Corrosion Engineers Standard implies a consensus of those individual members substantially concerned with this document, its scope, and provisions. This Standard is intended to aid the manufacturer, the consumer, and the general public. Its acceptance does not in any respect preclude anyone, whether he has adopted the Standard or not, from manufacturing, marketing, purchasing, or using products, processes, or procedures not in conformance with this Standard. NACE Standards are subject to periodic review, and the user is cautioned to obtain the latest edition.

CAUTIONARY NOTICE: This NACE Standard may be revised or withdrawn at any time without prior notice. NACE requires that action be taken to reaffirm, revise, or withdraw this Standard no later than two years from the date of initial publication. Purchasers of NACE Standards may receive current information on all Standards by writing to NACE Publications Department, 1440 South Creek, Houston, Texas 77084.

Approved October, 1970
National Association of Corrosion Engineers
1440 South Creek, Houston, Texas 77084
(713) 492-0535

Copyright 1970, National Association of Corrosion Engineers

1. General

1.1 This test method describes a procedure for conducting controlled velocity corrosion tests in the laboratory in which a corrosive solution may be moved at a known tangential velocity across the face of corrosion test specimens. The test method is useful in comparing the effects of the velocity of a solution on the corrosion of a number of metals at the same time, utilizing small circular metal samples. The equipment is inexpensive and requires little space, and the costs of operation and maintenance are low. Because of the velocity limitations given below, the apparatus is more useful for studying candidate materials for agitated vessels and pipelines than for pumps and valves.

2. Limitations

2.1 **Velocity:** Velocities to 8 ft/sec (244 cm/sec) can be obtained when using a glass shaft and paddle with conventional laboratory stirring motors and bearing seals. Velocities to 15 ft/sec (457 cm/sec) are practical when using a fluorocarbon coated metal drive shaft and bearing mechanism plus a heavy duty motor (e.g., drill press).

2.2 **Gas Blanketing:** In cases where excessive aeration may not reflect actual process conditions, the tester should be blanketed with nitrogen to prevent air pickup in the vortex area.

2.3 **Crevice Corrosion:** To minimize possible crevice corrosion, the corrosion samples can be protected either by a fluorocarbon resin coating (applied by a fluidized bed technique and then stripped from the face) or other impervious coatings resistant to the test solution, or by machining the sample so it is completely circular (without a shoulder) and protected with fluorocarbon resin tape. In the latter case, the specimen holders will have to be bored out to accommodate the circular test specimen.

3. Equipment and Apparatus

3.1 A general view of the apparatus is shown in Figure 1. Figure 2 is a cross sectional side elevation view of the support ring. Figures 3 through 5 are detailed sketches showing dimensions and tolerances of the specimen support apparatus.

3.2 The solution is contained in a standard 2-gallon glass jar which is preferably provided with an internal circumferential groove or alternately three or four equally spaced depressions.

3.3 Support ring apparatus[1]

3.3.1 The support ring consists of an annulus or ring of polytetrafluoroethylene resin. A suitable size is 6-1/2 in. (16.5 cm) O. D. by 5-1/4 in. (13.3 cm) I. D. by 5-1/2 in. (14.0 cm) high for an 8-port, 1-tier port ring. A 16-port, 2-tier port ring should be 6 in. (15.24 cm) high.

3.3.2 The support ring is provided with a number (8 or 16) of radially disposed shoulder ports which are adapted to receive the individual test coupon holders.

3.3.3 Three or four positioning screws are required to

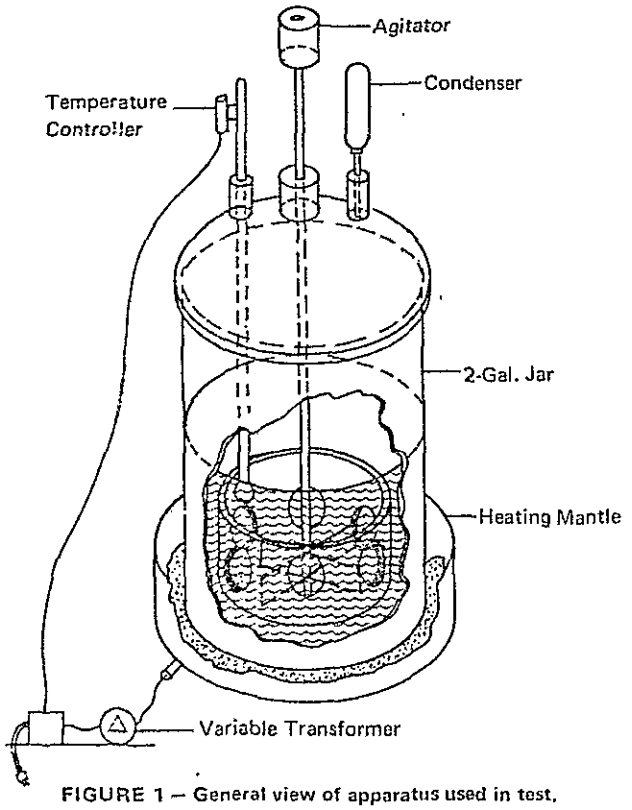


FIGURE 1 — General view of apparatus used in test.

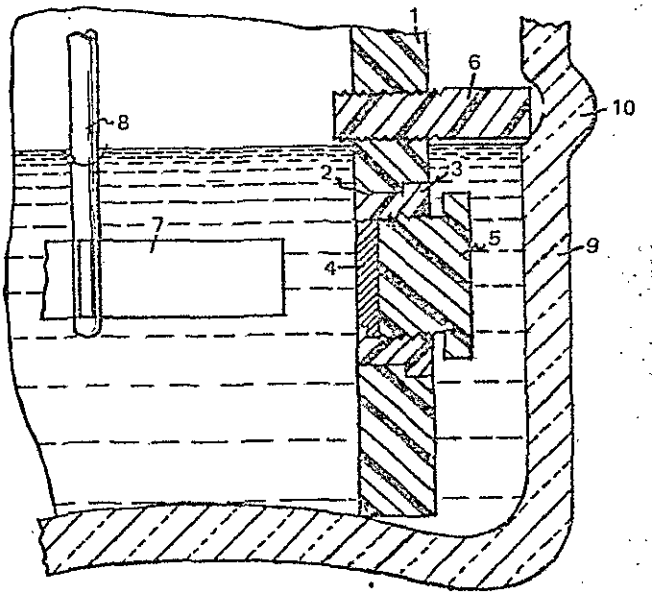


FIGURE 2 — Cross-sectional side view of stirrer and apparatus used to support test specimens. Diagram shows support ring (1), shoulder port (2), specimen holder (3), metal test coupon (4), threaded screw cap (5), positioning screw (6), paddle blade (7), paddle shaft (8), glass jar (9), and depression or groove in glass jar (10).

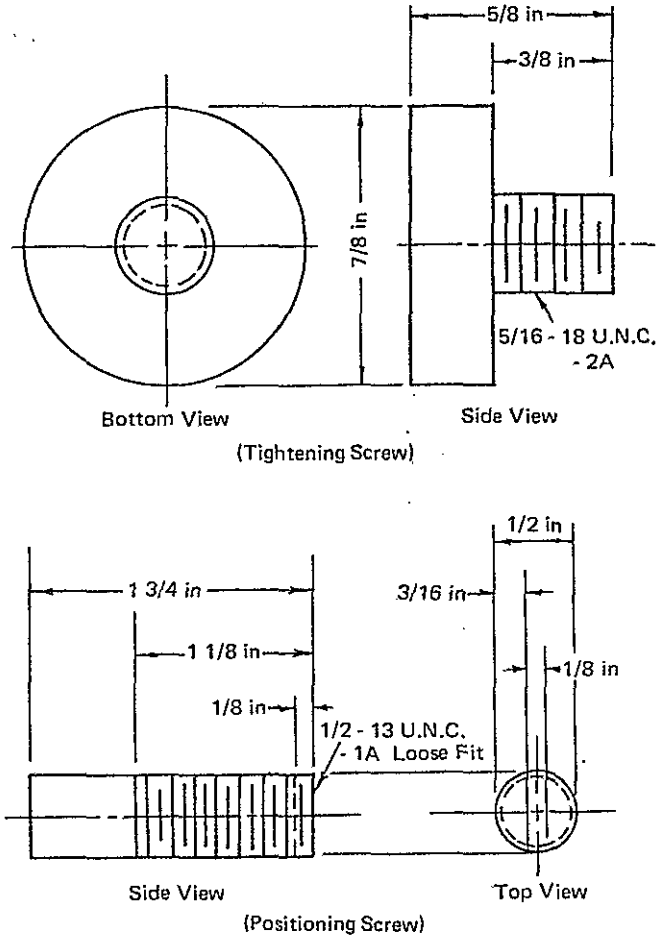


FIGURE 3 — Dimensions for tightening screw (top) which are necessary to prevent the specimen holders from being pushed out by the force of the agitator. Three or four positioning screws (bottom) are necessary to space the holder precisely in the test jar and to keep the holder from rotating.

space the holder precisely and to restrain the holder from rotating. The outboard end of the screws seat in the groove or depressions in the glass jar. The screws are slotted on the inboard end so that they can be tightened with a coin or small screwdriver.

3.4 Test coupon holders

3.4.1 The test coupon holders (machined from rods of polytetrafluoroethylene resin) are machined on the outside to fit snugly in the radial ports and flush with the inside diameter of the support ring. The inside surfaces are bored in order to have a tight, forced fit with the metal corrosion coupon, the shoulder providing an additional seal for leak tightness. The coupon is further locked in place by a threaded polytetrafluoroethylene resin screw cap (specimen retainer), sealing off the back face of the coupon against corrosive fluid leakage from the outside of the ring.

3.4.2 The coupon, holder, and retainer are inserted in the radial ports and held in place with polytetrafluoroethylene tightening screws, which fit tapped holes in the support ring (Figure 5) between each port.

3.5 Test coupons

3.5.1 Test coupons typically have a 1 in. (2.54 cm) diameter face, a 1-1/8 in. (2.86 cm) diameter shoulder and are 1/4 in. (0.64 cm) thick with the shoulder disposed at half thickness (Figure 6).

3.5.2 The face of the coupon must be absolutely flush

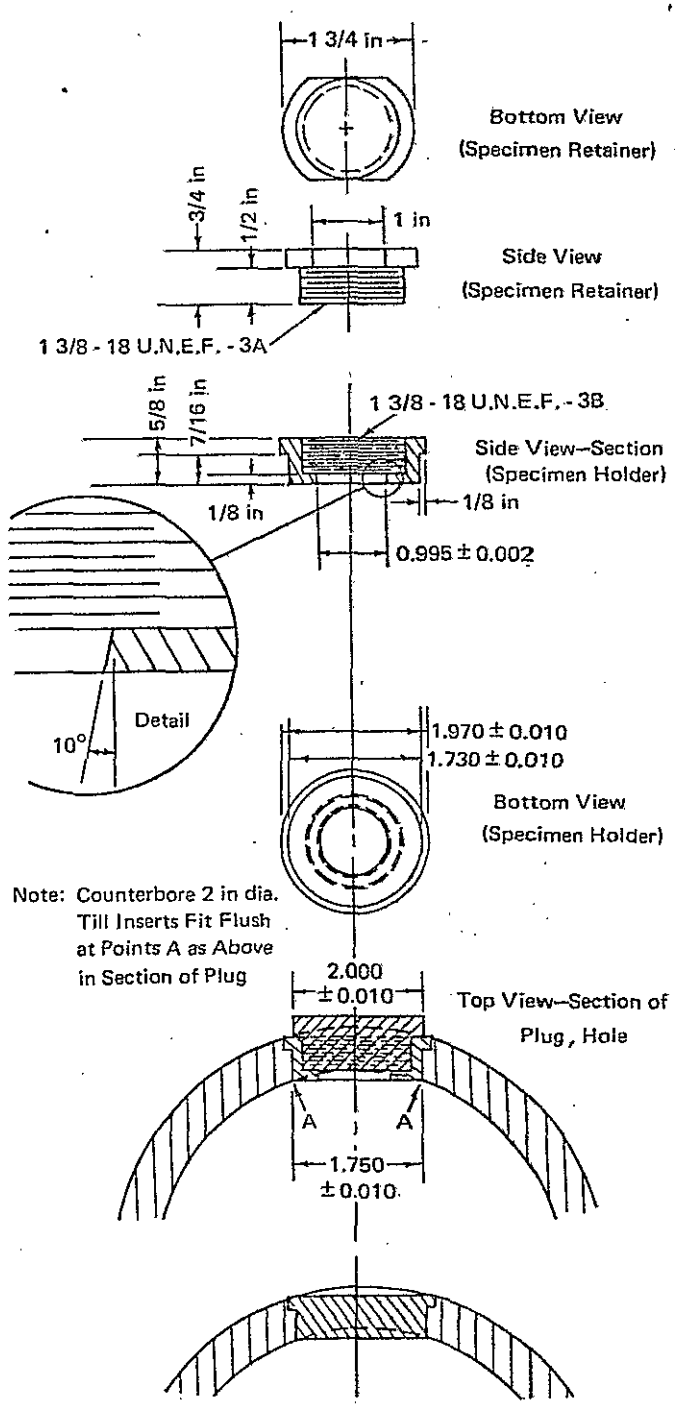


FIGURE 4 — Details of test specimen holders and retainers and the plugs used to blank-off ports not in use.

60. National Fire Protection Association, Inc. Flammable and Combustible Liquids Code, (NFPA30), Quincy, Massachusetts, June 1983, pp. 36-37

NFPA

30

ANSI / NFPA 30
An American
National
Standard
November 20, 1980

Stephen A. Fagundes

FLAMMABLE AND COMBUSTIBLE LIQUIDS CODE

1981

NFPA

Copyright © 1980
All Rights Reserved

4M-583-FP-(15M)
Printed in U.S.A.

NATIONAL FIRE PROTECTION ASSOCIATION, INC.
Batterymarch Park, Quincy, MA 02269

Committee on Flammable Liquids

Correlating Committee

Paul C. Lamb, *Chairman*
Englewood, NJ

Martin F. Henry, *Secretary*
National Fire Protection Assn.
(Nonvoting)

G. E. Cain, Hercules Inc
Rep Chemical Manufacturers Assn.

Donald M. Johnson, Standard Oil Co. of California
Rep Western Oil & Gas Assn.

F. Owen Kubias, Glidden Durkee Div. of SCM Corp

Steven Landon, Washex Machinery Corp.
Rep Laundry-Cleaners Allied Trades Assn.

William R. Rucinski, Department of State Police, MI

W. J. Smith, Underwriters Laboratories Inc.

E. C. Sommer, Exxon Research & Engineering Co.
Rep. American Petroleum Institute

Nonvoting

Dr. Ing Gert Magnus, Mannheim, Germany

Technical Committee on General Storage of Flammable Liquids

Donald M. Johnson, *Chairman*
Standard Oil Co. of California
Rep. Western Oil & Gas Assn.

Martin F. Henry, *Secretary*
National Fire Protection Assn.
(Nonvoting)

Charles D. Adcock, Dow Chemical Co.
Rep Chemical Manufacturers Assn.

Wayne E. Ault, Rolf Jensen & Assoc., Inc.

William G. Bluhm, Shell Oil Co
Rep American Petroleum Institute

Weldon L. Brundrett, Middle South Services Inc
Rep Edison Electric Institute

J. A. Cedervall, Underwriters Laboratories Inc

John D. Coons, Factory Mutual Research Corp

John R. Doggett, II, American Warehouses Inc.
(vote limited to Chapter 4)

William H. Doyle, Simsbury, CT

David M. Eide, Roll Tank Co.
Rep. Steel Tank Institute

H. M. Faulconer, Phillips Petroleum Co.
Rep. American Petroleum Institute

Herbert C. Fothergill, Chelsea Fire Department, MA
Rep International Assn. of Fire Chiefs

Technical Committee Personnel, Cont.

Gregory A. Harrison, Gaithersburg, MD

Donald L. Hierman, Union Carbide Corp.
Rep Chemical Manufacturers Assn.

Larry V. Hill, Schenley Distillers, Inc.
Rep Distilled Spirits Council U.S., Inc

Oliver W. Johnson, Ph.D Palo Alto, CA

Joshi Paul Kallungal, Insurers Advisory Organization of Canada

F. Kiefer, Insurance Services Office

Wallace D. Malmstedt, American Insurance Assn

Paul A. Mankin, Bennett Pump Co.
Rep Gasoline Pump Manufacturers Assn.

William E. Rehr, Wheaton, IL

Gerald J. Rosicky, General Motors Corp.
Rep. NFPA Industrial Fire Protection Section

Jack C. Sanders, Oklahoma City, OK
Rep. Fire Marshals Assn of North America

Leon C. Schaller, E.I. Dupont De Nemours & Co.
Rep National Paint & Coatings Assn.

R. I. Spencer, Industrial Risk Insurers

Richard D. Stalker, Stauffer Chemical Co.

Hugh E. Thompson, Hiram Walker & Sons Ltd

Harold S. Wass Jr., Improved Risk Mutuals

Alternates

Dr. John Doggett, III, American Warehousemens Assn.
(Alternate to J. Doggett, II)

Victor G. Geibeder, Industrial Risk Insurers
(Alternate to R. I. Spencer)

James D. Kieffer, Hiram Walker & Sons Ltd.
(Alternate to H. F. Thompson)

Frederick B. Killmar, American Petroleum Institute
(Alternate to E. C. Sommer)

W. S. Marsh, Factory Mutual Research Corp.
(Alternate to J. D Coons)

A. E. Mittermaier, Fokheim Corp.
(Alternate to P. A. Mankin)

Marshall E. Petersen, Rolf Jensen & Assoc. Inc.
(Alternate to W. E. Ault)

Thomas Shand, Insurance Services Office
(Alternate to F. Kiefer)

Richard Southers, American Petroleum Institute
(Alternate to H. M. Faulconer)

Nonvoting

Michael B. Moore, U.S. Occupational Safety & Health Admin.

Terence P. Smith, U.S Occupational Safety & Health Admin
(Alternate to Michael B. Moore)

This list represents the membership at the time the Committee was balloted on the text of this edition. Since that time, changes in the membership may have occured.

NOTE: Membership on a Committee shall not in and of itself constitute an endorsement of the Association or of any document developed by the Committee on which the member serves.

Immediately following the balloting, but prior to adoption at the 1980 Fall Meeting, former Chairman E. C. Sommer passed away.

Vapor Recovery System. A system designed to capture and retain, without processing, vapors displaced during filling operations at service stations, bulk plants, or terminals. Examples are balanced-pressure vapor displacement systems and vacuum assist systems without vapor processing.

Ventilation. As specified in this code, ventilation is for the prevention of fire and explosion. It is considered adequate if it is sufficient to prevent accumulation of significant quantities of vapor-air mixtures in concentration over one-fourth of the lower flammable limit.

Warehouses.

General Purpose Warehouse. A separate, detached building or portion of a building used only for warehousing-type operations.

NOTE: Warehousing operations referred to above are those operations not accessible to the public and include general purpose, merchandise, distribution and industrial warehouse-type operations.

Liquid Warehouse. A separate, detached building or attached building used for warehousing-type operations for liquids.

1-3 Storage. Liquids shall be stored in tanks or in containers in accordance with Chapter 2 or Chapter 4.

1-4 Pressure Vessel. All new pressure vessels containing liquids shall comply with 1-4.1, 1-4.2 or 1-4.3, as applicable.

1-4.1 Fired pressure vessels shall be designed and constructed in accordance with Section I (Power Boilers) 1971, or Section VIII, Division 1 or Division 2 (Pressure Vessels) 1974, as applicable, of the ASME *Boiler and Pressure Vessel Code**.

1-4.2 Unfired pressure vessels shall be designed and constructed in accordance with Section VIII, Division 1 or Division 2, 1974 of the ASME *Boiler and Pressure Vessel Code**.

1-4.3 Fired and unfired pressure vessels which do not conform to 1-4.1 or 1-4.2 may be used provided approval has been obtained from the state or other governmental jurisdiction in which they are to be used. Such pressure vessels are generally referred to as "State Special."

1-5 Exits.

1-5.1 Egress from buildings and areas covered by this code shall be in accordance with NFPA *101*®, the *Life Safety Code*®.

*Available from the American Society of Mechanical Engineers, United Engineering Center, 345 East 47th St., New York, NY 10017.

Chapter 2 Tank Storage

2-1 Design and Construction of Tanks.

2-1.1 Materials. Tanks shall be designed and built in accordance with recognized good engineering standards for the material of construction being used, and shall be of steel with the following limitations and exceptions:

(a) The material of tank construction shall be compatible with the liquid to be stored. In case of doubt about the properties of the liquid to be stored, the supplier, producer of the liquid, or other competent authority shall be consulted.

(b) Tanks constructed of combustible materials shall be subject to the approval of the authority having jurisdiction and limited to:

1. Installation underground, or
2. Use where required by the properties of the liquid stored, or
3. Storage of Class IIIB liquids aboveground in areas not exposed to a spill or leak of Class I or Class II liquid, or
4. Storage of Class IIIB liquids inside a building protected by an approved automatic fire extinguishing system.

(c) Unlined concrete tanks may be used for storing liquids having a gravity of 40 degrees API or heavier. Concrete tanks with special linings may be used for other services provided the design is in accordance with sound engineering practice.

(d) Tanks may have combustible or noncombustible linings.

(e) Special engineering consideration shall be required if the specific gravity of the liquid to be stored exceeds that of water or if the tank is designed to contain liquids at a liquid temperature below 0°F (−17.8°C).

2-1.2 Fabrication.

2-1.2.1 Tanks may be of any shape or type consistent with sound engineering design.

2-1.2.2 Metal tanks shall be welded, riveted and caulked, or bolted, or constructed by use of a combination of these methods.

2-1.3 Atmospheric Tanks.

2-1.3.1 Atmospheric tanks shall be built in accordance with recognized standards of design. Atmospheric tanks may be built and used within the scopes of the following:

(a) Underwriters Laboratories Inc., *Standard for Steel Aboveground Tanks for Flammable and Combustible Liquids*, UL142 — 1972; *Standard for Steel Underground Tanks for Flammable and Combustible Liquids*, UL58 — 1976; or *Standard for Steel Inside Tanks for Oil Burner Fuel*, UL80 — 1974.*

(b) American Petroleum Institute Standard No. 650, *Welded Steel Tanks for Oil Storage*, Sixth Edition, 1978.**

(c) American Petroleum Institute Specifications 12B, *Bolted Tanks for Storage of Production Liquids*, Twelfth Edition, January 1977**; 12D, *Field Welded Tanks for Storage of Production Liquids*, Eighth Edition, January 1977**; or 12F, *Shop Welded Tanks for Storage of Production Liquids*, Seventh Edition, January 1977**.

(d) Steel Tank Institute Standard No. STI-P3, *Specification for STI-P3 System of Corrosion Protection of Underground Steel Storage Tanks*, 1980***.

2-1.3.2 Low pressure tanks and pressure vessels may be used as atmospheric tanks.

2-1.3.3 Atmospheric tanks shall not be used for the storage of a liquid at a temperature at or above its boiling point.

2-1.4 Low Pressure Tanks.

2-1.4.1 The normal operating pressure of the tank shall not exceed the design pressure of the tank.

2-1.4.2 Low pressure tanks shall be built in accordance with recognized standards of design. Low pressure tanks may be built in accordance with:

(a) American Petroleum Institute Standard No. 620, *Recommended Rules for the Design and Construction of Large, Welded, Low-Pressure Storage Tanks*, Fifth Edition, 1973.**

*Available from Underwriters Laboratories Inc., 333 Pfingsten Rd., Northbrook, IL 60062.

**Available from America Petroleum Institute, 2101 L St., N.W., Washington, DC 20037.

***Available from Steel Tank Institute, 666 Dundee Rd, Northbrook, IL 60062.

(b) The principles of the *Code for Unfired Pressure Vessels*, Section VIII, Division I of the ASME *Boiler and Pressure Vessels Code*, 1974 Edition*.

2-1.4.3 Tanks built according to Underwriters Laboratories Inc. requirements in 2-1.3.1 may be used for operating pressures not exceeding 1 psig (6.895 kPa) and shall be limited to 2.5 psig (17.24 kPa) under emergency venting conditions.

2-1.4.4 Pressure vessels may be used as low pressure tanks.

2-1.5 Pressure Vessels.

2-1.5.1 The normal operating pressure of the vessel shall not exceed the design pressure of the vessel.

2-1.5.2 Storage tanks designed to withstand pressures above 15 psig shall meet the requirements of Section 1-4.

2-1.6 Provisions for Internal Corrosion.

2-1.6.1 When tanks are not designed in accordance with the American Petroleum Institute, American Society of Mechanical Engineers or the Underwriters Laboratories Inc. Standards, or if corrosion is anticipated beyond that provided for in the design formulas used, additional metal thickness or suitable protective coatings or linings shall be provided to compensate for the corrosion loss expected during the design life of the tank.

2-2 Installation of Outside Aboveground Tanks.

2-2.1 Location With Respect to Property Lines, Public Ways and Important Buildings on the Same Property.

2-2.1.1 Every aboveground tank for the storage of Class I, Class II or Class IIIA liquids, except as provided in 2-2.1.2 and those liquids with boil-over characteristics and unstable liquids, operating at pressures not in excess of 2.5 psig (17.24 kPa) and designed with a weak roof-to-shell seam or equipped with emergency venting devices which will not permit pressures to exceed 2.5 psig (17.24 kPa), shall be located in accordance with Table 2-1.

(a) For the purpose of Section 2-2, a floating roof tank is defined as one which incorporates either:

1. A pontoon or double deck metal floating roof in an open top tank in accordance with API Standard 650, or

*Available from the American Safety of Mechanical Engineers, United Engineering Center, 345 East 47th St., New York, NY 10017.

2-2.6 Vent Piping for Aboveground Tanks.

2-2.6.1 *Vent piping shall be constructed* in accordance with Chapter 3.

2-2.6.2 Where vent pipe outlets for tanks storing Class I liquids are adjacent to buildings or public ways, they shall be located so that the vapors are released at a safe point outside of buildings and not less than 12 ft (3.7 m) above the adjacent ground level. In order to aid their dispersion, vapors shall be discharged upward or horizontally away from closely adjacent walls. Vent outlets shall be located so that flammable vapors will not be trapped by eaves or other obstructions and shall be at least 5 ft (1.5 m) from building openings.

2-2.6.3 The *manifolding of tank vent* piping shall be avoided except where required for special purposes such as vapor recovery, vapor conservation or air pollution control. When tank vent piping is manifolded, pipe sizes shall be such as to discharge, within the pressure limitations of the system, the vapors they may be required to handle when manifolded tanks are subject to the same fire exposure.

2-2.6.4 Vent piping for tanks storing Class I liquids shall not be manifolded with vent piping for tanks storing Class II or Class III liquids unless positive means are provided to prevent the vapors from Class I liquids from entering tanks storing Class II or Class III liquids, to prevent contamination (*see 1-1.2*) and possible change in classification of the less volatile liquid.

2-2.7 Tank Openings Other Than Vents for Aboveground Tanks.

2-2.7.1 Each connection to an aboveground tank through which liquid can normally flow shall be provided with an internal or an external valve located as close as practical to the shell of the tank.

2-2.7.2 Each connection below the liquid level through which liquid does not normally flow shall be provided with a liquidtight closure. This may be a valve, plug or blind, or a combination of these.

2-2.7.3 Openings for gaging on tanks storing Class I liquids shall be provided with a vaportight cap or cover. Such covers shall be closed when not gaging.

2-2.7.4 For Class IB and Class IC liquids other than crude oils, gasolines and asphalts, the fill pipe shall be so designed and installed as to minimize the possibility of generating static electricity. A fill pipe entering the top of a tank shall terminate within 6 in. (152.4 mm) of the bottom of the tank and shall be installed to avoid excessive vibration.

2-2.7.5 Filling and emptying connections for Class I, Class II and Class IIIA liquids which are made and broken shall be located outside of buildings at a location free from any source of ignition and not less than 5 ft (1.5 m) away from any building opening. Such connections for any liquid shall be closed and liquidtight when not in use and shall be properly identified.

2-3 Installation of Underground Tanks.

2-3.1 Location. Excavation for underground storage tanks shall be made with due care to avoid undermining of foundations of existing structures. Underground tanks or tanks under buildings shall be so located with respect to existing building foundations and supports that the loads carried by the latter cannot be transmitted to the tank. The distance from any part of a tank storing Class I liquids to the nearest wall of any basement or pit shall be not less than 1 ft (0.3048 m), and to any property line that can be built upon, not less than 3 ft (0.91 m). The distance from any part of a tank storing Class II or Class III liquids to the nearest wall of any basement, pit or property line shall be not less than 1 ft (0.3048 m).

2-3.1 Burial Depth and Cover.

2-3.2.1 Steel underground tanks shall be set on firm foundations and surrounded with at least 6 in. (152.4 mm) of noncorrosive inert material such as clean sand or gravel well-tamped in place. The tank shall be placed in the hole with care, since dropping or rolling the tank into the hole can break a weld, puncture or damage the tank, or scrape off the protective coating of coated tanks.

2-3.2.2 Steel underground tanks shall be covered with a minimum of 2 ft (.6096 m) of earth, or shall be covered with not less than 1 ft (0.3048 m) of earth, on top of which shall be placed a slab of reinforced concrete not less than 4 in. (101.6 mm) thick. When they are, or are likely to be, subjected to traffic, they shall be protected against damage from vehicles passing over them by at least 3 ft (0.91 m) of earth cover, or 18 in. (457.2 mm) of well-tamped earth plus either 6 in. (152.4 mm) of reinforced concrete or 8 in. (203.2 mm) of asphaltic concrete. When asphaltic or reinforced concrete paving is used as part of the protection, it shall extend at least 1 ft (0.3048 m) horizontally beyond the outline of the tank in all directions.

2-3.2.3 Nonmetallic underground tanks shall be installed in accordance with the manufacturer's instructions. The minimum depth of cover shall be as specified in 2-3.2.2 for steel tanks.

2-3.2.4 For tanks built in accordance with 2-1.3.1(a), the burial depth shall be such that the static head imposed at the bottom of the tank will not exceed 10 psig if the fill or vent pipe are filled with liquid. If the depth of cover is greater than the tank diameter, the tank manufacturer shall be consulted to determine if reinforcement is required.

2-3.3 Corrosion Protection. Unless tests show that soil resistivity is 10,000 ohm-centimeters or more, and there are no other corrosive conditions, tanks and their piping shall be protected by either:

(a) a properly installed and maintained cathodic protection system with or without coatings, or

(b) corrosion resistant materials of construction such as special alloys, fiber glass reinforced plastic, or fiber glass reinforced plastic coatings, or equivalent approved system. Selection of the type of protection to be employed shall be based upon the corrosion history of the area and the judgment of a qualified engineer.

(*See API Publication 1615-1979, Installation of Underground Petroleum Storage Systems, for further information.* *)

2-3.4 Abandoned Underground Tanks.

2-3.4.1 Underground tanks taken out of service shall be safeguarded or disposed of in a safe manner. (*See Appendix B.*)

2-3.5 Vents for Underground Tanks.

2-3.5.1 Location and Arrangement of Vents for Class I Liquids. Vent pipes from underground storage tanks storing Class I liquids shall be so located that the discharge point is outside of buildings, higher than the fill pipe opening, and not less than 12 ft (3.7 m) above the adjacent ground level. Vent pipes shall not be obstructed by devices provided for vapor recovery or other purposes unless the tank and associated piping and equipment are otherwise protected to limit back-pressure development to less than the maximum working pressure of the tank and equipment by the provision of pressure-vacuum vents, rupture discs or other tank venting devices installed in the tank vent lines. Vent outlets and devices shall be protected to minimize the possibility of blockage from weather, dirt or insect nests, and shall be so located and directed that flammable vapors will not accumulate or travel to an unsafe location, enter building openings or be trapped under eaves. Tanks containing Class IA liquids shall be equipped with pressure and vacuum venting devices which shall be normally closed except when venting under pressure or vacuum conditions. Tanks storing Class IB or Class IC liquids shall be equipped with pressure-vacuum vents or with listed

*Available from American Petroleum Institute, 2101 L St., N.W., Washington, DC 20037.

flame arresters. Tanks storing gasoline are exempt from the requirements for pressure and vacuum venting devices, except as required to prevent excessive back pressure, or flame arresters, provided the vent does not exceed 3 in. (76.20 mm) nominal inside diameter. (*See also 7-2.1.1.*)

2-3.5.2 Vent Capacity. Tank venting systems shall be provided with sufficient capacity to prevent blowback of vapor or liquid at the fill opening while the tank is being filled. Vent pipes shall not be less than 1¼ in. (31.75 mm) nominal inside diameter. The required venting capacity depends upon the filling or withdrawal rate, whichever is greater, and the vent line length. Unrestricted vent piping sized in accordance with Table 2-10 will prevent back-pressure development in tanks from exceeding 2.5 psig (17.24 kPa). Where tank venting devices are installed in vent lines, their flow capacities shall be determined in accordance with 2-2.5.9.

Table 2-10
Vent Line Diameters

Maximum Flow GPM	Pipe Length* 50 ft.	100 ft.	200 ft.
100	1¼-inch	1¼-inch	1¼-inch
200	1¼-inch	1¼-inch	1¼-inch
300	1¼-inch	1¼-inch	1½-inch
400	1¼-inch	1½-inch	2-inch
500	1½-inch	1½-inch	2-inch
600	1½-inch	2-inch	2-inch
700	2-inch	2-inch	2-inch
800	2-inch	2-inch	3-inch
900	2-inch	2-inch	3-inch
1000	2-inch	2-inch	3-inch

SI Units: 1 in. = 25.40 mm; 1 ft = 0.3048 m.
*Vent lines of 50 ft., 100 ft. and 200 ft. of pipe plus 7 ells.

2-3.5.3 Location and Arrangement of Vents for Class II or Class IIIA Liquids. Vent pipes from tanks storing Class II or Class IIIA liquids shall terminate outside of building and higher than the fill pipe opening. Vent outlets shall be above normal snow level. They may be fitted with return bends, coarse screens or other devices to minimize ingress of foreign material.

2-3.5.4 Vent piping shall be constructed in accordance with Chapter 3. Tank vent pipes and vapor return piping shall be installed without sags or traps in which liquid can collect. Condensate tanks, if utilized, shall be installed and maintained so as to preclude the blocking of the vapor return piping by liquid. The vent pipes and condensate tanks shall be located so that they will not be subjected to physical damage. The tank end of the vent pipe shall enter the tank through the top.

2-3.5.5 When tank vent piping is manifolded, pipe sizes shall be such as to discharge, within the pressure limitations of the system, the vapors they can be required to handle when manifolded tanks are filled simultaneously. Float-type check valves installed in tank openings connected to manifolded vent piping to prevent product contamination may be used provided that the tank pressure will not exceed that permitted by 2-3.2.4 when the valves close.

Exception: For service stations, the capacity of manifolded vent piping shall be sufficient to discharge vapors generated when two manifolded tanks are simultaneously filled.

2-3.5.6 Vent piping for tanks storing Class I liquids shall not be manifolded with vent piping for tanks storing Class II or Class III liquids unless positive means are provided to prevent the vapors from Class I liquids from entering tanks storing Class II or Class III liquids, to prevent contamination (*see 1-1.2*) and possible change in classification of the less volatile liquid.

2-3.6 Tank Openings Other Than Vents for Underground Tanks.

2-3.6.1 Connections for all tank openings shall be liquidtight.

2-3.6.2 Openings for manual gaging, if independent of the fill pipe, shall be provided with a liquidtight cap or cover. Covers shall be kept closed when not gaging. If inside a building, each such opening shall be protected against liquid overflow and possible vapor release by means of a spring loaded check valve or other approved device.

2-3.6.3 Fill and discharge lines shall enter tanks only through the top. Fill lines shall be sloped toward the tank. Underground tanks for Class I liquids having a capacity of more than 1,000 gal (3,785 L) shall be equipped with a tight fill device for connecting the fill hose to the tank.

2-3.6.4 For Class IB and Class IC liquids other than crude oils, gasolines and asphalts, the fill pipe shall be so designed and installed as to minimize the possibility of generating static electricity by terminating within 6 in. (152.4 mm) of the bottom of the tank.

2-3.6.5 Filling and emptying and vapor recovery connections for Class I, Class II or Class IIIA liquids which are made and broken shall be located outside of buildings at a location free from any source of ignition and not less than 5 ft (1.5 m) away from any building opening. Such connections shall be closed and liquidtight when not in use and shall be properly identified.

2-3.6.6 Tank openings provided for purposes of vapor recovery shall be protected against possible vapor release by means of a spring-loaded check valve or dry-break connection, or other approved device, unless the opening is pipe-connected to a vapor processing system. Openings designed for combined fill and vapor recovery shall also be protected against vapor release unless connection of the liquid delivery line to the fill pipe simultaneously connects the vapor recovery line. All connections shall be vaportight.

2-4 Installation of Tanks Inside of Buildings.

2-4.1 Location. Tanks shall not be permitted inside of buildings except as provided in Chapters 5, 6, 7, 8 or 9.

2-4.2 Vents. Vents for tanks inside of buildings shall be as required in 2-2.4, 2-2.5, 2-2.6.2 and 2-3.5, except that emergency venting by the use of weak roof seams on tanks shall not be permitted. Automatic sprinkler systems designed in accordance with the requirements of NFPA 13, *Standard for the Installation of Sprinkler Systems*, may be accepted by the authority having jurisdiction as equivalent to water spray systems for purposes of calculating the required air flow rates for emergency vents in 2-2.5.7. Except for tanks containing Class IIIB liquids, vents shall terminate outside the buildings.

2-4.3 Vent Piping. Vent piping shall be constructed in accordance with Chapter 3.

2-4.4 Tank Openings Other Than Vents for Tanks Inside Buildings.

2-4.4.1 Connections for all tank openings shall be liquidtight.

2-4.4.2 Each connection to a tank inside of buildings through which liquid can normally flow shall be provided with an internal or an external valve located as close as practical to the shell of the tank.

2-4.4.3 Tanks for storage of Class I or Class II liquids inside buildings shall be provided with either:

(a) a normally closed remotely activated valve,

(b) an automatic-closing heat-activated valve, or

(c) another approved device on each liquid transfer connection below the liquid level, except for connections used for emergency disposal, to provide for quick cut-off of flow in the event of fire in the vicinity of the tank.

This function can be incorporated in the valve required in 2-4.4.2, and if a separate valve, shall be located adjacent to the valve required in 2-4.4.2.

2-4.4.4 Openings for manual gaging of Class I or Class II liquids, if independent of the fill pipe, shall be provided with a vaportight cap or cover. Openings shall be kept closed when not gaging. Each such opening for any liquid shall be protected against liquid overflow and possible vapor release by means of a spring loaded check valve or other approved device. Substitutes for manual gaging include, but are not limited to, heavy-duty flat gage glasses, magnetic, hydraulic or hydrostatic remote reading devices and sealed float gages.

2-4.4.5 For Class IB and Class IC liquids other than crude oils, gasolines and asphalts, the fill pipe shall be so designed and installed as to minimize the possibility of generating static electricity by terminating within 6 in. (152.4 mm) of the bottom of the tank.

2-4.4.6 The fill pipe inside of the tank shall be installed to avoid excessive vibration of the pipe.

2-4.4.7 The inlet of the fill pipe and the outlet of a vapor recovery line for which connections are made and broken shall be located outside of buildings at a location free from any source of ignition and not less than 5 ft (1.5 m) away from any building opening. Such connections shall be closed and tight when not in use and shall be properly identified.

2-4.4.8 Tanks storing Class I, Class II and Class IIIA liquids inside buildings shall be equipped with a device, or other means shall be provided, to prevent overflow into the building. Suitable devices include, but are not limited to, a float valve, a preset meter on the fill line, a valve actuated by the weight of the tank contents, a low head pump which is incapable of producing overflow, or a liquidtight overflow pipe at least one pipe size larger than the fill pipe discharging by gravity back to the outside source of liquid or to an approved location.

2-4.4.9 Tank openings provided for purposes of vapor recovery shall be protected against possible vapor release by means of a spring-loaded check valve or dry-break connections, or other approved device, unless the opening is pipe-connected to a vapor processing system. Openings designed for combined fill and vapor recovery shall also be protected against vapor release unless connection of the liquid delivery line to the fill pipe simultaneously connects the vapor recovery line. All connections shall be vaportight.

2-5 Supports, Foundations and Anchorage for All Tank Locations.

2-5.1 Tanks shall rest on the ground or on foundations made of concrete, masonry, piling or steel. Tank foundations shall be designed to minimize the possibility of uneven settling of the tank and to minimize corrosion in any part of the tank resting on the foundation. Appendix E of API Standard 650, *Specification for Welded Steel Tanks for Oil Storage*, and Appendix B of API Standard 620, *Recommended Rules for the Design and Construction of Large, Welded, Low-Pressure Storage Tanks*,* provide information on tank foundations.

2-5.2 When tanks are supported above the foundations, tank supports shall be installed on firm foundations. Supports for tanks storing Class I, Class II or Class IIIA liquids shall be of concrete, masonry or protected steel. Single wood timber supports (not cribbing) laid horizontally may be used for outside aboveground tanks if not more than 12 in. (304.8 mm) high at their lowest point.

2-5.3 Steel supports or exposed piling for tanks storing Class I, Class II or Class IIIA liquids shall be protected by materials having a fire resistance rating of not less than 2 hrs, except that steel saddles need not be protected if less than 12 in. (304.8 mm) high at their lowest point. At the discretion of the authority having jurisdiction, water spray protection in accordance with NFPA 15, *Standard for Water Spray Fixed Systems for Fire Protection*, or NFPA 13, *Standard for the Installation of Sprinkler Systems*, or equivalent may be used.

2-5.4 The design of the supporting structure for tanks such as spheres shall require special engineering consideration. Appendix N of the API Standard 620, *Recommended Rules for the Design and Construction of Large, Welded, Low-Pressure Storage Tanks*,* contains information regarding supporting structures.

2-5.5 Every tank shall be so supported as to prevent the excessive concentration of loads on the supporting portion of the shell.

2-5.6 Where a tank is located in an area subject to flooding, provisions shall be taken to prevent tanks, either full or empty, from floating during a rise in water level up to the established maximum flood stage.

2-5.6.1 Aboveground Tanks.

2-5.6.1.1 Each vertical tank shall be located so that its top extends above the maximum flood stage by at least 30 percent of its allowable storage capacity.

*Available from American Petroleum Institute, 2101 L St., N.W., Washington, DC 20037.

2-5.6.1.2 Horizontal tanks located so that more than 70 percent of the tank's storage capacity will be submerged at the established flood stage shall be anchored; attached to a foundation of concrete or of steel and concrete of sufficient weight to provide adequate load for the tank when filled with flammable or combustible liquid and submerged by flood water to the established flood stage; or adequately secured from floating by other means. Tank vents or other openings which are not liquidtight shall be extended above maximum flood stage water level.

2-5.6.1.3 A dependable water supply shall be available for filling an empty or partially filled tank, except that where filling the tank with water is impractical or hazardous because of the tank's contents, tanks shall be protected by other means against movement or collapse.

2-5.6.1.4 Spherical or spheroid tanks shall be protected by applicable methods as specified for either vertical or horizontal tanks.

2-5.6.2 **Underground Tanks.**

2-5.6.2.1 At locations where there is an ample and dependable water supply available, underground tanks containing flammable or combustible liquids, so placed that more than 70 percent of their storage capacity will be submerged at the maximum flood stage, shall be so anchored, weighted or secured as to prevent movement when filled or loaded with water and submerged by flood water to the established flood stage. Tank vents or other openings which are not liquidtight shall be extended above maximum flood stage water level.

2-5.6.2.2 At locations where there is no ample and dependable water supply or where filling of underground tanks with water is impractical because of the contents, each tank shall be safeguarded against movement when empty, and submerged by high ground water or flood water by anchoring or by securing by other means. Each such tank shall be so constructed and installed that it will safely resist external pressures if submerged.

2-5.6.3 **Water Loading.** The filling of a tank to be protected by water loading shall be started as soon as flood waters are predicted to reach a dangerous flood stage. Where independently fueled water pumps are relied upon, sufficient fuel shall be available at all times to permit continuing operations until all tanks are filled. Tank valves shall be closed and locked in closed position when water loading has been completed.

2-5.6.4 ***Operating Instructions.***

2-5.6.4.1 Operating instructions or procedures to be followed in a flood emergency shall be readily available.

2-5.6.4.2 Personnel relied upon to carry out flood emergency procedures shall be informed of the location and operation of valves and other equipment necessary to effect the intent of these requirements.

2-5.7 In areas subject to earthquakes, the tank supports and connections shall be designed to resist damage as a result of such shocks.

2-6 **Sources of Ignition.**

2-6.1 In locations where flammable vapors may be present, precautions shall be taken to prevent ignition by eliminating or controlling sources of ignition. Sources of ignition may include open flames, lightning, smoking, cutting and welding, hot surfaces, frictional heat, sparks (static, electrical and mechanical), spontaneous ignition, chemical and physical-chemical reactions and radiant heat. NFPA 77, *Recommended Practice on Static Electricity*, and NFPA 78, *Lightning Protection Code*, provide information on such protection.

2-7 **Testing.**

2-7.1 All tanks, whether shop-built or field-erected, shall be tested before they are placed in service in accordance with the applicable paragraphs of the Code under which they were built. The ASME Code stamp, API monogram, or the Listing Mark of Underwriters Laboratories Inc. on a tank shall be evidence of compliance with this test. Tanks not marked in accordance with the above Codes shall be tested before they are placed in service in accordance with good engineering principles and reference shall be made to the sections on testing in the Codes listed in 2-1.3.1, 2-1.4.2, or 2-1.5.2.

2-7.2 When the vertical length of the fill and vent pipes is such that when filled with liquid the static head imposed upon the bottom of the tank exceeds 10 lbs per sq in. (68.95 kPa), the tank and related piping shall be tested hydrostatically to a pressure equal to the static head thus imposed. In special cases where the height of the vent above the top of the tank is excessive, the hydrostatic test pressure shall be determined by using recognized engineering practice.

2-7.3 In addition to the test called for in 2-7.1 and 2-7.2, all tanks and connections shall be tested for tightness. Except for underground tanks, this tightness shall be made at operating pressure with air, inert gas or water prior to placing the tank in service. In the case of field-erected tanks the test called for in 2-7.1 or 2-7.2 may be considered to be the test for tank tightness.

Underground tanks and piping, before being covered, enclosed, or placed in use, shall be tested for tightness hydrostatically, or with air pressure at not less than 3 lbs per sq in. (20.68 kPa) and not more than 5 lbs per sq in. (34.475 kPa). (*See 3-7.1 for testing pressure piping.*)

2-7.4 Before the tank is initially placed in service, all leaks or deformations shall be corrected in an acceptable manner. Mechanical caulking is not permitted for correcting leaks in welded tanks except pin hole leaks in the roof.

2-7.5 Tanks to be operated at pressures below their design pressure may be tested by the applicable provisions of 2-7.1 or 2-7.2 based upon the pressure developed under full emergency venting of the tank.

2-8 Fire Protection and Identification.

2-8.1 A fire extinguishing system in accordance with an applicable NFPA standard shall be provided or be available for vertical atmospheric fixed roof storage tanks larger than 50,000 gal (189,250 L) capacity storing Class I liquids if located in a congested area where there is an unusual exposure hazard to the tank from adjacent property or to adjacent property from the tank. Fixed roof tanks storing Class II or III liquids at temperatures below their flash points and floating roof tanks storing any liquid generally do not require protection when installed in compliance with Section 2-2.

2-8.2 The application of NFPA 704, *Identification of the Fire Hazards of Materials*, to storage tanks containing liquids shall not be required except when the contents have a health or reactivity degree of hazard of 2 or more or a flammability rating of 4. The marking need not be applied directly to the tank but located where it can readily be seen, such as on the shoulder of an accessway or walkway to the tank or tanks or on the piping outside of the diked area. If more than one tank is involved, the markings shall be so located that each tank can readily be identified.

2-9 Prevention of Overfilling of Tanks.

2-9.1 Tanks receiving transfer of Class I liquids from mainline pipelines or marine vessels and located in an area where overfilling may endanger a place of habitation or public assembly shall be either:

(a) Gaged at frequent intervals while receiving transfer of product, and communications maintained with mainline pipeline or marine personnel so that flow can be promptly shut down or diverted, or

(b) Equipped with an independent high level alarm located where personnel are on duty during the transfer and can promptly arrange for flow stoppage or diversion, or

(c) Equipped with an independent high level alarm system that will automatically shut down or divert flow.

2-10 Leakage Detection and Inventory Records for Underground Tanks.

2-10.1 Accurate inventory records or a leak detection program shall be maintained on all Class I Liquid Storage Tanks for indication of possible leakage from the tanks or associated piping. (*See NFPA 329, Underground Leakage of Flammable and Combustible Liquids.*)

Chapter 3 Piping, Valves and Fittings

3-1 General.

3-1.1 The design, fabrication, assembly, test and inspection of piping systems containing liquids shall be suitable for the expected working pressures and structural stresses. Conformity with the applicable sections of ANSI B31, *American National Standard Code for Pressure Piping*, and the provisions of this chapter shall be considered prima facie evidence of compliance with the foregoing provisions.

3-1.2 This chapter does not apply to any of the following:

(a) Tubing or casing on any oil or gas wells and any piping connected directly thereto.

(b) Motor vehicle, aircraft, boat or portable or stationary engine.

(c) Piping within the scope of any applicable boiler and pressure vessel code.

3-1.3 Piping systems consist of pipe, tubing, flanges, bolting, gaskets, valves, fittings, the pressure containing parts of other components such as expansion joints and strainers, and devices which serve such purposes as mixing, separating, snubbing, distributing, metering, or controlling flow.

3-2 Materials for Piping, Valves and Fittings.

3-2.1 Pipe, valves, faucets, fittings and other pressure containing parts as covered in 3-1.3 shall meet the material specifications and pressure and temperature limitations of ANSI B31.3-1973*, *Petroleum Refinery Piping*, or ANSI B31.4-1974*, *Liquid Petroleum Transportation Piping Systems*, except as provided by 3-2.2, 3-2.3, and 3-2.4. Plastic or similar materials, as permitted by 3-2.4, shall be designed to specifications embodying recognized engineering principles and shall be compatible with the fluid service.

3-2.2 Nodular iron shall conform to ASTM A395—74, *Ferritic Ductile Iron Pressure Retaining Castings for Use at Elevated Temperatures*.**

*Available from the American Society of Mechanical Engineers, United Engineering Center, 345 East 47th St., New York, NY 10017.

**Available from American Society for Testing and Materials, 1916 Race St., Philadelphia, PA 19103.

3-2.3 Valves at storage tanks, as required by 2-2.7.1 and 2-4.4.2, and their connections to the tank shall be of steel or nodular iron except as provided in 3-2.3.1 or 3-2.3.2.

3-2.3.1 Valves at storage tanks may be other than steel or nodular iron when the chemical characteristics of the liquid stored are not compatible with steel or when installed internally to the tank. When installed externally to the tank, the material shall have a ductility and melting point comparable to steel or nodular iron so as to withstand reasonable stresses and temperatures involved in fire exposure, or otherwise be protected such as by materials having a fire resistance rating of not less than 2 hrs.

3-2.3.2 Cast iron, brass, copper, aluminum, malleable iron, and similar materials may be used on tanks described in 2-2.2.2 or for tanks storing Class IIIB liquids when the tank is located outdoors and not within a diked area or drainage path of a tank storing a Class I, Class II or Class IIIA liquid.

3-2.4 Low melting point materials, such as aluminum, copper and brass; or materials which soften on fire exposure, such as plastics; or nonductile material, such as cast iron, may be used underground for all liquids within the pressure and temperature limits of ANSI B31, *American National Standard Code for Pressure Piping**. If such materials are used outdoors in aboveground piping systems handling Class I, Class II or Class IIIA liquids or within buildings handling any liquid, they shall be either: (a) suitably protected against fire exposure, or (b) so located that any leakage resulting from the failure would not unduly expose persons, important buildings or structures, or (c) located where leakage can readily be controlled by operation of an accessible remotely located valve or valves.

3-2.5 Piping, valves and fittings may have combustible or noncombustible linings.

3-3 Pipe Joints.

3-3.1 Joints shall be made liquidtight and shall be either welded, flanged or threaded, except that listed flexible connectors may be used when installed in accordance with 3-3.2. Threaded joints shall be made up tight with a suitable thread sealant or lubricant. Joints in piping systems handling Class I liquids shall be welded when located in concealed spaces within buildings.

3-3.2 Pipe joints dependent upon the friction characteristics or resiliency of combustible materials for mechanical continuity or liquid-tightness of piping shall not be used inside buildings. They may

*Available from the American Society of Mechanical Engineers, United Engineering Center, 345 East 47th St., New York, NY 10017.

be used outside of buildings above or below ground. If used aboveground outside of buildings, the piping shall either be secured to prevent disengagement at the fitting, or the piping system shall be so designed that any spill resulting from disengagement could not unduly expose persons, important buildings or structures, and could be readily controlled by remote valves.

3-4 Supports.

3-4.1 Piping systems shall be substantially supported and protected against physical damage and excessive stresses arising from settlement, vibration, expansion or contraction. The installation of nonmetallic piping shall be in accordance with the manufacturer's instructions.

3-5 Protection Against Corrosion.

3-5.1 All piping for liquids, both aboveground and underground, where subject to external corrosion, shall be painted or otherwise protected. (*See 2-3.3 for protection of piping connected to underground tanks.*)

3-6 Valves.

3-6.1 Piping systems shall contain a sufficient number of valves to operate the system properly and to protect the plant. Piping systems in connection with pumps shall contain a sufficient number of valves to control properly the flow of liquid in normal operation and in the event of physical damage. Each connection to piping by which equipment such as tank cars, tank vehicles or marine vessels discharge liquids into storage tanks shall be provided with a check valve for automatic protection against back-flow if the piping arrangement is such that back-flow from the system is possible. (*See also 2-2.7.1.*)

3-7 Testing.

3-7.1 Unless tested in accordance with the applicable sections of ANSI B31, *American National Standard Code for Pressure Piping*,* all piping before being covered, enclosed or placed in use shall be hydrostatically tested to 150 percent of the maximum anticipated pressure of the system, or pneumatically tested to 110 percent of the maximum anticipated pressure of the system, but not less than 5 lbs per sq in. (34.48 kPa) gage at the highest point of the system. This test shall be maintained for a sufficient time to complete visual inspection of all joints and connections, but for at least 10 minutes.

*Available from the American Society of Mechanical Engineers, United Engineering Center, 345 East 47th St., New York, NY 10017.

Chapter 4 Container and Portable Tank Storage

4-1 Scope.

4-1.1 This chapter shall apply to the storage of liquids, including flammable aerosols, in drums or other containers not exceeding 60 gal (227.1 L) individual capacity and portable tanks not exceeding 660 gal (2,498.1 L) individual capacity and limited transfers incidental thereto. For portable tanks exceeding 660 gal (2,498.1 L), Chapter 2 shall apply.

4-1.2 This chapter shall not apply to the following:

(a) Storage of containers in bulk plants, service stations, refineries, chemical plants and distilleries.

(b) Liquids in the fuel tanks of motor vehicles, aircraft, boats or portable or stationary engines.

(c) Beverages when packaged in individual containers not exceeding a capacity of one gallon.

(d) Medicines, foodstuffs, cosmetics and other consumer products containing not more than 50 percent by volume of water miscible liquids and with the remainder of the solution not being flammable when packaged in individual containers not exceeding one gallon in size.

(e) The storage of liquids that have no fire point when tested by ASTM D 92-72, the Cleveland Open Cup Test Method, up to the boiling point of the liquid, or up to a temperature at which the sample being tested shows an obvious physical change.

(f) The storage of distilled spirits and wines in wooden barrels or casks.

4-1.3 For the purpose of this chapter, unstable liquids and flammable aerosols shall be treated as Class IA liquids.

4-2 Design, Construction, and Capacity of Containers.

4-2.1 Only approved containers and portable tanks shall be used. Metal containers and portable tanks meeting the requirements of, and containing products authorized by, Chapter I, Title 49 of the *Code of Federal Regulations* (DOT Regulations), or NFPA 386, *Standard for Portable Shipping Tanks*, shall be acceptable. Polyethylene containers meeting the requirements of, and containing products authorized by, DOT Specification 34, and polyethylene drums authorized by DOT Exemption Procedures, shall be acceptable. Plastic containers, meeting the requirements of ANSI/ASTM

61. National Fire Protection Association, Inc. Flammable and Combustible Liquids Code 1981, (NFPA 329), Quincy, Massachusetts, June 1983

NFPA

329

ANSI / NFPA 329
An American
National
Standard
June 9, 1983

UNDERGROUND LEAKAGE OF FLAMMABLE & COMBUSTIBLE LIQUIDS 1983

NFPA®

we've changed our name
leak lokator LD2000
now a division of
Hunter Environmental Services, Inc.
18 GREAT VALLEY PARKWAY
SUITE 6 • MALVERN, PA 19355
215-296-7380 • 800-523-4370

Copyright © 1983
All Rights Reserved

2.5M-6-83-FP
Printed in U.S.A.

NATIONAL FIRE PROTECTION ASSOCIATION, INC.
Batterymarch Park, Quincy, MA 02269

617 - 770-3000

NOTICE

All questions or other communications relating to this document should be sent only to NFPA Headquarters, addressed to the attention of the Committee responsible for the document.

For information on obtaining Formal Interpretations of the document, proposing Tentative Interim Amendments, proposing amendments for Committee consideration, and appeals on matters relating to the content of the document, write to the Vice President and Chief Engineer, National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.

A statement, written or oral, that is not processed in accordance with Section 16 of the Regulations Governing Committee Projects shall not be considered the official position of NFPA or any of its Committees and shall not be considered to be, nor be relied upon as, a Formal Interpretation.

Users of this document should consult applicable Federal, State and local laws and regulations. NFPA does not, by the publication of this document, intend to urge action which is not in compliance with applicable laws and this document may not be construed as doing so.

Policy Adopted by NFPA Board of Directors on December 3, 1982

The Board of Directors reaffirms that the National Fire Protection Association recognizes that the toxicity of the products of combustion is an important factor in the loss of life from fire. NFPA has dealt with that subject in its technical committee documents for many years.

There is a concern that the growing use of synthetic materials may produce more or additional toxic products of combustion in a fire environment. The Board has, therefore, asked all NFPA technical committees to review the documents for which they are responsible to be sure that the documents respond to this current concern. To assist the committees in meeting this request, the Board has appointed an advisory committee to provide specific guidance to the technical committees on questions relating to assessing the hazards of the products of combustion.

Licensing Provision

This document is copyrighted by the National Fire Protection Association (NFPA). Public authorities and others are urged to reference this document in laws, ordinances, regulations and administrative orders or similar instruments. Any deletions, additions, and changes desired by the adopting authority must be noted separately. Those using this method ("adoption by reference") are requested to notify the NFPA (Attention: Vice President and Chief Engineer) in writing of such use.

The term "adoption by reference" means the citing of the title and publishing information only.

(For further explanation, see the Policy Concerning the Adoption, Printing and Publication of NFPA Documents which is available upon request from the NFPA.)

MGR-AM-85

© 1983 NFPA, All Rights Reserved

Recommended Practice for Handling Underground Leakage of Flammable and Combustible Liquids

NFPA 329-1983

1983 Edition of NFPA 329

This edition of NFPA 329, *Recommended Practice for Handling Underground Leakage of Flammable and Combustible Liquids*, was prepared by the Technical Committee on Tank Leakage and Repair Safeguards (released by the Correlating Committee on Flammable Liquids), and acted on by the National Fire Protection Association, Inc. on May 18, 1983 at its Annual Meeting in Kansas City, Missouri. It was issued by the Standards Council on June 9, 1983 with an effective date of June 29, 1983 and supersedes all previous editions.

The 1983 edition of this standard has been approved by the American National Standards Institute.

Changes other than editorial are indicated by a vertical rule in the margin of the pages on which they appear. These lines are included as an aid to the user in identifying changes from the previous edition.

Origin and Development of NFPA 329

This Recommended Practice is an update of the *Recommended Practice for Handling Underground Leakage of Flammable and Combustible Liquids*, NFPA 329 — 1977 edition.

This Recommended Practice replaces the 1977, 1972, 1965 and 1964 editions and a manual on this subject issued in 1959. The manual was preceded by a report (NFPA 30B) on the same subject which was withdrawn from publication in 1950.

Committee on Flammable Liquids

Correlating Committee

Paul C. Lamb, *Chairman*
Englewood, NJ

Martin Henry, *Secretary*
National Fire Protection Association
(Nonvoting)

G. E. Cain, G. E. Cain & Co.
J. A. Cedervall, Casualty & Chemical Hazards Dept., ULI
Donald M. Johnson, Standard Oil Co. of California
Rep. Western Oil & Gas Assn.
F. Owen Kubias, Glidden-Durkee Div., SCM Corp.
Steven Landon, Washex Machinery Corp.
Rep. Laundry-Cleaners Allied Trades Assn.
Capt. William R. Rucinski, MI State Police
W. J. Smith, Underwriters Laboratories Inc.

Nonvoting
Dr. Ing Gert Magnus, Krs Mannheim, Germany

Technical Committee on Tank Leakage and Repair Safeguards

J. A. Cedervall, *Chairman*
Underwriters Laboratories, Inc.

Martin Henry, Secretary
National Fire Protection Association
(Nonvoting)

Paul R. Guerra, Oil Recovery Systems, Inc.
William C. Jackson, Phillips Petroleum Co.
Rep. American Petroleum Inst.
Donald M. Johnson, Standard Oil Co. of California
Rep. Western Oil & Gas Assn.
Frederick B. Killmar, Killmar Assoc., Inc.
H. Kolodner, Celanese Corp.
Rep. Chemical Manufacturers Assn.
Edwin Liu, NJ Dept. of Enviromental Protection
Rafael J. Nieves, Prince George County Fire Dept.
Rep. Fire Marshals Assn. of N. America
Emily E. Schirding, Steel Tank Inst.
Bruce R. Sharp, Armor Shield Inc.
Pat R. Wrigley, Nat'l Petroleum Refiners Assn.

Alternates

John A. Ainlay, Steel Tank Institute
(Alternate to E. E. Schirding)
Richard Southers, American Petroleum Inst.
(Alternate to W. C. Jackson)

This list represents the membership at the time the Committee was balloted on the text of this edition. Since that time, changes in the membership may have occurred.

NOTE: Membership on a Committee shall not in and of itself constitute an endorsement of the Association or any document developed by the Committee on which the member serves.

Contents

Chapter 1 Introduction 329- 5
1-1 The Problem 329- 5
1-2 Cooperation and Responsibility 329- 6

Chapter 2 Procedure When Life or Property May Be in Danger 329- 8
2-1 General 329- 8
2-2 Conditions 329- 8
2-3 Condition 2-2.1(a) 329- 8
2-4 Condition 2-2.1(b) 329-11
2-5 Condition 2-2.1(c) 329-12
2-6 Condition 2-2.2 329-14

Chapter 3 Primary Search for the Source 329-15
3-1 General 329-15
3-2 Primary Search Procedure 329-16

Chapter 4 Testing for Underground Leaks 329-20
4-1 General 329-20
4-2 Action Preliminary to Testing 329-21
4-3 Checking Inventory Records 329-21

Chapter 5 Tracing Liquids Underground 329-33
5-1 General 329-33
5-2 Background 329-33
5-3 Test to Determine Underground Flow 329-40
5-4 Other Tracing Test Methods 329-42
5-5 Chromatographic and Spectrographic Identification of Components 329-42
5-6 Other Chemical Analysis 329-43

Chapter 6 Removal and Disposal 329-44
6-1 329-44
6-2 329-44
6-3 329-44
6-4 329-44
6-5 329-44

6-6 Basements 329-45
6-7 Subways, Tunnels and Mines 329-45
6-8 Utility Conduits 329-47
6-9 Sewers 329-48
6-10 Underground Soil Contamination 329-49
6-11 Removal of Liquids 329-50

Appendix A Physical Properties
Common Flammable and Combustible Liquids 329-56

Appendix B Referenced Publications 329-57

Recommended Practice for Handling Underground Leakage of Flammable and Combustible Liquids

NFPA 329-1983

Chapter 1 Introduction

The purpose of this Recommended Practice is to provide a guide for the safe and efficient handling of flammable and combustible liquids when, for whatever reason, they are found unconfined and unwanted. For the proper installation of underground tanks, see NFPA 30, *Flammable and Combustible Liquids Code*.

1-1 The Problem.

1-1.1 Flammable liquids [those having a flash point below 100°F (37.8°C)] and combustible liquids [those having a flash point at or above 100°F (37.8°C)] are used by the millions of gallons daily and, of necessity, are stored and handled in locations immediately adjacent to structures, facilities, and people. These liquids include chemicals, cleaning fluids, motor gasolines, diesel fuel and heating oils. Motor gasolines are the most widely used of these liquids and they are commonly stored underground at service stations.

1-1.2 In spite of constant effort to maintain and operate storage and transfer equipment properly, accidents do happen, equipment does fail, and people do make mistakes that sometimes permit the escape of these liquids. Leaks may develop from corrosion, or be caused by mechanical damage, or some liquid may be spilled during transfer. Generally, the amount of liquid lost is small and it is dissipated by evaporation or is otherwise assimilated before it creates a serious problem. However, it occasionally happens that some flammable or combustible liquid finds its way into an underground facility, such as a basement, utility conduit, sewer, or well. Whether or not it creates an immediate hazard will depend on many things, such as how much liquid or its vapor is involved, where it is found, how it is confined, possible sources of ignition, etc. But, because a flammable or combustible liquid unconfined in the ground can move

from place to place, any indication that such liquids have escaped into the ground must be considered as a potential, if not immediate, hazard.

1-2 Cooperation and Responsibility.

1-2.1 The responsibility for proper handling of a suspected escape of flammable or combustible liquids, or a potential hazard from such an escape, will fall upon various individuals and organizations. The successful handling of these problems will depend upon the best possible cooperation between them.

1-2.2 One of the prime purposes of this guide is to provide a basis for this cooperation. Because of the almost infinite variables involved, it can't be a rule book in the strict sense of the word. It can, however, provide a definite course of cooperative action that will ensure the most effective use of skills and equipment, the fairest assessment of responsibility, and will result in the best possible protection of life and property. A positive, cooperative attitude of anyone potentially involved will benefit everyone, regardless of the final results. Lack of cooperation could result in inadequate protection of life and property.

1-2.3 Since leakage of flammable liquids, especially such liquids having low flash points, is a fire problem, necessary steps to be taken will normally be under the jurisdiction of the fire officials. It therefore becomes important for such officials to understand the many facets of the problem, and to secure the cooperation of interested groups as outlined above.

1-2.4 Recent developments, problems and attitudes have now also involved health and environmental officials. When dealing particularly with water pollution and the more persistent slow or non-evaporating combustible liquids, the concern of these officials may be paramount.

1-2.5 The location of leaks, testing of tanks and piping, removal of leaky tanks and removal of liquid in the earth will require equipment and facilities which may be more available to the industries involved than to the public authorities. In addition, much of the work is not the responsibility of the fire department or other agencies, but rather is the responsibility of the owner of the leakng equipment.

1-2.6 Regardless of the willingness of individuals or companies to cooperate with governmental agencies during an emergency, the agencies should recognize that they should officially request such cooperation.

1-2.7 When tanks are to be removed, or other work done on private equipment, or on private property, such as holes being dug, this work must be authorized by the owner. Such authorization generally is easy to secure if the work has been requested by officials. In some cases, these requests may of necessity be in the form of a written order. Regardless of conditions leadership and a close spirit of cooperation should be established by the responsible agency.

1-2.8 In addition, those in industry having special qualifications in dealing with leakage should be called upon for help and guidance. Their knowledge and experience should merit careful consideration.

1-2.9 This guide is intended for the information of all organizations and persons involved.

Chapter 2 Procedure When Life or Property May Be in Danger

2-1 General. The need for cooperative effort by many individuals and organizations is stressed in the introduction preceding this chapter. Good judgment must be used in assembling the various groups. Always seek assistance in the interests of safety, but avoid creating unnecessary alarm or unwarranted interruption of normal activities. Owners, operators or others becoming aware of a hazardous condition should notify the fire department, police, or other proper authority. However, make every reasonable effort to determine the degree of the problem. Excessive alarming, such as may be caused by unwarranted evacuation or publicity, can create more hazard than the original problem. Good judgment applied to the following step-by-step guide will materially improve the chances for successful results.

2-2 Conditions. The potential that unconfined flammable or combustible liquids exist underground will normally become known by discovery of one of the following conditions:

2-2.1 Combustible or flammable liquids or their vapors are reported in:

(a) Normally inhabited subsurface structures such as basements, subways, and tunnels;

(b) Other subsurface structures such as sewers, utility conduits and observation wells near tanks;

(c) Groundwater such as drawn from wells, on or in surface water, or emerging from cuts or slopes in the earth.

2-2.2 User reports loss of stock or presence of water in the storage facility. *Each condition requires different handling*:

2-3 Condition 2-2.1(a) — Normally Inhabited Subsurface Structures such as Basements, Subways, and Tunnels.

2-3.1 General. This condition implies a strong potential hazard to life or property and immediate steps must be taken to protect the public from the danger of explosion and fire.

2-3.2 Eliminating Sources of Ignition.

2-3.2.1 Smoking or other sources of ignition should not be permitted in the suspected area. Lights and other electrical switches should not be turned on or off and extension cords should not be removed from outlets. Such action may create a spark capable of igniting flammable vapors. Use only those switches located well away from the contaminated area to cut off electrical power, which may require the electric utility to make a remote cutoff.

2-3.2.2 After the presence of flammable vapors has been verified, the electric and gas services to the building, where possible and feasible, should be disconnected or cut off outside the structure. The shutting off of the gas service outside of the building removes the fuel from pilot lights and gas burners, which may be sources of ignition.

2-3.2.3 No one should enter the contaminated area except as described in "Entering the Area." Where liquids or vapor within or above their flammable range are found in a building, the building should not be entered, and evacuation of building occupants, at least in areas exposed, should be ordered. Construction and layout as well as occupancy are factors to be considered in ordering evacuation. Traffic should be stopped through tunnels and subways until qualified personnel determine there is no danger of explosion or fire.

2-3.3 Entering the Area.

2-3.3.1 The presence of flammable vapors in a building is generally reported because of an odor. Most persons can detect gasoline vapor in concentrations as low as .005 percent. However, smell cannot be relied upon to determine the type of vapor or its concentration. The use of a combustible gas indicator is the only practical, positive method to determine the presence and extent of a flammable vapor concentration.

2-3.3.2 To enter an area in which there is an undetermined concentration of some unknown vapor is to risk the possibility of fire or explosion. Entry should not be made until the vapor concentration has been checked with a combustible gas indicator. Portable combustible gas indicators are reasonable in price and are recommended for use by all fire departments. If the fire department does not have such an indicator, arrangements should be made for securing one or more from utilities, oil companies or others who may have them available. A trained operator should use the combustible gas indicator, which must be well maintained.

2-3.3.3 Also an additional life hazard may exist because of toxic vapors or insufficient oxygen. If these conditions are suspected, instruments to detect toxic vapors or insufficient oxygen should be used.

2-3.3.4 Use the combustible gas indicator continuously to determine the range of vapor concentrations in the affected area. If areas of vapor concentration above 50 percent of the lower flammable limits (LEL on indicators) are exposed to a source of ignition, leave the area and evacuate everyone within the danger zone. Ventilate the area to remove or reduce the flammable vapors and thus reduce the fire or explosion hazard. As soon as the flammable vapor has been re-

duced below 50 percent of the lower flammable limit, entry may be made to locate and eliminate the source of vapor. Wear self-contained breathing apparatus when entering.

2-3.4 Ventilating the Area.

2-3.4.1 Natural ventilation by opening doors and windows may be adequate. Grounded mechanical exhaust ventilating equipment may be required to remove vapors from all areas, particularly from low, confined spaces. Use fans driven by motors approved for Class I, Group D locations, hand-driven fans, or air eductors to remove vapors. (*See Figure 1.*) Eliminate sources of ignition near the exhaust outlets. Provide openings for free entry of fresh air, but never force air into the area. A water hose with the nozzle set in a spray pattern may be used for ventilating the area when set in a window and discharging outwardly.

2-3.5 Locating Seepage into Building.

2-3.5.1 When the area has been made safe for entry, it may be examined to determine the source of the flammable vapors. If the place or places of entry of the liquid or vapors can be determined, appropriate steps should be taken to seal off such places. Untrapped drains, dry traps, pipes or other openings through floors or foundations are common sources of liquid or vapor entry into a building. Check any gas pipes in the area; the flammable vapor may be fuel gas. If this appears to be the source, call the gas company.

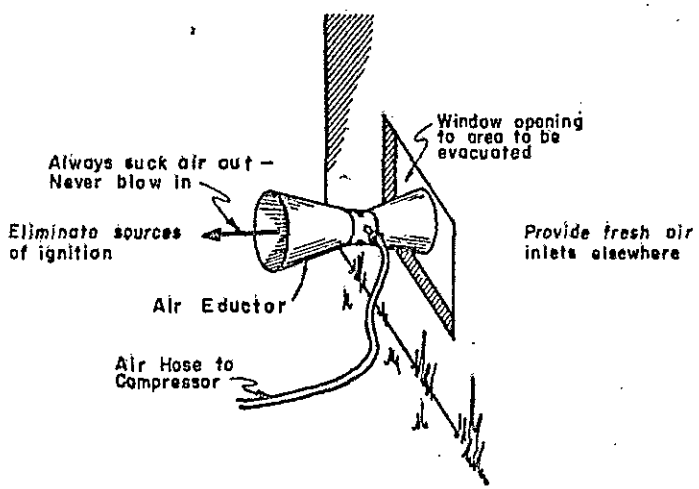


Figure 1 Exhaust Venting

2-3.6 Preventing Seepage into Buildings.

2-3.6.1 Entrance of vapors or liquids through drains, pipes, or other openings may be stopped by plugging such openings. Sewer pipes may be the source of entry. If only vapor is entering through a sewer pipe, it may be because the trap is dry. Filling the trap with water is an effective means of blocking further gas or vapor entry.

2-3.6.2 The nature of seepage may be such that it cannot be effectively stopped from the inside of the structure. In this case an intercepting hole or trench, holes for pumps, or well points may be used outside the contaminated structure, between it and the suspected source. (*See Chapter 6 for details.*)

2-4 Condition 2-2.1(b) — Other Subsurface Structures such as Sewers, Utility Conduits, and Observation Wells near Tanks.

2-4.1 Liquids or vapors in such structures imply a potential for explosion or fire but, generally, a low potential of hazard to life and property other than to the structure involved. If the detection of flammable or combustible liquids or their vapors indicates an unusual condition wherein vapors are escaping from the sewer or conduit into an area similar to Condition 2-2.1(a), or if the proximity to other structures or facilities is such that an explosion or fire would be relatively as serious as Condition 2-2.1(a); then proceed with the guides of 2-2.1(a) in addition to the following procedures.

2-4.1.1 Contact those directly responsible for the facility involved: the municipal sanitary department or highway or street department for sewers; for conduit, the electrical, telephone and gas companies' engineering departments. Normally, the maintenance and engineering departments of such organizations will be well equipped to take charge of the situation; police, if needed, may be asked to keep the public clear of the danger areas. The fire department may be needed to assist in fire control and purging. Those involved with the storage and handling facilities of flammable and combustible liquids that may be the source of the problem should offer all possible assistance. (*See NFPA 328, Flammable Liquids and Gases in Manholes and Sewers, and Chapter 5 of this guide for further details.*)

2-4.2 Entering the Area.

2-4.2.1 Basically the same as for Condition 2-2.1(a); however, the flammable vapors in a sewer or conduit may not originate from flammable liquids. They may be vapors from overheated insulation, sewer-generated gases, fuel gases, or industrial gases. Consequently,

special instruments, equipment and skills may be needed. The guidance of the utility owning and operating the facility should be solicited and followed.

2-4.3 Ventilating the Area.

2-4.3.1 Some type of grounded mechanical ventilating will normally be required. Use explosionproof equipment if the vapors are drawn out. Remove all sources of ignition from the vicinity of vapor exit.

2-4.3.2 It may be that water flushing is the better means of purging the area of flammable vapors. For example, the generation of sewer gas may be stopped or significantly reduced by this method. In a similar fashion, flammable and combustible liquids may be removed from the area.

2-4.3.3 In any case, follow the guidance of the owner or operator of the facility as he will be most familiar with its characteristics and the consequences of any action taken.

2-4.4 Locating the Seepage.

2-4.4.1 Assist the facility owner in any way practicable. See Chapter 5 for information on tracing liquids underground.

2-4.5 Preventing Continued Seepage.

2-4.5.1 When leakage is detected in a sewer, location of the source of the leak should be determined by backtracking with combustible gas indicators. If points of entry to the sewer system are limited in number, interception of the leak can be achieved by use of trenches, well holes, or well points. (*See API 1628-1980, Underground Spill Cleanup Manual, for additional information.*)

2-4.5.2 If entry of liquid or vapor into the conduit or sewer is to be stopped, and the inside of the facility is not accessible, probe or drill alongside the facility to determine the extent of its exposure to the saturated soil. Uncover the exposed area and caulk the facility from the outside.

2-5 Condition 2-2.1(c) — Groundwater such as Drawn from Wells, on or in Surface Water, or Emerging from Cuts or Slopes in the Earth.

2-5.1 General. These liquid seepages on water will often be more of a problem because of pollution than as an explosion or fire hazard. However, until the source of the flammable or combustible liquid is found and stopped and all liquid and vapor safely removed, there is a potential hazard of explosion or fire.

2-5.2 Wells.

2-5.2.1 When flammable or combustible liquids are found in well water, stop pumping and avoid any source of ignition around well houses and water storage tanks until vapor concentrations are checked. Turn power off outside any well house or similar trap that may collect vapors from the well or stored water.

2-5.2.2 If vapor concentrations are below 50 percent of the lower explosive limit, pumping may be resumed if desirable for purging. (*See Chapter 6 for details.*)

2-5.3 Surface Water.

2-5.3.1 When flammable or combustible liquids are found on surface water or water emerging from hillsides or cuts, concentrations may develop in ditches or collection points that may create an explosion or fire hazard. Normally, the amount of flammable or combustible liquid found on the surface water will be in such a thin layer that it does not create a fire hazard. This is the case when the liquid is dispersed into small bubbles or pools, or when only color patterns are visible on the surface of the water.

2-5.3.2 However, if the entire surface of the water is covered, or there are large pools in the order of 20 ft (6 m) or more across, a fire hazard does exist. If this occurs in an inhabited area or along a street or highway, and the police and fire department are not present, they should be called. Traffic should be stopped and the public kept away from the area. If large amounts of vapor are being generated, check the wind and remove all sources of ignition within at least 100 ft (30 m) downwind of the source. It is unlikely that vapors will be in the flammable range farther than 100 ft (30 m) away. However, if large amounts are involved, and the air is relatively still, a combustible gas indicator should be used to determine the extent of the hazardous area. Its use is desirable in any event if flammable liquids are involved.

2-5.3.3 Normally, the only effective means to stop further accumulation will be to find the source and stop it. (*See Chapters 5 and 6.*) It may be desirable to construct dikes or dams to prevent further spreading of the liquids or of contaminated water.

2-5.3.4 Floating booms can be used on flowing water to hold the contaminating liquid. (*See Chapter 6 for details.*)

2-5.3.5 Once the source of flammable or combustible liquids is stopped, evaporation or normal dispersal and dilution will often be the best means of removal. Collection with adsorbents or skimming devices or filtering devices may be necessary. (*See Chapter 6 for details.*)

2-6 Condition 2-2.2 — User Reports Loss of Product or Presence of Water in Storage Facility.

2-6.1 An inventory loss, or water in tanks, does not directly imply a hazard of fire and explosion. Check the immediate vicinity for any signs of escaping liquid; if any exist, apply Conditions 2-2.1(a), 2-2.1(b), or 2-2.1(c), as appropriate. Otherwise, proceed in accordance with Chapter 4, Testing for Underground Leaks.

Chapter 3 Primary Search for the Source

3-1 General.

3-1.1 Once all necessary precautions have been taken to protect life and property, the next most important step is to determine the source of the flammable or combustible liquid and prevent any further escape.

3-1.2 Generally, the source of a flammable or combustible liquid will be relatively near the location of the discovery of unconfined liquids or vapors. However, liquids can travel blocks or even miles underground through porous soil or rock, trenches filled with porous soil, alongside pipes or conduits, or in sewer pipes. Consequently, the area from which an escaped liquid could have come may be remote and extensive, and include many facilities storing and handling flammable or combustible liquids. If a check of potential sources (*see 3-2.2.1 for check list*) immediately adjacent to, or within a few hundred feet of, the discovery does not reveal an obvious or possible source, organize a general search of the area.

3-1.3 Efforts should be made to secure information on ground water flow from the local United States Geological Survey (USGS) office, public works departments, or equivalent agency and primary search efforts should be initiated upgradient of the leak.

3-1.4 Obtain (or sketch) a map of the area, mark each facility found on the map, and record all the information obtained in a notebook. Good data, well organized, will prove invaluable in subsequent efforts to solve the problem.

3-1.5 Organize teams of as many qualified persons as are needed and available to conduct the search. A very efficient method is to assign two-person teams (with one person representing the local public authority) to specific areas on the map. Begin with the nearest and most obvious potential sources and work out from the point of discovery, concentrating on moving uphill, upstream of underground water flow, or upstream of sewer or conduit flow.

3-1.6 Quite often the source can be found by inquiry or simple inspection. Begin with the "Primary Search." If this fails to discover an obvious or very likely source within the first few hours, it is advisable,

while the Primary Search continues, to begin testing equipment for concealed leaks at the closest and most probable sources (*see Chapter 4*) and to take the first steps in tracing underground liquids (*see Chapter 5*).

3-2 Primary Search Procedure.

3-2.1 Flammable or combustible liquids will escape into the ground from one of two principal sources: (a) liquid has been spilled during transfer and has run into a sewer or soaked into porous soil; or (b) a leak has developed in storage, transporting or handling equipment.

Use the list below to check for spills or other possible sources by asking questions and by a careful inspection of premises and equipment. Unless an obvious source is found, substantial enough to account for the seepage, do not stop the search at the first sign of a potential source. First impressions can be misleading.

3-2.2 Liquids may travel slowly underground or may not move at all until the water table rises. As a result, there can be a considerable time lapse between the occurrence of a leak or spill and the report of finding liquid or vapor. Record all history or evidence of potential sources regardless of how long ago they occurred; do not eliminate any potential sources on the basis of time, until data is available and the analysis of that data justifies elimination.

3-2.2.1 Possible sources to check:

(a) Gasoline service stations.

(b) Automotive garages or agencies.

(c) Fleet operators such as taxicab companies, dairies, bakeries, municipal garages, etc.

(d) Contractors or equipment dealers who may store fuels on their premises.

(e) Fuel distributors that supply service stations or commercial users.

(f) Heating oil distributors.

(g) Cleaning establishments.

(h) Chemical companies.

(i) Industrial plants that may use and store flammable or combustible liquids.

(j) Airports and marinas.

(k) Check public records, make inquiries about any high-pressure petroleum or gas lines in the area. They may be marked with signs at street and railroad crossings.

(l) Any abandoned flammable or combustible liquid tanks.

(m) Any other properties on which flammable or combustible liquids may be stored.

3-2.2.2 Questions to ask:

(a) Has there been a spill during loading or unloading?

(b) Any storage or handling equipment leaking, or has there been a leak? Check for excavations that may have damaged underground facilities or give evidence of repairs.

(c) Has any maintenance work involved release of liquids from tanks, pipes, or equipment?

(d) Has there been any odor or sign of liquids where they should not be?

(e) Are inventory and use records kept?

(f) Has water been found in the storage facility?

(g) Is there any knowledge of an accident in the area that may have released liquid from tank trucks, barrels, or large fuel tanks? (A check with local police may be in order.)

(h) Ask about the age of underground facilities. If subsequent equipment checks are made, the older equipment is suspect as a leaking source because of corrosion.

(i) Have any pumping problems been experienced?

If inquiry fails to disclose any potential source, ask the owner or operator for his cooperation in checking the equipment and the area around the premises. If he refuses because he does not own the equipment, contact the owner for his cooperation. If necessary, governmental authority such as exercised by fire officials, may be used to obtain such cooperation.

3-2.2.3 Checking equipment:

(a) Check the area around fill pipes where liquid is transferred from truck to tank for signs of frequent spills. Saturated and darkened soil, stained concrete, or disintegrated asphalt indicates repeated spills that may accumulate underground.

(b) Check the area around aboveground tanks for similar signs that may indicate a leak or overfilling.

(c) Check any exposed piping for signs of leaks.

(d) Check pumping equipment for leaks. It is advisable to use a combustible gas indicator when checking pumps/dispensers of the type used in service stations. Open the cover of the unit just far enough to insert the indicator probe into the bottom area. Opening the cover wide may provide sufficient ventilation to give such a low reading as to indicate no leak. Also, check the hose and nozzle.

(e) If a remote pumping unit is used, check its housing or pit with a gas indicator before opening and then open for visual check for signs of leaks.

(f) Check automotive repair areas for signs of waste liquids being dumped into floor drains or sumps.

3-2.2.4 Checking the area:

3-2.2.4.1 If all equipment seems to be in order and there is no obvious sign of spilling or dumping into sumps or sewers, check around the grounds and adjoining areas.

(a) Look for signs of dumping waste liquids on the ground.

(b) Check nearby streams and bodies of water for signs of flammable or combustible liquids.

(c) Check vegetation in the area for any indication of damage by spillage, dumping or contaminated ground water.

(d) Using a combustible gas indicator, check sewers and other underground cavities such as telephone and utility conduit manholes for presence of vapors and make visual inspection for signs of foreign liquids on water surfaces.

(e) Check nearby excavations and steep cuts or natural slopes below the potential source for signs of liquid coming through the soil.

3-2.2.4.2 When leaks in equipment are discovered, ask the user and owner to stop use of the equipment until the leak is repaired. Pump out liquid in storage if it is still escaping through the leak.

3-2.2.4.3 If large spills have been reported or there are indications that there has been repeated dumping or spilling of flammable or combustible liquids into sewers or on the ground, ask those involved to modify their operations to prevent recurrence.

3-2.2.4.4 Be reasonable and fair; recognize that small spills may inadvertently occur and that a very small amount of petroleum liquid (just one cup of gasoline, for example) on a wet pavement will spread over a large area, appearing to be a more severe spill than it actually is. Spills on the surface that spread out will dissipate rapidly and are not likely sources of underground contamination. The significant spills are large spills that can flow to points of access to underground structures or areas of porous soil, or repeated smaller spills that immediately flow into structures or soak into soils and reach the water table.

3-2.2.4.5 If an obvious source, or one or more likely sources, has been found and further escape of liquids eliminated, further search may be temporarily suspended to determine if, in fact, the located

source(s) is the cause of the problem. While removal and protective measures are taken, monitor and record the flow of liquid, the amount of liquid, and the vapor concentration at those locations where the problem exists. If there is a distinct and continuous decrease it may be assumed that the source(s) has been found and further contamination eliminated. The decrease may not show up immediately; it may, in fact, require days or weeks to remove liquid that has accumulated underground or for it to dissipate. Refer to Chapter 5, Tracing Liquids Underground, to determine how much time may be required before a decrease at the monitoring point may be expected.

3-2.2.4.6 If, after a reasonable length of time as determined with the reference above, the supply of liquid to the threatened area does not stop or show definite decrease, further investigation should be conducted simultaneously along two paths. These two paths also should be followed if no source is found.

3-2.2.4.7 One is a test of flammable or combustible liquid storage and handling equipment in the vicinity of the contaminated area; the other is to trace the liquid underground from its point of discovery. Tracing is conducted to determine the extent of the contamination, the direction of flow, and any potential more remote source(s). Tests on underground equipment are performed to determine definitely whether or not they are a source. (*See Chapter 4, Testing for Undergound Leaks, and Chapter 5, Tracing Liquids Underground.*)

Chapter 4 Testing for Underground Leaks

4-1 General.

4-1.1 Tests to determine the tightness of underground liquid handling equipment will have to be conducted when:

1. The search procedures of Chapter 3 or the tracing procedures of Chapter 5 indicate a probable or likely leakage source, but the actual cause is not determined from surface observation;
2. There is a suspicion of a leak because of reported stock losses;
3. There is a report of the accumulation of water in a tank.

4-1.2 Review all data previously gathered to determine the most efficient method or methods of testing. There are several quick and simple tests described in this chapter that may reveal a leak under certain circumstances. If one of these preliminary tests does not reveal the source of a suspected leak, it cannot be concluded that the liquid-handling system is tight, but the possibility of quickly solving the problem will often warrant the limited effort involved before a precise Precision Test is undertaken. (*See 4-3.10.*)

4-1.3 One or more of these preliminary tests would be particularly desirable if precise final test equipment is not immediately available. If such equipment is available, time and labor costs may be reduced by immediately making a Precision Test.

4-1.4 Regardless of the testing procedure involved, keep in mind that liquid-handling equipment should be tested in a condition as close as possible to normal operating condition, particularly equipment which is underground or otherwise concealed. There are several important reasons for this.

4-1.4.1 Uncovering and exposing can very easily cause a leak which did not previously exist and its discovery might imply the problem is solved when, in fact, it is not.

4-1.4.2 Responsibility resulting from unconfined liquids or vapors underground might be falsely placed by a leak created by uncovering and removal activity.

4-1.4.3 Uncovering underground liquid-handling equipment is costly and time consuming and is not justified without valid reasons to suspect leakage.

4-1.4.4 Excessive pressures or tests by nonrepresentative liquids may indicate leaks where none existed or conceal leaks where one, in fact, exists.

4-2 Action Preliminary to Testing.

4-2.1 Before actual equipment testing is undertaken, review the results of the Primary Search in Chapter 3. This review may reveal information that will eliminate the need for further testing or this information will be useful in making further tests.

4-2.2 Ensure that spills or deliberate disposal are not the leakage source, keeping in mind the possible transit of liquids by trenches and underground water. (*See Chapter 5.*)

4-2.3 Recheck stock records for indications of loss; but do *not* jump to conclusions. Meters may be off calibration causing only a paper loss, not a physical loss.

4-2.4 Temperature change may falsely indicate a loss. The volume of petroleum products is highly sensitive to temperature change. A drop of one degree Fahrenheit will shrink 1000 gal (3785 L) of gasoline by 0.6 gal (2.2 L). This may at first seem small but consider a typical example. In the spring, the ground will still be relatively cool from the preceding cold weather, while liquids stored and transported aboveground may be relatively warm.

4-2.5 A typical underground storage tank may handle 20,000 gal (75 700 L) in one month. If, on the average, this liquid cooled 5°F (2.8°C) after delivery, stock records will show a loss of 5 × .6 × 20 = 60 gal (227 L). Ten degrees cooling would appear as a 120 gal (454 L) loss for 20,000 gal (75 700 L) handled, and 240 gal (908 L) loss for 40,000 gal (151 400 L) handled. Obviously, a temperature increase would have the opposite effect and could actually conceal a physical loss.

4-2.6 Finally, theft may be the cause of reported stock loss.

4-2.7 Consequently, further checking must be performed before a facility is implicated on book stock losses alone. Check meters for calibration. Check relative temperature of delivered and stored product during the period in question. Check for the possibility of theft.

4-3 Checking Inventory Records.

4-3.1 A careful check of inventory records will be very helpful in determining the course of further investigation.

4-3.1.1 If the reason for the check is a report of loss of inventory but no liquid or vapor has been reported in unexpected locations:

(a) Loss due to meters out of correct calibration, loss by contraction due to lower temperatures, or theft would indicate that a hazard need not be expected. Further testing is not necessary;

(b) If not solved as in (a), evidence of an inventory loss requires further testing to determine the cause. It also indicates that a potential hazard may develop from the escaped liquids and a check of the surrounding area should be made for signs of contamination. (*See 3-2.2.4 — 3-2.2.4.7.*)

4-3.1.2 If the reason for the check is discovery of escaped liquids or vapors found underground:

(a) Evidence of inventory loss strongly implies the source has been found but subsequent checks to determine how the loss has occurred must be made before definite conclusions can be drawn;

(b) Loss partially or totally explained by off-calibration meters, temperature shrinkage or theft cannot be considered as conclusive evidence that the site in question is not a source. Records are often *incorrect or inadequate; unless another source is found and* considered to be a satisfactory solution to the problem, other tests must be performed to draw definite conclusions.

4-3.1.3 When a review of the Primary Search Procedure (*see Section 3-2*) fails to reveal a probable source, any leak that may exist is probably underground, and testing of the liquid-handling equipment is required.

4-3.1.4 Many methods have been devised to test for leakage. Recent extensive studies and experience have clarified their effectiveness and limitations.

4-3.2 Pressure Testing with Air or Other Gases.

NFPA 30

4-3.2.1 Pressure testing, with air or other gases, of tanks or piping containing flammable or combustible liquids is not recommended, should not be required by regulations or ordinances, and should be discouraged in practice. Such tests are not likely to detect a leak that is below the liquid level in the tank, and there is severe danger of causing a tank rupture, or expulsion of contained liquid through normal openings.

NOTE: There are systems that use unique gases that are not dependent on pressure for detection of leaks. helium 4-5 psi

4-3.3 Testing Underground Facilities.

4-3.3.1 Using the information gained from the Primary Search Procedure (*see Section 3-2*), use the following tests in a logical process of elimination. For example, if water is reported as entering a tank, or if the tanks are old and corrosion is known to exist in the area, make the preliminary checks on the tanks first. On the other hand, if pumping troubles are reported, the piping is suspected and preliminary tests should be performed on underground piping first.

4-3.3.2 The tests described on the following pages are listed in approximate order of ease of performance, the easiest being first. The sequence should be varied to fit the circumstances, as noted in the preceding paragraph.

4-3.4 *Checking Underground Pipe.*

4-3.4.1 Check for:

(a) Recent digging, driveway repair, or other work in the area which may have damaged underground lines.

(b) Any recent repairs that may have been made indicating a previous leak or perhaps creating a leak due to faulty work.

(c) Any evidence of shifting ground, such as frost heave, which may have damaged lines.

(d) *Soft spots in asphalt paving indicating solvent action of liquids* or vapor.

4-3.4.2 If information on the location of liquid underground has been compiled by methods described in Chapter 5, Tracing Liquids Underground, review this information for possible patterns that may indicate a specific pipe is likely to be the source. It may be advisable to drive or drill additional holes to define more definitely where the liquids are and how they are flowing. (Review in particular the information in connection with Figure 11 in Chapter 5.)

4-3.4.3 The test to be used on piping will depend on the method used to move or pump the stored liquid.

4-3.5 Suction Line Testing.

4-3.5.1 If the pump used in moving the liquid is above ground the supply pipe operates under vacuum or suction and certain pumping characteristics indicate either a leaking check valve or a leaking pipe. If there is a leak, air will enter the pipe as liquid drains back into the tank through the check valve or through a pipe leak into the ground. The presence of air will be indicated by the action of the pump in the first few seconds of operation after an idle period. If the pump is equipped with a meter and cost/quantity display device such as is found in a gasoline service station, pumping of air is indicated by the display wheels skipping or jumping. Other indications of air in the suction line are:

(a) The pump is running but not pumping liquid.

(b) The pump seems to overspeed when first turned on and then slow down as it begins to pump liquid.

(c) A rattling sound in the pump and erratic liquid flow indicates air and liquid are mixed.

4-3.5.2 If any of the preceding conditions indicate a leak in the suction line, the check valve should be inspected first. Some check valves are located close to the pump inlet, others are mounted in the underground pipe just above the tank, and some may be on the end of the suction stub inside the tank. Some of those valves located in the pipe above the tank can be inspected and repaired from the surface of the ground through a special extractor mechanism installed with the valve. If not, or if the valve is inside the tank, it may be necessary to dig down to the tank to check the valve or disconnect and seal off the pipe for a hydrostatic pressure test. (*See 4-3.6.*)

4-3.5.3 Generally, digging down to the check valve or tank should be delayed until other more easily performed surface tests have failed to reveal the leak. If there is any doubt that the check valve seats tightly, repair it, replace it or seal it off. Then repeat the pumping test and, if air is still entering the suction line, it may be assumed the pipe is leaking underground and it should be exposed for inspection. Dig carefully to avoid damage to the pipe which might make it impossible to verify whether a leak actually existed prior to uncovering.

4-3.5.4 If the pumps do not exhibit the symptoms of a leak as described above but there is still reason to suspect a pipe leak; or, if a complete system check has been performed and it is now necessary to isolate and check the piping system, individual pipe runs may be isolated and hydrostatic pressure tested.

4-3.6 Hydrostatic Test of Piping.

4-3.6.1 Isolate the piping and conduct a hydrostatic pressure test at 50 psi (2600 mm Hg) or greater. If the pressure drops more than 5 psi (260 mm Hg) per minute, it indicates the probability of a leak in the line. Repeat the test at least once to ensure against compression of entrained air. Any pressure drop less than 5 psi (260 mm Hg) per minute is inconclusive as it may be caused by cooling. If the test continues to indicate a leak, appropriate action must be taken.

4-3.7 Discharge Pipe Line Testing (pipe under pressure from remote pump).

4-3.7.1 Quite often pumps are located in the tank, or, on some rare occasions, just above the tank but remote from the dispensing devices. In such cases, the pipe to the dispensing equipment operates

under pressure. A leak in this line will cause rapid loss of pressure after the pump is turned off. This can be checked in the following manner.

4-3.7.2 At the dispenser end of the pipe, close the emergency shutoff valve at the base of the dispensers or close any valve upstream of any hose to hold pressure at the dispenser end. The pump end can be sealed off by setting the check and relief valves in the head of the pump. The check valve is readily accessible in the manhole over the pump, and most are equipped with a screw or bolt supplied for the specific purpose of positively seating these valves for line checking. Install a pressure gage in the line [a minimum 3 in. (76 mm) dial with maximum 60 psi (3100 mm Hg) range should be used to clearly show graduations of 1 psi (51.72 mm Hg)]. Generally, the best location for the gage is in the emergency shutoff valve under the dispenser where ¼ in. or other small size plugs are installed for this purpose. Start the pump, note the maximum pressure [generally 25 to 35 psi (1290-1760 mm Hg)], seat the check valve, turn off the pump and observe any pressure drop. If the pressure drops more than 5 psi (260 mm Hg) per minute, it indicates the probability of a leak in the line. Repeat the test at least once to ensure against compression of entrained air. Any pressure drop less than 5 psi (260 mm Hg) per minute is inconclusive as it may be caused by cooling or a small valve leak. If the test continues to indicate a leak, appropriate action must be taken.

4-3.7.3 If the preceding tests do not reveal a leak, they should not be considered as conclusive and undergound piping must be included in the Precision Test described in 4-3.10.

4-3.8 Checking Underground Tanks.

4-3.8.1 Review the information obtained from the Primary Search described in Chapter 3. Ask about, observe, and note in particular:

(a) Method of filling tanks — damaged fill pipes, poorly maintained tight-fill connections or hose couplings, driver carelessness, or even overemphasis on full deliveries may cause some of the product to be spilled around the pipe when a delivery is made. Particularly, check fill pipes installed under manhole covers. On night deliveries in which the tank is filled into the fill pipe a warmer underground product temperature can cause considerable overflow due to expansion before dispensing begins the following day;

(b) Any evidence of ground settlement around tanks and any sign of work that may have damaged the tank or its fittings;

(c) History of past or recent work on the tanks or attached piping;

(d) The presence of excessive amounts of water in the tank and any history of past water removal. (Use water-finding paste on the gage stick.) Ascertain, if possible, if the water increases during periods of heavy rainfall and remains constant or diminishes during dry spells. Also, if possible, ascertain the depth of the water table, i.e., the static level of the ground water, by using an easily drilled, probed or excavated area close to the tank(s) or some existing undrained opening;

(e) The age of the tank; in particular, as it relates to the history of corrosion in the vicinity;

(f) The location and flow of liquid found underground by gas sensors or visual inspection. It may be advantageous to drive or drill additional holes to develop more detailed information.

4-3.8.2 Use this information to guide subsequent inspection and testing.

4-3.9 When Water is Reported to be Entering a Tank.

4-3.9.1 Check the fill pipe to ensure that water is not entering through a loose fill cap.

4-3.9.2 Check the surface area around vent lines for evidence that water may be entering by this route. Standing water over vent lines may be the source. Note this possibility for future use.

4-3.9.3 If no explanation, except a possible leak, is found for water in the tank, carefully record the depth of water by water-finding paste, and tightly close and lock the fill cap. After 8 to 12 hours, remove the cap and again check for water. If the rise in 12 hours exceeds ½ in., close and lock the cap and check for another 8 to 12 hours. If the rise in the second period closely matches that of the first period, a leak is probable. A rise of less than ¼ in. in 8 hours is inconclusive due to the inability to measure the water level closer than to within ¼ in. Longer test periods will have to be used to determine definitely if a leak does, in fact, exist. Best results will be obtained if the water depth is less than 3 in. (75 mm) at the beginning of the test.

4-3.9.4 The above tests are not conclusive if the water table is above the top of the tank, as water could be entering around pipe connections into the tank top or through unused plugged or capped openings in the top of the tank which are not watertight. Also, if water is entering the tank at these top openings it is not significant from the standpoint of tank leakage. Likewise, these tests are not conclusive if the tank is full, or substantially full, of product.

4-3.9.5 In fact, water may not enter the tank if the level of product is at or above the level of the water table outside the tank. These tests are relatively effective if the tank is practically empty and the water table is high but still below the tank top. A tank partially below the water table can have water enter, or lose product, through the same leak depending on the relative levels of the ground water and the product in the tank.

4-3.9.6 If a leak is indicated by the above test, take appropriate action.

4-3.10 Precision Test.

4-3.10.1 Precision Test, as used throughout this pamphlet, means any test that takes into consideration the temperature coefficient of expansion of the product being tested as related to any temperature change during the test, and is capable of detecting a loss of 0.05 gal (190 ml) per hour.

4-3.10.2 A test should be used which is chosen from currently available technology to reasonably determine whether or not an underground liquid storage and handling system is leaking. Any testing device used for the Precision Test must be capable of detecting leaks as small as 0.05 gal (190 ml) in one hour, adjusted for variables, a limiting criterion widely accepted by most authorities.

4-3.10.3 The test procedure should measure the amount of liquid lost based upon fundamentally sound principles. It should detect a leak anywhere in the complete underground storage and handling equipment. If the net change exceeds 0.05 gal (190 ml) per hour or equivalent criterion established for the technology employed, a leak is likely to exist, and appropriate corrective action is necessary.

4-3.10.4 The Precision Test should account for all the variables which will affect the determination of the leak rate. An understanding of what these variables are and how they are handled is essential to effective performance of the test. Following is a discussion of some of those variables and how they affect the measurement.

4-3.11 The Effect of Temperature.

4-3.11.1 Liquids expand with an increase in temperature and contract with a decrease in temperature. Figure 2 lists the thermal coefficient of expansion for some of the more common flammable and combustible liquids.

Thermal Expansion of Liquids	Volumetric Coefficient of Expansion per Degree
Acetone	0.00085
Amyl acetate	0.00068
Benzol (benzene)	0.00071
Carbon disulfide	0.00070
Ethyl ether	0.00098
Ethyl acetate	0.00079
Ethyl alcohol	0.00062
*Fuel Oil #1 - Kerosene	0.0005
*Fuel Oil #2 - Diesel	0.00045
*Gasoline	0.0007
Methyl alcohol	0.00072
Toluol (toluene)	0.00063
Water — at 68°F	0.000115

Figure 2

*These are typical coefficients of expansion, but may vary depending on components of the mixture and on the temperature. See ASTM D 1250-80, Petroleum Measurement Tables, for further information.

4-3.11.2 Note that a temperature decrease of only .02°F (.056°C) in one hour in a 6,000 gal (22 710 L) tank containing gasoline would cause a volumetric decrease of .02° (.056°C) × .0007 × 6,000 gal (22 710 L) = .084 gal (318 ml) which exceeds the .05 gal (190 ml) considered to indicate a leak. If this temperature change was not detected and accounted for in a test, a leak would be assumed where none existed. And in a like manner, if the temperature increased, a leak could be concealed by volumetric expansion if the temperature change was not detected.

4-3.11.3 It is sometimes proposed that this problem can be overcome by filling the tank 10 or 12 hours before a test run, on the assumption that the product temperature will stabilize. Extensive tests have shown that this is seldom if ever true. When liquid is added to fill a tank for testing, it will often require several days for the liquid to stabilize to ground temperature, which in itself is constantly changing. The rate of temperature change in the first day or two will generally be in the range of .02°F (0.56°C) per hour to .25°F (0.7°C) per hour. Obviously, the test must be capable of detecting any very small temperature changes if it is to be conducted in a reasonable length of time.

4-3.11.4 Another temperature effect that must be recognized and accounted for is temperature stratification or temperature "layering." Figure 3 illustrates how temperature may vary in a typical underground tank after cool product has been added to warmer product already in the tank.

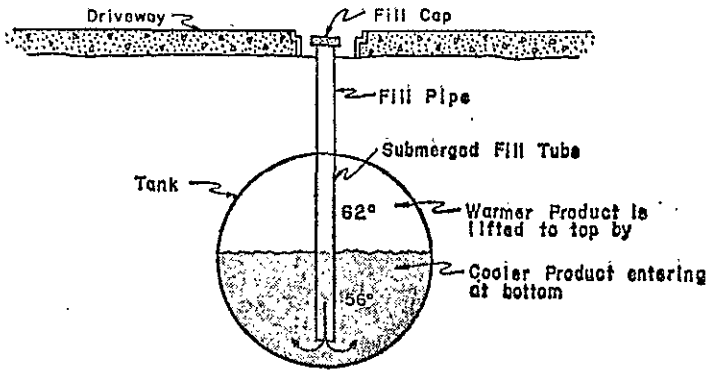


Figure 3

4-3.11.5 Temperature measurement must include a method for averaging any differences in temperature because the rate of change *will not be the same. If the product in the ground prior to filling is at* or close to ground temperature [62°F (16.7°C) in Figure 3] its rate of change will be nil. However, the temperature of the liquid added to fill the facility will immediately begin to change toward the temperature of the ground [56°F to 62°F (13.3°C to 16.7°C) in Figure 3]. The rate of temperature change in this case would probably average about .12°F (0.3°C) per hour. If a 4,000 gal (15 140 L) tank was half full prior to filling for the test, this would mean an average change of .06°F (0.17°C) per hour or a volume expansion of .06°F (0.17°C) × .0007 × 4,000 gal (15 140 L) = 1.68 gal (6.4 L) per hour: almost 33 times the minimum leak criteria. In this case, a leak of 1.68 gal (6.4 L) per hour or 40 gal (150 L) per day would be concealed by temperature rise.

4-3.12 *The Effect of Pressure.*

4-3.12.1 Measuring very small volumetric changes in a storage facility requires the filling of that facility to a point abovegrade where volumetric measuring equipment can be used. This increase in height of liquid increases the pressure inside the underground tank over the normal operating pressure. This is illustrated in Figure 4.

4-3.12.2 In a 6 ft (1.8 m) diameter tank the average pressure on the end or "head" of a tank full of typical gasoline is .98 psi (50 mm Hg). If the tank is buried 3 ft (1 m) under the driveway (typical for most gasoline tanks), the average pressure on the head will increase to approximately 2.95 psi (153 mm Hg) when the fill pipe and standpipe are filled to 3 ft (1 m) abovegrade. The increase of approximately 1.95 psi (100 mm Hg) in the average pressure exerts an additional force on the end or "head" of the tank of about 8,000 pounds, or 4 tons.

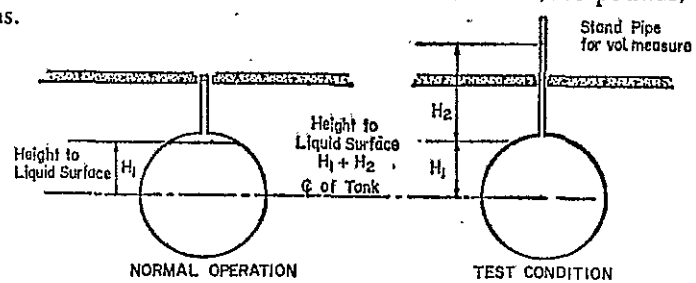


Figure 4

4-3.12.3 Most tank ends[1] of the type normally used underground are made of ¼ in. thick steel plate and will deflect outward as pressure inside the tank increases. (*See Figure 5.*)

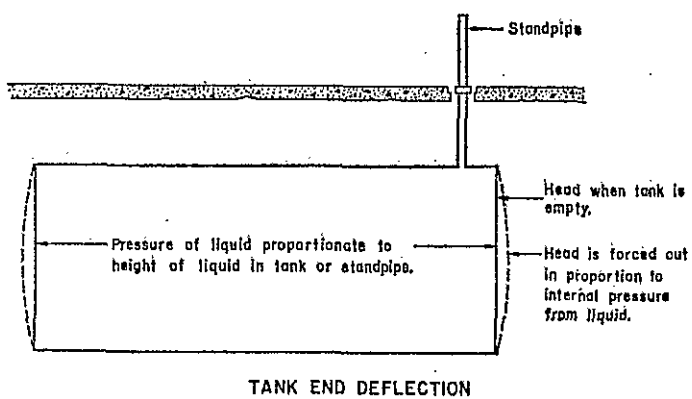


Figure 5 Tank End Deflection

[1]Although most fiberglass tanks have oval or spherical ends, the same phenomenon of expansion will occur due to flexure between the ribs on the sides of the tank.

4-3.12.4 If the tank is located aboveground and the heads are not supported in any way, it is possible to predict the amount of movement that will result from any given change in pressure and, when the amount of movement is known, the resulting increase in volume of the tank can be calculated. However, when tanks are located underground they are subject to an infinite variation in support from the surrounding soil, and it is not possible to predict how much movement will take place. Very solid soil may provide close to full support, but normally soils will consolidate to some degree, particularly if they are wet, thereby allowing tank expansion and end deflection.

4-3.12.5 Extensive study and testing have revealed that in almost all cases tank movement significant to the test for leaks will occur. It will not occur suddenly because of the time required to consolidate the soil. Under a constant increased pressure it will normally take several hours for the tank to stabilize. The table in Figure 6 shows the volume increase as a result of various degrees of movement in the tank ends. The figures underlined are the maximum normally encountered with underground steel tanks; the last figure in each horizontal row is the maximum possible for the tank size in that row.[1]

Apparent Loss of Liquid Volume in Gallons Due to Increased Pressure in a Tank

Outward Deflection at Center of Head in Inches

Tank Dia. Inches	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	5/8	3/4	7/8	1
48	.49	.98	1.47	1.95	2.44	2.93	3.42					
64	.87	1.74	2.61	3.48	4.35	5.22	6.10	6.97				
72	1.10	2.20	3.31	4.41	5.51	6.62	7.72	8.82	11.0			
84	1.50	3.00	4.50	6.00	7.50	9.00	10.50	12.00	15.0	18.0	21.0	
96	1.96	3.91	5.87	7.82	9.77	11.75	13.70	15.65	19.6	23.5	27.4	31.3
102	2.21	4.42	6.65	8.25	11.06	13.30	15.50	17.70	22.6	26.6	31.0	35.4
120	3.06	6.12	9.18	12.25	15.30	18.4	21.4	24.5	30.6	36.7	42.8	49.0

Figure 6

4-3.12.6 In summary, three major factors must be accounted for in the Precision Test to determine the presence or absence of a leak in an underground liquid storage facility.

1. The gross volume change in a given period of time.
2. The temperature change of the liquid in that period of time.
3. The movement of tank ends as pressure is increased.

[1]Compatible figures are not yet available for fiberglass tanks. Latest data indicates that expansion due to side flexure may exceed that for flexure of steel tanks.

4-3.13 Water Testing.

4-3.13.1 Tests involving the addition of water to a tank may be useful when tanks are empty. Water is difficult to use in cold weather. It will not detect leaks of less viscous liquids, and contamination of the storage and dispensing system can be a major problem.

Chapter 5 Tracing Liquids Underground

5-1 General. The "Underground," as referred to in this recommended practice, consists of an almost infinite variety of rocks and soils, tunneled, pierced and trenched by man-made structures and pipes. All these provide paths for movement of liquid underground. Flow of liquid in tunnels, sewer pipes, and open trenches is obvious and relatively easy to trace by observation and vapor testing. Flow in soil and rocks is a complicated matter. A few basic principles will provide an understanding that will often prove sufficient to solve many problems of tracing the source of unconfined liquids. Even though such basic understanding may prove inadequate for a particular problem, it is essential to select and coordinate the particular expert skills necessary to solve the more complex problems.

5-2 Background.

5-2.1 The principal characteristic that permits liquids to enter, and accumulate or flow through soil or rock is porosity or, simply, the space or "voids" between the particles that make up the soil or rock. The size of the voids in soil will vary from large in gravel, through small in sand and top soil, to essentially zero in fine, dense clay. Rock almost never has large voids but sandstones and limestones have voids similar to a fine sand.

5-2.2 Rate of flow through soils and rocks depends largely on the size of the voids; with large voids (gravel) the flow can be several feet per minute; medium voids (sand) will provide several feet per hour; and fine voids (shale or sandstone) may be as slow as one foot per day.

5-2.3 The term used to express this rate of flow is "pervious." A very pervious soil will permit fast liquid flow; a relatively "impervious" soil will permit only very slow flow. When the word impervious is used alone, it implies no flow; thus glass is impervious to the flow of water.

5-2.4 Porosity does not insure a pervious condition. If the pores of a rock are not interconnected, the rock will be impervious.

5-2.5 Crystalline rocks, such as granite and marble, are essentially impervious in their solid state but these rocks often have fractures or cracks that do permit flow. Rate of flow through rock fractures will vary from large continuous cracks which will act like a pipe, to very small irregular cracks which may result in flows similar to fine sand.

5-2.6 Almost all flammable and combustible liquids are lighter than water and consequently they will float on water unless they are water soluble. When these liquids escape into the ground they will normally flow down to the water in the ground and there move with that water. An understanding of groundwater flow is essential to trace flammable and combustible liquids underground.

5-2.7 Water is almost universally found underground at some level in soil or rock. It may be in very limited quantities and only "dampen" the soil. But when it fills all the voids and "saturates" the soil or rock up to a certain level, it becomes similar to water in a pail and establishes a definite top, referred to as the water table.

5-2.8 Figure 7 illustrates that this ground water may occur in several layers underground. A porous layer between two nonporous layers may be completely filled or it may be only partially filled and have its own water table. The primary concern with unconfined flammable and combustible liquids is with the uppermost layer and its water table. However, other layers must be recognized because even though they may be very deep at one location, they may be near the surface and hence the top layer at other locations. (*See Figure 8.*)

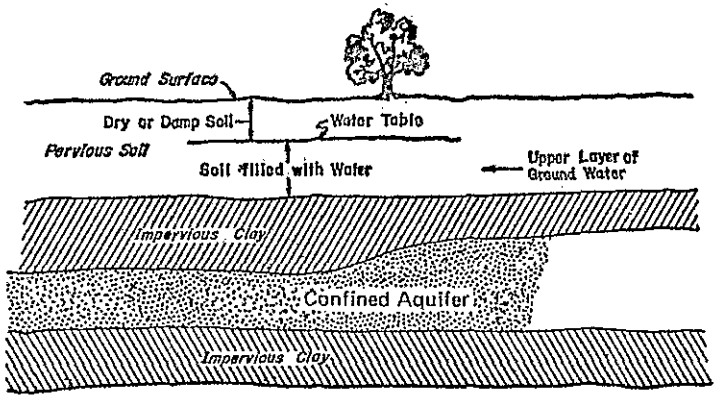


Figure 7

5-2.9 All groundwater, with the exception of narrow bands along the seacoasts, comes from rain or snow falling on the surface and flowing down into the soil. Figure 8 shows that, at any given location, the water may have come from rain or snow on the surface immediately above; or it may have flowed underground for long distances through pervious soil or rock from a point where the pervious layer "outcrops" or comes to the surface. Water from rain and snow may also flow to lakes and rivers and then into underground layers.

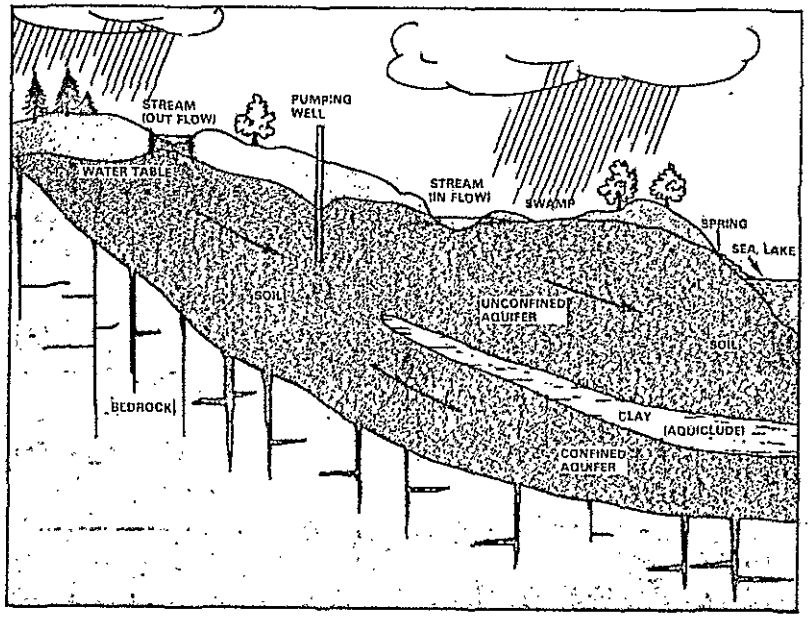


Figure 8 Hypothetical Groundwater System

5-2.10 Water tends to seek its own level underground just as it does on the surface as it flows through the soil. However water flowing underground will not flow as fast as water on the surface because of the interference or resistance of the particles in the soil. This has the effect of steepening the slope of the water table because the water does not move through the soil to lower levels as fast as it fills the soil at the higher elevation. The same effect is shown where the lake is supplying water to the pervious soil. Expressed in another way, pressure is required to overcome the resistance to flow, and the increase in elevation of the water table provides the necessary pressure.

5-2.11 The height or elevation of the water table will not only depend on how fast the water flows out of the strata, but also on how fast it is fed into the strata by rain or melting snow. When no water is being added, the water table will drop as water flows out at springs and is taken out by wells, or "wicks," through dry soil to eventually evaporate into the air. When water is being added faster than it flows out, the water table will rise. This rise and fall can be several feet in a few days as the weather changes from wet to dry, or from dry to wet.

5-2.12 In summary, the principal factors important to tracing unconfined liquids underground are:

1. Most flammable and combustible liquids float on water.

2. When unconfined in the ground, these liquids will float on the top or water table of the groundwater and move with that water.

3. Groundwater will flow through pervious soil or rock toward lower elevations. Flow rate will vary from several feet per minute to only one or two feet per day.

4. Groundwater may be trapped underground and be stationary as if in a lake.

5. The top or water table will be level with no flow but slope down in the direction of flow when flow occurs.

6. The water table will rise and fall (in some cases several feet in a few days) depending on supply by rain or melting snow.

5-2.13 The following examples illustrate how these principles are applied to tracing flammable and combustible liquids.

5-2.13.1 Figure 9 shows the effect of the slope of underground strata on the direction of flow of liquids. A and B show identical surface conditions. A four-story apartment building is approximately midway in the block, between two streets 400 ft (122 m) apart. The surface of the ground slopes up from left to right at a 5 percent grade, placing the elevation of the upper street (on the right) 20 ft (6 m) higher than the lower street.

5-2.13.2 In Figure 9-A, the underground strata follows the general slope of the surface and groundwater in the sand and gravel layer flows from right to left. Under these circumstances, if gasoline in liquid or vapor form was discovered in the subbasement of the apartment building, the source of that gasoline would most likely be from the service station on the right at the higher elevation, or from other tanks farther up the hill.

5-2.13.3 However, Figure 9-B shows an underground strata condition in which the station downhill is the most probable source. In this case, the water-bearing strata of sand and gravel slopes down from left to right, opposite that of the surface of the ground. Groundwater flow would also be from left to right and would carry gasoline escaping from the lower station to the basement of the apartment building.

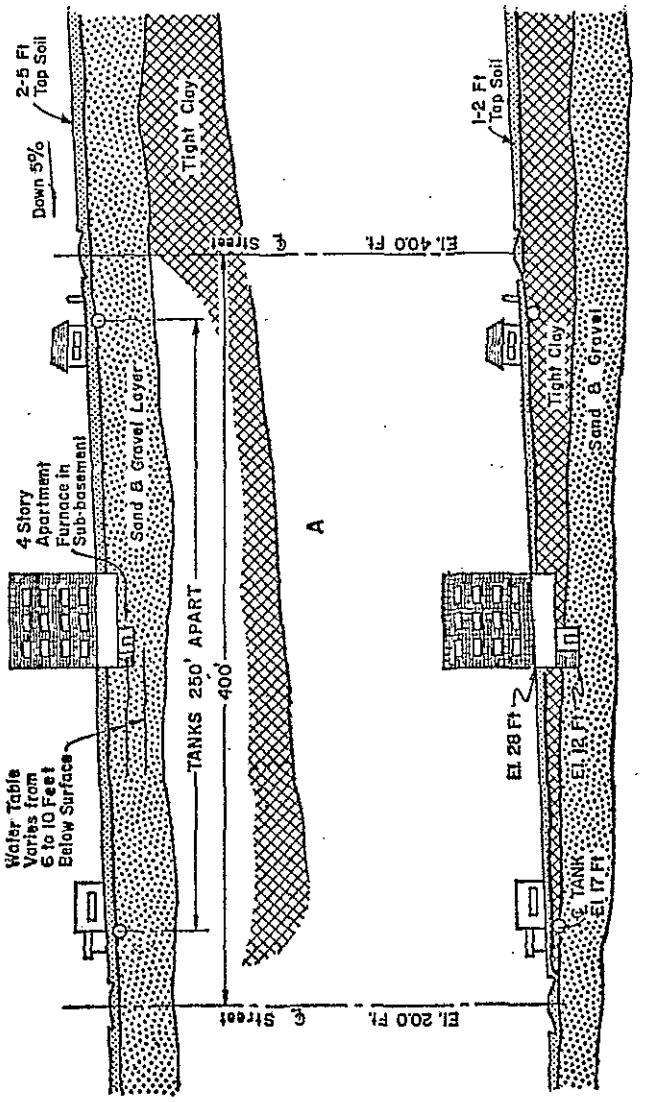


Figure 9

5-2.13.4 One other condition illustrated in Figure 9-A is the effect of a rising and falling water table. During the dry season, when the water table is below the subbasement floor of the apartment building, gasoline on the water table would not be discovered. But when the water table rises the gasoline will be lifted above the subbasement floor. There have been many cases where this was the cause of alternating discovery and disappearance of escaped gasoline due to a significant rise in the water table with each significant rain.

5-2.13.5 Figure 10 illustrates another example of how underground water flow can be contrary to the surface slope of the ground. In this case, flammable liquids are stored in an underground tank a few hundred feet from, and 30 or 40 ft (9 or 12 m) above, a small lake. From the surface, it would appear that an escape of liquids from this tank would show up in the lake. But, because the tank is in a pervious water-bearing layer that slopes away from the lake, wells at houses high above the service station are contaminated by the gasoline that has escaped.

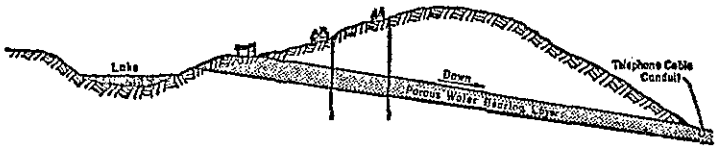


Figure 10

Note also that if an underground leak existed unknown for a long period of time and there were no wells in the strata to discover contamination, the first discovery of escaped flammable or combustible liquids could occur in the telephone cable conduit on the other side of the hill from the service station, possibly several miles distant.

5-2.13.6 Figure 11 illustrates other important effects of a rising and falling water table and the ability of trenches dug in relatively impervious soil but filled with sand or other porous material to act like interconnected piping. Figure 11-A is a phantom view of a tank containing gasoline installed in a hole dug in clay and backfilled with sand. The suction and vent lines are likewise in trenches dug in clay and backfilled with sand.

5-2.13.7 Figure 11-B is a plan showing the layout of a tank installed next to a building with a basement. A water line to the building on the left is also a trench backfilled with sand as is the city water main and sewer. And, finally, a low area between the buildings was filled with sand and gravel during construction.

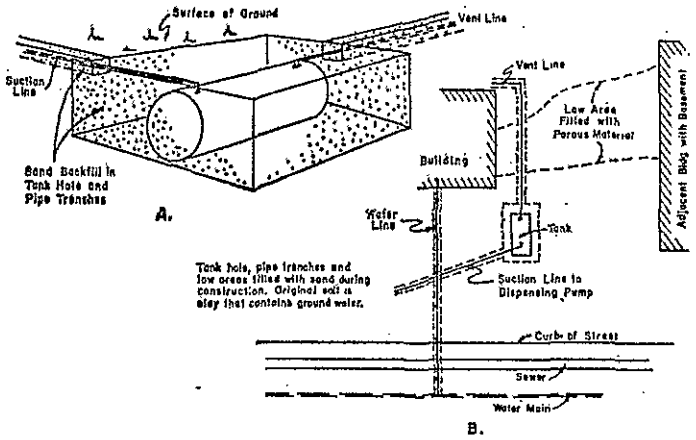


Figure 11

5-2.13.8 The "parent" or original soil is clay. A water table exists in the clay but has very little horizontal movement because of the resistance of the clay to flow. As a consequence, the water table rises and falls in direct response to supply of water from rain. During wet periods the water table will be within a foot of the surface and during dry periods will drop to or below the bottom of the tank hole.

5-2.13.9 It is easy to see how a leak in this tank could cause a collection of gasoline on a low water table in this hole much as if it were in an open square tank. Then, if rainfall raised the water table above the bottom of the pipe trenches, water with gasoline on top could flow along the sand-filled trenches much as it would through a pipe. At points where the trenches intersected other trenches or the sand and gravel fill between the buildings, the flow could find its way to the building or to the sewer or water main in the street.

5-2.13.10 Note that it will not necessarily enter the sewer pipe in the street. The water and gasoline may flow along the outside of the sewer or water pipe in the porous backfill of those pipe trenches and not appear until it comes to some point where it could leak into a manhole or sewer inlet.

5-2.13.11 Another condition illustrated by Figure 11 is the potential for a flammable or combustible liquid to move without the aid of groundwater. If a severe leak occurred in the suction line, pure gasoline could flow along the trenches.

5-2.13.12 The principles and concepts discussed in the preceding pages point up the importance of knowledge about underground soil conditions and underground facilities when tracing the source of escaped liquids. It will not always be possible to obtain all the data desired but the effort should be made.

5-3 Test to Determine Underground Flow.

5-3.1 The sequence of what to inspect and what test to use will depend to considerable degree on the circumstances of the problem, information gained from the Primary Search, and previous tests. Consequently, the following methods are not necessarily in the proper sequence for all conditions. They are, however, in an approximate descending order of importance. Tools are noted as they are needed.

5-3.1.1 On a sketch of the local area (Scale from 1 in. = 100 ft) note underground facilities as illustrated in Figure 11-B and any geological data available. Be sure to include abandoned ditches and streambeds that have been filled and covered. Sources of information are:

(a) Surface observation of manholes, fill pipes, pumps, vent risers, etc.

(b) City engineer; sewer, water and street departments; highway engineer; city, state, and federal geological departments.

(c) Utility companies.

(d) Owners of the facilities and local residents. Do not overlook the old-timer who may have valuable knowledge of the area before it was built up.

(e) Metal detectors can be used to locate steel pipe if conditions warrant.

5-3.1.2 Information gathered to this point and plotted on the sketch may indicate that a certain nearby facility is a very likely source. If so, proceed with a test for leaks as described in Chapter 4. If not:

5-3.1.3 Check potential paths for liquid flow by:

(a) Visual check in manholes, inlet boxes, wells, open trenches, exposed slopes or cuts, etc. Put samples of water in a glass bottle for close inspection to determine the possible presence of flammable liquids.

(b) Use a combustible gas indicator to determine presence of vapors. To check underground porous backfill or pervious strata use a bar (¾ in. to 1 in.) and a sledge hammer to drive a hole to the level to be checked. A small hand-operated earth auger is very useful for this purpose. A larger auger, as used for power posthole digging, is also good and has the added advantage of providing a visual check and the opportunity to obtain both liquid and soil samples. This equipment is usually available from a state highway department. Maintain an accurate log of soil samples, and, in particular, note the top and bottom depths at which any soil samples have an odor indicating contamination. Retain representative samples of soil in vapor-tight containers.

(c) Use a rod or stick with water-finding paste and a paste sensitive to the contaminating liquid to determine the water table elevation. Note these elevations on the sketch and determine the probable direction of flow.

5-3.1.4 If the potential of natural or sewer gas still exists at this point in the search, make particular note of indications by the combustible gas indicator relative to the location of sewer and gas lines.

5-3.1.5 When this testing has determined the probable direction from which the contamination is coming, extend the search upstream using these same methods to determine the next most likely source. Check on both sides of the direction of flow to determine its width.

5-3.1.6 There is new technology to determine ground water flow direction without the need for drilling numerous test wells.

5-3.1.7 As the area of search extends beyond the original sketch, obtain a smaller scale map or sketch, plot and record all data. As the area becomes larger, the data becomes more important to the search and subsequent disposal of contamination.

5-3.1.8 If the initial efforts, approximately one day's checking, fail to establish a clearly defined problem, additional expert help should be engaged. Ask industry for the assistance of experts who have had experience with these problems; and, whenever possible, obtain help from a local geologist familiar with local geology.

5-3.1.9 It is beyond the scope of this recommended practice to cover the problem in all its potential complexities; that is the purpose of seeking the assistance of experts. However, it will probably be advisable for those originally in charge to maintain control while the experts act as consultants and advisors. The following information will be helpful in understanding, appraising and coordinating the expanded effort.

5-3.1.10 When the investigation fails to locate an active source of seepage, it is possible that the product could be a residual accumulation from some previous equipment failure, spill, or improper

disposal of petroleum product. Experience has indicated that many such residual deposits have existed and remained undetected over a long period of time before they became sufficiently large to make their presence known.

5-3.1.11 As the problem becomes more complex, other methods of testing and tracing may be helpful or suggested. However, both the advantages and disadvantages of these tests must be recognized if valid conclusions are to be reached.

5-4 Other Tracing Test Methods.

5-4.1 Dye.

5-4.1.1 The use of dye is often suggested as a means of tracing. The method is to add a strong dye to the stored liquid suspected of being the source and see if it shows up at the point of discovery. This is seldom successful for several reasons.

(a) Dye may cause pollution of underground water supplies.

(b) If only vapor is found at the discovery point, dye will be useless.

(c) The dye may be leeched out or bleached by chemicals in the soil before it reaches the point of discovery.

(d) If underground flow is very slow, too much time will be consumed in the tests.

(e) It may very likely make the liquid tested unusable.

(f) If it is used but does not appear at the point of discovery, it is not conclusive because of item c. It would be of benefit only if it did appear.

5-4.1.2 Dye is not a recommended method of tracing but may be used as one possible source of information in special cases.

5-5 Chromatographic and Spectrographic Identification of Components.

5-5.1 The chromatograph and spectrograph are instruments capable of detecting traces of elements in almost any compound. They can, for example, detect a trace of some element unique to a particular method of manufacture and therefore identify where the liquid originated. They can also detect the amount of an element involved. They are relatively inexpensive tests and only involve a sample of the product found at the point of discovery. These tests should be used in complex cases of products as a possible source of additional information. However, they may not be conclusive because some identifying element may be lost in the ground, or an element not in the original liquid may be picked up from the ground or from contact with buried materials.

5-6 Other Chemical Analysis.

5-6.1 Any other chemical analysis is essentially the same as the chromatographic test and the same comments apply to both. One significant factor that may be determined by chemical analysis is the age of the contaminant.

Chapter 6 Removal and Disposal

6-1 The presence of unconfined flammable and combustible liquids will continue to be a potential hazard until the contamination has been reduced to a safe level. While methods by which this can be accomplished depend upon the physical circumstances of the polluted areas, the most effective results are obtained when the efforts of all interested parties are coordinated under the direction of the fire marshal's office or other enforcing authority. It is their inherent authority to recommend compliance in all phases of the cleanup operation, and it is their recognized responsibility to the public to exercise this jurisdiction from the moment that migration of flammable liquid or vapors in sizable volume is reported until safety is assured.

6-2 Removal and disposal methods will depend on the liquid involved and the area contaminated.

6-3 The characteristics of liquids significant to methods of removal and disposal are:

1. Liquids that rapidly vaporize at ambient temperatures and leave little or no residue. Typical examples are solvents and gasolines. These are referred to as "volatile" liquids.

2. Liquids that do not readily vaporize. Typical examples are heating oils and food processing oils. These are referred to as nonvolatile liquids.

6-4 In general, purging a facility of volatile liquids is primarily a matter of ventilation, while nonvolatile liquids must be collected and picked up.

6-5 The principal categories of area relating to methods of removal are:

6-5.1 Normally inhabited subsurface structures.

(a) Basements and similarly confined areas.

(b) Subways, tunnels and mines.

6-5.2 Normally uninhabited substructures (*see NFPA 328, Control of Flammable and Combustible Liquids and Gases in Manholes, Sewers, and Similar Underground Structures*).

(a) Utility conduits.

(b) Sewers.

6-5.3 Water surfaces.

6-5.4 The soil.

(a) Surface.

(b) Subsurface.

6-6 Basements.

6-6.1 With very few exceptions, the quantity of liquids found in basements will be relatively small, as detection will normally occur before significant quantities can accumulate and further flow will be quickly stopped. When volatile liquids and their vapors are involved, the primary removal and disposal action is ventilation as described in 2-3.4. Small amounts of liquid not evaporated can be picked up with rags or commercial absorbents.

6-6.2 Be sure to put contaminated rags or absorbents in covered metal containers to prevent further spread of vapors. Final cleanup is accomplished by flushing out basement sumps and floor drains with water and washing down contaminated surfaces. Only water is necessary for flushing volatile liquids from drains; biodegradable detergents may be used on surfaces. *Maintain ventilation and checks for vapor throughout the cleaning period.*

6-6.3 In those rare cases involving relatively large volumes of volatile liquids, ventilation may not be able to sufficiently reduce the vapor concentration to a safe level due to continuing evaporation from the liquid. In such cases, bail or pump the liquid into barrels, drums or tank trucks, and dig holes outside the structure to prevent further contamination (*see Section 6-11*).

6-6.4 When nonvolatile liquids (fuel oils, etc.) are involved, ventilation will not be an effective method of removal. Use absorbents for thin films or solid surfaces. Whenever possible, pick up liquids with pumps or by bailing. Put water mixtures into barrels or drums for separation by settling. Siphon off the water and carry the contaminating liquid to a disposal facility (*see Figure 12*). If final cleanup requires flushing sumps and drains and washing surfaces, check with local sanitation and pollution authorities before flushing such liquids into sewers.

6-7 Subways, Tunnels and Mines.

6-7.1 If only small amounts of volatile liquid are involved, ventilation may be adequate to permit entry and possibly even continued use of the facility. In such cases, the same removal and disposal methods as described previously for basements may be used. However, additional precautions must be employed because of

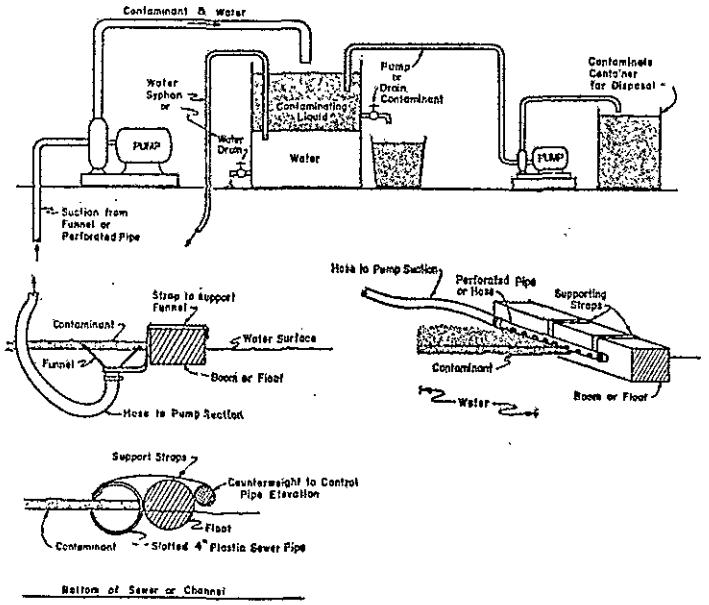


Figure 12

greater exposure to the public and, normally, more exposure to sources of ignition. The authority responsible for the facility, the fire department, and police must effect a cooperative effort for maximum safety.

Subways, tunnels and mines will normally have much greater exposure to underground seepage than other substructures such as basements. Consequently, even though entry of a flammable liquid is thought to have been stopped, monitoring with a combustible gas indicator must be continued for an extended subsequent period to ensure against recurrence. Maintain a constant check for at least 24 hours after cleanup.

6-7.2 If results are negative, extend check periods to 8, 12, or 24 hours depending on use of the facility. Subsequent checks should be continued to include extreme conditions of groundwater changes. Significant rainfall and rising groundwater may carry additional liquids from the soil.

6-7.3 If relatively large amounts of volatile liquids are involved or leakage continues, it may be necessary to close the facility to the public and suspend normal operations. Maintain ventilation, and

provide a pumping point, and pump liquids out with explosion-proof equipment. Use a drum or tank for separating water by settling; transfer the volatile liquids to drums or tanks for transport to disposal facilities (*see Figure 12*). Consult with the authority operating the facility to determine the degree to which flushing and cleanup is necessary. Normally, once further entry of volatile liquids has been stopped, such facilities can be adequately purged of volatile liquids with reasonable periods of ventilation.

6-7.4 When nonvolatile liquids are involved, the potential for fire or explosion is greatly reduced. However, make sure that continued use or operation does not present a potential ignition source; for example, it may be necessary to deactivate high power electric lines and tracks if they are anywhere near the contaminating liquid.

6-7.5 Absorb, bail or pump the liquid as appropriate, using drums or tanks for separation by settling, and remove the nonvolatile liquid for transport to disposal facilities. Consult with the authority operating the facility to determine the acceptability of using detergents, dispersants or coagulants for final flushing and cleaning. As with volatile liquids, periodic monitoring must be performed to detect any possible recurrence. Use the same time periods and groundwater changes as described above for volatile liquids.

6-8 Utility Conduits.

6-8.1 Removal and disposal methods for these facilities are different from the other substructures previously covered for three principal reasons:

1. Normally, concentrations of contaminating liquids will be much higher because early discovery and preventive measures are unlikely.

2. Access to entry points and contaminated areas is usually from manholes but in some cases such access is not available.

3. Exposure and danger to the public are greatly reduced. The utility operator must be consulted on all details of the proposed purging procedures; his special knowledge is essential in such work and normally he will select the exact procedures and techniques used.

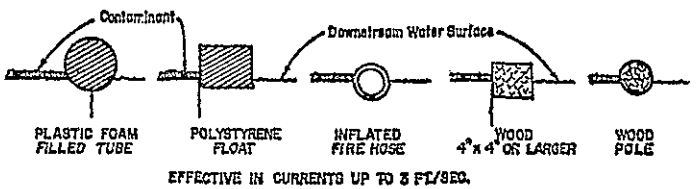
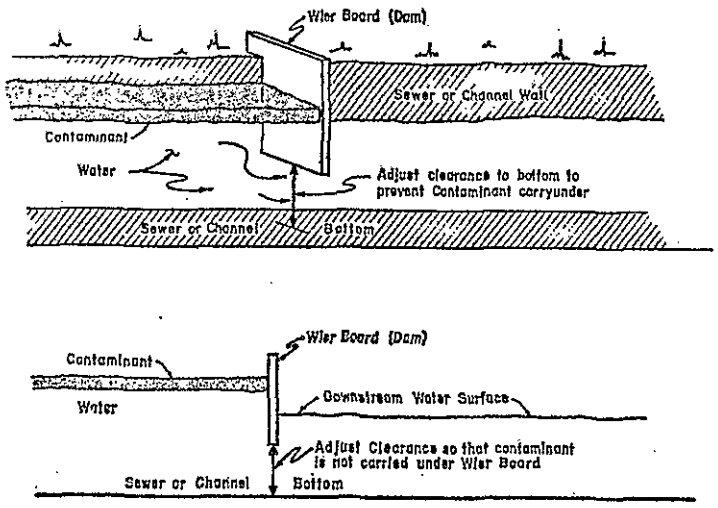


Figure 13

6-8.2 Where water is mixed with the contaminating liquid, it is preferable to separate the two by settling in drums or tanks to avoid contamination of downstream drainage facilities.

6-9 Sewers.

6-9.1 Sewers, on occasion, may collect flammable or combustible liquids from a surrounding contaminated area, and it is seldom practical to effectively seal off all entry points. Consequently, removal of contaminating liquids will normally be a continuing effort until the entire area is purged. When relatively large amounts of the contaminating liquid are involved, every reasonable effort should be made to divert the affected sewer flow to a separator where water and contaminant can be separated by gravity. If this is not practical, it may be possible to set up a skimming facility somewhere on the stream flow. One method is to throw a floating boom of polyurethane foam or an inflated tube such as a fire hose across the stream flow. If the contaminant is mostly on top of the water and surface flow is not turbulent, significant amounts of the contaminated liquid can be trapped behind the boom and removed with skimmer pumps and/or absorbent materials (*see Figures 12 and 13*). Weir boards can be used in the same way by raising them to permit water flow underneath and should be used whenever possible because of their greater efficiency, particularly when flow rates exceed 3 ft (1 m) per second (*see Figure 14*).



When current flow exceeds 3 ft./sec., Contaminates can be trapped by creating a difference in upstream and downstream surface with a Baffle or Wier Board.

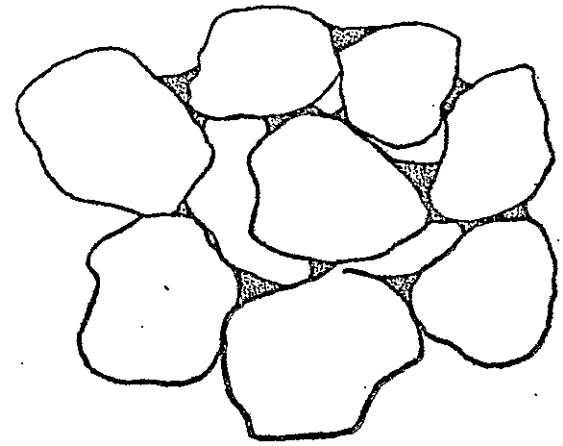
Figure 14

6-9.2 When relatively small amounts of liquid are involved, or the contaminating liquid is mixed with the water, settling tanks or basins must be used for separation by gravity (sewage treatment plants may have such facilities).

6-9.3 Water surfaces, as referred to in this chapter, are those on top of the ground exposed to the open air. When such contamination exists, the problem should be referred to the proper water pollution authority. Water surfaces underground, such as in sewers, are covered in Sections 6-8 and 6-9.

6-10 Underground Soil Contamination.

6-10.1 A knowledge of the local geology is basic to effective removal of flammable and combustible liquids from subsurface areas. Consequently, a geologist, familiar with the area, should be consulted whenever possible.



After a liquid has passed through a porous soil each particle will be coated with a thin film of that liquid and surface tension will hold small amounts of that liquid in corners of the voids as shown here in the dark areas.

Figure 15

6-10.2 The removal of flammable or combustible liquids from underground will involve gathering of the liquid in some pooling point, generally from the top of groundwater, or mixed in with that groundwater. However, the liquid will often be present above the

water table as well as on it, and removal and disposal is not complete until this liquid is also purged. Some concept of how this occurs is essential to an understanding of methods of removal. Reference to the discussion on geology in Chapter 5 will be helpful. When a liquid is released into a porous soil or rock, gravity will pull it downward through the pores or cracks. As it moves, some will be left behind on the surface of each particle that it contacts and some will be suspended by surface tension between two surfaces that are nearly in contact (*see Figure 15*).

6-10.3 The liquid will continue to move downward until the supply is exhausted by the coating action and by retention in the corners of the voids or until it reaches a barrier such as an impervious layer of soil or rock or the water table. If the supply of liquid continues after the barrier has been reached, the lower portion of the porous layer will begin to fill (*see Figure 16*).

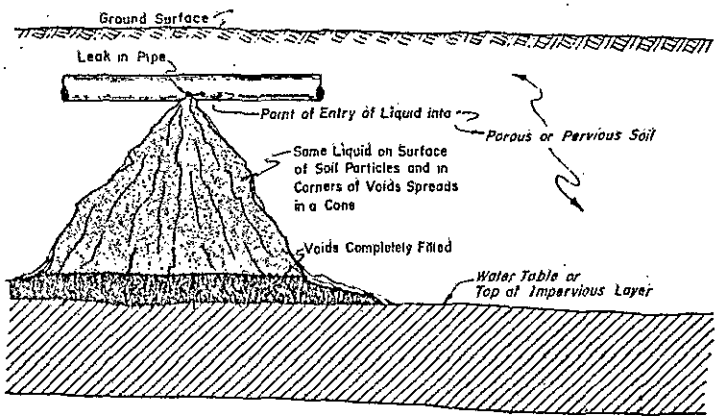


Figure 16

6-10.4 If the barrier is the water table and the groundwater is moving, the contaminating liquid will tend to move with it. However, most of the contaminating liquid that has remained up in the porous soil above the water table will stay there until it is washed down by subsequent rainfall or other water flowing down through the contaminated soil.

6-11 Removal of Liquids.

6-11.1 Trenches.

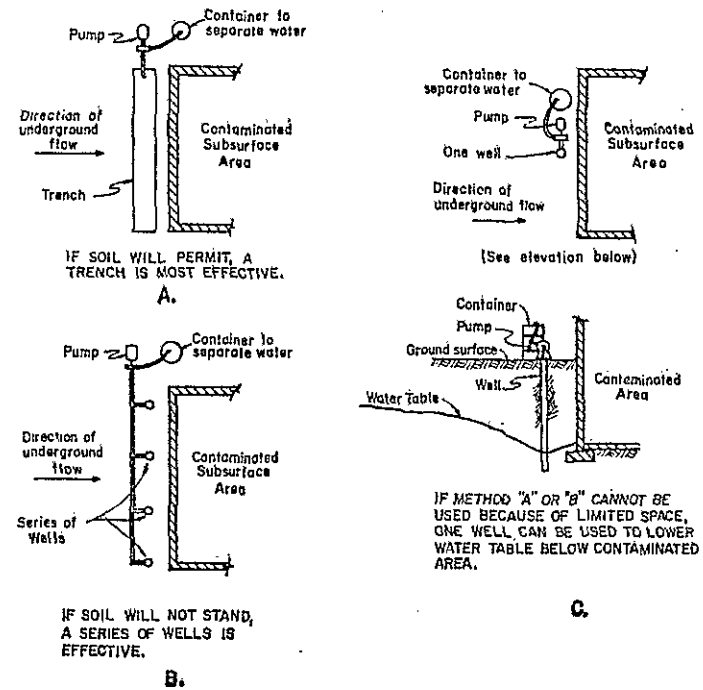


Figure 17

6-11.1.1 Sometimes the same method used for removing liquids from underground will serve to limit further spread. An intercepting hole or holes or trench illustrated in Figure 17 and Figure 18 are such methods. It will greatly improve the ability of the trench to prevent escape of the contaminating liquid if the downstream side of the trench at the water surface is lined with an impervious barrier. Figure 17 further illustrates various methods of using wells or trenches as interceptors upstream of contaminated buildings.

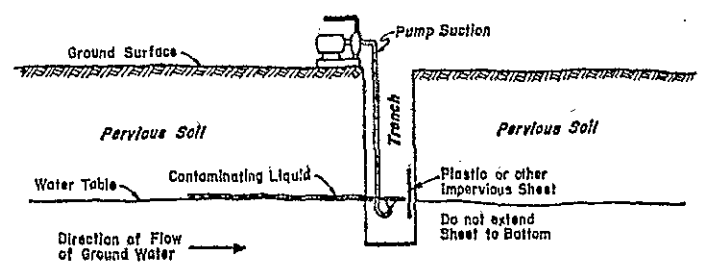


Figure 18

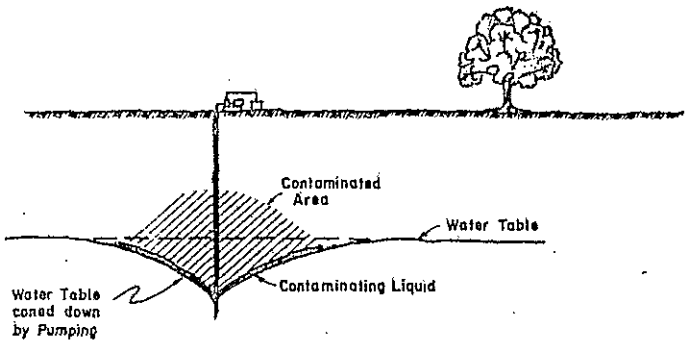


Figure 19

6-11.2 Wells.

6-11.2.1 Recovery wells can be used instead of intercepting trenches. These wells are practical in cases when the contaminated strata is both shallow and deep. A cone of depression is created by lowering the water level in the well below the surrounding natural water table. Flammable liquids will then migrate along the top of the water table into the well (*see Figures 20 and 21*). This procedure will establish an underground funnel radiating outward in all directions.

6-11.2.2 Care must be exercised in drilling and casing monitoring wells to ensure that the proper depth is not exceeded and that the well does not create conduits through impermeable layers.

6-11.2.3 When the area is extensive, a line of recovery wells with overlapping cones of depression can be used to create an effective underground barrier preventing the further migration of contaminant, while at the same time collecting it for removal.

6-11.2.4 If significant lowering of the water table near buildings is possible check with local engineering authorities to ensure against damage to substructures. (*See API 1628, Underground Spill Cleanup Manual, for additional information.*)

6-11.3 Pumping the Contaminant Out.

6-11.3.1 Refer to Figure 12 for the method of separating the oil and water mixture once it is raised to the surface. If large quantities of water are involved, bolted steel tanks can be obtained in sizes of several thousand gallons.

6-11.3.2 If the water table is reasonably shallow, two methods are available for removing the volatile liquid. One, a recovery well using a cone of depression to cause the contaminant to flow into the well.

Floating filter buoys, skimmer and pumps (*see Figure 22*) are available to collect and remove the contaminant. Two, if soil conditions permit, a trench may be dug (*see Figure 18*) and the same floating filter buoys and skimmers may be used.

It should be noted that the cone of depression will greatly speed the recovery process since it is drawing the spilled liquid to the recovery point.

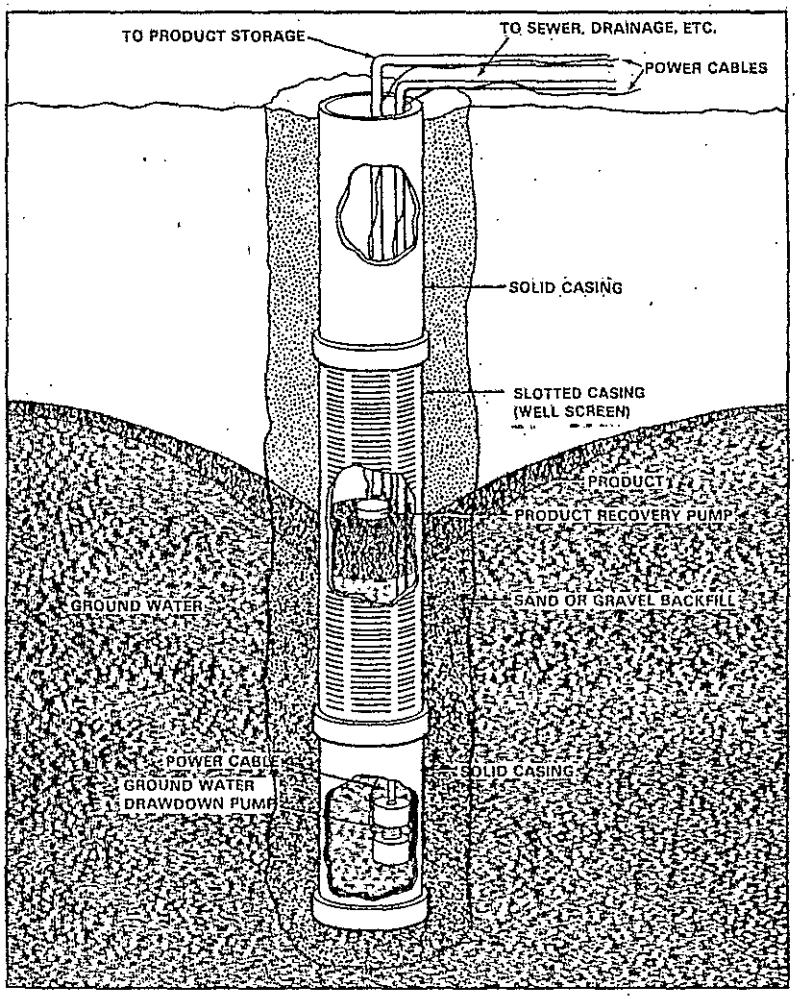


Figure 20 Double Pump Recovery Well

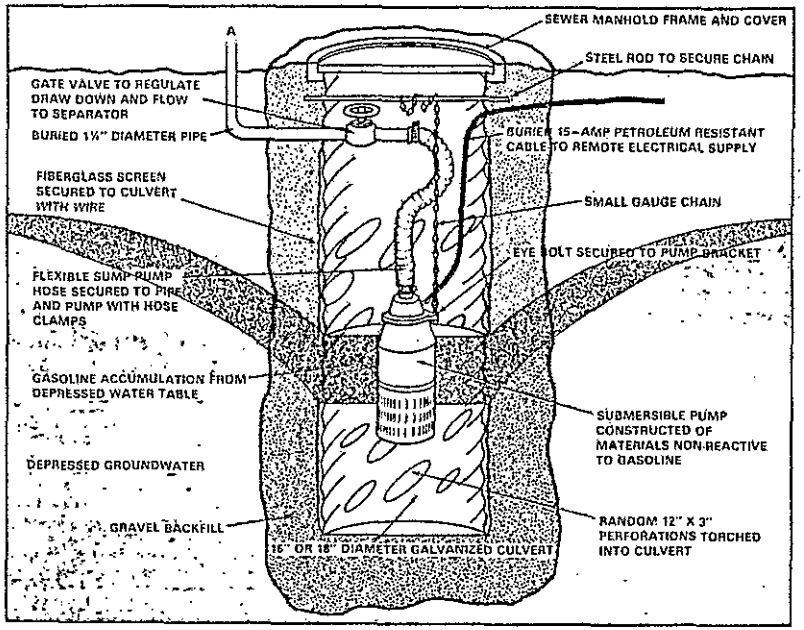


Figure 21 Recovery Well

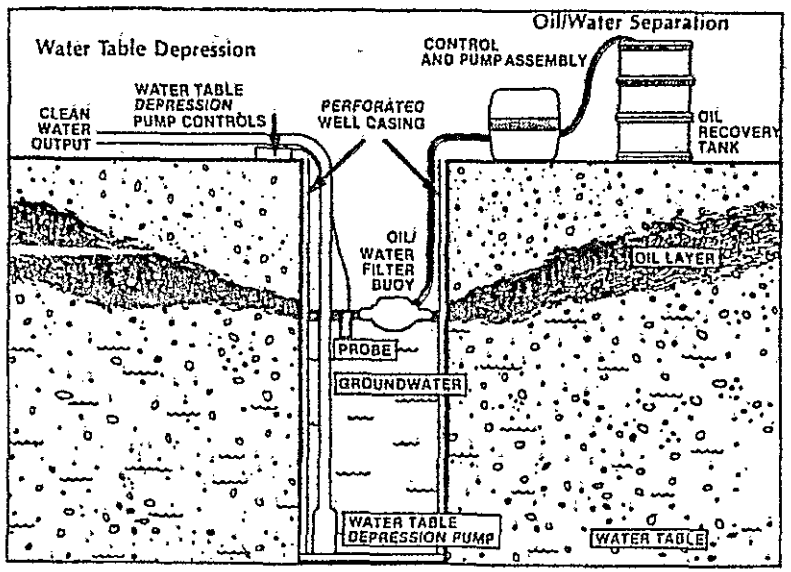


Figure 22 Recovery from Groundwater Using Filter and Water Table Depression Probe Pump.

6-11.3.3 If the water table is reasonably shallow [20 ft (6 m) or less] and the soil permits the digging of a trench, a "skimmer" suction at the top of the water table can be used. Figure 20 illustrates one method of skimming by using a funnel on the end of the suction hose mounted on the end of a pole for control.

6-11.3.4 Another method of skimming at shallow depths is illustrated in Figure 21. The depth at which this can be done will depend on the pump used. There are several available for use in decorative fountains; most will have a lift of 8 ft to 10 ft (2.5 to 3 m), but some special units are available for lifts up to 20 ft (6 m). The pump is lowered by a rope or wire into the hole upside down to a level where its suction is just covered by the liquid surface. It is run intermittently or continuously depending on how fast the contaminating liquid is being generated.

6-11.4 Disposal.

6-11.4.1 In disposing of mixtures of contaminated material, local regulatory officials should be consulted to ensure that the disposal method has their approval.

Appendix A

This Appendix is not a part of the recommendations of this NFPA document. . . but is included for information purposes only.

Physical Properties
Common Flammable and Combustible Liquids

	Flash Point °F (°C)	Flammable Limits Lower % by Vol.	Flammable Limits Upper % by Vol.	Specific Gravity Water = 1.0
Acetone	-4 (-20)	2.16	13	0.8
Amyl acetate	60 (16)	1.1	7.5	0.9
Amyl alcohol	91 (33)	1.2	10	0.8
Benzene (Benzol)	12 (-11)	1.3	7.1	0.9
Butyl acetate	72 (22.2)	1.7	7.6	0.9
Butyl alcohol	84 (28.9)	1.4	11.2	0.8
Carbon disulfide	-22 (-30)	1.3	50.0	1.3
Ethyl acetate	24 (-4.4)	2.0	11.5	0.9
Ethyl alcohol	55 (12.8)	3.3	19	0.8
Ethyl benzene	59 (15)	1.0	6.7	0.9
Fuel oil (diesel furnace & kerosene)	100-130 (37.8-54.4)	0.7	5	<1.0
Gasoline	-45 (-43)	1.4	7.6	0.8
Heptane	25 (-3.9)	1.05	6.7	0.7
Hexane	-7 (-21.1)	1.1	7.5	0.7
Isopropanol	53 (11.7)	2.0	12.7	0.8
Methyl alcohol	52 (11.1)	6.0	36	0.8
Methyl cyclohexane	25 (-3.9)	1.2	6.7	0.8
Naphtha (high flash)	85 (29.4)	1.0	6.0	<1.0
Naphtha (regular)	28 (-2.2)	0.9	6.0	<1.0
Stoddard solvent	100-130 (37.8-54.4)	0.7	5	<1.0
Toluene	40 (4.44)	1.2	7.1	0.9
Xylene-o	90 (32.2)	1.0	6.0	0.9

Appendix B Referenced Publications

B-1 This portion of the Appendix lists publications which are referenced within this NFPA document for information purposes only . . . and thus is not considered part of the recommendations of the document.

B-1.1 NFPA Publications. The following publications are available from the National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.

NFPA 30-1981, *Flammable and Combustible Liquids Code.*

NFPA 328-1982, *Recommended Practice for the Control of Flammable and Combustible Liquids and Gases in Manholes, Sewers, and Similar Underground Structures.*

B-1.2 Other Publications.

ASTM D 1250-80, *Petroleum Measurement Tables*

API 1628-1980, *Underground Spill Cleanup Manual.*

Official NFPA Definitions

APPROVED: means "acceptable to the authority having jurisdiction."

NOTE: The National Fire Protection Association does not approve, inspect or certify any installations, procedures, equipment or materials nor does it approve or evaluate testing laboratories. In determining the acceptability of installations or procedures, equipment or materials, the authority having jurisdiction may base acceptance on compliance with NFPA or other appropriate standards. In the absence of such standards, said authority may require evidence of proper installation, procedure or use. The authority having jurisdiction may also *refer to the listings or* labeling practices of an organization concerned with product evaluations which is in a position to determine compliance with appropriate standards for the current production of listed items.

AUTHORITY HAVING JURISDICTION: The "authority having jurisdiction" is the organization, office, or individual responsible for "approving" equipment, an installation, or a procedure.

NOTE: The phrase *"authority having jurisdiction" is used in NFPA documents in a broad* manner since jurisdictions and "approval" agencies vary as do their responsibilities. Where public safety is primary, the "authority having jurisdiction" may be a federal, state, local, or other regional department or individual such as a fire chief, fire marshal, chief of a fire prevention bureau, labor department, health department, building official, electrical inspector, or others having statutory authority. For insurance purposes, an insurance inspection department, rating bureau, or other insurance company representative may be the "authority having jurisdiction." In many circumstances the property owner or his designated agent assumes the role of the *"authority having jurisdiction"; at government installations, the com*manding officer or departmental official may be the "authority having jurisdiction."

LABELED: Equipment or materials to which has been attached a label, symbol or other identifying mark of an organization acceptable to the "authority having jurisdiction" and concerned with product evaluation, that maintains *periodic inspection of production of labeled equipment or materials and by* whose labeling the manufacturer indicates compliance with appropriate standards *or performance in a specified manner.*

LISTED: Equipment or materials included in a list published by an organization acceptable to the "authority having jurisdiction" and concerned with product evaluation, that maintains periodic inspection of production of listed equipment or materials and whose listing states either that the equipment or material meets appropriate standards or has been tested and found suitable for use in a specified manner.

NOTE: The means for identifying listed equipment may vary for each organization concerned with product evaluation, some of which do not recognize equipment as listed unless it is also labeled. The "authority having jurisdiction" should utilize the system employed by the listing organization to identify a listed product.

SHALL: indicates a mandatory requirement.

SHOULD: indicates a recommendation or that which is advised but not required.

Notes and footnotes are informatory only and are not mandatory.

Statement on NFPA Procedures

This material has been developed under the published procedures of the National Fire Protection Association, *which are designed to assure the appointment* of technically competent Committees having balanced representation. While these procedures assure the highest degree of care, neither the National Fire Protection Association, its members, nor those participating in its activities accepts any liability resulting from compliance or noncompliance with the provisions given herein, for any restrictions imposed on materials or processes, or for the completeness of the text.

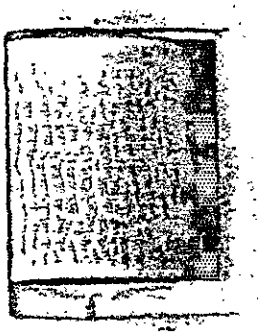
NFPA has no power or authority to police or enforce compliance with the contents of this document and any certification of products stating compliance with requirements of this document is made at the peril of the certifier.

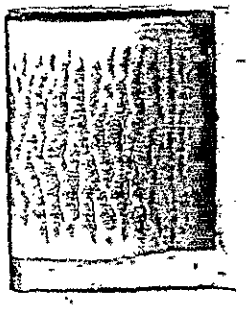
Bibliography of NFPA Standards

1 Fire Prevention Code
3M Health Care Emerg. Preparedness
10 Portable Extinguishers
10L Model Enabling Act
11 Foam Ext. Systems
11A Medium and High Expansion Foam Syst.
11C Mobile Foam Apparatus
12 Carbon Dioxide Systems
12A Halon 1301 Systems
12B Halon 1211 Systems
12CT Halon 2402 Systems
13 Sprinkler Systems
13A Sprinkler Maintenance
13D Sprinkler Sys., Dwellings
13E Sprinkler Prop., F.D. Operations at
14 Standpipe, Hose Systems
15 Water Spray Fixed Syst.
16 Deluge Foam-Water Systems
16A Closed Head Foam-Water Sprinkler Systs.
17 Dry Chem. Ext. Systems
18 Wetting Agents
20 Centrifugal Fire Pumps
21 Steam Fire Pumps
22 Water Tanks
24 Private Fire Service Mains
26 Supv'n, Water Supply Valves
27 Private Fire Brigades
291 Fire Hydrants
295 Wildfire Control
30 Flam. Liquids Code
31 Oil Burning Equipment
32 Drycleaning Plants
321 Class. Flam. Liquids
325M Prop. Flam. Liquids
327 Cleaning Small Tanks
328 Manholes, Sewers, Flam. Liquids and Gases in
329 Underground Leakage, Flam. Liquid Tanks
33 Spray Application
34 Dipping and Coating Processes
35 Mfg. Organic Coatings
36 Solvent Extraction
37 Combustion Engines
385 Tank Vehicles
386 Portable Shipping Tanks
395 Farm Stg. Flam. Liquids
40 Motion Picture Film
40E Pyroxylin Plastic
43A Liquid, Solid Oxidizing Materials
43C Gaseous Oxidizing Materials
43D Pesticides in Port. Containers
44A Fireworks, Mfg. Trans. Stge.
45 Labs Using Chemicals
46 Forest Products, Storage
48 Magnesium
481 Titanium
482 Zirconium
49 Hazardous Chem. Data
490 Ammonium Nitrate
491M Chem. Reactions
493 Intrinsically Safe Apparatus
495 Explosives, Stge., Use
496 Purged Enclosures
497 Class. of Class I Haz. Locations for Elec. Inst.
497M Class of Gases, Vapors, Dusts for Elec. Equip. in Haz. (Classified) Locations
498 Explosives, Motor Term.
50 Bulk Oxygen Systems
50A Gaseous Hydrogen Syst.
50B LH-Syst., Consumer Sites
51 Welding and Cutting
51A Acetylene Charging Plants
51B Welding Processes
53M Oxy. Atmospheres
54 Nat'l Fuel Gas Code
56A Inhalation Anesthetics
56B Respiratory Therapy
56C Labs in Health Inst.
56D Hyperbaric Facilities
56E Hypobaric Facilities
56F Nonflam. Med. Gases
56G Inhalation Anesthetics, Amb. Facil.
56HM Home Resp. Therapy
56K Medical-Surgical Vacuum Systems
58 LP-Gas Storage, Use
59 LP-Gas, Utility Plants
59A LN-Gas. Stg., Handling
61A Starch, Mfg. Handling
61B Grain Elevators
61C Feed Mills
61D Agricultural Commodities
65 Aluminum Processing
651 Aluminum, Magnesium Powder

Continued on back cover.

653 Coal Preparation Plants
654 Plastics, Expl. Prevent.
655 Sulfur Fires
66 Pneumatic Conveying
664 Wood Processing, Woodworking
68 Explosion Venting
69 Explosion Prev. Syst.
70 *Nat'l Electrical Code®*
70A Dwelling Electrical Code
70B Elect. Equip. Maint.
70E Employee Electrical Safety
70L Inspection of Elect. Installations
71 Central Station Sig.
72A Local Protective Syst.
72B Auxiliary Sig. System
72C Remote Station System
72D Proprietary Sig. Syst.
72E Auto. Fire Detectors
74 Household Warning Equip.
75 Electronic Computer Syst.
76A Hospital Elec. Systems
76B Electricity in Patient Care Areas
76C High-Freq. Electricity
77 Static Electricity
78 Lightning Prot. Code
79 Electrical Metalworking Machine Tools and Plastics Processing Machinery
80 Fire Doors, Windows
80A Exposure Fires, Prot.
81 Fur Storage & Cleaning
82 Incinerators, Rubbish
85A Single Burner Boiler-Furnaces
85B Gas Multi-Burner Boiler
85D Oil Multi-Burner Boiler
85E Coal Multi-Burner Boiler
85F Pulverized Fuel Systems
85G Implosions in Multi-Burner Boiler
86A Ovens and Furnaces
86B Industrial Furnaces
86C Ind. Furn., Sp. Processing
86D Ind. Vacuum Furnaces
87 Piers and Wharves
88A Parking Structures
88B Repair Garages
90A Air Conditioning Syst.
90B Warm Air Htg., Air Cond.
91 Blower and Exhaust Syst.
96 Vapor Removal Cooking Eq.
97M Heating Terms, Glossary
101® Life Safety Code®
102 Assembly Seating, Tents, Air-Supported Structures
110T Legally Required Emergency and Standby Power Systs.
121 Mobile Surface Mining Equip
130 Fixed Guideway Transit Systs
150 Racetrack Stables
172 Fire Protection Symbols for Architectural & Engineering Drawings
174 Fire Protection Symbols for Risk Analysis Diagrams
178 Symbols — Fire Fighting Operations
203M Roof Coverings
204M Smoke, Heat Venting
206M Building Areas
211 Chimneys, Fireplaces, Vents
214 Water Cooling Towers
220 Types Bldg. Construction
224 Homes, Forest Areas
231 Indoor General Storage
231C Rack Storage of Mat'ls.
231D Storage of Rubber Tires
232 Protection of Records
232AM Archives Centers
241 Bldg. Constr. Operation
251 Fire Tests Bldg. Constr. & Mat'ls
252 Fire Tests Door Assem.
253 Flooring Radiant Panel Test
255 Burning Character. Bldg. Mat'ls.
256 Tests Roof Coverings
257 Window Assemblies
258 Tests Smoke Generated
259 Tests Heat of Bldg. Mat'ls.
260A Cig. Ignition Resistance — Components of Furniture
260B Cig. Ignition Resistance — Composites of Furniture
302 Pleasure and Commercial Motor Craft
303 Marinas and Boatyards
306 Gas Hazards on Vessels
312 Vessels, Constr., Repair
402 Aircraft Rescue Proced.
403 Aircraft Rescue Services
406M Aircraft Resc., Fire Fighting, Using Structural Equip.
407 Aircraft Fuel Servicing
408 Aircraft Extinguishers
409 Aircraft Hangars
410 Aircraft Maintenance
412 Testing, Foam Vehicles
414 Rescue Vehicles
415 Fueling Ramp Drainage
416 Airport Terminals
417 Loading Walkways
418 Roof-top Heliports
419 Airport Water Systems
421 Aircraft Interior F. P.
422M Aircraft Fire Investigators Manual
423 Aircraft Engine Test Facilities
424 Airport/Community Emerg. Planning
501A Mobile Home Instal., Sites
501C Recreational Vehicles
501D Recreational Vehicle Pks.
502 Highways, Tunnels, Bridges
505 Powered Industrial Trucks
512 Truck Fire Protection
513 Motor Freight Terminals
601 Guard Service
601A Guard Operations
701 Fire Tests, Textiles; Films
702 Wearing Apparel
703 Fire-Retardant Treatments of Bldg. Mat'ls.
704 Ident. of Materials
801 Radioactive Mat'l. Facil.
802 Nuclear Research Reactors
803 Light Water Nuclear Power Plants
901 Uniform Coding for F. P.
902M Field Incident Manual
903M Property Survey Manual
904M Investigative Report Manual
907M Investigation of Fires of Elec. Origin
910 Libraries and Library Collections
911 Museums and Museum Collections
1001 Fire Fighter Prof. Qual.
1002 Driver Prof. Qual.
1003 Airport Fire Fighter Prof. Qual.
1021 Fire Officer Prof. Qual.
1031 Fire Inspector Prof. Qual.
1041 Fire Instructor Prof. Qual.
1121L Model State Fireworks Law
1122 Unmanned Rockets Code
1123 Fireworks, Public Display
1201 Organization, Fire Services
1202 Fire Dept. Organization
1221 Public Fire Serv. Comm.
1231 Suburban & Rural Water Supplies
1401 Training Reports, Records
1410 Initial Fire Attack
1501 Fire Dept. Safety Officer
1901 Automotive Fire Apparatus
1904 Aerial Ladders & Elev. Platforms
1921 Portable Pumping Units
1931 Fire Dept. Ground Ladders
1961 Fire Hose
1962 Fire Hose Care, Use
1963 Hose Connection Threads
1971 Protective Clothing
1972 Fire Fighters' Helmets
1973 Gloves for Structural Fire Fighters
1981 Self-Contained Breathing App.
1982 Personal Alert Safety System for Fire Fighters





62. National Sanitation Foundation. "Standard 54 for Flexible Membrane Liners," Ann Arbor, Michigan, November 1983

Stephen A. Fagundes

NATIONAL SANITATION FOUNDATION
STANDARD 54
FOR
FLEXIBLE MEMBRANE LINERS

As Prepared by
The Joint Committee
on
Flexible Membrane Liners
and
Recommended for Adoption
by
The NSF Council of Public Health Consultants
Adopted
by
The NSF Board of Trustees

November 1983

National Sanitation Foundation
3475 Plymouth Road
P.O. Box 1468
Ann Arbor, Michigan 48106 USA

Received DTS
JAN 28 1985

The following is a list of nationally uniform sanitation standards and criteria established by the National Sanitation Foundation.

Current standards and criteria include:

1 Soda Fountain and Luncheonette Equipment
2 Food Service Equipment
3 Spray-Type Dishwashing Machines
4 Commercial Cooking and Hot Food Storage Equipment
5 Commercial Hot Water Generating and Heat Recovery Equipment
6 Dispensing Freezers
7 Food Service Refrigerators and Storage Freezers
8 Commercial Powered Food Preparation Equipment
12 Automatic Ice Making Equipment
13 Refuse Compactors and Compactor Systems
14 Plastic Piping System Components and Related Materials
18 Manual Food and Beverage Dispensing Equipment
20 Commercial Bulk Milk Dispensing Equipment and Appurtenances
21 Thermoplastic Refuse Containers
23 Marine Sanitation Devices
24 Plumbing System Components for Mobile Homes and Recreational Vehicles
25 Vending Machines for Food and Beverages
26 Pot, Pan and Utensil Commercial Spray Type Washing Machines
29 Detergent and Chemical Feeders for Commercial Spray Type Dishwashing Machines
30 Cabinetry and Laboratory Furniture for Hospitals
31 Polyethylene Refuse Bags
35 Laminated Plastics for Surfacing Food Service Equipment
36 Dinnerware
37 Air Curtains for Entranceways in Food Establishments
38 Test Kits for Swimming Pool Water
39 Resilient Artificial Recreational Surfaces
40 Individual Aerobic Wastewater Treatment Plants
41 Wastewater Recycle/Reuse and Water Conservation Systems
42 Drinking Water Treatment Units — Aesthetic Effects
43 Chemical Feeding and Processing Equipment Relating to Supplementary Treatment of Potable Water
44 Cation Exchange Water Softeners Relating to Supplementary Treatment of Potable Water
49 Class II (Laminar Flow) Biohazard Cabinetry
50 Circulation System Components for Swimming Pools
51 Plastic Materials and Components Used in Food Equipment
52 Supplemental Flooring
53 Drinking Water Treatment Units — Health Effects
54 Flexible Membrane Liners
C-2 Special Equipment and/or Devices
C-6 Continuous Cloth Towel Dispensers
C-8 Pitless Well Adapters
C-9 Evaluation of Special Processes or Devices Used in Treating Wastewater
C-10 Ductless Air Circulating and Treatment Devices

THE NATIONAL SANITATION FOUNDATION

Purpose and Organization

The Foundation, popularly referred to as NSF, is a nonofficial and noncommercial agency. It is incorporated under the laws of Michigan as a not-for-profit organization devoted to research, education and service. It seeks to solve problems involving man and his environment. It wishes to promote man's health and enrich the quality of life through conserving and improving that environment. Its fundamental principle of operation is to serve as a neutral medium in which business and industry, official regulatory agencies, and the public come together to deal with problems involving products, equipment, procedures, and services related to health and the environment.

NSF is perhaps best known for its role in the developing of standards and criteria for equipment, products, and services that bear upon health. The NSF seal is widely recognized as a sign that the article to which it is affixed complies with public health requirements. NSF early in its existence established its own testing laboratory as a subsidiary corporation. This laboratory conducts research; tests and evaluates equipment, products and services for compliance with NSF standards and criteria; and grants and controls the use of the NSF seal.

A brochure is available discussing in some detail the purpose, objectives, and philosophy of NSF and its standards and listing programs. It describes the way in which distinguished leaders from business, industry, public health, and related professions give generously of their time and talent in helping achieve NSF objectives. The brochure is available upon request.

DISCLAIMERS

The National Sanitation Foundation (NSF) in performing its functions in accordance with its objectives, does not assume or undertake to discharge any responsibility of the manufacturer or any other party. The opinions and findings of NSF represent its professional judgment given with due consideration to the necessary limitations of practical operation and state-of-the-art at the time the standard is processed. NSF shall not be responsible to anyone for the use of or reliance upon this standard by anyone. NSF shall not incur any obligation or liability for damages, including consequential damages, arising out of or in connection with the use, interpretation of, or reliance upon this standard.

Participation in NSF standards development activities, committees or Council by Federal agency representatives does not constitute the endorsement by the Federal Government or any of its agencies of NSF or the standards which they develop.

Preference is given to the use of performance criteria measurable by examination or testing in NSF standards development when such performance criteria may reasonably be used in lieu of design, materials or construction criteria.

The illustrations, if provided, are intended to assist in understanding their adjacent standard requirements. However, the illustrations may not include *all* requirements for a specific product or unit, nor do they show the only method of fabricating such arrangements. Such partial drawings shall not be used to justify improper or incomplete design and construction.

The appendices referenced in NSF standards are not considered an integral part thereof. The appendices are provided as general guidelines to the manufacturer, regulatory agency, user or certifying organization.

PREFACE

The development of the NSF Standard for Flexible Membrane Liners (FML) began as a response to a growing national interest in responsible containment of certain hazardous waste materials. In January of 1978, a meeting of lining industry, regulatory and user representatives was held to explore the interest and feasibility of an NSF standard covering polymeric membrane liners for land disposal of solid wastes.

At the first few meetings, it became clear that an NSF standard would serve a very useful purpose for national, state and local regulatory agencies responsible for safe containment of hazardous and toxic materials; to FML manufacturers and fabricators who produce the FML; to engineers who design such installations; and to private and governmental organizations who would have a use for such liners. Further, it was determined that the NSF standard for FML should cover the broad use of polymer lining materials encompassing not only solid waste disposal sites, but a broad range of containment of hazardous and toxic fluids and the retention of fresh water for a variety of uses such as reservoirs, canals and recreational ponds.

The scope of the standard was to cover the existing and recently developed polymer linings which could be installed as prefabricated linings which may or may not require field seaming to form the finished lining. The objective of the standard was to establish a reliable and dependable means of industry furnishing an FML of known and consistent quality. Suitability of any particular FML for a specific application remains the responsibility of the user.

Following the normal NSF procedure, a Joint Committee was established to write the standard and furnish NSF technical information for appropriate policy on the use of the standard.

One of the major tasks of the Joint Committee has been to establish the requirements for various materials. These requirements now appear as the materials properties tables in the standard. At first, there was an attempt to generate a general, all inclusive standard requirement for all FML based upon the service needs of the FML. However, it was soon recognized that the engineering requirements would vary from application to application. More important is the fact that good FML of different chemical composition would have different physical properties. Consequently, the standard has been prepared on the basis of key tests which charactertize a good quality FML of a particular chemical composition. As a result, the requirements for a good 30 mil PVC plastic liner are different from a 30 mil EPDM rubber liner.

Selection of the properties to be listed was based upon current knowledge in the field of important parameters for which reasonable test methods had been established or could readily be devised. In general, the test methods selected are based upon test procedures established by the American Society for Testing and Materials (ASTM) or other widely recognized standards setting organizations. In some cases, these have been modified to reflect the technical knowledge and experience of the Joint Committee. In a few selected uses, special tests have been developed to meet a special need.

The properties, test methods, and required values appearing in the material properties tables were specifically chosen as those that are critical in the characterization of the individual FML. There are differences from one material to another in the tests required, test methods used and the values required. This is because the chemical nature and physical properties of different membrane materials are not the same. Hence, the material property tables should be dealt with separately as properties, methods and values that are critical to one FML may not be critical in describing another type.

Two important qualities for FML have not been included in the requirements set forth in this standard. These are impermeability and puncture resistance. For these properties, either they are not appropriate for a materials requirement or a good test does not exist.

An important basic FML property is impermeability. However, the inherent impermeability of the lining material itself is so great as to make the property meaningless in evaluating a material for use as an FML. In actual use, flexible membrane liners do not leak unless there is a hole in the liner, a failure of a seam, or the liner is degraded by the particular service condition. Falling head or constant head permeameters are typically used in the laboratory to determine permeability of soils. However, for FML, such measurement of permeability is a measure more of vapor transport than of fluid permeability or porosity. Therefore, a permeability test is not included in the materials properties tables.

The resistance of an FML to the attack of the chemicals to be contained is an obviously important concern. There is a wide variety of different chemicals which are to be contained in industrial and municipal applications. The response of different FML materials is quite different to many chemicals. The environmental conditions of temperature, phase separation, etc., vary from case to case. There is no test method universally accepted for precisely establishing the chemical resistance of any FML materials. For these reasons, standard requirements for FML have not been included and NSF makes no representations as to the chemical resistance. Guidelines are given in Appendices C, D and E for selection and evaluation of possible FML materials for applications requiring the containment of fluids other than fresh water.

A committee will be formed to recommend procedures, conditions, chemicals and methods of evaluation for chemical resistance of FML and guidelines will be developed.

FML should have reasonable resistance to puncture from rapid point stress such as falling rock in earth cover operation or the dropping of tools during installation. The FML should also be resistant to prolonged point stress resulting from soil and fluid loading over occasional stone or hard dirt clods under the liner. The Joint Committee found that although some tests do exist which relate to puncture resistance, none is acceptable as standard requirement. Some are very useful as research and development tools in the comparative study of different materials or the aging of materials after field or artificial exposure. These tests, however, lack the ability to be reproducible from laboratory to laboratory and do not have sufficient consistency to have been accepted as a material standard.

In preparing the standard, the Joint Committee recognized that the successful application of an FML in a particular situation depended upon several factors beyond the use of a good quality FML. To assist in the successful use of the liner, some guidelines and recommendations are given in the appendices. Final acceptance of FML for any application covered under governmental regulation will be subjected to the approval of the appropriate federal, state and/or local regulatory agency having jurisdiction.

NOTE: The standard covers both existing and recently developed polymeric liners. The purpose of the standard is to provide a reliable and dependable means for industry to furnish such materials of known and consistent quality. Before selection of any material for an FML, however, the user should consult with appropriate manufacturers, because these materials may not be appropriate for every application. Specific information should be obtained from the manufacturers regarding installation requirements, exposure conditions, performance expectations, and experience factor.

CONTENTS

Page

Current NSF Standards and Criteria i
National Sanitation Foundation Purpose and Organization iii
Disclaimers v
Preface vii

SECTION 1. GENERAL

1.0 Scope 1
1.1 Minimum Requirements 1
1.2 Reviews and Revisions 1

SECTION 2. DEFINITIONS

2.0 General 1
2.1 Alloys, Polymeric 1
2.2 Bonded Seam Strength 1
2.3 Breaking Factor 1
2.4 Breaking Strength 1
2.5 Butyl Rubber (IIR) 1
2.6 Chlorinated Polyethylene (CPE) 1
2.7 Chlorosulfonated Polyethylene (CSPE) 2
2.8 Crosslinking 2
2.9 Elasticity 2
2.10 Elongation 2
2.11 Elongation at Break 2
2.12 Elongation at Yield 2
2.13 Elastomer 2
2.14 Ethylene Propylene Diene Terpolymer (EPDM) 2
2.15 Fabric Reinforcement 2
2.16 Film Tearing Bond 2
2.17 High Density Polyethylene (HDPE) 2
2.18 Hydrostatic Resistance 2
2.19 Membrane 2
2.20 Modulus (Force) at 100% Elongation 2
2.21 Modulus of Elasticity 2
2.22 Nitrile Rubber 2
2.23 Permeability 2
2.24 Plastic 2
2.25 Plasticizer 2
2.26 Polyethylene-Ethylene Propylene Alloy (PE-EP-A) 2
2.27 Polymer 3
2.28 Polyvinyl Chloride (PVC) 3
2.29 Rubber 3
2.30 Scrim 3
2.31 Seams 3
2.31.1 Adhesive Seams 3
2.31.2 Bodied Solvent Seams 3
2.31.3 Dielectric Seams 3
2.31.4 Extrusion Welded Seams 3
2.31.5 Solvent Seams 3
2.31.6 Tape Seams 3
2.31.7 Thermal Seams 3
2.31.8 Vulcanized Seams 3
2.32 Special Engineered (SE) 3
2.33 Supported Membrane 3
2.34 Tear Strength 3
2.35 Thermoplastic 3
2.36 Thermoplastic Elastomers 3
2.38 Unsupported Membrane 3

SECTION 3. MATERIALS

3.0 General 4
3.0.1 Formulation 4
3.0.2 Membrane Materials 4
3.0.3 Installation Condition 4
3.0.4 Service Grade 4
3.0.5 Identification/Naming of Materials 5
3.1 Materials Properties 5
Table 1A - Polyvinyl Chloride (PVC) 6
Table 1B - Polyvinyl Chloride (PVC-OR) Oil Resistant Grade 7
Table 2A - Chlorinated Polyethylene (CPE) Unsupported 8
Table 2B - Chlorinated Polyethylene (CPE) Supported 9
Table 3 - Butyl Rubber (IIR) 10
Table 4 - Polychloroprene (CR) 11
Table 5 - High Density Polyethylene (HDPE) 12
Table 6 - Ethylene-Propylene Diene Terpolymer (EPDM) 13
Table 7 - Epichlorohydrin Polymers (CO) 14
Table 8 - Polyethylene Ethylene Propylene Alloy (PE-EP-A) 15
Table 9 - High Density Polyethylene Elastomeric Alloy (HDPE-A) 16
Table 10A - Chlorosulfonated Polyethylene (CSPE) 17
Table 10B - Chlorosulfonated Polyethylene (CSPE-LW) Low Water Absorption 18
Table 11 - Thermoplastic Nitrile - PVC (TN-PVC) Oil Resistant Grade 19
Table 12 - Thermoplastic EPDM (T-EPDM) 20
Table 13 - Ethylene Interpolymer Alloy (EIA) 21
Table 14A - Chlorinated Polyethylene Alloy (CPE-A) Unsupported 22
Table 14B - Chlorinated Polyethylene Alloy (CPE-A) Supported 23
3.2 Retention Applications 24
3.2.1 Potable Water Applications 24
3.2.2 Recreational Applications 25
3.2.3 Nonrecreational Applications 25
3.3 Containment Applications 25

SECTION 4. DESIGN AND CONSTRUCTION

4.0 General 25
4.1 Materials 25
4.2 Seams 25
4.2.1 Types of Seam Joints 25
4.2.2 Factors Affecting Strength of Seam Joints 25
4.3 Potable Water Applications 26

Section 5. Identification

5.0 General 26
5.1 Material 26
5.1.1 Flexible Membrane Liner Material Chemical Composition 26
5.1.2 Unsupported - Supported Material Type 26
5.1.3 Membrane Type 26
5.1.4 Flexible Membrane Liner Thickness 26
5.2 Installation Condition 26
5.3 General Intended Service 26

Appendix A - Special Test Methods and Revision of Standard Test Procedures
Part 1 - Water Extraction A1
Part 2 - Bonded Seam Strength A2
Part 3 - Soil Burial A3
Part 4 - Peel Adhesion A3
Part 5 - Tear Strength A3
Part 6 - Optical Method for Measuring Thickness of Material Over Scrim A4

Part 7 - Chemical/Taste and Odor
A - Review Procedures A5
B - Laboratory Procedures A7
Part 8 - Ply Adhesion A21
Part 9 - Accelerated Weathering Test A21
Part 10 - Dead Load Seam Strength A24
Part 11 - Dead Load Seam Strength at Elevated Temperature A24
Part 12 - Environmental Stress Crack Resistance A25

Appendix B - Recommendations and Precautions B1

Appendix C - Considerations for Site Evaluation, Material Selection, Construction, Operation, and Maintenance C1

Appendix D - Recommended Test Method for Estimating Long-Term Performance of Membrane Liners in a Chemical Environment D1

Appendix E - Identification System E1

Appendix F - Recommended Protocol for Developing Testing and Field Experience Data for New Materials F1

Appendix G - Participating Committees
NSF Joint Committee For Flexible Membrane Liners G1
NSF Council of Public Health Consultants G3

NSF STANDARD 54
FOR
FLEXIBLE MEMBRANE LINERS

SECTION 1. GENERAL

1.0 SCOPE: This standard covers flexible membrane liners used in the retention of waters and containment of pollutants or chemicals in an environmentally acceptable manner. The successful application of the flexible membrane liners covered by this standard depend upon appropriate site evaluation, design, materials selection, construction and operation and maintenance. Guidelines covering these factors are presented in Appendix C. The standard includes requirements for evaluation of flexible membrane liners and fabrication techniques. Accordingly, materials properties tables for the various membranes are provided to indicate requirements for liner characterization and evaluation; liner fabrication requirements are also developed to accommodate evaluation for the indicated applications. Special test methods or revisions of standard test procedures are included in Appendix A to provide uniformity and consistency in the analytical protocol supportive of the standard.

1.1 MINIMUM REQUIREMENTS: These standards are established as a guide to the evaluation of flexible membrane liners covered herein and are considered to be basic and minimum requirements.

1.2 REVIEWS AND REVISIONS: A comprehensive review of the standard shall be conducted at intervals of not more than five years to determine what changes, deletions or additions, if any, are necessary to maintain current and effective requirements consistent with new technology and progress. These reviews shall be conducted by appropriate representatives of regulatory, industry and user groups. Final adoption of any revision shall be in accordance with the procedures established by the NSF Joint Committee for Flexible Membrane Liners.

SECTION 2. DEFINITIONS

2.0 GENERAL: The definitions included in this section explain words or terms specifically used in this standard for which dictionary definitions either do not exist or are not applicable to the term as used within the context of this standard.

2.1 ALLOYS, POLYMERIC: A blend of two or more polymers such as a rubber and a plastic to modify a given property; e.g., tensile strength.

2.2 BONDED SEAM STRENGTH: Strength of a seam of liner material measured either in shear or dead load, or peel modes. Strength of the seams is reported either in absolute units; e.g., pounds per inch of width; or as a percent of the strength of the sheeting.

2.3 BREAKING FACTOR: Tensile force per unit of width at break measured in pounds per inch (Newtons per meter) and used to describe properties of membranes.

2.4 BREAKING STRENGTH: Tensile force to break measured in pounds (Newtons) on a supported membrane.

2.5 BUTYL RUBBER (IIR): A synthetic rubber based on isobutylene and a small amount of isoprene to provide sites for vulcanization.

2.6 CHLORINATED POLYETHYLENE (CPE): Family of polymers produced by the chemical reaction of chlorine with polyethylene. The resultant polymers presently contain 25 - 45% chlorine by weight and 0 - 25% crystallinity.

2.7 CHLOROSULFONATED POLYETHYLENE (CSPE): Family of polymers produced by the reaction of polyethylene with chlorine and sulfur dioxide. Present polymers contain 23.5 - 43% chlorine and 1.0 - 1.4% sulfur. A "low water absorption" grade is identified as significantly different from standard grades (see Table 11B).

2.8 CROSSLINKING: A general term referring to the formation of chemical bonds between polymeric chains to yield a three-dimensional polymeric structure. Crosslinking of rubbers is vulcanization.

2.9 ELASTICITY: The property of matter by virtue of which it tends to return to its original size and shape after removal of the stress which caused the deformation.

2.10 ELONGATION: Extension produced by a tensile stress.

2.11 ELONGATION AT BREAK: The extension of a uniform section of a specimen at rupture expressed as percent of the original length.

2.12 ELONGATION AT YIELD: The extension of a uniform section of specimen at yield expressed as percent of the original length.

2.13 ELASTOMER: See "Rubber".

2.14 ETHYLENE PROPYLENE DIENE TERPOLYMER (EPDM): A synthetic elastomer based on ethylene, propylene, and a small amount of nonconjugated diene to provide sites for vulcanization.

2.15 FABRIC REINFORCEMENT: A fabric, scrim, etc., used to add structural strength to a two or more ply polymeric sheet. Such sheeting is referred to as "supported".

2.16 FILM TEARING BOND: Failure of one of the parts of a ply by tearing, instead of separating from the other part of the specimen at the separation line.

2.17 HIGH DENSITY POLYETHYLENE (HDPE): A polymer prepared by low-pressure polymerization of ethylene as the principal monomer.

2.18 HYDROSTATIC RESISTANCE: Resistance to bursting using the flexible membrane liner as the diaphragm.

2.19 MEMBRANE: A prefabricated continuous sheet of flexible polymeric material.

2.20 MODULUS (FORCE) AT 100% ELONGATION: Stress at 100% elongation.

2.21 MODULUS OF ELASTICITY: The ratio of stress to strain below the yield point.

2.22 NITRILE RUBBER: A family of copolymers of butadiene and acrylonitrile that are oil resistant and can be vulcanized into oil resistant compounds.

2.23 PERMEABILITY: The capacity of a porous medium to conduct or transmit fluids. The amount of liquid moving through can be measured in a unit time, unit area, and unit pressure gradient not normalized for but directly related to thickness.

2.24 PLASTIC: A material that contains as an essential ingredient one or more polymeric substances of high molecular weight, is solid in its finished state and at some stage in its manufacture or processing into finished articles, can be shaped by flow.

2.25 PLASTICIZER: A material, frequently "solvent-like" incorporated in a plastic or rubber to increase ease of workability, flexibility or extensibility.

2.26 POLYETHYLENE-ETHYLENE PROPYLENE ALLOY (PE-EP-A): Blend of polyethylene and ethylene proplyene polymer resulting in a thermoplastic elastomer.

2.27 POLYMER: A macromolecular material formed by the chemical combination of monomers having either the same or different chemical composition. Plastics, rubbers and textile fibers are all high molecular weight polymers.

2.28 POLYVINYL CHLORIDE (PVC): A synthetic thermoplastic polymer made by polymerizing vinyl chloride monomer, or vinyl chloride/vinyl acetate monomers. Normally rigid, plasticizers are added to provide properties required for flexible membrane liners.

2.29 RUBBER: A polymeric material which, at room temperature, is capable of recovering substantially in shape and size after removal of a deforming force. Refers to both synthetic and natural rubber and is also called an elastomer.

2.30 SCRIM: A reinforcing fabric.

2.31 SEAMS:

2.31.1 ADHESIVE SEAMS: A chemical system is used to develop bond strength between two membrane surfaces. The chemical adhesive becomes an additional element to the seam system.

2.31.2 BODIED SOLVENT SEAMS: The parent material dissolved in a solvent is used to soften and bond the membrane materials.

2.31.3 DIELECTRIC SEAMS: High frequency dielectric equipment is used to generate heat and pressure on an overlap seam joint resulting in a homogeneous melt of the two membrane surfaces.

2.31.4 EXTRUSION WELDED SEAMS: A bond between the two flexible membrane sheets is achieved by heat extruding the parent material between or over the overlap areas followed by applied pressure.

2.31.5 SOLVENT SEAMS: Solvents are used to soften and bond the membrane surfaces.

2.31.6 TAPE SEAMS: A width of material to which a chemical adhesive has been applied is used to tape a seam joint. The tape provides the bond and the tensile strength of the joint.

2.31.7 THERMAL SEAMS: High temperature is produced between an overlap seam joint to melt the membrane surfaces, followed by a pressure system that results in the homogeneous bond of the two membrane surfaces.

2.31.8 VULCANIZED SEAMS: Overlapped unvulcanized sheets cured together using heat and pressure.

2.32 SPECIAL ENGINEERED (SE): Specifically designed for a particular end use or application.

2.33 SUPPORTED MEMBRANE: See "Fabric Reinforcement".

2.34 TEAR STRENGTH: The force required to tear a specimen. The value is determined by the specific test procedure being used.

2.35 THERMOPLASTIC: A material capable of being repeatedly softened by increase of temperature and reformed by decrease in temperature.

2.36 THERMOPLASTIC ELASTOMERS: Polymeric materials having elasticity characteristics similar to rubber and capable of being repeatedly softened and reformed.

2.37 TYPE: A designation relating to the strength of the fabric reinforcement.

2.38 UNSUPPORTED MEMBRANE: A polymeric membrane one or more plies thick without a reinforcing fabric layer or scrim.

SECTION 3. MATERIALS AND MEMBRANE MANUFACTURE

3.0 GENERAL: Flexible membrane liners shall meet the specific physical, chemical, taste and odor requirements as established herein for the intended application. Liners shall be free of pinholes, blisters, holes and contaminants which include, but are not limited to wood, paper, metal and nondispersed ingredients.

3.0.1 FORMULATION: The compounding ingredients used in producing membrane liners shall be first quality, virgin material meeting specific public health and safety requirements as well as providing durable and effective formulations for liner applications. Clean rework materials containing encapsulated scrim or other fibrous materials shall not be used in the manufacture of FML used in Containment Applications as defined in Item 3.3 only. Clean rework materials of the same virgin ingredients generated from the manufacturer's own production may be used by the same manufacturer, provided that the finished products meet the requirements of this standard.

3.0.2 MEMBRANE MATERIALS: The membrane materials covered by this standard include the following:

- Polyvinyl Chloride (PVC) - Table 1A
- Oil Resistant Polyvinyl Chloride (PVC-OR) - Table 1B
- Chlorinated Polyethylene (CPE) - Tables 2A and 2B
- Butyl Rubber (IIR) - Table 3
- Polychloroprene (CR) - Table 4
- High Density Polyethylene (HDPE) - Table 5
- Ethylene-Propylene Diene Terpolymer (EPDM) - Table 6
- Epichlorohydrin Polymers (CO) - Table 7
- Polyethylene Ethylene Propylene Alloy (PE-EP-A) - Table 8
- High Density Polyethylene Elastomeric Alloy (HDPE-A) - Table 9
- Chlorosulfonated Polyethylene (CSPE) - Table 10A
- Chlorosulfonated Polyethylene Low Water Absorption (CSPE-LW) - Table 10B
- Thermoplastic Nitrile - PVC (TN-PVC) - Table 11
- Thermoplastic EPDM (T-EPDM) - Table 12
- Ethylene Interpolymer Alloy (EIA) - Table 13
- Chlorinated Polyethylene Alloy (CPE-A) Tables 14A and 14B

Some materials are unsupported; others are supported with a reinforcing scrim. The scrim affects the physical properties of the membrane.

3.0.2.1 NEW MEMBRANE MATERIALS: New membrane materials will be added to the standard provided data (field experience and test data) to characterize the materials and assure satisfactory liner performance are provided. (A recommended protocol for developing the data is included in Appendix F.)

3.0.3 INSTALLATION CONDITION: Some materials are intended to be buried membranes; others are intended to be exposed membranes. Both membrane materials and factory seams for exposed linings shall pass the weathering test for a minimum of 1,000,000 Langleys given in Appendix A with a rating of 7 or better.[1]

3.0.4 SERVICE GRADE: The flexible membrane material shall be considered as industrial grade, not suitable for potable water applications unless it meets the requirements of Item 3.2.1, Potable Water Applications. Furthermore, the flexible membrane liner will not be considered oil resistant unless it meets the requirements as given in the Materials Properties Tables, Item 3.1.

[1]This requirement is to become effective three years after the implementation of this standard.

3.0.5 IDENTIFICATION/NAMING OF MATERIALS: In order to name any material by a specific polymer name, it must contain more than 50% of the total polymer content of that polymer. If no polymer is greater than 50% of the total polymer content, then it shall be called by the principle polymer with the term alloy, or the principle polymer shall be the first in the string of modifiers.

3.1 MATERIALS PROPERTIES: The materials properties tables present minimum requirements necessary to meet the provisions of the standard. Test methods shall comply with applicable American Society for Testing and Materials (ASTM) procedures or as amended (See Appendix A). Values contained in the tables characterize the materials and should not be used for direct application to indicate field performance. The information presented in the tables is based upon the properties of materials submitted for evaluation during the preparation of the standard.

TABLE 1B. MATERIAL PROPERTIES

POLYVINYL CHLORIDE (PVC-OR) OIL RESISTANT GRADE

Property	Test Method	Unsupported (U) 30
Gauge (Nominal)	—	30
Thickness, mils minimum	ASTM D1593 Para 8.1.3	28.5
Specific Gravity (minimum)	ASTM D792 Method A	1.20
Minimum Tensile Properties (each direction)	ASTM D882	
1. Breaking Factor (pounds/inch width)	Method A or B (1 inch wide)	69
2. Elongation at Break (percent)	Method A or B	300
3. Modulus (force) at 100% Elongation (pounds/inch width)	Method A or B	27
Tear Resistance (pounds, minimum)	ASTM D1004 Die C	8
Low Temperature, °F	ASTM D1790	0
Dimensional Stability (each direction, percent change maximum)	ASTM D1204 212°F, 15 min.	5
Water Extraction (percent loss maximum)	ASTM D3083 (as modified in Appendix A)	-0.35
Volatile Loss (percent loss maximum)	ASTM D1203 Method A	0.5
Resistance to Soil Burial (percent change maximum in original value)	ASTM D3083 (as modified in Appendix A)	
1. Breaking Factor		5
2. Elongation at Break		20
3. Modulus at 100% Elongation		20
Hydrostatic Resistance (pounds/sq. in. minimum)	ASTM D751 Method A	82

Oil Resistance Requirements

See ASTM D471, Oil Extraction, 7 days, percent maximum change, machine direction

	Neats Foot	Gulf Harmony #68	Corn (Mazola)	ASTM No. 2
Weight @73.4±3°F	- 5	- 5	- 5	- 5
Weight @158±3°F	- 15	- 15	- 15	- 10
Tensile @73.4±3°F	+5	+10	+10	+10
Tensile @ 158±3°F	+15	+15	+15	+15
Elongation @ 73.4±3°F	- 10	- 10	- 10	- 10
Elongation @ 158±3°F	- 25	- 15	- 25	- 25

Factory Seam Requirements[1]

Bonded Seam Strength (factory seam, breaking factor, ppi width)	ASTM D3083 (as modified in Appendix A)	55.2
Peel Adhesion (pounds/in. minimum)	ASTM D413 (as modified in Appendix A)	FTB[2] or 10 lb/in
Resistance to Soil Burial (percent change maximum in original value)	ASTM D3083 (as modified in Appendix A)	
Peel Adhesion		-20
Bonded Seam Strength		-20

[1]Factory seam requirements are the responsibility of the fabricator. Factory seams are further discussed in Item 4.2.

[2]FTB - Film Tearing Bond.

This table provides a reliable and dependable means for industry to furnish such materials of known and consistent quality. Before selection of any material for an FML, however, the user should consult with appropriate manufacturers, because these materials may not be appropriate for every application. Specific information should be obtained from the manufacturers regarding installation requirements, exposure conditions, performance expectations, and experience factor.

TABLE 2A. MATERIAL PROPERTIES

CHLORINATED POLYETHYLENE (CPE)

Property	Test Method	Unsupported (U) 20	30
Gauge (nominal)	—	20	30
Thickness, mils minimum	ASTM D1593 Para. 8.1.3	19	28.5
Specific Gravity (minimum)	ASTM D792 Method A	1.20	1.20
Minimum Tensile Properties (each direction)	ASTM D882		
1. Breaking Factor (pounds/inch width)	Method A or B	34	43
2. Elongation at Break (percent)	Method A or B	250	300
3. Modulus (force) at 100% elongation (pounds/inch width)	Method A or B	8	12
Tear Resistance (pounds, minimum)	ASTM D1004 Die C	3.5	4.5
Low Temperature, °F	ASTM D1790	-20	-20
Dimensional Stability (percent change maximum)	ASTM D1204 212°, 15 min.	16	16
Water Extraction (percent loss maximum)	ASTM D3083 (as modified in Appendix A)	-0.35	-0.35
Volatile Loss (percent loss maximum)	ASTM D1203 Method A	0.7	0.5
Resistance to Soil Burial (percent change maximum in original value)	ASTM D3083 (as modified in Appendix A)		
1. Breaking Factor		5	5
2. Elongation at Break		20	20
3. Modulus at 100% Elongation		20	20
Hydrostatic Resistance (pounds/sq. in. minimum)	ASTM D751 Method A	75	100
Factory Seam Requirements[1]			
Bonded Seam Strength (factory seam, breaking factor, ppi width)	ASTM D3083 (as modified in Appendix A)	27	34
Peel Adhesion (lbs/in minimum)	ASTM D413 (as modified in Appendix A)	FTB[2] or 10 lb/in	FTB[2] or 10 lb/in
Resistance to Soil Burial (percent change maximum in original value)	ASTM D3083 (as modified in Appendix A)		
Peel Adhesion		-20	-20
Bonded Seam Strength		-20	-20

[1]Factory bonded seam strength is the responsibility of the fabricator. Factory seams are further discussed in Item 4.2.

[2]FTB - Film Tear Bond

[3]Film Tearing Bond is acceptable.

This table provides a reliable and dependable means for industry to furnish such materials of known and consistent quality. Before selection of any material for an FML, however, the user should consult with appropriate manufacturers, because these materials may not be appropriate for every application. Specific information should be obtained from the manufacturers regarding installation requirements, exposure conditions, performance expectations, and experience factor.

TABLE 2B. MATERIAL PROPERTIES

CHLORINATED POLYETHYLENE (CPE)

Property	Test Method	Supported (S) 2-30	3-36	3-45
Gauge (nominal)	—	27	36	45
Thickness, mils minimum	ASTM D751			
1. Overall		32	34	41
2. Over Scrim	Optical Method (see Appendix A)	11	11	11
Breaking Strength (pounds, minimum)	ASTM D751	120	200	200
Tear Strength (pounds, minimum)	ASTM D751 (as modified in Appendix A)			
1. Initial		25	35	35
2. After Aging		20	25	25
Low Temperature, °F	ASTM D2136 ⅛ in. mandrel 4 hrs. Pass	-40	-40	-40
Dimensional Stability (each direction, percent change maximum)	ASTM D1204 212°F, 1 hr.	2	2	2
Volatile Loss (percent loss maximum)	ASTM D1203 Method A 30 mil sheet	0.5	0.5	0.5
Resistance to Soil Burial (percent change maximum in original value)	ASTM D3083 30 mil sheet (as modified in Appendix A)			
a. Unsupported Sheet				
1. Breaking Strength		5	5	5
2. Elongation at Break		20	20	20
3. Modulus at 100% Elongation		20	20	20
b. Membrane Fabric Breaking Strength	ASTM D751 Method A	25	25	25
Hydrostatic Resistance (pounds/sq. in. minimum)	ASTM D751 Method A, Proc. 1	160	250	250
Ply Adhesion (each direction pounds/in. width minimum)	ASTM D413 machine method Type A	10	7	7
		Factory Seam Requirements[1]		
Bonded Seam Strength (factory seam, breaking strength, lbs min.)	ASTM D751 (as modified in Appendix A)	96	160	160
Peel Adhesion (lb/in minimum)	ASTM D413 (as modified in Appendix A)	Ply sep in plane of scrim or 10 lbs./in.	Ply sep in plane of scrim or 10 lbs./in.	Ply sep in plane of scrim or 10 lbs./in.
Resistance to Soil Burial (percent change maximum in original value	ASTM D3083 (as modified in Appendix A)			
Peel Adhesion		-20	-20	-20
Bonded Seam Strength		-20	-20	-20

[1]Factory seam requirements are the responsibility of the fabricator. Factory seams are further discussed in Item 4.2.

This table provides a reliable and dependable means for industry to furnish such materials of known and consistent quality. Before selection of any material for an FML, however, the user should consult with appropriate manufacturers, because these materials may not be appropriate for every application. Specific information should be obtained from the manufacturers regarding installation requirements, exposure conditions, performance expectations, and experience factor.

TABLE 3. MATERIAL PROPERTIES

BUTYL RUBBER (IIR)

Property	Test Method	Unsupported (U) 30	45	60
Gauge (nominal)	—	30	45	60
Thickness, mils minimum	ASTM D412	27	40.5	54
Specific Gravity	ASTM D792	1.20±.05	1.20±.05	1.20±.05
Minimum Tensile Properties (each direction)	ASTM D412			
1. Breaking Factor (pounds/inch width)		36.0	54.0	72.0
2. Elongation at Break (percent)		300	300	300
Tear Resistance (pounds, minimum)	ASTM D624 Die C	4	6	8
Low Temperature, °F	ASTM D746 Procedure B	-40	-40	-40
Dimensional Stability (each direction, percent change maximum)	ASTM D1204 212°F, 7 days	2	2	2
Resistance to Soil Burial (percent change maximum in original value)	ASTM D3083 (as modified in Appendix A)			
1. Breaking Factor		10	10	10
2. Elongation at Break		20	20	20
Water Absorption (percent change, maximum)	ASTM D471 158°F, 168 hours	2	2	2
Durometer A Hardness (points)	ASTM D2240 5 second reading	60±10	60±10	60±10
Ozone Resistance	ASTM D1149 100 hours, 50 pphm 104°F, 20% extension	No Cracks 7X	No Cracks 7X	No Cracks 7X
Heat Aging	ASTM D573 7 days at 240°F			
1. Elongation (percent, minimum)		210	210	210
2. Breaking Factor (pounds/inch width, minimum)		25.2	37.8	50.4
Factory Seam Requirements[1]				
Bonded Seam Strength (factory seam, breaking factor, ppi width)	ASTM D3083 (as modified in Appendix A)	28.8	43.2	57.6
Peel Adhesion (lb/in minimum)	ASTM D413 (as modified in Appendix A)	FTB[2] or 6 lb/in	FTB[2] or 8 lb/in	FTB[2] or 10 lb/in
Dead Load				
Room Temperature 73°F 50% Bonded Seam Load	See Appendix A	Pass	Pass	Pass
Resistance to Soil Burial (percent change maximum in original value)	ASTM D3083 (as modified in Appendix A)			
Peel Adhesion		-20	-20	-20
Bonded Seam Strength		-20	-20	-20

[1]Factory bonded seam strength is the responsibility of the fabricator. Factory seams are further discussed in Item 4.2.

[2]FTB - Film Tearing Bond

This table provides a reliable and dependable means for industry to furnish such materials of known and consistent quality. Before selection of any material for an FML, however, the user should consult with appropriate manufacturers, because these materials may not be appropriate for every application. Specific information should be obtained from the manufacturers regarding installation requirements, exposure conditions, performance expectations, and experience factor.

TABLE 4. MATERIAL PROPERTIES

POLYCHLOROPRENE (CR)

Property	Test Method	Unsupported (U) 30	45	60
Gauge (nominal)	—	30	45	60
Thickness, mils minimum	ASTM D412	27	40.5	54
Specific Gravity	ASTM D297	1.48±.05	1.48±.05	1.48±.05
Minimum Tensile Properties (each direction)	ASTM D412			
1. Breaking Factor (pounds/inch width)		45.0	67.5	90.0
2. Elongation at Break (percent)		250	250	250
Tear Resistance (pounds, minimum)	ASTM D624 Die C	4	6	8
Low Temperature, °F	ASTM D746 Procedure B	-30	-30	-30
Dimensional Stability (each direction, percent change maximum)	ASTM D1204 212°F, 7 days	2	2	2
Resistance to Soil Burial (percent change maximum in original value)	ASTM D3083 (as modified in Appendix A)			
1. Breaking Factor		10	10	10
2. Elongation at Break		20	20	20
Water Absorption (percent change, maximum)	ASTM D471 158°F, 168 hours	12	12	12
Durometer A Hardness (points)	ASTM D2240 5 second reading	60±10	60±10	60±10
Ozone Resistance	ASTM D1149 100 hours, 100 pphm 104°F, 20% extension	No Cracks 7X	No Cracks 7X	No Cracks 7X
Heat Aging	ASTM D573 70 hours at 212°F			
1. Elongation (percent, minimum)		150	150	150
2. Breaking Factor (pounds/inch width, minimum)		38.2	57.4	76.5
Factory Seam Requirements[1]				
Bonded Seam Strength (factory seam, breaking factor, ppi width)	ASTM D3083 (as modified in Appendix A)	28.8	43.2	57.6
Peel Adhesion (lb/in minimum)	ASTM D413 (as modified in Appendix A)	FTB[2] or 6 lb/in	FTB[2] or 8 lb/in	FTB[2] or 10 lb/in
Dead Load				
Room Temperature 73°F 50% Bonded Seam Load	See Appendix A	Pass	Pass	Pass
Resistance to Soil Burial (percent change maximum in original value)	ASTM D3083 (as modified in Appendix A)			
Peel Adhesion		-20	-20	-20
Bonded Seam Strength		-20	-20	-20

[1]Factory bonded seam strength is the responsibility of the fabricator. Factory seams are further discussed in Item 4.2.

[2]FTB - Film Tear Bond

This table provides a reliable and dependable means for industry to furnish such materials of known and consistent quality. Before selection of any material for an FML, however, the user should consult with appropriate manufacturers, because these materials may not be appropriate for every application. Specific information should be obtained from the manufacturers regarding installation requirements, exposure conditions, performance expectations, and experience factor.

TABLE 5. MATERIAL PROPERTIES

HIGH DENSITY POLYETHYLENE (HDPE)

Property	Test Method	Unsupported (U) 80	100
Gauge (nominal)	—	80	100
Thickness, mils minimum	ASTM D1593 Para. 8.1.3	72	90
Specific Gravity (minimum)	ASTM D792 Method A	0.930	0.930
Minimum Tensile Properties (each direction)	ASTM D638		
1. Tensile Strength Yield (lb/in width)		120	150
2. Tensile Strength at Break (lb/in width)		120	150
3. Elongation at Yield (percent)		10	10
4. Elongation at Break (percent)		500	500
5. Modulus of Elasticity (lb/sq in)		80,000	80,000
Tear Resistance (lb, minimum)	ASTM D1004 Die C	40	50
Low Temperature, ° F	ASTM D746 Procedure B	-40	-40
Dimensional Stability (each direction, percent change maximum)	ASTM D1204 212°F, 15 min.	±3	±3
Resistance to Soil Burial (percent change maximum in original value)	ASTM D3083 (as modified in Appendix A)		
1. Tensile Strength Yield		10	10
2. Tensile Strength at Break		10	10
3. Elongation at Yield		10	10
4. Elongation at Break		10	10
5. Modulus of Elasticity		10	10
Environmental Stress Crack (minimum, hours)	ASTM D1693 (as modified in Appendix A)	500	500
Factory and Field Seam Requirements[1]			
Bonded Seam Strength (factory seam, breaking factor, ppi width)	ASTM D3083 (as modified in Appendix A)	108	135
Peel Adhesion (lb/in minimum)	ASTM D413 (as modified in Appendix A)	FTB[2]	FTB[2]
Dead Load			
Room Temperature 73°F 50% Bonded Seam Load	See Appendix A	Pass	Pass
Elevated Temperature 158°F 25% Bonded Seam Load	See Appendix A	Pass	Pass
Resistance to Soil Burial	ASTM D3083		
Peel Adhesion	(as modified in	FTB[2]	FTB[2]
Bonded Seam Strength (percent change maximum in original value)	Appendix A)	-20	-20

[1]Factory bonded seam strength is the responsibility of the fabricator. Factory seams are further discussed in Item 4.2.

[2]FTB - Film Tear Bond

This table provides a reliable and dependable means for industry to furnish such materials of known and consistent quality. Before selection of any material for an FML, however, the user should consult with appropriate manufacturers, because these materials may not be appropriate for every application. Specific information should be obtained from the manufacturers regarding installation requirements, exposure conditions, performance expectations, and experience factor.

TABLE 6. MATERIAL PROPERTIES

ETHYLENE-PROPYLENE DIENE TERPOLYMER (EPDM)

Property	Test Method	Unsupported (U) 30	45	60
Gauge (nominal)	—	30	45	60
Thickness, mils minimum	ASTM D412	27	40.5	54
Specific Gravity	ASTM D792	1.18±.03	1.18±.03	1.18±.03
Minimum Tensile Properties (each direction)	ASTM D412			
1. Breaking Factor (pounds/inch width)		42.0	63.0	84.0
2. Elongation at Break (percent)		300	300	300
Tear Resistance (pounds, minimum)	ASTM D624 Die C	4	6	8
Low Temperature, °F	ASTM D746 Procedure B	-55	-55	-55
Dimensional Stability (each direction, percent change maximum)	ASTM D1204 212°F, 7 days	2	2	2
Resistance to Soil Burial (percent change maximum in original value)	ASTM D3083 (as modified in Appendix A)			
1. Breaking Factor		10	10	10
2. Elongation at Break		20	20	20
Water Absorption (percent change, maximum)	ASTM D471 158°F, 168 hours	2	2	2
Durometer A Hardness (points)	ASTM D2240 5 second reading	60±10	60±10	60±10
Ozone Resistance	ASTM D1149 7 days, 100 pphm 104°F, 50% extension	No Cracks 7X	No Cracks 7X	No Cracks 7X
Heat Aging	ASTM D573 7 days at 240°F			
1. Elongation (percent, minimum)		210	210	210
2. Breaking Factor (pounds/inch width, minimum)		36.0	54.0	72.0
	Factory Seam Requirements[1]			
Bonded Seam Strength (factory seam, breaking factor, ppi width)	ASTM D3083 (as modified in Appendix A)	33.6	50.4	67.2
Peel Adhesion (lb/in minimum)	ASTM D413 (as modified in Appendix A)	FTB[2] or 6 lb/in	FTB[2] or 8 lb/in	FTB[2] or 10 lb/in
Dead Load	See Appendix A			
Room Temperature 73°F 50% Bonded Seam Load		Pass	Pass	Pass
Resistance to Soil Burial (percent change maximum in original value)	ASTM D3083 (as modified in Appendix A)			
Peel Adhesion		-20	-20	-20
Bonded Seam Strength		-20	-20	-20

[1]Factory bonded seam strength is the responsibility of the fabricator. Factory seams are further discussed in Item 4.2.

[2]FTB - Film Tear Bond

This table provides a reliable and dependable means for industry to furnish such materials of known and consistent quality. *Before selection of any material for an FML, however, the user should consult with appropriate manufacturers, because these materials may not be appropriate for every application. Specific information should be obtained from the manufacturers regarding installation requirements, exposure conditions, performance expectations, and experience factor.*

TABLE 7. MATERIAL PROPERTIES

EPICHLOROHYDRIN POLYMERS (CO)

Property	Test Method	Unsupported (U) 60
Gauge (nominal)	—	60
Thickness, mils minimum	ASTM D1593 Para 8.1.3	54
Specific Gravity	ASTM D297	1.49±.06
Minimum Tensile Properties (each direction)	ASTM D412	
1. Breaking Factor (pounds/inch width)		90
2. Elongation at Break (percent)		210
Tear Resistance (pounds, minimum)	ASTM D624 Die C	8
Low Temperature, °F	ASTM D746	0
Dimensional Stability (each direction, percent change maximum)	ASTM D1204 212°F, 7 days	2
Resistance to Soil Burial (percent change maximum in original value)	ASTM D3083 (as modified in Appendix A)	
1. Breaking Factor		10
2. Elongation at Break		25
Oil Absorption (percent change, maximum)	ASTM D471 ASTM # 1 oil 158°F, 168 hours	10
Durometer A Hardness (points)	ASTM D2240 5 second reading	70±8
Ozone Resistance	ASTM D1149 7 days, 100 pphm 104°F, 20% extension	No Cracks 7X
Heat Aging	ASTM D573 7 days at 240°F	
1. Elongation (percent, minimum)		125
2. Breaking Factor (pounds/inch width, minimum)		60.0
	Factory Seam Requirements[1]	
Bonded Seam Strength (factory seam, breaking factor, ppi width)	ASTM D3083 (as modified in Appendix A)	57.6
Peel Adhesion (lb/in minimum)	ASTM D413 (as modified in Appendix A)	FTB[2] or 10 lb/in
Dead Load	See Appendix A	
Room Temperature 73°F 50% Bonded Seam Load		Pass
Resistance to Soil Burial (percent change maximum in original value)	ASTM D3083 (as modified in Appendix A)	
Peel Adhesion		-20
Bonded Seam Strength		-20

[1]Factory bonded seam strength is the responsibility of the fabricator. Factory seams are further discussed in Item 4.2.

[2]FTB - Film Tear Bond

This table provides a reliable and dependable means for industry to furnish such materials of known and consistent quality. Before selection of any material for an FML, however, the user should consult with appropriate manufacturers, because these materials may not be appropriate for every application. Specific information should be obtained from the manufacturers regarding installation requirements, exposure conditions, performance expectations, and experience factor.

TABLE 8. MATERIAL PROPERTIES

POLYETHYLENE ETHYLENE PROPYLENE ALLOY (PE-EP-A)

Property	Test Method	Unsupported (U) 20
Gauge (nominal)	—	20
Thickness, mils minimum	ASTM D412	17
Specific Gravity	ASTM D792	0.92±.05
Minimum Tensile Properties (each direction)	ASTM D412 Die C	
1. Breaking Factor (pounds/inch width)		34
2. Elongation at Break (percent)		500
3. Modulus (force) at 100% elongation (pounds/inch width)		12.8
Tear Resistance (pounds, minimum)	ASTM D1004 Die C	5
Low Temperature, °F	ASTM D746	-76
Dimensional Stability (each direction, percent change maximum)	ASTM D1204 212°F, 15 min.	4
Water Extraction (percent loss maximum)	ASTM D1239 (as modified in Appendix A)	-0.35
Volatile Loss (percent loss maximum)	ASTM D1203 Method A	0.5
Resistance to Soil Burial (percent change maximum in original value)	ASTM D3083 (as modified in Appendix A)	
1. Breaking Factor		10
2. Elongation at Break		10
3. Modulus at 100% Elongation		10
Ozone Resistance	ASTM D1149 7 days, 100 pphm 104°F, 20% strain,	No Cracks 7X
Heat Aging	ASTM D573 14 days, 158°F	
1. Breaking Factor (pounds/inch width minimum)		33
2. Elongation at Break (percent)		425
	Factory Seam Requirements[1]	
Bonded Seam Strength (factory seam, breaking factor, ppi width)	ASTM D3083 (as modified in Appendix A)	27
Peel Adhesion (lb/in minimum)	ASTM D413 (as modified in Appendix A)	FTB[2]
Resistance to Soil Burial	ASTM D3083 (as modified in Appendix A)	
Peel Adhesion	(as modified in Appendix A)	FTB[2] or 8 lb/in
Bonded Seam Strength (percent change maximum in original value)		-20

[1]Factory bonded seam strength is the responsibility of the fabricator. Factory seams are further discussed in Item 4.2.

[2]FTB - Film Tear Bond

This table provides a reliable and dependable means for industry to furnish such materials of known and consistent quality. Before selection of any material for an FML, however, the user should consult with appropriate manufacturers, because these materials may not be appropriate for every application. Specific information should be obtained from the manufacturers regarding installation requirements, exposure conditions, performance expectations, and experience factor.

TABLE 9. MATERIAL PROPERTIES

HIGH DENSITY POLYETHYLENE ELASTOMERIC ALLOY (HDPE-A)

Property	Test Method	Unsupported (U) 30	40	60
Gauge (nominal)	—	30	40	60
Thickness, mils minimum	ASTM D1593 Para. 8.1.3	27	36	54
Specific Gravity (Minimum)	ASTM D792 Method A	0.930	0.930	0.930
Minimum Tensile Properties (each direction)	ASTM D638 Type IV Dumb-bell at 2 ips			
1. Tensile Strength Yield (pounds/inch width)		45	60	90
2. Tensile Strength at Break (pounds/inch width)		105	140	190
3. Elongation at Yield (percent)		20	20	20
4. Elongation at Break (percent)		600	600	600
5. Modulus of Elasticity (pounds/square inch)	ASTM D882	45,000	45,000	45,000
Tear Resistance (pounds, minimum)	ASTM D1004 Die C	15	20	30
Low Temperature, °F	ASTM D746 Procedure B	-40	-40	-40
Dimensional Stability (each direction, percent change maximum)	ASTM D1204 212°F, 15 min.	2	2	2
Volatile Loss (percent loss maximum)	ASTM D1203 Method A	0.1	0.1	0.1
Resistance to Soil Burial (percent change maximum in original value)	ASTM D3083 (as modified in Appendix A)			
1. Tensile Strength Yield		10	10	10
2. Tensile Strength at Break		10	10	10
3. Elongation at Yield		10	10	10
4. Elongation at Break		10	10	10
5. Modulus of Elasticity		10	10	10
Ozone Resistance	ASTM D1149 7 days, 100 pphm 104°F, bent loop	No Cracks 7X	No Cracks 7X	No Cracks 7X
Environmental Stress Crack (hours minimum)	ASTM D1693 (as modified in Appendix A)	500	500	500
	Factory and Field Seam Requirements[1]			
Bonded Seam Strength (factory seam, breaking factor, ppi width)	ASTM D3083 (as modified in Appendix A)	60	80	120
Peel Adhesion (lb.in minimum)	ASTM D413 (as modified in Appendix A)	FTB[2]	FTB[2]	FTB[2]
Dead Load	See Appendix A			
Room Temperature 73°F 50% Bonded Seam Load		Pass	Pass	Pass
Elevated Temperature 153°F 25% Bonded Seam Load		Pass	Pass	Pass
Resistance to Soil Burial	ASTM D3083 (as modified in Appendix A)			
Peel Adhesion		FTB[2]	FTB[2]	FTB[2]
Bonded Seam Strength (percent change maximum in original value)		-10	-10	-10

[1]Factory bonded seam strength is the responsibility of the fabricator. Factory seams are further discussed in Item 4.2.

[2]FTB - Film Tear Bond

This table provides a reliable and dependable means for industry to furnish such materials of known and consistent quality. Before selection of any material for an FML, however, the user should consult with appropriate manufacturers, because these materials may not be appropriate for every application. Specific information should be obtained from the manufacturers regarding installation requirements, exposure conditions, performance expectations, and experience factor.

TABLE 10A. MATERIAL PROPERTIES
CHLOROSULFONATED POLYETHYLENE (CSPE)

Property	Test Method	Supported (S) Type 1-30	Type 1-45	Type 2-36	Type 2-45	Type 3-36	Type 3-45
Gauge (nominal)	—	30	45	36	45	36	45
Plies, Reinforcing	—	1	2	1	1	1	1
Thickness, mils minimum	ASTM D751						
1. Overall		27	41	32	41	34	41
2. Over Scrim	Optical Method (Reference Appendix A)	11	11	11	11	11	11
Breaking Strength-Fabric (pounds, minimum)	ASTM D751 Method A	60[1]	90[1]	120	125	200	200
Tear Strength (pounds, minimum)	ASTM D751 (As modified in Appendix A)						
1. Initial		10	16	25	30	60	70
2. After Aging		5	5	20	25	25	25
Low Temperature, °F	ASTM D2136 ¼ in. mandrel, 4 hrs., Pass	-40	-40	-40	-40	-40	-40
Dimensional Stability (each direction percent change maximum)	ASTM D1204 212°F, 1 hr.	7.5	5	2	3	2	2
Volatile Loss (percent loss maximum)	ASTM D1203 Method A, 30 mil sheet	0.5	0.5	0.5	0.5	0.5	0.5
Resistance to Soil Burial (percent change maximum in original values)	ASTM D3083 30 mil sheet (as modified in Appendix A)						
a. Unsupported sheet							
1. Breaking Strength		5	5	5	5	5	5
2. Elongation at Break		20	20	20	20	20	20
3. Modulus at 100% Elongation		20	20	20	20	20	20
b. Membrane Fabric Breaking Strength	ASTM D751 Method A	25	25	25	25	25	25
Hydrostatic Resistance (pounds/sq. in. minimum)	ASTM D751 Method A, Procedure 1	80	140	160	180	250	250
Ply Adhesion (each direction pounds/in. width minimum)	ASTM D413 Machine Method Type A	10	10	10	10	7	7
		Factory Seam Requirements[2]					
Bonded Seam Strength (factory seam, breaking factor, lb, width)	ASTM D751 (as modified in Appendix A)	80	96	96	100	160	180
Peel Adhesion (lb/in minimum)	ASTM D413 (as modified in Appendix A)	Ply sep in plane of scrim or 10 lb/in	Ply sep in plane of scrim or 10 lb/in	Ply sep in plane of scrim or 10 lb/in	Ply sep in plane of scrim or 10 lb/in	Ply sep in plane of scrim or 10 lb/in	Ply sep in plane of scrim or 10 lb/in
Resistance to Soil Burial (percent change maximum in original value)	ASTM D3083 (as modified in Appendix A)						
Peel Adhesion		20	20	20	20	20	20
Bonded Seam Strength		-25	-25	-25	-25	-25	-25

[1]Type 1 gauge liner has two values. Coating is stronger than fabric and gives a breaking strength value of 100 pounds for nominal 30 mil and 120 pounds for nominal 45 mils with 150% minimum elongation at break for both.

[2]Factory seam requirements are the responsibility of the fabricator. Factory seams are further discussed in Item 4.2.

This table provides a reliable and dependable means for industry to furnish such materials of known and consistent quality. Before selection of any material for an FML, however, the user should consult with appropriate manufacturers, because these materials may not be appropriate for every application. Specific information should be obtained from the manufacturers regarding installation requirements, exposure conditions, performance expectations, and experience factor.

TABLE 10B. MATERIAL PROPERTIES
CHLOROSULFONATED POLYETHYLENE (CSPE-LW)
LOW WATER ABSORPTION

Property	Test Method	Supported (S) Type 1-30	Type 2-36	Type 2-45	Type 2-60	Type 3-36	Type 3-45	Type 3-60
Gauge (nominal)	—	30	36	45	60	36	45	60
Plies, Reinforcing	—	1	1	1	2	1	1	1
Thickness, mils minimum	ASTM D751							
1. Overall		27	32	41	55	34	41	55
2. Over Scrim	Optical Method (Reference Appendix A)	11	11	11	11	11	11	11
Breaking Strength-Fabric (pounds, minimum)	ASTM D751 Method A	60[1]	120	125	300	200	250	300
Tear Strength (pounds, minimum)	ASTM D751 (As modified in Appendix A)							
1. Initial		10	25	30	100	60	70	80
2. After Aging		5	20	25	40	25	25	25
Low Temperature, °F	ASTM D2136 ⅛ in. mandrel, 4 hrs., Pass	-40	-40	-40	-40	-40	-40	-40
Dimensional Stability (each direction percent change maximum)	ASTM D1204 212°F, 1 hr.	7.5	2	3	4	2	2	4
Volatile Loss (percent loss maximum)	ASTM D1203 Method A, 30 mil sheet	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Resistance to Soil Burial (percent change maximum in original values)	ASTM D3083 30 mil sheet (as modified in Appendix A)							
a. Unsupported sheet								
1. Breaking Strength		5	5	5	5	5	5	5
2. Elongation at Break		20	20	20	20	20	20	20
3. Modulus at 100% Elongation		20	20	20	20	20	20	20
b. Membrane Fabric Breaking Strength	ASTM D751 Method A	25	25	25	25	25	25	25
Hydrostatic Resistance (pounds/sq. in. minimum)	ASTM D751 Method A, Procedure 1	80	160	180	300	250	250	300
Ply Adhesion (each direction pounds/in. width minimum)	ASTM D413 Machine Method Type A	10	10	10	10	7	7	7
Water Absorption (percent weight gain maximum 30 mil unsupported sheet)	ASTM D471							
	14 days @ 70°F	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	30 days @ 70°F	2.0	2.0	2.0	2.0	2.0	2.0	2.0
	14 days @ 158°F	30.0	30.0	30.0	30.0	30.0	30.0	30.0
	30 days @ 158°F	30.0	30.0	30.0	30.0	30.0	30.0	30.0
Factory Seam Requirements[2]								
Bonded Seam Strength factory seam, breaking factor, lb. width)	ASTM D751 (as modified in Appendix A)	80	96	100	180	200	250	275
Peel Adhesion (lb/in minimum)	ASTM D413 (as modified in Appendix A)	Ply sep in plane of scrim or 10 lb/in	Ply sep in plane of scrim or 10 lb/in	Ply sep in plane of scrim or 10 lb/in	Ply sep in plane of scrim or 10 lb/in	Ply sep in plane of scrim or 10 lb/in	Ply sep in plane of scrim or 10 lb/in	Ply sep in plane of scrim or 10 lb/in
Resistance to Soil Burial (percent change maximum in original value)	ASTM D3083 (as modified in Appendix A)							
Peel Adhesion		-20	-20	-20	-20	-20	-20	-20
Bonded Seam Strength		-25	-25	-25	-25	-25	-25	-25

[1]Type 1 liner has two values. Coating is stronger than fabric and gives breaking strength values of 100 pounds for nominal 30 mil with 150% minimum elongation at break.

[2]Factory seam requirements are the responsibility of the fabricator. Factory seams are further discussed in Item 4.2.

This table provides a reliable and dependable means for industry to furnish such materials of known and consistent quality. Before selection of any material for an FML, however, the user should consult with appropriate manufacturers, because these materials may not be appropriate for every application. Specific information should be obtained from the manufacturers regarding installation requirements, exposure conditions, performance expectations, and experience factor.

TABLE 11. MATERIAL PROPERTIES
THERMOPLASTIC NITRILE - PVC (TN-PVC)
Oil Resistant Grade

Property	Test Method	Type 1-30 Supported (S)
Gauge (nominal)	—	30
Thickness, mils minimum	ASTM D751	
1. Overall		27
2. Over Scrim	Optical Method (Reference Appendix A)	11
Breaking Strength - fabric (pounds, minimum)	ASTM D751 Method A	50[1]
Tear Strength (pounds, minimum)	ASTM D751 (As modified in Appendix A)	
1. Initial		8
2. After Aging		5
Low Temperature, °F	ASTM D2136 ¼ in. mandrel, 4 hrs., Pass	-20
Dimensional Stability (each direction, percent change maximum)	ASTM D1204 212°F, 1 hr.	7.5
Volatile Loss (percent loss maximum)	ASTM D1203 Method A 30 mil sheet	1.0
Resistance to Soil Burial (percent change maximum in original values)	ASTM D3083 30 mil sheet (as modified in Appendix A)	
a. Unsupported Sheet		
1. Breaking Strength		20
2. Elongation at Break		20
3. Modulus at 100% Elongation		30
b. Membrane Fabric Breaking Strength	ASTM D751 Method A	25
Hydrostatic Resistance (pounds/sq. in. minimum)	ASTM D751 Method A, Procedure 1	80
Ozone Resistance	ASTM D1149 (As modified, 7 days, 100 pphm 104°F, ¼ in. bent loop)	No Cracks 7X
Ply Adhesion (each direction pounds/in. width minimum)	ASTM D413 Machine Method Type A	8

Oil Resistance Requirements
See ASTM D471, Oil Extraction, 7 days, percent maximum change.

	Neats Foot	Gulf Harmony #53	Corn (Mazola)	ASTM No. 2
Weight @73±3°F	-2	-2	-2	-2
Weight @158±3°F	-5	-5	-5	-5
Tensile @73.4±3°F	+10	+10	+10	+5
Tensile @150±3°	+25	+10	+20	+15
Elongation @73.4±3°F	-20	-10	-20	-30
Elongation @158±3°F	-30	-15	-30	-30

Factory Seam Requirements[2]

Bonded Seam Strength (factory seam, breaking factor, lb minimum)	ASTM D751 (as modified in Appendix A)	64
Peel Adhesion (lb/in minimum)	ASTM D413 (as modified in Appendix A)	Ply sep in plane of scrim or 12 lb/in
Resistance to Soil Burial (percent change maximum in original value)	ASTM D3083 (as modified in Appendix A)	
Peel Adhesion		-20
Bonded Seam Strength		-25

[1]Type 1 liner has two values. Coating is stronger than fabric and gives breaking strength values of 80 pounds with 120% minimum elongation at break.
[2]Factory seam requirements are the responsibility of the fabricator. Factory seams are further discussed in Item 4.2.

This table provides a reliable and dependable means for industry to furnish such materials of known and consistent quality. Before selection of any material for an FML, however, the user should consult with appropriate manufacturers, because these materials may not be appropriate for every application. Specific information should be obtained from the manufacturers regarding installation requirements, exposure conditions, performance expectations, and experience factor.

TABLE 12. MATERIAL PROPERTIES

THERMOPLASTIC EPDM (T-EPDM)

Property	Test Method	Supported (S) Type 1-30	Supported (S) Type 2-36
Gauge (nominal)	—	30	36
Thickness, mils minimum	ASTM D751		
1. Overall		27	33
2. Over Scrim	Optical Method (Reference Appendix A)	11	11
Breaking Strength (pounds, minimum)	ASTM D751 Method A	50[1]	100
Tear Strength (pounds, minimum)	ASTM D751 (As modified in Appendix A)		
1. Initial		10	25
2. After Aging		5	20
Low Temperature, °F	ASTM D2136 ⅛ in. mandrel, 4 hrs., Pass	-20	-20
Dimensional Stability (each direction percent change maximum)	ASTM D1204 212° F, 1 hr.	7.5	2
Volatile Loss (percent loss maximum)	ASTM D1203 Method A 30 mil sheet	0.5	0.5
Resistance to Soil Burial (percent change maximum in original values)	ASTM D3083 30 mil sheet (as modified in Appendix A)		
a. Unsupported Sheet			
1. Breaking Strength		10	10
2. Elongation at Break		20	20
3. Modulus at 100% Elongation		30	30
b. Membrane Fabric Breaking Strength	ASTM D751 Method A	25	25
Hydrostatic Resistance (pounds/sq. in. minimum)	ASTM D751 Method A, Procedure 1	80	160
Ozone Resistance	ASTM D1149 7 days, 100 pphm 104°F, ⅛ in. bent loop	No Cracks 7X	No Cracks 7X
Ply Adhesion (each direction pounds/in. width minimum)	ASTM D413 Machine Method Type A	8	8
	Factory Seam Requirements[2]		
Bonded Seam Strength (factory seam, breaking factor, lb, minimum)	ASTM D751 (as modified in Appendix A,	64	80
Peel Adhesion (lb/in minimum)	ASTM D413 (as modified in Appendix A)	Ply sep in plane of scrim or 12 lb/in	Ply sep in plane of scrim or 12 lb/in
Resistance to Soil Burial (percent change maximum in original value)	ASTM D3083 (as modified in Appendix A)		
Peel Adhesion		-20	-20
Bonded Seam Strength		-25	-25

[1]Type 1 liner has two values. Coating is stronger than fabric and gives breaking strength values of 80 pounds, with 150% minimum elongation.

[2]Factory bonded seam strength is the responsibility of the fabricator. Factory seams are further discussed in Item 4.2.

is table provides a reliable and dependable means for industry to furnish such materials of known and consistent quality. efore selection of any material for an FML, however, the user should consult with appropriate manufacturers, because these materials may not be appropriate for every application. Specific information should be obtained from the manufacturers regarding installation requirements, exposure conditions, performance expectations, and experience factor.

TABLE 13. MATERIAL PROPERTIES

ETHYLENE INTERPOLYMER ALLOY (EIA)

Property	Test Method	Type 4-30	Supported (S) Type 5-30
Gauge (nominal)	—	30	30
Thickness, mils minimum	ASTM D751		
1. Overall		27	27
2. Over Scrim	Optical Method (Reference Appendix A)	9	7
Breaking Strength (pounds, minimum)	ASTM D751 Method A	300	400
Tear Strength (pounds, minimum)	ASTM D751 (As modified in Appendix A)		
1. Initial		60	125
2. After aging		40	75
Low Temperature, °F	ASTM D2136 ¼ in. mandrel, 4 hrs., Pass	-30	-30
Dimensional Stability (each direction, (percent change, maximum)	ASTM D1204 212°F, 1 hr.	2	2
Volatile Loss (percent loss maximum)	ASTM D1203 Method A 30 mil sheet	-1.0	-1.0
Resistance to Soil Burial (percent change maximum in original values)	ASTM D3083 30 mil sheet (as modified in Appendix A)		
a. Unsupported Sheet			
1. Breaking Strength		10	10
2. Elongation at Break		20	20
3. Modulus at 100% Elongation		20	20
b. Membrane Fabric Breaking Strength	ASTM D751 Method A	25	25
Hydrostatic Resistance (pounds.sq. in., minimum)	*ASTM D751* Method A, Procedure 1	*500*	500
Ozone Resistance	ASTM D1149 7 days, 100 pphm 104°F, ⅛ in. bent loop)	No Cracks 7X	No Cracks 7X
Ply Adhesion (each direction pounds/in. width minimum)	ASTM D413 Machine Method Type A	FTB[2] or 8 lb/in	FTB[2] or 8 lb/in
Water Extraction	ASTM D3083, Para. 9.6 (as modified in Appendix A)	-0.35%	-0.35%
Water Absorption (percent gain, maximum)	ASTM D471 14 days @ 158°F 14 days @ 70°F	5 1	5 1
	Factory Seam Requirements[1]		
Bonded Seam Strength (factory seam, breaking strength, lb minimum)	ASTM D3083 (as modified in Appendix A)	240	320
Peel Adhesion (lb/in minimum)	ASTM D413 (as modified in Appendix A)	10 lb/in	10 lb/in
Dead Load	See Appendix A		
Room Temperature 73°F 50% Bonded Seam Load		Pass	Pass
Elevated Temperature 158°F 25% Bonded Seam Load		Pass	Pass
Resistance to Soil Burial (percent change maximum *in original value*)	ASTM D3083 (as modified in *Appendix A*)		
Peel Adhesion		-20	-20
Bonded Seam Strength		-20	-20

[1]Factory bonded seam strength is the responsibility of the fabricator. Factory seams are further discussed in Item 4.2.

[2]FTB - Film Tear Bond

This table provides a reliable and dependable means for industry to furnish such materials of known and consistent quality. Before selection of any material for an FML, however, the user should consult with appropriate manufacturers, because these materials may not be appropriate for every application. Specific information should be obtained from the manufacturers regarding installation requirements, exposure conditions, performance expectations, and experience factor.

TABLE 14A. MATERIAL PROPERTIES

CHLORINATED POLYETHYLENE ALLOY (CPE-A)

Property	Test Method	Unsupported (U) 30
Gauge (nominal)	—	30
Thickness, mils minimum	ASTM D751	28.5
Specific Gravity (minimum)	ASTM D792 Method A	1.28
Minimum Tensile Properties (each direction)	ASTM D882	
1. Breaking Factor (pounds/inch width)	Method A or B	45
2. Elongation at Break (percent)	Method A or B	300
3. Modulus (force) at 100% elongation (pounds/inch width)	Method A or B	25
Tear Resistance pounds, minimum)	ASTM D1004 Die C	6
Low Temperature, °F	ASTM D1790	-10
Dimensional Stability (each direction, percent change maximum)	ASTM D1204 212°F, 15 min.	7
Water Extraction (percent loss maximum)	ASTM D1239	-0.35
Volatile Loss (percent loss maximum)	ASTM D1203 Method A	0.7
Resistance to Soil Burial (percent change maximum in original value)	ASTM D3083 (as modified in Appendix A)	
1. Breaking Factor		5
2. Elongation at Break		20
3. Modulus at 100% Elongation		20
Hydrostatic Resistance (pounds/sq. in. minimum)	ASTM D751 Method A	85
Factory Seam Requirements[1]		
Bonded Seam Strength (factory seam, breaking factor, ppi width)	ASTM D3083 (as modified in Appendix A)	36
Peel Adhesion (lbs/in minimum)	ASTM D413 (as modified in Appendix A)	FTB[2] or 10 lb/in
Resistance to Soil Burial (percent change maximum in original value)	ASTM D3083 (as modified in Appendix A)	
Peel Adhesion		-20
Bonded Seam Strength		-20

[1]Factory bonded seam strength is the responsibility of the fabricator. Factory seams are further discussed in Item 4.2.

[2]FTB - Film Tear Bond

This table provides a reliable and dependable means for industry to furnish such materials of known and consistent quality. Before selection of any material for an FML, however, the user should consult with appropriate manufacturers, because these materials may not be appropriate for every application. Specific information should be obtained from the manufacturers regarding installation requirements, exposure conditions, performance expectations, and experience factor.

TABLE 14B. MATERIAL PROPERTIES
CHLORINATED POLYETHYLENE ALLOY (CPE-A)

Property	Test Method	Supported (S) Type 3-36	Supported (S) Type 3-45
Gauge (nominal)	—	36	45
Thickness, mils minimum	ASTM D751		
1. Overall		34	41
2. Over Scrim	Optical Method (see Appendix A)	11	11
Breaking Strength (pounds, minimum)	ASTM D751	200	250
Tear Strength (pounds, minimum)	ASTM D751 (as modified in Appendix A)		
1. Initial		60	70
2. After Aging		25	25
Low Temperature, °F	ASTM D2136 ⅛ in. mandrel 4 hrs. Pass	-40	-40
Dimensional Stability (each direction, percent change maximum)	ASTM D1204 212°F, 1 hr.	2	2
Volatile Loss (percent loss maximum)	ASTM D1203 Method A 30 mil sheet	0.7	0.7
Resistance to Soil Burial (percent change maximum in original value)	ASTM D3083 30 mil sheet (as modified in Appendix A)		
a. Unsupported Sheet			
1. Breaking Strength		5	5
2. Elongation at Break		20	20
3. Modulus at 100% Elongation		20	20
b. Membrane Fabric Breaking Strength	ASTM D751 Method A	25	25
Hydrostatic Resistance (pounds/sq. in. minimum)	ASTM D751 Method A, Proc. 1	250	250
Ply Adhesion (each direction pounds/in. width minimum)	ASTM D413 mach. method Type A	7	7
Factory Seam Requirements[1]			
Bonded Seam Strength (factory seam, breaking strength, lb minimum)	ASTM D751 (as modified in Appendix A)	160	200
Peel Adhesion (lb/in minimum)	ASTM D413 (as modified in Appendix A)	Ply sep in plane of scrim or 10 lbs/in	Ply sep in plane of scrim or 10 lbs/in
Resistance to Soil Burial (percent change maximum in original value	ASTM D3083 (as modified in Appendix A)		
Peel Adhesion		-20	-20
Bonded Seam Strength		-20	-20

[1]Factory seam requirements are the responsibility of the fabricator. Factory seams are further discussed in Item 4.2.

This table provides a reliable and dependable means for industry to furnish such materials of known and consistent quality. Before selection of any material for an FML, however, the user should consult with appropriate manufacturers, because these materials may not be appropriate for every application. Specific information should be obtained from the manufacturers regarding installation requirements, exposure conditions, performance expectations, and experience factor.

3.2 RETENTION APPLICATIONS: Flexible membrane liners covered by this standard which are intended for retention of waters shall be suitable for a variety of municipal, industrial, agricultural, recreational and wildlife uses. Here the emphasis is upon the retention of the water by prevention of losses through seepage during transportation in canals or during storage or use in reservoirs. The water retained in these applications is considered a valuable resource and not a contaminant to the environment.

3.2.1 POTABLE WATER APPLICATIONS: Materials used for flexible membrane liners suitable for use in lining canals and reservoirs for potable water shall meet the physical requirements given in Item 3.1 and the specific requirements on chemical/taste and odor given in Item 3.2.1.1 and for tracers given in Item 3.2.1.2. Flexible membrane liners used for potable water applications shall contain only materials that are regulated, prior sanctioned, generally recognized as safe or nonmigratory ingredients.

3.2.1.1 CHEMICAL/TASTE AND ODOR: Chemical/taste and odor evaluations of membrane materials shall be conducted in accordance with the procedures set forth in Appendix A, and the extractant water therefrom shall not exceed the maximum contaminant levels established in the U.S. Environmental Protection Agency's Interim Primary Drinking Water Regulations - 1975 and the limits of acceptance as shown in Table 3.2-1.

TABLE 3.2-1

CHEMICAL AND PHYSICAL ANALYSES

Parameter	Max. Per. Level mg/l
Antimony	0.05
Arsenic	0.05 [2]
Barium	1.0 [2]
Cadmium	0.01 [2]
Chromium (Hexavalent)	0.05 [2]
Lead	0.05 [2]
Mercury	0.002[2]
pH	
Phenolic Substances	0.05
Selenium	0.01 [2]
Solids Dissolved (Total)	70.
Tin	0.05
TTHM	0.1

TASTE AND ODOR EVALUATIONS

Characteristic	Permissible Level
Odor	80
Taste	Satisfactory

[2]Established in the National Interim Primary Drinking Water Treatment Regulations, USEPA, 1975 (Published in Federal Register, Vol. 40, No 248, December 14, 1975).

3.2.1.2 TRACERS: The addition of innocuous tracers to materials covered by this standard may be required.

3.2.2 RECREATIONAL APPLICATIONS[3]: Flexible membrane liners for recreational water applications in canal and reservoirs for swimming, fishing and boating shall meet the physical requirements presented in Item 3.1.

3.2.3 NONRECREATIONAL APPLICATIONS[3]: Flexible membrane liners for nonrecreational applications, canals, ponds and reservoirs used in the transport and/or storage of waters for industrial, commercial, fisheries, landscaping or agricultural purposes shall meet the physical requirements presented in Item 3.1.

3.3 CONTAINMENT APPLICATIONS: Flexible membrane liners for containment applications other than those referenced in Items 3.2.1, 3.2.2 and 3.2.3, such as hazardous waste and nonhazardous waste landfills and surface impoundments, shall meet the physical requirements in Item 3.1. Considerations should be given to site specificity and chemical compatibility as covered in Appendices C and D.

SECTION 4. FABRICATION

4.0 GENERAL: This section covers factory fabrication of flexible membrane liner materials so as to give a fabricated part which conforms to the requirements set forth in Section 3 of this standard for the appropriate intended application. Repairs as well as primary seams are included and all shall meet the same physical property requirements.

4.1 MATERIALS: Flexible membrane liner materials shall meet the physical property requirements per applicable sections of the standard and shall have been qualified for the product being fabricated.

4.2 SEAMS: The seam joint is a critical part of any flexible membrane liner system. Seam joints are constructed in a controlled factory environment (factory seams) to fabricate panel sizes that can be adequately handled in field installation. Large factory fabricated panels are joined together with seam joints constructed in an uncontrolled outside field environment (field seams). The quality of both the factory and field seams are equally critical to the successful performance of a flexible membrane liner. Factory seam joints shall meet the physical property requirements listed in Item 3.1.

4.2.1 TYPES OF SEAM JOINTS: There are many techniques used to provide effective factory and field seams as follows:

- Adhesive Seams
- Bodied Solvent Seams
- Dielectric Seams
- Extrusion Welded Seams
- Solvent Seams
- Tape Seams
- Thermal Seams
- Vulcanized Seams

4.2.2 FACTORS AFFECTING STRENGTH OF SEAM JOINTS: Any seam joint technique should provide adequate initial seam strength to meet installation and service requirements. However, many factors affect seam joints that can affect the long term performance of the seam. The seam joint may be exposed to a long term aging, to moisture environment, to soil environment, to a chemical environment, and to a constant stress under load both at normal temperatures and at elevated temperatures. Considerations should be given to site specificity and chemical compatibility as covered in Appendices C and D.

[3]Recommendations and precautions are given in Appendix B for the use of flexible membrane liners where a specific aquatic environment is required.

4.3 POTABLE WATER APPLICATIONS: Joining or bonding materials used in factory seams for potable water applications shall meet the applicable requirements set forth in Section 3.

SECTION 5. IDENTIFICATION

5.0 GENERAL: The identification method is to identify the materials contained within the standard. The code consists of three parts: the first part covers the flexible membrane liner material; the second part covers the installed condition of buried or exposed; and the third part covers the general intended service. (See Appendix E for examples of the identification system)

5.1 MATERIAL: This group consists of the following:

5.1.1 FLEXIBLE MEMBRANE LINER MATERIAL CHEMICAL COMPOSITION: Flexible membrane liner material chemical composition referenced in Item 3.0.2 shall be used.

5.1.2 UNSUPPORTED - SUPPORTED MATERIAL TYPE: The following designations shall be used:

U - Unsupported
S - Supported

5.1.3 MEMBRANE TYPE: For supported materials, membrane type, principally influenced by the type of reinforcement used. The number designations for flexible membrane liner material type referenced in the materials properties table, Item 3.1, shall be used.

5.1.4 FLEXIBLE MEMBRANE LINER THICKNESS: The nominal gauge referenced in the material properties tables in Item 3.1 shall be used.

5.2 INSTALLATION CONDITION: Some flexible membrane liner materials are intended to be buried; others may be exposed or buried. The requirements are given in Item 3.0.3. The following designations shall be used:

Bu - Buried
Ex - Exposed or Buried

5.3 GENERAL INTENDED SERVICE: The designation is to show the particular service grade of the material as covered in Item 3.0.2. The following designations shall be used:

PW - Potable Water Grade
In - Industrial Grade, not for Potable Water Applications
OR - Oil Resistant Grade, satisfies specific requirements for oil resistant material

APPENDIX A

Special Test Methods and Revision of Standard Test Procedures

TABLE OF CONTENTS

Part 1	Water Extraction
Part 2	Bonded Seam Strength
Part 3	Soil Burial
Part 4	Peel Adhesion
Part 5	Tear Strength
Part 6	Thickness Over Scrim
Part 7	Chemical/Taste and Odor
Part 8	Ply Adhesion
Part 9	Weather Resistance
Part 10	Dead Load Seam Strength
Part 11	Dead Load Seam Strength at Elevated Temperature
Part 12	Environmental Stress Crack Resistance

Part 1

Water Extraction

ASTM D3083 Paragraph 9.6 modified to be::

A. Apparatus

1. Balance: An analytical balance

2. Containers: Pint jars or cans with a diameter of at least 2.5 inches (6.5 cm) (one container for each specimen)

3. Oven

4. Desiccator

B. Materials

Water: Freshly prepared distilled or deionized water.

C. Test Specimens

The test specimens for plastic films shall be in the form of squares 50 ± 0.25 mm (2 inches) on each side. At least three specimens of each sample shall be tested with each chemical reagent.

D. Conditioning

Condition the test specimens at 73.4 ± 3.6°F (23 ± 2°C) in a desiccator for not less than one hour prior to test.

E. Procedure

1. Maintain the water at the test temperature for at least 4 hours before the specimens are immersed.

2. After being weighed, immerse the specimens in the water, one specimen to each container. Each jar shall contain 400 ml. Suspend the specimen freely in a vertical position, but fully covered by the liquid. To prevent each specimen from floating or curling, it may be necessary to attach small weights, such as paper clips.

3. Cover the jars containing the specimens and keep at 122 ± 3.6°F for 24 hours.

4. Remove the specimens from the liquids and gently wipe with a soft cloth or absorbent tissue. Dry the specimens for 24 hours in a desiccator at 73.4 ± 3.6°.

5. It is realized that there may be an increase in weight of the test specimen due to water absorption. It is necessary to determine if a correction factor is needed, and the value of the correction factor. Prepare and condition control specimens in the same manner as for the standard test, but expose them for only 5 mintues and dry as specified in Section E.5. If the control sample has a weight gain the calculated percent weight gain of the control is the correction factor that is used to adjust the value obtained in the test.

F. Calculations

1. The percentage loss in weight from extraction, expressed as percentage weight loss compared to the original specimen weight, shall be calculated as follows:

   Weight loss, percent = $(W_1 - W_2)/W_1 \times 100$ where:

   W_1 = weight of specimen after the conditioning period and,
   W_2 = weight of specimen at the end of the test.

2. The values obtained for the three specimens for percentage weight loss shall be averaged and this value reported as the percentage weight loss of the sample being tested.

Part 2

Bonded Seam Strength

Unsupported Materials:

ASTM D3083, Paragraph 9.3 is modified to permit either Method A or Method B of ASTM D882.

A specimen 1 inch wide is used with a grip separation of 4 inches plus the width of the seam. The seam is to be centered between the clamps. The rate of grip separation will be 20 inches per minute or as specified in the materials properties tables.

Supported Materials:

ASTM D751 Section A Grab Method shall be modified as follows:

Section 10.1 - Last sentence shall be changed to read: "the distance between the clamps at the start of the test shall be 6 inches plus the seam width. Seam is to be centered between the clamps."

Sections 11 and 12 of ASTM D751 shall be revised to be:

11. Test Specimens

Specimens 100 mm (3.93 in.) in width and not less than 200 mm (7.87 in.) plus the seam width in length shall be cut from the membrane for test. One set of five specimens will be required.

12. Procedure

12.1 Test Conditions

Heat-sealed test specimens shall be conditioned for a minimum of 24 hours at 23°C (73.4°F).

Adhesive seamed specimens shall be conditioned for a minimum of 12 days at 23° (73.4°F). After this period, if it appears that the adhesive seam is not dry and suitable for testing, the seams may be placed in a circulating oven at 70°C (158°F) for 3 hours and allowed to rest at 23° (73.4°F) for 48 hours before retesting.

12.2 Procedure

Place the specimen symmetrically in the clamps of the machine (see Figure 1) with the longer dimension parallel to and the shorter dimension at right angles to the direction of application of the force.

The rate of loading shall be at the rate of 12 ± 0.5 in./min. (5 ± 0.1 mm/s).

Record the maximum stress applied to the specimen at yield or breakage.

SEAM STRENGTH

MODIFIED ASTM D 751 GRAB METHOD

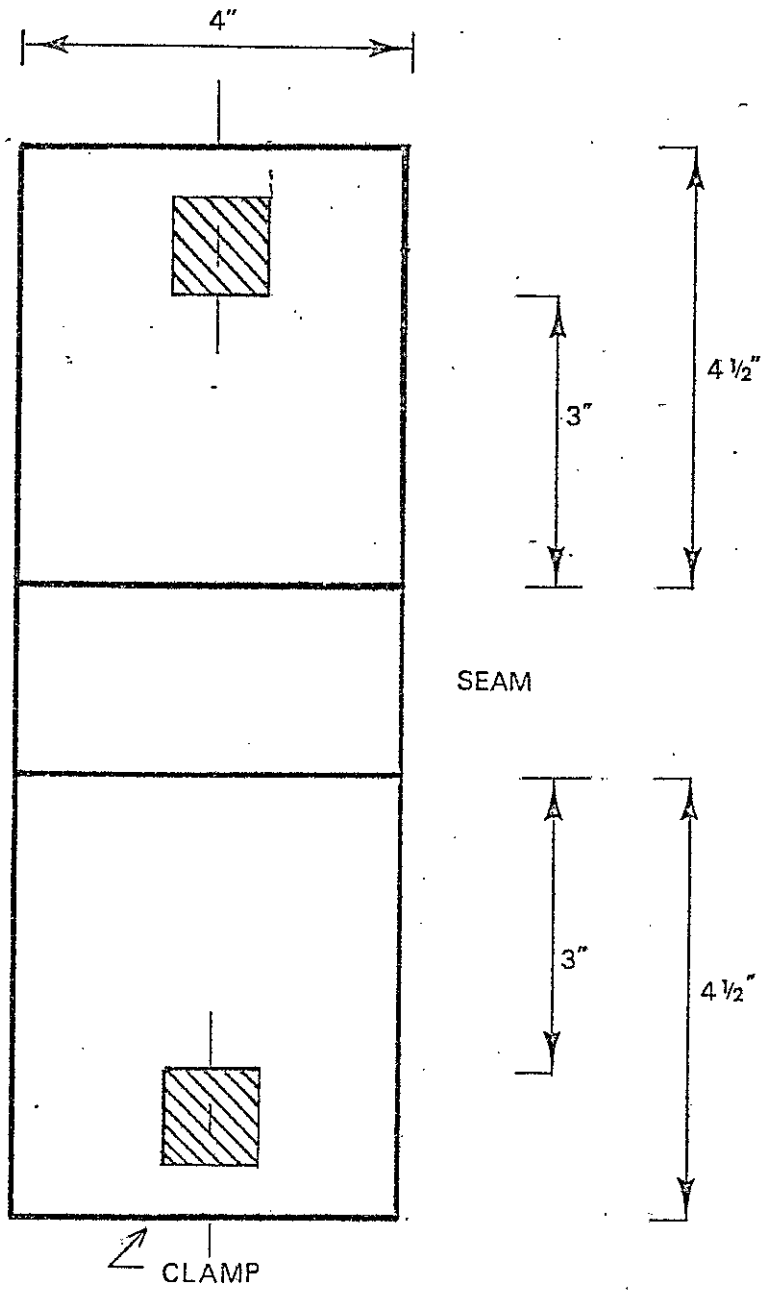


FIG. 1

Part 3

Soil Burial

ASTM D3083, Paragraph 9.5 is modified to be:

The test value of the after-exposure specimen shall be based upon the precut sample dimension.

The test method used to determine before and after exposure tensile properties shall be the test method specified in the materials properties tables for the tensile properties of the material.

Specimens are to be prepared and buried vertically to a depth of 5 inches and exposed as specifed in ASTM D3083, Paragraph 9.5.

Tests for Unsupported Materials

Testing shall be conducted on specimens prepared from the actual flexible membrane liner.

Tests for Supported Materials:

Fabric: Testing shall be conducted on specimens of the fabric used in the supported sheet. Six specimens (4 inches wide by 6 inches long) shall be prepared, three in the warp direction and three in the fill direction. When testing the fabric by itself (no polymeric membrane coating) before and after soil burial, it will be necessary to make sure slippage does not occur. This can be done by using tape, sandpaper or cloth material, special jaws, etc., It is also important to note that consecutive fibers that are grabbed in one jaw correspond to exactly the same fibers grabbed in the other jaw.

Sheet Material: Testing shall be conducted on 30 mil unsupported sheet prepared from the sheeting or coating compound used to produce the supported flexible membrane liner.

Tests for Factory Seams

Testing shall be conducted on specimens prepared from actual flexible membrane liner factory fabricated seams with sealed edges.

Part 4

Peel Adhesion

ASTM D413 shall be modified to be:

Strip specimen Type A, 180° peel, modified to be 1 inch sample width pulled at a rate of 2 inches/minute, Use bonding technique employed in seam joint construction.

Part 5

Tear Strength

ASTM D751 shall be modified to be:

Tear strength of supported materials shall be determined using Method B - Tongue Tear Method. The test specimen shall be 8 x 8 inches. For oven aging tear strength, initial values and values after aging in an oven at 212°F for 30 days shall be determined.

PART 6

OPTICAL METHOD FOR MEASURING THICKNESS OF MATERIAL OVER SCRIM (SUPPORTING FABRIC)

A. Scope and Application

This is a method for measuring the thickness of a membrane over the reinforcing fabric.

B. Principle

The thickness of membrane material over reinforcing fabric can be observed with a standard reflectance microscope. Measurement is made with a calibrated eyepiece.

C. Accuracy

Measurements are accurate to ±0.5 mils when the thickness is about 20 mils.

D. Apparatus

1. Microscope, 60X with reticle

2. Light source

If light source on the microscope is not adequate, a small tensor lamp can also be used.

3. Stage Micrometer (0.001 inch divisions)

E. Procedure

1. Calibration

a. Place a standard reflectance stage micrometer in the plane of the sample.

b. Turn on the microscope light source.

c. Position the reticle eyepiece and the micrometer such that the scales are superimposed. Focus the reticle by turning the eyepiece. Focus the sample and reticle by turning the vertical adjustment knob.

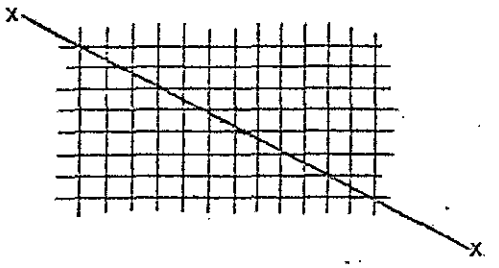
d. Locate a point at which both scales line up. Count the number of micrometer divisions between that point and several reticle divisions away. Measure to the nearest 0.5 mil.

The calibration may be optimized by increasing the number of divisions measured.

e. Repeat the calibration three times and average the results.

2. Sample Analysis

a. Carefully center a sharp, single edge razor or equivalent over the fiber intersections along the x - x line.



b. Make a clean bias cut *completely* through the liner.

c. Remove the razor cut section and mount in common putty with the cut surface facing upward.

d. Observe the cut surface with the eyepiece reticle. Measure the thickness of the liner on either side of the thread intersection by counting the number of reticle divisions (to the nearest one-half division).

e. Sample two or three areas of the liner and average the results.

F. Calculations

1. Calibration

A calibration example is given below:

In the above example, 4.5 micrometer divisions (MD) are equal to 4 reticle divisions (RD).

4 (RD) = 4.5 (MD)
1 (RD) = 4.5/4 (MD)
1 (RD) = 1.1 (MD)

One micrometer division is equal to one mil, therefore:

1 RD = 1.1 mils

This calculated value (1.1 mils in the example) is the calibration factor.

2. Sample

Multiply the number of reticle divisions by the calibration factor. Report results to the nearest 0.5 mil.

PART 7
Chemical/Taste and Odor
A - Review Procedures
for
Ingredients Intended for NSF Listed
Potable Water Formulations

SECTION I. GENERAL

A. GENERAL: The ingredient review procedures detailed below include those for:

1. ACCEPTANCE of a new ingredient[1] and a generically similar ingredient[2]

2. QUALIFICATION of a new compound or material or change in formulation

3. MONITORING of a listed product

---

[1]New Ingredient - any chemical or substance not previously accepted for use in products intended for application in potable water liners.

[2]Generically Similar Ingredient - an ingredient that is not considered a "new ingredient" and while generically similar to an accepted ingredient, it may vary in composition due to manufacturing process, source of materials, potential trace contaminants, etc.

B. ACCEPTANCE STAGE - NEW INGREDIENTS: Samples shall be submitted of liner formulated to contain the ingredient of interest at twice the recommended maximum use level. Consult NSF if the physical characteristics are significantly modified at twice the recommended maximum use level.

1. Samples shall be exposed by NSF using the standard (multiple) exposure procedure.

2. No level of a constituent of interest greater than 10 times the MCL (NSF Standard 54, Table 3.2-1) shall be measurable in water from the first exposure; and no greater than the MCL (NSF Standard 54, Table 3.2-1) shall be measurable in water from the third exposure.

3. If the basic constituent of the ingredient is not on the FDA list of sanctioned materials or the EPA List of Accepted Ingredients, 90-day animal feeding study[3] and Ames test data shall be conducted and the data submitted to NSF. The protocol for the 90-day animal feeding study shall include feeding levels at effect, no known effect, and an intermediate level.

4. If the ingredient is accepted in the U.S. Code of Federal Regulations, Title 21 Food and Drugs Regulations, the applicable section shall be referenced.

5. The ingredient supplier shall provide the chemical abstracts registry number.

6. The ingredient supplier shall submit the chemical description of the ingredient including molecular structure, and percent of components. A list of known contaminants shall be provided and the amounts in ppb. NSF shall be notified of ingredient(s) containing known carcinogens with appropriate references cited.

7. A complete literature review may be required to support application for acceptance.

8. The ingredient manufacturer shall certify that the ingredient is suitable for use in a potable water product.

9. If the extraction test and 90-day feeding study (if required) as well as the other information submitted by the ingredient supplier are acceptable, the ingredient shall be accepted for use in products listed under NSF Standard No. 54 for potable water applications.

C. ACCEPTANCE STAGE — GENERICALLY SIMILAR INGREDIENT: Samples shall be submitted of liner formulated to contain the ingredient of interest at twice the recommended maximum use level. Consult NSF if the physical characteristics are significantly modified at twice the recommended use level.

1. Samples shall be exposed by NSF using the standard (multiple) exposure procedure.

2. No level of a constituent of interest greater than 10 times the MCL (NSF Standard 54, Table 3.2-1) shall be measurable in water from the first exposure; and no level greater than the MCL (NSF Standard 54, Table 3.2-1) shall be measurable in water from the third exposure.

3. If the ingredient is accepted in the U.S. Code of Federal Regulation, Title 21 - Food and Drugs, the applicable section shall be referenced.

4. The ingredient supplier shall provide the chemical abstracts registry number.

5. The ingredient supplier shall submit the chemical description of the ingredient including molecular structure and percent of components. A list of known contaminants shall be provided and the amounts in ppb. NSF shall be notified of ingredient(s) containing known carcinogens with appropriate references cited.

6. A complete literature review may be required to support application for acceptance.

7. The ingredient supplier shall certify that the ingredient is suitable for use in a potable water product.

[3]It is suggested that the protocol for the feeding study be reviewed by toxicologists for their suggestions prior to the beginning of any actual animal feeding studies.

8. If the extraction test as well as the other information submitted by the ingredient supplier is acceptable, the ingredient shall be accepted for use in products listed under NSF Standard 54 for potable water applications.

D. QUALIFICATION STAGE: To qualify a new material, compound or product, or to change an ingredient in an accepted formula, the formulation and a sample shall be submitted for evaluation.

1. Samples shall be exposed by NSF using the standard (multiple) exposure procedure.

2. No level of a constituent of interest greater than 10 times the MCL (NSF Standard 54, Table 3.2-1) shall be measurable in water from the first exposure; and no level greater than the MCL (NSF Standard 54, Table 3.2-1) shall be measurable in water from the third exposure.

E. MONITORING STAGE (LISTED PRODUCTS): Samples of listed products shall be selected randomly by NSF personnel during unannounced visits to production facilities. Samples may be taken during production or from inventory.

1. Sample shall be extracted by NSF under standard (multiple) exposure procedures.

2. Levels measured shall not be greater than the established MCL specified for "monitoring."

ACCEPTANCE	QUALIFICATION	MONITORING
(New Ingredient or Generically Similar)	*(New Product or Change in Formulation)*	
Twice Recommended Maximum Use Level	Recommended Maximum	Use Level
Multiple Exposure	Multiple Exposure	Multiple Exposure
pH 5.0	pH 5.0	pH 5.0
MCL[4]: 1st extraction ≤10 X MCL[4] 3rd extraction ≤ MCL[4]	MCL[4]: 1st extraction ≤10 X MCL[4] 3rd extraction ≤ MCL[4]	3rd extraction ≤MCL[4]

B - Laboratory Procedures for Sample Preparation Extractant Water Exposure Taste and Odor

SECTION I. SAMPLES

A. REQUIREMENTS:

Liner: Use a "standard" ratio equivalent to 50 cm^2 surface area of liner sample to 1 liter of extractant water for all exposures.

Joining Materials: Use a "standard" ratio equivalent to 2.5 cm^2 surface area to 1 liter of extractant water.

[4]Maximum Contaminant Level, U. S. Environmental Protection Agency's National Interim Primary Drinking Water Regulations - 1978 and NSF limits of acceptance as shown in NSF Standard 54, Table 3.2-1.

B. SAMPLE PREPARATION:

Liners: Cut a portion of the liner into four individual circles 3¼ inches in diameter. Place the samples in a labeled stainless steel backet and wash in cold water utilizing a "detergent wash" and a "distilled water rinse" (EL detergent 101 and El detergent additive 601 are used for washing; Economics Laboratories, Inc., St. Paul, MN 55102). Finally, rinse the samples in an organic-free[1] water, and place in a laminar flow hood until they are dry and/or to be exposed.

Joining Materials: Coat one-fourth of the surface (on one side) of two standard laboratory glass slides (1 x 3 inch) with the adhesive, solvent, or bodied solvent. Allow the specimens to cure for 48 hours at ambient temperature. Wash the sample as for liners.

SECTION II. EXTRACTANT WATER

A. CHEMICAL CHARACTERISTICS: Prepare "standard" extractant water to contain 100 mg/l hardness (as $CaCO_3$) and 0.5 mg/l chlorine in organic-free water[1]. Adjust pH to 5.0 ± 0.2 with CO_2.

B. REAGENTS: Buffer Stock Solution: Dissolve 3.36 g sodium bicarbonate ($NaHCO_3$) in organic-free water.[1] Make up to one liter. Make fresh daily.

Hardness Stock Solution: Dissolve 4.44 g chloride (anhydrous $CaCl_2$) in organic-free water[1]. Make up to one liter. Make fresh daily.

Chlorine Stock Solution: Add 7.3 ml sodium hypochlorite (5 percent NaOCl) to 200 ml distilled water. Make fresh weekly. Keep in tightly stoppered bottle. Determine the strength of the chlorine stock solution by diluting 1 ml to 1 liter with standard extractant water, and immediately analyze for total available residual chlorine. Reference this determination as "A." Determine the volume of Cl_2 stock solution necessary to add to the exposure water with the formula:

$$Cl_2 \text{ stock solution (ml)} = \frac{0.5\ B}{A}$$

where:
A = ppm Cl_2 equivalent per ml of Cl_2 stock solution
B = liters of standard extractant water

C. WATER: Prepare "standard" extractant water by adding stock reagent solutions to organic-free water[1], as shown in Table A-I.

Table A-I

"Standard" Extractant Water

Organic-free Water[1] (liters)	Buffer Stock Solution (ml)	Hardness Stock Solution (ml)	Chlorine Stock Solution (ml)
1	25	25	0.5
6	150	150	3.0
12	300	300	6.0
15	375	375	7.5

Bubble with CO_2 until pH 5.0 ± 0.2 is attained.

[1]Organic-free water is defined as water free of interference when employed in the procedure described herein.

SECTION III. EXPOSURE

A. VESSEL EXPOSURES, LINER: Use 2 one quart "Mason" type jars to expose 50 cm^2 of liner sample in 1 liter of "standard" water. When cut as a lid liner, approximately 30 cm^2 of liner material will be exposed. Therefore, the volume of water used must be determined to maintain the required 50 cm^2/liter surface area to water volume ratio.

JOINING MATERIALS: Coat one-fourth of the surface (on one side) of two standard laboratory glass slides (1 x 3 inch) with the adhesive, solvent, or bodied solvent to obtain approximately 10 cm^2 of exposed surface. Allow the specimens to cure for 48 hours at ambient temperature. The specimens shall be immersed in 4 liters of extractant water to obtain a surface area to water volume ratio of 2.5 cm^2/l.

B. EXPOSURE CONDITIONS, GENERAL: All tests for acceptance, qualification and routine monitoring shall be conducted with the multiple exposure procedure.

1. 24±1 hour at 37±0.5°C
2. 24±1 hour at 37±0.5°C
3. 72±4 hours at 37±0.5°C

Controls: Place equivalent volume of formulated water in extraction vessel and expose as a control. Include one control for each combination of extraction vessel and/or exposure condition in the daily sample run.

Liners: Use A "Wide Mouth" one quart "Mason" type jar to expose each of the four specimens. Place a 11.6 cm length of 1¼ inch glass rod in each exposure jar (to displace the exposure water enough to fill the jar). Fill the jar with extractant water and seal without a head space utilizing the sample specimen as a cap liner. During the course of the exposure period, lay the exposure vessel upside down.

Joining Materials: Place one of the prepared slides on the bottom of each of two, two quart "Mason" type jars. Fill the jars with extractant water and seal without a head space utilizing an aluminum foil lined cap.

SECTION IV. RECOVERY OF WATER FOLLOWING EXPOSURE

A. TRIHALOMETHANE SAMPLE: Obtain an exposure water sample from one of the jars immediately after opening. Specifically, place 2.5 to 3 mg ACS Reagent Grade sodium sulfite in a 40 ml vial. Overflow it with the exposure water sample and seal without a head space utilizing a Teflon lined cap.

B. CHEMICAL, TASTE AND ODOR SAMPLE: Separate water from exposed samples immediately after exposure vessels are removed from the elevated temperature environment by pouring through filter paper (white, crepe, VWR Grade 6.5) into a ground glass stoppered bottle. Combine the waters from each of the four liner specimens or two joining materials samples into one bottle.

SECTION V. TASTE AND ODOR EVALUATION

ODOR TEST:

A. GENERAL REQUIREMENTS: Final extractant water exposed to liners shall have a threshold odor number less than 80. A paired sample technique in which the stronger odor in each pair is identified shall be used in determining threshold odor levels.

B. TEST PROCEDURES: The NSF odor procedure is a modification of the paired sample technique described in American Society for Testing and Materials (ASTM) Special Technical Publiation 434: *Manual on Sensory Testing Methods,* prepared by ASTM Committee E-18. The modified procedure permits the panel member to identify the member of the sample/control pair containing the strongest odor versus identification of the control bottle in the pair. Statistical basis for the paired sample technique is noted.

Odor Pairs: (Sample/Control)

Sample: Dilute the sample 1 to 80 by combining 2.5 ml of the final extractant with 197.5 ml of odor-free water in a BOD bottle.

Control: Dilute the control 1 to 80 by combining 2.5 ml of the final extractant with 197.5 ml of odor-free water in a BOD bottle.

Generate a second pair of the same by duplicating the above.

(Note: Odor-free water is prepared by passing distilled water through activated carbon.)

Numbers of Samples: No less than 4 and no more than 14 odor pairs shall be evaluated at any time.

Panel: Use panel of at least 10 members prescreened to eliminate persons who are unusually sensitive or insensitive to tastes and odors.

Preselect a random arrangement of the odor pairs for evaluation. For any given sample insure that the control is located once on the left and once on the right of the sample within its two odor pairs.

Hold BOD bottles containing samples and paired controls in a water bath at 22°C.

A minimum of 10 panel members shall examine each pair in turn to determine which member of the pair has the strongest odor.

C. RESULTS: Data from all panel members are summed and reported as to the number of times the sample was selected as the member of the pair which contained th stronger odor. Table A-II is then used to determine the confidence level (%) that the sample has the stronger odor. A sample fails the odor test when that confidence level reaches 99% or greater.

TABLE A-II

CONFIDENCE LEVELS[3]

No.[1]	No. of responses 20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
10	N.S.[2]														
11	N.S.	N.S.													
12	75.00	60.00	N.S.												
13	90.00	75.00	60.00	N.S.											
14	95.00	75.00	75.00	60.00	N.S.										
15	97.50	90.00	75.00	75.00	60.00	N.S.									
16	98.00	97.50	90.00	75.00	75.00	60.0	N.S.								
17	99.50	98.00	95.00	90.00	75.00	75.00	60.00	N.S.							
18	99.50	99.50	97.50	95.00	90.00	75.00	75.00	N.S.	N.S.						
19	99.95	99.50	99.50	97.50	95.00	90.00	75.00	75.00	60.00	N.S.					
20	99.95	99.95	99.50	99.00	99.00	95.00	90.00	75.00	60.00	60.00	N.S.				
21		99.95	99.50	99.50	99.00	97.50	95.00	90.00	75.00	60.00	60.00	N.S.			
22		99.95	99.95	99.50	99.50	99.00	97.50	95.00	90.00	75.00	60.00	60.00	N.S.		
23			99.95	99.95	99.50	99.50	97.50	97.50	95.00	75.00	75.00	60.00	60.00	N.S.	
24			99.95	99.95	99.95	99.50	99.00	97.50	97.50	90.00	75.00	75.00	60.00	60.00	N.S.
25				99.95	99.95	99.95	99.95	99.00	97.50	95.00	90.00	90.00	75.00	60.00	60.00
26				99.95	99.95	99.95	99.95	99.50	99.00	97.50	95.00	90.00	75.00	75.00	60.00
27					99.95	99.95	99.95	99.50	99.50	99.00	97.50	95.00	90.00	75.00	75.00
28					99.95	99.95	99.95	99.95	99.95	99.50	99.00	97.50	95.00	90.00	75.00
29						99.95	99.95	99.95	99.95	99.50	99.50	99.00	97.50	95.00	90.00
30						99.95	99.95	99.95	99.95	99.50	99.50	99.50	97.50	97.50	95.00
31							99.95	99.95	99.95	99.95	99.50	99.50	99.50	97.50	97.50
32							99.95	99.95	99.95	99.95	99.95	99.50	99.50	99.00	97.50
33								99.95	99.95	99.95	99.95	99.95	99.50	99.50	99.00
34								99.95	99.95	99.95	99.95	99.95	99.95	99.50	99.50
35									99.95	99.95	99.95	99.95	99.95	99.50	99.50
36									99.95	99.95	99.95	99.95	99.95	99.95	99.50

[1]Number of times sample identified as strongest odor in sample/control pair

[2]N.S. = No significant difference.

The confidence levels given in Table A-II are described as 1-p, where p is the probability of getting at least the specified number of correct identifications of the control, given that the control is identical to the sample (e.g., 99 percent confidence level means that 1 percent of the time, at least the specified number is expected when there is no difference in the odor of the sample and control).

Confidence levels in Table A-II are obtained from the percentiles of the "t" distribution. This distribution is parameterized by the sampling degrees of freedom. The degree of freedom is 19 for the test procedure using ten panel members and two pairs containing the sample and control.

The t-value is computed by the formula:

$$t = \frac{F - 0.5}{\sqrt{\frac{.5 \times .5}{19}}} = \sqrt{19}\,(2F - 1)$$

where F = the fraction of correct choices, t can be evaluated for different numbers of correct identifications of the control:

Number Correct	t-value	Confidence Level (%)
14	1.74	90.0
15	2.18	97.5
16	2.62	98.0
17	3.05	99.50
18	3.49	99.50
19	3.92	99.95

These are the entries for No. responses equal to 20 in Table A-II; the other entries in Table A-II were obtained in a like manner.

TASTE TEST:

D. TEST PROCEDURES: Place 200 ml final extractant water (i.e., water from final exposure period) for each sample in separate BOD bottles. Place 200 ml control water in BOD bottle.

Maintain all bottles - extractant water and control - at room temperature.

Arrange samples and control in random order for evaluation by panel.

Do not indicate to the panel which bottle contains control water.

A panel member shall pour taste samples into 25 ml beaker and record taste as "sweet," "sour," "bittler" or "salty."

Panel member shall rinse mouth with odor-free water before proceeding to the next taste sample.

E. RESULTS: If panel consistently reports the taste of a particular sample to be more disagreeable than taste of the control, sample fails the taste test.

SECTION VI. CHEMICAL METHODS

A. HEAVY METALS

1. GENERAL: The determination of heavy metals in extractant water is accomplished, using atomic absorption analysis. This technique is based on the quantum mechanical principle that atoms absorb light at energy levels corresponding to characteristic orbital energies of the atom. By measuring the attenuation of a monochromatic light beam passing through the sample atoms, the concentration of metal in the sample can be determined using Beer's Law.

   NSF employs an external standard technique for calibration and sample determination. Three standard solutions are made in concentrations corresponding to the region in which the samples are expected to lie. Standards are run concurrently with samples to insure quality control and to indicate any significant deviations in instrumental response. The concentrations of the samples are then obtained from graphs of absorbance versus concentration for the standards.

   A study of testing results for several routine analyses was made to determine reproducibility and levels of detection obtained on average working days in the NSF laboratories. This study was done without the prior knowledge of laboratory personnel.

   Detection limits were determined as twice the noise level of the recorder output for an analysis. Reproducibility was determined to be the standard deviation of the absorbance values obtained for a specific concentration of a standard. Arithmetic mean values of the standard were then plotted against concentration, and a least squares line drawn. Detection limits and reproducibility values were then determined from this graph. This procedure was followed for each metal. The results are shown in Table A-III.

   Updating analytical procedures is a continuous process at NSF.

   All standards and samples are made in the matrix of NSF formulated extractant water[2].

[1]Reference ASTM Special Technical Publication 434: *Manual on Sensory Testing Methods,* sponsored by ASTM Committee E-18 on Sensory Evaluation of Materials and Products.

[2]NSF Standard No. 14, Appendix A, Section 2.

TABLE A-III

DETECTION LIMITS AND REPRODUCIBILITY OF METALS ANALYSES

Metal	MCL[1] (mg/l)	Reproducibility at MCL (mg/l)	DL[2] (mg/l)	Reproducibility at lowest standard (mg/l)
Antimony	0.05	±0.0007	0.007	±0.0005
Arsenic	0.05	±0.0007	0.004	±0.0008
Barium	1.0	±0.05	0.008	±0.004
Cadmium	0.01	±0.0002	0.0005	±0.0001
Chromium	0.05	±0.002	0.005	±0.002
Lead	0.05	±0.0009	0.002	±0.0007
Mercury	0.002	±0.0004	0.0003	±0.0004
Selenium	0.01	±0.001	0.003	±0.0005
Tin	0.05	±0.002	0.005	±0.0009

[1]maximum contaminant level (MCL)

[2]detection limit (DL)

2. EQUIPMENT:

Perkin-Elmer Model No. 560 atomic absorption spectrophotometer

E.D.L. Power Supply, P.E. No. 040-0354

Perkin-Elmer Graphite Furnace, H.G.A. 2200

Perkin-Elmer PRS-10 Printer Sequencer

Perkin-Elmer AS-1 Auto Sampling System

Burner Control Box, P.E. No. 057-0262

Perkin-Elmer Hitachi 200 Recorder

Acetylene Gas Tank and Regulator

Argon Gas Tank and Regulator

Nitrous Oxide Gas Tank and Regulator

Inorganic 1000 ppm metal standards in matrix of dilute hydrochloric acid

Eppendorf micro-pipets

3. PROCEDURE, (Atomic Absorption Spectrophotometer) AAS:

Atomization Method - graphite furnace (except mercury)

Sample Matrix - 0.1 ml of Suprapur® HNO_3 in 50 ml of extractant water

Slit - Alternate

Gain — Set between 35 - 40 units

Source — Set to specifications of lamp being used

Signal — Absorbance

Mode — Continuous

Recorder - Absorbance

Background Corrector - AA (Background correction not used routinely)

Recorder Chart Expansion - Set as desired

The lamp is allowed its specified warm up time

Standards are made by adding appropriate aliquots of 1000 ppm standards to the correct matrix. Controls are made with the same matrix but with no exposure to plastics and no addition of the standard.

After proper alignment, each standard is analyzed at least two times. Following this, controls and samples are analyzed two times. Standards are interspersed in the analysis with a total standard frequency of no less than 5 percent of analysis time. Following the completion of the sample run, each standard is rerun. If the instrument response has changed, all questionable samples are rerun immediately followed by a series of standards.

4. METHODS:

Antimony (Sb):

Standards — 0.1, 0.05, 0.02 mg/l

Graphite Furnace Settings

	Temperature °C	*Time* Sec.
Dry	110	20
Char	825	22
Atomization	2700	6

Purge gas - Argon
Purge gas flow rate - 300 cc/min
Purge gas interrupt — 3 sec.
Sample volume 20 2μl

Instrumental Parameters

- Slit — 0.2 mm
- Source — HCL, P.E. No. 303-6010
- Wave length — 217.6 nm

Photometric Range - 0.5

Arsenic (As):

Standards — 0.100, 0.050, 0.020 mg/l

Graphite Furnace Settings

	Temperature °C	*Time,* Sec.
Dry	110	20
Char	250	20
Atomization	2700	6

Purge gas - Argon
Purge gas flow rate - 300 cc/min
Purge gas interrupt — 3 sec.
Sample volume 20 μl

Instrumental Parameters

- Slit — 0.7
- Source — EDL, P.E. No. 303-6211
- Wave length — 193.7 nm

Photometric Range - 0.5

Barium (Ba):

Standards — 0.100, 0.050, 0.020 mg/l

Graphite Furnace Settings

	Temperature °C	*Time,* Sec.
Dry	110	23
Char	1100	36
Atomization	2700	5

Purge gas - Argon
Purge gas flow rate - 300 cc/min
Purge gas flow reduction rate - 110 cc/min for 3 sec.
Sample volume — 20 μl

Instrumental Parameters

- Slit — 0.2
- Source — HCL, P.E. No. 303-6012
- Wave length — 553.6 nm

Photometric Range - 0.5

Cadmium (Cd):

Standards - 0.0100, 0.0050 0.0020 mg/l

Graphite Furnace Settings

	Temperature °C	Time, Sec.
Dry	110	20
Char	280	32
Atomization	2100	6

Purge gas - Argon
Purge gas flow rate - 300 cc/min
Purge gas interrupt - 3 sec.
Sample volume - 20 μl

Instrumental Parameters

- Slit - 0.2
- Source - HCL, P.E. 303 .601b
- Wave length - 228.8 nm

Photometric Range - 1.0

Chromium (Cr):

Standards - 0.100, 0.050 0.020 mg/l

Graphite Furnace Settings

	Temperature °C	Time, Sec.
Dry	110	20
Char	1100	32
Atomization	2700	6

Purge gas - Argon
Purge gas flow rate - 300 cc/min
Purge gas interrupt - 3 sec.
Sample volume - 20 μl

Instrumental Parameters

- Slit - 0.7
- Source - HCL, P.E. 303-6021
- Wave length - 357.9 nm

Photometric Range - 1.0

Lead (Pb):

Standards - 0.050, 0.030, 0.010 mg/l

Graphite Furnace Settings

	Temperature °C	*Time,* Sec.
Dry	110	20
Char	700	20
Atomization	2300	6

Purge gas - Argon
Purge gas flow rate - 300 cc/min
Purge gas interrupt - 3 sec.
Sample volume - 20 μl

Instrumental Parameters

- Slit - 0.7
- Souce - HCL, P.E. 303-6111
- Wave length - 217.0 nm

Photometric Range - 0.2

Mercury (Hg):

Sample Matrix - sample water treated in accordance with Perkin-Elmer instructions for Mercury Analysis System No. 303-0830

Standards - 0.010, 0.0050, 0.0020 mg/l

Atomization Method - Perkin-Elmer Flameless Mercury Analysis System 303-0830

Instrumental Parameters

- Slit - 0.7
- Souce - HCL, P.E. 303-6044
- Wave length - 253.7 nm

Photometric Range - 0.5

Selenium (Se):

Standards - 0.050, 0.020, 0.0050 mg/l

Graphite Furnace Settings

	Temperature, °C	*Time,* Sec.
Dry	110	20
Char	370	36
Atomization	2700	5

Purge gas - Argon
Purge gas flow rate - 300 cc/min
Purge gas interrupt - 3 sec.
Sample volume - 20 μl

Instrumental Parameters

- Slit - 0.7
- Source - EDL, P.E. 303-6262
- Wave length - 196.0 nm

Photometric Range - 0.2

Tin (Sn):

Standards - 0.100, 0.050, 0.020 mg/l

Graphite Furnace Settings

	Temperature °C	*Time* Sec.
Dry	110	30
Char	700	32
Atomization	2700	5

Purge gas - Argon
Purge gas flow rate - 300 cc/min
Purge gas interrupt - 3 sec
Sample volume - 20 μl

Instrumental Parameters

- Slit - 0.7
- Source - EDL, P.E. 303-6274
- Wave length - 224.6 nm

Photometric Range - 0.5

5. QUALITY CONTROL: Any liner sample which fails any chemical parameter is retested to assure that the problem is associated with the sample versus the analysis or analytical technique.

   In accordance with the 15th Edition of *Standard Methods for the Examination of Water and Wastewater,* the NSF laboratory utilizes two methods of quality control, internal and external. The internal method includes standard solutions and controls which correct for chemical interference in the extractant water. Standards and controls comprise 15% of the analytical time for heavy metals determinations; i.e., one in six randomly spaced controls.

   External quality control samples are analyzed on an average of once every three months, either as EPA reference standards or solutions of NSF extractant water spiked with metals at concentrations which approximate a "typical" liner sample. The quality control samples are prepared by personnel other than those involved in the analysis and are coded in a manner which simulates actual liner samples. The analyst receives the quality control sample, along with actual liner samples, with no knowledge of its status as a quality control sample.

B. TOTAL TRIHALOMETHANES (TTHM)

1. GENERAL: Total trihalomethanes (TTHM) [chloroform ($CHCl_3$) bromodichloromethane ($CHCl_2Br$) chlorodibromothane ($CHClBR_2$), and bromoform ($CHBr_3$)] in extractant water are determined using gas chromatography.

   10 ml of the sample's final exposure water are extracted with 2 ml of pentane and analyzed in accordance with the procedures outlined for the liquid/liquid extraction method (Federal Register/Vol. 44, No. 231/November 29, 1979, p. 68683).

   Three standards ranging from 5—100 ppb are prepared and then extracted in the same way. 4 μl of each are injected into the gas chromatograph equipped with a linearized electron capture detector. After calibration, 4 μl of each sample's extract are analyzed for TTHM content.

2. EQUIPMENT:

   Perkin-Elmer Sigma 3 B Gas Chromatograph

   Perkin-Elmer Sigma 10B Data Station

Perkin Elmer Auto Sampler (AS-100)

Electron Capture Detector (E.C.D.)

Column - 4 mm ID (6' x ¼" OD) 10% Squalane Chrom W-AW80/100 NOC

Nitrogen 4.5 grade

Compressed air Grade E

40 ml screw cap vials with Teflon faced silicone septa, Pierce #13075 and #13733

Sample vials with septa and aluminum seals for auto sampler

Extraction bottles and caps Sci/Spec #B 69110

Syringes
- 10, 25 and 100μl
- 5 and 10 cc with luer-lok tip

Gas stoppered volumetric - 25 and 100 ml

3. REAGENTS:

Pentane, suitable for TTHM GC analysis

Methanol, reagent grade

Chlorine reducing agent: Sodium thiosulfate

Standards
Chloroform, reagent grade
Bromodichloromethane, reagent grade
Chlorodibromomethane, reagent grade
Bromoform, reagent grade
Carbon tetrachloride, reagent grade

Organic-free water[1]

4. INSTRUMENT PREPARATION:

Pneumatic Settings
Carrier gas:
Nitrogen - 80 psi
Auto sampler:
Air - 40 psi
Nitrogen - 5 psi

Temperature Settings
Oven - 67°C
Injection port - 150°C
Detector - 350°C

Total analysis time - 13 minutes

Flow rate through column - 70 cc/min plus 5 cc makeup.

[1]Note: Organic-free water is defined as water free of interference when employed in the procedure described herein.

5. ANALYTICAL PROCEDURE

TTHM and CCl_4 are measured in accordance with the method for "Analysis of Trihalomethanes in Drinking Water by Liquid/Liquid Extraction," Federal Register/Volume 44, No. 231/November 29, 1979, p. 68683.

C. OTHER CHEMICAL PARAMETERS

1. PHENOLS: Phenols are measured in accordance with *Standard Methods for the Examination of Water and Wastewater,* 15th Edition, page 510 (4-aminoantipyrine method with preliminary distillation step).

2. TOTAL AVAILABLE RESIDUAL CHLORINE: Total available residual chlorine is measured in accordance with the method outlined in *Standard Methods for the Examination of Water and Wastewater*, 15th Edition, page 286 (Amperometric Titration Method, Procedure 4c).

Part 8

Ply Adhesion

ASTM D413 Section &. Procedure, Paragraph 9.1 Strip Specimens - Type A, 180 degree peel - . . .The next sentence shall be deleted and substituted in its place:

The cut strip shall be 1 inch wide measured to the nearest 0.01 inch.

ASTM D413 Section 12,Calculations, Paragraph 12.2 shall be modified to be:

For the machine method the value of adhesion is determined by taking the average of the five highest peaks shown on the autographic chart and is reported as the adhesion value as follows:

N/m (lbf/in) = force/actual width

If other than a 1 inch strip is tested show both the force and the actual width in the report.

Part 9

Accelerated Weathering Test

A. GENERAL

The test will be the Equatorial Mount with Mirrors for Acceleration plus water spray (EMMAQUA). Minimum specimen size will be 5 inches wide x 4 inches long. (Maximum width is 5 inches x 55 inches long within target area.)

Minimum number of specimens will be one for each FML type that is recommended for outdoor exposure.

The EMMAQUA Test machine is covered by U. S. patents. The testing service is provided by:

Desert Sunshine Exposure Test Inc.
Box 185
Black Canyon Stage
Phoenix, Arizona 85029

B. Exposure Rating Table

The following table rates the state of condition for the FML after exposure due to crazing.

Crazing is the phenomenon manifested by slight breaks or checks in the surface. The break should be called a "crack" if the underlying surface is visible. For precision evaluation, crazing is described as microscopic crazing as observed with a stated magnification of 10 power.

EXPOSURE RATING TABLE

Rating No.		Number of Checks[1]	Width of Checks[2]
9		S	Maximum
8	Microscopic	M	width
7	(10 X magnification)	L	.006 in.
6		S	Maximum
5	Naked eye at close range	M	width
4	(12 inches)	L	.015 in.
3		S	Not
2	Naked eye at distance	M	Acceptable
1	(3 feet)	L	
0	Complete failure		

[1]S = Small
M = Medium
L = Large

[2]When bent around ½ inch diameter mandrel.

Materials which have a rating of 7, 8 and 9 will be considered to have passed.

Materials which have a rating of 4, 5 and 6 will be required to make the proper corrections in the compound within three months after notification of the results and resubmitted for testing.

If, after the second submission, the material fails to obtain a minimum ranking of 7, the material in question will lose its NSF listing until such time the material meets the requirement.

A transparent crack width gauge, similar to that shown in Figure 1 along with a 10 power microscope may be used to measure the crack width.

CRACK WIDTH GAGE

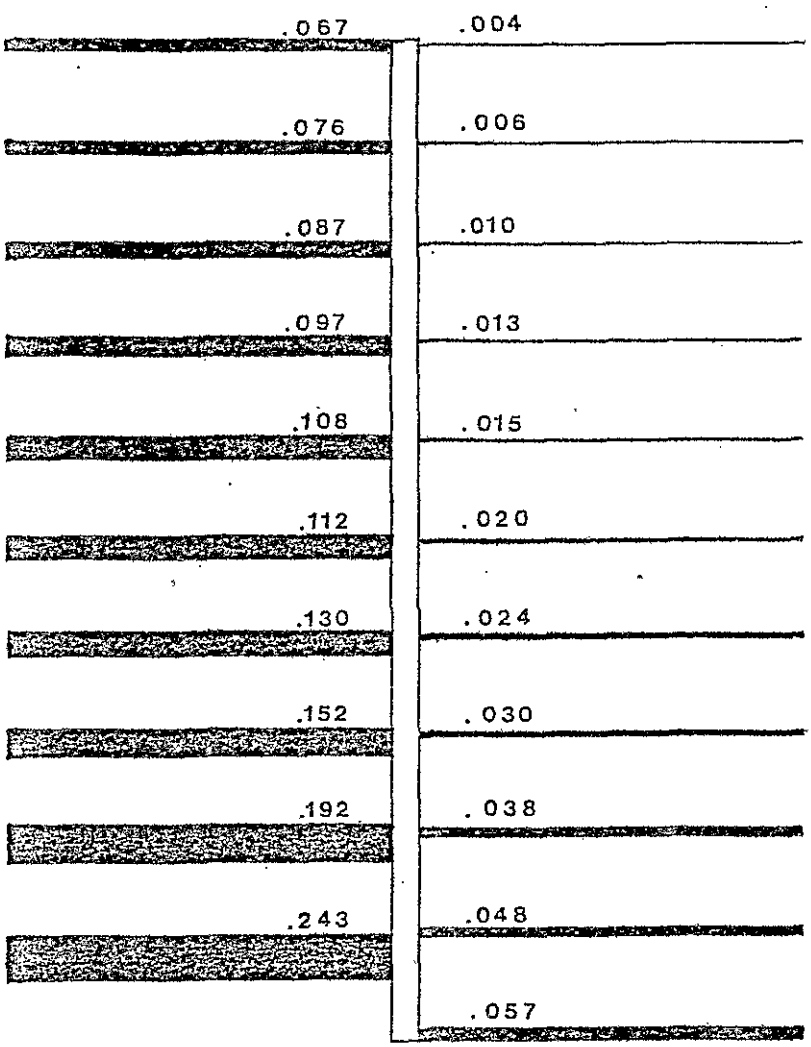


FIG.1

Part 10

Dead Load Seam Strength

A. Scope

To determine the ability of factory seam joints to withstand constant stress under load at room temperature (73°F).

B. Test Specimen

The supported specimen size shall be a 4-inch width of the seam joint and a 12-inch length, sufficient to fit in the clamps of the testing machine. The unsupported specimen size shall be a 1 inch width of the seam joint and an 8 inch length.

C. Procedure

The clamping mechanism will grip a 1 inch wide section and should be centered in the width of the test specimen, above and below the seam joint. The clamps shall not grip any portion of the overlap area of the seam joint.

1. Room Temperature Test: A designated load shall be applied to seam joint after it is fastened in the clamps. This load shall be equal to a percentage of the Bonded Seam Strength Value indicated in the Materials Properties Tables. The load shall be maintained for 4 hours at a temperature of 73°F. The stressed sample must be closely observed. Excessive elongation may require clamp adjustent to maintain consistent loading. When elongation reaches 50% of the original jaw separation, no additional adjustment need be made. Retain existing load for balance of test duration.

2. A "failure" will be noted when the seam joint separates entirely

D. Reporting of Results

The results shall be reported by indicating the designated load, the temperature, the time duration of the test, the length of the overlap seam, and a "pass" or "fail" designation.

PART 11

Dead Load Seam Strength at Elevated Temperature

A. Introduction

Sun exposure and high air temperatures sometimes result in the portion of an exposed FML above the water (or contained fluid) surface to reach temperatures over 120°F. If seams are improperly made and/or the FML material formula will not allow good seams to be made, then the lining may separate under temperatures and forces sometimes encountered in actual service. The dead load seam strength test at elevated temperature is designed to identify seams which are likely to be subjected to failure under such conditions.

The temperature selected for the test should be consistent with the thermal physical/chemical properties of the FML and the anticipated service condition. The temperature and load given in this test method may need to be revised. The FML material manufactuer should be consulted if changes in the test conditions appear appropriate.

B. Test Specimen

Unsupported Materials: The specimen shall be 1 inch wide, and at least 8 inches long. The seam shall be located in the center of the specimen and across the full width of the specimen.

Supported Materials: The specimen shall be 4 inches wide and at least 12 inches long. The seam shall be in the center of the specimen and across the full width of the specimen.

C. Procedure

The clamping mechanism will grip the full 1-inch width of an unsupported specimen. The grip separation shall be 4 inches plus the seam width.

A 1-inch wide section of a supported specimen in the center of the width of the test specimen should be gripped. The grip separation shall be 6 inches plus the seam width. The clamps shall not grip any portion of the overlap area of the seam joint.

The load equal to 25 percent of the required bonded seam strength should be applied to the seam joint after it is fastened in the clamps. The load shall be maintained for 4 hours at the temperature specified in the table for the particular material.

The stressed sample must be closely observed. Excessive elongation may require clamp adjustment to maintain consistent loading. When elongation reaches 50 percent of the original jaw separation, no additional adjustment need be made. Retain existing load for balance of test duration.

A "failure" will be noted when the seam joint separates entirely.

D. Reporting of Results

The results shall be reported by indicating the designated load, the temperature, the time duration of the test, the length of the overlap seam, and a "pass" or "fail" designation.

For example: 25 percent Bonded Seam Strength 158°F, 4 hours, 4 inch seam length, Pass.

Part 12

Environmental Stress Crack Resistance

ASTM D1693 shall be modified to be:

Condition C to be used with 100°C using 100% Igepal. Samples shall be 80 mils or finished product if thicker.

APPENDIX B

RECOMMENDATIONS AND PRECAUTIONS

APPENDIX B

RECOMMENDATIONS AND PRECAUTIONS

Aquatic Environmental Considerations

In selecting flexible membrane liners for use in fishing ponds, agriculture, fish hatcheries, certain recreational reservoirs, etc., attention should be given to aquatic environmental considerations. If there is an established history of successful use of a particular flexible membrane liner material for the intended purpose, the material can be expected to be used without adverse aquatic environmental effects. Where such a history of successful application has not been established, special attention should be given to the needs for studies designed for the specific application. An analysis of the aquatic situation and the flexible membrane liner being considered may dictate the need for specific studies. The needs will vary widely depending upon the specific application. Therefore, no specific studies are proposed in this standard. The user of the flexible membrane liner is advised to contact specialists in the field, if necessary, for guidance in establishing the need for and procedures for any special tests.

APPENDIX C

CONSIDERATIONS FOR SITE EVALUATION, MATERIAL SELECTION, CONSTRUCTION, OPERATION, AND MAINTENANCE

APPENDIX C

CONSIDERATIONS FOR SITE EVALUATION, MATERIAL SELECTION, CONSTRUCTION, OPERATION, AND MAINTENANCE

PURPOSE: These considerations are intended to address the application of a membrane liner. The purpose of this appendix is to make users of flexible membrane liners aware of important parameters that must be examined through site evaluation, material selection, construction, operation and maintenance.

I. SITE CONSIDERATIONS AND PREPARATION:

A. GENERAL: The supporting surface slopes and foundation to accept the liner should be stable and structurally sound. Particular attention should be paid to the potential of sink hole development and differential settlement. The design should incorporate gas venting provisions. Removal of organics contained in the subgrade is recommended.

B. GROUNDWATER: Lateral and/or vertical movement of groundwater should be considered. When a landfill or surface impoundment area is to be lined with a flexible membrane, it should be constructed above the maximum high water table. If this cannot be achieved, pressure relief provisions should be included.

C. SURFACE DRAINAGE: Runoff should be diverted from the area surrounding the lined landfill or surface impoundment.

D. COMPACTION: Flexible membrane linings should not be used as a structural component. Flexible liners should be installed over properly compacted slopes and supporting surfaces to reduce stresses which may be induced in the liner after placement.

E. SLOPES: Embankment design will effect the choice of liners. Specific attention should be given to the angle and length of slopes. (See Section II.C.1.)

G. SOIL STABILIZERS: Soil stabilizers (e.g., cementatious or chemical binding agents and geotextiles), when used to control erosion below the liner should not adversely affect the membrane. Cementatious or chemical binding agents may be potentially abrasive agents.

II. MATERIAL SELECTION:

A. COMPOSITION OF CONTAINED LIQUIDS AND/OR SOLIDS:

1. GENERAL: Membrane material selection is dependent on the nature of the contained liquid and/or solids. Characteristics of importance are chemical composition, temperature, and pH. A detailed analysis should be made for all potential constituents, especially organic compounds.

2. CHEMICAL COMPOSITION: The chemical composition of a liquid/solid to be contained should be known before liner selection is made. If the chemical composition of the liquid/solid to be contained is not known, it is recommended a sample of the liquid/solid be made available by the owner for the determination of liquid/solid liner compatibility. Liner compatibility should be verified by liner manufacturers prior to liner material selection (see Section II.B.). If phase separation of the solid/liquid occurs, the liner compatibility should be determined for each identified phase. The selection of the liner material should also consider the possibilities of concentration build-up; e.g., by evaporation or separation, components that tend to accumulate, synergistic effects and shock loadings.

The intended user should provide the manufacturer with a sample of the solids to be contained and/or a chemical analysis of the waste, along with site and service conditions so that the manufacturer can provide to the intended user a letter characterizing the chemical resistance of the candidate liner material to the waste provided or described. The letter should explain how the chemical resistance of the liner to the material was determined; e.g., direct exposure tests, historical data and/or field applications. The purpose of the letter is to aid the user in determining the acceptability of the candidate liner for his intended use. Site specific conditions must also be considered in the selection of the liner.

3. TEMPERATURE: The influent and operational temperature of the solid/liquid to be contained should be considered before liner material selection. It is recommended that the chemical resistance of a liner material to a solid/liquid be performed at the maximum temperatures. The possibility of shock temperature loadings should be evaluated.

4. CONCENTRATION: Compatiblity testing should be performed at or near the concentration of the solid/liquid to be contained. However, if the possibility exists for concentration build-up and/or dilution and/or shock loadings, these situations should also be evaluated.

5. pH CONDITIONS: The acid/alkaline nature of solid/liquid to be contained can have an adverse affect on the membrane liner. The acid/alkaline properties of a solid/liquid should be characterized before liner material selection.

B. BURIED LININGS: Certain lining materials whose properties might be adversely affected during the projected use period due to the effects of heat, ultraviolet radiation (U.V.) or other factors associated with weathering should only be used as buried membrane liners. Generally speaking, maximum side slopes of 3:1 are suitable for earth covering, but some covering materials like gravels will stay on somewhat steeper side slopes. Conversely, sandy soil backfilled materials may require a flatter slope. Earth covering should be of materials which will not cause puncturing of the lining; i.e., silts, sands, rounded gravels and should have good erosion-resistance. If silts and sands are used for covering materials, gravels or other erosion-resistant materials are frequently placed at the waterline to minimize erosion.

All flexible membrane lining materials benefit from being covered. These benefits include weathering (i.e., U.V., heat, wind, etc. effects) as well as damage from animal life or severe or unusual climatic conditions (such as hail, hurricanes, etc.).

Care must be taken during covering operations to prevent mechanical damage to the liner. Critical aspects of a backfilling operation include stability of the subgrade, surface preparation, depth of backfill and surface-loading caused by earthmoving equipment during earthen placement. Proper preparation of the subgrade and the use of clean fill for the cover material is required to prevent puncture, tearing or abrasion of the membrane. It is recommended that the site engineer provide for visual inspection during earth covering (backfilling) operations.

NOTE: Linings designed to be buried may be used in an exposed condition for a limited time. The user should consult with the manufacturer.

C. EXPOSED LININGS: Certain linings may be suitable for exposed applications, particularly where steeper banks and sediment-free systems are desired. It can also serve to facilitate inspection. In these cases, consideration should be given to design features including ground stability, membrane attachment, slope angles, venting and wind uplift.

D. BIOLOGICAL STRESSES: Membrane liners, scrims and adhesives that are susceptable to biological attack, as determined by, but not limited to, soil burial testing, should be formulated by the manufacturer to resist this attack. Problems of an animal or botanical nature may be controlled by fencing, soil sterilization, or mechanical protection in those areas where the problem could exist.

E. SUPPORTED OR UNSUPPORTED MEMBRANE MATERIALS:

1. UNSUPPORTED LININGS: Unsupported linings have high elongation and can conform to irregular surfaces and follow settlements. The tensile strength, tearing, and other physical properties of some exposed liners may be altered by temperature extremes and aging.

2. SUPPORTED LININGS: Fabric reinforcement, such as nylon or polyester scrims, are used in linings to improve tensile strength, tear resistance, burst strength and dimensional stability. Reinforcement decreases the elongation of linings so that they may not follow settlement.

3. COMBINATION LINER SYSTEMS: A number of lining materials can be used in combination. For example, a reinforced side slope lining may be used with an unreinforced bottom

lining or, a side slope lining may be of a different thickness than a bottom lining. Combinations of dissimilar materials may be used, but care should be taken to insure the integrity of seams and the compatibility of liner materials.

F. REPAIRABILITY: See Section VI.E.8.

III. POTABLE WATER APPLICATIONS: Materials used in the manufacture of membrane liners for potable water applications should conform to the following requirements:

A. CHEMICAL/TASTE AND ODOR: Chemical/taste and odor evaluations of membrane liner materials should be conducted in accordance with procedures set forth in Appendix A. The extractant water therefrom should not exceed the maximum contaminant levels established in the U.S. Environmental Protection Agency's National Primary Drinking Water Standards of 1978 and Federal Register publication 40CFR Part 141. Limits of acceptance as required by this standard are shown in Table C-I.

TABLE C-I. MAXIMUM PERMISSIBLE CONTAMINANT LEVELS

Contaminant	Max. Per. Level* mg/l(ppm)
Antimony	0.05
Arsenic	0.05
Barium	1.0
Cadmium	0.01
Chromium (Hexavalent)	0.05
Lead	0.05
Mercury	0.002
pH	
Phenolic Substances	0.05
Silver	0.05
Selenium	0.01
TTHM	0.1

Taste and Odor Evaluation

Characteristic	Permissible Level
Odor	80
Taste	Satisfactory

*In finished product

B. MATERIAL REQUIREMENTS: Materials shall conform with the requirements set forth in Sections 3 and 4 of the standard.

IV. WASTEWATER/SLUDGE APPLICATIONS: Surface impoundments and/or landfills receiving municipal wastewater liquids or sludges require special consideration. This type of waste could contain industrial wastes. Since some of these wastewaters/sludges exhibit increased biological activity and promote chemical attack, care should be taken in the final membrane selection.

V. SOLID AND HAZARDOUS WASTE APPLICATIONS:

A. GENERAL: Landfills and surface impoundments receiving solid or hazardous wastes when lined and/or covered require consideration of the nature and stability of the materials contained and/or released with time. Moisture, when accumulated to permit leaching, will expose the liner to changing environmental conditions; the choice of membrane type and seaming system may be affected by elevated temperature and other factors. This exposure may be anticipated to occur throughout the life of the liner and will be brought about by inherent physical, chemical and microbiological processes as well as the landfill management techniques employed.

B. OTHER CONSIDERATIONS: Although landfills may contain residential-type wastes, some sites may only receive contributions of commercial and/or industrial wastes which may be classified as hazardous. Selected waste systems may be classified as special (reference the December 18, 1978 Federal Register). The nature and characteristics of the waste materials and the anticipated release of constituents must be considered in the selection of the liner and cover as well as the methods of operation and maintenance of the site.

VI. CONSTRUCTION OF SITE:

A. SURFACE CONDITION:

1. PREPARATION OF EARTH SUBGRADE: The prepared subgrade should be of soil types no larger than Unified Soil Classification System (USCS) sand (SP) to a minimum of 6 inches below the surface and free from loose earth, rock, fractured stone, debris, cobbles, rubbish and roots. The surface of the completed subgrade should be properly compacted, smooth, uniform and free from sudden changes in grade.

2. MAINTENANCE OF SUBGRADE: The earth subgrade shall be maintained in a smooth, uniform and compacted condition during installation of the lining.

B. CLIMATIC CONDITIONS:

1. TEMPERATURE: The desirable temperature range for membrane installation is 5°C to 40°C. Lower or higher temperatures may have an adverse effect on transportation, storage, field handling and placement, seaming and backfilling where required.

2. WIND: Wind may have an adverse effect on liner installation such as interfering with liner placement, alignment of seams, and cleanliness of seam area; mechanical damage may result.

3 PRECIPITATION: When field seaming is adversely affected by moisture, portable protective structures and/or other methods should be used to maintain a dry sealing surface.

C. EROSION CONTROL: Wind and wave action may cause erosion where protective soil cover is used on the liner. Protective measures should be considered.

D. STRUCTURES: Penetration of a flexible liner by any designed means should be avoided. Where structures are necessary, such as:

- pipes (both horizontal and vertical)
- vertical support columns
- inlets, outlets
- sumps
- divider walls

it is essential to obtain a secure, liquid-tight seal between the structure and the flexible liner. Liners should be attached to structures with a mechanical type seal supplemented by a chemically compatible caulking or adhesives to effect a liquid-tight seal. The highest order of compaction should be provided in the area adjacent to the structure to compensate for any settlement.

E. LINER PLACEMENT:

1. SHOP DRAWINGS: Shop drawings with panel sizes, layout, and details should be prepared.

2. PACKAGING, TRANSPORTATION, HANDLING AND STORAGE: Packaging, transportation, handling and storage procedures should be planned to prevent material damage. Material should be stored in a secured area and protected from adverse weather.

3. SITE INSPECTION: A site inspection should be carried out by the owners representative and the installer prior to liner installation to verify grades, measurements, structures and surface conditions.

4. DEPLOYMENT: Panels should be positioned to minimize handling. Seaming should follow as close as practical. Bridging or stressed conditions should be avoided with proper slack allowances for shrinkage. Panels should be secured following deployment to prevent movement.

5. ANCHORING TRENCHES: The liner should be secured in a backfilled trench.

6. FIELD SEAMING: Field seaming should be performed when weather conditions are favorable. The contact surfaces of the materials should be clean of dirt, dust, moisture, or other foreign materials. The contact surfaces should be aligned with sufficient overlap and bonded in accordance with the suppliers recommended procedures. Wrinkles should be smoothed out and seams should be inspected by nondestructive testing techniques to verify their integrity. Seam samples should be taken to verify seam integrity or on-site seam samples can be made with identical liner material, adhesive and technique which need not be taken from an actual field seam.

7. VENTING: Where it is anticipated that gas will accumulate under the liner, a gas relief system may be required. Various methods or combinations are used depending upon the severity such as:

   - Liner Weighted by Protective Cover
   - Gas Relief System Under Liner:
     - perforated pipe
     - open granular filled trenches
     - open granular fill over subgrade
     - geotextile drainage fabric over subgrade
     - sloped bottom

   These systems should be constructed to permit gas escape from under the liner. Consideration should be given to use a soil cover as a complement to the gas relief system under the liner.

8. INSPECTION AND REPAIR: As seaming occurs during installation, the field seams should be inspected and any faulty area repaired. It is important that traffic on the lined area be minimized. Any necessary repairs to the liner should be patched using the same type of lining material and following the recommended procedure of the supplier

9. FINAL INSPECTION AND ACCEPTANCE: As completed, the liner installation should be tested for functional integrity. All joints, seams and mechanical seals should be checked both during and after installation. A variety of testing methods can be used such as:

   - hydrostatic test
   - vacuum
   - ultrasonics
   - air jet

   Final acceptance should be between responsible parties as contracted on each individual installation.

F. OPERATION AND MAINTENANCE: The owner should be provided with guidelines for operation and maintenance of the liner system, which should include recommendations on subjects such as:

   - Frequency and documentation of inspection
   - Testing and repair of liner
   - Monitoring of waste characteristics
   - Monitoring of observation wells
   - Animal and plant control
   - Erosion control
   - Security and safety
   - Unacceptable practices

APPENDIX D

Recommended Test Method for Estimating Long-Term Performance of Membrane Liners in a Chemical Environment

APPENDIX D

Recommended Test Method for Estimating Long-Term Performance of Membrane Liners in a Chemical Environment

A. INTRODUCTION

These test methods are for the initial and long-term evaluation of flexible membrane liner materials intended to contain chemicals in a pit, pond, lagoon or landfill-type installation. The effects upon the physical properties of the liner materials will be determined. Data from these tests will assist in deciding whether a liner material should be used in a given chemical environment.

In selecting a liner material for a given chemical environment, it is advantageous for the user to work with flexible membrane liner manufacturers. The user should provide the manufacturer/fabricator with a sample of the material to be contained and/or its chemical analysis along with the specific site and service conditions. The manufacturer can then provide the user a letter characterizing the chemical resistance of flexible membrane liner to the materials to be contained. The letter should explain how the chemical resistance of the liner material was determined; e.g., direct exposure tests such as described in this appendix. Other useful data could include historical data and/or field applications. The purpose of the letters from manufacturers is to assist the user in determining the acceptability of various materials for the intended use.

The test method is based upon ASTM D543 and ASTM D471 which specify the particular physical properties to be measured for plastics and rubber, respectively.

The scope of this appendix is to cover general test methods which may be of assistance in selecting a flexible membrane liner where other than fresh water is to be contained. Specific applications may require additional tests related to the particular environment. Some tests in this appendix may not be applicable to certain other applications. Some installations may not require long term evaluation testing per Appendix D if the manufacturer can provide similar test data and/or service experience for similar applications.

B. INITIAL EVALUATION

Specimens are exposed in the test environment for 1, 3 and 7 days at 23°C and 50°C. At least three specimens shall be used for each material being tested, at each temperature and for each chemical environment to be involved. Data on weight, dimensions and visual changes are obtained as described in Procedure I (Section I).

C. LONG-TERM EVALUATION

Sets of three test specimens are immersed in the chemical environment for each flexible membrane liner material being tested, at each temperature, and for each set of physical properties being tested. For example:

Property	No. of Specimens
Tensile, Modulus & Elongation	3
Weight & Dimensions	3
Ply Adhesion	3
Tear Test	3
Factory Seams	3
Visual	any/all of above samples

The weight and dimensional changes shall be determined after immersion in the chemical environment for 1, 7, and 14 days, and 1, 2 and 4 months at 23°C and 50°C. The changes in tensile (breaking strength), modulus, elongation and tear shall be determined after immersion for 1 day, 7 days, 1 month and 4 months. This data will assist in determining the properties after long-term service. The specific nature of the FML being tested should be considered when interpreting the data.

D. SIGNIFICANCE

1. The limitations of the results obtained from this test should be recognized.

2. Correlation of test results with the actual performance or serviceability of FML materials is necessarily dependent upon the similarity between the testing and end-use conditions. For applications involving continuous immersion, the data obtained in short time tests are of interest only in eliminating the most unsuitable materials or indicating a probable relative order of resistance to chemical reagents.

3. The selection of test conditions should take into account the manner and duration of contact with the chemical environment, the temperature of the system, and other performance factors involved in the particular application. If the highest expected temperature in service exceeds the 50°C recommended in this appendix, then use the higher temperature.

4. Note should be taken of the fact that different ratios or even trace amounts of different materials in the immersion liquid may affect the FML in an entirely different manner if concentrated or localized even for short periods of time in repeat tests or in actual application. Trace amounts of deleterious chemicals can be cumulative; this may require a repeated supply of chemical liquid to show the true immersion effect.

E. APPARATUS

1. Balance - a chemical balance accurate to 1 mg.

2. Micrometers - Micrometers capable of measuring dimensions of test specimens to 0.025 mm (0.001 in).

3. Room or enclosed space capable of being maintained at the standard laboratory atmosphere, at temperature 23 ± 2°C and relative humidity of 50 ± 5% (ASTM D618).

4. Containers - Suitable containers for immersing specimens in chemical reagents. They must be resistant to the corrosive effects of the reagents being used. Safety precautions must be taken when using highly volatile reagents at elevated temperatures.

5. Oven or Constant-temperature Bath - Capable of maintaining temperature within ± 2°C of the specified test temperatures.

6. Testing Devices - Testing devices for determining specified strength properties of specimens before and after immersion, conforming to the requirements prescribed in the ASTM methods of test for the specific properties being determined.

F. TEST ENVIRONMENTS

The FML liner material should be immersed in the actual chemical process solutions to be provided by the plant involved. If this is not possible, a synthesized solution may be used and must include all chemicals, especially solvents, even though they are present in small quantities. See Section D.4 concerning special studies with aggressive trace materials.

Caution: In all cases, it is necessary to determine whether the solution is homogenous or consists of more than one phase. When a multiphase solution exists, test samples must be placed in each of the phases. Each phase should be in a separate container. Past experience indicates that a solvent has limited solubility in an aqueous system and may form a separate layer either on top or bottom of the liquid. It is likely that the solvent phase may adversely affect the liner material while the aqueous phase may not. If highly volatile chemicals are part of the solution being tested, the solution should be changed at equal time intervals (weekly or monthly) so as to compensate for any escaping components of the chemical environment.

G. TEST SPECIMENS

The type and dimensions of test specimens to be used for original and immersion testing shall be those described in Section J.3. for each type of FML. Specimen surface area greatly affects the

weight change due to immersion in chemical reagents. Thickness influences percentage dimension change as well as percentage change in mechanical properties. Consequently, comparison of materials should be made only on the basis of results obtained from specimens of identical dimensions and like methods of specimen preparation. The number of specimens used shall be as stated in Sections B and C. The specimens shall be as follows: specimens from sheet material shall be cut from a representative sample of material in a manner depending upon the tests to be performed and the thickness of the sheet as follows:

1. Weight and dimension changes - Standard specimens shall be in the form of bars 76.2 mm (3 in) in length by 25.4 mm (1 in) in width by the thickness of the material. 2 inch by 1 inch specimens or 2-inch diameter discs can be alternates.)

2. Mechanical property changes - Standard machined, sheared, or cut tensile specimens shall be used according to the methods of test prescribed.

H. CONDITIONING

1. Condition the test specimens at 23 ± 2°C (73.4 ± 3.6°F) and 50 ± 5 percent relative humdiity for not less than 40 hours prior to test.

2. Test conditions - Conduct tests at the standard temperatures of 23 ± 2°C (73.4 ± 3.6°) and 50 ± 2°C (122 ± 3.6°F). In cases where the FML material will have a chemical environment at elevated temperatures, the immersion testing shall be run at the elevated temperature if higher than the above.

I. PROCEDURE I - WEIGHT AND DIMENSION CHANGES

1. Weigh each conditioned specimen separately and measure its thickness at the center and its length and width to the nearest 0.25 mm (0.001 in). In the case of laminates, edge swelling is not uncommon under certain conditions. Consequently, it may be necessary to measure thickness both at the center and at the edges and report the percentage change separately for each position.

2. Place specimens in appropriate containers for the chemicals being used and allow the specimens to be totally immersed in fresh chemical for the appropriate time in the standard laboratory atmosphere. Suspend the specimens to avoid any contact with the walls or bottom of the container. For specimens of thin sheeting or those having a lower density than the chemical, it may be necessary to attach small weights such as nichrome wire to prevent floating or curling. Several specimens of a given material may be immersed in the same container provided sufficient reagent is allowed for the total surface area exposed and the specimens do not touch each other. The quantity of chemical solution shall be approximately 40 ml/in² of total specimen surface area.

   For test at other than room temperatures, it is recommended that the test temperature be 50°C or at the highest expected service temperature, whichever is the highest. It is important that the test solution be at the elevated test temperature before the specimens are immersed. In the event that the liner is expected to impound certain substances in trace quantities which can be aggressive to FML materials, special investigations should be instituted by the testing agency.

3. Stir the test solutions every 24 hours by moderate manual rotation of the containers or other suitable means. In making tests for longer periods of time than 7 days, the containers should be stirred once each day during the first week, and once each week thereafter. Where the field service condition will involve aeration or other continuous agitation, the containers should be stirred daily.

4. After the test period, individually remove each specimen from the chemical solution, blot excess material, dip into acetone or other suitable solvent, wipe and dry with lint-free material, immediately weigh in a weighing bottle, remeasure its dimensions and place back into chemical environment until next time period. When dealing with an oily material, it may be necessary to follow the following procedure: wipe and dry with lint-free material; dip into detergent solution; wipe and dry with lint-free material; dip into water and then acetone or

other suitable solvent; wipe and dry with lint-free material; dip into water and then acetone; wipe and dry with lint-free material; and weigh and measure immediately. Some specimens may become tacky due to dissolved material on the surface or solvent absorbed throughout the specimen. Take care in wiping such specimens not to disturb or contaminate the surface.

5. Observe the appearance of each specimen after exposure to chemical reagent. Observe and report appearance on the basis of examination for evidence of blistering, loss of gloss, developed texture, decomposition, discoloration, swelling, tackiness, crazing, bubbling, cracking, softening, solubility, etc. For some materials, absorption of the reagent over the immersion period is nearly balanced by the removal of soluble constituents. This type of behavior may be revealed by comparing the initial conditioned weight of the specimen with its weight when dried for 7 days at 23°C and 50 percent relative humidity, after removal from the chemical reagent. (A final weight lower than the initial weight may indicate removal of soluble constituents. However, only for particular combinations of reagent and test specimen can this weight difference be considered as due strictly to the removal of soluble constituents.) If this drying out procedure is used, it should be tried after all test-time periods have elapsed.

J. PROCEDURE II - MECHANICAL PROPERTY CHANGES

1. Immerse and handle the mechanical test specimens in accordance with the instructions given under Procedure I (Sections 2, 3 and 4).

2. Determine the mechanical properties of identical nonimmersed and immersed specimens in accordance with the standard methods for the physical property test described. Make mechanical property tests as nonimmersed and immersed specimens prepared from the same sample or lot of material in the same manner and run under identical conditions. Test immersed specimens immediately after they are removed from the test solution. Where specimens are exposed to test solutions at elevated temperatures, they shall be placed in another container of the reagent at the standard laboratory temperature for approximately one hour to effect cooling prior to testing.

3. Test samples for materials with fiber scrim support - The effect of chemicals on the liner material without support material must be determined because it is the main chemical barrier while the function of the scrim is to provide added mechanical properties. Most of the time, the liner material without support will have to be a laboratory-milled sample of the same formulation, milled to a thickness of 20 or 30 mils. The processing conditions of laboratory-prepared samples should be as close as possible to actual factory conditions.

   All samples containing a fiber scrim support must be flood-coated along all exposed edges with a solution recommended by the FML manufacturer. This solution will typically contain 5 - 15% solids dissolved in a solvent (or mixture of solvents). The solids content is usually the FML formula or simply the base polymer used.

   The physical properties after immersion are determined using the original unimmersed thickness or cross-sectional area, as described in ASTM D471.

4. Test samples for material with no scrim - These test samples are designed to measure the mechanical and physical properties of the liner material. Tests shall be conducted as prescribed and the properties after immersion are determined using the original unimmersed thickness or cross-sectional area, as described in ASTM D471.

5. Condition of samples before physical testing - After the samples have been removed from the test solution, they should be kept saturated with the test solution until just before testing. If the test solution contains organic solvents, the coupons should be wrapped in aluminum foil during this interval to prevent loss of solvent. In many cases, a material that has been degraded by solvent will regain almost all its original properties after the solvent has evaporated away. The time between removal from solution and testing should be kept as short as practical.

6. Test data required:

Crosslinked elastomers unsupported - ASTM D412 (Method A)

- Breaking strength, pounds/inch width
- Elongation at break, percent
- Modulus at 100 percent elongation

Thermoplastics, unsupported

Materials without a yield point - ASTM D882

- Breaking strength, pounds/inch width
- Elongation at break, percent
- Modulus at 100 percent elongation, pounds/inch width

Materials with a yield point - ASTM D638

- Breaking strength at yield and break, pounds/inch width
- Elongation at yield and break, percent
- Modulus of elasticity, pounds/inch width
- Tear, unsupported FML - ASTM D1004

Supported flexible membrane liners

Supported finished FML material - ASTM D751

- Breaking strength, Grab Method, pounds or Strip Method, pounds/inch width

Ply adhesion, all supported FML - ASTM D413, Machine method, strip specimen, Type A, 180° peel, pounds/inch width

Visual inspection, unsupported and supported FML - Procedure I (Sections 1 thourgh 5)

K. Procedure III - Effect of Strain on Mechanical Properties

1. Standard specimens shall be in the form of bars 75.2 mm (3 inches) in length and 25.4 mm (1 inch) in width by thickness of the material.

2. Form a bent loop from the standard specimen by folding the specimen together and holding the ends together with a suitable fastener or adhesive which is resistant to the test solution. Approximately 2 inches of the specimen shall be in contact with itself.

3. The specimens should be conditioned and immersed as in Procedure I (Section I).

4. After immersion periods of 7 days for initial evaluation and 4 months for long-term evaluation, the specimen shall be inspected for visible deterioration as described in Procedure I.

5. This test is qualitative in character and to be used to identify materials which are highly susceptible to deterioration in the chemical solution when strained.

L. Procedure IV - Factory Seams

All seaming methods and techniques should be evaluated in the chemical environment in which they are to be employed. Samples are to be prepared and tested using methods as prescribed in ASTM D3083 (as modified in Appendix A) for unsupported FML and ASTM D751 (Appendix A) for supported FML. These methods provide for the testing of seams in the shear direction. It should be noted that testing in the peel direction (as in ASTM D413) can be a more sensitive test for

determining chemical resistance of seams. Samples should be immersed for 7 days for the short-term initial evaluation and 4 months for the long-term test. Samples containing a fabric scrim support must be flood-coated as described earlier (Section J.3.)

M. Report

The report shall include the following:

1. Procedure I

   a. Complete identification of the material tested including type source, manufacturer's code, form and previous history.

   b. Temperature of tests.

   c. Test solutions

   d. Duration of immersion

   e. Initial length, width and thickness of each specimen, in inches, measured to the nearest 0.025 mm (0.001 in)

   f. Initial weight of each specimen in grams to ± 0.005 g

   g. Length, width and thickness after immersion

   h. Weight after immersion

   i. Average percentage increase or decrease in length and width, and in the thickness, taking the dimensions of the conditioned specimen as 100 percent.

   j. Averge percentage gain or loss in weight calculated to the nearest 0.01 percent, taking the conditioned weight as 100 percent.

   k. General appearance of specimens after immersion.

2. Procedure II

   Items 1 through 4 as for Procedure I and the following:

   a. Specimen type and dimensions

   b. Method of test

   c. Mechanical properties of identical nonimmersed and immersed specimens

   d. Average pecentage increase or decrease in mechanical properties, taking the properties of the conditioned nonimmersed specimens as 100 percent.

3. Procedure III

   General appearance of specimens after exposure

4. Procedure IV

   a. Original bonded seam strength

   b. Bonded seam strength after immersion

   c. Average change in bonded seam strength using original bonded seam strength as 100 percent

APPENDIX E

IDENTIFICATION SYSTEM

APPENDIX E

IDENTIFICATION SYSTEM

The code in Section 5 of the standard consists of three parts: the FML material; installation condition; and general intended service. Thus the code could be considered three-part sequence x/y/z.

Example 1: PVC, 30 mil suitable for potable water use

x: Material - PVC
Unsupported = U
Thickness - Nominal Gauge 30 mils = 30

or x = PVC-U-30

y: PVC is to be buried =
Bu

z: Material evaluated suitable for potable water = PW

Identification is PVC-U-30/Bu/PW

Example 2: Supported CPE, Type 2, not evaluated for potable water use

x: Material - CPE
Supported = S
Type - 2
Thickness - Nominal Gauge 36 mils = 36

or x = CPE-S-2-36

y: CPE is evaluated suitable for exposed service = Ex

z: Material evaluated not suitable for potable water = In

Identification is CPE-S-2-36/Ex/In

APPENDIX F

RECOMMENDED PROTOCOL
FOR
DEVELOPING TESTING AND FIELD EXPERIENCE DATA
FOR
NEW MATERIALS

APPENDIX F

RECOMMENDED PROTOCOL
FOR
DEVELOPING TESTING AND FIELD EXPERIENCE DATA
FOR
NEW MATERIALS

This protocol is to provide guidance for developing the testing and field experience data for submittal for the purpose of adding new materials or additional types or gauges to the standard. Additions to the standard will require balloting on the proposed changes by the NSF Joint Committee for Flexible Membrane Liners, Council of Public Health Consultants, and final adoption by the NSF Board of Trustees. It may be necessary to have a review of the data by the Industry Advisory Committee or a technical review committee, as appointed by NSF, prior to balloting at the Joint Committee level.

The following basic information is to be provided:

1. A recommended materials properties table shall be submitted which will include details of the test method and values along with the test data to substantiate the recommended table. (It is recommended that data on other potential tests also be provided to substantiate that they are not appropriate for the particular material.) The recommended material properties should characterize the material and a satisfactory liner as manufactured from the material.

2. For an exposed liner, data shall be submitted as evidence of compliance with Item 3.0.3 (EMMAQUA, 1,000,000 Langleys rating of 7 or better).

3. Evidence of production on full-scale equipment shall be provided.

4. Evidence of a monitored field installation that has experienced seasonal variations (minimum one year) shall be provided. The installation shall include both factory and field seams.

5. The data of testing conducted on the liner exposed for at least one year shall be provided. The testing should be of the material properties of the recommended table and should include testing of the seams. (EMMAQUA testing and 120-day soil burial are excluded.)

General guideline for the reviewing process: The specified minimum test values to be stated in the proposed material properties table should be based on actual test results of unexposed FML. These minimums should be within 25% of the actual test values. Exception to this requirement may exist depending on the precision, accuracy or nature of the test. In addition, the data for the exposed FML should correlate with the data for the unexposed FML.

In addition to the basic submittal as detailed, it is recommended that additional data and information for weathering (other than EMMAQUA) and chemical resistance be provided to support a request for an addition to the standard.

APPENDIX G

Participating Committees

NSF JOINT COMMITTEE

FOR

FLEXIBLE MEMBRANE LINERS
(1983)

Chairman, Gray, Melville W., Chief Engineer and Director, Environmental Health Division, State Department of Health, Forbes AFB/Bldg. 740, Topeka, KS 66620

Alther, George R., Foundry Products Division, International Minerals and Chemicals Corp., 17350 Ryan Road, Detroit, MI 48212, (Liaison, ASTM D34)

Fogg, Charles, Soil Conservation Service, U. S. Department of Agriculture, 5248 South Agriculture Building, P. O. Box 2890, Washington, DC 20013

Geswein, Allen, U. S. Environmental Protection Agency (WH564), 401 M Street SW, Washington, DC 20460

Giroud, Jean-Pierre, Director, Geotextiles and Geomembranes Group, Woodward-Clyde Consultants, 11 East Adams, Suite 1500, Chicago, IL 60603(Liaison, ASTM D18.20)

Golden, Dean M., Project Manager, Solids By-Product & Hazardous Waste Disposal Subprogram, Electric Power Research Institute, P. O. Box 10412, Palo Alto, CA 94303

Highfill, Gene, Soil Conservation Service, U. S. Department of Agriculture, P. O. Box 2890, 5248 South Agriculture Building, Washington, DC 20013

Kittredge, David, Manchester Water Works, 281 Lincoln Street, Manchester, NH 03102 (American Water Works Association)

Landreth, Robert E., Sanitary Engineer, U. S. Environmental Protection Agency, National Environmental Research Center, Cincinnati, OH 45268

Newell, Edward L., Jr., US Army Environmental Hygiene Agency, ATTN:HSE-ES, Aberdeen Proving Ground, MD 21010

Pacey, John G., President, EMCOM Associates, 90 Archer Street, San Jose, CA 95112 (American Society for Civil Engineering)

Pohland, Dr. Frederick G., Department of Civil Engineering, Georgia Institute of Technology, Atlanta, GA 30332 (American Society of Civil Engineering)

Powitz, Dr. Robert W., Wayne State University, 625 Mullett, Detroit, MI 48226(National Environmental Health Association)

Sytron, C. R., III, Research Civil Engineer, Material Development Division, Geotechnical Laboratory, Department of the Army, Waterway Experiment Station, Corps of Engineers, P. O. Box 631, Vicksburg, MS 39180

Timblin, L. O., Jr., Chief, Applied Sciences Branch, U. S. Department of the Interior, Water and Power Resources Service, Code D-1520, P. O. Box 25007, Denver, CO 80225

INDUSTRY

Baseden, Tod, E.I. du Pont Co., Elastomers Lab,Chestnut Run, Wilmington, DE 19898

Blatt, John M., President, Pacific Lining Company Inc., P. O. Box 35, Stanton, CA 90680

Cain, Richard, President, Palco Linings, Inc., 7571 Santa Rita Circle, Stanton, CA 90680

Crepeau, Allen, Uniroyal Chemical,Technical Sales, Service Center, Spencer Street, Building 112, Naugatuck, CT 06770

Dickinson, Richard, Marketing Manager, Dynamit Nobel of America, Film Sheeting Department, 10 Link Drive, Rockleigh, NJ 07647

Gish, Brian, Carlisle Tire & Rubber Co., P. O. Box 99, Carlisle, PA 17013

Kamp, Larry, The Pantasote Company of New York, Inc., 26 Jefferson Street, Passaic, NJ 07055

Kutnewsky, D., Vice President, Burke Industries, Inc., 2250 South Tenth Street, San Jose, CA 95112

Lussier, Paul W., Supervisor R&D, Canadian General-Tower Ltd., P. O.Box 160, Cambridge, Ontario, Canada N1R 5T7

Magrans, Juan, Marketing Department, Hercules Incorporated, 910 Market Street, Wilmington, DE 19899

Main, Buster, Maineline Sales Company, Inc., 3292 South Highway 97, Redmond, OR 97756

Peterson, Arnold G., Stevens Elastomeric and Plastics Products, P. O. Box 431, Easthampton, MA 01027

Pezzoli, Paul A., Dow Chemical Co., Building 2307, Box 150, Plaquemine, LA 70764

Pomeroy, John, Tenneco Chemicals, 300 Needham Street, Newton Upper Falls, MA 02164

Ross, Bert, R & D, Reeves Brothers, Inc., P.O. Box 26596, Charlotte, NC 28213,

Salberg, G. W., Synflex Industries, Inc., 301-255 1st Street West, Vancouver, BC, Canada V7M 3G8

Schmidt, Richard, Gundle Lining Systems, Inc., 1340 East Richey Road, Houston, TX 77073

Shackleton, John, Technical Advisor, Product & Applications Division, Polysar Limited, Sarnia, Ontario, Canada N7T 7M2

Silverman, Alfred, President, Spartan-Aqualon Corp., 17 Cotters Lane, East Brunswick, NJ 28816

Slifer, William J. III, President, Watersaver Company, Inc., 5870 East 56th Avenue, Commerce City, CO 80022

Sparks, Hay F., Jr., Milliken & Company, P. O.Box 1926, Spartanburg, SC 29304,

Staff, Charles E., President, Staff Industries, 78 Dryden Road, P. O. Box 797, Upper Montclair, NJ 07043

Vandervoort, John, Schlegel Area Sealing Systems, Inc., 200 South Trade Center Parkway, P. O. Box 7730, The Woodlands, TX 77380

Ward, Richard, B. F. Goodrich Company, Box 657, Marietta, OH 45750

Watson, Jack, Rutland Plastics Inc., 610 Minuet Lane, P. O. Box 11007, Charlotte, NC 28209 (Shelter-Rite)

NATIONAL SANITATION FOUNDATION

COUNCIL OF PUBLIC HEALTH CONSULTANTS
(1983)

Chairman, Broadway, William A., Jr., Regional Sanitarian (retired), 22 Ashbury Road, Asheville, NC 28804

Vice-Chairman, Foster, Charles K., Chief, Bureau of Environmental Health, Texas Department of Health, 1100 W. 49th Street, Austin, TX 78756

Secretary, Sherlaw, Gary W., National Sanitation Foundation, 3475 Plymouth Road, P. O. Box 1468, Ann Arbor, MI 48106

Baker, Ned E., AHEC Program Coordinator, Medical College of Ohio, C.S. #10008, Toledo, OH 43699

Banks, Arthur L., Director, Retail Food Protection Branch (HFF-342), Food and Drug Administration, USPHS, 200 C Street SW, Washington, DC 20204

Coleman, Mark S., Deputy Commissioner, Environmental Health Services, Oklahoma State Department of Health, Northeast 10th & Stonewall, P. O. Box 53551, Oklahoma City, OK 73152

Cotruvo, Joseph A., PhD, Director, Criteria and Standards Division, Office of Drinking Water (WH-550), US Environmental Protection Agency, Washington, DC 20460

DeRoos, Roger L., PhD, Director, Environmental Health and Safety, University of Washington, 4725 30th Avenue, NE, Seattle, WA 98105

Doull, John, MD, PhD, Department of Pharmacology, University of Kansas Medical Center, Kansas City, KS 66103

Eich, Henry F., Public Health Engineer, Director, Office of Environmental Health, 590 Hamilton Street, Redwood City, CA 94063

Fish, John O., Special Assistant to the Vice President for Health Services, University of Washington (SC-61), Seattle, WA 98195

Gordon, Larry J., Director, Albuquerque Environmental Health Department, P. O. Box 1293, Albuquerque, NM 87103

Gray, Melville W., Deputy Director of Environment, Department of Health; and Environment, Forbes Field/Building 740, Topeka, KS 66620

Herndon, J. Earl, Jr., Colonel, Chief Sanitary Engineer, Medical Services Corps, Office of the Surgeon General, Headquarters, Department of the Army, Washington, DC 20310

Hickman, J. Roy, Director, Bureau of Chemical Hazards, Environmental Health Directorate, Health and Welfare Canada, Tunney's Pasture, Ottawa, Ontario, Canada K1A OL2

Hilbert, Morton S., Professor and Chairman, Department of Environmental & Industrial Health, School of Public Health, University of Michigan, Ann Arbor, MI 48109

Kupfer, George A., Superintendent, Bureau of Consumer Protection and Environmental Health, 841 N. Broadway, Room 105, Milwaukee, WI 53202

Lisella, Frank S., PhD, Assistant Director, Chronic Diseases Division, Centers for Disease Control, Atlanta, GA 30333

Marsh, Boyd T., Director, Environmental Health Division, Summit County General Health District, 1100 Graham Circle, Cuyahoga Falls, OH 44224

McIntire, Matilda S., MD, Creighton School of Medicine, Pediatrics Department, 601 North 30th Street, Suite 6820, Omaha, NB 68131

Menzel, Daniel B., PhD, Professor of Pharmacology and Medicine, Duke University Medical Center, Box 3813, Durham, NC 27710

Middendorf, William B., Special Project Manager, Susquehanna River Basin Commission, 1721 North Front Street, Harrisburg, PA 17120

Mitchell, H. Clifford, Associate Director (retired), Health & Hospital Department, St. Louis County, 507 Bambury Way, Kirkwood, MO 63122

Mood, Eric W., PhD, Associate Clinical Professor of Public Health, Yale University School of Medicine, Department of Epidemiology and Public Health, 60 College Street, New Haven, CT 06510

Morgan, Monroe T., DrPH, Professor and Chairman, Department of Environmental Health, East Tennessee State University, P. O. Box 22960A, Johnson City, TN 37614-0002

Olson, Donald E., Chief, Division of Environmental Health, Omaha-Douglas County Health Department, Room 1113, Omaha-Douglas Civic Center, 1819 Farnam Street, Omaha, NE 68183

Peabody, Frank R., PhD, Professor and Associate Chairman, Department of Microbiology and Public Health, Michigan State University, East Lansing, MI 48824

Pickard, Ralph C., Assistant Commissioner for Environmental Health, Indiana State Board of Health, 1330 West Michigan Street, P. O. Box 1964, Indianapolis, IN 46206

Pitts, Travis, Assistant Chief, Manufactured Housing Section, Department of Housing & Community Development, Division of Codes and Standards, 6007 Foulson Boulevard, P. O. Box 1407, Sacramento, CA 95807

Preston, David B., Executive Director, American Water Works Association, 6666 W. Quincy Avenue, Denver, CO 80235

Rhodes, Martha E., PhD, Chief, Food Laboratory, Division of Chemistry, Florida Department of Agriculture and Consumer Services, 3125 Conner Boulevard, Tallahassee, FL 32301

Roberts, Richard L., Director, Environmental Health Services, County of San Bernardino, San Bernardino, CA 92415

Sorg, Tom, Chief, Inorganic and Particulate Control Section, Physical and Chemical Contaminant Removal Branch, Drinking Water Research Division, Office of Research and Development, US Environmental Protection Agency, 26 West St. Clair, Cincinnati, OH 45268

Wellings, Flora Mae, ScD, Director, Epidemiology Research Center, Department of Environmental Health & Rehabilitative Services, 4000 W. Buffalo Avenue, Tampa, FL 33614

Young-Horvath, Viola Mae, PhD., Consultant in Microbiology and Public Health, 5203 Bangor Drive, Kensington, MD 28095

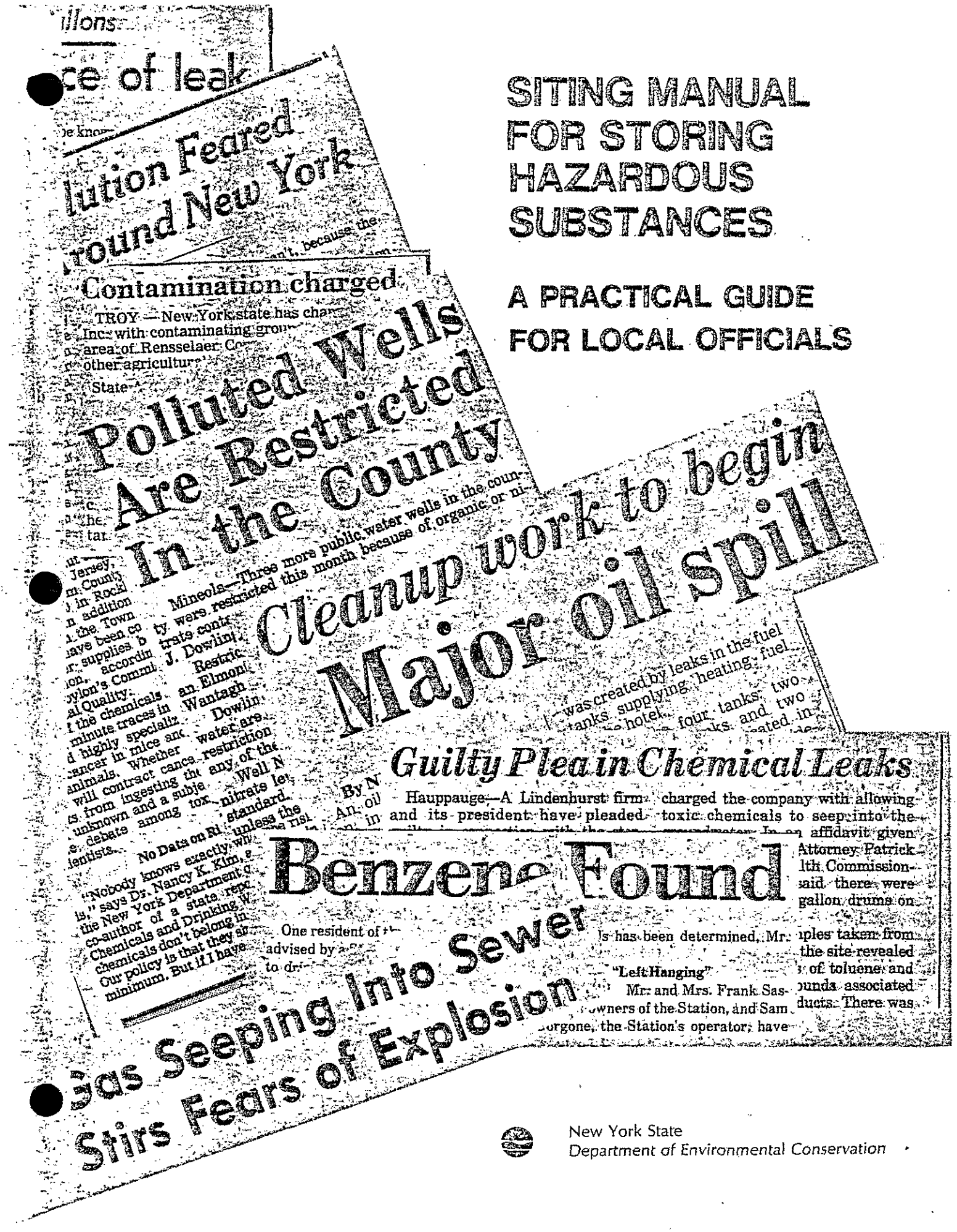
1983-84 membership

63. New York State Department of Environmental Conservation. Siting Manual for Storing Hazardous Substances - A Practical Guide for Local Officials, Albany, New York, October 1982

Stephen Fagundes

SITING MANUAL FOR STORING HAZARDOUS SUBSTANCES

A PRACTICAL GUIDE FOR LOCAL OFFICIALS



New York State
Department of Environmental Conservation

MANUALS IN NEW YORK STATE'S BULK STORAGE PROGRAM

The **Technology Assessment Manual** compiles much of the latest information on the equipment available for storing and handling hazardous liquids. Included are data on tanks, hoses, overfill prevention devices, piping, valves, and pumps. Important information is also provided on the field practices and equipment available for leak detection and spill cleanup.

The **Manual on Criteria and Guidance for Storing Hazardous Substances** provides information on the proper installation and storage methods for bulk storage facilities. The manual brings together recommended practices for preventing spills and leaks.

The **Model Local Ordinance for Storage of Hazardous Substances** provides suggested wording and format for local ordinances to regulate the storage of hazardous materials. Alternatives to fit specific needs are presented.

This **Siting Manual** presents information and procedures to assist local officials prevent leaks and spills of hazardous substances in sensitive environments. Discussed are: types of hazards, causes of leaks and spills, site evaluation procedures, and practices for spill prevention and mitigation.

The manuals are available from:

Bureau of Water Resources
NYS Department of Environmental Conservation
50 Wolf Road
Albany, NY 12233
telephone 518 457-4351

Preparation of this Manual
was financed by a grant from the
U. S. Environmental Protection Agency
under Section 208
of the
Federal Water Pollution Control Act.

K. Hardoz

SITING MANUAL FOR STORING HAZARDOUS SUBSTANCES ~

A Practical Guide for Local Officials

NEW YORK STATE

DEPARTMENT OF ENVIRONMENTAL CONSERVATION
DIVISION OF WATER
BUREAU OF WATER RESOURCES

ALBANY

OCTOBER 1982

Table of Contents

Preface ii

Acknowledgments iii

1 Introduction 1
- The Siting Manual at a Glance
- Siting Roles and Responsibilities
- Legal Authority, Administration, and Enforcement
- Importance of Proper Siting
- Causes of Leaks and Spills

2 Hazardous Substances 11
- Chemical Characteristics
- Listing of Hazardous Substances

3 Storage Systems and Precautionary Designs 13
- Types of Storage
- Precautionary Designs and Practice

4 Separation Criteria for Storage of Hazardous Substances 23

5 Data Needed for Evaluating a Proposed Site 29
- Data Collection Responsibility of Project Sponsor

6 Risk-Assessment Methods 33
- LeGrand Analysis
- Soil Corrosivity Assessment
- Predicting Useful Life of Steel Tanks
- Models for Predicting Environmental Fate
- Health Risk Assessment

7 Evaluation and Decision Alternatives 36
- Decision Framework
- Coordination of Review Process
- Working Together on Project Planning
- Decision Alternatives
- Defending the Decision

Glossary 41

Bibliography 45

Appendices

A List of Hazardous Substances 49

B Precautionary Storage Designs 53

C SEQR Short Environmental Assessment Form 65

D Information Sources 67

E Evaluation Procedure for Ground Water Contamination Potential 81

F Programs Which Have a Relationship to Siting a Hazardous Substance Storage Facility 97

PREFACE

The Department of Environmental Conservation knows the frustration that can develop in a community faced with possible exposure to hazardous substances. The relationships among environmental resources, human health, and hazardous chemicals are complicated and not fully understood even by professionals. Citizens and local officials are often ill-equipped technically to weigh the risks and safeguards when a bulk storage facility, say a petroleum tank farm, is proposed for development. Should a spill or leak occur, they are, again, often ill-equipped to know what remedial action to take or who to contact. This Manual provides municipal officials, people in industry, and private citizens with essential information.

The Manual is a guide and a reference document which can assist in making prudent decisions for the siting of bulk storage facilities for hazardous substances. As a resource document, it helps identify key factors which must be considered, and it identifies information that must be obtained to ensure proper siting.

In using this Manual as a siting guide, it is the duty of the responsible local official and of the developer to obtain professional assistance from engineers, geologists, planners, and others and to find pertinent data specific to the parcel of land under consideration. A sound decision for the site of a bulk storage facility can then be made.

The mention of trade names or commercial products in this Manual does not constitute endorsement or recommendation for use by the NYS Department of Environmental Conservation.

ACKNOWLEDGEMENTS

This Manual was prepared by O'Brien & Gere Engineers, Inc. and by staff from the New York State Department of Environmental Conservation, Bureau of Water Resources. Precautionary storage design drawings were provided by Fred C. Hart Associates, Inc.

The project managers are grateful to the many people who contributed to this report. Those on the Review Committee deserve special gratitude, because they provided valuable comments and suggestions beginning with the Manual's outline.

Individuals who made major contributions to the Manual are:

O'BRIEN & GERE ENGINEERS, INC.

Cornelius B. Murphy, Jr., Ph.D.
Steven R. Garver, P.E.
Ralph E. McClurg

DEPARTMENT OF ENVIRONMENTAL CONSERVATION

Paul J. Sausville, P.E.
William B. Morton

REVIEW COMMITTEE

William Hess, Executive Director, Southern Tier Central Regional Planning & Development Board

Edith Tanenbaum, Bi-County Planning Coordinator, Long Island Regional Planning Board

George Hodgson, Environmental Director, Saratoga County Planning Board

William Clarke, Director, Albany County Environmental Management Council

David Foster, Senior Planner, Schenectady County Planning Department

Section 1
INTRODUCTION

Most of the goods and commodities that are an integral part of today's lifestyle depend on the use of an ever-expanding number of chemical substances. Pick an item around you at random–your refrigerator: It circulates freon gas; cutting oils were used in the fabrication of the metal parts; the shiny chrome comes from metal being dipped into a bath of chromic acid; large quantities of solvents and pigments were used to produce the finish. Tonight's dinner involves the use of pesticides, fertilizer, and fuel for transport, not to mention all the machinery involved in harvesting, processing, packaging, and distribution.

Producers and manufacturers must store and use large quantities of hazardous substances to supply the goods we demand. Sometimes–through mismanagement, neglect, or unforeseen accidents–leaks or spills of these substances introduce them into the air, land, and water we all share. The news media almost daily focuses public attention on spills. The damage can be immediate and obvious, or it can go unnoticed for a long time.

Although it is important to reduce all spills of hazardous substances, it is essential to reduce spills to ground water. Once most substances reach ground water, they are almost impossible to recover. Contaminants may remain emulsified or adsorbed on soil particles for an indefinite time even after cleanup efforts. Because ground water contamination is irreversible, prevention is paramount. **Prevention is the ultimate solution in protecting the environment.**

Several laws and regulations have been enacted by Federal and State governments to prevent chemical substances from escaping into the environment. Many of these deal with substances in the workplace and in transport; others address the treatment and disposal of expected waste products and the removal of environmental contamination after it has occurred.

These Federal and State programs provide a degree of chemical pollution control. Alone, they cannot entirely safeguard a community's drinking water supply or protect ground and surface water resources. However, local governments can exercise an additional measure of control themselves to protect their precious water and related land resources through their powers of local land use planning, zoning, site plan review, building inspection, and protection of public health.

Typical Local Officials
Concerned with
Storage Facility Siting

- zoning board members
- planning board members
- conservation advisory council members
- water authority members
- building and fire department officials
- parks and recreation officials
- legislative representatives
- councilmen and supervisors
- city or village mayor/manager
- law enforcement officials
- county executive/manager
- health officials
- environmental management council members

THE SITING MANUAL AT A GLANCE

This Manual will assist localities with land use planning for siting storage facilities for hazardous substances. It is one of a series of New York State Department of Environmental Conservation guides on the subject. See box.

Included in this Manual are the following:

- listings of hazardous substances and their chemical characteristics,
- information, both engineering and environmental, that should be considered in the siting of storage facilities,
- precautionary designs and measures for reducing risks of leaks and spills,
- distance criteria that may be used for separating storage sites from ground water supplies and other environmentally sensitive areas and land uses,
- listing of Federal, State, and local agencies where data and assistance may be obtained, and
- procedures and analytical tools for evaluating a proposed site.

SITING ROLES AND RESPONSIBILITIES

Local governments have the primary responsibility for land use planning and siting of facilities for storage of hazardous substances. Not all local governments exercise their land use regulatory power to the same degree, but most have master plans and zoning ordinances which contain proscriptive standards that regulate the pattern, type and density of development and performance standards which establish a code of conduct that land developers must follow. Table 1 and Figure 1 summarize the responsibilities of municipal officials with regard to land use planning.

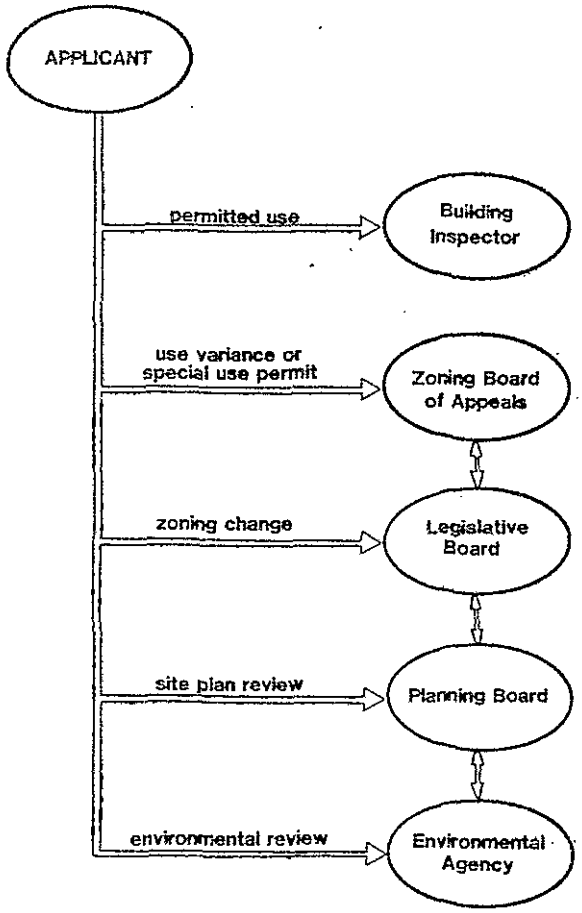
Table 1

Siting Responsibilities of Local Government Officials

Regulatory Tool (Siting Control Point)	Building Inspector	Zoning Board of Appeals (ZBA)	Planning Board	Legislative Board
Zoning/Rezoning	-	-	Makes recommendations to Legislative Board	Enacts Zoning and Rezoning Ordinances Identifies Review Agencies, Scope of Authority and Review Procedures
Building Permit	Issues/Denies Permit Performs inspection for conformance with construction codes	Review appeals on permits and denials	-	Hires Building Inspector Appoints Members to ZBA
Variances	-	Grants or denies variances	-	-
Special Use Permits	-	Either the ZBA or Planning Board may be designated responsibility for issuing special use permits or approve site plans for projects in a zoning district.		Usually delegates responsibility for zoning special use permits to ZBA or Planning Board Appoints members to ZBA and Planning Board
Subdivision Approval	-	-	Approves or disapproves subdivision plats	Delegates responsibility to Planning Board
Planned Unit Development	-	-	Makes recommendations to Legislative Board	Appoints Planning Board Members
PUD Site Plan Review	-	-	Approves/disapproves PUD site plan	-

Figure 1

Local Roles and
Responsibilities in the Siting Decision Process



Local Legislative Body

At the heart of local government, whether it be county, city, village, or town government, is the governing body who sets policy, establishes laws, develops programs and defines the administrative agencies and procedures of that municipality. County governing bodies have powers to initiate legislation and broad environmental health controls; city, village, and town legislative boards and councils provide for planning, zoning and building regulations, and exercise general police powers for public health, safety and welfare by way of ordinances or local laws. The local governing body is responsible not only for establishing the administrative framework for planning, zoning and building control but for the passage of effective ordinances through which these administrative agencies function.

At the local level, it is the governing body which is responsible for protecting ground and surface water supplies and the public welfare. This body must decide on whether or not there is a need for controls over siting and storing hazardous materials.

Planning Board

Acting generally in an advisory role to the community's governing body, planning boards, commissions, or agencies recommend a comprehensive plan for development appropriate for the community. Provisions are made in land use plans to accommodate residential, commercial, and industrial areas; transportation corridors; health services; educational needs; and other community facilities. These plans may also separate hazardous substance storage facilities from sensitive environmental areas. Frequently, the planning board is given responsiblity to approve project proposals and site plans.

Comprehensive plans developed by the planning agency are not meant to provide a specific layout of prescribed land uses. Rather, these plans give expression to the overall direction for development that the community wants to follow. The comprehensive plan does not constitute a strict limitation on development. The recommendations of the planning board are given substance only through the adoption of zoning regulations or ordinances and official land use mapping. The siting of hazardous substance storage facilities should conform with a community's comprehensive plan whenever possible.

Building Inspector

In New York State, a developer generally obtains a building permit or site approval through application to the town, village, or city municipal offices. Typically, the building inspector or other responsible official issues the permit. The building inspector is also responsible for determining whether performance standards of the building permit, zoning regulations and codes for building, fire, sanitary waste disposal, etc. are being met. Where a proposed hazardous material storage facility would not be in conformance with an existing zoning regulation, it is necessary for a developer to request a variance from the zoning restrictions.

Zoning Board of Appeals

The local zoning board or agency reviews requests for zoning variances. Variances are not an automatic right but rather a privilege that may be granted to an applicant depending on individual circumstances. The zoning board may require a site plan and other information deemed necessary to provide adequate data to decide properly on the variance request.

In granting permits or approvals, it is the responsibility of the zoning board to ensure that the public health, safety, and welfare of the community have been protected. Built into some zoning regulations are criteria for

the protection of ground water, wetlands, flood plains and residential areas and for the storage of hazardous substances.

To ensure that all the concerns of hazardous substance storage are addressed within a given locality, it is important that specific prescriptive and performance standards be included within the local ordinance. Such standards reflect the manner in which a community chooses to protect its environment.

Other Agencies

The officials involved in land use control are frequently assisted by specialized agencies or consultants. For instance, the fire marshal, county health department, county planning board, water authority, and environmental management council may be called upon to provide information upon which decisions can be based.

LEGAL AUTHORITY, ADMINISTRATION, AND ENFORCEMENT

Establish the Authority

Before local officials can review and make decisions over the location and type of facilities to be used for storing hazardous substances, they first must enact appropriate zoning ordinances and standards. However, adopting a zoning ordinance in and of itself may not entirely provide a locality with the necessary control, review tools, and safeguards. Under many existing ordinances, construction of gasoline service stations or facilities for storage of other hazardous substances can be initiated simply by requesting a building permit. **It is therefore important that the local zoning ordinance include proper legal provisions: 1) site plan review on all proposed storage facilities, 2) the use of precautionary storage practices and 3) perhaps set-back and separation distances between facilities and sensitive environmental areas, especially water supplies.**

As a supplement to zoning, watershed rules and regulations can be enacted. These can be an effective tool for protecting ground and surface water supplies from contamination, especially when the watershed or ground water recharge area to be protected is relatively small in area. Approximately 245 communities in New York State have adopted watershed regulations (Chapter III of Title 10 of the New York Official Compilation of Codes, Rules and Regulations). Such regulations may prohibit disposal of waste or prohibit storage of toxics within specified distances of a watercourse or sensitive recharge area. Enforcement is usually through voluntary compliance after a municipality notifies the violator of requirements. If this fails, penalties can be imposed by the local health agency or if necessary by the State Health Department.

Zoning and land use controls, as discussed above, address the siting of new facilities, but what about the risks posed by hazardous substances at existing facilities? Table 2 identifies a number of options or alternative actions which can be taken to control spills and leaks at both existing and new facilities. These alternatives (including model laws for local zoning) are discussed in a companion manual entitled **Model Local Ordinance for Storage of Hazardous Substances**, prepared by the Department of Environmental Conservation.

Implementation

Once the authority for controlling land use has been established, a commitment to effective implementation is necessary for success. Conscientious planning, zoning, and building department officials must be appointed. Regular board meetings and staff activities should be encouraged. Education and training is necessary, and procedures for fair and smooth administration of the ordinances must be established.

Implementation can mean more than just administration of your local program. The negative local consequences that can result from improperly stored hazardous substances is sufficient to warrant a close interface and liasion with programs being implemented at higher units of government. Local officials and others should insist on strict compliance with Federal and State regulations.

Enforcement of Local Laws

It has often been argued that enforcement of existing laws is the answer to controlling the storage of hazardous substances rather than enacting new laws and regulations. This is frequently true. A municipality which has effective land use controls and site plan review requirements for new storage facilities (as discussed above) and has adopted the State building and fire code may very well have the necessary tools to successfully protect air, land, and water resources. Enforcement is the key to this success. Consistent application of zoning ordinances and any watershed rules which may exist, and inspection of facilities for compliance with codes or special requirements should be applied as a condition of project approval. Periodic reporting of operations by the owner of a facility may also assist in monitoring the success of a leak and spill prevention program.

IMPORTANCE OF PROPER SITING

Many communities ignore proper management of hazardous substances until a spill has occurred. In some cases, relatively large volumes of hazardous substances have caused widespread or immediate damage; these have been the most publicized. However, there are many incidents where small amounts of materials have leaked or

Table 2

Preventing Spills and Leaks of Hazardous Materials –Actions at the Local Level

Method	Legislative Body	Planning/ Zoning Board	Inspection/ Enforcement Officer	Developer or Owner of Storage Site
Establish Authority				
Planning and Zoning				
. Adopt/Amend Zoning Ordinances	x			
. Require Plan Review and Permits	x			
. Adopt Standards/Criteria for Storing Hazardous Substances	x			
. Establish Procedures	x			
. Adopt Watershed Rules to Protect Drinking Water Supplies	x*			
Adopt Fire Prevention Code	x			
Adopt County Regulations on Storage and Handling Hazardous Substance	x			
Implementation				
Prepare Land Use Plan		x		
Review/Approve Plans and Proposals		x		
Seek Input and Expertise (Universities, State/County Agencies)	x	x		x
Use Precautionary Storage Designs and Practices		x		x
Monitor Compliance with Federal and State Regulations				
. Reporting of Hazardous Materials in Storage (State General Municipal Law 209-u)			x	x
. State Environmental Regulations (Bulk Storage Control, SPDES Permits)			x	x
. Post Spill Prevention Control and Countermeasure Plan (SPCC Plan); 40 CFR112			x	x
. Department of Transportation Requirements			x	x
Comply with Industry Policies and Standards				x
Enforcement of Local Laws				
Inspect Construction for Compliance with Codes			x	x
Enforce Ordinances/Rulings/Conditions			x	x

* NYS Dept. of Health may promulgate rules and regulations upon request of purveyor of water (often a municipality).

spilled. The cumulative impact of small incidents may cause significant injury to the environment.

The Effects of Spills

Spills have many diverse ramifications. They include:

Environmental Impacts (Contamination of Resources)

- water supplies (surface and ground water)
- crops, soils
- food chain
- fish, wildlife, plants
- air (odors and hazardous gases)
- wetlands

Public Health and Safety Impacts

- Chronic effects
  - carcinogenicity
  - mutagenicity
  - teratogenicity
- Acute effects
  - nausea
  - headache
  - gastric disturbances
  - nervous system disorders
- Fire and explosion

Social and Economic Impacts

- dislocation of people
- property damage
- land use conflicts
- loss of valuable product
- cost for spill response and cleanup

Ground Water Contamination: Nearly 35% of the water in New York State is drawn from aquifers and serves domestic, commercial, and industrial uses. Contamination of ground water occurs from a variety of causes including tank trunk accidents, train derailments, pipeline breaks, and leaks from ground water and underground storage tanks and pipelines. In many instances, the material spilled reaches surface or ground water and contaminates water supplies. Transportation accidents, train derailments, or pipeline breaks will occur even with the use of the latest spill prevention practices. When accidents happen, the best that can be done is to implement a quick and determined effort to contain and remove any spilled or leached material.

However, bulk storage facilities are relatively permanent structures. Consideration for proper siting and design of these facilities can minimize the potential contamination problems that might arise from leakage or from accidental spills.

Among the most important considerations are the physical characteristics of a potential site: soils, depth to ground water, distance to surface waters, slope and so forth; socio-economic factors: land use, zoning, cultural resources, public health, safety and so forth; and, the potential degree of hazard of the material to be stored. By giving careful attention to these factors during the site planning and review stages, the potential for ground water contamination can be lessened significantly.

Considerations for Siting and Design of Storage Facilities

Physical Characteristics

- soils
- depth to groundwater
- distance from drinking water supplies
- distance from surface water or wetlands
- slope
- potential for accident
  - flood hazard area
  - highway accident
- previous use of site

Socio-Economic Factors

- land use
- zoning
- cultural resources
- public health
- safety

Substance Hazard Level

- toxicity
- flammability
- reactivity
- corrosivity

CAUSES OF LEAKS AND SPILLS

In 1979, 25 families in East Meadow, Nassau County were evacuated from their homes. The people were suffering from nausea and headaches. In addition, a potentially explosive concentration of gasoline fumes had accumulated in the basements of their houses from a nearby underground gasoline storage tank which had been leaking for perhaps a year.

In 1980, at the other end of the State in Wellsville, Allegany County, 700 people were evacuated when a retail store housing 2 to 3 tons of pesticides and herbicides caught fire. Residents faced not only the immediate danger of toxic fumes but a longer, more subtle and insidious threat: Water used for extinguishing the fire had become contaminated with pesticides and drained into ground and surface water supplies.

These are but two examples of the several hundreds of spills and leaks which occur annually in New York State. Leaks, as opposed to spills, may generally be described as the gradual loss of material over a long time. Spills, on the other hand, occur as an instantaneous discharge to the environment, as in the Wellsville fire. Due to the basic difference between leaks and spills, the conditions which cause them also differ. Both leaks and spills can be minimized by using precautionary designs and careful handling practices; while the risk of contaminating sensitive environmental areas such as water supplies can be reduced by the proper siting of storage facilities.

Contaminated Wells Cause Anxiety In a Small Town in Putnam County

By ROBERT HANLEY
Special to The New York Times

LAKE CARMEL, N.Y. — Every day, housewives in the hillside neighborhood around Cottage Road in this small Putnam County community drive to the homes of friends or relatives, sometimes miles away, to fill big jugs or gallon containers with water.

Others buy bottled water at about 75 cents a gallon at the supermarket and complain about the cost straining family budgets. Their husbands bring water home from their jobs, and some kitchens now have water coolers with the five-gallon jugs common in offices.

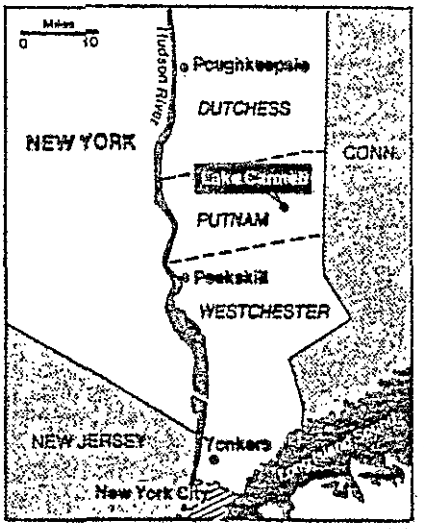
Since July 1979, the chemical components of gasoline — including toluene, xylene and benzene, a known cause of leukemia — have been found in the wells of 32 homes here. Last February and again in March, the Putnam County Department of Health advised those well owners to get their water for cooking and drinking elsewhere.

The rural neighborhood is now dominated by talk of illness — skin rashes, diarrhea, raspy voices, nausea, chronic dry, hacking coughs, respiratory infections, slow-healing cuts and visions of black spots and lines and white flashes impairing eyesight. Residents say that the ailments subside or disappear when they switch from well water to imported water and that that has convinced them of a direct link between the sicknesses and ground-water contamination.

An Operation for Pain

Carole Anne LaConte, for example, had her gall bladder and appendix removed last July because of constant pain in her right side, but the pains persisted even after the operation. "The doctor said it was gallbladder syndrome and could last for a year," said Mrs. LaConte, who is 36 years old. "We stopped drinking our water in February, and I haven't had a pain since."

In recent weeks, medical and toxic specialists from the New York State and Putnam County Health Departments have explained to noisy community meetings that medical science had no tests to verify direct correlations between the chemicals and the illnesses. Nor can the specialists say with certainty what ill effects



The New York Times / June 6, 1981

could result from long-term exposure to, or ingestion of, the chemicals.

These explanations have only heightened the feelings of anxiety, helplessness and apprehension common around Cottage Road.

"We haven't found a doctor who's treating them that's blamed the water," Anthony Cazzari, Supervisor of the Town of Kent, which includes Lake Carmel, said recently.

Crisis of Confidence

"If we were fish or birds, you could find volumes of data on how it affects us," said Joanne Nappi, chairman of the Action for Quality Water Association, a self-help group of about 70 families. "I really hate to say this, but nobody is going to believe anything we say until some of our children start to develop leukemia."

A year ago, 54-year-old Harry Holmes, who had lived for 17 years on Huntington Road, just outside the known zone of contamination, died of leukemia that his widow, Helen, said was first diagnosed in February 1976.

Because the state has never tested the Holmes's well, there is no way of establishing that contamination elsewhere in the community's aquifer could have contributed to his illness. Mrs. Holmes says she had never detected in her water the oily smell that some other families notice in their tap water.

"But the girl across the street sometimes has an oily film on her water," Mrs. Holmes said, "and her kids have diarrhea."

State officials assume from the oily smell that the contamination has come from a ruptured underground gasoline or fuel-oil storage tank. Under New York State's 1978 Navigation Act, the State Department of Transportation has prime investigatory responsibility for oil spills in surface or ground water. Thus far, 14 buried tanks in the neighborhood have been tested without finding a leak, and the source of the chemicals remains a mystery, according to John Scaff, the department's assistant regional oil-spill engineer.

The assumption of an oil or gasoline spill has prompted laboratory analysts hired by the state to test water samples only for benzene, toluene and xylene. Levels of hydrocarbons are also obtained, but the hydrocarbons are not identified individually. Unlike benzene, toluene and xylene are not known to cause cancer. Toluene can affect the central nervous system, while xylene irritates the eyes, nose, lungs and gastrointestinal tract.

Under current state guidelines, drinking water is considered unsafe if it contains more than 5 parts benzene or 100 parts hydrocarbons per billion parts of water. The xylene and toluene guideline is 50 parts per billion for each.

Initial tests on some wells in Lake Carmel turned up levels of benzene, the most dangerous of the chemicals, ranging from a few parts per billion to up to 90 parts per billion, far above the guideline. Total hydrocarbons ranged from several hundred to more than 4,000 parts per billion.

At some homes, early tests showed well water within the state's guidelines, but subsequent analysis detected gross contamination. Then, however, sampling in mid-April found that contamination levels were back within the guidelines. These variations have led to cynicism within the community about the testing abilities of the laboratories the state had hired and the care its workers take in collecting samples.

"We're reviewing our quality control," said Joseph R. Stellato, director of the Transportation Department's Waterways Maintenance Division and overall head of the investigation here. He added that two more series of tests on all 90 wells would be run in the next two months.

Leaks

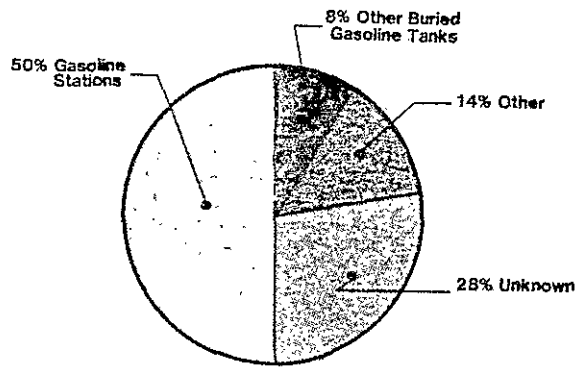
By understanding the causes of leaks, it is possible to begin to understand just how these leaks can be prevented through proper siting and engineering design (see Figures 2 and 3). The five primary causes of leaks in storage systems are:

- defects in materials; inadequate design or selection of storage facilities,
- poor installation procedures (use of improper backfill materials, damage of protective coatings, improper bedding, etc.),
- corrosion or "normal" aging,
- poor maintenance practices which permit developing problems to go undetected, and
- improper use of the storage facilities including storage of material incompatible with the tank or piping materials.

Figure 2

Sources of Well Contamination by Gasoline

Where ground waters in New York State have been contaminated by gasoline, local service stations most frequently were the source.



Source: NYS Department of Health

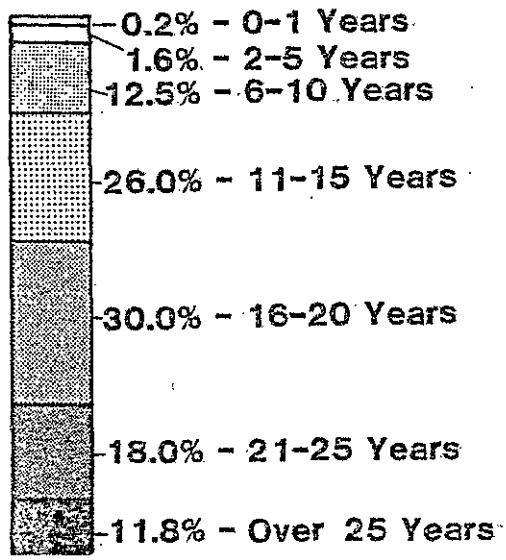
Small structural flaws or design inadequacies are occasionally the cause of a leak. Most manufacturers of storage equipment follow rigid quality control specifications and perform sophisticated tests to assure that their product is structurally sound. However, no human activity can ever be foolproof, and leaks may develop where a storage tank has a structural or design weakness or where it is prone to damage. For example, many leaks from underground tanks occur immediately below the fill holes. These leaks are caused by the metal being worn away from the repeated strikings of the tank bottom by the dip stick when the level of the tank is checked. In fiberglass tanks, punctures of the tank bottom have occurred due to improper use of the dip stick. Improved tank designs incorporate a striker plate to protect the bottom of the tank or an automatic level indicator to avoid the continual use of the manual dip stick.

Poor installation, especially of undergound storage systems, is the root cause of many leaks. Unless tanks are carefully placed in the excavation, properly bedded, backfilled, and anchored against the buoyant forces of ground water, they may be structurally damaged or shifted out of alignment with their connecting pipe system. Improper installation, which results in the scratching of a protective coating or clay globs on the surface of a steel tank or pipe, can set the stage for accelerated rust and corrosion.

Figure 3

Tank Leaks by Age

Almost 90 percent of leaking underground steel tanks are over 10 years of age.



Source: American Petroleum Institute

Leaks and spills can be kept to a mimimum by

- using precautionary designs
- careful handling practices

The risk of contaminating sensitive environmental areas, such as water supplies, can be reduced by proper siting of storage facilities.

Corrosion (rusting) of steel tanks and pipes is perhaps the most common cause of leaks. Depending on the corrosivity of the soil, the life of a buried steel tank may

be as little as 5 years or as much as 50 years. The average life of unprotected tanks is on the order of 12 to 15 years. Corrosion takes place where there is a difference in the electrical potential between various parts of a tank or piping system or between the storage system as a whole and the surrounding soils. Underground steel tanks and the bottoms of above ground tanks are particularly vulnerable. Depending on the particular situation, either electrolytic or galvanic corrosion may occur. Electrolytic corrosion is the result of direct currents acting on the storage system from outside sources or "stray currents" (subways, underground electrical cables, etc.). In galvanic corrosion, the electrical potential is generated from within the storage system itself.

By judiciously selecting a site with a non-corrosive soil environment or with proper design, the problem of corrosion of storage tanks and pipes can be made manageable. Several manufacturers have developed methods of cathodically protecting underground steel storage systems against corrosion. With cathodic (corrosion) protection provided at the outset, tank life may reasonably be extended to 20 years or more.

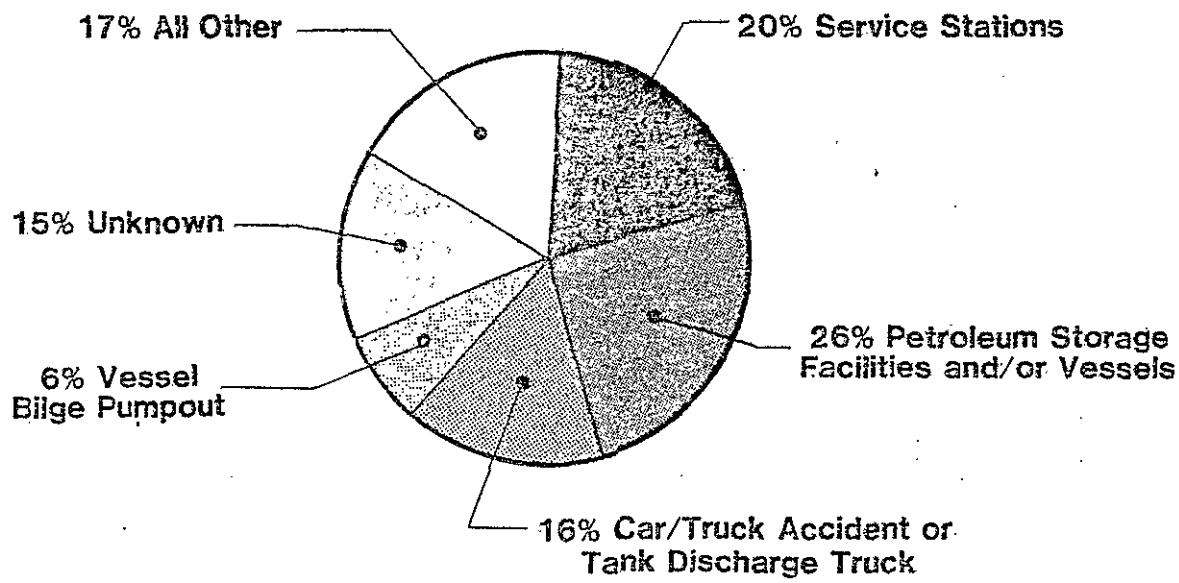
Spills

Many significant hazardous substance spills are from transportation accidents. Highway accidents can result in the loss of the contents of an automobile gasoline tank, a maximum of 20 to 25 gallons for most cars, or the loss of the entire contents of a tank truck, perhaps as much as 5,000 gallons from a single vehicle. Even greater amounts of hazardous materials may be lost when a barge runs aground or is involved in a collision. See Figures 4 and 5. It is impossible to prevent all transportation accidents; therefore, the spilling of hazardous materials cannot be eliminated. Improved fuel tank, truck tank, and barge designs are being used to minimize losses due to transportation accidents.

However, transfer spills and spills from carelessness can be prevented. These spills are caused by operator inattention, overfilling of storage tanks, improper closing of storage tank valves, failure to replace worn hoses, and poor housekeeping. Better employee training and improved work habits can significantly reduce such spills. Poor equipment design or sudden mechanical failures can

Figure 4
Petroleum Spills Reported in New York State by Source (1978 - 1980)

Handling, transport, and transfer operations have been a significant source of petroleum spills.



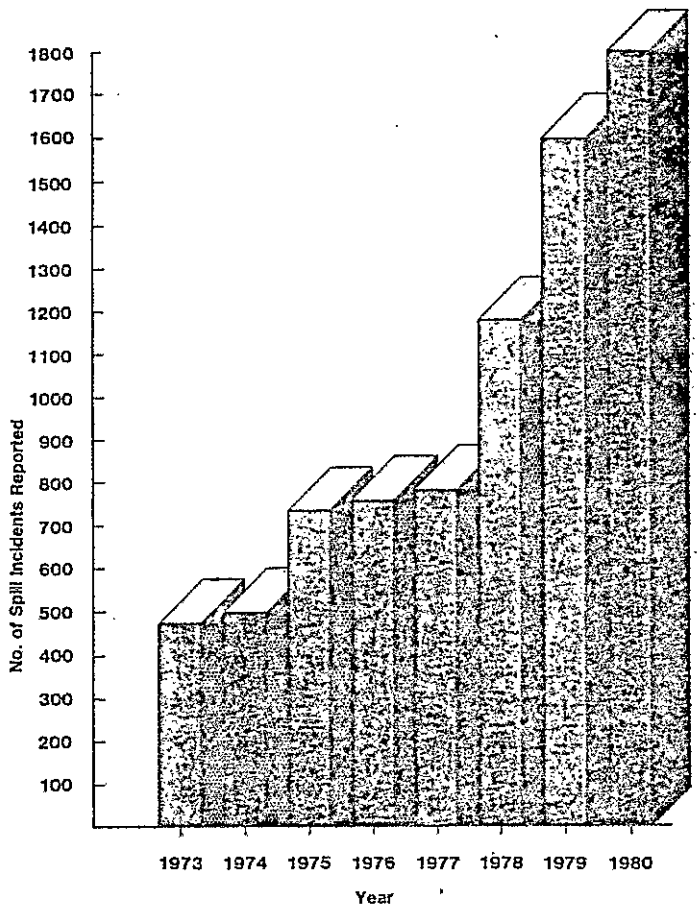
Source: NYS Department of Transportation

also be causes of spills. Such failures can result from corrosion, improper fittings, structural failure (such as cracking due to soil settlement), tank flotation, gauge stick punctures, or the use of improper backfill materials. Spills can also be caused by structural damages to storage tanks and piping due to natural and accidental occurrences such as floods, earthquakes, wind damage, fire, and vehicle collisions.

It must be recognized that spills cannot be eliminated. However, if storage tanks have been sited and designed with proper concern given to minimizing potential environmental damages, spills that do occur will pose less of a threat to the public health and safety.

Figure 5

Petroleum Spills and Leaks in New York State



As part of the State's Petroleum Spill Response and Cleanup Program, the Department of Transportation has been directly involved in cleanup operations from numerous leak or spill incidents. In the first three years of the program alone (1978-80), approximately 4500 separate spills or leaks were reported. Many of these individual incidents involved the loss of less than 100 gallons, yet collectively, over 3 million gallons of petroleum products were involved.

Section 2
HAZARDOUS SUBSTANCES

Over four million distinct chemical compounds are known today; about 55,000 of these are used commercially to a significant extent. The chemical, physical and toxic properties of these compounds are varied and diverse; they range from innocuous to hazardous. Uncontrolled in the environment they may:

- be toxic to humans when present in drinking water supplies
- volatilize and contaminate air spaces or create nuisance odors
- be persistent and bioaccumulate
- pose fire or explosion hazards
- be corrosive to structures or underground utilities
- react with other substances to produce hazards (for example, sodium cyanide in contact with acid will produce the lethal gas hydrogen cyanide).

Chemicals can float, sink, or dissolve in water depending on the characteristics of the chemical. Once released to a hydrologic system, especially a ground water supply, it may take years--even decades--for it to be diluted or flushed away. The question, then, is: "Which of these thousands of chemicals should really be considered hazardous?"

> Toxic substances are a subset of hazardous substances. All toxics are hazardous, but not all hazardous substances are toxic.

CHEMICAL CHARACTERISTICS

The chemical behavior of hazardous compounds is extraordinarily variable. Some are highly dangerous to handle; they may detonate when subjected to shock, or eat through a container made of an incompatible material. Others are passive and present a hazard which is more subtle in nature. Chemical characteristics can generally be categorized thus:

- human poison
- flammable
- corrosive
- reactive
- volatile
- floater
- soluble
- amenable to biological waste treatment
- biodegradable
- highly toxic to aquatic life

Additional information on the chemical characteristics of hazardous substances is included in the Technology Assessment Manual.

LISTINGS OF HAZARDOUS SUBSTANCES

To minimize hazards to the public, Congress passed legislation to control the transportation, discharge, and disposal of chemical substances. With such authority, the U.S. Environmental Protection Agency (EPA) and the Department of Transportation (DOT) have prepared a number of different lists of hazardous chemicals, each of which provides distinctions pertinent to transportation hazards, toxicity, fire prevention, physical and chemical properties and waste streams. The EPA list of hazardous substances, as promulgated under Section 311 of the Federal Clean Water Act, is included in this Manual as Appendix A. Data on the type of hazard--toxic, corrosive, flammable, etc.--and on the physical state--liquid, solid, gas--can be found in the Chemical Hazard Response Information System (CHRIS) of the U.S. Coast Guard or by contacting chemical manufacturers or from the NYS Department of Environmental Conservation.

> Contaminants in Ground Water
>
> The New York State Health Department has investigated various incidents of ground water contamination. While there is not a comprehensive monitoring program, Department data indicate that the following organic compounds often are found in New York State contaminated ground waters.
>
> | | |
> |---|---|
> | Tetrachloroethane | Freons |
> | Trichloroethylene | Carbon tetrachloride |
> | Tetrachloroethylene | Petroleum constituents: |
> | Vinyl chloride | Benzene |
> | Methylene chloride | Toluene |
> | 1,1,1-trichloroethane | Xylene |
> | Chloroform | |

These various lists and how they are used can be confusing. It is important to remember that the DOT's list of hazardous materials is used in the administration of regulations pertaining to transportation, while EPA's list of hazardous substances is used for administration of the Federal Clean Water Act. Table 3 outlines these listings and should help the reader correlate the correct list with his specific control program. The ten most commonly used hazardous substances in New York State are listed in Table 4.

Table 3

Hazardous Substances
Hazardous Materials
Hazardous Wastes

Which List is What?

Hazardous Substances

Under Section 311 of the Clean Water Act, the U.S. EPA has compiled a list of 299 hazardous substances (40 CFR 116). The substances on this list must be reported to the EPA if they are spilled or discharged. Control of these substances may be subject to additional future EPA regulations.

Priority Pollutants

In accord with a consent agreement between the Natural Resources Defense Council and EPA in 1967, EPA identified 129 specific chemical compounds as priority toxic pollutants. These pollutants have since been incorporated into several regulatory programs including NPDES permits (40 CFR 124), pretreatment standards (40 CFR 403), hazardous wastes (40 CFR 261) and Superfund (PL 96-510).

Hazardous Materials

The U.S. DOT has listed about 1700 hazardous materials within several general classes: explosives, flammables, corrosives, compressed gases, poisons, etiological agents, radioactive materials, and ORM (other regulated materials). DOT regulates the transportation of these materials via 49 CFR 171-177. These regulations cover such practices as packaging, tank car design standards, labeling, use of shipping papers, incident reports, separation and materials.

The New York State Office of Fire Prevention and Control requires that storage of materials on the DOT list be reported to local fire authorities.

Hazardous Wastes

The EPA has adopted regulations to control hazardous wastes under the Resource Conservation and Recovery Act (RCRA). These regulations (40 CFR 162) list 462 hazardous wastes. It should be noted that controls under RCRA apply to waste only and not to hazardous substances that are being stored prior to use in product manufacturing or which are to be reclaimed, recycled or reused. RCRA regulates the generation, transportation, storage, treatment and disposal of hazardous wastes.

Toxic Substances

Under the Toxic Substances Control Act (TSCA), the EPA has compiled a chemical substances inventory of over 55,000 chemicals manufactured, imported or processed for commercial purposes between January 1, 1975 and May 1, 1978. Under TSCA, the EPA may restrict the commercial distribution of certain toxic substances.

Superfund Hazardous Materials

Hazardous materials incorporated into the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (Superfund) include by reference the Section 311 list of hazardous substances, priority pollutants and hazardous wastes under RCRA. Superfund includes spill reporting requirements for release of 1 pound or more of those materials not on the Section 311 list.

Table 4

Top Ten Hazardous Liquids in New York State

Substance	Use in NYS (Million lb/yr)	Number of Reported Users in NYS	Major Uses
Petroleum			
Gasoline	41,321*	10,600*	automotive fuel
Fuel Oil	-	1,100*	heating fuel
Toluene	432	287	gasoline component, solvent, explosives, detergents
Phenol	156	107	glue, plywood, pharmaceuticals, laboratory reagents
Trichloroethylene	118	146	degreasing solvent, extraction solvent, chemical intermediate
Tetrachloroethylene	113	70	dry cleaners, spot remover, heat transfer medium, fluorocarbons
Methylene Chloride	80	194	paint remover, solvent for insecticides
Diazinon	78	86	insecticide
Benzene	60	75	solvent, anti-knock gasoline
Xylene	48	248	solvent, gasoline, organic chemicals
Styrene	40	39	plastics, copolymer resins

Source: New York State Industrial Chemical Survey.

* Petroleum stations and terminals estimated from other sources.

Section 3
STORAGE SYSTEMS AND PRECAUTIONARY DESIGNS

TYPES OF STORAGE

Hazardous substances are most often stored in above ground bulk storage tanks or underground tanks; or, they are warehoused in 55-gallon drums or other containers. Examples respectively are: large petroleum distribution tank farms, on-site chemical storage at industrial plants, tanks at neighborhood gasoline stations, and bulk storage of pesticides and fertilizers at warehouses.

Each storage system usually consists of five basic components:

- storage tanks/containers;
- transfer facilities;
- an overfill prevention system;
- a spill containment and collection system; and
- a leak detection system.

These components may be seen on the schematic drawings of typical bulk storage facilities in Figure 6.

PRECAUTIONARY DESIGNS AND PRACTICES

Precautionary designs and management practices can reduce the risk of contamination. Some precautionary measures are simply common sense. They are economical and effective and should be employed at virtually every storage facility. Other effective but more elaborate safeguards are appropriately used where:

- high risk chemicals are to be stored,
- chemicals are stored in large volumes,
- incompatible land uses or sensitive environmental areas are nearby, or
- where chemicals are on or near readily permeable aquifers.

Whatever the circumstances, it is the joint responsibility of the design engineer, the owner of the facility, and the public officials to select and apply appropriate precautionary measures for all aspects of the bulk storage

Figure 6a

Typical Underground Storage Tank Installation

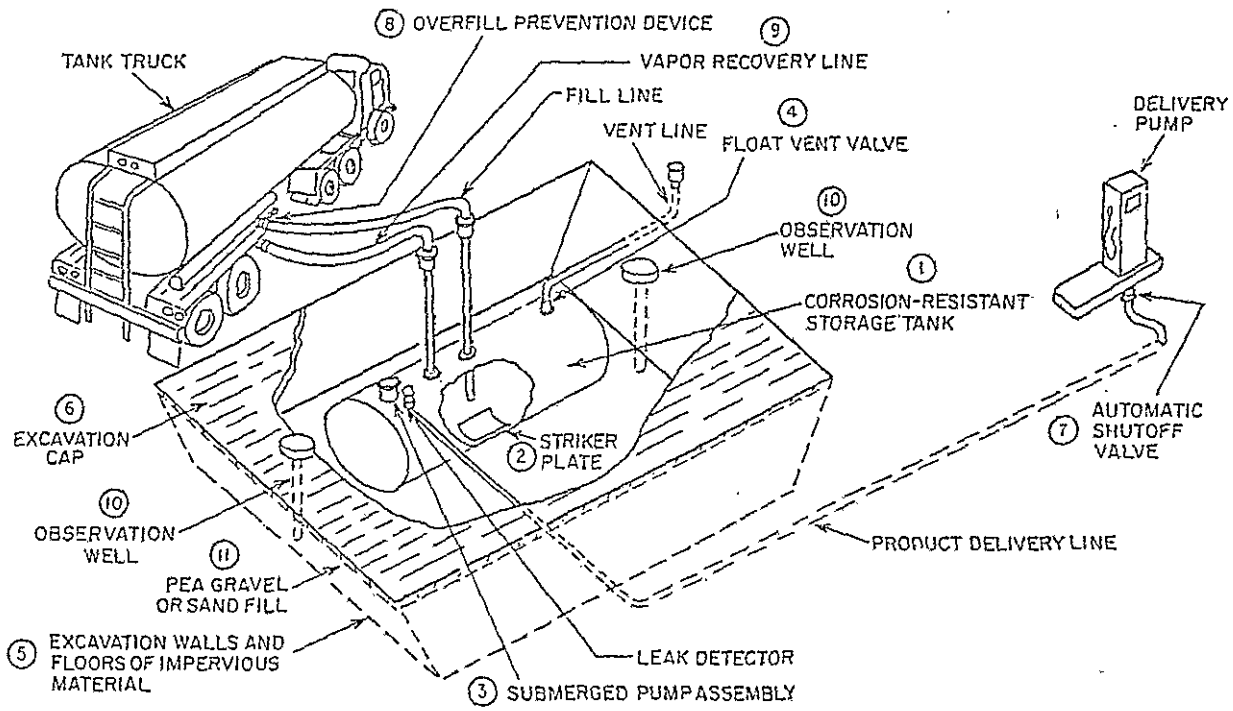
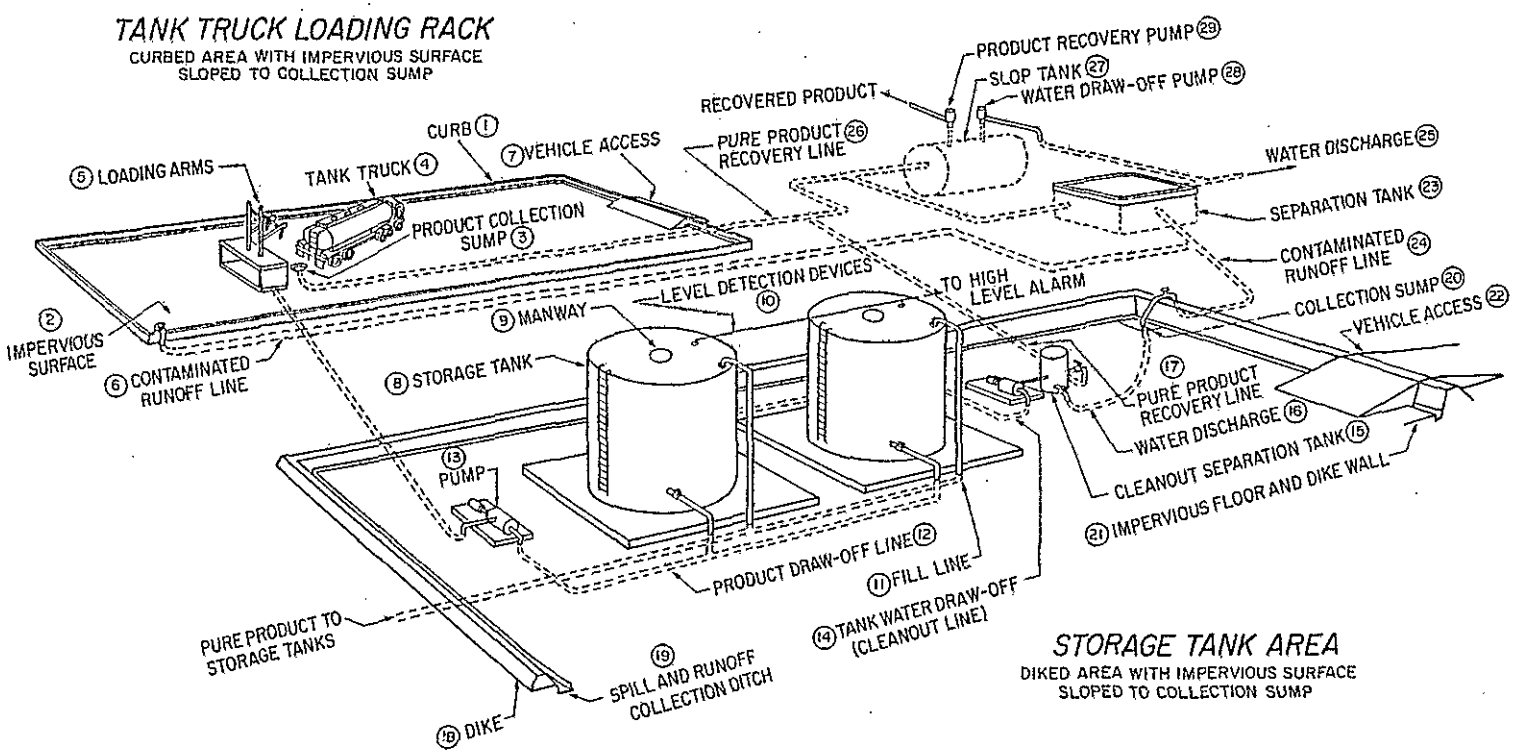


Figure 6b

Typical Above Ground Storage Tank Installation



facility. Factors to be considered include technical feasibility, local land use, environmental resources to be protected, community values and cost. Appendix B contains several drawings which illustrate designs for reducing the risk of environmental contamination. See Table 5, also.

Table 5

Storage of Hazardous Substances: Design Considerations and Practices

Product Storage	Product Transfer	Overfill Protection	Spill Containment
.aboveground tanks	Piping and Accessories	.high level alarms	.impervious perimeter dikes and cutoff walls
.underground tanks	.surface/sub-surface piping	.redundant instrumentation	.curbing, impervious slabs, troughs
.single wall tanks	.hoses	.automatic overflow diversion devices	.liners
.double-wall tanks	.loading racks	.dry disconnection hose valves	.in situ abosorbing/neutralizing media for spill containment
.tank linings and coatings	.design considerations -corrosive resistance -chemical/materials compatibility -structural strength -factors of safety	.check valves	.double-walled tanks
.tank wrappings	.materials selection -carbon steel -stainless steel -fiberglass reinforced plastic (FRP) -polyvinyl chloride (PVC) -polypropylene	.catchment	.spill/leachate collection systems
.design considerations -corrosion resistances -chemical/materials compatability -structural strength -factors of safety	.emergency shutoff valves	.level control and automatic shut-off devices -floats -displacers -gas bubblers -hydrostatic head devices -capacitance devices -thermal conductivity devices -ultrasonic devices -optical devices -nucleonic devices	.catchment (slop) tanks
.materials selection -carbon steel -stainless steel -fiberglass reinforced plastic (FRP) -fiberlass/steel bonded	.check valves	.sound operating practices	**Leak Detection**
	.coupling mates to prevent mixing of incompatible chemicals		.inventory control
			.visual inspection
			.interstitial monitoring of double wall tanks
			.soil/groundwater monitoring
			.tightness tests
			.structural tests

Storage Tanks

Storage tanks are manufactured in a large variety of shapes, sizes and materials. They may be vertical or horizontal; spherical or cylindrical. They may be as small as a 55-gallon drum or large enough to store 100,000 gallons or more. Tanks which are less than 12 feet in diameter are generally shop-fabricated; those larger than 12 feet in diameter are generally field-erected. Bulk storage tanks may be designed with compartments for storing different products. They may be double-walled for added protection against leakage.

> Certain industrial chemicals are designated hazardous because they threaten public safety, human health, and the environment. These threats occur only when the substances are improperly stored, improperly handled, or improperly disposed of.

Above ground tanks are usually made of carbon steel, stainless steel, polyvinyl chloride (PVC) or fiberglass reinforced plastic (FRP). Aluminum is occasionally used for small tanks and for special applications. Steel tanks

may be coated or lined with synthetic materials which augment resistance to corrosion. Fiberglass may be fused to steel for use when high strength in addition to chemical and corrosion resistance are required. Underground tanks usually are horizontal, cylindrical structures. They typically are made of carbon steel, fiberglass reinforced plastic or steel clad with fiberglass reinforced plastic. The type of tank and materials of construction must be chemically compatible with (1) the chemical to be stored and (2) the environmental setting of the container.

Many substances are corrosive and, therefore, incompatible with steel or fiberglass tanks. For example, aqueous solutions of many salts and most mineral acids are highly corrosive to carbon steel. Special resins are used in the fabrication of fiberglass tanks designed for storing gasohol or organic solvents such as methylene chloride or trichloroethylene. Chemical compatibility charts, available from most tank suppliers, must be consulted during design. Manufacturers, dealers, and suppliers should also be contacted whenever a tank is considered for storage of a substance for which it was not specifically designed. See Table 6. The compatibility of a container with its environment, especially underground installations in corrosive soils, is as important as compatibility with its contents. Subsurface conditions with acidic or saline ground water; fine-grained, moist soils; or buried electrical cables can accelerate rust (corrosion) and deterioration.

When underground tanks are to be installed in a corrosive soil environment, designers should consider alternatives to the standard, unprotected steel tank. These alternatives, which have corrosion allowances, are rust resistant, and have an overall longer design life with less risk of a leak, include:

- steel tanks with thicker walls for corrosion allowance
- cathodically protected steel tanks
- fiberglass reinforced plastic tanks
- steel/glass bonded tanks
- double-wall or double-bottom tanks.

Alternatives should be used if it is unlikely the tank will get routine maintenance, inspection, or testing for tightness.

Above ground storage is sometimes preferred over underground storage, because leaks from above ground facilities are readily discovered and remedied. However, above ground storage poses a greater fire and safety hazard, is more vulnerable in high risk flood areas, and sometimes presents an aesthetic or space problem. Having recognized these limitations, however, toxic materials which pose a threat to aquifers should be stored above ground. **If underground storage of toxics is the only alternative, continuous monitoring of the space between the walls of double-walled tanks is essential.**

Tank design must consider structural as well as chemical factors. The structural design will depend on the horizontal or vertical alignment of the tank, above ground or underground placement, density of the stored substance and support of the tank. Design elements such as material selection, wall thickness, and impact resistances must be carefully considered. The type of welds in a steel tank can be an important factor. Double-welded, butt joints are stronger than lap-welded joints and less susceptible to crevice corrosion at the head and shell seams. Steel tanks are widely used because of their high strength and relatively low capital cost. Steel is particularly well suited for above ground storage tanks where structural strength is a critical factor.

Transfer Facilities

Pipes, fittings, valves and pumps are used to transfer and control the flow of liquid, vapor and air to and from storage tanks. These components are made of a variety of materials and come in numerous designs to compensate for the corrosivity and physical properties of the fluid being handled. Precautionary design considerations for piping and valve systems are similar to those for tanks. Careful structural design and selection of materials compatible with the contained substance are very important. As with steel tanks, steel piping should be protected against rust and corrosion by use of cathodic protection or galvanized coating or lining of a permanent nature. Properly installed fiberglass and plastic pipes are a suitable alternative when the plastic or resin is compatible with the chemical to be transported. They have excellent corrosive resistance in most soils, but they do not have the strength of steel pipes.

Breakage of underground pipes or loosening of pipe fittings can be minimized if swing joints are installed to allow for thermal expansion and differential settlement. These are installed at points of connection with tanks, pump stations, and vent risers. Fiberglass and plastic pipes are inherently flexible and do not require swing joints where there is at least a 4 foot straight run of pipe between fixed connections.

Emergency shut-off valves should be strategically placed and designed to close automatically when a pipeline rupture occurs. Such devices are frequently used at the pump island of gasoline service stations: Should the dispenser be accidentally knocked down by a vehicle, a remote pump shut-off valve at the base of the dispenser will automatically close the gasoline delivery line.

Good piping installations require proper identification of all lines with tags, plates, or painted colors; underground pipes should be mapped and files of them maintained. Operators should know the function of every line and the location of critical valves so that they can be operated properly and quickly in case of an emergency.

Transfer points are where loading and unloading take place; they should be impervious to leaks and spills. Physical barriers should be used to prevent accidental tank truck or tank car movement. Containment or flow diversion systems should be provided to collect leaks from the transfer connections or lines. Drains or sloped pavements are often used for this purpose. Several other precautionary measures which can be taken to minimize leaks and spills at transfer areas include: use of dry break couplings on transfer pipes and hoses, redundant valves and instrumentation, and overfill prevention instruments.

Table 6

General Properties of Materials Used for Storage Tanks and Piping

Structural Materials	Advantages	Disadvantages	Relative Cost
carbon steel	compatible with petroleum products but incompatible with corrosive chemicals	subject to attack by corrosive chemical and corrosive soils	low
stainless steel	Has better corrosion resistance than carbon steel and higher structural strength (There are more than 80 standard types of stainless steel and many special alloys).	lower grade steels (martensitic steels) are not suitable for reducing acid such as HCl.	Medium to high depending on grade of steel
fiberglass	compatible with a wide range of petroleum and chemical products	lacks the structural strength and impact resistance of steel tanks	comparable to coated steel
polyvinyl chloride	excellent chemical resistance to acids, alkalis and gasoline	plastics have low structural strength and are less resistant to mechanical abuse than steels; generally not suited for the storage or handling of organic solvents such as benzene, carbon benzene, carbon tetrachloride and acetone	low
concrete	generally good resistance to chemical attack; epoxy coatings often applied to concrete to increase chemical resistance	subject to cracking and spalling with changes in temperature such as during freeze/thaw cycles	high
aluminum	excellent resistance to atmospheric conditions and compatible with mineral and organic acids	in pure state, has relatively low structural strength and generally not used in fabrication of tanks and pipes; alloys are available but costly	high
steel clad fiberglass	has chemical resistance of fiberglass and structural strength of steel	relatively high cost	high
Linings and Coatings			
alkyds	alkyd-phenolic and aklyd-silicones have good weather resistance and good to excellent resistance to gasoline, non-halogenated organic solvents and alcohols; may be applied to both the interior of tanks and pipes	incompatible with mineral acids, alkalis, chlorinated solvents, and organic acids	low
epoxies	(include epoxyamine, epoxy-ester and epoxyphenolic). excellent weather-resistance and excellent chemical resistance to gasoline, non-halogenated organic solvents, alkalis and mineral acids; may be applied to both interior and exterior of tanks and pipes	good to poor resistance to organic acids depending on the acid	low
phenolic	excellent durability and excellent resistance to gasoline, non-halogenated organic solvents, and alcohols; may be applied to both interior and exterior of tanks and pipes	generally exhibit poor resistance to alkalis, mineral acids, chlorinated solvents, and organic acids	low
Wrappings			
vinyl	good resistance to gasoline, non-halogenated solvents, alkalis and mineral acids; usually applied as loose wrappings around tanks and pipes	incompatible with chlorinated solvents, excellent to poor resistance to organic acids depending on the acid; wrappings usually not as effective as coatings because water often penetrates space between wrapping material and tank	low
Polyethylene	very good resistance to oxidizing acids and some organic acids and alkalis; usually applied as a loose wrapping around tanks and pipe	incompatible with gasoline and organic solvents; wrappings usually not as effective as coatings because water often penetrates space between wrapping material and tank	

Source: Chemical Engineers Handbook, Fifth Ed., 1973.

Overfill Prevention

Overfill prevention is usually accomplished by measuring and/or controlling the level of liquids in the tank. It may consist of a device as simple as the shutoff nozzle commonly employed at a gas station to prevent overfilling an automobile gasoline tank or a valve which closes the vent line of an underground tank and thereby stops the filling process.

It could also be a sophisticated system consisting of:

- level sensor and visual gauge
- high level alarm, audible and visual
- automatic shutdown of valve and pumps or automatic flow diversion
- emergency overflow to adjacent tanks
- on-the-scene operator.

The five components of a sophisticated system provide reliable overfill prevention and can be used on bulk storage facilities sited in sensitive areas. It should be emphasized that these items are not alternatives but are separate components of the system. There is no redundancy in the system. Each item has its separate function and each function decreases the chance of an overfill caused by human error. The fifth, nontechnical, component of the overfill prevention system is the human element. Despite all technological safeguards which may be in place, there should always be a trained operator present and prepared to respond to limit and contain an accidental spill.

Equipment and
Practices for
Preventing Transfer
Spills

1. Overfill prevention systems
   a. level sensor and gauge
   b. high level alarm
   c. automatic shutdown of valve and pumps or automatic flow diversion
   d. emergency overflow to adjacent tanks
2. Proper transfer practices
   a. operator on duty
   b. established procedure
3. Dry break couplings on transfer pipes/hoses
4. Transfer product at established stations equipped with curbing, paving, and catchment facilities
5. Redundant valves and instrumentation
6. Regular inspection and maintenance of spill prevention equipment

Spill Containment

Dikes, curbs, liners, doubled-walled storage tanks and storage basins are used to contain accidental spills or leaks and prevent contamination of ground and surface waters. On above ground storage systems such as that pictured in Figure 7, perimeter diking or depressed storage reservoirs are used to contain large accidental spills. Such dikes/reservoirs are required by the U.S. Environmental Protection Agency for most above ground storage tanks holding petroleum products. Curbing and impervious pads are used to contain small spills at loading and unloading areas while drip pans are used for small leaks from pumps, valves and fittings.

Well designed containment facilities usually have the following features:

- reservoir floors; pads and dikes made of materials impervious to the substance stored;
- curbs, dikes, pans, etc., made of materials compatible with the substance stored;
- perimeter diking and storage reservoirs sufficiently large to contain 110% of the largest tank plus a 24-hour, 10-year rainfall event;
- manually operated pumps, drain valves or siphons for emptying rainwater which accumulates in the containment area; and
- operating personnel trained in spill response procedures.

Two separate underdrain systems are usually needed at large containment facilities. One system is used to collect pure product which may be accidentally spilled at transfer stations and pumps. Product usually drains to a "slop tank" where it is held for later use or recovery. A second separate drain system is used for collecting storm water. If the storm water is uncontaminated, it usually flows to a sump where it is pumped over the dike to the nearest storm drain. If it is contaminated, it is delivered for treatment and disposal.

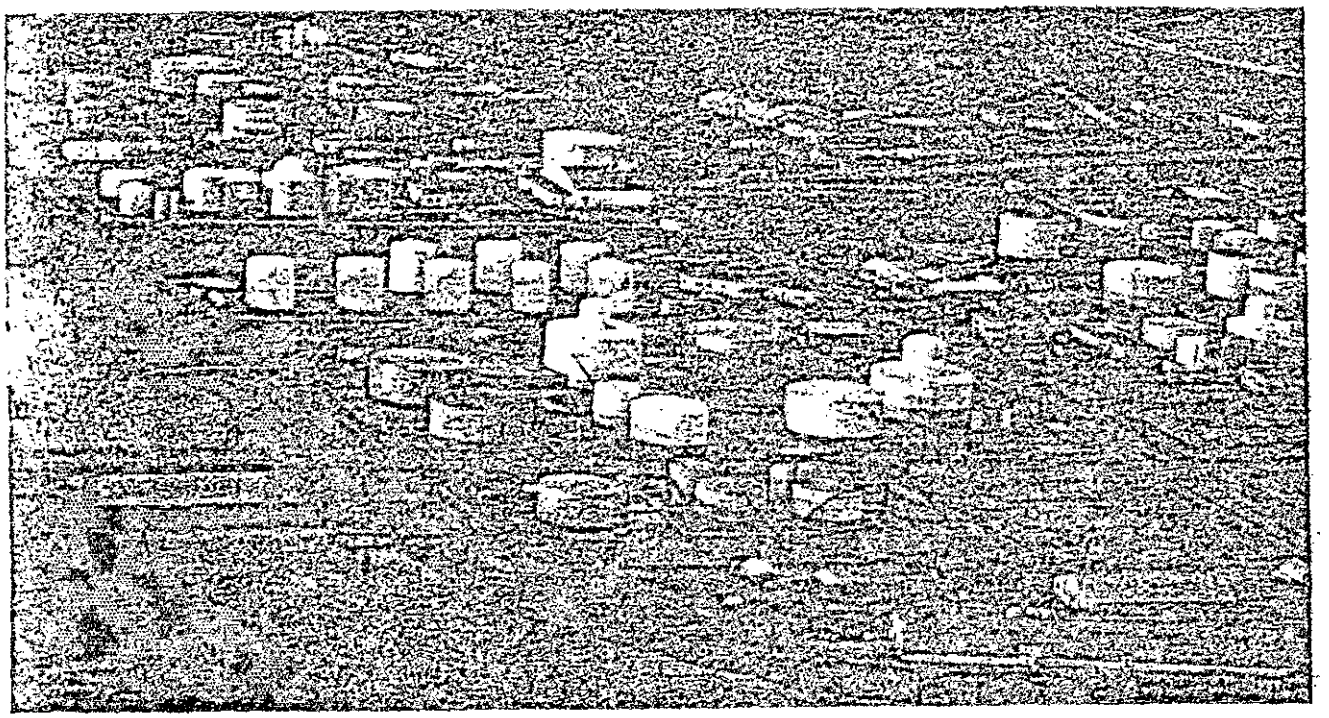
At some bulk storage sites, there is insufficient room to install dikes and holding basins of adequate size. At these sites, large spills are usually diverted to off-site storage areas via lined ditches and pipelines. For volatile compounds, pipelines are more appropriate than open ditches.

The secondary containment concept is also used to confine spills or leaks from underground storage tanks. Double-walled tanks with monitoring of the walls' interstitial space provides security under almost any site condition. Single-walled tanks can be used in conjunction with carefully constructed under-liners of clay or synthetic materials or with concrete vaults in low ground water areas. It is important to provide an impervious cover over these installations in addition to bottom and sidewall lining. Without the top cover, an imperviously lined excavation would quickly fill with rainwater, much like a bathtub, and lose its containment capability.

The secondary containment system for an underground tank is a monitor to detect a leak or spill and a well for spill recovery. Appendix B shows precautionary

Figure 7

Spill containment and management practices are especially important where large volumes are stored, such as at this tank farm.



designs which illustrate containment-monitoring-recovery for underground storage.

Leak Detection

Early detection of leaks is necessary to protect the environment and public health and for the safety of workers and others in the area. The primary methods used for detecting leaks in above ground storage facilities are:

- daily visual inspection
- periodic intensive inspections involving entry of the tank to check on tank dimensions and structural deformity
- testing wall thickness
- cleaning
- tests on the storage system to check for tightness
- checking for stock losses through inventory audits.

Monitoring ground water, storm water and treated releases may also be necessary at large storage facilities. This can be accomplished by direct measurement of the substance of concern or by measuring indicator parameters such as pH, turbidity, conductivity, total organic carbon, total oxygen demand, or specific ions. The need for monitoring is especially important for underground storage systems where leaks could go undetected for years. Each of the following are used for successful, early detection of underground storage leaks:

- stock inventory control
- tank tightness tests
- tile drain fields under tanks
- vapor (sniff) wells for aromatic substances
- sensor instrumentation
- monitoring the interstitial space of double-walled tanks
- sampling wells
- internal inspections
- nondestructive testing of shell thickness
- leak forecasting.

Sampling or vapor wells do not need to be elaborate expensive monitoring systems but can be simple, inexpensive PVC pipe installations.

Installation of Facilities

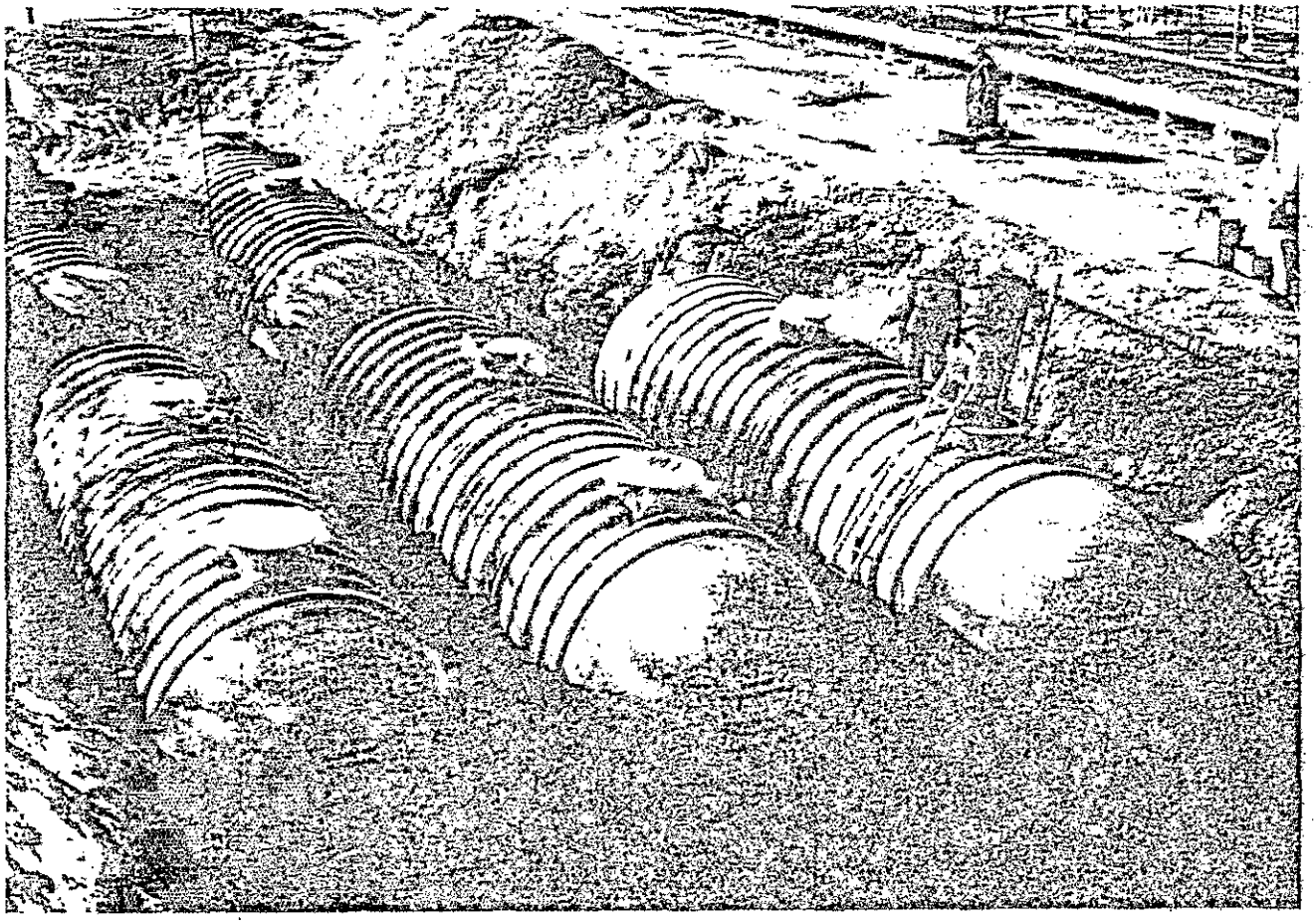
Installation of a facility is as important as its design in reducing environmental risks. Above ground tanks are usually installed on concrete pads designed to support the full load of the tank and its content and on a foundation designed to prevent settling and heaving due to freezing. Special designs and installation practices are necessary in high ground water areas. Floodways should be avoided.

Underground tanks and pipes should be installed with proper bedding and backfill material compacted in one-foot lifts to prevent differential settlement and flattening

of the bottom of the tank and heads. See Figure 8. Proper backfill material for steel tanks is usually sand; pea gravel is most appropriate for fiberglass tanks. Rocks, clay, topsoil, cinders and refuse should not be used for backfill, because they accelerate corrosion of steel or damage protective coatings. Fiberglass reinforced plastic tanks are inherently weaker than steel tanks, and they require the special installation recommended by manufacturers and the Department of Environmental Conservation. Depending on the structural material of the tank or pipe, buried tanks or pipes should be covered with 2 to 4 feet of earth and pavement to protect against structural damage from vehicles.

Figure 8

Proper installation of underground storage tanks is every bit as important as the design of the facilities.



Tanks installed at sites with high ground water or where flooding is possible should be anchored such that buoyant forces cannot float the tank to the surface or cause the tank to collapse. During installation, tanks should receive incremental increases in ballast (water in the tank) corresponding with the progress of backfilling and compaction. Proper "wet hole" installation is especially important when installing tanks constructed of materials with low structural strength or long, small-diameter tanks which are more susceptible to buckling. Placement of anchor straps is also important. Improperly placed straps on fiberglass reinforced plastic tanks have caused tanks to rupture. See Figure 9.

Management Practices

Proper management of a storage facility is as important as proper facilities. Facility design cannot anticipate every possible contingency, and it is necessary to have management procedures which lead to early problem identification, and to have handling practices and actions which can be implemented when a spill or emergency occurs. In some cases, there can even be a tradeoff between investments in precautionary facilities and precautionary management practices.

Anticipatory management practices, sometimes called best management practices or BMPs, are often imple-

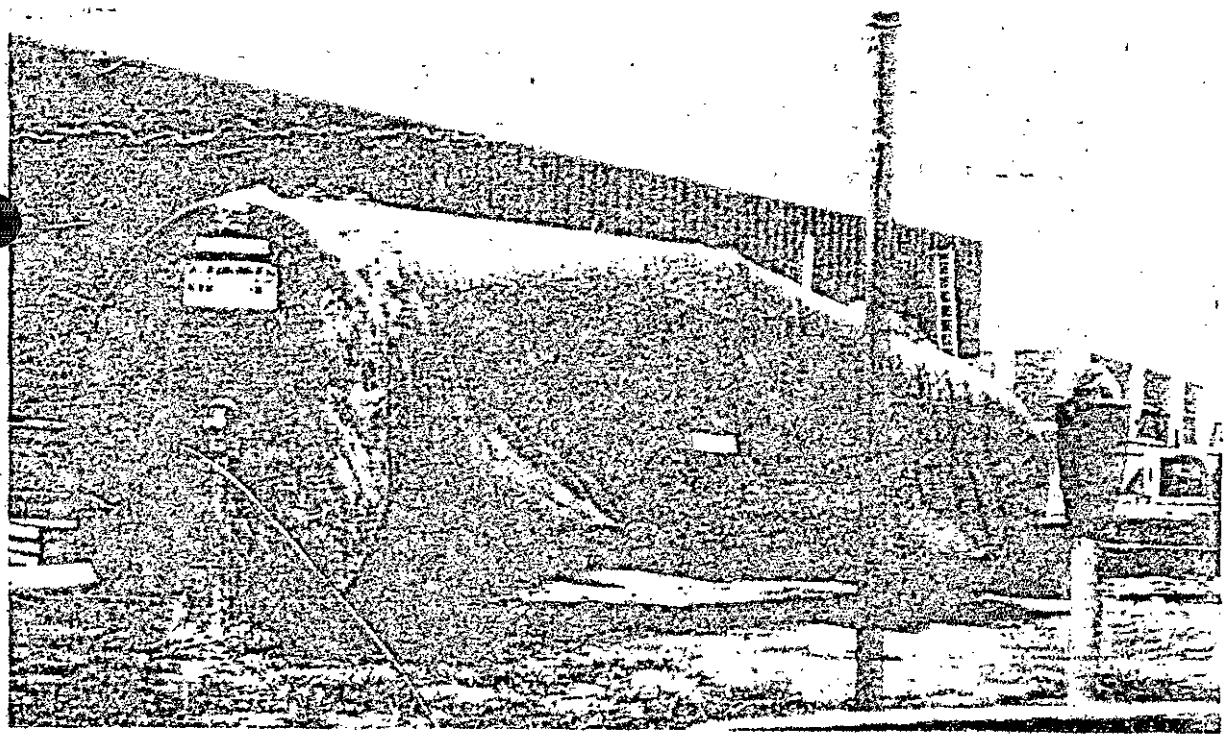
mented as a matter of policy by companies which use and store large quantities of hazardous substances. They are also required by law or regulation in New York State and by the U.S. EPA for oil storage facilities; see Table 14. In general, the following elements are included in a management plan:

- identification of responsible parties (day-to-day and in emergencies)
- spill reporting procedures
- employee training manuals
- inspection and testing schedules
- maintenance requirements and schedule
- record keeping requirements
- security provisions.

A number of other practices including periodic evaluations of material compatibility, labeling of tanks and pipes as to chemical hazards, and use of coupling mates to prevent mixing of incompatible chemicals can be used effectively to reduce the risk of a leak or spill. Storage facilities are dependent on the substances spilled, their concentrations, the amount of the substances, and the layout of the particular installation. Provisions should be incorporated in the facility's design to address spill cleanup, treatment, and disposal.

Figure 9

This tank was installed with anchor straps and no ballast. Heavy rains at the partially backfilled site caused external pressures of around 7 psi at the bottom of the tank.



Section 4
SEPARATION CRITERIA FOR STORAGE OF HAZARDOUS SUBSTANCES

A key issue in siting storage facilities is establishing a "safe distance" between populated areas and the facility. Proper setback requirements and sometimes vegetative and topographic buffers can decrease potential risks to human health and the environment and minimize fire hazards, adverse visual impacts, and land use conflicts as well.

Several municipalities in New York State have already incorporated specific separation standards and buffer requirements into their land use ordinances. Others have established policies and guidelines on "safe distances" which are used in the site plan review process. Legally based standards have two advantages; they simplify the approval process and are applied consistently and uniformly throughout the municipality. The disadvantage is that some flexibility in project planning is lost. Just which approach to use will depend on the needs and attitudes of the community.

> Rules for separating storage tanks from environmentally sensitive areas may vary from project to project. Appropriate separation distances depend on just how dangerous the stored substance is, what precautionary storage practices are to be used, how sensitive the resource, and how serious the environmental impact of a leak or spill.

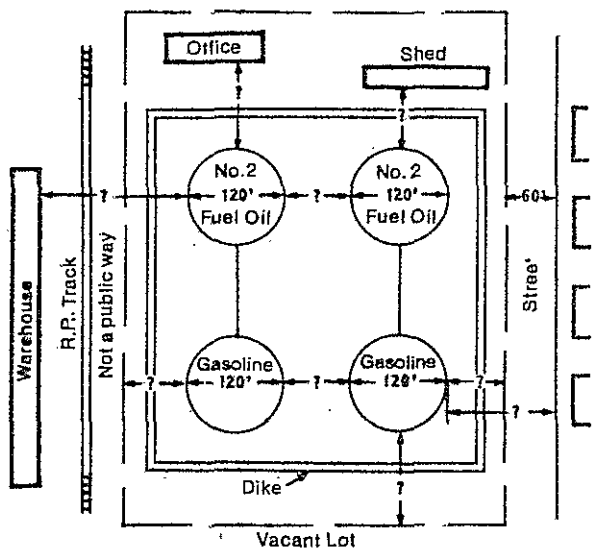
In general, separation requirements should be stringent in urban settings, near residential or hospital areas, in flood plains, wetland areas, or near potable water supplies where spills of hazardous substances could cause health emergencies. Less stringent measures can be employed for nonpersistent and less hazardous materials or when facilities have been designed with extra precautions for leak and spill prevention. There are few hard and fast rules. Obviously, many factors should be considered in the selection of separation distances on a specific project.

For fire prevention, separation distances for above ground storage are specified in the NYS Building Code and Fire Code, and they are listed in standards of practice prepared by the National Fire Protection Association (NFPA) for storage of oils, gasoline, and other flammable or unstable substances. Figure 10 shows the distances which minimize the risk of explosion or fires spreading and meet safety and emergency needs of firefighters.

The U.S. Coast Guard has recommendations of the distances to be maintained from burning, flammable liquids. See Table 7. Minimum and maximum values reflect the fact that not all chemicals burn with the same intensity; petroleum products fall between the middle and lower limits of the range, for example. For additional information see references 6 and 7 listed on Table 8. Separation of flammable liquid storage facilities from buildings and occupied areas should take into account the potential radius of a spill which may occur.

Figure 10

The National Fire Protection Association (NFPA) has established criteria for separating storage tanks from property lines and structures. This schematic shows the questions which must be answered for fire protection and public safety for an hypothetical storage facility consisting of 120-foot diameter tanks of gasoline and No. 2 fuel oil. Anyone proposing a facility for storing a flammable, combustible or unstable (explosive) material should consult the NFPA Code 30 Handbook to determine the separation distances required.



Criteria for separating storage facilities from environmentally sensitive areas are more difficult to develop because of the poor understanding of the way substances migrate in the environment. For this reason, conservative factors of safety, consisting of both precautionary storage practices and separation distances, are usually considered when siting a storage facility. Table 9 identifies the critical distances which should trigger a detailed review of any projects proposed for siting near wells, ground water recharge areas, streams, flood plains, wildlife habitat, or scenic areas. Specific factors which would affect the selection of separation distances are also listed.

Table 7

Fire Safety Separation Distances for Flammable Liquids*

Spill Radius (in feet)	Safe distance from pool edge for people (in feet)			Safe distance from pool edge for wooden buildings (in feet)		
	minimum	maximum	petroleum products	minimum	maximum	petroleum products
10	110	210	150	25	50	32
100	600	1,500	900	150	310	200
1,000	4,000	9,000	6,000	800	2,000	1,100
2,000	8,000	15,000	10,100	1,300	3,500	1,900

*Assumes critical flame angle of 60°.

Source: U.S. Coast Guard, Hazard Assessment Handbook

Table 8

Guides for Determining Separation Distances

1. LeGrand, H.E., A Standardized System For Evaluating Waste Disposal Sites. Prepared for the National Water Well Association, 1980. This procedure, highlighted in Section 6 and Appendix E of this manual, evaluates the potential for groundwater contamination due to the storage of hazardous substances. It is structured to permit the evaluation of the contamination potential associated with a given facility and siting conditions. However, by trial and error it may be used to develop minimum separation distances to attain a predetermined degree of protection using local hydrogeological factors.

2. Toxic Substances Control Act (PL 94-469). Annex III Storage for Disposal. Storage facilities for toxic substances should not be located below the 100-year floodplain.

3. Resource Conservation and Recovery Act (PL 96-482). Federal regulations for operation of hazardous waste management facilities 40 CFR 122.25 (46 FR 2890) require identification of the 100-year floodplain and special analyses where structures are located below this area.

4. U.S. Department of Transportation. Hazardous Materials Early Response Guidebook. DOT P 5800.2. Research and Special Programs Administration. Printed and distributed by Labelmaster, 7252 N. Wolcott Ave., Chicago, IL 60626. Table of isolation and evacuation distances for 44 volatile hazardous substances, recommends distances for small and large spills.

5. National Fire Protection Association. National Fire Codes. Volume 3. 1981. The National Fire Codes consists of a sixteen-volume compilation of documents developed by technical committees of the Association to provide guidance in the reduction of loss of life and property by fires. Suggested separation distances are included for many specific situations.

6. U.S. Coast Guard. Hazard Assessment Handbook. Commandant Instruction Manual M 16465.13. Chemical Hazard Response Information System (CHRIS). Procedures and charts for estimating the flammability hazard for flammable liquids are contained on pages 135-211. Safe distances from the edge of a burning pool of flammable liquid may be determined for structures and personal exposure. Other data may be needed for this assessment (see note 7).

7. U.S. Coast Guard. Hazardous Chemical Data Manual. Commandant Instruction Manual M 16465.12. Chemical Hazard Response Information System (CHRIS). Values for specific gravity and burning rate and flame angles for various liquids may be found.

8. Resource Conservation and Recovery Act (PL 96-482). Interim Status Standards For Owners and Operators of Hazardous Waste Treatment, Storage and Disposal Facilities, Subpart I - Use and Management of Containers. 40 CFR Part 265.176 (45 FR 33244).

9. National Fire Protection Association. Flammable and Combustible Liquids Code Handbook. First Edition. 1981. A commentary on NFPA 30, the Flammable and Combustible Liquids Code. Separation distances cover distances from tanks to property lines, buildings and public ways (Sec. 2-2.1), spacing between adjacent tanks (Sec. 2-2.2), spillage control (Sec. 2-2.3), location of tank vents (Sec. 2-2.5), underground tank locations (Sec. 2-3), container storage (Sec. 4), electrical equipment classified areas in industrial plants (Sec. 5-7.5), bulk plants and terminals (Sec. 6-5.4) and service stations (Sec. 7-6.4), and locations of processing vessels (Sec. 8).

10. Institute of Makers of Explosives. American Table of Distances for Storage of Explosives.

11. New York State Fire Prevention Code. Chapter 9 NYCRR 1150. The code establishes "rules and regulations to safeguard life and property from the hazards of fire, explosion, or release of toxic gases arising from the storage, handling or use of hazardous substances, materials or devices".

12. New York City Department of City Planning, Bulk Oil Facilities in New York City, 2 Lafayette St., New York, New York 10007, August 1981. Contains NYC Fire Department regulations for storage tanks.

Table 9

Typical Separation Distances

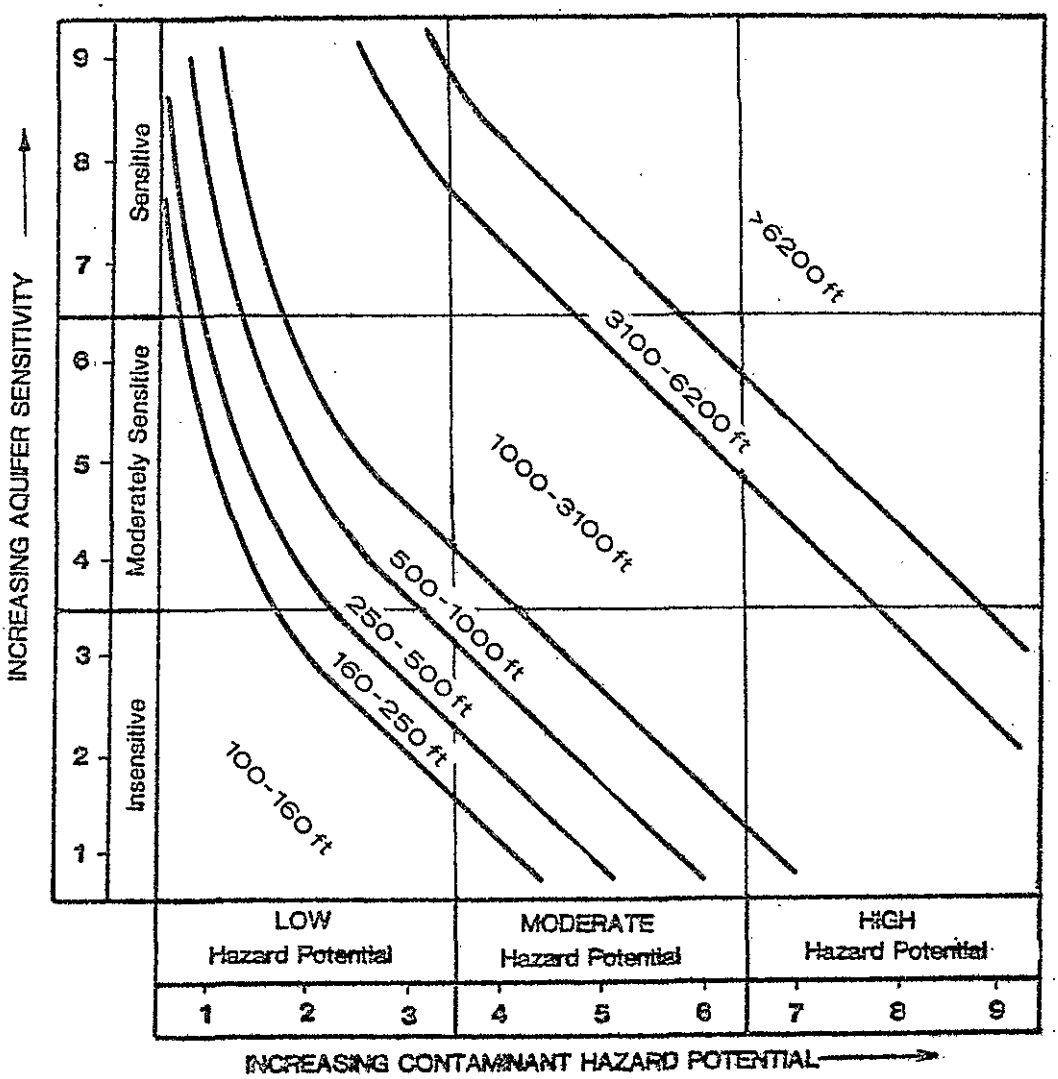
Effects	Factors Affecting Separation	Typical Separation Distances
ENVIRONMENTAL		
.to prevent contamination of groundwater supplies	.substance stored facility design soil characteristics water table gradient	.special attention should be given to facilities located within 150 m (500 ft) of water supply wells or where the seasonally high groundwater table is within 1.5 m (5 ft) from the bottom of a storage tank (Note 1). .facilities should be located outside aquifer recharge areas.
.to prevent contamination of surface water supplies	.substance stored facility design site drainage	.special spill or leak control practices should be applied to facilities located within 150 m (500 ft) of surface waters or where contaminants can enter storm drains or sewers (Note 1). Tanks should preferably be located outside of the 500-year floodplain area and, at a minimum, outside of the 100-year floodplain area (Notes 2,3).
.to prevent impacts to environmentally sensitive areas	.substance stored facility design type of habitat	.storage facilities should be avoided in the proximity of wetlands, scenic, and unique habitat areas, especially those with official designation. Minimum separation may range from 20 m to 1 km (50-3000 ft) (Note 3).
PUBLIC HEALTH & SAFETY		
.to prevent inhalation of toxic or volatile vapors	.substance stored spill area wind direction	.population should be evacuated from a spill site to distances ranging from (10 m to 8 km (30 ft to 5 mi) (Note 4). Particularly stringent spill control designs should be applied to facilities located near dense or nonmobile population centers (hospitals, nursing homes, schools, etc.)
.to prevent spread of fire	.substance stored .type of structure .spill area	.the distance from a wooden structure to the pool edge of a potential spill of flammable liquid should be greater than 1 to 5 times the potential spill radius (Note 6). Containers holding ignitable or reactive hazardous wastes must be located at least 15 m (50 ft) from the facility's property line (Note 8). .Above ground tanks should be located not less than 300 m (1000 ft.) from schools and hospitals and not less than 77 m (250 ft.) from public parks and residentially zoned land (Note 12).
SOCIAL & ECONOMIC IMPACTS		
.to prevent structural damage	.substance stored type of structure soil type facility design	.above ground tanks should be located a minimum of 1/2 to 4 times the tank diameter from the nearest property line (Note 5). Underground tanks should be located a minimum of 1 m (3 ft) from the nearest property line (Note 5).
.to prevent traffic disruption	.substance stored facility design	.above ground tanks should be located not less than 10 to 40 m (30-130 ft) from public highways (Note 9). .Large above ground tanks of flammable or explosive materials should be located not less than 300 m (1000 ft) from exits and entrances to tunnels (highway, subway, train) or tunnel ventilating shafts or buildings (See Note 12).
.to prevent damage by traffic	.traffic patterns	.underground steel tanks in areas subject to vehicular traffic should be covered by at least 1 m (3 ft) of earth or 0.5 m (18 in) of earth and a slab of either 15 cm (6 in) reinforced concrete or 20 cm (8 in) asphaltic concrete (Note 5). Tanks should not be sited near high potential accident areas (e.g., near the outside of a sharp curve.

(for notes, see Table 8)

Figure 11 presents recommended separation distances from water supplies derived from the LeGrand Analysis. The mitigating effects of distance depend upon the sensitivity of the aquifer and the contaminant's hazard potential. These recommended separation distances should be used as a guide tempered by expert advice from a hydrogeologist and data on soil permeability, type of bedrock, depth to water table, and water table gradient. Where the distances contained on Figure 11 cannot be maintained, it is especially important that the LeGrand Analysis be conducted and that special precautionary features be included in the facility design; see chapters 3 and 6 of this Manual.

Figure 11

Recommended Separation Distances from Water Supplies



Note: Derived from LeGrand (1980). Serious contamination of water supplies is not likely to occur from a leak or spill if the separation distances above are maintained. This figure was prepared for conditions where poorly permeable (solid) bedrock exists. For fractured or permeable bedrock, separation distances should be greater. It is recommended that the entire LeGrand Analysis be conducted to assess ground water contamination potential. See Appendix E.

Table 10 lists isolation and evacuation distances recommended by the U.S. Department of Transportation for spills of volatile substances (Reference 4, Table 8). The range in distances illustrates that some chemicals have more hazardous properties than others. Also, the distances listed are merely suggested, and common sense must prevail in any particular situation. For example, if a hazardous material cloud travels between several tall buildings or down a valley, the cloud may affect people much farther away than is specified in the Table and the evacuation distances should be increased in the downwind direction; if a fire begins to involve the spill material, the poisonous effect of gases on the population may be reduced considerably, as may the evacuation distances. On the other hand, if undamaged containers are involved in a fire, their potential for fragmenting would require isolation in all directions for one-half mile. On-site assessments may dictate distances which are more or less than those suggested in the Table.

Table 10

Isolation and Evacuation Distances

NAME OF MATERIAL SPILLING OR LEAKING (ID No.)	INITIAL ISOLATION: SPILL or LEAK FROM (drum, smaller container, or small leak from tank) — ISOLATE in all Directions feet	INITIAL EVACUATION: LARGE SPILL FROM A TANK (or from many containers, drums, etc.) — FIRST ISOLATE in all Directions feet	THEN EVACUATE IN A DOWNWIND DIRECTION Width miles	Length miles
Acrolein (1092)	550	1140	3.0	4.7
Acrylonitrile (1093)	30	60	0.1	0.2
Ammonia, anhydrous (1005)	100	200	0.4	0.7
Ammonia solution, not less than 44% (2073)	100	200	0.4	0.7
Boron trifluoride (1008)	320	670	1.7	2.6
Bromine (1744)	300	620	1.5	2.4
Carbon bisulfide (1131) Carbon disulfide (1131)	30	70	0.2	0.2
Chlorine (1017)	250	520	1.3	2.0
Dimethylamine, anhydrous (1032)	80	170	0.4	0.6
Dimethyl sulfate (1595)	80	170	1.4	2.2
Epichlorohydrin (2023)	40	80	0.2	0.3
Ethylene imine (1185)	270	570	1.4	2.2
Ethylene oxide (1040)	40	70	0.2	0.2
Fluorine, liquid (1045)	460	880	2.5	3.9
Hydrochloric acid, anhydrous (1050) Hydrogen chloride, anhydrous (1050) Hydrogen chloride, refrigerated liquid (2186)	190	450	1.0	1.4
Hydrocyanic acid (1051) Hydrogen cyanide, anhydrous (1051)	90	190	0.5	0.7
Hydrofluoric acid (1790) Hydrogen fluoride, anhydrous (1052)	240	490	1.2	1.8
Hydrogen sulfide (1053)	120	240	0.6	0.9
Methylamine, anhydrous (1061) Monomethylamine, anhydrous (1061)	110	220	0.5	0.8
Methyl bromide (1062)	50	90	0.2	0.3
Methyl chloride (1063)	30	60	0.1	0.2
Methyl mercaptan (1064)	370	770	1.9	3.0
Methyl sulfate (1595)	80	170	1.4	2.2
Nitric acid, fuming Nitric acid, red fuming (2032)	100	210	0.5	0.7
Nitric oxide (1660) Nitrogen dioxide (1067) Nitrogen tetroxide, and mixtures (1067)	110	220	0.5	0.8
Oleum (1831)	280	580	1.5	2.2
Perchloromethyl-mercaptan (1670)	220	450	1.1	1.6
Phosgene (1076)	600	1250	3.3	5.2
Phosphorus trichloride (1809)	110	220	0.5	0.8
Pyrosulfuric acid (1831)	280	580	1.5	2.2
Sulfur dioxide (1079)	100	220	0.5	0.8
Sulfuric acid, fuming (1831) Sulfuric anhydride (1829) Sulfur trioxide (1829)	280	580	1.5	2.2
Titanium tetrachloride (1838)	30	60	0.2	0.2
Trimethylamine, anhydrous (1083)	90	170	0.4	0.6

Section 5
DATA NEEDED FOR EVALUATING A PROPOSED SITE

For communities and developers (project sponsors) wrestling with a need to store hazardous substances, asking the right questions and collecting relevant supporting information is essential to the proper siting of a facility. Questions such as the following should be addressed:

- Does the proposal conflict with neighboring land uses?
- What are the hazards and risks of storing a particular substance?
- How well can the health and safety of the public be protected?
- Where will the substance go if there is an accidental spill or leak at the site?

These and others will guide the process of project review and may point out specific areas of concern requiring further investigation. See the Initial Project Review Fact Sheet which is reproduced below. For example, if there is a potential for contaminating a ground water aquifer that is used as a drinking water supply, then it would be appropriate to look at this particular concern in detail.

Local officials may wish to expand or revise this list of questions to address specific local issues, or they may use the "short" Environmental Assessment Form adopted from the New York State environmental impact statement procedures. See Appendix C. This "short form" provides initial guidance on information needed for minor projects. A "long form" has been prepared as an information checklist for major projects. This "long form" is available from the Office of Regulatory Affairs, NYS Department of Environmental Conservation, 50 Wolf Road, Albany, New York 12233.

DATA COLLECTION RESPONSIBILITY OF PROJECT SPONSOR

Before focusing on specific information needed to address these questions, it is important at the onset to distinguish between the roles of local officials and the project sponsors in the collection and use of data. In general:

- **local officials should require the project sponsor to gather the necessary data, and assume responsibility for evaluating alternatives and risks posed by the proposed storage facility.**
- **local officials should review data and findings for:**
  - **completeness**
  - **sufficiency (does it address the questions and issues?)**
  - **validity (are the data and findings valid and can they be substantiated or supplemented?)**

Types of Data Needed

The following data must be obtained for evaluating a proposed storage facility:

- **project data** - to provide an understanding of the proposed project and its component parts
- **land use and natural resource data** - to provide an understanding of the physical setting of the site and any land use or environmental constraints
- **socio-economic data** - to identify impacts on public safety, cultural resources and economy
- **public values, attitudes and concerns** - to provide information on public views toward the proposed facility.

Project Data: Materials stored, and method of storage are most important if the fundamental questions discussed at the beginning of this Section are to be addressed. The project sponsor and public official will need the following information.

- project name
- applicant name, address, and phone number
- proposed site map (showing project boundaries, nearby buildings, roads, waterways, etc.)
- types, volume and throughput of substance stored (including information on toxicity, flammability, reactivity and chemical compatability with storage tank, pipe and valve materials)
- methods of storage
- proposed safety measures.

Land Use and Natural Resource Data: Data on land uses and natural resources proximate to the site of the proposed storage facility should be collected. This may involve field surveys (where appropriate) and mapping of both the physical characteristics of the site and the other natural resources information:

- land use inventory
  - zoning districts
  - transportation corridors
  - utilities (in place)
  - location of parks, hospitals, apartment buildings, fire stations, residential areas, schools, etc.
  - previous uses of site
  - historical and archeological features
- physical site characteristics
  - soils and related development constraints and potentials (soil depth, soil erodibility, soil structure, soil wetness, soil percolation and

permeability, soil corrosivity and slope)
- surface bedrock and geology
- depth to ground water
- aquifer recharge areas
- highly permeable aquifers
- distance from drinking water supplies

- natural resources features
  - major vegetative types
  - distance to surface water and wetlands
  - floodplains and areas of tidal inundation (including floodplains not identified on maps of the U.S. Department of Housing & Urban Development)
  - fish and wildlife habitat
  - rare or endangered plant and animal species
  - areas of scenic and aesthetic quality

These are examples of relatively hard data which can be measured or physically identified and located on maps. Prior uses of the land are often overlooked. There have been cases where underground steel tanks have been placed in abandoned landfills that had been used to

Initial Project Review Fact Sheet - Hazardous Substance Storage Facility Siting

Applicant
Name: _____
Address: _____
_____
Phone: _____

Site
Name: _____
Address: _____
_____
Phone: _____

Attach map showing project boundaries, buildings, roads, water bodies, and water supply sources.

Brief description of facilities: _____
Substances to be stored: _____
Volumes _____
Describe special precautionary designs _____

1. Will the project include the storage of hazardous substances? _____
2. Is the proposed site located in a predominantly residential area? _____
3. Is the proposed use compatible with existing land uses or zoning regulations? _____
4. Is there a possible negative impact on the property values of neighboring lands including visual and aesthetic impacts? _____
5. Will there be a possible negative impact on future economic growth and activity? _____
6. Will a failure of the storage, transport, or pumping of the stored substances cause one or more of the following problems:
   - create a potential public health problem? _____
   - result in the release of toxic fumes or gases? _____
   - increase the risk or potential for fire or explosion? _____
   - cause corrosion of on-site or off-site facilities? _____
7. Would the discharge of hazardous materials from the project site potentially impact any surface water bodies? _____
8. Is the proposed site within the drainage area of surface water bodies used as a source of potable, agricultural or industrial water? _____
9. Is there the potential to contaminate the groundwater below the site? _____
10. Is the underlying ground water aquifer used as a water supply source? _____
11. Will the proposed facilities be in compliance with State and Federal regulations regarding the preparation of Spill Prevention Control and Countermeasure plans, contingency plans, etc.? _____
12. Have the police & fire departments within the area of influence been contacted concerning security, fire protection, traffic control and other operating issues? _____
13. Is there a particular need for siting the facilities at the proposed location which cannot be satisfied by alternate sites? _____

Suggested Rating Criteria

Desirable -The effects of project implementation are clearly advantageous and would greatly benefit the goals and objectives of the community.
Acceptable-There is a little likelihood that the project would greatly influence community goals and objectives. Measures to mitigate such problems are readily available.
Uncertain -There is indication that the project may have some negative influence on community goals and objectives. Measures may be available to mitigate these problems.
Undesirable-There is a high likelihood that the project would have significant negative affects on community goals and objectives. Measures to mitigate these problems are not available.

dispose of highly corrosive materials such as cinders. Storage facilities have also been placed over agricultural tile drains which have discharge points directly to environmentally sensitive areas.

Socio-Economic Data: Socio-economic data are not easily measured or identified. For example, land use trends, public acceptability of a project, the probability of obtaining a zoning variance or special use permit if required, political interactions, as well as expected effects on public health, community economics, and aesthetic concerns, are examples of intangible or "soft" data. It takes a genuine feeling for and knowledge of the characteristics of the community and the individuals in key positions within the community to be able to evaluate these factors. The difficulty in quantifying these factors make them an imprecise part of a site evaluation. However, as difficult as they are to measure, these data must be given consideration together with the hard data in the evaluation of a site's suitability for storage of hazardous substances.

Determining the economic effects on a community (such as tax rate changes, employment, primary and secondary spending in the private sector, new public revenues or expenditures) resulting from the development of any project requires a variety of data and may include: capital cost of the facilities, demands of the project on community services (fire and police protection, water supply, wastewater treatment, etc.), new income generated by the project, commercial and housing needs of project employees, etc. Evaluating economic data allows local officials to determine the benefits that may be derived from a project and compare them with the expected costs.

Public safety and emergency response needs should also be studied. Law enforcement and fire officials should specify safety needs and requirements such as separation distances, evacuation procedures, and spill and fire response contingency plans.

Public Attitudes and Concerns: The attitudes and concerns of the general public are even more difficult to assess than socio-economic factors, yet they are crucial in determining the acceptability of a site. Community leaders are usually aware of public attitudes toward specific types of facilities, and adjacent landowners may be in the best position to know about unique conditions at a proposed site which will be important in determining the site's overall suitability for the storage of hazardous substances.

Sources of Information

Agency Reports and Plans: Local officials and project sponsors who will be storing the hazardous substance have the responsibility and, indeed, the obligation to obtain and analyze all pertinent information about a proposed project and the factors which may affect the siting decision.

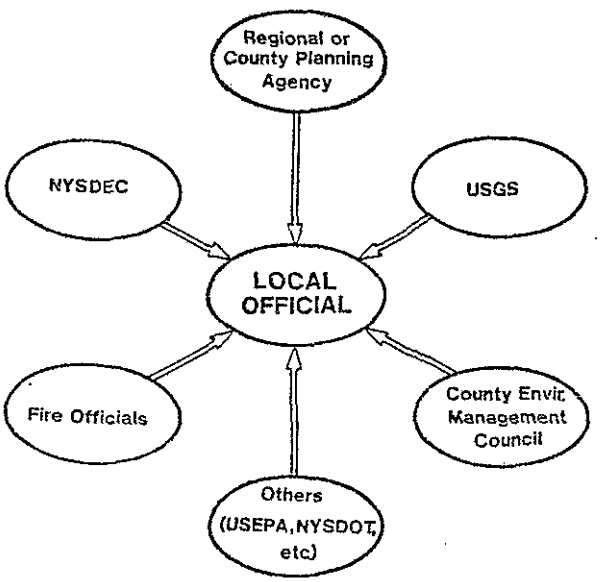
Due to the potential short- and long-term dangers that might result from accidental spills of hazardous substances, public officials need to utilize a variety of data resources available to them. Appendix D lists many of the Federal, State, and local government agencies where data may be found. See, too, Figure 12. For instance, published soil surveys, generally available on a countywide basis, from the U.S. Soil Conservation Service, contain a wealth of pertinent reconnaissance information which can be used for site screening or for designing the detailed soil study at a specific site. The soil surveys include not only information on soil types but also data on characteristics of the soil (permeability, corrosivity, erodibility, etc.), probable depth to the ground water table, and depth to bedrock. This information is important in estimating the rate of corrosion and longevity of an unprotected steel tank or underground piping. It must be noted, however, that data obtained from soil surveys or other reports, such as countywide land use wetlands or inventories, will need to be augmented by precise site-specific information.

Countywide land use development plans are a useful source of information. These plans provide the basis for evaluating projects for consistency with the goals and objectives of a community. Useful plans include:

- county and local land use plans, zoning ordinances and subdivision regulations
- economic development plans
- county environmental plans
- natural resource management plans
- agricultural district plans
- open space management plans
- state (and local) outdoor recreation plans

Figure 12

Information Sources Available to the Local Official



- plans for housing developments
- air quality implementation plans
- transportation plans
- utility plans
- solid waste management plans.

> County and regional planning, departments, county environmental management councils, and city, town or village conservation advisory councils are valuable sources of information and technical assistance

Field Surveys: At a minimum, all the people evaluating the project should visit the site to see conditions firsthand. Often, potential problems are not recorded on available maps and reports but are readily observed by field investigation. Data gathered through field work, such as soil borings, resistivity studies, well drilling and so forth, provide the best information for use in a site evaluation. The concern over public health and safety or environmental protection usually dictate that site-specific data be utilized.

Public Participation: There remains another source of information which should not be overlooked. There is no substitute for public participation including direct personal contact with those persons who have specialized knowledge either about a specific site or about a general area of concern such as land use trends in a given municipality. Often, this information is paramount in the site evaluation process.

In addition, the staffs of Federal, State, or local government agencies may have access to pertinent but unpublished data that might be helpful. Public officials and project sponsors should use a variety of methods to obtain the participation of the public to gather information; personal contacts with local people are often the only way that some data will ever be brought to light.

Section 6
RISK-ASSESSMENT METHODS

Several analytical tools can be used to assess the risks and the potential environmental impacts of a proposed storage facility. These are:

- LeGrand Analysis
- soil corrosivity assessment
- method for predicting life expectancy of steel tanks
- models for predicting environmental fate
- health risk assessment.

LeGRAND ANALYSIS

The LeGrand Analysis is presented in detail in Appendix E. It is a useful, relatively simple, and practical method for evaluating the risk of ground water contamination when determining suitability of a proposed storage site. It can be used for evaluating any site and any substance which could contaminate ground water. It may be used for screening and selecting the best and worst sites from among several alternatives, or it may be used to set inspection priorities among facilities which are already in place. Factors which are considered in the analysis include:

- ground water hydrology
- hazard level of chemical to be stored
- aquifer sensitivity and importance as a water supply.

Sites evaluated using the LeGrand procedure receive a grade of A through F. Sites receiving a grade of A are most suitable for storing hazardous substances. For these sites, the risk of ground water contamination is low. Sites which receive a grade of F are poorly suited for storing hazardous substances; the risk for ground water contamination is high for these sites. See Table 11.

One advantage of the LeGrand Analysis is that it can be performed with data which are normally available, although site-specific field data increase reliability and confidence in the answer. Data requirements include project data, which would be provided by the applicant; site data, available from area soils reports; and chemical characteristics of stored substances. For most siting proposals, the analysis requires 2 to 30 man-hours to complete. Local officials and project sponsors can draw upon private consultants with expertise in this area or upon engineering or planning staff available through the county. Also, Environmental Management Council staff members, particularly those having a geology background, usually have the skills to perform the LeGrand Analysis.

Table 11

LeGrand Site Suitability Chart

Grade	Site Suitability	Groundwater Contamination Potential
A	Excellent	Low
B	Good	
C	Somewhat Inadequate	Moderate
D	Poor	
F	Very Poor	High

The LeGrand Analysis provides useful information upon which to base a siting decision. However, the NYS Department of Environmental Conservation strongly recommends that local officials and developers seek professional advice in performing the analysis, especially where doubt exists about the adequacy or accuracy of the data available for input to the LeGrand Analysis or where the possibility exists that a ground water aquifer serving as a source of drinking water may be affected.

SOIL CORROSIVITY ASSESSMENT

Studies of soil corrosivity provide valuable information on the suitability of sites for underground steel pipes or steel storage tanks. Corrosion of steel is a physical-biochemical process that converts iron into its ions. Before corrosion can take place, soil moisture is needed to form solutions of soluble salts. Any factors that influence the soil solution, such as soil texture (clay/sand/gravel), moisture content, conductivity of the soil solution, soil acidity, oxygen concentration, and the activity of organisms capable of causing oxidation-reduction reactions, influence corrosivity.

Reconnaissance information on corrosivity is available from modern soil surveys. Usually, those data should be supplemented with site-specific resistivity surveys which measure the resistance in the soil to the flow of electrical current. Resistivity surveys usually cost a few hundred dollars to perform. Once such surveys have been made, the soils can be assigned to one of five classes of corrosivity, as noted in Table 12.

Analysis of soil corrosivity requires interpretation of soils information by a qualified soil scientist or soil engineer. County Soil and Water Conservation Districts are a logical place to make initial contact for obtaining assistance.

Table 12

Classes of Soil Corrosivity

Soil Corrosivity	Soil Characteristics	Resistivity (Ohm-centimeters)
Very low	Well Drained Gravel	10,000
Low	Well Drained Sand & Gravel	5,000-10,000
Medium	Poorly Drained Sand & Gravel	2,000 - 5,000
High	Poorly Drained Fine sand and silt	1,000 - 2,000
Very High	Poorly Drained Clay	Less than 1,000

PREDICTING USEFUL LIFE OF STEEL TANKS

The American Petroleum Institute (API) sponsored research which lead to the development of a method for predicting when a leak will occur in an uncoated, underground steel tank. With data on sulfide level, soil resistivity, pH, soil moisture, backfill material, and tank size, the API method predicts to within a year when a tank leak will occur. The cost for the analysis ranges between $300 and $500 per site.

> The question is not: will an uncoated, underground steel tank corrode? Rather, the question is: When will it corrode? Analysis of soil corrosivity can provide the answer.

MODELS FOR PREDICTING ENVIRONMENTAL FATE

Once released into the environment, a contaminant may degrade, persist, disperse, bioaccumulate; or, it may even cycle and spread from one environmental media to another, such as from water to air, to land, to living organisms; it may cycle from organism to organism via the food chain. Scientists are just beginning to understand these phenomena and are on the frontier of developing complex ecosystem models allowing prediction of environmental fate, transport, and bioaccumulation.

A number of pollution transport models have been developed. These allow prediction of the movement of chemicals in the environment, particularly their flow and dispersion in surface and ground waters. The WALRAS (Water and Land Resources Analysis System) is one such model that can be used to analyze potential ground water pollution problems. The cost and time requirements for this analysis are greater than for the LeGrand Analysis. It can be used with available ground water and land use data to determine water and materials budgets. Given the possibility of a spill or leak at a site, an analyst can predict the probable distribution of a contaminant, the degree of contamination, and the duration of contamination. Information about WALRAS and its uses may be obtained from the Water Resources Program at Cornell's Center for Environmental Research, 468 Hollister Hall, Ithaca, New York 14853.

> Some chemicals can build up on the tissue of animals and man. Such a buildup is called bioaccumulation.

Other transport models have been developed for modeling surface water spill movement and ground water flows. Investigators in the United States Geological Survey (USGS), in particular, have developed sophisticated models which require a considerable amount of data and a highly skilled, interdisciplinary team of researchers. These models and the other data-intensive models for predicting the environmental dispersion of a chemical contaminant are expensive to use and would normally be justified only when the less complex methods (LeGrand Analysis and WALRAS) are considered unsatisfactory or insufficiently precise. Such complex methods are appropriate for large controversial storage proposals which would threaten major drinking water supplies. Further information about some of these models and how they may be used in studying ground water contamination problems may be obtained directly from the USGS or by contacting the Department of Environmental Conservation.

HEALTH RISK ASSESSMENT

Local decision-makers may wish to examine and consider the potential risks to human health associated with hazardous substances entering drinking water supplies from spills and leaks. One major obstacle in assessing a health risk stems from the difficulty in quantifying risk. To date, risk factors have been calculated only for carcinogenic compounds. These risk factors are determined through epidemiological studies, animal studies, and through statistical analysis, usually at great expense.

Numerous other toxic effects beside carcinogenic effects can be produced by exposure to chemicals (teratogenic effects, mutagenic effects, polyneuropathy, central nervous system disorders, liver damage, blood

disorders, and many others). So far, no numerical expression for risk has been developed which can relate the probability of predicting these types of adverse effects with a dose (Kim and Stone, 1981).

In considering the potential health risk of a hazardous substance, the chronic effects of lifetime exposure of the public to a hazardous substance must be the primary concern. A **chronic toxic effect** is defined as an injury that persists because it is irreversible or progressive or because the rate of injury is greater than the rate of repair during a prolonged exposure period. The New York State Department of Health has summarized the cancer risks from chronic exposure to various hazardous chemicals in drinking water in which an intake of two liters of water (about two quarts) per day would produce one excess cancer death per lifetime for a population of 10,000. See Table 13.

To evaluate the potential health risk of any of these chemicals in relation to the siting of a storage facility, the LeGrand Analysis may be used. See Step 7 and Table E8 in Appendix E. It may be assumed that all chemicals included in Table 13 will range between 7 and 9 in hazard potential ranking. The assessor must use personal judgment in assigning a specific ranking within this range.

Table 13

Risk of Cancer (1 death in population of 10,000)

Chemical	Concentration (in parts per billion)
Aldrin	0.3
Benzene	4.0
Carbon tetrachloride	450.0
Chlordane	3.2
DDT	4.0
Dieldrin	0.3
Kepone	1.0
Mirex	9.2
Parathion	4.5
PCB	16.0
Tetrachloroethylene	220.0
1,2,2,-Trichloroethane	46.0
Trichloroethylene	460.0
Vinyl Chloride	110.0

Source: Kim and Stone (1981). Ingestion concentrations which will cause one additional death per population of 10,000 are given for 85 compounds.

Section 7
EVALUATION AND DECISION ALTERNATIVES

The preceding sections of this Manual address the problems which can occur with hazardous substances and the practices that can be employed to assure proper storage. Technical and socio-economic factors that should be considered in the siting of storage facilities and several techniques for assessing risks were also discussed. This section provides a decision-making framework within which to assess the overall suitability of a storage site; it also examines the need for coordination and discusses the decision alternatives available to local officials and the project sponsor.

DECISION FRAMEWORK

Overall, the siting decision should consist of a several step evaluation as follows:

- Collect data on the proposed facility and surrounding environment. Section 5 identifies requisite data needs for the siting decision.
- Define all potential risks. Section 6 provides risk assessment techniques by which data can be used and analyzed.
- Define available engineering approaches and mitigating measures. Section 3 identifies the kinds of storage systems that are available and identifies precautionary measures that may be adopted to prevent leaks and spills. Section 4 provides separation criteria that can be used in the siting decision which will help to mitigate the effects of an accidental spill.
- Make risk assessment decision on suitability of the site, and require engineering controls based on technical, environmental, socio-economic, legal (program) requirements and political considerations. The siting decision should properly weigh factors considered in the evaluation. For example, service stations of necessity must be located on roadways and in areas of high traffic density. Any siting decision based solely on risk of environmental damage fails to also consider the dictates of the market. A desirable business location may also be a high risk environmental site. The siting decision should be made only after precautionary spill and leak prevention designs and mitigation measures have received full consideration in the overall risk assessment.

COORDINATION OF REVIEW PROCESS

State Environmental Quality Review Act

The State Environmental Quality Review Act (SEQR, Environmental Conservation Law, Art. 8) provides an excellent mechanism for reviewing a proposed project and for coordinating the review among local officials, the project sponsor, other agencies, and the public. SEQR was enacted to encourage review of environmental impacts concurrent with the planning, review, and decision-making process of state, regional and local agencies. To accomplish this goal, SEQR requires that all agencies determine whether the actions they approve, fund, or undertake have an impact on the environment. If it is determined the action may have a significant impact, the agency must prepare (or request the project sponsor to prepare) an environmental impact statement (EIS). The EIS is a concise document on the project and its environmental impacts which is distributed for review and comment to those who have a stake in the project's implementation.

With respect to any action such as the siting of a facility for the storage of hazardous substances, a local agency must take five basic steps under the SEQR law.

1. Determine if the action is subject to SEQR; if it is not, no further steps are necessary.
2. Determine if the action may have a significant effect on the environment.
3. Prepare (or have project sponsor prepare) a Draft EIS; circulate it to any concerned agencies and citizens, and, possibly hold a public hearing.
4. Complete a Final EIS which addresses the comments received, and circulate it to concerned agencies and citizens.
5. Make the decision on whether or not to approve the action.

> What is an EIS?
>
> An environmental impact statement (EIS) provides a tool for local officials and project sponsors jointly to examine the suitability of a proposed site and methods of preventing contamination of environmentally sensitive areas. An EIS usually:
>
> - describes the proposed project
> - inventories adjacent environmental resources
> - discusses short- and long-term impacts
> - lists unavoidable impacts
> - measures commitments
> - examines methods for lessening or mitigating environmental impacts
> - lists growth-inducing aspects of the project
> - provides a listing of supporting documents

More information on SEQR may be obtained from the Division of Regulatory Affairs, New York State

Department of Environmental Conservation, 50 Wolf Road, Albany, New York 12233. The reader is directed to Environmental Impact Assessment (Canter, 1977) for a summary of over 40 different evaluation procedures that may be adapted for use as a site evaluation procedure.

Coordination with Federal and State Programs

Many proposed storage projects are subject to existing Federal and State regulatory programs that control the transportation and handling of hazardous substances; major programs are listed in Table 14. Local officials and project sponsors should be aware of them.

However, local officials should not be misled by Federal and State programs into thinking that no further control is necessary by their actions. Although Federal and State programs are important elements, their scope is limited, and they cannot address the details of each proposal for hazardous substances storage that every municipality might receive. Local officials, therefore, must take charge of siting details.

Many types of projects, including construction of bulk storage facilities, are frequently subject to intergovernmental review and consistency requirements. Local officials, therefore, should be aware of regulatory and permit review requirements of agencies and programs that might be applicable to the siting of a storage facility. They should notify project sponsors of possible Federal and State requirements. To the extent that such requirements are applicable, local officials should attempt to coordinate their review with the appropriate agency(s). Table 15 lists the types of permits or approvals commonly administered at the various levels of government for which interagency coordination might be required. Appendix F briefly describes each of the program requirements.

Table 14

Major Federal and State Requirements for Storage and Handling of Hazardous Substances

Federal

Clean Water Act - Section 311 directs EPA to develop regulations which designate substances which, when discharged to the nation's waters, may affect natural resources or which present imminent or substantial danger to the public health and welfare. It is the intent of this Section to establish regulations designed to promote improved practices for the management and movement of hazardous substances.

SPCC Plans (40 CFR 112) - The U.S. Environmental Protection Agency requires any person with above ground storage of over 1320 gallons of petroleum to prepare and keep on the premises a spill prevention control and countermeasure plan. Containment dikes are also required.

Transportation of Hazardous Materials (40 CFR 171-177) - The U.S. Department of Transportation sets standards for packaging, tank cars and labeling of hazardous materials.

New York State

Fire Prevention Code (9B NYCRR) - The Department of State has prepared a code for the storage and handling of flammable substances. The code is administered and enforced by local units of government in the same manner as the NYS building and construction code.

Hazardous Materials Reporting (GML 209-u) - In 1980, the Legislature passed a law that requires anyone who has purchased fire insurance to report to local fire chiefs the amount and location of hazardous substances in storage.

SPDES Permits (Article 17 ECL) - Title 8 of Article 17 of the Environmental Conservation Law requires the Department of Environmental Conservation to set limits and issue permits for the discharge of pollutants (including hazardous substances).

Bulk Storage of Hazardous Liquids - Concurrent with the preparation of this siting manual, the Department of Environmental Conservation is preparing a code of practices for storage and handling of hazardous liquids. Other standards and legal measures which will aid in the prevention and control of leaks and spills are also under consideration. Many leaks and spills can be prevented by complying with DEC's code on storage of hazardous substances. Owners of storage facilities and local authorities should work in concert to assure compliance with these requirements.

Petroleum Liquids, Storage and Transfer (ECL Article 19) - Sections 19-0301 to 19-0303 of the Environmental Conservation Law requires a vapor recovery system for the handling and transfer of petroleum products.

Licensing of Major Oil Storage Facilities (Article 12 Navigation Law) - Article 12 provides certification, licensing, and joint inspection of major oil storage facilities by DEC and DOT on an annual basis. Article 12 also contains provisions for a State Spill Cleanup Fund supported with license fees and penalties collected.

In many instances where a project may be reviewed by more than one agency, procedures have been developed to coordinate and facilitate this review. For example, New York State's Uniform Procedures Act and its implementing regulations (6 NYCRR 621) specifically allow for the simultaneous review of programs administered by the DEC. Other regulations at all government levels, such as the State Environmental Quality Review Act, incorporate provisions which seek to minimize duplication of effort in the review process. Project applicants have benefited from these efforts, since less time and money is required.

It is in both the applicant's and the regulator's interests to complete the review process in as short a time as possible while assuring that the evaluation is sufficient for informed decision-making. To satisfy both parties, early and open exchanges of information are necessary. Holding a preliminary meeting to discuss a proposed project, having available data about a project and having information about the necessary review procedures will allow the review process to run in a smooth and timely manner.

Table 15

Siting Permits or Reviews

Permit	Agency
State Pollution Discharge Elimination System (SPDES)	NYSDEC
development in freshwater wetlands	NYSDEC
air pollution control	NYSDEC
hazardous waste management	NYSDEC
disposal of construction & demolition debris	NYSDEC
dredging and filling waterways	NYSDEC
zoning variances	zoning board of appeals
site plan review	local planning board
conditional-use permits	local planning board
building permits	local building department
discharge of materials into water bodies	US Army Corps of Engineers
construction in navigable waters	US Army Corps of Engineers

To Speed the Development Review Process and Save Time and Money.....

For Project Applicants

- Take advantage of the many sources of information available in preparing the project plans.
- Try to identify all the development reviews required for the project before you apply for any given review.
- Apply for the development reviews early; you could always encounter unexpected delays.
- If there are options of when you may submit and you are pressed for time, submit first those applications which have longer review periods or which must be approved as a precondition for other approvals.
- Check with the review agencies to determine their standards and requirements, and take them into consideration in designing your project and completing your application.
- Try to meet with the review agencies early in the design of your project to uncover potential problems before you spend a lot of time and money on detailed design. Remember that most review agencies encourage preapplication conferences, preliminary reviews, and sketch plan reviews.
- Be sure to conform with the requirements of the State Environmental Quality Review Act (SEQR), as they apply to your project.

For Review Agency Staff

- Notify the applicant early about the standards and requirements which apply in review of applications. If possible, enclose a copy of standards and requirements with the application forms.
- If you are aware of other reviews that will be required for an application, let the applicant know about them early on.
- If you suspect that there could be problems with an application, encourage the applicant to meet with you to resolve such problems before a lot of time and money is spent on the design of the project.
- Be sure to conform with the requirements of the State Environmental Quality Review Act (SEQR), as they apply to an application.
- Conduct your reviews expeditiously without sacrificing quality.

Source: Guide to Development Permits, Monroe County Department of Planning, Rochester, NY, January 1981.

WORKING TOGETHER ON PROJECT PLANNING

Conceptual Planning Phase

At the storage facility's conceptual phase, while the project is still a general idea, local officials have the opportunity to work with the sponsor to obtain the most desirable development. In the long run, the sponsor will save time and money by getting guidance on regulatory review early. This is an opportune time to satisfy the environmental review requirements of SEQR and determine if an environmental impact statement must be prepared. The conceptual and planning phase also allows local officials to identify special concerns such as environmental resources (say, wetlands or an aquifer) or public health and safety concerns (say, a nursing home nearby) that should be considered in preliminary site plans.

Preliminary Site Plan Development Phase

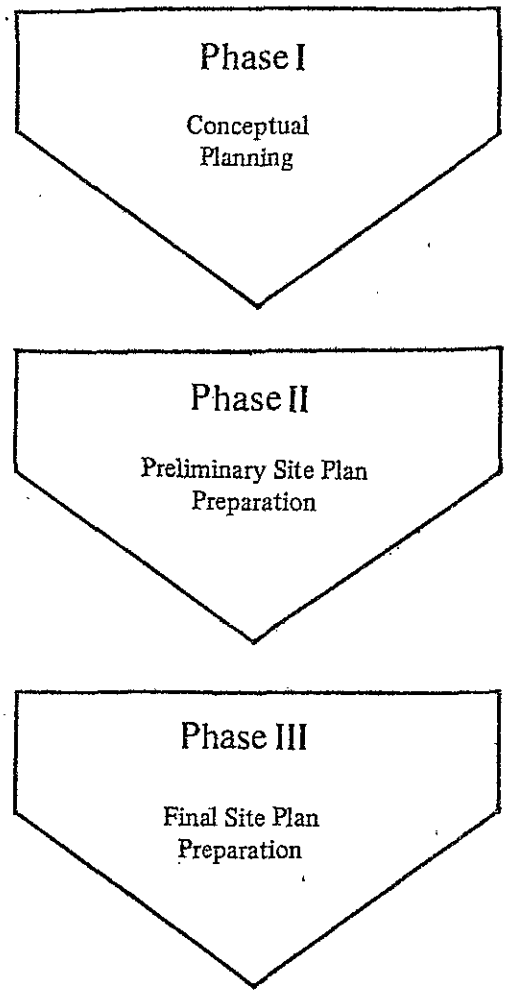
The project sponsor next formally submits an application and preliminary site plan to local officials for approval. This site plan provides the basis for local officials to determine what modifications or precautions are required in the plan to minimize risk. If a public hearing is required, it should be held now. Local officials may indicate their intent to impose financial requirements, such as bonding or insurance requirements.

Final Site Plan Development Phase

The final site plan should reflect all the modifications of the original required by local officials. The final plan also should address the concerns and interests expressed by the public at hearings. See Figure 13.

Figure 13

Project Planning Phases



Negotiating

The importance of negotiation during each of the phases cannot be underestimated. **Negotiation** is a process of resolving differences between parties who have a stake in the outcome of an issue. All parties should have an opportunity to express their concerns. The combined resources and commitments of all parties often result in innovative, creative, and more thoughtful decisions. Furthermore, there is often a greater commitment to the decision when all parties assist in its development.

Early on in the negotiations, the negotiable items should be identified; in addition, the interests of each party must be identified, since they will be different. Negotiation is not a contest but a series of legitimate trade-offs during each planning phase. It involves effort, flexibility, organization, anticipation of actions, and timing. Successful negotiation requires that all parties understand the scope and effect of the proposal. Constructive, business-like relationships should be maintained throughout the decision-making process.

DECISION ALTERNATIVES

When handling an application for siting hazardous substance storage facilities, local officials will dispose of the application in one of the following ways:

- approval, where the hazard potential is low in relation to the site or where appropriate mitigating measures are contained in the plan;
- disapproval, when environmental or land use conflicts are too great and no engineering alternatives can adequately mitigate the risk;
- conditional approval, where siting risks can be overcome with appropriate precautionary design or mitigating measures.

Once the governing body has issued a decision on a site plan, all affected parties have the right to learn the rationale behind the decision.

Conditional Approvals

Conditions which local officials choose to attach to site approval might include requirements for close engineering supervision of design and construction, special storage tank site designs or layouts, distance standards between the facility and environmentally sensitive areas, vegetative buffers, requirements of periodic monitoring or safety inspections, restrictions on types or amounts of substances that may be stored, development of site closure plans, and the requirement of environmental liability insurance or bonding. With any siting approval, it should be brought home to all parties concerned with construction, operation and maintenance that the facility must be in compliance with all Federal, State and local regulatory requirements. If new regulations are adopted facilities will be required to adjust their operations to conform.

> No single formula can be given to guide the siting of storage facilities, since there is so broad a range of substances for storage, types of communities, environmental settings, and local concerns. The final decision must be tailored to address the specific issues and concerns of the project and the location while maintaining compliance with regulatory requirements.
>
> There are locations where siting a facility will be unacceptable, and no engineering measures could reasonably be employed to bring risks within suitable limits.

The role of the building inspector is critical when conditional approval is granted. The inspector monitors the construction and operation of the facility to insure all conditions of approval imposed by the governing body are satisfied. Failure to enforce and check could bring disastrous consequences to the community.

DEFENDING THE DECISION

It is important that all the steps of the review, negotiation, and decision-making process be carefully documented. In many cases, this information must be presented at a public meeting or hearing. Where the outcome will be particularly controversial, it is advisable to involve State or county officials and legal or technical consultants and to use sound analytical approaches. The steps presented in this Siting Manual should permit local officials to identify the significant issues, compile the relevant data, and present the criteria and rationale upon which decisions will be based.

By becoming aware of the areas of concern relative to siting decisions, and by using the suggested procedures described in this Manual, local officials will be able to control the siting of hazardous substance storage facilities in a manner which will protect the public health and welfare of the community yet encourage desirable industrial or commercial growth within their localities.

GLOSSARY

Above Ground. Refers to storage tanks in which 100% of the tank volume is above final ground elevation.

Aquifer Sensitivity. Refers to the likelihood of, and degree to which groundwater resources may be contaminated at a particular site or area.

Asphalts. Black, solid or semisolid bitumens which occur in nature or are obtained as residues during petroleum refining.

Atmospheric Tank. A storage tank which has been designed to operate at pressures from atmosphere through 0.5 psig.

Barrel. Strictly speaking, a statistical measure equalling 42 U.S. gallons. Actual barrels (or drums) used by oil companies, hold 55 gallons.

Biodegradables. Compounds that can be degraded by microorganisms to normal biological end products such as carbon dioxide and water. Biochemical oxidation requires an acclimated seed of microorganisms and dilution of the chemical compounds to levels that will not be toxic or inhibitory to the microorganisms.

Bottom Loading. A method for loading liquid into a tank truck from ground level with a dry disconnect type fitting which usually incorporates a system designed to provide overflow protection. This type of loading operation eliminates the need for visual inspection of the inside of the tank during loading.

Bulk Storage. Materials stored in large quantities which are usually dispensed in smaller units for use or consumption. Warehousing of 55 gallon drums, underground tanks at gas stations and petroleum/chemical storage tank farms are examples of bulk storage facilities.

Bulk Storage Plant. A terminal where flammable or liquid or hazardous substances are received by tank vessel, pipe lines, tank car, tank vehicle, and are stored or blended in bulk for the purpose of distributing such liquids.

Bunker Fuel. A general term for heavy oils used as fuel on ships and in industry. It often refers to No. 5 and No. 6 fuel oils.

Coatings. Corrosion and chemical resistant materials which are sprayed, brushed, or rolled onto the metal surface of a storage tank. Coatings serve one of two main purposes: (1) they protect the metal from attack by a corrosive liquid or environment, (2) they protect the product from contamination by corrosion products.

Collection System. A series of components that collect storm water, waste or spills. Collection systems are used at tank farms to collect spills through a network of pipes, channels, sewers, culverts, etc. necessary to transport the flow from collection points to slop tanks, retention areas, treatment facilities or outfall.

Combustible Liquid. Any liquid having a flashpoint at or above 100°F and below 200°F.

Compounds Highly Toxic To Aquatic Life. Compounds that have an LC_{50} (concentration of materials that is lethal to one-half of the test population of aquatic animals upon continuous exposure for 96 hrs or less) of less than 1 mg/liter include all compounds classified as X and A by EPA classification of hazardous substances. (See 40 CFR 117.)

Containment. The prevention of the spreading of oil or other hazardous materials by the placing of booms or physical barriers and the use of absorbants, gelling or herding agents or other materials to mitigate the effects of the spill.

Containment System. A structure having an impervious surface (concrete, asphalt, membrane, etc.) surrounded by curbs, gutters, dikes, etc. The purpose is to prevent any flow from leaving a defined area.

Corrosion. The deterioration of a material, usually a metal such as steel, resulting from a flow of electricity from a metal (anode) to a positively charged material (cathode) through an electrolyte.

This electrochemical action causes destructive alteration or eating away of the metal anode where positively charged atoms of metal detach themselves from the solid surface and enter into solution, while the corresponding negative charges, in the form of electrons, are left behind in the metal.

Anode. A metal electrode from which electric current leaves the surface and enters a solution (electrolyte). The electrical-chemical action causes destructive alteration, or eating away, of the metal, typically through the process of oxidation.

Cathodic Protection. An electrical process for preventing corrosion on a wide variety of metallic structures which are in electrolytes such as soil or water. It operates by passing direct current continuously from electrodes which are installed in the electrolyte to the structure protected. The typical cathodic protection installation consists of a buried steel tank which becomes the cathode, and a separate "sacrificial" anode, which usually consists of a bar,

rod, or wire of metal. The anode is literally consumed as electrical current passes from it through the electrolyte to the cathode (steel tank). Hence, the material which undergoes corrosion is the sacrificed anode; not the steel tank.

Galvanic Corrosion. Self-generated corrosion which results when dissimilar metals placed in the soil electrolyte produce electrical currents. Corrosion occurs at the anodic surface where current leaves the metal to enter the soil electrolyte.

Electrical Insulation. A non-conductive material used for preventing corrosion caused by dissimilar metals; for example, by using insulating couplings to connect copper pipe and fittings to steel pipe.

Electrolyte. A chemical substance either a liquid, paste, or gas which facilitates the flow of electrons in an electric field. Soil and ground water adjacent to and in contact with a buried steel tank act as an electrolyte with respect to the electrochemical process of corrosion.

Electrolytic Corrosion. Corrosion as a result of direct current from outside sources entering and then leaving a particular metal structure by way of an electrolyte. Where current enters the structure, that structure is usually unaffected or is provided with some degree of protection. Where the current leaves the structure, corrosion occurs. In underground work, this type of corrosion is often referred to as stray current corrosion and is a result of currents entering the ground from sources of direct current such as street railways or DC machinery.

Sacrificial Protection. Reduction or prevention of corrosion of a metal in an electrolyte by galvanically coupling it to a more anodic metal which literally is consumed; hence, sacrificial.

Stray Current Corrosion. Corrosion resulting from direct current flow through paths other than the extended circuit. Service stations, for example, built near cathodic protection rectifiers, factories, or shops using DC, or electrified railways or transit systems, may experience stray current corrosion.

Corrosive Material. Any liquid that causes destruction of human skin tissue or that has a severe corrosion rate on steel, aluminum or other metallic or nonmetallic substance.

Discharge. Includes, but is not limited to, any spilling, leaking, pumping, pouring, emitting, emptying or dumping except those activities duly permitted by any local, State, or Federal agency.

Dispersing Agents. Chemical agents or compounds which emulsify, disperse or solubilize oil into the water column or act to further the surface spreading of oil slicks in order to facilitate dispersal of the oil into the water column.

Emulsion. A mechanical mixture of two liquids which do not naturally mix, such as oil and water. Water-in-oil emulsions have the water as the internal phase and oil as the external. Oil-in-water emulsions have water as the external phase and the internal phase is oil.

Flammable Liquid. Any liquid having a flash point below 100°F as determined by prescribed testing procedures.

Flammable Solid. Any solid material other than explosives which is liable to cause fires through friction, adsorption or moisture, spontaneous chemical changes, retained heat from manufacturing or processing, or which can be ignited readily and when ignited burns so vigorously and persistently that it creates a serious transportation hazard.

Flash Point. The lowest temperature at which substances give off sufficient vapor to form a mixture which will ignite, under standard conditions.

Floaters. Materials that will float on the surface of water in a spill situation; all chemicals with solubilities of less than 1 percent and specific gravities of less than 1.0.

Fuel Oil Grade. Numerical ratings ranging from 1 to 6. The lower the grade number, the thinner the oil is and the more easily it evaporates. A high number indicates a relatively thick, heavy oil. No. 1 and 2 fuel oils are usually used in domestic heaters, and the others are used by industry and ships. No. 5 and 6 oils are solids which must be liquefied by heating. Kerosene, coal oil, and range oil are all No. 1 oil. No. 3 fuel oil is no longer used as a standard term.

Gas (or natural gas). Simply speaking, petroleum in a gaseous state. Natural gas should not be confused with motor gasoline, which must ordinarily be refined from crude oil.

Human Poisons. Those substances ranked as Class A or Class B Poisons by the Department of Transportation as described in 49 CFR 173 (H).

LeGrand Analysis. A procedure to evaluate the potential for ground water contamination at a specific site under consideration for the storage of a hazardous substance. Evaluation factors include physical site characteristics, ground water data, and the hazard potential of the substance that may be stored at the site.

Liner. Corrosion and chemical resistant materials which are sprayed, brushed, or applied to the interior of a tank to protect the metal from attack from a corrosive liquid or environment, and to protect the product from contamination by corrosion products.

LNG. Liquid natural gas.

LPG. Liquefied petroleum gas, such as propane or butane, commonly known as bottled gas.

NFPA. Refers to the National Fire Protection Association and its codes and generally accepted standards.

Oil. Refers to oil in any form including gasoline, crude oil, fuel oil, diesel oil, lubricating oil, oil refuse, sludge, and any other petroleum related products.

pH. Term used to express the apparent acidity or alkalinity of aqueous solutions; values below 7 indicate acid solutions and values above 7 indicate alkaline solutions.

Reactives. Those materials which in themselves or in contact with water are readily capable of detonation or of explosive decomposition or explosive reaction at normal temperatures and pressures as well as those materials which are sensitive to mechanical or localized thermal shock at normal temperatures and pressures.

Resistivity. A unit measure of the electrical resistance of the soil.

Saturation Zone. That portion of the earth's soil and rock in which the functional interstices or permeable rocks are saturated with water under hydrostatic pressure.

Solubility. The property of a chemical to dissolve or pass into solution. Solubility in water refers to the pounds of a chemical that will dissolve in 100 pounds of pure water. Solubility usually increases when the temperature increases.

Solubles. Solids with solubilities in water of greater than 0.1% or 1000 ppm.

Specific Gravity. The ratio of the weight of a given volume of the material at 4°C (or at some stated temperature) to the weight of an equal volume of distilled water.

Storage Facility. Refers to warehouses, yards, tanks, containers, pipes and equipment for storing and handling hazardous materials.

Storm Runoff. A flow containing only water and no hydrocarbons.

Striker Plate. A 12 inch x 12 inch steel plated welded at the bottom in the interior of a tank under the fill opening; insures that the dip stick will not strike tank wall, thereby lessening potential for corrosion at that spot.

Substances Amenable to Biological Treatment. Solids or liquids which, while not necessarily biodegradable, can be accepted into biological waste treatment systems without causing adverse impact on treatment of the pollutants normally present. Compounds in this classification group would be introduced to biological treatment systems at rates so as not to cause a toxic or inhibiting effect on the treatment process.

Unsaturated Zone. That portion of the lithosphere in which the functional interstices of permeable rock or earth are not (except temporarily) filled with water under hydrostatic pressure; that is, the water in the interstices is held by capillarity.

Unstable (Reactive) Liquid. A liquid in the pure state or as commercially produced or transported which will vigorously polymerize, decompose, condense, or become self-reactive under conditions of shock, pressure, or temperature.

Vapor Recovery System. A system designed to capture and retain, without processing, vapors displaced during filling operations at service stations, bulk storage plants, or terminals.

Viscosity. The property of liquids which causes them to resist instantaneous change of shape, or instantaneous rearrangement of their parts, due to internal friction caused by molecular attraction.

Viscous. Thick, resistant to flow, having a high viscosity.

Volatiles. Chemicals with vapor pressures greater than 1300 Pa (10 mm Hg) at 10°C.

Bibliography

SECTION 1

American Petroleum Institute. Results of API Tank and Piping Leak Survey. Washington, D.C. January 21, 1981.

___. Underground Spill Cleanup Manual. API Publication No. 1628, 1st Edition. Washington, D.C. June 1980.

Berg, O. and J. Askham. Gasoline, An Underground Water Pollutant in Monroe County. Bulletin 239. The Rochester Committee for Scientific Information. Rochester, NY. May 1980.

Byer, H.G., Jr. "Ground Water Contamination by Chlorinated Hydrocarbons: Causes and Prevention," Civil Engineering -ASCE. March 1981.

Flacke, R. F. et al. Annual Report of the New York State Oil Spill Prevention, Control, and Compensation Program, April 1, 1979 - March 31, 1980. Albany. n.d.

___. Annual Report of the NYS Oil Spill Prevention, Control and Compensation Program, April 1, 1978 - March 31, 1979. Albany, n.d.

Herleth, G.L., Jr. Spill Events in Maryland, July 1, 1979 - June 30, 1980. State of Maryland, Department of Natural Resources. Annapolis. July 31, 1980.

New York State Department of Health. Well Contamination By Gasoline--Survey Report. Albany, NY. May 22, 1979.

SECTION 2

National Wildlife Federation. The Toxic Substances Dilemma, A Plan for Citizen Action. Washington, D.C. n.d.

U.S. Environmental Protection Agency. Proposed Ground Water Protection Strategy. Office of Drinking Water. Washington, D.C. November 1980.

___. Hazardous Materials Spill Monitoring: Safety Handbook and Chemical Hazard Guide, Part A. Office of Research and Development. EPA-600/4-79-008a. Las Vegas, NV. January 1979.

SECTION 3

American Petroleum Institute. Recommended Practice for Bulk Liquid Stock Control at Retail Outlets. API Publication 1621, 3rd Edition. Washington, D.C. 1977.

___. Safe Operation of Inland Bulk Plants. API Publication No. 2008, 3rd Edition Washington, D.C. November 1976.

___. Recommended Good Practices for Bulk Liquid Loss Control in Terminals and Depots. API Bulletin No. 1623. Washington, D.C. June 1972.

___. Service Station Tankage Guide. API Bulletin No. 1611. Washington, D.C. January 1961.

Product Storage and Handling Committee, Bulk Plant Design Guidelines for Oil Spill Prevention and Control, Pace Report No. 80-3, Petroleum Association for Conservation of the Canadian Environment. September 1980.

Rizzo, F.E. Detection of Active Corrosion, Paper No. HC-14. Harco Corporation, Medina, OH.

Standards of the Suffolk County Department of Health Services for the Administration of Article 12 of the Suffolk County Sanitary Code. October 3, 1979.

Suggested Ways to Meet Corrosion Protection Codes for Underground Tanks and Piping. The Hinchman Company. Detroit, MI. April 8, 1981.

SECTIONS 5 & 6

American Petroleum Institute. The Migration of Petroleum Products in Soil and Ground Water. API Publication No. 4149. Washington, D.C. December 1972.

Burgess, W.S. "A Simplified Method for Locating Flammable Products Underground." Spill Technology Newsletter. July-August 1979.

Husock, B. Corrosion and Cathodic Protection of Underground Tanks at Service Stations. Paper No. HC-15. Harco Corporation, Cathodic Protection Division. n.d.

Maryland Petroleum Association. Operating Handbook, Maryland Petroleum's Association's Task Force on Underground Petroleum Product Loss. Annapolis. n.d.

Petroleum Association for Conservation of the Canadian Environment. Bulk Plant Design Guidelines for Oil Spill Prevention and Control. Pace Report No. 80-3. Ottawa, Ontario. September 1980.

Standards of the Suffolk County Department of Health Services for the Administration of Article 12 (Toxic and Hazardous Materials Storage and Handling Control) of the Suffolk County Sanitary Code, Design of Underground Gasoline and Oil Storage Facilities. October 3, 1979.

Texas Research Institute. Underground Movement of *Gasoline on Ground Water and Enchanced Recovery* by Surfactants. For American Petroleum Institute. API Publication No. 4317. n.d.

U.S. Environmental Protection Agency. NPDES Best Management Practices Guidance Document. EPA 600/g-79045, December 1979, pp. 20-40.

___. Methods of Preventing. Detecting, and Dealing with Surface Spills of Contaminants Which May Degrade Underground Water Resources for Public Water Systems. EPA-510/ 8-79-018. Washington, D.C. July 1979.

Weber, E.C. 1980 Fiscal Year, 8th Annual Report - Administration of the Maryland Oil Disaster Containment, Cleanup and Contingency Fund July 1, 1979 - June 30, 1980. State of Maryland, Department of Natural Resources. Annapolis. July 1, 1980.

SECTION 7

Battelle Columbus Laboratories. Bacterial Activity in Ground Waters Containing Petroleum Products. For American Petroleum Institute. API Publication No. 4211. November 1973.

Canter, L.W. Environmental Impact Assessment. McGraw-Hill Book Company. New York, NY. 1977.

Clark-McGlennon Associates. A Decision Guide for Siting Acceptable Hazardous Waste Facilities in New England. Prepared for New England Regional Commission. Boston, MA. November 1980

___. An Introduction to Facilities for Hazardous Waste Management. Prepared for New England Regional Commission. Boston, MA. November 1980.

___. Criteria for Evaluating Sites for Hazardous Waste Management. Prepared for New England Regional Commission. Boston, MA. November 1980.

___. Negotiating to Protect Your Interests. Prepared for New England Regional Commission. Boston, MA, November, 1980.

Dudley, E.F. "Environmental Aspects of Site Selection." Journal of the Power Division, Proceedings of the American Society of Civil Engineers. June 1972.

Freeze, R.A. and J.A. Cherry. Ground Water. Prentice-Hall Inc. Englewood Cliffs, NJ. 1979.

Kim, N.K. and D.W. Stone. Organic Chemicals and Drinking Water. NYS Department of Health. Albany, NY. April, 1981.

Kolpack, R.L. et al. Rate of Oil in a Water Environment, Phase I-Vol. 1A Review and Evaluation of the Literature. Environmental Geology Program, University of Southern California. For American Petroleum Institute. API Publication No. 4212. October 1973.

LeGrand, H.E. "Management Aspects of Ground Water Contamination." Journal Water Pollution Control Federation. V. 36 NJ. September 1964.

Massachusetts Department of Environmental Management. Proposed Siting Regulations Implementing the Massachusetts Hazardous Waste Facility Siting Act. Boston, MA. April 1981.

___. Hazardous Waste Management in Massachusetts - A Draft Environmental Impact Report. Boston, MA. January 1981.

___. Building the Local Role. Harvard University. John F. Kennedy School of Government. Cambridge, MA. June 1980.

Monroe County Department of Planning. Guide to Development Permits. Rochester, NY. January 1981.

National Fire Protection Association, Inc. Underground Leakage of Flammable and Combustible Liquids. Batterymarch Park, Quincy, MA 02269.

New York State Department of Environmental Conservation. River Conservation Directory. Albany, NY. 1981.

___. Draft Regulations for Siting of Industrial Hazardous Waste Facilities. 6 NYCRR Part 361. Pursuant to ECL Article 27, Title 11. October 1, 1980.

___. Draft Environmental Impact Statement, Regulatory Impact Statement - Proposed Adoption of Regulations for Siting Industrial Hazardous Waste Facilities. 6 NYCRR Part 361. Pursuant to ECL Article 27 Title 11. October 1, 1980.

___ "Environmental Conservation Handbook, Water Quality Accident Handbook, Chapter 600 - Technical Information." Albany, NY. September 1, 1977.

___. Environmental Directory. 1st Edition. Albany, NY. 1977.

___. State Environmental Quality Review Act Handbook for Local Government. Albany, NY. October 1976.

Osgood, J.O. "Hydrocarbon Dispersion in Ground Water: Significance and Characteristics." Ground Water. Vol. 12. No. 6. Nov-Dec. 1974.

Soil Conservation Service, U.S. Department of Agriculture (by Department of Agronomy, Cornell University). Soil Survey Interpretations of Soils in New York State. Syracuse, NY. December 1973.

___. Guide for Interpreting Engineering Uses of Soils. November 1971.

Appendix A

LIST OF HAZARDOUS SUBSTANCES

Under Section 311 of the Clean Water Act, the U.S. EPA has designated the following hazardous substances. (40 CFR 116; reportable quantities for spills may be found in 40 CFR 117).

Data on the physical state of the chemical (liquid, solid, gas) and type of hazard of each can be obtained from the U.S. Coast Guard Chemical Hazard Response Information System (CHRIS) Manual or by contacting the Department of Environmental Conservation.

Common name	CAS No.	Synonyms
Acetaldehyde	75070	Ethanal, ethyl aldehyde, acetic aldehyde.
Acetic acid	64197	Glacial acetic acid, vinegar acid
Acetic anhydride	108247	Acetic oxide, acetyl oxide
Acetone cyanohydrin	75865	2-methyllactonitrile, alpha-hydroxyisobutyronitrile.
Acetyl bromide	506967	
Acetyl chloride	79367	
Acrolein	107028	2-propenal, acrylic aldehyde, acrylaldehyde, acraldehyde.
Acrylonitrile	107131	Cyanoethylene, Fumigrain, Ventox, propenenitrile, vinyl cyanide.
Adipic acid	124049	Hexanedioic acid
[illegible]	309002	Octalene, HHDN
[illegible]lcohol	107186	2-propen-1-ol, 1-propenol-3, vinyl carbinol.
Allyl chloride	107051	3-chloropropene, 3-chloropropylene, Chlorallylene.
Aluminum sulfate	10043013	Alum
Ammonia	7664417	
Ammonium acetate	631618	Acetic acid ammonium, salt
Ammonium benzoate	1863634	
Ammonium bicarbonate	1066337	Acid ammonium carbonate, ammonium hydrogen carbonate.
Ammonium bichromate	7789095	
Ammonium bifluoride	1341497	Acid ammonium fluoride, ammonium hydrogen fluoride
Ammonium bisulfite	10192300	
Ammonium carbamate	1111780	Ammonium aminoformate
Ammonium carbonate	506876	
Ammonium chloride	12125029	Ammonium muriate, sal ammoniac, salmiac, Amchlor.
Ammonium chromate	7788989	
Ammonium citrate dibasic	3012655	Diammonium citrate, citric acid diammonium salt.
Ammonium fluoborate	13826830	Ammonium fluoroborate, ammonium borofluoride.
Ammonium fluoride	12125018	Neutral ammonium fluoride
Ammonium hydroxide	1336216	
Ammonium oxalate	6009707	
	5972736	
	14258492	
Ammonium silicofluoride	16919190	Ammonium fluosilicate
Ammonium sulfamate	7773060	Ammate, AMS, ammonium amidosulfate.
Ammonium sulfide	12135761	
Ammonium sulfite	10196040	
	10192300	
Ammonium tartrate	3164292	Tartaric acid ammonium salt
	14307438	
Ammonium thiocyanate	1762954	Ammonium rhodanide, ammonium sulfocyanate, ammonium sulfocyanide.
Ammonium thiosulfate	7783188	Ammonium hyposulfite
Amyl acetate	628637	Amylacetic ester
		Pear oil
		Banana oil
Aniline	62533	aniline oil, phenylamine, aminobenzene, aminophen, hynol.
A[illegible]y pentachloride	7647189	

Common name	CAS No.	Synonyms
Antimony potassium tartrate.	28300745	Tartar emetic, tartrated antimony, tartrated antimony, potassium antimonyltartrate.
Antimony tribromide	7789619	
Antimony trichloride	10025919	Butter of antimony
Antimony trifluoride	7783564	Antimony fluoride
Antimony trioxide	1309644	Diantimony trioxide, flowers of antimony.
Arsenic disulfide	1303328	Red arsenic sulfide
Arsenic pentoxide	1303282	Arsenic acid anhydride, arsenic oxide.
Arsenic trichloride	7784341	Arsenic chloride, arsenious chloride, arsenous chloride, butter of arsenic.
Arsenic trioxide	1327533	Arsenious acid, arsenious oxide, white arsenic.
Arsenic trisulfide	1303339	Arsenious sulfide, yellow arsenic sulfide.
Barium cyanide	542621	
Benzene	71432	Cyclohexatriene, benzol
Benzoic acid	65850	Benzenecarboxylic acid, phenylformic acid, dracylic acid.
Benzonitrile	100470	Phenyl cyanide, cyanobenzene
Benzoyl chloride	98884	Benzenecarbonyl chloride
Benzyl chloride	100447	
Beryllium chloride	7787475	
Beryllium fluoride	7787497	
Beryllium nitrate	7787555	
	13597994	
n-butyl phthalate	84742	1,2-benzenedicarboxylic acid, dibutyl ester, dibutyl phthalate.
Butyl acetate	123864	acetic acid butyl ester
Butylamine	109739	1-aminobutane
Butyric acid	107926	Butanoic acid, ethylacetic acid
Cadmium acetate	543908	
Cadmium bromide	7789426	
Cadmium chloride	10108642	
Calcium arsenate	7778441	Tricalcium orthoarsenate
Calcium arsenite	52740166	
Calcium carbide	75207	Carbide, acetylenogen
Calcium chromate	13765190	Calcium chrome yellow, gelbin, yellow ultramarine.
Calcium cyanide	592018	
Calcium dodecylbenzenesulfonate.	26264062	
Calcium hypochlorite	7778543	
Captan	133062	Orthocide-406, SR-406, Vancide-59
Carbaryl	63252	Sevin
Carbofuran	1563662	
Carbon disulfide	75150	Carbon bisulfide, dithiocarbonic anhydride.
Carbon tetrachloride	56235	Tetrachloromethane Perchloromethane
Chlordane	57749	Toxichlor, chlordan
Chlorine	7782505	

Common name	CAS No.	Synonyms
Chlorobenzene	108907	Monochlorobenzene benzene chloride
Chloroform	67663	trichloromethane
Chlorpyrifos	2921882	Dursban
Chlorosulfonic acid	7790945	Sulfuric chlorohydrin
Chromic acetate	1066304	
Chromic acid	11115745	chromic anhydride, chromium trioxide.
Chromic sulfate	10101538	
Chromous chloride	10049055	
Cobaltous bromide	7789437	Cobalt bromide
Cobaltous formate	544183	Cobalt formate
Cobaltous sulfamate	14017415	Cobalt sulfamate
Coumaphos	56724	Co-Ral
Cresol	1319773	Cresylic acid Hydroxytoluene
Crotonaldehyde	4170303	2-butenal propylene aldehyde
Cupric acetate	142712	Copper acetate, crystallized verdigris.
Cupric acetoarsenite	12002038	Copper acetoarsenite, copper acetate arsenite, Paris green.
Cupric chloride	7447394	Copper chloride
Cupric nitrate	3251238	Copper nitrate
Cupric oxalate	5893663	Copper oxalate
Cupric sulfate	7758987	Copper sulfate
Cupric sulfate, ammoniated	10380297	Ammoniated copper sulfate
Cupric tartrate	815827	Copper tartrate
Cyanogen chloride	506774	
Cyclohexane	110827	Hexahydrobenzene, hexamethylene, hexanaphthene.
2,4-D acid	94757	2,4-dichlorophenoxyacetic acid
2,4-D ester	94111 94791 94804 1320189 1928387 1928616 1929733 2971382 25168267 53467111	2,4-dichlorophenoxyacetic acid ester
DDT	50293	p,p'-DDT
Diazinon	333415	Dipofene, Diazitol, Basudin, Spectracide.
Dicamba	1918009	2-methoxy-3,6-dichlorobenzoic acid
Dichlobenil	1194656	2,6-dichlorobenzonitrile, 2,6-DBN
Dichlone	117806	Phygon, dichloronaphthoquinone
Dichlorobenzene	25321226	Di chloricide Paramoth (Para)
Dichloropropane	26638197	Propylene dichloride
Dichloropropene	26952238	
Dichloropropene dichloropropane (mixture)	8003198	D-D mixture Vidden D
2,2-Dichloropropionic acid	75990	Dalapon
Dichlorvos	62737	2,2-dichlorovinyl dimethyl phosphate, Vapona.
Dieldrin	60571	Alvit
Diethylamine	109897	
Dimethylamine	124403	
Dinitrobenzene (mixed)	25154545	Dinitrobenzol
Dinitrophenol	51285 (2,4-)	Aldifen
Dinitrotoluene	25321146	DNT
Diquat	85007 2764729	Aquacide Dextrone, Reglone, Diquat dibromide.
Disulfoton	298044	Di-syston
Diuron	330541	DCMU, DMU
Dodecylbenzenesulfonic acid.	27176870	
Endosulfan	115297	Thiodan
Endrin	72208	Mendrin, Compound 269
Epichlorohydrin	106898	chloropropylene oxide
Ethion	563122	Nialate, ethyl methylene, phosphorodithioate.
Ethylbenzene	100414	Phenylethane
Ethylenediamine	107153	1,2-diaminoethane
Ethylenediaminetetraacetic acid (EDTA).	60004	Edetic acid, Havidota, (ethylenedinitrilo)-tetraacetic acid.
Ethylene dibromide	106934	1,2-dibromoethane acetylene dibromide sym-dibromoethylene

Common name	CAS No.	Synonyms
Ethylene dichloride	107062	1,2-dichloroethane sym-bichloroethane
Ferric ammonium citrate	1185575	Ammonium ferric citrate
Ferric ammonium oxalate	2944674 55488374	Ammonium ferric oxalate
Ferric chloride	7705080	Flores martis, iron trichloride
Ferric fluoride	7783508	
Ferric nitrate	10421484	Iron nitrate
Ferric sulfate	10028225	Ferric persulfate, ferric sesquisulfate, ferric tersulfate.
Ferrous ammonium sulfate	10045893	Mohr's salt, iron ammonium sulfate.
Ferrous chloride	7758943	Iron chloride, iron dichloride, iron protochloride.
Ferrous sulfate	7720787 7782630	Green vitriol Iron vitriol, iron sulfate, iron protosulfate.
Formaldehyde	50000	Methyl aldehyde, methanal, formalin.
Formic acid	64186	Methanoic acid
Fumaric acid	110178	Trans-butenedioic acid, trans-1,2-ethylenedicarboxylic acid, boletic acid, allomaleic acid.
Furfural	98011	2-furaldehyde, pyromucic aldehyde
Guthion	86500	Gusathion, azinphos-methyl
Heptachlor	76448	Velsicol-104, Drinox, Heptagran
Hexachlorocyclopentadiene	77474	Perchlorocyclopentadiene
Hydrochloric acid	7647010	Hydrogen chloride; muriatic acid
Hydrofluoric acid	7664393	Fluohydric acid
Hydrogen cyanide	74908	Hydrocyanic acid
Hydrogen sulfide	7783064	Hydrosulfuric acid Sulfur hydride
Isoprene	78795	2-methyl-1,3-butadiene
Isopropanolamine dodecylbenzenesulfonate.	42504461	
Kelthane	115322	Di(p-chlorophenyl)-trichloromethylcarbinol, DTMC, dicofol.
Kepone	143500	Chlordecone-1,1a,3,3a,4,5,5,5a,5b,6-decachlorooctahydro-1,3,4-metheno-2H cyclobuta(cd)pentalen-2-one
Lead acetate	301042	Sugar of lead
Lead arsenate	7784409 7645252 10102484	
Lead chloride	7758954	
Lead fluoborate	13814965	Lead fluoroborate
Lead fluoride	7783462	Lead difluoride, plumbous fluoride
Lead iodide	10101630	
Lead nitrate	10099748	
Lead stearate	7428480 1072351 52652592	Stearic acid lead salt
Lead sulfate	7446142	
Lead sulfide	1314870	Galena
Lead thiocyanate	592870	Lead sulfocyanate
Lindane	58899	Gamma-BHC, gamma-benzene hexachloride.
Lithium chromate	14307358	
Malathion	121755	Phospothion
Maleic acid	110167	Cis-butenedioic acid, cis-1,2-ethylenedicarboxylic acid, toxilic acid.
Maleic anhydride	108316	2,5-furandione, cis-butenedioic anhydride, toxilic anhydride.
Mercaptodimethur	2032657	Mesurol
Mercuric cyanide	592041	Mercury cyanide
Mercuric nitrate	10045940	Mercury nitrate, mercury pernitrate
Mercuric sulfate	7783359	Mercury sulfate, mercury persulfate.
Mercuric thiocyanate	592858	Mercury thiocyanate, mercuric sulfocyanate, mercuric sulfocyanide.
Mercurous nitrate	7782867 10415755	Mercury protonitrate
Methoxychlor	72435	DMDT, methoxy-DDT
Methyl mercaptan	74931	Methanethiol, mercaptomethane, methyl sulfhydrate, thiomethyl alcohol.
Methyl methacrylate	80626	Methacrylic acid methyl ester, methyl-2-methyl-2-propenoate.
Methyl parathion	298000	Nitrox-80
Mevinphos	7786347	Phosdrin
Mexacarbate	315184	Zectran
Monoethylamine	75047	Ethylamine, aminoethane
Monomethylamine	74895	Methylamine, aminomethane
Naled	300765	Dibrom
Naphthalene	91203	White tar, tar camphor, naphthalin.
Naphthenic acid	1338245	Cyclohexanecarboxylic acid, hexahydrobenzoic acid.
Nickel ammonium sulfate	15699180	Ammonium nickel sulfate
Nickel chloride	37211055 7718549	Nickelous chloride

Common name	CAS No.	Synonyms
Nickel hydroxide	12054487	Nickelous hydroxide
Nickel nitrate	14216752	
Nickel sulfate	7786814	Nickelous sulfate
Nitric acid	7697372	Aqua fortis
Nitrobenzene	98953	Nitrobenzol, oil of mirbane
Nitrogen dioxide	10102440	Nitrogen tetraoxide
Nitrophenol (mixed)	25154556	Mononitrophenol
Nitrotoluene	1321126	
Paraformaldehyde	30525894	Paraform, Formagene, Triformol, polymerized formaldehyde, polyoxymethylene.
Parathion	56382	DNTP, Niran
Pentachlorophenol	87865	PCP, Penta
Phenol	108952	Carbolic acid, phenyl hydroxide, hydroxybenzene, oxybenzene.
Phosgene	75445	Diphosgene, carbonyl chloride, chloroformyl chloride.
Phosphoric acid	7664382	Orthophosphoric acid
Phosphorus	7723140	Black phosphorus, red phosphorus, white phosphorus, yellow phosphorus.
Phosphorus oxychloride	10025873	Phosphoryl chloride, phosphorus chloride.
Phosphorus pentasulfide	1314803	Phosphoric sulfide, thiophosphoric anhydride, phosphorus persulfide.
Phosphorus trichloride	7719122	Phosphorous chloride
Polychorinated biphenyls	1336363	PCB, Aroclor, polychlorinated diphenyls.
Potassium arsenate	7784410	
Potassium arsenite	10124502	Potassium metaarsenite
Potassium bichromate	7778509	Potassium dichromate
Potassium chromate	7789008	
Potassium cyanide	151508	
Potassium hydroxide	1310583	Potassium hydrate, caustic potash, potassa.
Potassium permanganate	7722847	Chameleon mineral
Propargite	2312358	Omite
Propionic acid	79094	Propanoic acid, methylacetic acid, ethylformic acid.
Propionic anhydride	123628	Propanoic anhydride, methylacetic anhydride.
Propylene oxide	75569	Propene oxide
Pyrethrins	121299	Pyrethrin I
	121211	Pyrethrin II
Quinoline	91225	1-benzazine, benzo(b)pyridine, leucoline, chinoleine, leucol.
Resorcinol	108463	Resorcin, 1,3-benzenediol, meta-dihydroxybenzene.
Selenium oxide	7446084	Selenium dioxide
Silver nitrate	7761888	Nitric acid silver (1+) salt, lunar caustic
Sodium	7440235	Natrium
Sodium arsenate	7631892	Disodium arsenate
Sodium arsenite	7784465	Sodium metaarsenite
Sodium bichromate	10588019	Sodium dichromate
Sodium bifluoride	1333831	
Sodium bisulfite	7631905	Sodium acid sulfite, sodium hydrogen sulfite.
Sodium chromate	7775113	
Sodium cyanide	143339	
Sodium dodecylbenzenesulfonate.	25155300	
Sodium fluoride	7681494	Villiaumite
Sodium hydrosulfide	16721805	Sodium hydrogen sulfide
Sodium hydroxide	1310732	Caustic soda, soda lye, sodium hydrate.
Sodium hypochlorite	7681529	Bleach
	10022705	
Sodium methylate	124414	Sodium methoxide
Sodium nitrite	7632000	
Sodium phosphate, dibasic	7558794	
	10039324	
	10028247	
	10140655	
Sodium phosphate, tribasic.	7785844	
	7601549	
	10101890	
	10361654	
	7758294	
	10124568	
Sodium selenite	10102188	
	7782823	

Common name	CAS No.	Synonyms
Strontium chromate	7789062	
Strychnine	57249	
Styrene	100425	Vinylbenzene, phenylethylene, styrol, styrolene, cinnamene, cinnamol.
Sulfuric acid	7664939	Oil of vitriol, oleum
Sulfur monochloride	12771083	Sulfur chloride
2,4,5-T acid	93765	2,4,5-trichlorophenoxy acetic acid
2,4,5-T amines	6369966	Acetic acid (2,4,5 trichlorophenoxy)-compound with N,N-dimethylmethanamine (1:1)
	6369977	Acetic acid (2,4,5-trichlorophenoxy)-compound with N-methylmethanamine (1:1).
	1319728	Acetic acid (2,4,5-trichlorophenoxy)-compound with 1-amino 2-propanol (1:1).
	3813147	Acetic acid (2,4,5-trichlorophenoxy)-compound with 2,2,2 nitrilotris (ethanol) (1:1).
2,4,5-T esters	2545597	2,4,5-trichlorophenoxy acetic esters.
	93798	
	61792072	
	1928478	
	25168154	
2,4,5-T salts	13560991	Acetic acid (2,4,5-trichlorophenoxy)-sodium salt.
2,4,5-TP acid	93721	Propanoic acid 2-(2,4,5-trichlorophenoxy)
2,4,5-TP esters	32534955	Propanoic acid, 2-(2,4,5 trichlorophenoxy), isooctyl ester
TDE	72548	DDD
Tetraethyl lead	78002	Lead tetraethyl, TEL
Tetraethyl pyrophosphate	107493	TEPP
Thallium sulfate	10031591	
	7446186	
Toluene	108883	Toluol, methylbenzene, phenylmethane, Methacide.
Toxaphene	8001352	Camphechlor
Trichloroethylene	79016	Ethylene trichloride
Trichlorfon	52686	Dipterex
		Dylox
Trichlorophenol	25167822	Colitmosol, Dowicide 2 or 2S, Omal, Phenachlor.
Triethanolamine dodecylbenzenesulfonate.	27323417	
Triethylamine	121448	
Trimethylamine	75503	TMA
Uranyl acetate	541093	
Uranyl nitrate	10102064	
	36478769	
Vanadium pentoxide	1314621	Vanadic anhydride, vanadic acid anhydride.
Vanadyl sulfate	27774136	Vanadic sulfate, vanadium sulfate
Vinyl acetate	108054	Acetic acid ethylene ether
Vinylidene chloride	75354	1,1-dichloroethylene 1,1-dichloroethene
Xylene (mixed)	1330207	Dimethylbenzene
		Xylol
Xylenol	1300716	Dimethylphenol, hydroxydimethylbenzene.
Zinc acetate	557346	
Zinc ammonium chloride	14639975	
	14639986	
	52628258	
Zinc borate	1332076	
Zinc bromide	7699458	
Zinc carbonate	3486359	
Zinc chloride	7646857	Butter of zinc
Zinc cyanide	557211	
Zinc fluoride	7783495	
Zinc formate	557415	
Zinc hydrosulfite	7779864	
Zinc nitrate	7779886	
Zinc phenolsulfonate	127822	Zinc sulfocarbolate
Zinc phosphide	1314847	
Zinc silicofluoride	16871719	Zinc fluorsilicate
Zinc sulfate	7733020	White vitriol, zinc vitriol, white copperas.
Zirconium nitrate	13746899	
Zirconium potassium fluoride.	16923958	
Zirconium sulfate	14644613	Disulfatozirconic acid
Zirconium tetrachloride	10026116	

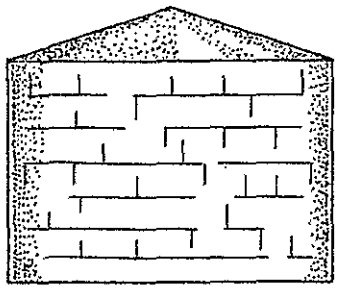
Appendix B
PRECAUTIONARY STORAGE DESIGNS

Contamination of the environment and even the risk of such contamination can be reduced when the design of a bulk storage facility incorporates precautions against accidents. Precautionary designs are not complicated, and they generally are economical. They should, therefore, be used at every storage facility.

The following drawings show simple but effective designs which will both reduce the risk of compromising the environment or public health and also reduce liability in the event of an accident. Additional details on the technologies illustrated here may be found in the **Technology Assessment Manual** available from the NYS Department of Environmental Conservation.

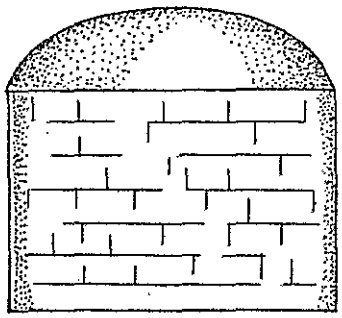
Figure B1

Types of Atmospheric
and Low-Pressure Tanks



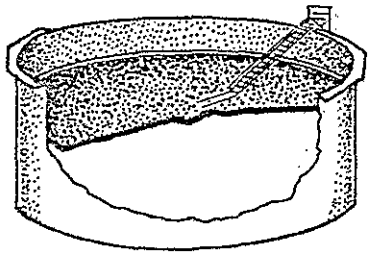
CONED ROOF TANK

- Simplest type of atmospheric tank
- Usually large, field-erected structure; can reach 300 feet in diameter and 64 feet in height
- Used for storage of liquids with low volatility



HEMISPHEROID TANK

- Low pressure tank
- Usually large, field-erected structure
- Used for storage of volatile liquids

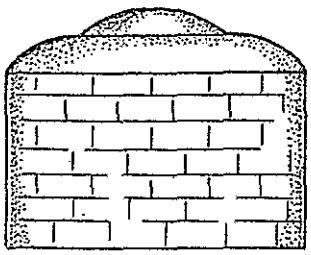


FLOATING ROOF TANK

- Atmospheric tank
- Usually large, field-erected structure
- Designed to reduce evaporation losses and increase protection from fire

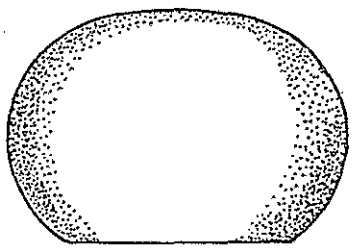
CYLINDRICAL TANK

- Low pressure tank
- Usually shop-erected and thus restricted to transportable sizes (e.g. 11-12 feet in diameter and 60 feet in length)



NODED HEMISPHEROID TANK

- Low pressure tank
- Usually field erected structure
- Used for storage of volatile liquids



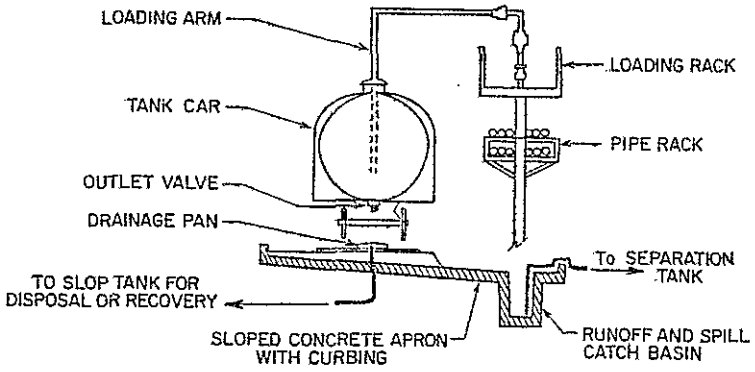
SPHEROID TANK

- Low pressure tank
- Usually large, field-erected structure; can reach 90 feet in diameter
- Used for storage of volatile liquids under pressure

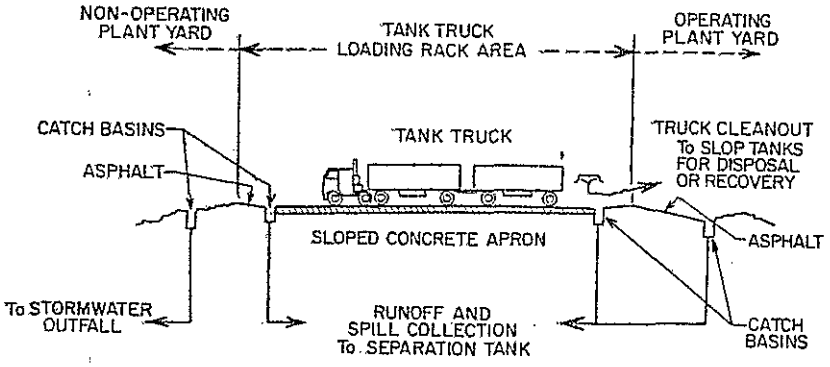
Figure B2

Loading and Equipment Spill Catchment and Treatment

(a) Tank Car Loading Rack Area



(b) Tank Truck Loading Rack Area



(c) Pump and Equipment Slab Area

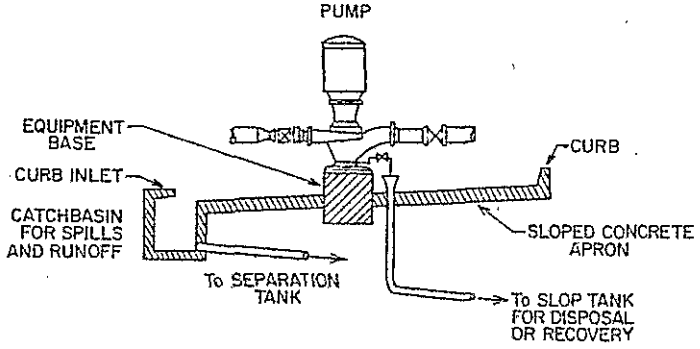


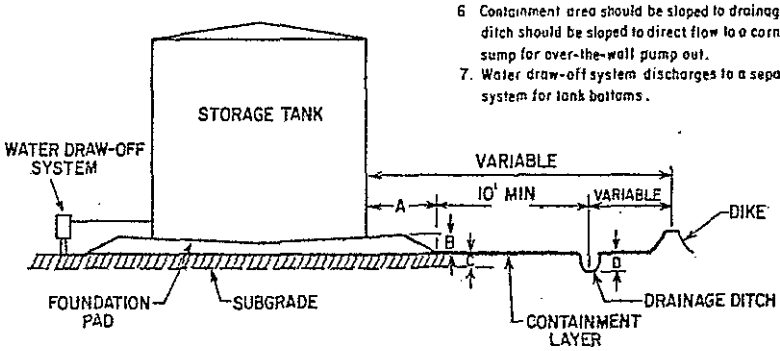
Figure B2 (continued)

Loading and Equipment Spill Catchment and Treatment (continued)

(d) Bulk Plant Layout

NOTES:

1. Dimension A is 1/25 of tank diameter plus one foot
2. Dimension B is 1 1/2' minimum.
3. Dimension C is 1' minimum.
4. Dimension D is 1 1/2' minimum.
5. Containment volume must equal 110% of tank volume.
6. Containment area should be sloped to drainage ditch and ditch should be sloped to direct flow to a corner collection sump for over-the-wall pump out.
7. Water draw-off system discharges to a separate treatment system for tank bottoms.



(e) Gravity Separation Tank

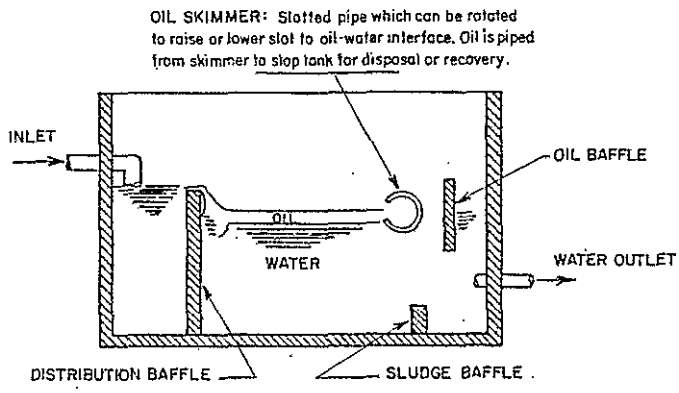


Figure B3

Typical Remote Pump Shut-off Valve

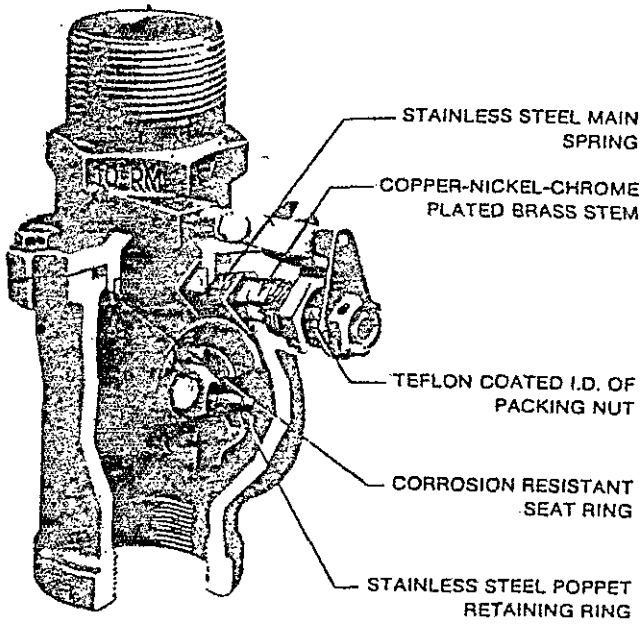


Figure B4

Float Vent Valves Used for Overfill Prevention

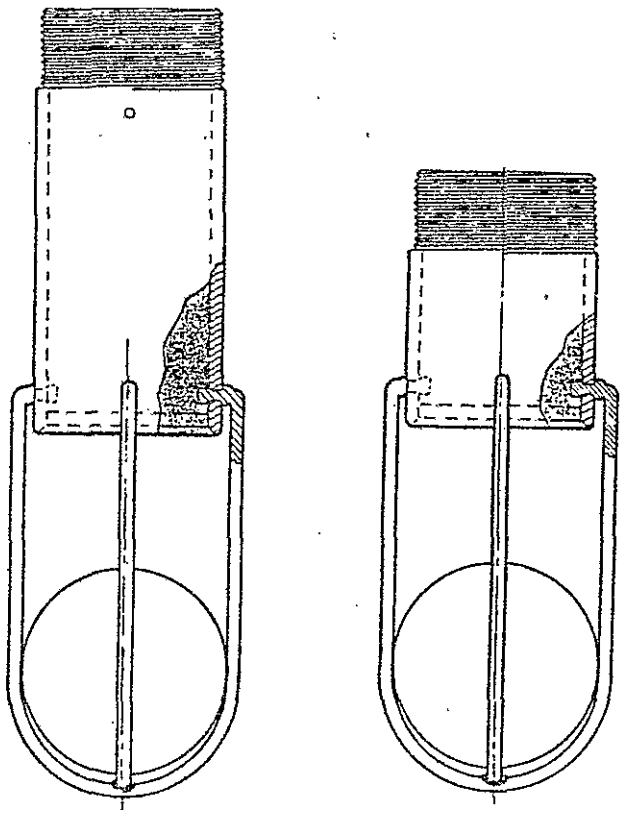
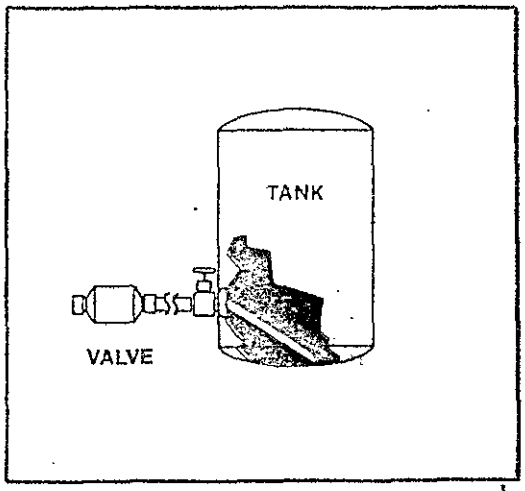
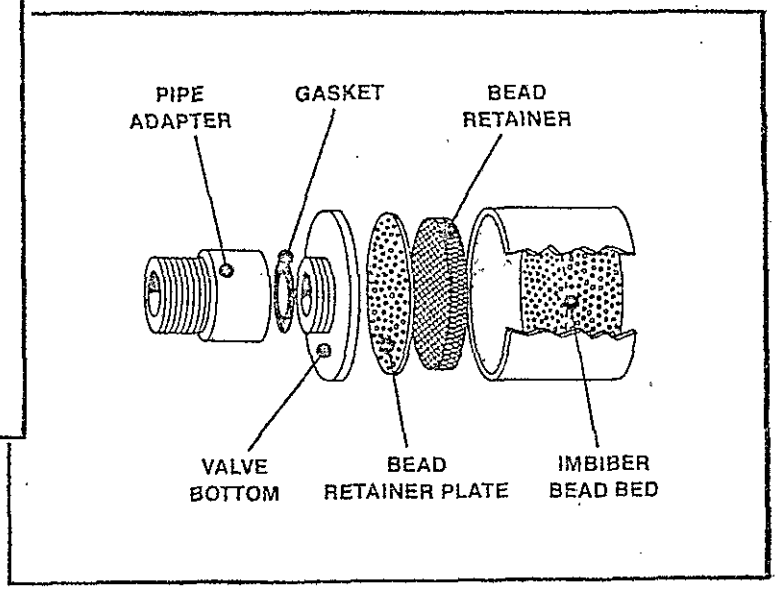


Figure B5

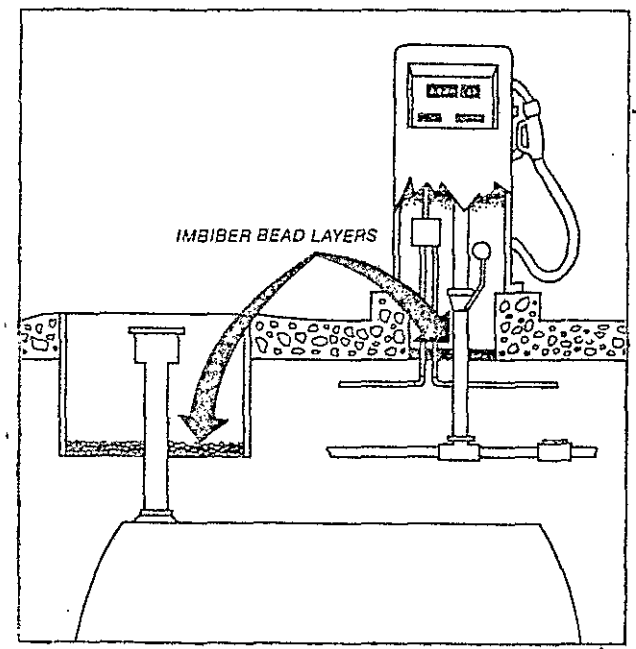
Imbiber Bead Applications

(a) Storage tank water draw-off valve: Imbiber beads permit water drainage but block off flow of product.





(b) Fuel spill soil sealant: Imbiber beads permit drainage of water runoff but block flow of product, permitting recovery.



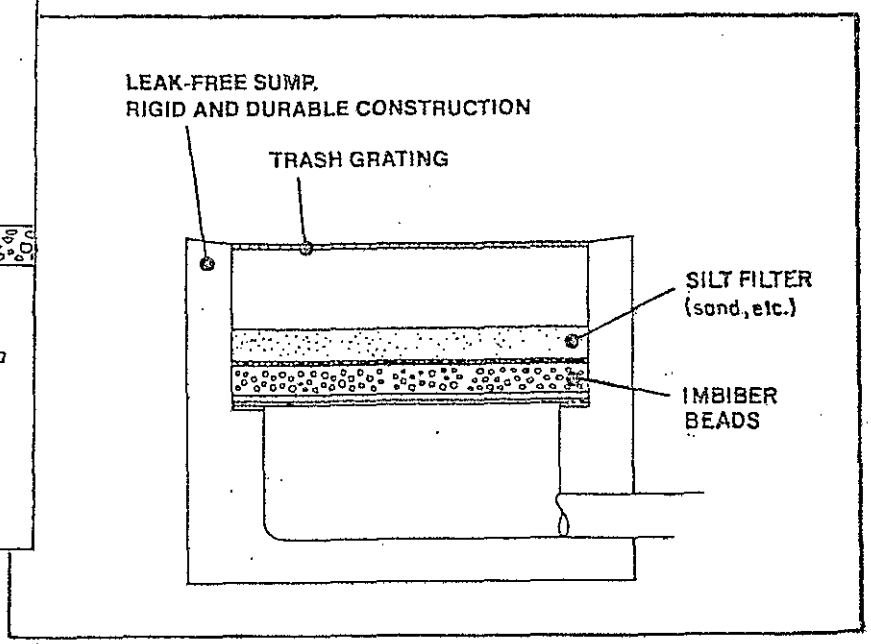


Figure B6

Typical Earth Dikes

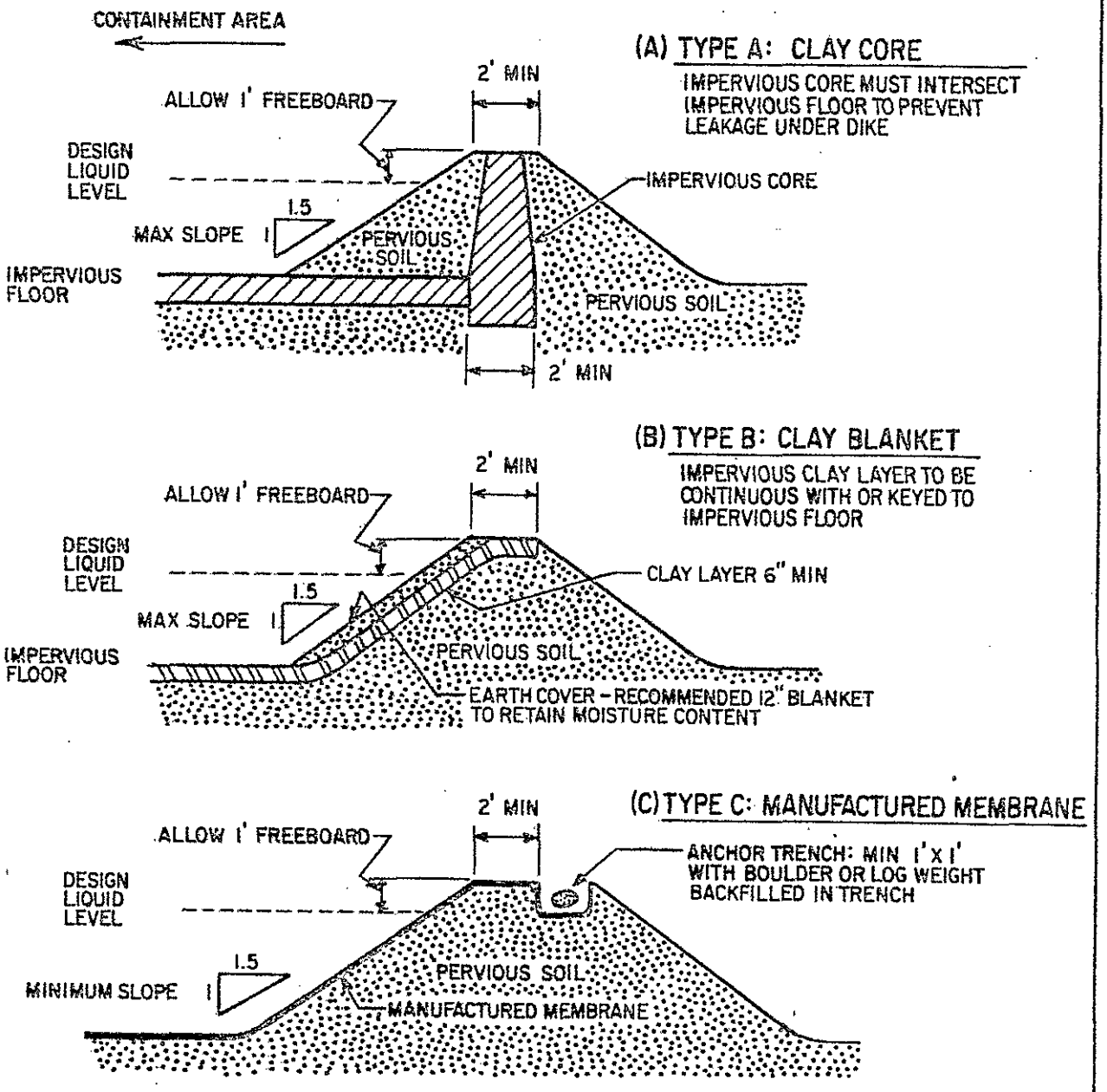
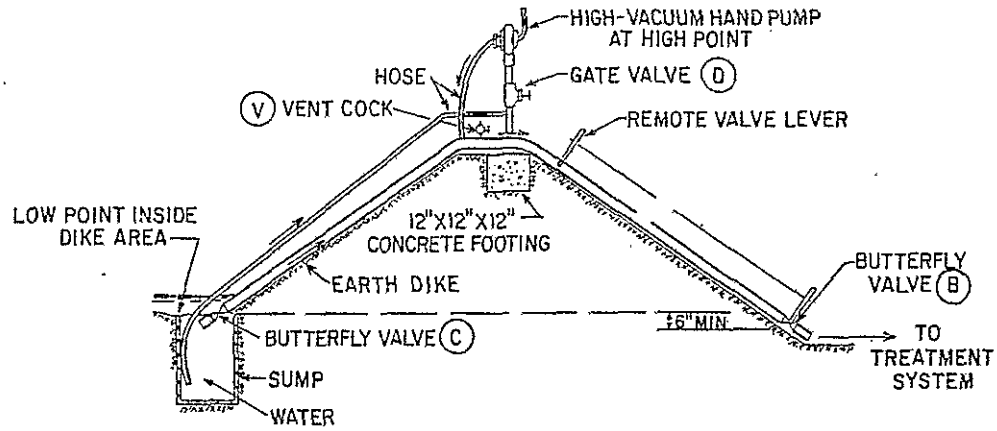


Figure B7

Dike and Siphon



PIPE DRAINS, WITH OR WITHOUT VALVES DIRECTLY THROUGH DIKE WALL SHALL NOT BE USED

OPERATION OF SIPHON:
- CLOSE VALVE (B) & (C)
- OPEN VENT COCK (V) & GATE VALVE (D)
- PRIME SIPHON PIPE BY OPERATING PUMP; SUCKING WATER FROM INSIDE DIKED AREA TO BE DRAINED UNTIL WATER COMES OUT OF VENT COCK (V)
- CLOSE VENT COCK (V) & GATE VALVE (D)
- OPEN VALVE (B) & (C)
- BEFORE LEAVING, ATTENDANT MUST OPEN VENT COCK (V), GATE VALVE (D), DRAIN PIPING & PRIMING PUMP

Figure B8

Typical Wet Well Cluster

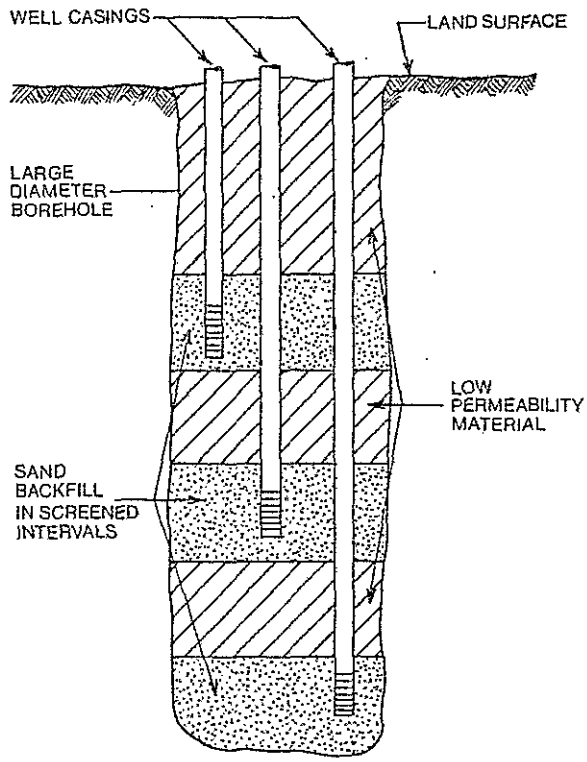


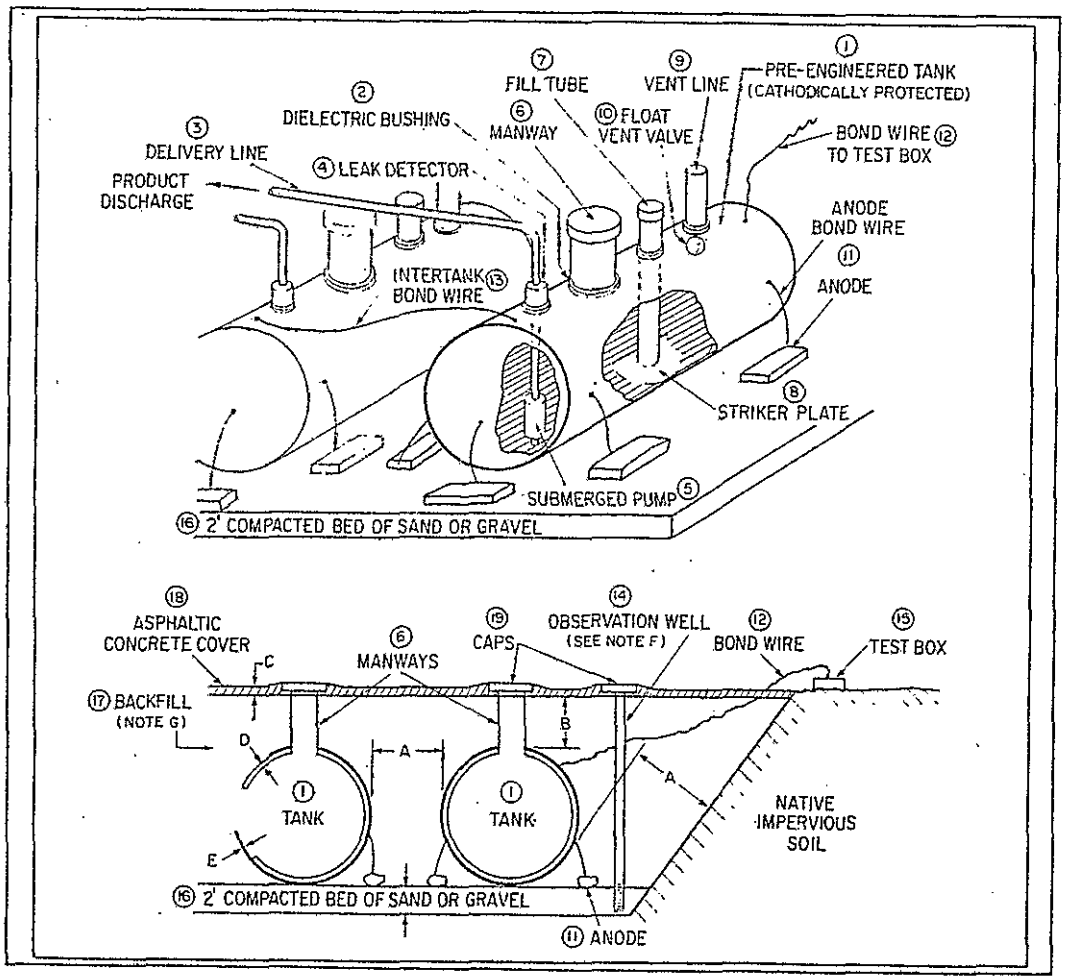
Figure B9

Pre-engineered Underground Storage Tank

This figure shows the components typically found in a pre-engineered (sacrificial anode cathodic protection) underground storage tank installation. These components include the following:

① cathodically-protected, epoxy-coated steel tank; ② dielectric bushings providing electrical insulation between tank and all connecting lines; ③ product delivery line; ④ leak detector on product delivery line; ⑤ submerged product delivery pump, ⑥ access manway; ⑦ fill tube; ⑧ striker plate below fill tube; ⑨ vent line; ⑩ float vent valve in vent line for overfill protection; ⑪ anodes bonded to tank; ⑫ bond wire to electric test box on the surface, ⑬ bond wire between tanks; ⑭ leak observation well inside the excavation; ⑮ electrical test box to insure proper cathodic protection; ⑯ compacted bed of sand or gravel (same material as backfill), ⑰ sand or gravel backfill; ⑱ asphaltic concrete cover; ⑲ waterproof, tamper-proof caps on fill lines, manways and observation wells.

—— Please note that this figure is not drawn to scale ——



NOTES

A – 12" MINIMUM DISTANCE

B – 24" MINIMUM DISTANCE

C – ASPHALTIC CONCRETE COVER AT LEAST 8" THICK

D – INNER WALL, 1/4" STEEL

E – COAL TAR EPOXY COATING SET TO RIGID MANUFACTURERS' SPECIFICATIONS. TYPICALLY THE COATING ON THE TANK HEAD IS THICKER THAN THE COATING ON THE TANK SIDES. FOR EXAMPLE, TYPICAL DRY THICKNESS MAY BE 10 MILS (TANK SIDES) AND 15 MILS (TANK HEADS).

F – OBSERVATION WELL NOMINALLY CONSTRUCTED OF 4" DIAMETER PVC PIPE, SLOTTED (0.02 INCHES) NEAR THE BOTTOM WITH THE SLOTTED AREA WRAPPED IN FILTER CLOTH. WELL ALSO HAS SEALED CAP ON BOTTOM.

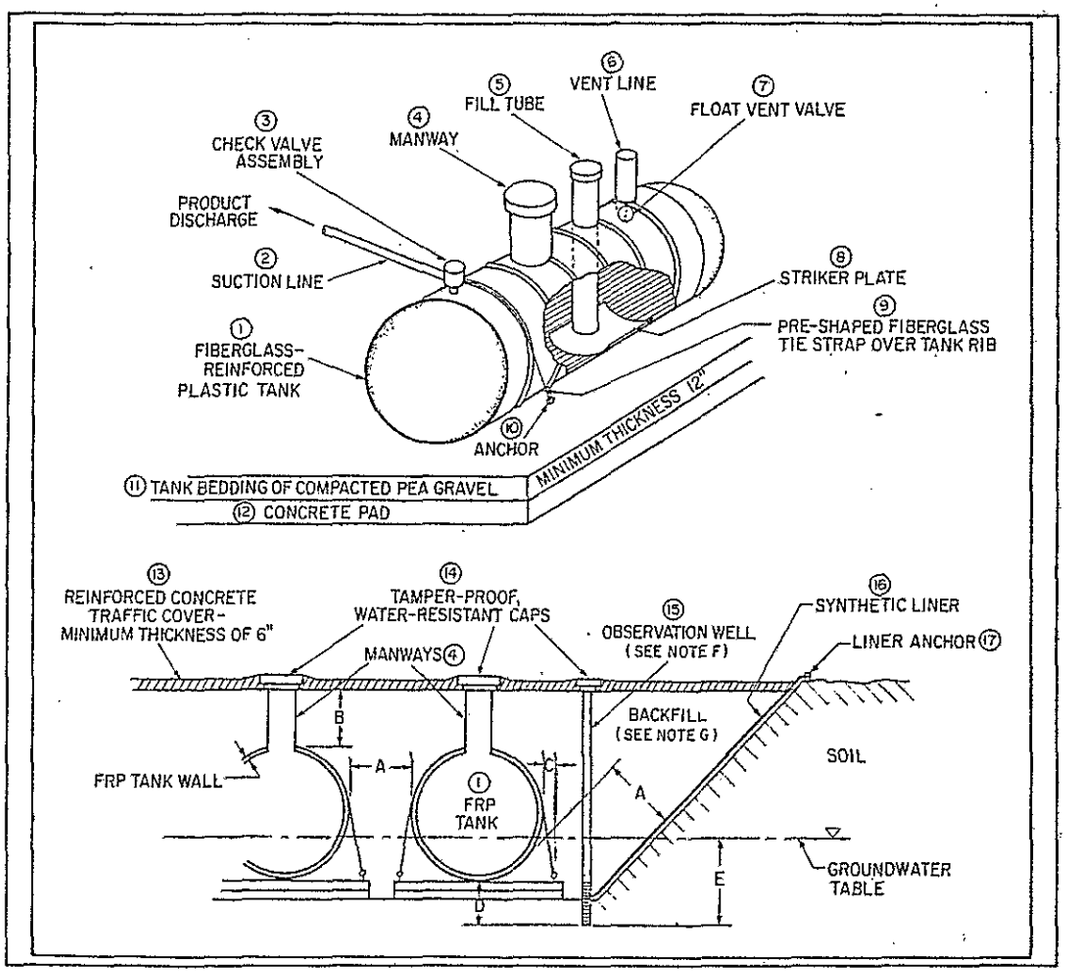
G – WASHED SAND OR GRAVEL BACKFILL, COMPACTED IN 12" LIFTS

Figure B10 (a)

Tank Installed in Area of High Ground Water

This figure shows the components typically found in a fiberglass-reinforced plastic (FRP) underground tank installation in an area with a high groundwater table. These components include the following: ① fiberglass reinforced plastic tank; ② suction line for delivery of product; ③ check valve assembly on the suction line; ④ access manway, ⑤ tank fill tube, ⑥ tank vent line; ⑦ float vent valve in vent line for overfill prevention; ⑧ striker plate below fill tube; ⑨ pre-shaped fiberglass tie (anchor) straps which are tied over tank ribs to anchor tank to concrete foundation pad; ⑩ tank anchors; ⑪ tank bedding of compacted pea gravel with a minimum thickness of 12 inches; ⑫ concrete foundation pad; ⑬ reinforced concrete traffic cover with a minimum thickness of 6 inches; ⑭ tamper-proof, water-resistant caps over all access ways; ⑮ excavation observation well (there should be 4 such wells, one each, opposite the sides and ends of the installed tanks); ⑯ synthetic liner around excavation walls which is resistant to the stored product; ⑰ anchor for synthetic liner, ⑱ excavation backfill of crushed pea gravel (same substance as tank bedding).

—— Please note that this figure is not drawn to scale ——



NOTES

A – MINIMUM TANK CLEARANCE OF 18"

B – MINIMUM COVER DEPTH OF 36"

C – 1' DISTANCE

D – MINIMUM DISTANCE OF 2'

E – MINIMUM DISTANCE OF 5'

F – OBSERVATION WELL NOMINALLY CONSTRUCTED OF 4" DIAMETER PVC PIPE, SLOTTED (0.02 INCHES THICK) NEAR THE BOTTOM WITH THE SLOTTED AREA WRAPPED IN FILTER CLOTH. WELL ALSO HAS SEALED CAP ON BOTTOM.

G – BACKFILL, TYPICALLY OF NATURALLY ROUNDED WASHED PEA GRAVEL, NOMINAL SIZE 1/4", COMPACTED IN 12" LIFTS.

Figure B10 (b)

Tank Installed in Area of Low Ground Water

The U tube monitoring and recovery well system illustrated in this drawing can be used successfully in well-drained soils where the groundwater table is below the bottom of excavation. Any product which leaks from the tank percolates through the soil to a slotted tile pipe draining to a sump where it can be observed and removed. The U shape of the system allows the option of stringing sensor cables for continuous monitoring. Impervious liners are not used underneath the tube because they would catch groundwater and flood the slotted tile pipe. Although this figure shows a fiberglass steel clad tank in use, other tanks made of fiberglass or cathodically protected steel can be used with equal success.

The components of this system include the following: (1) fiberglass steel clad tank; (2) observation wells; (3) half slotted PVC pipe; (4) striker plate; (5) submerged pump; (6) leak line detector; (7) float vent valve.

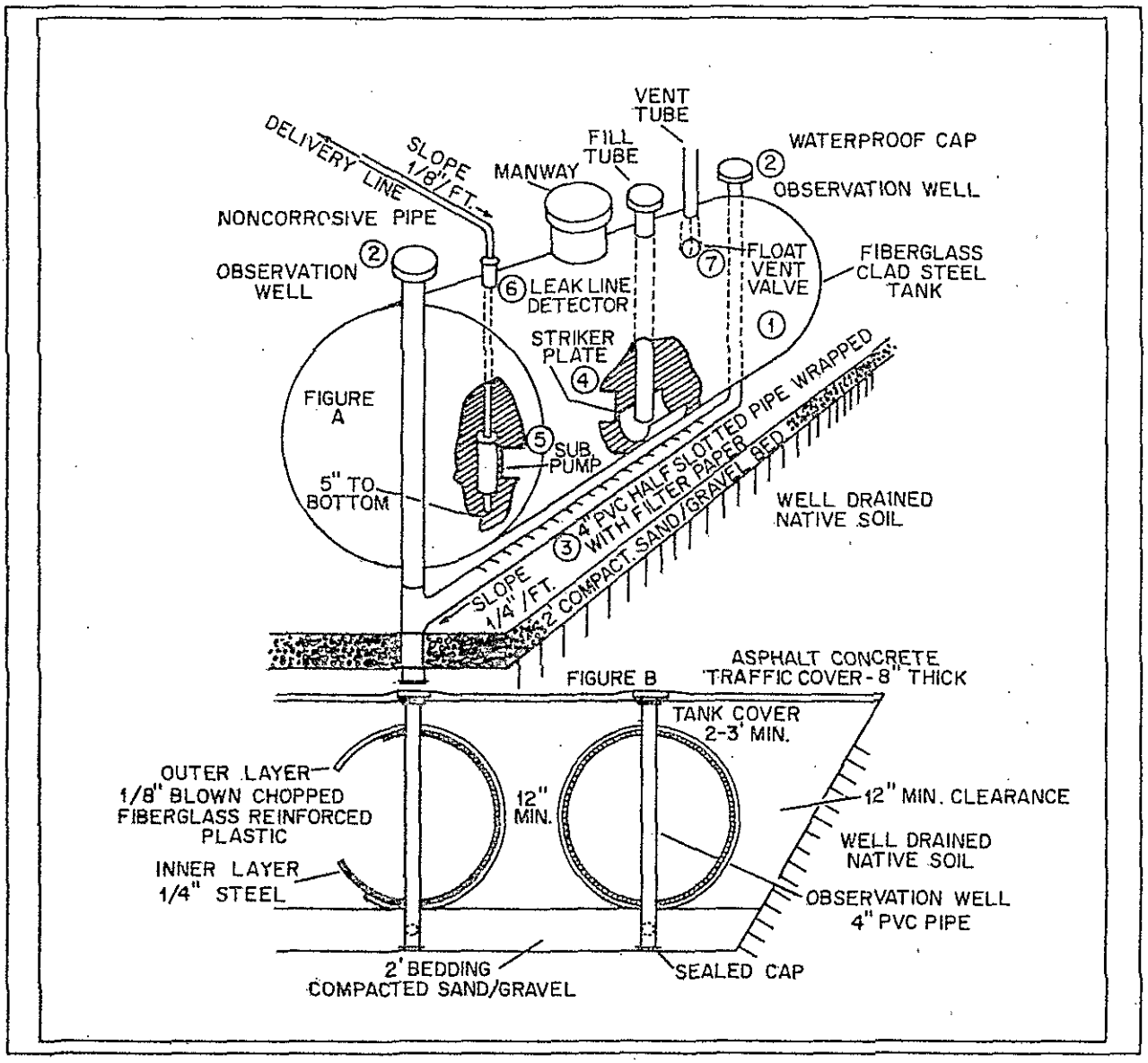


Figure B10 (c)

Double-walled Tank in Area With Low Ground Water Table

This figure presents a generic representation of a double-walled underground storage tank in an area of low groundwater, and a monitoring well located down-gradient (in the direction of groundwater flow away from the tank excavation). The items which are highlighted here at the tank include

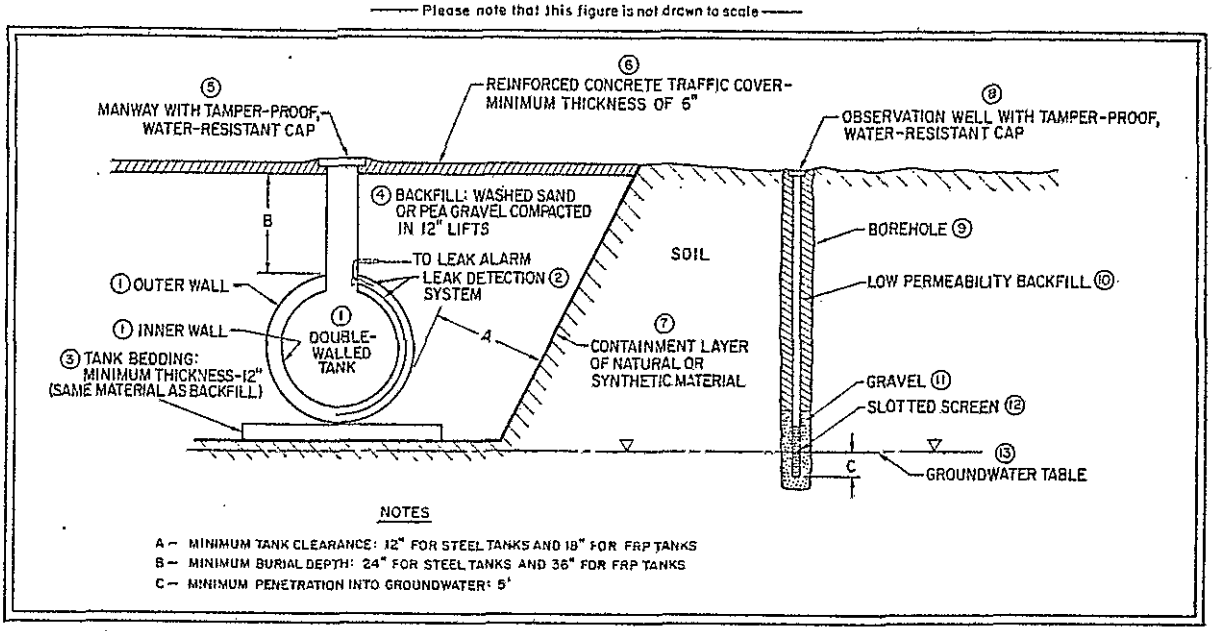
① the double-walled tank, which is commonly constructed of either steel or FRP; ② the tank leak detection system, located between the inner and outer walls; ③ the tank bedding, ④ the excavation backfill; ⑤ the tank manway with cap; ⑥ a reinforced concrete traffic cover, and ⑦ the excavation containment layer.

Items which are not shown, but should be considered important parts of an underground storage system are: the product delivery line; the fill tube with striker plate; the vent line with float vent valve; and cathodic protection and protective coatings for steel tanks.

The items shown in this figure at the monitoring well include the following:

⑧ the monitoring well, constructed of 4" PVC pipe, and slotted in the region of leak detection; ⑨ the monitoring well borehole; ⑩ low permeability backfill in the non-sensing section of the borehole; ⑪ gravel backfill in the borehole in the region of leak detection, ⑫ a slotted screen, covered with filter cloth, to detect product leaks; ⑬ the groundwater table

—— Please note that this figure is not drawn to scale ——



NOTES

A – MINIMUM TANK CLEARANCE: 12" FOR STEEL TANKS AND 18" FOR FRP TANKS
B – MINIMUM BURIAL DEPTH: 24" FOR STEEL TANKS AND 36" FOR FRP TANKS
C – MINIMUM PENETRATION INTO GROUNDWATER: 5'

Appendix C

SEQR SHORT FORM FOR ENVIRONMENTAL ASSESSMENT

Instructions:

(a) In order to answer the questions in this short EAF, it is assumed that the preparer will use currently available information concerning the project and the likely impacts of the action. It is not expected that additional studies, research or other investigations will be undertaken.

(b) If any question has been answered yes, the project may be significant and a completed environmental assessment form is necessary.

(c) If all questions have been answered no, it is likely that this project is not significant.

(d) Environmental assessment:

(1) Will project result in a large physical change to the project site or physically alter more than 10 acres of land? _____Yes _____No

(2) Will there be a major change to any unique or unusual land form found on the site? _____Yes _____No

(3) Will project alter or have a large effect on an existing body of water? _____Yes _____No

(4) Will project have a potentially large impact on groundwater quality? _____Yes _____No

(5) Will project significantly affect drainage flow on adjacent sites? _____Yes _____No

(6) Will project affect any threatened or endangered plant or animal species? _____Yes _____No

(7) Will project result in a major adverse effect on air quality? _____Yes _____No

(8) Will project have a major effect on visual character of the community or scenic views or vistas known to be important to the community? _____Yes _____No

(9) Will project adversely impact any site or structure of historic, prehistoric or paleontological importance or any site designated as a critical environmental area by a local agency? _____Yes _____No

(10) Will project have a major effect on existing or future recreational opportunities? _____Yes _____No

(11) Will project result in major traffic problems or cause a major effect to existing transportation systems? _____Yes _____No

(12) Will project regularly cause objectionable odors, noise, glare, vibration or electrical disturbance as a result of the project's operation? _____Yes _____No

(13) Will project have any impact on public health or safety? _____Yes _____No

(14) Will project affect the existing community by directly causing a growth in permanent population of more than 5 percent over a one-year period, or have a major negative effect on the character of the community or neighborhood? _____Yes _____No

(15) Is there public controversy concerning the project? _____Yes _____No

PREPARER'S SIGNATURE: _____ TITLE: _____

REPRESENTING: _____ DATE: _____

Appendix E
EVALUATION PROCEDURE FOR GROUND WATER CONTAMINATION POTENTIAL

INTRODUCTION

Several factors must be considered in evaluating the overall suitability of a site for storing hazardous substances. These factors include the following:

Siting Factors
- ground water contamination potential
- adjacent land use
- zoning regulations and master plans

Management Factors
- storage system reliability
- monitoring coverage
- adequate storage facilities maintenance
- use of careful handling practices

This Appendix describes a practical methodology for evaluating the potential for ground water contamination due to the storage of hazardous substances.* It is intended for use as a guide to planners, engineers, geoscientists and public officials in New York State who need information on the risk of ground water contamination associated with an existing or proposed hazardous substances storage site. When used in conjunction with the factors listed above, it can be a useful tool whether for evaluating the overall suitability of a single site, for selecting a preferred site from among several proposed alternatives or for setting inspection priorities for facilities which are already in place.

THE RATING SYSTEM

Completion of the evaluation procedure results in a grading of the site from A to F. Those sites with grades of A are identified as best suited for storing hazardous substances, all other factors being equal. For these sites, the risk of ground water contamination is low. Sites which receive a grade of F are poorly suited for storing hazardous materials; the risk for ground water contamination is high for these sites.

OVERVIEW OF METHOD

The evaluation procedure is completed in 8 steps as shown in Figure E1. The steps and terminology presented in this Appendix have been adapted from the LeGrand methodology. Modifications have been made in order to simplify the process; however, the basic evaluation concepts developed in the LeGrand methodology have not been changed.

The first four steps involve the assignment of point ratings for the following key hydrogeologic factors of a site.

1. The horizontal distance from the storage facility to the nearest individual well or municipal water supply.
2. The depth of the water table below the storage facility.
3. The approximate slope or gradient of the water table.
4. The character of the geological strata through which the stored material would likely pass, expressed in terms of permeability and sorption.

These factors can often be estimated or determined using data from existing topographic maps, master plans, well logs, geologic reports and soil maps. Using field data specific to the particular site being evaluated may increase the confidence level of the analysis. However, newly obtained data are not necessarily required to complete the analysis.

Step No. 5 is accomplished by adding the hydrogeologic point ratings of Steps No. 1 through No. 4.

In Step No. 6, the sensitivity of the aquifer is classified into one of three types:

- Sensitive Aquifer (very productive)
- Moderately Sensitive (variably productive)
- Insensitive Aquifer (relatively unproductive)

In Step No. 7, the hazard rating of the substance to be stored at the site is identified. The hazard ratings are presented in the Contaminant Hazard Potential Ranking chart (Table E8).

In Step No. 8, the site is graded from A (excellent) to F (very poor) considering only the risk for ground water

*This procedure has been adapted directly from reports entitled "Evaluation of Ground-Water Contamination Potential From Waste Disposal Sources" 1977, Harry E. LeGrand and Henry S. Brown, prepared for Office of Drinking Water, U.S. EPA, Washington, D.C., EPA Contract Number 68-01-4405 and "A Standardized System for Evaluating Waste Disposal Sites", 1980, Harry E. LeGrand prepared for the National Water Well Association. The reader is referred to those reports for additional detail.

contamination. The grading is determined by using the grading chart (Contamination Potential Rating Matrix, Figure E3) which compares the hydrogeologic ratings, aquifer sensitivity, and chemical hazard rating with a standard rating for an aquifer with minimal potential for ground water contamination.

The above numerical analysis should be footnoted by:

- the evaluator's determination of an overall degree of confidence in the data used, and
- other miscellaneous information not directly accounted for in the analysis such as knowledge of zones of ground water recharge that may be distant from the aquifer, knowledge of cavernous rock, etc.

The degree of confidence in the data used in the analysis and miscellaneous site information both may have a bearing on the final analysis of the ground water contamination potential. These considerations may alert the site evaluator that additional on-site investigation is necessary prior to making a final decision on the suitability of a specific site or that atypical geologic conditions exist at the site which may limit the validity of the analysis. The approach to considering the confidence factor and miscellaneous information is discussed in further detail later in this Appendix.

Analyzing the ground water contamination potential can be accomplished in one to three days by a planner, engineer or environmental analyst or qualified private consultant using data that are normally available through a variety of resources. It is not necessary that the evaluator have extensive training in ground water hydrogeology or soil sciences although professional knowledge of the environmental sciences is essential. Experience with the LeGrand methodology has shown that when persons who are familiar with the procedure independently analyze the risk of ground water contamination, similar ratings are determined. These ratings show even more consistency when site-specific data (with a high confidence factor) are used in the evaluation.

USE OF THE DATA FORM

A data form is included which may be used to assist the evaluator in the completion of the site evaluation.

Part I of the data form provides spaces to include basic information on the project, the site and the applicant. Information which should be included will identify the project by name, provide the name, address, and telephone number of the applicant or his representative who may be contacted for further information, and also present a brief description of the project.

Part II of the data form provides spaces where information developed for each of the eight steps of the evaluation procedure should be recorded. The "Value" column should show the actual value which has been used for the evaluation of the proposed site. For instance, in Step 1 – Distance to Water Supply, the straight line distance from the project site to the nearest individual well or municipal water supply should be recorded in feet or meters.

Under the "Rating" column, the point value obtained from the appropriate table should be recorded for each step in the evaluation process as required.

The "Degree of Confidence" column should be filled in with the appropriate rating (High, Medium or Low) based on the evaluator's judgement on the accuracy of the data used in the evaluation. Suggested criteria for judging the degree of confidence are provided for each step.

The spaces provided for Steps 5 through 8 permit recording of the total of the point ratings from Steps 1 through 4, the Aquifer Sensitivity rating, the Hazard Potential rating, and the Contamination Potential rating, respectively.

Part III of the data form should be used to indicate the overall degree of confidence which the evaluator considers to best describe the quality or accuracy of the data utilized. Also, any additional information not specifically accounted for in Steps 1 through 8 but which are of significance in determining the site's ultimate suitability may be indicated.

Part IV of the data form provides information on the person who has completed the evaluation of the proposed site.

STEPS OF ANALYSIS

The following is a step-by-step description of the ground water contamination potential analysis.

Step 1 - Distance

The first step in the evaluation procedure is the determination of the numerical rating for the distance between a proposed storage facility and the nearest point of water supply. In general, the greater the distance between the two points, the less potential there is for contamination of the water supply due to a spill or leak at the storage site. The water supply may be either an individual residence well or a municipal supply source.

The natural attenuation provided by the soil and/or rock material between the proposed site and the water supply tends to minimize the contamination potential. While the amount of contamination reduction is dependent to a large degree on the type of soils and underlying rock materials as well as the physical integrity of that material, for Step 1, the distance is the prime factor of concern.

The numerical ratings for Step 1 are given in Table E1. Where the water table lies in permeable consolidated rock the standard procedure is to assign six distance points for the permeable fractured rock and cavernous rock setting (category II of step 4) and to assign four

GROUNDWATER CONTAMINATION POTENTIAL DATA FORM

I. PROJECT INFORMATION

Project Name: _____

Site Location	Applicant
Name: _____	Name: _____
Address: _____	Address: _____
_____	_____
Phone: _____	Phone: _____

Project Description: _____

_____

II. SITE EVALUATION

	Value	Rating		Degree of Confidence
Step 1 - Distance.....	_____	R1=_____	(from Table E1)	_____
Step 2 - Depth to Water Table.....	_____	R2=_____	(from Table E2)	_____
Step 3 - Water Table Gradient.....	_____	R3=_____	(from Table E3)	_____
Step 4 - Permeability-Sorption.....	_____	R4=_____	(from Table E4)	_____
Bedrock category.....	_____			
Depth category.....	_____			
Soil category.....	_____			
Step 5 - Overall Hydrogeological Rating.....		R5=_____	(R1+R2+R3+R4)	
Step 6 - Aquifer Sensitivity.....		R6=_____	(from Table E7)	
Step 7 - Hazard Potential				
Substance: _____		R7=_____	(from Table E8)	
Step 8 - Contamination Potential				
Site Hydrogeological Rating.....		R5=_____	R1=_____ R4=_____	(from above)
Standard Site Rating.....		S1=_____	S2=_____ S3=_____	(from Fig.E3)
Difference (R5-S1; R4-S3).....		D1=_____	D2=_____	
Combined Value (D1 + D2).....		_____		
Grade (circle) (from Table E10).....		A B	C D F	
Contamination Potential (circle).....		low	medium high	

III. COMMENTS

Overall Confidence Rating (see Table E11) _____

Miscellaneous Site Information (see Table E12) (circle appropriate symbol(s)):

R D F E W K C M I

IV. EVALUATOR

Name: _____ Date: _____

Address: _____

_____

Phone: _____

distance points where the rock is essentially unfractured (category I of step 4). Suggested criteria for assigning a degree of confidence for Step 1 are also included in Table E1.

Step 2 - Depth to Water Table

The depth to the water table is defined as the distance from the ground surface to the surface of water standing in an unpumped well (pumped wells will lower the water table locally). Since many potential contaminants may be attenuated by soil to some extent as they move toward the ground water through the unsaturated zone, (i.e., above the water table), the chance of contamination lessens as the depth to the water table increases.

The rating assigned decreases with greater depth to the water table as shown in Table E2. The rating scale indicates the relative sensitivity of a water table which is close to the ground surface as compared to the situation where the water table is well below the surface. For example, the 1-meter difference between a 2- and a 3-meter depth to the water table is much more important than the 1-meter difference between a 50- and a 51-meter depth to the water table. In some regions the water table may be found at a relatively constant depth below the site being evaluated but may rise toward the surface during seasonally wet periods. It is this seasonal high position of the water table that is of concern in evaluating ground water contamination potential and should be used as the depth to the water table.

In some places a shallow aquifer is separated from a deeper aquifer by an impermeable layer, resulting in upper or "perched water table" (See Figure E2.) Many site-specific features are involved and it is difficult to describe generally how to assign a rating for such systems. For example, if there is local use of water from a perched aquifer, its water table depth should be utilized in the evaluation. However, the perched aquifer is commonly by-passed as a source for ground water and water is used from the deeper, more permanent aquifer. In this situation, however, contaminated ground water could leak from a perched aquifer down (perhaps alongside well casings) into the deeper aquifer. An intermediate rating from Table E2 may be assigned between the depth to the perched water table and the depth to the true water table. Reference should be made to the perched water table situation in Part III of the data form.

The water table ratings in Table E2 are based on a saturated zone in loose, unconsolidated granular materials. In areas where the water table lies in consolidated rock the standard procedure is to assign six water table points for the permeable fractured rock and cavernous rock setting (Category II of Step 4) and to assign four water table points where the rock is essentially unfractured (Category I of Step 4).

Step 3 - Water Table Gradient

It is important to know whether a contaminant is moving toward or away from a water supply. Since the gradient of slope of the water table is difficult to estimate, only five rating points are spread across this scale as shown in Table E3. Where the gradient is clearly away from a water supply, zero or one point may be assigned. Where the gradient is almost flat or where it does not seem to be great, one to three points may be assigned. A distinction of more or less than two percent for the water table gradient may be too slight to be concerned about, but in some cases water table maps may reveal this information and in others the evaluator may be able to make the distinction. If the water table gradient slopes toward a water supply, the potential for contamination of that supply becomes greater. As the gradient of the water table increases toward a water supply, the rating assigned in Step 3 also increases.

In some cases, determination of the gradient may not be readily accomplished. An optional rating scale is given in Table E3 which may be used. On this scale a distinction is made between a direction of contaminant movement toward a water supply and a direction away from existing water supplies. Procedures for determining underground flow may be found in ANSI/NFPA, 1977, Chap. V.

Step 4 - Permeability and Sorption

The permeability/sorption of the soil and rock materials through which contaminated water may move is rated in this step of the analysis. This evaluation factor is perhaps the most significant of the four key hydrogeological factors included in the evaluation procedure. Permeability is simply defined as the apparent velocity or rate of flow through the soil and rock materials. It is generally measured in values of centimeters per day or centimeters per hour and is dependent upon the size, total volume, and distribution of pore spaces within the particular soil or rock. Clays and consolidated rocks have low permeability values while sands and gravels have high permeability values.

The hazard potential of ground water contaminants may be reduced by physical or chemical sorption processes (i.e., through the replacement or exchange of ions from soil particles with contaminant ions in the ground water). Since sorption occurs primarily on the surface of colloidal sized ($< 10^{-3}$ mm) particles, those soil materials having relatively high percentages of colloids, such as clay soils, have higher sorption capacities. However, even soil consisting of apparently clean sands and gravels may have significant colloid content.

The scale for the permeability/sorption factor extends from 0, representing the low permeability and high sorption characteristics of "clay," to 9, representing the high permeability and low sorption characteristics of "clean gravel" as shown in Table E4. Clays and materials of low permeability and high sorption tend to prevent ground water contamination. On the other hand, clays

may provide an undesirable or unsuitable site since poor infiltration characteristics may cause surface runoff of contaminated water. The location and distance to the closest surface water in such instances should be noted in Part III of the data form as necessary.

The soil material categories listed in Table E4 have been simplified from those normally utilized in the U.S. Department of Agriculture, Soil Conservation Service (SCS) soil surveys. The SCS soil surveys are primary sources of information for many of the factors which are used in the site evaluation procedure. Table E5 compares the soil categories of Table E4 with their approximate equivalent soil categories from the SCS.

In determining the proper permeability/sorption rating from Table E4, consideration must be given to three separate factors.

1. The vertical profile of the unconsolidated soil material through which contaminants must move in order to reach the underlying ground water must be considered. Since the soils at the surface may not extend downward throughout the entire distance to the ground water, it may be necessary to use an average soil condition in the evaluation.

2. The thickness of the soil material over bedrock must be considered.

3. The nature of the bedrock must be taken into account. Bedrock Category I is comprised of relatively impermeable rock such as shale. Bedrock Category II is relatively permeable such as jointed or fractured igneous or metamorphic rock or cavernous limestone.

A wide and complex variety of geologic characteristics have been simplified and incorporated in the permeability/sorption table. The ratings in Table E4 have been modified from those contained in the original LeGrand methodology. However, the key concepts are included and emphasis is still placed on making appropriate interpolations. Through careful evaluation of the various ranges of permeability/sorption ratings and of the earth materials present at the site, evaluators should arrive at reasonably accurate and consistent ratings under all types of geologic environments.

Step 5 - Overall Hydrogeological Rating

Step 5 is accomplished by adding the ratings determined in each of the first four steps. This overall rating gives an indication of the characteristics of the particular site based solely on its hydrogeologic conditions. Table E6 shows rating categories based on hydrogeologic conditions only. All values listed for a site must be reached to justify the prescribed rating. For example, a Good site must have no more than 17 total points, as well as a maximum of 2 Distance and 4 Permeability/Sorption points. If only the maximum ratings of 2 and 4 have been assigned in Steps 1 and 4, then at least 11 additional points must have been allotted to Step 2 (rating for depth to water table) and Step 3 (rating for water table gradient) to attain the total point value of 17.

A given site may rate low in ratings and still be unacceptable because of serious problems with one parameter. For example, the site may be ideal in all respects except for a very shallow ground water table. Therefore, the total point value is not intended to stand alone but is to be viewed in conjunction with the ratings assigned in the separate steps. This allows both the weak and strong features of a site to be given consideration even after the initial compilation of the evaluation rating.

The empirical rating criteria shown in Table E6 can be very useful in evaluating and comparing the physical suitability of alternative sites. However, it does not factor in considerations such as: 1. type/severity of contaminant, nor 2. sensitivity (vulnerability) of a nearby aquifer. A site could receive a poor overall hydrogeologic rating but still be considered acceptable because the contaminant to be stored at the site has a low hazard potential and the nearby aquifer is of slight extent and importance.

Precautionary storage technology and measures can also mitigate the threat of aquifer contamination and bring the site to a level of acceptability. Although no methods have been developed to measure mitigating effects of precautionary storage technology and practices, LeGrand has developed a procedure for considering type/severity of contaminant and aquifer sensitivity. These factors are considered in Step 6 and Step 7.

Step 6 - Aquifer Sensitivity

In Step 6 the sensitivity of the aquifer underlying the site being evaluated is determined. The aquifer sensitivity is based on the permeability of the materials forming the aquifer at the site, the aquifer's areal extent, its importance (or potential importance) as a water supply source, and whether or not it is the only significant aquifer available. A highly sensitive aquifer is valuable because it can yield significant quantities of high-quality water but can easily become contaminated by activities within its recharge area.

Aquifers have been classified into three types: sensitive, moderately sensitive and insensitive as described below.

Sensitive Aquifers are very permeable, extensive aquifers overlain by very permeable material or are exposed at the surface in their recharge zones. They are or can be important drinking water sources. An aquifer designated as a sole source aquifer under Section 1424(e) of the Safe Drinking Water Act should be identified as sensitive. Sites that have a thickness of clean gravel or coarse sand materials of greater than 30 meters over rock from Step 4 as well as most other site conditions where relatively permeable rock formations (Bedrock Category II) underlie the soils, should be identified as sensitive.

Moderately Sensitive Aquifers are of variable permeability and moderate extent and are overlain by moderately

permeable material in their recharge zones. They are or can be important drinking water sources. Sites where the thickness of clear fine sand or sand with less than 15% clay is greater than 30 meters, as well as some site conditions underlain by Bedrock Categories I and II, should be identified as moderately sensitive.

Insensitive Aquifers are of moderately low permeability and/or of slight extent and of little importance as drinking water sources. They are overlain by low to essentially impermeable material in their recharge zones. They include deep confined aquifers, aquicludes (non-water-bearing materials) and may include "salt-water" beds of any permeability in areas where no freshwater occurs. Sites where the thickness of sand with 15-50% clay, clay with no more than 50% sand or clay soils of greater than 30 meters, as well as most site conditions underlain by Bedrock Category I, should be identified as insensitive.

Common near-surface aquifers and their sensitivity rankings are shown in Table E7. The evaluator must use judgement in assigning a rating where the range of values in Table E7 overlap more than one rating (e.g., medium to coarse sand). In cases where available information is not adequate to make a firm determination on the sensitivity of the aquifer, additional on-site information may be obtained as deemed appropriate.

Step 7 - Hazard Potential Rating

Substances that may enter the ground water offer potential for causing harm to human health (Hazard Potential). The Hazard Potential ratings for many substances are shown in Table E8 and range from 1 to 9, with 1 being least hazardous and 9 being most hazardous. For substances contained on the Section 311 list of Hazardous Substances (40 CFR Part 117) an alternate procedure is suggested on Table E9, whereby the Hazard Potential Rating is a function of the Reportable Quantity category.

Most of the substances listed show a Hazard Potential Rating range, say 5 to 8. The assessor must use personal judgment in assigning a specific ranking from this range. Information that may be useful in determining a specific Hazard Potential Rating for a substance includes knowledge of the nature of the particular type of hazard involved (i.e., is the substance explosive, pathogenic, carcinogenic, flammable, toxic, etc.), the volumes or concentrations of the substance that would be stored and the adequacy of available technology to treat and dispose of the substance if necessary. If no additional information is readily available, the worst case or highest rating shown should be assigned.

Step 8 - Determination of Contamination Potential

This final step in the site evaluation utilizes the hydrogeologic ratings developed in Steps 1 to 4 and the aquifer sensitivity and Hazard Potential Ratings of Steps 6 and 7, to determine the Ground Water Contamination Potential at a site due to spillage or leakage of a specific substance.

This step requires that hydrogeologic ratings for the site being investigated be compared against empirically derived standard ratings developed by LeGrand. These standard ratings are shown as isometric lines in the Contamination Potential Rating Matrix, Figure E3. The largest number on each isometric line is the standard used to compare the total hydrologic rating of the site. The middle number is the standard used to compare the distance rating. And the number to the right is used to compare the permeability/sorption rating. These standards are the approximate maximum ratings a site should not exceed to prevent serious contamination of ground water. If a site fails to meet any of the three rating criteria, it fails to meet the guide for minimum level of acceptability.

The isometric lines should be considered as approximate minimum levels of tolerance and not necessarily rigid "yes" or "no" (acceptance or rejection) criteria for a site. For this reason, LeGrand has developed a grading procedure for the final determination of ground water contamination potential.

The final grade for the site being evaluated is determined by subtracting the standard rating (obtained from the Contamination Potential Rating Matrix) from the overall hydrogeological rating (Step 5) for the site and from the permeability/sorption rating (Step 4). The standard rating values may be derived from the Contamination Potential Rating Matrix by plotting, on the vertical axis of the contamination potential rating matrix, the Aquifer Sensitivity Rating (Step 6) and, by plotting on the horizontal axis, the Hazard Potential Rating (Step 7). The standard rating in the matrix is found where the plotted Step 6 and Step 7 values intersect.

The following examples show how the resulting values are treated in this evaluation step.

	Overall Hydrogeologic Rating	Permeability/ Sorption Rating
Case 1		
Site Under Study	13 (from Step 5)	2 (from Step 4)
Standard Rating	13	4
Difference	0	-2
Combined Value	-2	
Case 2		
Site Under Study	18 (from Step 5)	8 (from Step 4)
Standard Rating	18	5
Difference	0	3
Combined Value	+3	

Utilizing the combined value as determined above, the site can be graded from A (Excellent) through F (Very Poor) as shown in Table E10.

OVERALL DEGREE OF CONFIDENCE

In order to be able to provide an interpretation of the complete site evaluation rating, it must be possible for the evaluator, and others who may be required to review the site evaluation, to have some basis for judging the quality of the data utilized. In the tables accompanying Steps 1 through 4, suggested criteria were provided which the evaluator could use to rate the degree of confidence that should be assigned to the data used in each step.

Table E11 provides suggested criteria for assigning the overall degree of confidence rating. It is left to the evaluator to use care and judgment in interpreting the degree of confidence ratings which had been assigned in the first four steps in comparison to the suggested criteria of Table E11. Where it is determined that a low degree of overall confidence is warranted, it may serve as a notice that additional on-site investigations are needed prior to making a final decision regarding the suitability of a specific site.

MISCELLANEOUS SITE INFORMATION

During the development of the evaluation methodology it was recognized that it would be impossible to incorporate all of the potential site characteristics into the numerical rating structure without making it overly complicated. By providing an opportunity for the site evaluator to indicate in the site rating special site characteristics that have gone into the evaluation procedure attention is drawn to other factors that may be of concern.

A listing of miscellaneous site information which can be used in the evaluation is given in Table E12. In reviewing site evaluation ratings, special attention should be given to the miscellaneous site information. By definition, this information indicates factors which are not directly discernible from the numerical ratings but which, nonetheless, are important to the final decision-making process. The Ground Water Contamination Potential Data Form provides an opportunity to record miscellaneous site information.

SUMMARY

The ground water contamination potential of this site evaluation is a part of the entire facilities siting procedure. The recommendations based on the evaluation of the site's hydrogeological characteristics, the hazard potential of substances to be stored, and the aquifer sensitivity should then be incorporated with other factors such as adjacent land use, zoning regulations, etc. before a final siting decision can be made.

The judgment and experience of the person completing the site evaluation is an important factor. While someone with little formal knowledge of hydrogeology or soils analysis can follow through the steps of the procedure and be able to determine a final Ground Water Contamination Potential, the more background knowledge or experience the evaluator has, the greater the reliance which may be placed on the interpretation of the data that go into the ratings and consequently, on the recommendations which are made based on those ratings.

Table E1

Step 1: Distance Rating Criteria

Distance* (Meters)	Point Value**
0-14	9
15-19	8
20-34	7
35-49	6
50-74	5
75-149	4
150-299	3
300-999	2
1000-2000	1
2000	0

* Distance on ground between contamination source and water supply.

** Where the water table lies in permeable consolidated rock (Bedrock category II in Step 4), six points should be allotted on distance scale. In poorly permeable rock (Bedrock category I in Step 4) four points should be allotted.

Degree of Confidence

High
Accurate measurement as from a survey, and "sites" are well known.
Careful measurement on 1:24,000 or larger scale map and sites are known and accurately located.

Medium
Pacing where gentle terrain is easily traversed as along side a highway or through an open field.
Measurement is on 1:24,000 scale map but distance is less than 200 feet.
Measurements are the same as above but "sites" are not well known or accurately located.

Low
Pacing conducted in difficult (hilly, wooded, swampy, etc.) terrain.
Measurements are made on poorly scaled maps or photographs.
Estimates.

Table E2:

Step 2: Depth to Water Table Rating Criteria

Depth * (Meters)	Point Value**
0	9
0.5-1	8
1.5-2.5	7
3-4	6
5-7	5
8-11	4
12-19	3
20-29	2
30-60	1
60+	0

* Estimated depth to water table below base of contamination source (more than 5% of the year).

** Where water table lies in permeable or moderately permeable consolidated rocks (II in Step 4), six points should be allotted in poorly permeable rock (I in Step 4) four points should be allotted.

Degree of Confidence

High
Accurate measurements of static water levels in wells at the site.

Medium
Elevation measurements of water levels in wells or caverns in the near vicinity of the site.
Groundwater table maps from responsible reports.

Low
Estimations based on evaluations of topography, climate and distance to the nearest stream (permanent) at the site.

Table E3

Step 3: Water Table Gradient Rating Criteria

Gradient & Flow Direction *	Point Value	Optional Method
Gradient greater than 2 percent toward water supply and is the anticipated direction of flow.	5	
Gradient greater than 2 percent toward water supply but is not the anticipated direction of flow.	4	Groundwater movement is toward an existing drinking water supply and may contaminate that supply.
Gradient less than 2 percent toward water supply and is the anticipated direction of flow.	3	
Gradient less than 2 percent toward water supply but is not the anticipated direction of flow.	2	Direction of groundwater movement appears to be indeterminable.
Gradient almost flat	1	
Gradient away from all water supplies that are closer than 1000 meters	0	Groundwater movement is away from all existing drinking water supplies and is not likely to contaminate any supply.

*Water table gradient and flow direction (related, in part, to land slope).

Degree of Confidence

High
Accurate measurements of elevations of static water levels in wells, springs, swamps, and permanent streams in the area immediately surrounding the sites in question.
Water table maps from responsible reports.

Medium
Topography in non-cavernous (limestone) areas containing permanent streams and being in a humid climate.
Arid regions of low relief and containing some permanent streams.

Low
Topography in cavernous, predominantly limestone areas.
Arid regions of highly irregular topography and few surface streams.

Table E4

Step 4: Permeability/Sorption Rating Criteria

Bedrock Category (2)	Depth Category	Depth (Meters) (3)	Soil Category (1) A: Clay	B: Clay with no more than 50% sand	C: Sand with 15-30% clay	D: Sand with Less than 15% clay	E: Clean fine sand	F: Clean gravel or coarse sand
I	A	> 30	0	2	4	6	8	9
	B	25-29	0	1	3	5	7	9
	C	20-24	0	1	4	5	7	9
	D	15-19	0	1	4	5	7	9
	E	10-14	0	2	4	5	7	9
	F	3-9	1	2	5	5	7	9
	G	< 3	2	3	5	5	7	9
	H	0(4)	5	5	5	5	5	5
II	A	> 30	0	2	4	6	8	9
	B	25-29	1	2	4	6	8	9
	C	20-24	2	3	5	6	8	9
	D	15-19	3	4	6	7	8	9
	E	10-14	4	5	6	7	9	9
	F	3-9	6	7	7	8	9	9
	G	< 3	8	8	9	9	9	9
	H	0(4)	9	9	9	9	9	9

Soil category, bedrock category and depth category should be noted on the Groundwater contamination Potential Data Form.

(1) Type of unconsolidated material assigned should represent that through which contaminated water is likely to flow (unsaturated zone above water table and generally the upper 2 to 10 meters of material below water table). For guidance in determining soil category use Table E5.
(2) Bedrock Category I - Unconsolidated material overlies shale or other poorly permeable consolidated rock.
Bedrock Category II - Unconsolidated material overlies permeable consolidated rock (fractured or jointed igneous and metamorphic rocks, cavernous carbonate rocks, and faults).
(3) Thickness of unconsolidated materials (soils) over bedrock.
(4) Bedrock at land surface.

Degree of Confidence

High
Drillers logs containing good, reliable descriptions.
U.S. Dept. Agr. soil surveys used in conjunction with large scale, modern geologic maps.
Some groundwater reports.

Medium
Soil surveys or geologic maps used alone.
Most groundwater reports.
Drillers logs with generalized descriptions.
Drill logs or some exposures such as deep road cuts located off site but which allow interpolation within the same general geologic unit.

Low
On site examination with no drill data and with no good exposures of subsurface conditions nearby.
Extrapolations of drill logs, road cuts, etc. where local geology is not well known.
Estimation based on generalized geologic maps.
Estimations based on topographic textures.

Table E5

Properties of Soils

Soil Material Categories	Unified Soil Classification System*	Permeability	Sorption Material
Clean coarse gravel Clean coarse sand Clean fine sand	GW, GP SW, SP SW, SP	Pervious ($> 10^{-2}$ to 10^{-3} cm/sec)	Little or no clays or silts
Sand with a little clay	GM, SM		Minor amount of fines - mostly silt
Thin layers of sand and clay	GM, SM	Semi-pervious	
Clayey sand	GC, ML	to	Moderate amount of fines - mixtures of silt and clay
Even mixtures of sand and clay	SC, ML	Impervious ($<10^{-3}$ to 10^{-6} cm/sec)	
Sandy clay	OL, MH		Mostly silt and clay
Clay	CL, CH, OH	Impervious ($< 10^{-6}$ cm/sec)	Essentially clay

*The unified soil classification system is widely used by soil scientists in New York State. A further explanation of the system can be obtained from the County Soil and Water Conservation District Office.

Table E6

Step 5: Overall Hydrogeological Ratings*

Site Grade	Total Rating Points	Critical Hydrogeologic Parameters: Step 1 Distance (Maximum)	Step 4 Permeability-Sorption (Maximum)
Excellent	< 10	0	2
Very Good	11-14	1	3
Good	15-17	2	4
Fair	18-20	3	5
Poor to (F) Very Poor	> 20	3	5

* Based on empirical work of LeGrand

Table E7

Step 6: Aquifer Sensitivity Rating Criteria

Aquifer Type	Sensitivity Ratings*: Full Range	Most Common Range
Clays and sandy clays	1-3	1-2
Crystalline rocks	1-7	2-4
Fine to medium sands	2-5	3-4
Floodplain (little aquifer potential)	3-6	3-4
Alluvial valleys (large aquifer potential)	6-9	7-8
Medium to coarse sands	6-9	7-8
Fractured/cavernous limestone	6-9	7-8

*Aquifer Sensitivity Rating Range

Insensitive	1-3
Moderately Sensitive	4-6
Sensitive	7-9

Table E8

Step 7: Contaminant Hazard Potential Rankings Classified by Type[1]

A. SOLIDS

Discription	Hazard Potential Initial Ranking
Ferrous Metals	1-4[2]
Non-Ferrous Metals	1-7[2]
Resins, Plastics and Rubbers	2
Wood and Paper Materials (except as noted below)	2
- Bark	4
Textiles and Related Fibres	2
Inert Materials (except as noted below)	2
- Sulfide Mineral-Bearing Mine Tailings	6
- Slags and other Combustion Residues	5
- Rubble, Construction & Demolition Mixed Wastes	3
Animal Product Wastes	4
Animal Processing Wastes (except as noted below)	2-4
- Processed Skins, Hides and Leathers	6
- Dairy Wastes	4
- Live Animal Wastes-Raw Manures (Feedlots)	5
- Composts of Animal Waste	2-4
- Dead Animals	5
Edible Fruit and Vegetable Remains - Putrescables	2-3

B. LIQUIDS

Organic Chemicals (Must be Chemically Classified)[2]	
- Aliphatic (Fatty) Acids	3-5
- Aromatic (Benzene) Acids	7-8
- Resin Acids	
- Alchohols	5-7
- Aliphatic Hydrocarbons (Petroleum Derivatives)	4-6
- Aromatic Hydrocarbons (Benzene Derivatives)	6-8
- Sulfonated Hydrocarbons	7-8
- Halogenated Hydrocarbons	7-9
- Alkaloids	7-9
- Aliphatic Amines and Their Salts	1-4
- Anilines	6-8
- Pyridines	2-6
- Phenols	7-9

Table E8 (continued)

Description	Hazard Potential Initial Ranking
- Aldehydes	6-8
- Ketones	6-8
- Organic Sulfur Compounds (Sulfides, Mercaptans)	7-9
- Organometallic Compounds	7-9
- Cyanides	7-9
- Thiocyanates	2-6
- Sterols	5-7
- Sugars and Cellulose	1-4
- Esters	6-8
Inorganic Chemicals (Must Be Chemically Classified)[2]	
- Mineral and Metal Acids	5-8
- Mineral and Metal Bases	5-8
- Metal Salts, Including Heavy Metals	6-9
- Oxides	5-8
- Sulfides	5-8
- Carbon or Graphite	1-3
Other Chemical Process Wastes Not Previously Listed (Must be Chemically Classified)[2]	
- Inks	2-5
- Dyes	3-8
- Paints	5-8
- Adhesives	5-8
- Pharmaceutical Wastes	6-9
- Petrochemical Wastes	7-9
- Metal Treatment Wastes	7-9
- Solvents	6-9
- Agricultural Chemicals (Pesticides, Herbicides, Fungicides, Etc.)	7-9
- Waxes and Tars	4-7
- Fermentation and Culture Wastes	2-5
- Oils, Including Gasoline, Fuel Oil, Etc.	5-8
- Soaps and Detergents	4-6
- Other Organic or Inorganic Chemicals, Includes Radioactive Wastes	2-9
Conventional Treatment Process Municipal Sludges	4-8
- From Biological Sewage Treatment	4-8
- From Water Treatment and Conditioning Plants (Must Be Chemically Classified)[2]	2-5

[1]Classification based on material in Environmental Protection Agency Publication, 670-2-75-024, pages 79-85, Prepared by Berkowitz, 1975.

[2]For individual material ranking refer to solubility-toxicity tables prepared by Versar, Inc. for the Environmental Protection Agency, under Contract No. 68-01-4620.

Table E9

Step 7: Contaminant Hazard Potential Rankings--Alternate Procedure for Section 311 Hazardous Substances(1)

Category(1)	Reportable Quantity (kg)	Hazard Potential Ranking(2)
X	0.454	7-9
A	4.54	6-9
B	45.4	6-9
C	454	6-9
D	2270	5-8

(1)For full list of Section 311 Hazardous Substances, see Appendix A.

(2)For stored quantities in excess of the reportable quantity, use the upper end of the Hazard Potential Range.

Table E10

Step 8: Ground Water Contamination Potential

Combined Value	Grade	Site Suitability*	Contamination Potential
-8 or less	A	Excellent	) Low
-4 to -7	B	Good	)
+3 to -3	C	Somewhat Inadequate	) Moderate
+4 to +7	D	Poor	
+8 or more	F	Very Poor	) High

*Does not include social factors such as adjacent land use and zoning nor precautionary measures which could be taken to minimize spills and leaks.

Table E11

Overall Degree of Confidence Rating Criteria

Confidence*	Suggested Criteria
High	Confidence in estimates of ratings for the parameters is high, and estimated ratings are considered to be fairly accurate.
Medium	Confidence in estimates of ratings for the parameters is fair.
Low	Confidence in estimates of ratings for the parameters is low, and estimated ratings are not considered to be accurate.

*Degree of Confidence in Accuracy of Overall Evaluation. Overall degree of confidence is based on a subjective consideration of the degrees of confidence assigned in Steps 1-4.

Table E12

Miscellaneous Site Information

Additional information which is not directly accounted for in the numerical portion of the site evaluation may be of significance in the final decision. Listed below are the types of information that should be noted as applicable. Other miscellaneous site information should be noted and considered in the evaluation as appropriate.

Identifier	Site Characteristic
R	Ground water recharge area.
D	Ground water discharge area.
F	Flood plain and is susceptable to flood hazard.
E	Earthquake prone area.
W	Area of influence of a pumping water supply well.
K	Karst topography or fractured, cavernous limestone region.
C	Ground water has been contaminated by man-made causes (e.g. road salt, feed lot, industrial waste).
M	Known ground water mound exists.
I	Interceptor wells or other method employed to inhibit contaminated ground water migration (endangerment to water supply wells may be reduced).

Figure E1

Analysis for Potential of Ground Water Contamination

	Activity	Rating Scale
Step #1	determine the distance to a water supply	0 (over 2000 meters) to 9 (under 15 meters)
Step #2	identify depth to water table	0 (over 60 meters) to 9 (0 meters)
Step #3	identify water table gradient	1 (flow away from well) to 5 (flow toward a well)
Step #4	estimate soil permeability	0 (clay) to 9 (clean gravel)
Step #5	determine overall hydrogeologic rating	summation of ratings of steps 1-4
Step #6	estimate aquifer sensitivity	sensitive to insensitive
Step #7	identify chemical hazard rating	1 (low) to 9 (high)
Step #8	grading the site using the grading chart	A (excellent) to F (very poor)

Figure E2

Depth to Ground Water

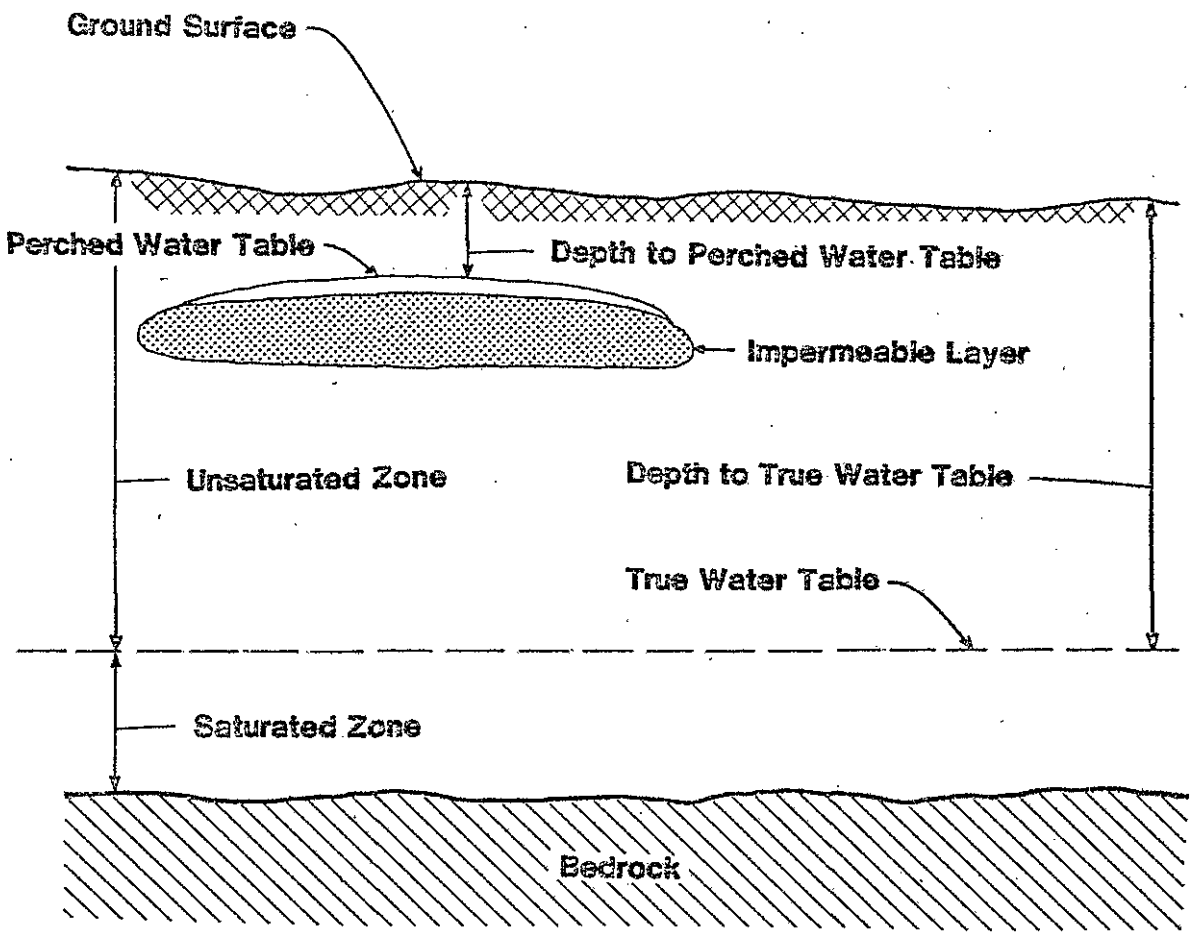
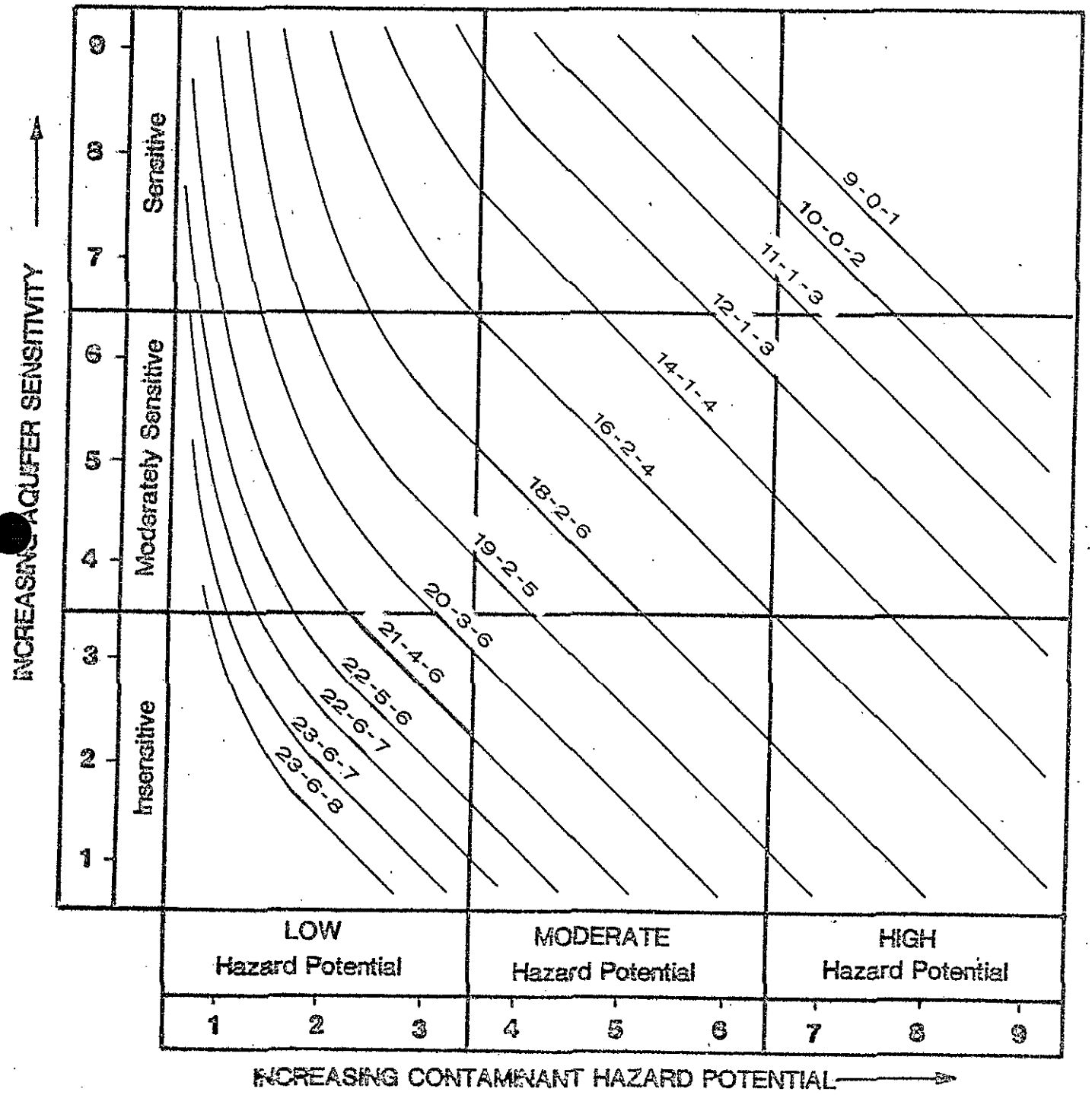


Figure E3

Contamination Potential
Rating Matrix*



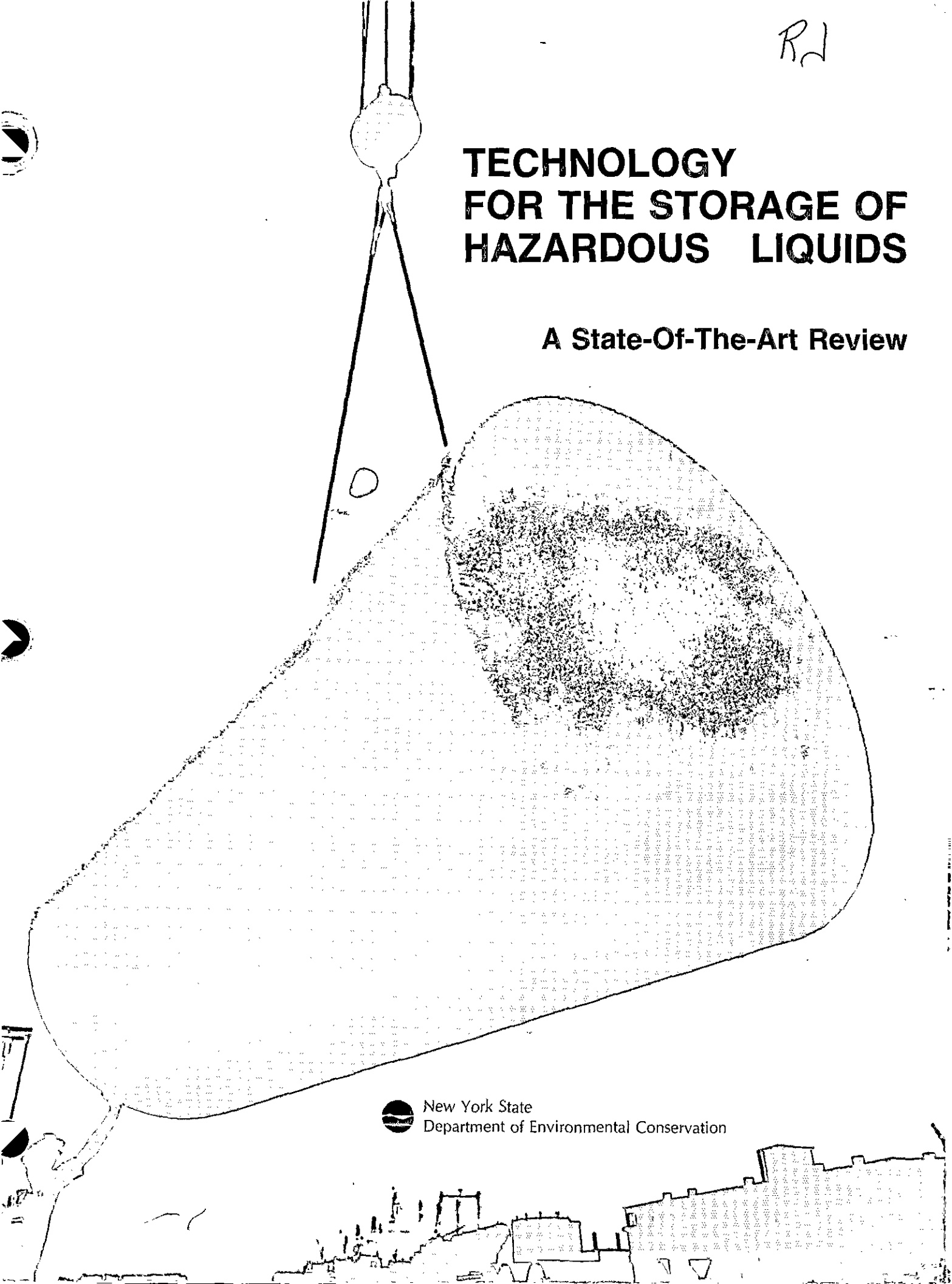
*Based on empirical work of LeGrand.

Note: Standard rating value includes:
Total Rating-Distance Rating-Permeability/Sorption rating.

64. New York State Department of Environmental Conservation. Technology for the Storage of Hazardous Liquids, A State of the Art Review, Albany, New York, January, 1983

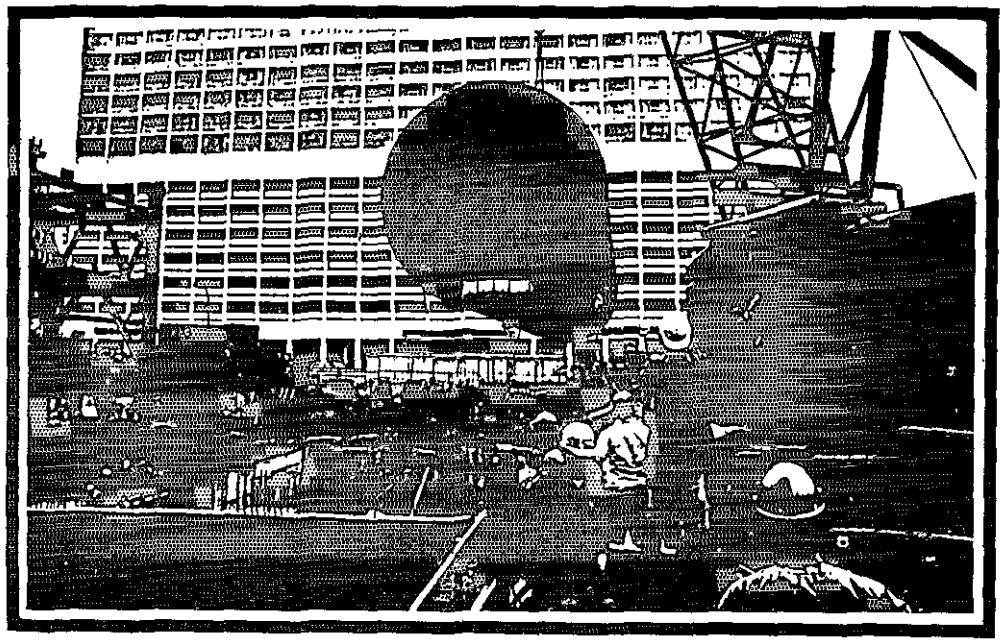
TECHNOLOGY FOR THE STORAGE OF HAZARDOUS LIQUIDS

A State-Of-The-Art Review



New York State
Department of Environmental Conservation

Special Seminar Edition



Underground Tank Storage of Hazardous Materials

A Comprehensive, Practical, "How-to-Comply" Seminar

PRESENTED BY:

ENVIRONMENTAL AWARENESS, INC.
1731 HOWE AVENUE · SUITE 126
SACRAMENTO, CALIFORNIA 95825
(916) 485·3729

TECHNOLOGY FOR THE STORAGE OF HAZARDOUS LIQUIDS

A State-Of-The-Art Review

MANUALS IN NEW YORK STATE'S BULK STORAGE PROGRAM

This **State-of-the-Art Review Manual** compiles much of the latest information on the equipment available for storing and handling hazardous liquids. Included are data on tanks, hoses, overfill prevention devices, piping, valve, and pumps. Important information is also provided on the field practices and equipment available for leak detection and spill cleanup.

Recommended Practices for Underground Storage of Petroleum provides information on the equipment, installation practices, and operating procedures which the Department considers most protective against spills and leaks from bulk storage facilities. Topics covered include: material specifications, installation techniques, secondary containment and leak detection, overfill protection, tightness testing, tank relining, and proper closure.

Administrative and Legal Options for Storing Hazardous Substances: A Guide for Local Officials provides suggested wording and format for local ordinances to regulate the storage of hazardous materials. Alternatives to fit specific needs are presented.

The **Siting Manual** presents information and procedures to help local officials prevent leaks and spills of hazardous substances in sensitive environments. Discussed are: types of hazards, causes of leaks and spills, site evaluation procedures, and practices for spill prevention and mitigation.

The manuals are available from:

Bureau of Water Resources
NYS Department of Environmental Conservation
50 Wolf Road
Albany, New York 12233
Telephone (518) 457-4351

NEW YORK STATE

DEPARTMENT OF ENVIRONMENTAL CONSERVATION
DIVISION OF WATER
BUREAU OF WATER RESOURCES

ALBANY, NEW YORK

JANUARY 1983

PREFACE

This Manual is a compilation of information on the state-of-the-art for aboveground and underground storage systems. It includes a discussion of the technology and practices for storage of petroleum and other hazardous liquids which could be accidentally released into the environment. The purpose of the report is primarily to provide timely information to those industry and government officials faced with rehabilitation and replacement decisions and secondly to encourage the use of technology and practices which would prevent leaks and spills from occurring.

Because hazardous liquids vary widely in their characteristics and in the manner in which they should be stored, this Manual can serve only as a guide. Each chemical requires its own specific storage design. It is the responsibility of the owner of the storage facility to seek the assistance of a professional engineer who has the skills to design a storage system which can be used safely and which provides the necessary measures for environmental protection.

The mention of trade names or commercial products in this manual does not constitute endorsement or recommendation for use by the Department of Environmental Conservation.

ACKNOWLEDGEMENTS

This Manual was prepared by Fred C. Hart Associates and staff from New York State Department of Environmental Conservation, Bureau of Water Resources.

The project managers wish to acknowledge the many people who contributed to this report, particularly those individuals on the review committee who provided valuable comments and suggestions on the manual outline and text.

The individuals who contributed to this manual are as follows:

FRED C. HART ASSOCIATES, Inc. 530 Fifth Avenue, New York, N.Y. 10036

Paul H. Woods, Jr.
Wayne K. Tusa

DEPARTMENT OF ENVIRONMENTAL CONSERVATION

Paul J. Sausville, P.E.
Joseph W. Ritz, P.E.
William E. Blain

REVIEW COMMITTEE

Richard H. Forbes – Environmental Technical Services – Eastman Kodak Company

M. B. Marton – Environmental Programs – IBM

Keith Ora — Empire State Petroleum Association

Lawrence Peterec – Long Island Regional Oil Spill Engineer – New York State Department of Transportation

James H. Pim – Suffolk County Department of Health Services

Albert D. Young, Jr. – Exxon Company, U.S.A.

TABLE OF CONTENTS

Page

Preface i

Acknowledgements ii

Table of Contents ..... iii-vii

List of Figures ..... viii-ix

List of Tables ..... x-xi

INTRODUCTION 1
A. Purpose 1
B. Report Overview 1

Part I STORAGE OF HAZARDOUS SUBSTANCES 2
INTRODUCTION 2
CHAPTER 1: LEAKS AND SPILLS OF HAZARDOUS LIQUIDS 2
A. Behavior of Hazardous Liquids in the Environment 2
1. Background 2
2. Spill Behavior 3
3. The Importance of Spill Prevention 8
B. Types and Causes of Spills and Leaks
1. General 8
2. Aboveground Storage Systems 9
3. Below Ground Storage Systems 10
C. Corrosion 11
1. Corrosion Mechanisms 11
2. Forms of Corrosion 12
3. Factors Influencing Corrosion 14
4. Corrosion Protection .....
References 21-22
CHAPTER 2: HAZARDOUS LIQUIDS 23
A. Listing of Hazardous Liquids 23
B. Properties of Hazardous Liquids 23
1. Chemical Properties 23
2. Relationship Between Temperature, Pressure and Volume Within a Storage Tank 25
C. Storage and Handling Protocol 32
1. Storage and Handling Systems 32
2. Aboveground vs. Underground Storage 33
3. Chemical Compatibility 36
References 37

Part II UNDERGROUND STORAGE SYSTEMS 40
INTRODUCTION 40
CHAPTER 1: UNDERGROUND STORAGE TANKS 42
A. Introduction 42
B. Tank Layout 42
C. Types of Underground Storage Systems 46
1. Bare Steel Tanks 46
2. Coated Steel Tanks 50
3. Cathodically Protected Steel Tanks – Galvanic Protection 50
4. Cathodically Protected Steel Tanks – (Impressed Currents) 52
5. Fiberglass-Reinforced Plastics 52
6. FRP/Steel Bonded Tanks 54
7. Tanks of Other Materials 54
8. Double Containment Systems 54
9. Relined Tanks 57

TABLE OF CONTENTS

Page

D. Tank Coatings and Linings 57
E. Wrappings 60
Information on Specifications for Tank Materials and Construction 60
References 61-62
CHAPTER 2: UNDERGROUND PIPING SYSTEMS 63
A. Introduction 63
B. Causes and Methods of Preventing Leaks 63
1. Proper Design 63
2. Piping System Installation 63
3. Periodic Testing 65
4. Timely Replacement 65
C. Types of Piping 66
D. Fittings 66
E. Expansion Joints and Swing Joints 66
F. Underground Pumps 66
References 72
CHAPTER 3: UNDERGROUND SPILL CONTAINMENT SYSTEMS 73
A. Introduction 73
1. Background 73
2. Containment Technology 73
B. Clay Liners 74
1. Chemical and Physical Properties 74
2. Design and Installation Requirements 74
C. Synthetic Membrane Liners 74
1. Chemical and Physical Properties 74
2. Design and Installation Requirements 76
D. Soil Cement 76
1. Soil Cement 76
2. Bentonites 79
E. Concrete Vaults 80
F. Double-Walled Tanks 80
References 81
CHAPTER 4: TRANSFER SPILL AND OVERFILL PREVENTION SYSTEMS FOR UNDERGROUND STORAGE TANKS 82
A. Introduction 82
B. Overfill Prevention Systems for Underground Storage Tanks 82
1. Elements of an Overfill Prevention System 82
2. Specific Level Sensing Devices 83
C. Transfer Spill Prevention Systems 86
1. Check Valves 87
2. Couplings 87
D. Operating Practices for Overfill Protection 87
References 90
CHAPTER 5: LEAK AND SPILL MONITORING FOR UNDERGROUND STORAGE 91
A. Introduction 91
B. Early Warning Leak Detection System 91
1. Inventory Control 91
2. Interstitial Monitoring in Double-Walled Tanks 94
3. Tank Excavation Monitoring Sensors 94
4. Tank Excavation Monitoring Systems 96
C. Area-Wide Surveillance Methods 97
1. Dyes and Tracers 97
2. Monitoring Wells 97
D. Recovery Wells 103
E. Examples 103
References 107

TABLE OF CONTENTS

Page

CHAPTER 6: TESTING AND INSPECTION OF UNDERGROUND STORAGE TANKS 108
A. Introduction 108
B. Tank Testing Methods 108
1. Pneumatic Testing 111
2. Hydrostatic (Standpipe) Testing 111
3. Heath Petro-Tite Tank and Line Testing Systems (Kent-Moore Test) 111
4. The J-Tube Manometer Test 113
5. The Sunmark Leak Detector 113
6. Laser-Beam Leak Detector 115
7. The ARCO Leak Test 115
C. Pipeline Testing Procedures 116
1. The Suction Piping Test 116
2. Discharge Line Testing 116
D. The Applicability of Tank Tests to the Associated Piping 117
E. Physical Inspection 117
1. Inspection Prior to Backfilling 117
2. Internal Inspection of Installed Tanks 117
3. Checking Tank Bottoms 117
4. Checking for Water in Tanks 118
5. Inspection of Cathodic Protection Systems 118
References 119
CHAPTER 7: TEMPORARY CLOSURE, ABANDONMENT AND REMOVAL OF UNDERGROUND TANKS 120
A. Introduction 120
B. Temporary Closures 120
C. Permanent Closure 122
1. Abandonment in Place 122
2. Removal of Tanks 122
References 123

PART III: ABOVEGROUND STORAGE SYSTEMS 124
INTRODUCTION 124
CHAPTER 1: ABOVEGROUND STORAGE TANKS
A. Introduction 126
B. Tank Layout 126
C. Storage Tank Materials 132
1. Carbon Steel Tanks 132
2. Stainless Steel Tanks 134
3. Fiberglass-Reinforced Plastic 135
4. Plastic Tanks 136
5. Concrete and Aluminum Tanks 136
D. Coatings, Linings and Cathodic Protection 138
References 138-139
CHAPTER 2: ABOVEGROUND PIPING SYSTEMS 140
A. Introduction 140
B. Causes and Methods of Preventing Leaks 140
1. Proper Design and Installaton 140
2. Periodic Inspection 140
3. Periodic Testing 142
4. Timely Replacement 142
C. Piping 142
1. Types of Piping Systems 142
2. Types of Piping 142
3. Hoses 145
4. Pipe Support Elements 145

TABLE OF CONTENTS

Page

D. Valves 145
1. Functions of Valves 145
2. Types of Valves 145
E. Pumps 150
1. Types of Pumps 150
2. Pump Seals 151
3. Spills and Leaks from Pumps 151
F. Fittings and Joints 153
References 153
CHAPTER 3: ABOVEGROUND SPILL CONTAINMENT SYSTEMS 154
A. Introduction 154
B. Degrees of Permeability 154
1. Levels of Protection 154
2. Surface Materials 159
3. Choosing a Surface Material 159
C. Spill Containment Systems 160
1. Dike Systems 160
2. Curbs 160
3. Slurry Trench Cut-Off Walls 160
4. Secondary Containment Tanks 166
D. Spill Collection Systems 166
E. On-Site Spill Cleanup 166
1. Sorbents 166
2. Soil Removal 168
3. Trenching and Skimming 168
4. Recovery Wells 170
5. On-Site Detoxification 170
6. Gelling Agents 170
7. Biodegradation of Petroleum and Organic Chemical Spills 171
References 172
CHAPTER 4: TRANSFER SPILLS AND OVERFILL PREVENTION SYSTEMS FOR ABOVEGROUND STORAGE 173
A. Introduction 173
B. Overfill Prevention Systems 173
1. Level Sensors and Gauges 175
2. High Level Alarms 181
3. Automatic Shutdown or Flow Diversion 181
4. Emergency Overflow to Adjacent Tank 181
5. Personal Monitoring of Systems 182
C. Dry Disconnect Couplings or Transfer Pipe and Hoses 183
D. Redundant Valving and Instrumentation 183
E. Use of Established Transfer Stations 183
F. Proper Transfer Practices 183
G. Regular Inspection and Maintenance 183
References 184
CHAPTER 5: LEAK MONITORING OF ABOVEGROUND TANKS 185
A. Introduction 185
B. Aboveground Leak Detection Systems 185
References 185
CHAPTER 6: INSPECTION AND MAINTENANCE OF ABOVEGROUND TANKS 186
A. Introduction 186
B. Visual Inspection of Tanks 186
1. External Inspection – Tank in Service 187
2. Internal Inspection – Tank Out of Service 188
C. Visual Inspection of Pipes, Valves, Fittings and Hoses 188
D. Inspection of Pumps and Compressors 189
E. Visual Inspection of Instruments, Control Equipment and Electrical Systems . 189

TABLE OF CONTENTS

Page

F. Inspection of Vapor Control Systems 190
G. Inspection Tools and Electromechanical Equipment 190
1. Hammering 190
2. Penetrant Dye Method 191
3. Vacuum Box 191
4. Ultrasonic Instruments 191
5. Radiographic Tools 191
6. Other Radiation-Type Instruments 192
7. Acoustic Emissions Testing 192
H. Frequency of Inspections 192
I. Maintenance of Aboveground Tanks 192
References 193
CHAPTER 7: TEMPORARY CLOSURE, ABANDONMENT AND REMOVAL OF ABOVEGROUND TANKS 194
A. Introduction 194
B. Tank Decontamination 194
C. Tank Dismantling 196
References 197
Appendix A: CHEMICAL AND PHYSICAL PROPERTIES OF VARIOUS HAZARDOUS SUBSTANCES 198
Various Hazardous Substances 198
Definitions 198
1. Human Poisons 199
Table A-1 199
2. Flammables 199
3. Corrosives 199
4. Volatiles 199
5. Floaters 199
6. Reactives 200
7. Solubles 200
8. Solids or Liquids Amenable to Biological Treatment 200
9. Biodegradables 200
10. Compounds Highly Toxic to Aquatic Life 200
Classifications 200
Table A-2 201-205
Table A-3 205-211
Table A-4 212
Appendix B: COMPATIBILITY CHART FOR FLUIDS, SEALS AND METALS 213-215
Appendix C: PROPERTIES OF PRINCIPAL COATING RESINS 216-218
References 216
Appendix D: GLOSSARY 219-223

LIST OF FIGURES

Number	Title	Page
1.1-1	Product Seepage	4
1.1-2	Trapped Product Droplets	4
1.1-3	Possible Migration of Product to Outcrop Followed by Second Cycle Contamination	5
1.1-4	Effect of Clay Lens in Soil	5
1.1-5	Typical Behavior in Porous Soil Following a Sudden High Volume Spill	6
1.1-6	Behavior of Product After Spill has Stabilized	7
1.1-7	Electrolytic Corrosion	12
1.1-8	Galvanic Corrosion	13
1.1-9	Corrosion Mechanisms at an Underground Steel Tank	15
1.1-10	More Corrosion Mechanisms at an Underground Steel Tank	16
1.1-11	Magnesium Anode Cathodic Protection Typical Configuration	19
1.1-12	Impressed Current Cathodic Protection Typical Configuration	20
1.2-1	Typical Annual Tank Temperature Variation for an Underground Gasoline Tank	28
1.2-2	Location of Temperature Sensors in the SRI Tank	29
1.2-3	Tank Temperature at Various Heights as a Function of Time for a 24-Hour Period After Tank Fill-Up	30
1.2-4	Mean Temperature Distribution as a Function of Depth for Four Different 24-Hour Periods	31
2.1	Elements of an Underground Storage Tank Installation	41
2.1-1	Tank Piping Details – Suction System	45
2.1-2	Tank Piping Details – Submerged Systems	45
2.1-3	Anchoring of Tanks Installed in High Groundwater Tables	49
2.1-4	Magnesium Anode Cathodic Protection – Typical Configuration	51
2.1-5	Impressed Current Cathodic Protection – Typical Configuration	53
2.1-6	Fiberglass-Reinforced Plastic Double Wall Tank	55
2.1-7	Double Wall Steel Tank with Epoxy Coating and Sacrificial Zinc Anode	56
2.2-1	Diagram of a Universal-Type Expansion Joint	64
2.2-2	Double Walled Pipe	68
2.2-3	Action of the Bellows of an Expansion Joint	69
2.2-4	Swing or Swivel Joints	69
2.2-5	Typical Remote Pump Shut-Off Valve	70
2.2-6	Typical Remote Pump Shut-Off Valve	71
2.3-1	Synthetic Liner Installation for Storage of Lighter-Than-Water Liquids in Area of High Groundwater	79
2.3-2	Synthetic Liner Installation for Storage of Heavier-Than-Water Liquids in Area of High Groundwater	80
2.4-1	Tape Float Gauge for Underground Storage Tank	86
2.4-2	Float Vent Valves Used for Overfill Prevention	87
2.4-3	Optical Liquid Level Sensing System for Tank Truck	88
2.4-4	Optical Liquid Level Sensing System for Storage Tank	88
2.4-5	Types of Couplings	89
2.5-1	Typical Applications of a Leak Monitoring System Based on Thermal Conductivity	95
2.5-2	Examples of Observation Wells	98
2.5-3	Example of a U-Tube Installation	99
2.5-4	Typical Wells for Continuous Gas or Vapor Monitoring	101
2.5-5	Typical Single Monitoring Wet Well	103
2.5-6	Typical Wet Well Cluster	104
2.5-7	Schematic of a Typical Nested Monitoring Well	105
2.5-8	Typical Single-Pump Recovery System	106

LIST OF FIGURES

Number	Title	Page
2.5-9	Typical Two-Pump Recovery System	106
2.6-1	J-Tube Underground Tank Leak Detector	114
3.1	Selected Components of an Aboveground Storage Facility	125
3.1-1	Types of Atmospheric and Low-Pressure Tanks	127
3.1-2	Aboveground Tank Connections	130
3.2-1	Types of Valves	147
3.2-2	Types of Valves	148
3.2-3	Check Valves Used to Prevent Backflow	149
3.2-4	Typical Control Valve	150
3.2-5	Mechanical Seal Components	151
3.3-1	Schematic Flow Diagram	155
3.3-2	Bulk Plant Layout	161
3.3-3	Dike and Siphon	162
3.3-4	Typical Earth Dikes	163
3.3-5	Typical Curbed Containment Area Drained Through Catch Basin	164
3.3-6	Underground Barrier and Cut-Off Wall	165
3.3-7	Imbiber Bead Applications	167
3.3-8	Spill Cleanup Using Interceptor Trench	169
3.3-9	Spill Cleanup Using Pumping Well	169
3.4-1	Elements of an Overfill Prevention System	174
3.4-2	Chain and Tape Float Guage Used for Level Control	177
3.4-3	Level and Shaft Float Used for Level Control	177
3.4-4	Magnetically Coupled Floats Used for Level Control	178
3.4-5	Torque Tube Displacer Used for Level Control	179
3.4-6	Magnetically Coupled Displacer Used for Level Control	179
3.4-7	Flexure Tube Displacer Used for Level Control	180
3.4-8	Bubble Tube System Used for Level Control	180
3.4-9	Loading Arm Equipment with Automatic Shutoff	182

LIST OF TABLES

Number	Title	Page
1.1-1	Types of Leaks from Bulk Storage and Handling Facilities	8-9
1.1-2	Guide to Discussions of Causes and Mitigative Measures for Spills or Leaks from Hazardous Liquid Storage Systems	9
1.1-3	Leaks by Source Categories	10
1.1-4	Causes of Leaks in Steel Tanks	10
1.1-5	Causes of Piping Leaks	11
1.1-6	The Galvanic Series of Metals and Alloys	14
1.1-7	Common Forms of Localized Corrosion	14
1.1-8	Soil Corrosivity vs. Soil Resistivity	17
1.2-1	Listing of Regulated Hazardous Substances	23
1.2-2	Reports Describing Hazardous Materials	24
1.2-3	Physical and Chemical Properties of the Twenty-Nine Most Commonly Used Hazardous Substances in New York State	26-27
1.2-4	Total Force on Tank Ends Due to Internal Pressure	32
1.2-5	Storage System Components – Methods, Materials and Design Considerations	33
1.2-6	General Properties of Materials Used for Storage Tanks and Piping	34-35
1.2-7	Aboveground vs. Underground Storage	35
1.2-8	Compatiblity Chart: Chemicals vs. Structural Materials	36
1.2-9	References on Materials and Chemical Compatibility	36
2.1-1	Characteristics of Underground Storage Tanks	43-44
2.1-2	Recommended Thickness of Steel Tanks	47
2.1-3	Gallon Capacity per Foot of Length	48
2.1-4	Surface Preparation Specifications	58
2.1-5	Latest Coating Techniques	59
2.2-1	Important Criteria in the Design of Piping Materials for Underground Service	63
2.2-2	Characteristics of Piping Materials for Underground Service	67
2.3-1	Comparison of Underground Spill Containment Systems	75
2.3-2	Comparison of Various Synthetic Polymeric Membranes	77-78
2.3-3	Chemical Compatibility of Membrane Liners with Hazardous Materials	78
2.3-4	Considerations During Liner Placement	76
2.3-5	Highlights of Soil Cement Design and Installation	79
2.4-1	Elements of a Good Overfill Prevention System	82
2.4-2	Characteristics of Pneumatic and Electronic Controls	84
2.4-3	Level Detection Devices for Underground Storage Tanks	85
2.4-4	Transfer Spill Prevention Systems	88
2.5-1	Comparison of Various Leak Monitoring Techniques	92-93
2.5-2	Applicability of Types of Leak Sensors in Tank Excavation Areas	96
2.5-3	Types of Site Data Needed to Design Appropriate Groundwater Monitoring Programs	100
2.5-4	Types of Groundwater Monitoring Wells	102
2.5-5	Leak Detection System for Manufacturers	104
2.6-1	Comparison of Various Leak Detection Tests for Underground Systems	109-110
2.6-2	Apparent Loss of Product Volume Due to Tank End Deflection (in Gallons)	112
2.7-1	Closure, Abandonment and Removal of Underground Tanks	121
3.1-1	Characteristics of Various Types of Aboveground Storage Tanks	128-129
3.1-2	Current Publications of the American Petroleum Institute Pertaining to Storage Tanks	133
3.1-3	Underwriters Laboratories Recommendations for Metal Thickness of Horizontal Steel Tanks	134
3.1-4	Underwriters Laboratories Recommendations for Metal Thickness of Vertical Steel Tanks	134
3.1-5	Miscellaneous Recommendations for Steel Tank Fabrication	135
3.1-6	Liquid Chemicals Commonly Stored in Fiberglass Tanks	135
3.1-7	Performance Factors for Various Types of Fiberglass Tanks	136
3.1-8	Partial Chemical Compatibility Chart for One Type of Polyolefin Tank	137
3.2-1	Piping Installation and Leak Prevention	141

LIST OF TABLES

Number	Title	Page
3.2-2	Characteristics of Piping Materials	143-144
3.2-3	The Functions of Valves	146
3.2-4	Items to Look for During Valve Maintenance	150
3.2-5	Comparison of Pump Seals	152
3.3-1	Spill Containment and Collection Systems	156
3.3-2	Characteristics of Various Surface Materials	157-158
3.3-3	Materials Absorbed by Imbiber Beads	168
3.4-1	Transfer Spills Are Prevented by Using the Following Equipment and Practices	173
3.4-2	Level Detection for Overfill Prevention Systems for Aboveground Storage Tanks	176
3.6-1	Tank Inspection Point Listing	186-187
3.7-1	Closure, Abandonment and Removal of Underground Tanks	195
3.7-2	References for Tank Cleaning Operations	196

INTRODUCTION

A. PURPOSE

Within the past five to ten years there have been major advances in the technology and practices of storing and handling hazardous liquids. New tank designs and tank materials have been applied to solve problems of corrosion and to prevent leaks. Mechanical and electronic flow control and level detection devices have been invented to prevent transfer spills and monitor storage volumes. Laser technology, capable of measuring the loss of product stored in a tank with a resolution of 0.000001 inches, has been used experimentally to test for tank leaks. Secondary containment designs have been developed and applied by many sectors of the industry.

It is the purpose of this report to evaluate these and other aboveground and underground storage practices. It is a report on the state-of-the-art for the following:

- Tanks for storing hazardous liquids.
- Secondary containment systems.
- Piping and safety valves.
- Overfill prevention systems and practices.
- Inspection, testing and monitoring.
- Closure and abandonment practices.

Hopefully, this report will provide timely information for the industry and government officials faced with problems on the storage of hazardous liquids and will encourage the use of the best technology and practices for preventing spills and leaks.

B. REPORT OVERVIEW

This report is divided into three parts. Part I represents an overview of the general concerns associated with the underground or aboveground storage of hazardous liquids. This part of the report includes discussion of:

- The properties and characteristics of various hazardous liquids.
- The compatability of various tank and piping system materials with certain hazardous liquids.
- The types of leaks and problems which can occur in bulk storage facilities.
- The cause of corrosion.
- Other technical factors that must be considered prior to the storing of hazardous liquids.

Part II of this report addresses the state-of-the-art for underground storage systems. Part III addresses these same items for aboveground storage systems.

Some of the material discussed applies to both aboveground and underground systems, therefore, cross referencing is employed throughout this report. More detailed references, such as those prepared by the American Petroleum Institute, the National Fire Protection Association, and other institutions, are identified in the text. The reader is specifically directed to these references for futher information on the technology and measures for spill and leak prevention.

Because of the large quantity of gasoline and other petroleum products handled and stored in the state and the extensive information on the storage of these materials available from the American Petroleum Institute and other organizations, much of the detailed material presented in this manual is drawn from the experience of the petroleum industry. Although the basic principles illustrated are applicable to the storage of all hazardous liquids, some of the specific details presented may not be directly applicable in all situations. There are many ways by which environmentally acceptable storage facilities can be achieved. The manual is intended to serve as a source of background information and guidance to aid government officials, designers and users of bulk liquid storage systems in understanding the many different considerations and features which may impinge upon design and installation of such systems. It is not intended as a standard or as a substitute for sound engineering practice as applied to the design and installation of bulk storage systems for specific materials at specific locations.

Part I
STORAGE OF HAZARDOUS SUBSTANCES

INTRODUCTION

The purpose of Part I of this report is to present background information describing the characteristics of hazardous substances, the types and causes of leaks and spills, and the behavior of these leaks and spills in the environment. Chapter 1 of this part of the report addresses the types and causes of leaks from both aboveground and underground storage systems, the sources of leaks and spills and methods available to control them. This chapter also includes a description of the behavior of hazardous substances when they are spilled on or in the ground.

Chapter 2 of this part of the report presents data on the types of hazardous materials of concern and their properties. This chapter refers to general listings of hazardous substances, and provides detailed information regarding such items as type of hazard, specific gravity, boiling point, melting point, solubility in water, etc. for a select group of these substances. This chapter also provides information regarding the compatibility of various types of hazardous substances with the metals or other materials which may be used to construct storage system components (tanks, pipes, fittings, etc.).

Part I
CHAPTER 1: LEAKS AND SPILLS OF HAZARDOUS LIQUIDS

A. BEHAVIOR OF HAZARDOUS LIQUIDS IN THE ENVIRONMENT

1. Background [1,2,3,4]

Spills (including leaks) of hazardous liquids can have substantial environmental, public health and social impacts. Such spills can result in the contamination of soils, surface water and groundwater supplies and air, all of which can directly affect crops, wildlife, plants and ultimately humans. Many hazardous liquids are conservative substances (i.e., they do not biodegrade or decompose), therefore, once the substance has been spilled it will remain a hazard unless it can be removed to below the level of harmful concentration.

A hazardous substance which finds its way into the environment may be a serious threat to the health of people who come in contact with it. It may contaminate water supplies, crops and food supplies, fisheries or wildlife habitat. The non-environmental impacts which result from spills of hazardous liquids can also be far-reaching. These impacts can include the following:

- The dislocation of people.
- The loss of valuable product.
- The loss of property resulting from contamination, fire, explosions, etc.
- The economic and social costs of spill cleanup [1].

Storage tank leakage problems are more readily controlled and resolved with aboveground structures because the leaks are more likely to be visible. Below ground systems present potentially more serious problems of contamination because of the likelihood of undetected leakage, but minimize the possibility of fires and explosions when flammable and reactive chemicals are to be stored. The threat of potential groundwater pollution must be balanced against other safety considerations. In some parts of New York State, groundwater is the only source of fresh water, and areas such as Long Island have already witnessed a large number of groundwater pollution incidents. A prime example occurred in East Meadow, Long Island where a service station leaked 50,000 gallons of gasoline from a below ground storage tank and the hazardous fumes seeped into the basements of more than a score of the surrounding homes. The gasoline distributor purchased the homes and they are still uninhabitable [1].

A contributing factor in the increasing number of documented incidents like this is the large number of active and abandoned underground storage tanks. New York State has more than 100,000 aboveground and buried bulk storage tanks containing a variety of chemicals (cleaning solvents, pesticides, industrial process chemicals, etc.). However, most contain petroleum, primarily gasoline. For these alone, the New york State Gasoline Retailers Association estimates that at least 68,000 are underground at gasoline service stations. Roughly 24,000 of these tanks are at abandoned service stations that went out of business during the recent period of gasoline shortages. Although in disuse, many are suspected of containing a residual gasoline supply. In addition to the gasoline retailers, thousands of storage tanks across the State are used at motor depots, contracting yards, farms, schools, industrial sites and at some private homes [2].

Many tanks were installed in the early 1950's when growth in the chemical industry and highway transportation was booming. These tanks are now 20-30 years old – at or beyond their life expectancy. Other contributing causes to the problem include improper material selection during the design stage and, just as important, improper installation practices. The percent of failure is not known but it is estimated that 10 to 20 percent are leaking [2].

The effects of underground leakage and spills can be both short-and long-term. the short-term effects from gasoline spills, for example, as well as other hydrocarbon type materials, are potentially devastating because of their volatile nature. Seepage of liquids and fumes into underground structures can result in gas and vapor accumulation and consequent explosion and health hazards. In the long-term, contaminated underground water supplies (aquifers) are practically impossible to reclaim once they have been contaminated. To understand the potential hazard posed by spills and leaks of hazardous liquids, one must develop some understanding of the behavior of such spills and leaks.

2. Spill Behavior

Spills and leaks of volatile hazardous liquids may pose potential air quality and explosion problems. The level of potential hazard is dependent upon several factors including the volatility of the spilled substance and vapor dispersion characteristics in the vicinity of the spill or leak. Surface waters may also be contaminated by spills and leaks traveling across or within soils posing a potential threat to aquatic life and human health.

However, of primary concern in New York State is the potential effect that spills or leaks may have upon soils, surface water and groundwater [1]. Hazardous liquids spilled or leaked into soil typically tend to flow downward, with some lateral spreading due to gravitational forces, as illustrated in Figure 1.1-1. The rate of movement in the soil will depend on product properties such as solubility, miscibility, viscosity, soil permeability and compaction, and the rate or volume of the leak or spill. For example, given the same soil properties, lighter liquids, such as gasoline, will penetrate the soil rapidly, while heavier, more viscous liquids will move more slowly. Alternately, if the soil has a low permeability, as is characteristic of clays, the product may have little or no penetration. However, if the soil is very porous, the product will penetrate it quickly.

Absorption by Soil [3,4]. As spilled liquids pass downward through soils, individual soil particles will be coated with a thin film of that liquid. In addition, surface tension will act to hold small amounts of that liquid in the voids between soil particles, as shown in figure 1.1-2. These actions combine to result in the absorption of the liquid into the soil. Once absorbed, extraction of the liquid is virtually impossible.

A spilled or leaked liquid will move downward in the soil until:

- It is absorbed by the soil.
- It encounters an impermeable bed or layer.
- It reaches the water table.
- It seeps from groundwater to surface water.

Movement at an Impermeable Layer [3,4]. The downward movement of a spilled liquid through soil is affected by variations in permeability of the soil layers through which it passes. If the flowing liquid encounters an impermeable layer of soil it will spread laterally until either it becomes immobile or it comes to the surface at the outcrop of the impermeable layer. Should the latter phenomenon occur, a second cycle of soil contamination could begin (Figure 1.1-3).

Note that Figures 1.1-3 through 1.1-6 illustrate the movement of product which is lighter than water and immiscible. A spilled chemical with a specific gravity greater than 1.0 will tend to sink to the bottom of the aquifer while one with a high solubility will tend to mix with the groundwater.

Downward movement of spilled material may also be complicated by the presence of thin lenses of material with low permeability (Figure 1.1-4). If such lenses are present, the fluid path could be substantially altered.

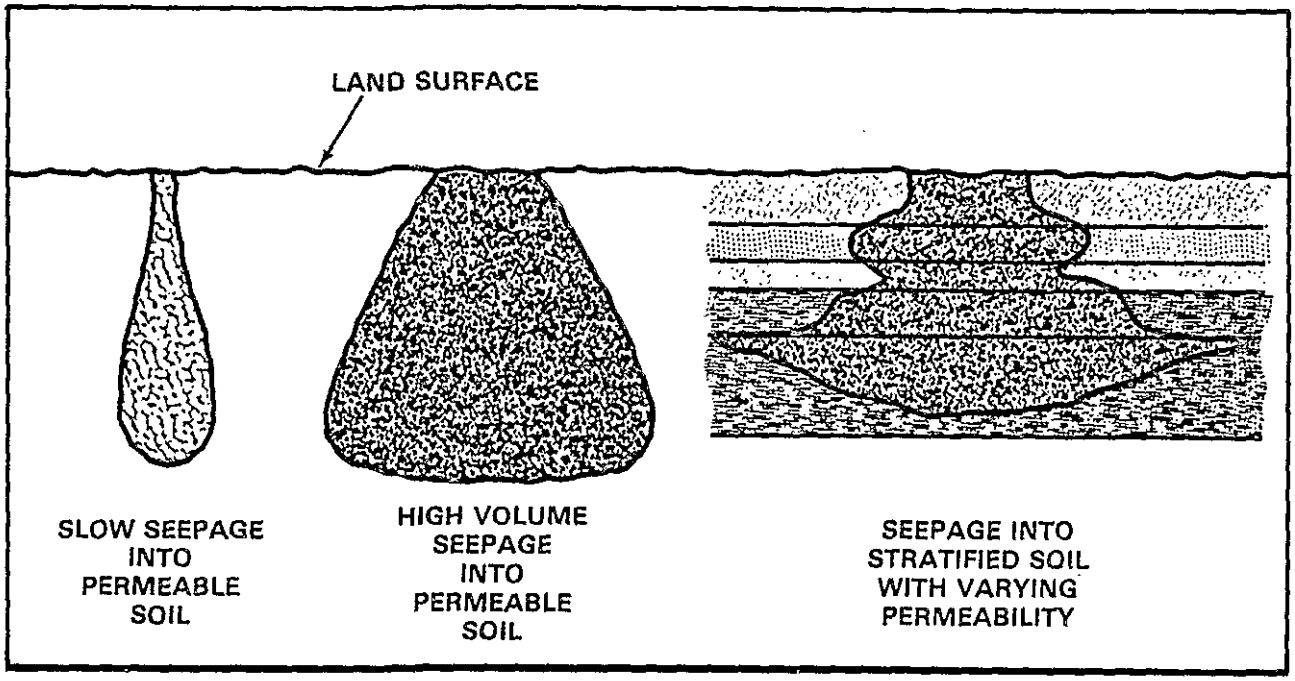
Movement Into Groundwater [3]. The following excerpt from API Publication 1628 describes the intrusion of spilled liquids into groundwater:

> "The contact of spilled product with the water table usually is the most troublesome result of an on-land spill. This condition greatly increases the risk of polluting a water supply, and may increase the chance of movement to some underground structure, such as a basement, sewer or conduit. The degree of risk depends on the nature of the groundwater system and the way it is utilized.
>
> Figure 1.15 illustrates a pattern of oil descent to a water table. A sudden, large-volume spill will depress the water table and spread in all directions in a layer above the water table. As the layer becomes thinner, it will begin to move in the direction of groundwater flow (Figure 1.1-6).
>
> A slower leak will descend in a narrow cone and spread in the direction of water movement. Lateral spreading will usually be slower than the flow rate of the groundwater."[3]

More detail discussions of this type can be found in API Publication 1628 [3], and NFPA 329 [4].

Figure 1.1-1

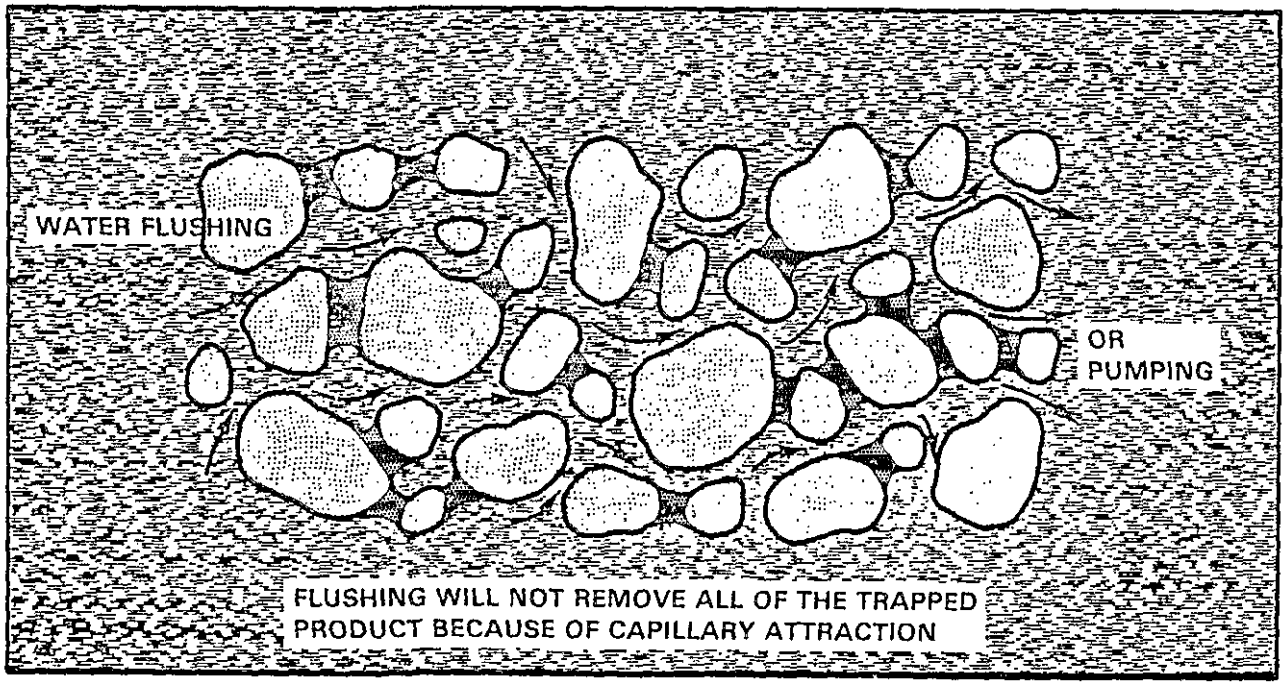
Product Seepage



Source: API Publication 1628, *Underground Spill Cleanup Manual*, 1980.

Figure 1.1-2

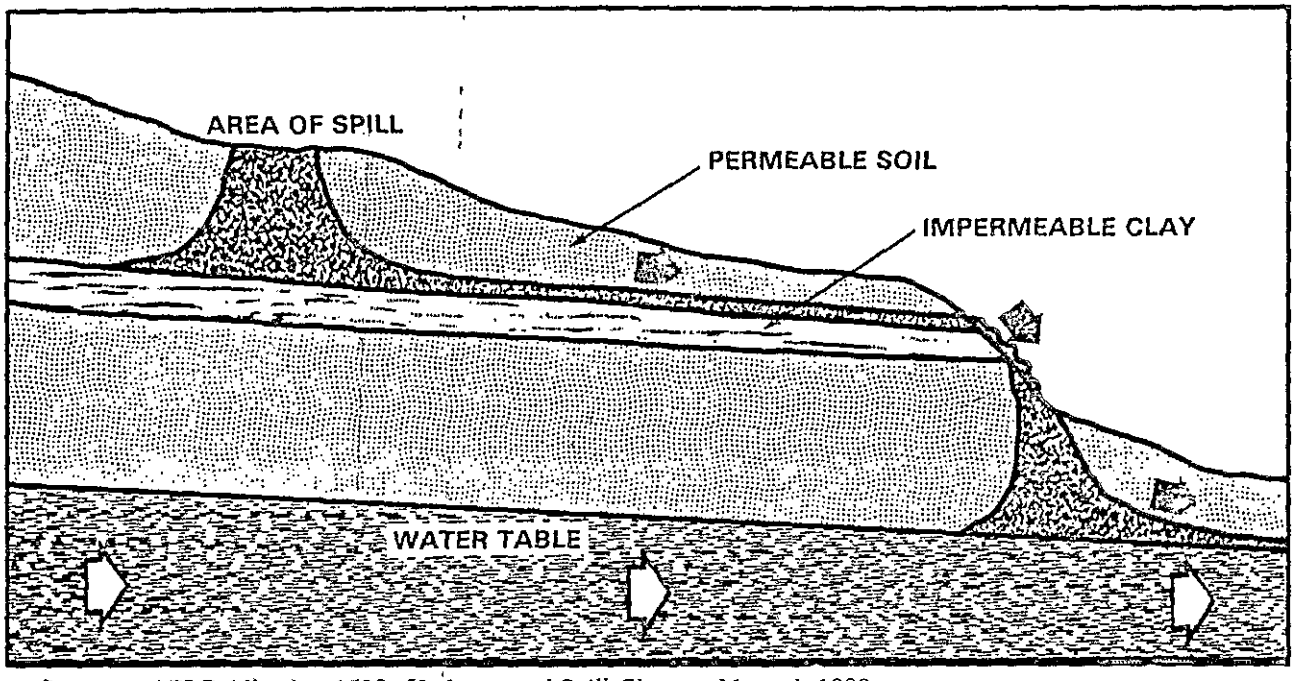
Trapped Product Droplets



Source: API Publication 1628, *Underground Spill Cleanup Manual*, 1980.

Figure 1.1-3

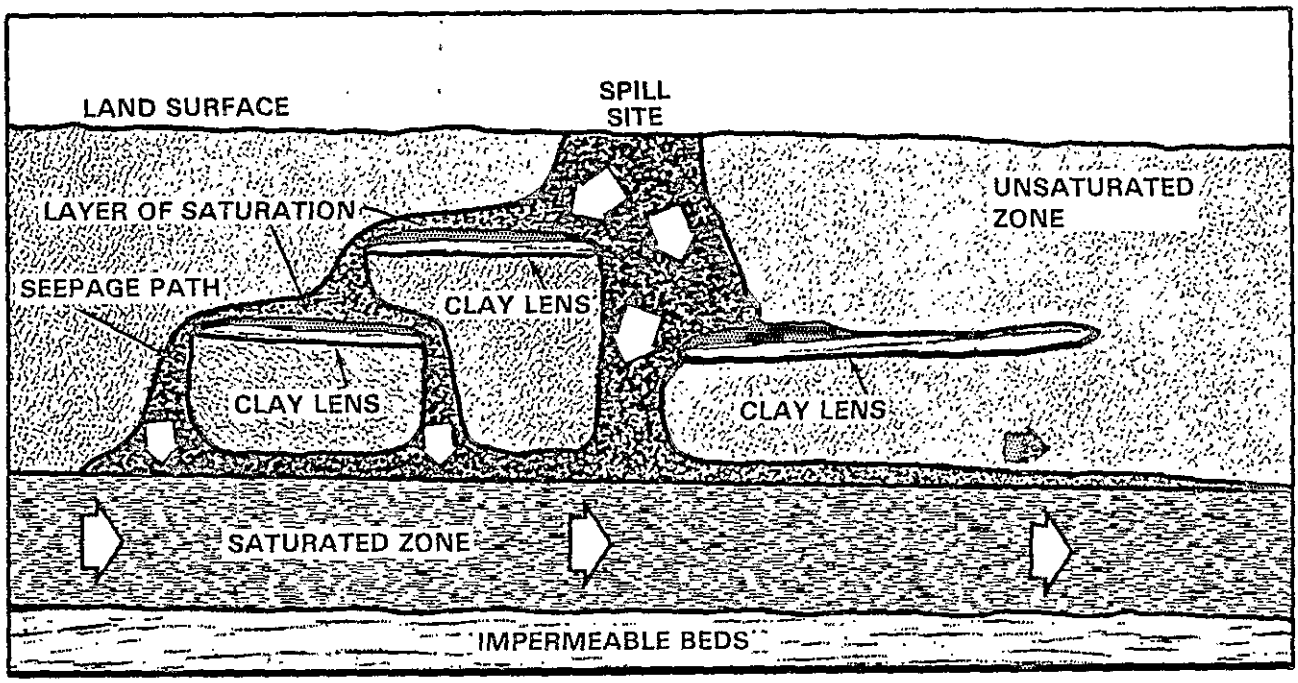
Possible Migration of Product to Outcrop Followed by Second Cycle Contamination



Source: API Publication 1628, *Underground Spill Cleanup Manual*, 1980.

Figure 1.1-4

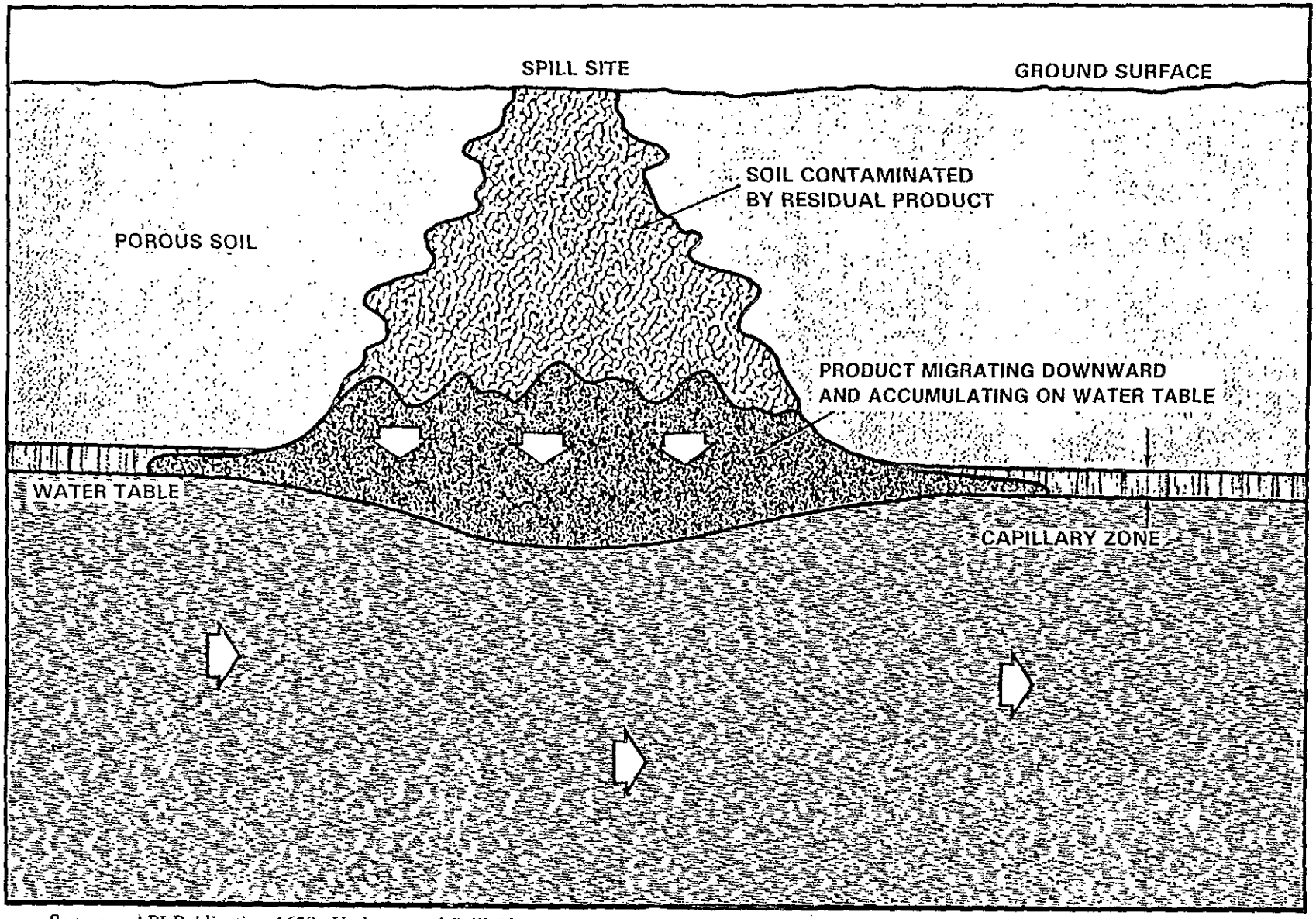
Effect of Clay Lens in Soil



Source: API Publication 1628, *Underground Spill Cleanup Manual*, 1980.

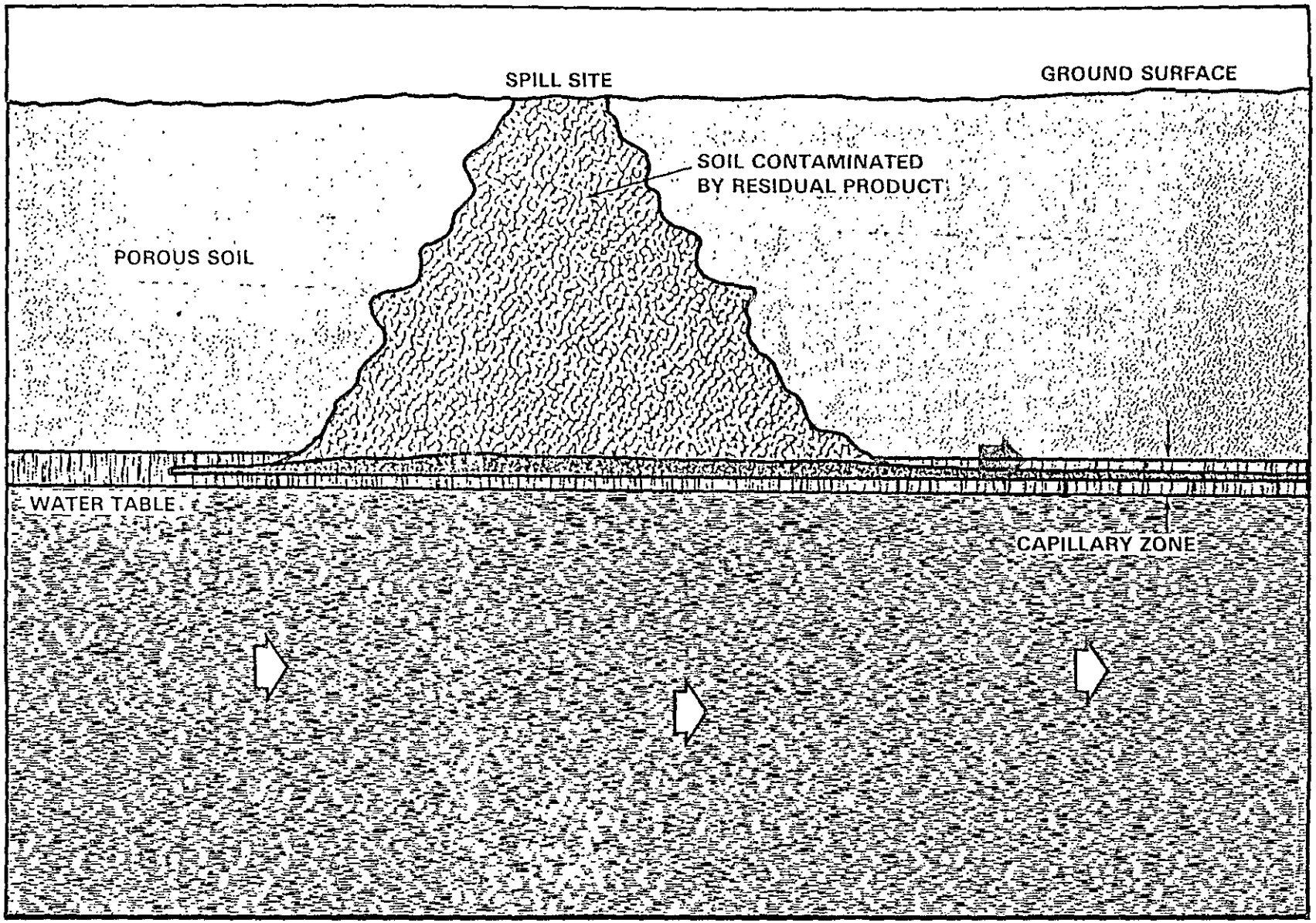
Figure 1.1-5

Typical Behavior in Porous Soil
Following a Sudden, High Volume Spill



Source: API Publication 1628, *Underground Spill Cleanup Manual*, 1980.

Figure 1.1-6
Behavior of Product After Spill Has Stabilized



Source: API Publication 1628, *Underground Spill Cleanup Manual*, 1980.

Movement from Groundwater to Surface Water. Contaminated groundwater may enter surface water through springs or by direct influent seepage into a creek, lake or river. It may now become visible or be detected by odor. The presence of the contaminant may also be apparent if there is a fish kill. It will cause immediate concern if the surface water is used for drinking water or for primary contact recreation (bathing).

3. The Importance of Spill Prevention

The first line of defense against the potential environmental and public health impacts of hazardous liquids spills and leaks is the implementation of good spill/leak prevention practices. Such prevention practices are always more cost-effective and environmentally effective than attempts to clean up a spill or leak after it has occurred. For this reason, the importance of adopting and rigidly following a spill/leak prevention and detection program cannot be overemphasized.

The practices which can be employed for spill and leak prevention are discussed in detail throughout the remainder of this document.

B. TYPES AND CAUSES OF SPILLS AND LEAKS [1,5,6,7]

1. General

Spills and leaks of hazardous liquids at bulk storage facilities, either above or below grade, may emanate from any of several sources and may be precipitated by one or more of several causes. The types of spills which may occur include: (1) large spills such as those that result from tank or pipe rupture; (2) slow leaks or drips such as those that result from slow deterioration (e.g. corrosion) of a storage system component; and (3) small spills such as those that result from fluid transfer mishaps (e.g. overfills) or other storage yard spills. Spills or leaks can also occur as a general result of poor housekeeping practices, or as a result of vandalism or acts of malicious intent. Spills or leaks can occur anywhere in the bulk storage facility where liquids are handled or stored if proper care is not taken. Examples of leak locations from bulk storage and handling facilities are presented in Table 1.1-1.

An adequate spill/leak prevention and detection program has a number of key elements, including the following:

- Tank (material) selection guidelines.
- Tank installation guidelines.
- Piping system (material) selection and installation guidelines.
- Steps for corrosion and tank failure prevention.
- An overfill prevention system and overfill protection guidelines.
- Standardized practices for periodic inspection and preventive maintenance.
- A leak detection system with periodic monitoring.
- Procedures for inventory control.
- Spill containment facilities.
- Emergency response procedures.
- Guidelines and procedures for the closure and abandonment of storage systems.
- Transfer facility design requirements.

Table 1.1-1

Types of leaks from Bulk Storage and Handling Facilities

Bulk Storage Facilities - Tank Farms and Tankage

1. Leaks and overfilling of tanks
2. Rupture of tanks
3. Leaks in pipe, valves and fittings
4. Leaks in containment dikes
5. Inadequate dike volume to hold contents of leaking tanks
6. Product flow from dike area through open dike valve
7. Leaks from pump seals and maintenance
8. Level instrument failure allowing tank overfilling
9. Piping damage by collision with mobile equipment
10. Spills from water drawoff from storage tanks
11. Spills from tank bottom cleanout and sludge disposal
12. Improper disposal of samples
13. Overflow of wastewater treatment systems by rainfall flooding
14. Poor maintenance of pipe, valves and fittings
15. Plugging of drainage system by debris
16. Wastewater treatment systems with insufficent capacity to remove product
17. Inadequate secondary containment devices
18. Spills from line flushing
19. Spills from pipe and tankage changes
20. Possible sabotage
21. Improper installation

Bulk Handling Facilities - Terminals, Pipelines

1. Spills from quick-connect coupling operation
2. Overfilling tank trucks, tank cars, barges, tankers, etc.
3. Lack of curbs, drains and spill collection system
4. Improper operation of product/water separators

Table 1.1-1 continued

5. Leaks from loading arms, especially joints and gaskets
6. Leaks from underground storage tanks
7. Improper disposal of sludge from product filters
8. Insufficent sump capacity (should be equal to volume of largest compartment of tank truck of rail car)
9. Leaks from damaged loading connections
10. Operators incorrectly setting loading meters and tanks overfilling
11. Level instrument and subsequent sump pump failure on oil sumps
12. Leaks from heating coils in heavy fuel tanks
13. Possible sabotage
14. Improper installation

Adapted from reference 5.

These causes of storage system leaks and spills and state-of-the-art methods of controlling them are addressed briefly in the discussions of aboveground and underground storage systems that follow this section. A guide to the more detailed discussions of these items throughout Parts II and III of this document is presented in Table 1.1-2.

2. Aboveground Storage Systems [1,5,8,9]

The deterioration of the components of aboveground storage systems can occur for any one of several reasons. The most common reason for component deterioration, particularly the deterioration of metal components, is corrosion [1], which is addressed in detail later in this section. Other reasons include the following:

- Mechanical failure, such as failure of valves, gaskets or pumps.
- Cracks in tanks, piping or fixtures which could result from faulty welding, unrelieved stress concentrations around fittings, insufficient reinforcement around openings, settlement or earth movement, vibration, or poorly designed repairs [8].

Methods of controlling the deterioration of storage system equipment include: (1) the use of better system designs; (2) the incorporation of a good preventive maintenance program; and (3) proper training of employees.

Leaks and spills due to overflow, overfilling and other liquid transfer operations are another important category of product loss from storage systems. These can be controlled through the use of overflow protection devices and level sensing devices in storage tanks; the use of secondary containment, curbing, pumps, etc.; and the incorporation of adequate housekeeping and operational procedures.

One of the most important causes of leaks is the improper installation of storage tanks and related equipment. Many leaks can be traced to problems such as:

Table 1.1-2

Guide to Discussion of Causes and Mitigative Measures for Spill and Leaks from Hazardous Liquid Storage Systems

Cause of Leak/Spill	Equipment Affected	Section of Report
Equipment deterioration		
Corrosion	All components	Part I, Chapter 2.
	Underground tanks	Part II, Chapter 1.
	Underground piping	Part II, Chapter 2
	Aboveground tanks	Part III, Chapter 1
	Aboveground piping	Part III, Chapter 2
Mechanical Failure and cracks	Underground Tanks	Part II, Chapter 1
	Underground piping	Part II, Chapter 3
	Aboveground tanks	Part III, Chapter 1
	Aboveground piping	Part III, Chapter 2
Transfer spills and leaks	Underground tanks, piping and spill containment systems	Part II, Chapters 3 and 4
	Aboveground tanks, piping and spill containment systems	Part III, Chapters 3 and 4
Improper installation of system components	Underground tanks	Part II, Chapter 1
	Underground piping	Part II, Chapter 2
	Aboveground piping	Part III, Chapter 2
Poor Housekeeping	Underground storage systems	PartII, Chapters 5 and 6
	Aboveground storage systems	Part III, Chapter 5
Improper Temporary or permanent closure	Underground storage systems	Part II, Chapter 7
	Aboveground storage systems	Part III, Chapter7

- Damage to tank coatings.
- Outright structural damage to the tank and other equipment during transportation and installation.
- The more subtle damage associated with the improper installation of beddings and foundations for tanks and piping systems.
- The improper connection of system components, such as the improper installation of valves, flanges or other fittings.
- Overpressurization caused by overfilling or improper venting of tanks.

Problems such as these can be avoided through careful adherence to the design and installation requirements of storage system components.

Sloppy housekeeping also results in spills and leaks. Such accidents can be avoided through the implementation of good housekeeping practicies. A clean and orderly work area reduces the possibility of accidental spills caused by mishandling of equipment and should reduce safety hazards to plant personnel. Examples of good housekeeping include neat and orderly storage of chemicals; prompt removal of small spillage; regular garbage and rubbish pickup and disposal; maintenance of dry and clean floors by use of brooms, vacuum cleaners, or cleaning machines; and provisions for storage of containers or drums to keep them from protruding into open walkways or pathways.

A good security system is helpful in preventing hazardous chemical spills or leaks due to vandalism, theft, sabotage or other improper and illegal use of storage plant facilities. The elements of such a system could include the following:

- Routine patrols of the plant by security personnel.
- Fencing.
- Good lighting.
- Vehicular traffic control.
- Controlled access to the plant.
- Locked entrances.
- Locks on drain valves and pumps for chemical storage tanks.
- Television monitoring.

3. Below Ground Storage Systems [1,5,10]

Underground storage systems are susceptible to leaks and spills from the same types of causes as aboveground storage systems, and, in general, the same methods of spill and leak control are applicable. In the case of thse systems however, data indicates that corrosion and poor installation are by far the most common causes of storage system leaks and spills [1,10]. For example, the American Petroleum Institute (API) conducted a survey of 1,717 underground tanks and piping systems that were known to be leaking. The data was collected via questionnaire from 1977 through 1980. A categorization of the reported leaks is displayed in Table 1.1-3. Since no data base exists in this study concerning the number or age of the various types of tanks in the ground at the time of this survey or the average ages of each type of tank, the use of the study for comparing types of tanks is meaningless. Much valuable data is contained in the study but any attempt to compare tank types would be a misuse of the data.

The life expectancy of any given tank is difficult to predict. Experience has shown that underground steel tanks have a finite life, but this life is variable between 5 and 45 years depending on the thickness of the steel, installation practices, soil resistivity, pH, soil moisture level, the presence of sulfides, the type of backfill material used, and the tank size. The average life expectancy of these tanks is about 15 years, but age by itself is a poor indicator of tank integrity.

The causes of leaks in steel tanks, as determined by the API Leak Survey, are shown in Table 1.1-4. Overall, roughly 91 percent of the leaks in steel tanks were caused by corrosion. Other causes included loose fittings and physical breakage. Of the 28 leaking fiberglass tanks included in the survey, 9 had dip stick punctures, 4 had breakage from improper handling, 1 had a backhoe puncture, and 14 had experienced physical breakage or separation due to other causes. For piping systems, corrosion was also the most common cause of leaks as shown in Table 1.1-5.

Table 1.1-3

Leaks by Source Categories

Source	Number	Percent of total
Unprotected Steel Tanks	913	62
Steel tanks with Impressed Current	13	0.9
Steel tanks with Sacrificial Anodes	0	0.0
Interior Coated Steel Tanks	7	0.5
Fiberglass tanks	28	1.9
Steel piping	454	30.8
Fiberglass piping	50	3.4
Steel piping with Impressed Current	7	0.5
Sub-Total	1472	100
Unspecified Tanks	216	
Unspecified Piping	29	
Total	1717	

Source Reference 10.

Table 1.1-4

Causes of Leaks in Steel Tanks

Cause	Total	Percent of Total
Corrosion	775	90.7
Loose Fittings	10	1.2
Physical Breakage	14	1.6
Other	55	6.4
Sub-Total	854	99.9
Unknown or unanswered	59	

Table 1.1-5

Causes of Piping Leaks

Cause	Number	Percent of Total
Corrosion	343	66.6
Flex Connector Failure	31	6
Physical Breakage	34	6.6
Loose Fittings	57	11.1
Other	50	9.7
Sub-Total	515	100
Unknown or Unanswered	25	

Note: These tables emphasize the importance of corrosion as a cause of storage system leaks.

Source: Reference 10.

Underground tanks which are connected together with siphoning pipes present unique problems. Leak testing becomes difficult, if not impossible, to accomplish. the ususal reason for siphoning between tanks is to add capacity to a system. When a small tank does not provide enough gallonage for increased business (usually after several years), a second tank is installed and is connected to the first with a siphon. The new tank and the new piping become targets for electrolytic corrosion from the old tank.

C. CORROSION [8,11,12,13,14,15,16,17,18,19,20]

The corrosion of tanks and piping systems is a complex phenomenon that may take one or more of several forms. Corrosion results from interactions betweeen the tanks and piping and their surroundings, both internal and external.

The deterioration of plastics and other non-metallic materials, which are susceptible to softening, cracking, swelling, etc., is essentially chemical in nature [11]. Non-metallic materials may deteriorate rapidly when exposed to corrosive elements. The corrosion of non-metallic storage system components can be controlled and essentially eliminated through proper selection and careful handling of tank and piping materials.

In metallic materials, corrosion is a chemical or electrochemical process. Corrosion control in these materials is therefore more complicated. The remainder of the discussion in this chapter focuses on the causes of internal and external corrosion of metals, the factors which influence this corrosion, and the steps which can be taken to protect against this form of deterioration.

1. Corrosion Mechanisms

As stated above, the corrosion of metals is primarily an electrical process; it may take the form of either galvanic or electrolytic corrosion. As shown in Figure 1.1-7, electrolytic corrosion is a result of direct current from outside sources entering and then leaving a particular metal structure by way of the electrolyte (surrounding material, such as soil for underground structures or water for submerged structures). The structure is usually unaffected or is provided with some degree of protection at the point the current enters (the cathodic area). Corrosion occurs where the current leaves the structure (the anodic area). In underground structures, this type of corrosion is often referred to as stray current corrosion, and is a result of current entering the ground from sources of DC current such as street railways or DC machinery.

The mechanisms of galvanic corrosion are illustrated in Figure 1.1-8. Galvanic corrosion is a self-generated activity resulting from differences in electrical potential that develop when metal is placed in an electrolyte. These differences in electrical potential can result from the direct coupling of dissimilar metals, or they can result from variations in conditions which exist upon the surface of a single metal. The variations could include:

- Variations resulting from non-homogeneity of the metal.
- Differences which exist within the electrolytes.

When two dissimilar metals are connected electrically and immersed in an electrolyte, as shown in Figure 1.1-8, current will be generated and galvanic corrosion will occur in one of the metals. Current from the corroding metal will flow into the electrolyte, over to the non-corroding metal, and then back through the connection between the two metals. The corroding metal (the one from which current leaves to enter the electrolyte) is known as the anode; the metal which receives current is known as the cathode. Table 1.1-6 shows the anodic-cathodic (galvanic) series of various metals.

Alternately, as stated previously, the same metal can develop differences in potential, and, as a result, portions of the surface of that metal become anodic with respect to the remainder of the surface. As shown in figure 1.1-8, corrosion will occur at these anodic locations.

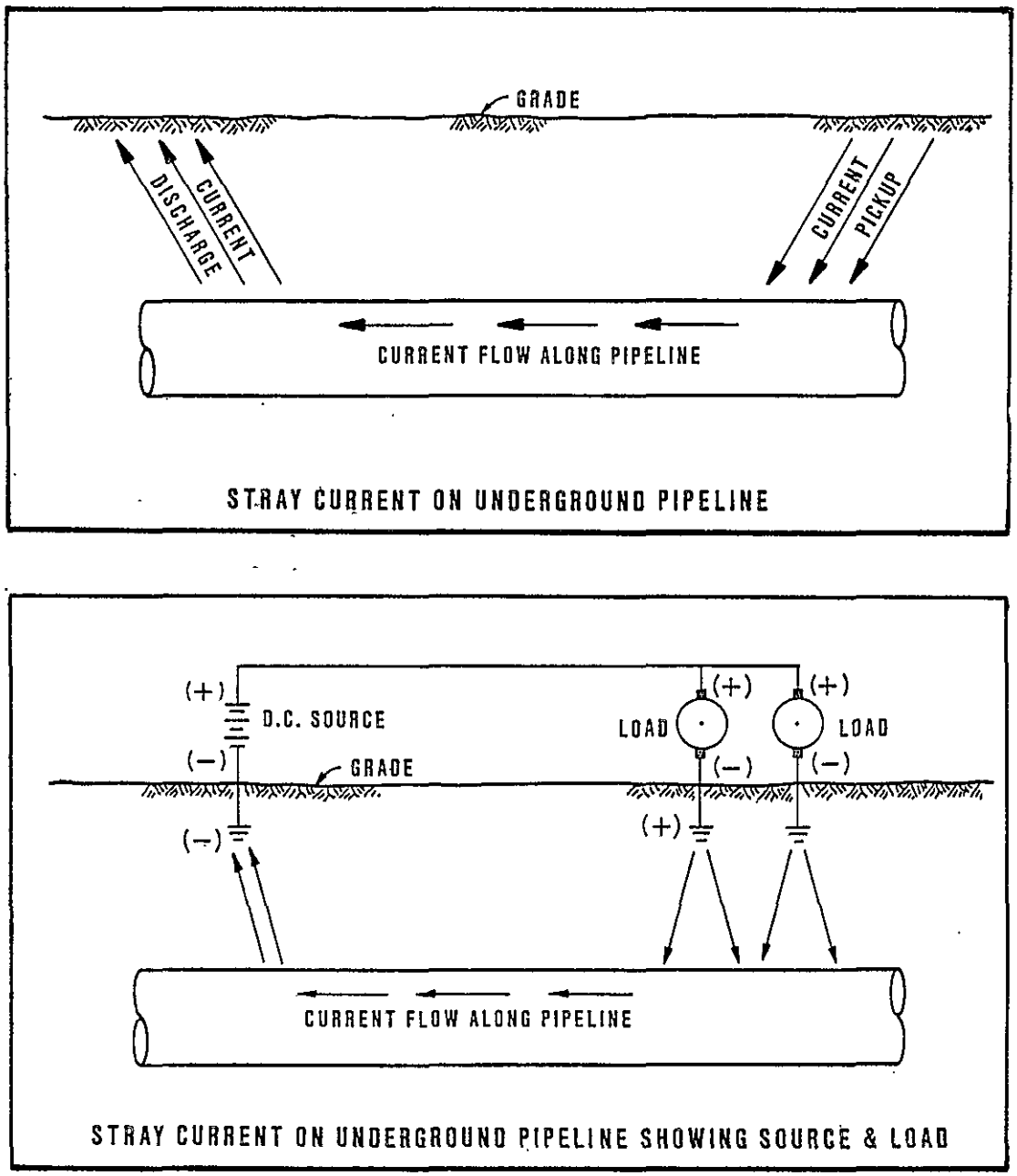
Electrolytic and galvanic corrosion are similar in that corrosion always occurs at the anodes. The essential difference between the two is that in electrolytic corrosion it is the external current which generates the corrosion, whereas in galvanic corrosion it is the corrosion activity which generates the current.

2. Forms of Corrosion [8,11]

The deterioration of tank or piping material may appear as either general or localized corrosion. General corrosion appears as a relatively uniform loss of surface material if viewed without magnification. Localized corrosion results in a non-uniform loss of material from the corroded structure. Types of localized corrosion are described briefly in Table 1.1-7.

Figure 1.1-7

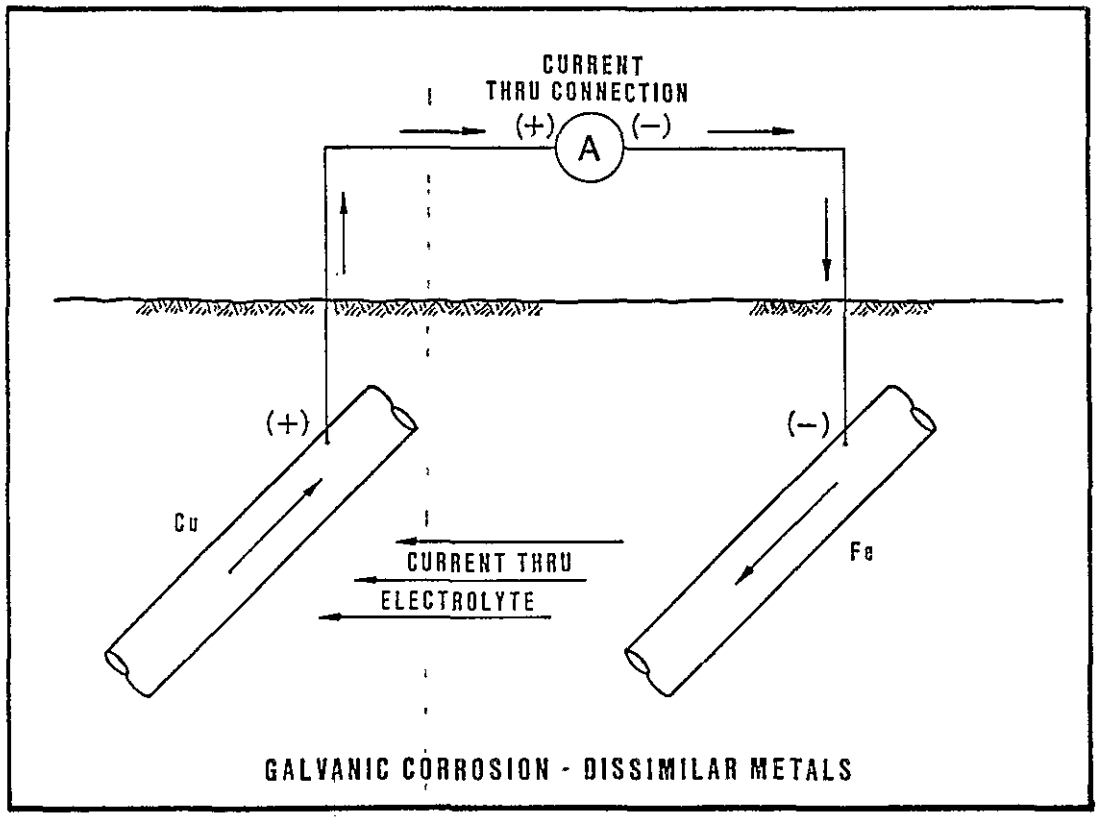
Electrolytic Corrosion

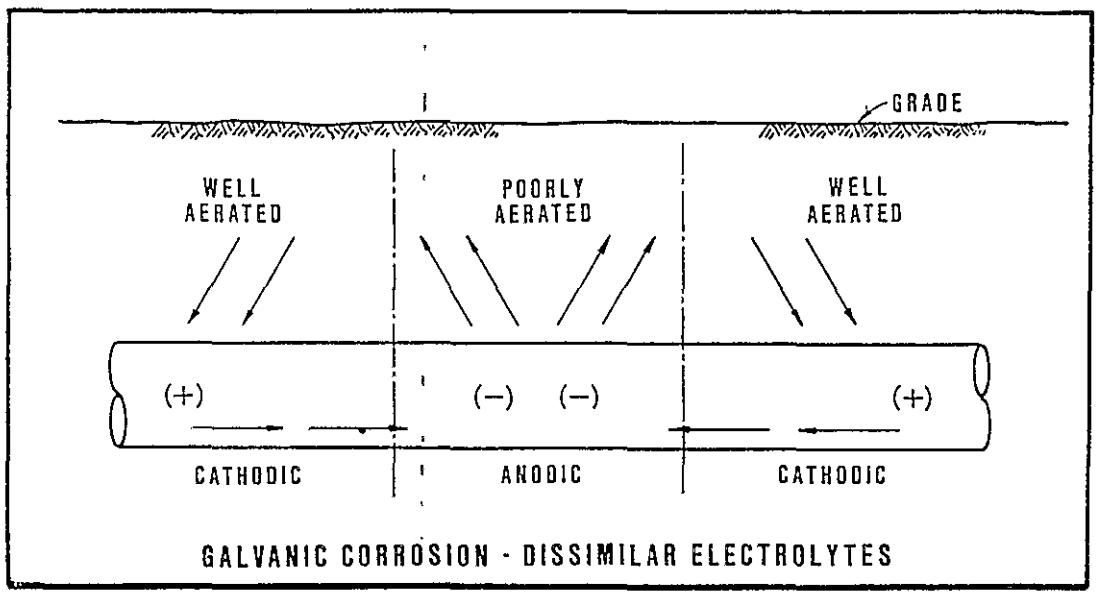


Source: Harco Corporation

Figure 1.1-8

Galvanic Corrosion





Source: Harco Corporation

Table 1.1-6

The Galvanic Series of Metals and Alloys

Corroded End (Anodic, or Least Noble)

- Magnesium
- Zinc
- Galvanized steel or galvanized wrought iron
- Aluminum
- Cadmium
- Mild Steel
- Wrought iron
- Cast iron
- 13 percent Chromium stainless
- 18-8 stainless type 304
- Lead
- Tin
- Naval brass
- Nickel (active)
- Inconel (active)
- Yellow brass
- Aluminum Bronze
- Red brass
- Copper
- Silicon bronze
- Nickel (passive)
- 18-8-3 stainless type 316
- Silver
- Graphite
- Gold
- Platinum

Protected end (Cathodic, or Most Noble)

Note: In general, when dissimilar metals are used in contact with each other in an electrically conductive enviroment, combinations of metals should be chosen that are as close as possible in the galvanic series. The coupling of two metals which are far apart in the series will result in more rapid deterioration of the more active metal. However, this table should be used only as a general guide since exceptions to this series may be encountered.

Adapted from reference 11.

3. Factors Influencing Corrosion [8,11]

There are innumerable factors that can influence the presence and rates of internal and external corrosion in both aboveground and underground storage tanks and piping systems. The more prominent of these factors include solution acidity, temperature, moisture levels, oxygen levels, soil resistivity, and bacterial action. The following discussion explains the importance of these and other factors. The more important of these factors are highlighted in figures 1.1-9 and 1.1-10.

Electrolyte Acidity. The acidity of the electrolyte (solution, soil, etc.) with which the material is in contact could have a substantial affect on the rate of corrosion. Acidic (low pH) electrolytes are, as a general rule, more corrosive than neutral (pH 7) or alkaline (high pH) electrolytes in the case of ordinary iron and steel. However, for the amphoteric metals, such as aluminum and zinc, highly alkaline electrolytes may be more corrosive than acidic electrolytes. The effects of electrolytic acidity are highlighted in Figure 1.1-9.

Presence of Oxidizing Agents. The presence of oxidizing agents, of which oxygen is the most prominent, may accelerate the corrosion of one type of material and retard corrosion in another type.

Table 1.1-7

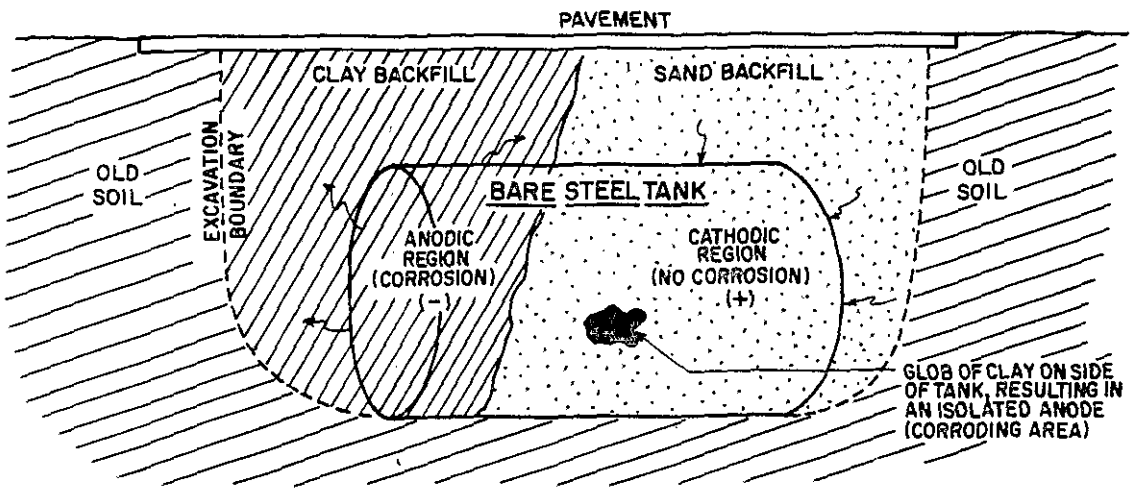
Common Forms of Localized Corrosion

Type	Description
Pitting Corrosion	Formation of shallow depressions or deep pits (cavities of small diameter).
Stess Corrosion Cracking	Corrosion accelerated by residual stresses resulting from fabrication operations or unequal heating and cooling of structure.
Contact or Crevice Corrosion	Occurs at the point of contact or crevice between a metal and non-metal or two metals.
Intergranular Corrosion	Selective corrosion at the grain boundaries (microscopic) of a metal or alloy.

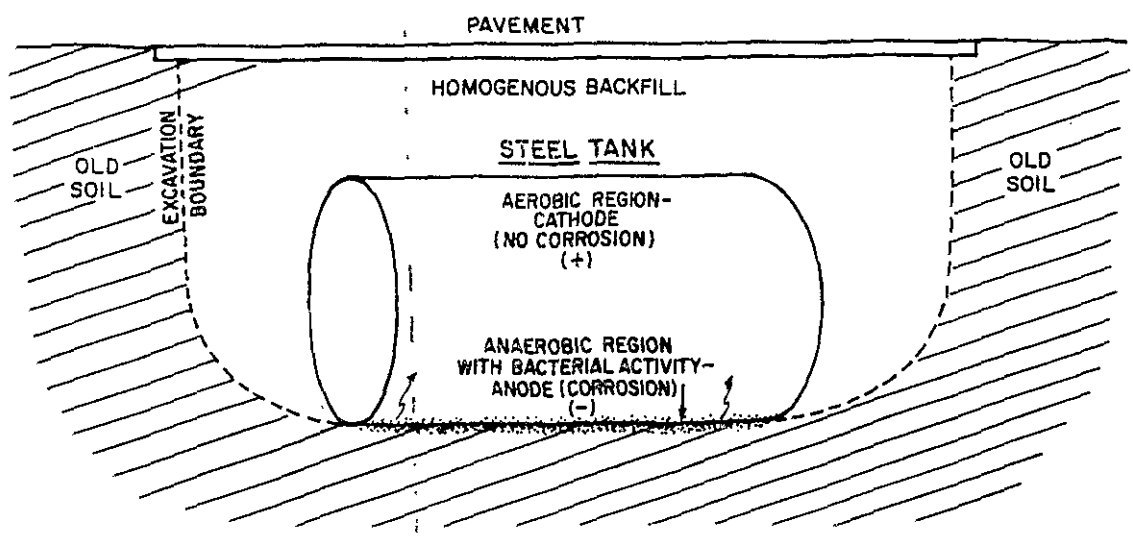
Figure 1.1-9

Some Corrosion Mechanisms at an Underground Steel Tank

Small differences in electric (ionic) potential can cause serious corrosion of underground steel tanks and pipes. Such differences can be created when there is a presence of dissimilar soils or bacterial activity, as shown in the figures below. The curled arrows (⇝) show the flow direction of electrical current in these figures.



(a) Dissimilar Soils. Variations in soil type or soil properties such as acidity or restivity can lead to corrosion in an underground steel structure.

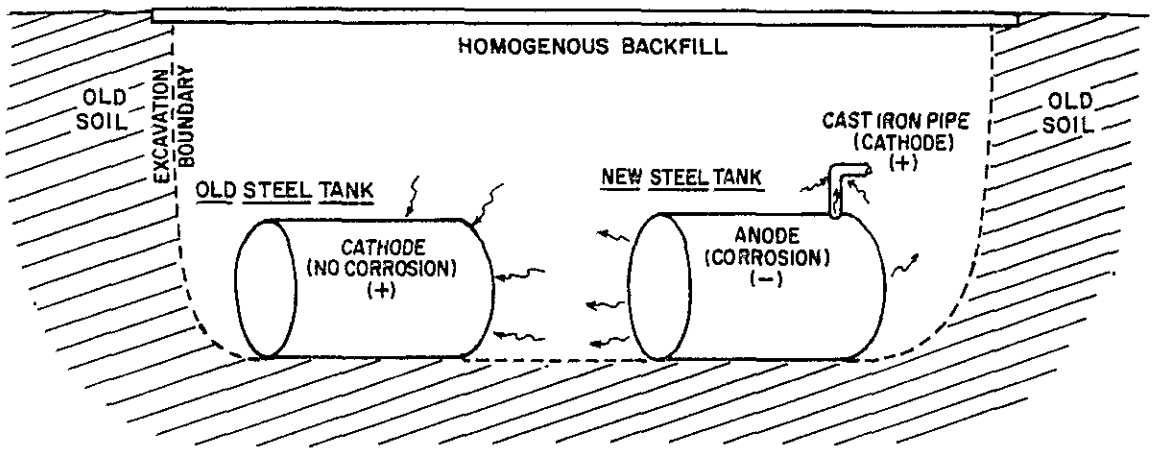


(b) Bacterial Activity. The metabolic activity of certain microorganisms can create corrosive environments around an underground structure.

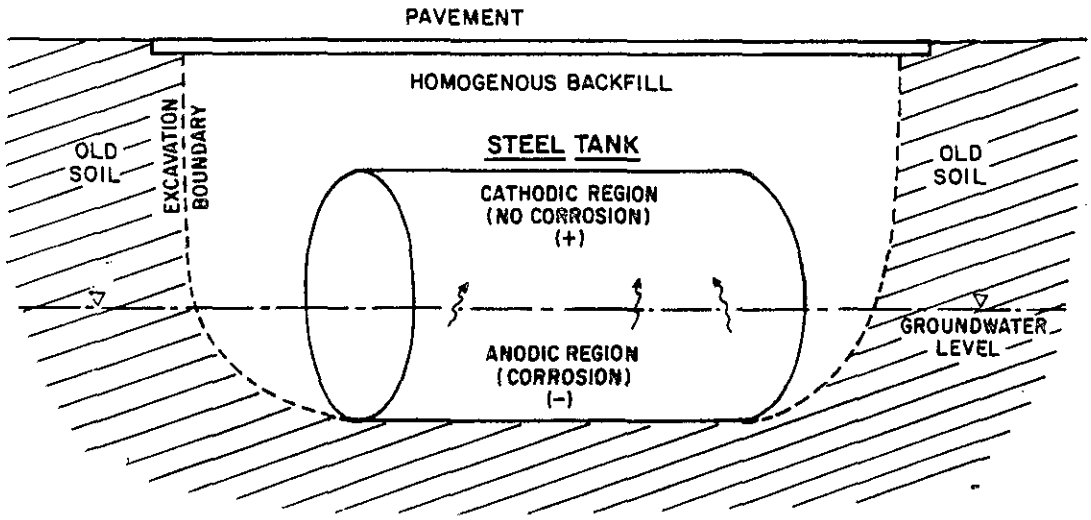
Figure 1.1-10

More Corrosion Mechanisms at an Underground Steel Tank

Other items which can promote corrosion at underground steel tanks include the presence of dissimilar metals or moisture, as shown in the figures below. The curled arrows (⇝) show the flow direction of electrical current in these figures.



(a) Dissimilar Metals. Exposure to dissimilar metals, such as connection of a tank with metal pipe with different properties, or burial of a new tank near an old tank, can lead to corrosion.



(b) Moisture. The presence of moisture can cause differences in electric potential which result in corrosion.

Temperature. The rate of corrosion tends to increase with rising temperature. Temperature also has a secondary effect through its influence on the solubility of air (oxygen), which is the most common oxidizing agent influencing corrosion.

Surface Films. Once corrosion has started, its progress is often controlled by the nature of the film that forms on the corroding metal. Some corrosion products may be insolubale and completely impervious to the corroding solution and, therefore, completely protective; or they may be very permeable and thus allow localized or general corrosion to proceed unhindered. In addition, discontinuous or non-uniform films may induce localized corrosion in particular areas.

Bacterial Action. The metabolic activity of certain microorganisms can either directly or indirectly affect the corrosion of metals. Such activity can:

- Produce a corrosive environment.
- Create electrolytic concentration cells, leading to crevice corrosion.
- Alter the resistance of surface films.
- Alter the environment composition.
- Influence the rate of anodic or cathodic reaction.

An example of microorganisms that directly influence corrosion rates are the sulfate-reducing bacteria found in many soils. These bacteria use hydrogen to reduce sulfate contained in the soil. The corrosion of metals results in the formation of hydrogen on the metals surface. If this hydrogen is not removed corrosion is inhibited. Sulfate-reducing bacteria can consume this hydrogen, thus speeding up the rate of corrosion. In addition, the reduction of sulfate results in the formation of hydrogen sulfide, which, in turn, causes further corrosion. This effect is shown in Figure 1.1-9.

Soil Resistivity. Soil resistivity is a measure of the resistance of soil to the flow of electric current, and is a very important factor in determining the potential rate of corrosion of underground pipes and tanks. The lower the resistivity of the soil, the greater the probability of corrosion. Soil resistivity is dependent upon several factors, including soil moisture content. In general, soil resistivity is low where soils are moist and groundwaters contain high levels of dissolved solids. The relationship between soil resistivity and corrosivity is demonstrated in Table 1.1-8.

Moisture Level. The presence of water can also promote corrosion of metals. The presence of moisture in soils acts to reduce soil resistivity thereby increasing the probability of corrosion (see Figure 1.1-10). Water accumulation inside tanks is also a major cause of internal corrosion. Water is often present in tanks due to condensation, precipitation from tank contents, and because water is often used as a ballast for underground tanks.

Soil Variations. Corrosion of underground tanks and pipes can be influenced by variations in soil conditions along the surfaces of those tanks and pipes. Variations in soil type, soil resistivity, moisture content, etc., can promote galvanic activity in the buried metal, thus accelerating the rate of corrosion.

Table 1.1-8

Soil Corrosivity vs. Soil Resistivity

The USDA Soil Conservation Service has categorized soil corrosivity levels as follows:

Class of Soil Corrosivity	Type of Soil	Resistivity (ohm-cm)
Very High	Well Drained Gravel	Below 1,000
High	Sand and Gravel	1,000 to 2,000
Medium	Poorly Drained Sand and Gravel	2,000 to 5,000
Low	Poorly Drained Fine Sand and Silt	5,000 to 10,000
Very Low	Poorly Drained Clay	Above 10,000

Environmental Elements. Corrosion can also be influenced by the presence of atmospheric pollutants, both externally and internally. For example, sulfur dioxide can form sulfuric acid in the presence of air and moisture and can thus promote corrosion of certain metals.

Adjacent Underground Metal Structures. Corrosion of underground tanks and piping can also result when new structures are installed near existing tanks or other underground metal structures or when new piping is installed. Since the older structures have rusted to some extent, they can become cathodic to the newer tanks or pipes. The system becomes an electrical cell. The older tank acts as a cathode. The newer metal (tanks or pipes) becomes an anode and the moist soil or fill which separates them becomes an electrolyte. A current flows through the system, carrying oxide, chloride, sulfide, etc., ions to the new metal surfaces and carrying metal ions away from the new surfaces. If the surface area of the old structure, as for instance a large tank, is much greater than the new structure (a replaced length of pipe), the replacement of the new surface with corrosion products (rust) will proceed at a relatively fast rate. This effect is illustrated in Figure 1.1-10.

Stray Electrical Currents. Stray underground currents from nearby electrical facilities using DC current, such as electrified railway or transit systems, factories, shops or nearby cathodic protection rectifiers can induce electrolytic corrosion in underground tanks and pipes. This effect has been shown in Figure 1.1-7.

Internal corrosion of underground tanks is also often found directly under the fill pipe. This is frequently caused by repeated impact of the measuring dip stick. If the stick does not have a soft tip, the impact breaks down any protective film which may have developed on the tank surface. The result is selective corrosion.

4. Corrosion Protection [8,11,20]

There are a number of methods available to protect against corrosion. These include the use of soluble inhibitors, protective coatings, cathodic protection and the use of corrosion resistant materials of construction. No method or material is a universal containment; the containing material or system must be "fitted" to the product being contained.

Soluble Corrosion Inhibitors. Soluble inhibitors are substances which can be added to the contents of a storage system to inhibit internal corrosion. The choice of a particular chemical for use as an inhibitor is largely dependent on the composition of the storage system and its contents. Typical examples of inhibitors that are used to minimize the corrosion of iron and steel in aqueous solutions are the chromates, phosphates and silicates. These substances act to increase anodic polarization and are therefore called anodic inhibitors. Substances which control cathodic polarization, such as certain organic sulfides or amine materials are effective in minimizing the corrosion of iron and steel in acid solutions. These substances are called cathodic inhibitors.

Paints, Coating and Linings. Paints and coatings are widely used as protective measures against corrosion, particularly corrosion due to exposure to atmospheric elements. In these instances the paint helps to exclude water and oxygen from the metal surface, thus minimizing corrosion. Inhibitive pigments, such as red lead or chromates, can be used in paints to protect metals against corrosion. These pigments can act to inhibit corrosion through several mechanisms:

- The pigment may neutralize acids.
- The pigment may promote the formation of protective ferric oxide films at the iron surface.
- Red lead breaks down sulfur dioxide, which is a very corrosive constituent of ambient air in urban and/or industrial areas.

Linings applied to the walls of tanks and piping can also serve to protect these structures from contact with their environment, thereby inhibiting corrosion. Examples of common lining materials are rubber, epoxies and silicones. A more detailed discussion of coating and lining properties, and their resistance to chemical and electrochemical attack, is included in Part II of this document. It should, however, be noted that no tank or pipe coating is impervious, no matter how carefully it is applied. Flaws will eventually develop and accelerated corrosion will occur at these breaks in the coatings. Consequently, tanks or pipes that are coated, without other forms of protection frequently fail faster than bare structures. Thus, most present-day installation codes require coating in concert with another form of corrosion prevention, such as cathodic protection.

Cathodic Protection. Cathodic protection is a widely used and highly recommended method of protection for tanks and pipes. It is particularly effective in underground applications. The method works by reversing the electrochemical action of corrosion. Instead of allowing electrons to flow away from the structure (thereby permitting corrosion to occur) an electron flow toward the structure is induced, thereby protecting the structure.

Cathodic protection can be applied to either bare metal or coated metal, but is more effective and less expensive on coated structures. On bare tanks, cathodic protection may be only 90 percent effective, due primarily to the existence of active pits into which the protective current cannot penetrate [19]. There are two basic types of cathodic protection. These are the sacrificial anode (or galvanic) cathodic protection method and the impressed current (or electromotive force) method.

The galvanic cathodic protection method employs a sacrificial anode, such as magnesium or zinc, in electrical contact with the metal structure to be protected. These may be anodes buried in the ground for the protection of underground tanks, or attached to the surface of materials in electrolytic solutions (i.e., the tank or pipe). The current required is generated by corrosion of the sacrificial anode material. A typical galvanic cathodic protection system for underground tanks and piping is illustrated in Figure 1.1-11.

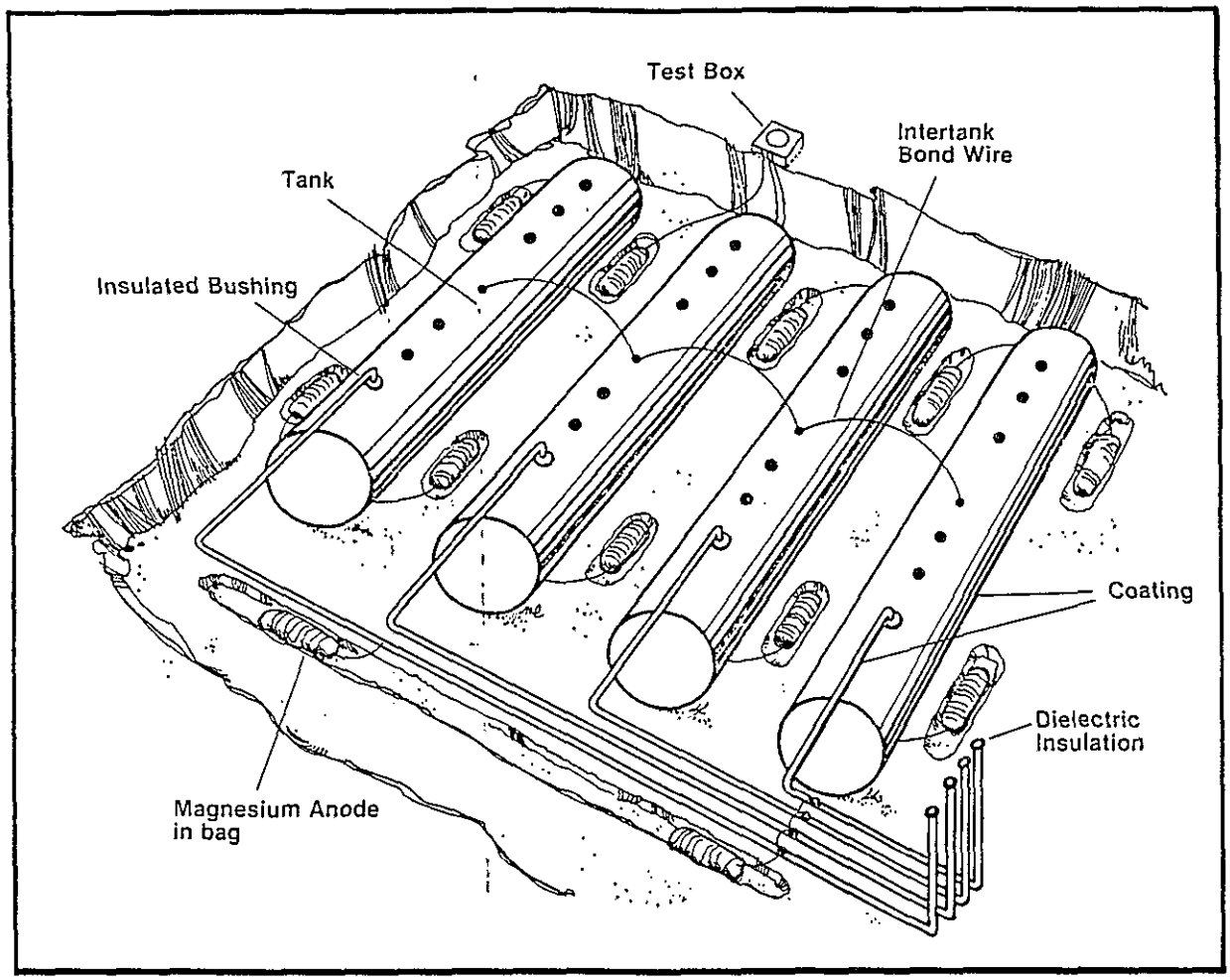
The impressed current cathodic protection method employs direct current provided by an external source. This current is passed through the system by the use of non-sacrificial anodes such as carbon, non-corrodible alloys, or platinum. These anodes are buried in the ground (in case of underground structures) or otherwise suspended in the electrolyte and connected to the external power supply. An impressed current system for underground tanks and piping is illustrated in Figure 1.1-12.

Note that the National Association of Corrosion Engineers' recommended practice NACE RP-01-69 recommends a –0.85 volt potential, tank to soil, as measured by a Cu-$CuSO_4$ half cell reference. This will ensure continued cathodic protection.

Electrical Isolation. Electrical isolation is another method of corrosion prevention. As the name implies, it involves the use of non-conductive dielectric fittings, bushings, connections, etc. to electrically isolate metal components in a storage system; this minimizes the potential for the generation of electrical currents between dissimilar metals. Electrical isolation is often employed in concert with other corrosion prevention methods, such as sacrificial anode cathodic protection, to further decrease the likelihood of corrosion.

Figure 1.1-11

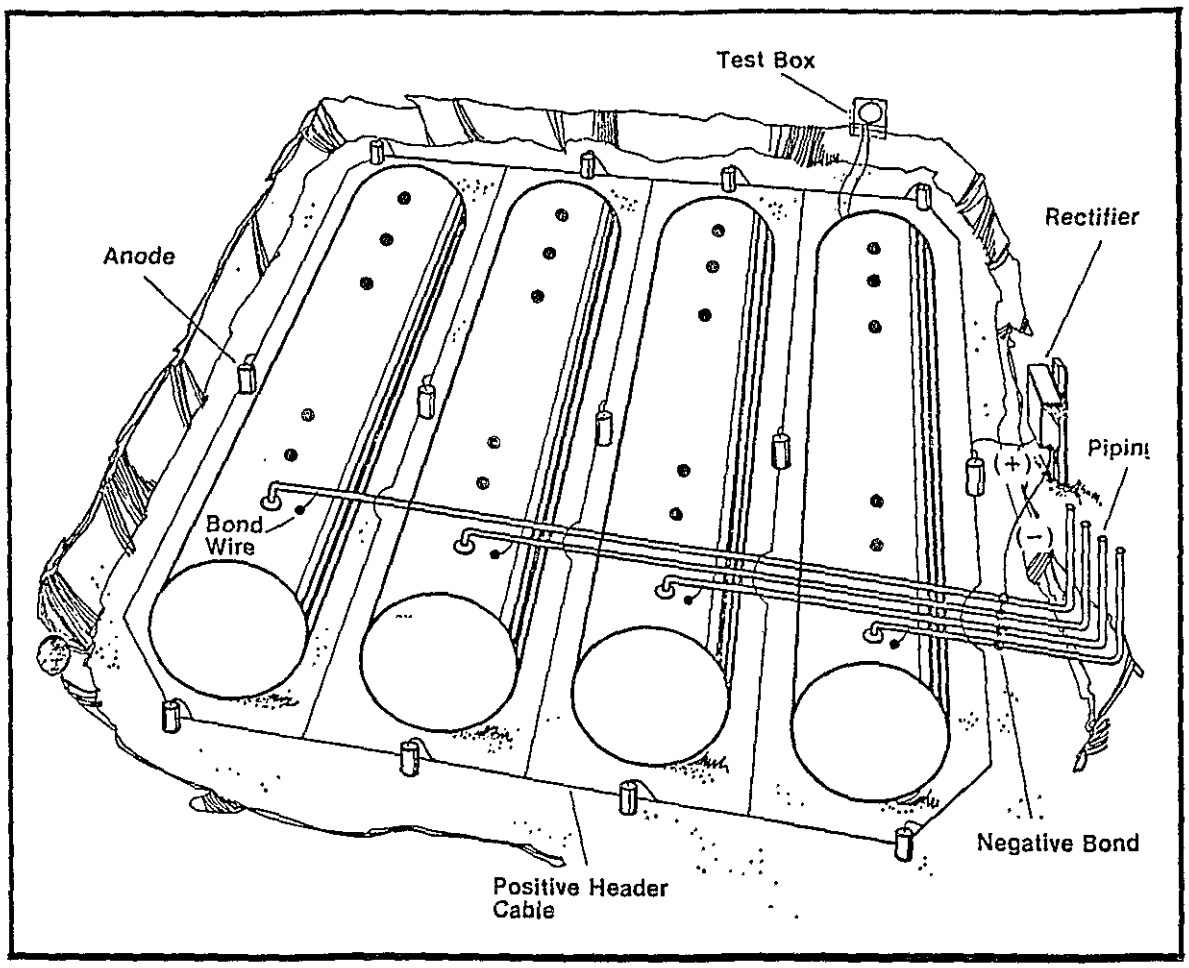
Magnesium Anode Cathodic Protection Typical Configuration



Source: *Suggested Ways to Meet Corrosion Protection Codes for Underground Tanks and Piping;* The Hinchman Company, Detroit, MI.

Figure 1.1-12

Impressed Current Cathodic Protection
Typical Configuration



Source: *Suggested Ways to Meet Corrosion Protection Codes for Underground Tanks and Piping;* The Hinchman Company, Detroit, MI.

Corrosion Allowance. Often corrosion is anticipated, and items are constructed with enough metal to allow for corrosion to proceed to a point without interfering with the normal function of that item. An example of such a corrosion allowance is a tank whose design thickness is such that appreciable corrosion can be tolerated before a leak or tank failure will occur.

Corrosion-Resistant Materials of Construction. Corrosion can also be controlled through the use of corrosion-resistant materials of construction. Examples of such items include special alloys, fiberglass reinforced plastic, and fiberglass reinforced plastic coatings. Special alloys are most often used when difficult-to-contain fluids are to be handled. Stainless steel is an example of such a material. Stainless steel is a family of alloys. The corrosion resistant properties of the specific material chosen for the containment vessel should be appropriate for the material being contained.

From the perspective of corrosion resistance, fiberglass reinforced plastic (FRP) tanks are an effective means of storing many fluids in underground storage systems, most notably petroleum products. These tanks are not subject to corrosion and are strong enough to withstand most soild and other loading stresses when they are properly installed. The importance of proper installation of FRP tanks is discussed in further detail in Part II. The FRP piping is also applicable in these types of situations.

Fiberglass reinforced plastic coatings are also available and generally consist of thick (on the order of ⅛ inch) coatings applied to steel tanks. The concerns expressed above and elsewhere in this document regarding the use of coatings apply to these types of coatings as well.

References

1. New York State Department of Environmental Conservation, *Bulk Storage of Hazardous Liquids Study Program – Problem Assessment Report*, Paper #5, New York State Department of Environmental Conservation, 50 Wolf Road, Albany, NY 12233, April, 1981.

2. New York State Department of Environmental Conservation, *New York State Bulk Storage Control – Study Program*, New York State Department of Environmental Conservation, 50 Wolf Road, Albany, NY 12233, May, 1980.

3. American Petroleum Institute, *Underground Spill Cleanup Manual*, API Publication, American Petroleum Institute, 2101 L Street, N.W., Washington, DC 20037, June, 1980.

4. National Fire Protection Association, *Underground Leakage of Flammable and Combustible Liquids*, NFPA 329, National Fire Protection Association, Inc., Batterymarch Park, Quincy, Massachusetts 02269, 1977.

5. Pace Company Consultants & Engineers, Inc., Spill Control Manual prepared under EPA Training Grant No. T-900-175-02-2 to the Department of Environmental Science and Engineering, Rice University, Houston, TX, February, 1975.

6. Annual Report of the New York State Oil Prevention, Control and Compensation Program, April 1, 1978 to March 30, 1979, New York State Department of Environmental Conservation, 50 Wolf Road, Albany, NY 12233.

7. Annual Report of the New York State Oil Prevention, Control and Compensation Program, April 1, 1979 to March 30, 1980, New York State Department of Environmental Conservation, 50 Wolf Road, Albany, NY 12233.

8. American Petroleum Institute, *Guide for Inspection of Refinery Equipment, Chapter I – Introduction, Chapter XIII – Inspection of Atmosphere and Low-Pressure Storage Tanks*, American Petroleum Institute, 2101 L Street, N.W., Washington, DC 20037, 1976.

9. U.S. Environmental Protection Agency, *NPDES Best Management Practices Guidance Document*, Draft, EPA-600/9-79-045, Industrial Environmental Research Laboratory, USEPA, Cincinnati, OH 45268, December, 1979.

10. American Petroleum Institute, Underground Leak Survey results as reported by F.B. Killman to API Underground Leak Task Force, American Petroleum Institute, 2101 L Street, N.W., Washington, DC 20037, February 5, 1981.

11. Perry, R.H., Chilton, C.H., *Chemical Engineers' Handbook*, Fifth Edition, McGraw-Hill Book Co., 1221 Avenue of the Americas, New York, NY 10020, 1973.

12. Husock, B., "Fundamentals of Cathodic Protection", Paper No. HC-2, Harco Corporation, Cathodic Protection Division, 1055 West Smith Road, Medina, Ohio 44256, March 6, 1962.

References, continued

13. Husock, B., "Cathodic Protection – One Way to Prevent Underground Corrosion", Paper No. HC-4, Harco Corporation, Cathodic Protection Division, 1055 West Smith Road, Medina, OH 44256.

14. Husock, B., "Corrosion and Cathodic Protection of Underground Tanks at Service Stations", Paper No. HC-15, Harco Corporation, Cathodic Protection Division, 1055 West Smith Road, Medina, OH 44256, February, 1965.

15. Husock, B., "Causes of Underground Corrosion", Paper No. NC-36, Harco Corporation, Cathodic Protection Division, 1055 West Smith Road, Medina, OH 44256, May, 1976.

16. Rothman, P.S., "Cathodic Protection of Tank and Underground Structures", Harco Corporation, Cathodic Protection Division, 244 East County Line Road, Hatboro, PA 19040, 1978.

17. U.S. Department of Agriculture, "Control of Underground Corrosion", Design Note No. 12, Soil Conservation Service, U.S. Department of Agriculture, Soil Conservation Service, Feb. 1, 1971.

18. National Association of Corrosion Engineers, *Recommended Practice – Control of External Corrosion on Underground or Submerged Metallic Piping Systems*, NACE Standard RP-01-69, National Association of Corrosion Engineers, 1440 South Creek, Houston, TX 77084, January, 1972.

19. Fitzgerald, J.H., "Corrosion Control for Buried Service Station Tanks", Paper No. 52, The International Corrosion Forum Devoted Exclusively to the Protection and Performance of Materials, April 14-18, 1975, Toronto, Canada, National Association of Corrosion Engineers, 1440 South Creek, Houston, TX 77084.

20. The Hinchman Company, *Suggested Ways to Meet Corrosion Protection Codes for Underground Tanks and Piping*, Job Number 1079-4542, The Hinchman Company, Corrosion Engineers, 1605 Mutual Building, Detroit, Michigan 48226, April 8, 1981.

21. Husock, B., "Use of Pipe-to-Soil Potential in Analyzing Underground Corrosion Problems", Paper No. HC-7, Harco Corporation, Cathodic Protection Division, 1055 West Smith Road, Medina, Ohio 44256.

22. Husock, B., "Pipe-to-Soil Potential Measurements and Cathodic Protection of Underground Structures", Paper No. HC-8, *Materials and Performance*, Vol. 10, No. 5, May, 1971.

23. Rizzo, F.E. "Detection of Active Corrosion", Paper No. HC-14, Harco Corporation, Cathodic Protection Division, 1055 West Smith Road, Medina, OH 44256.

24. Hosford, H.W. "Cathodic Protection of Marine Structures", Paper No. HC-16, Harco Corporation, Cathodic Protection Division, 1055 West Smith Road, Medina, OH 44256.

25. Rizzo, F.E., Miller, M., "New Technique for CP Monitoring of Offshore Pipelines", Paper No. HC-39, *Oil and Gas Journal*, February 13, 1978.

Part I
CHAPTER 2: HAZARDOUS SUBSTANCES

A. LISTINGS OF HAZARDOUS SUBSTANCES

The term hazardous liquids includes a broad range of chemicals and chemical types. They may be designated as hazardous because they are flammable, combustible, corrosive, toxic or explosive (reactive). By their nature, they are of great concern to society, and to those governmental agencies which are responsible for public health, environmental protection, transportation, occupational safety, and fire and emergency response.

Several agencies have prepared lists of hazardous substances and have included these lists in regulations to control use, transporation and disposal of these materials. The listings of materials regulated by the U.S. Environmental Protection Agency (EPA) and the U.S. Departments of Labor and Transportation are described in Table 1.2-1. These listings can be obtained from the Federal Register or the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

There are also several published reports which provide information on the physical and chemical properties of and safe handling practices for various hazardous materials. Some of the more widely used reports are described in Table 1.2-2. A more comprehensive list of references is provided at the end of this chapter.

B. PROPERTIES OF HAZARDOUS SUBSTANCES

1. Chemical Properties

Appendix A of this document includes a series of tables that identifies the chemical and physical characteristics of various solids, liquids and gases that are classified as toxic or hazardous substances. These tables identify substances which are poisonous to humans, flammable, corrosive, reactive and highly toxic to aquatic life. Other properties that are identified are the biodegradeability of liquids and solids, the amenability of liquids and solids to biological waste treatment, the volatility of liquids and the solubility of solids.

Table 1.2-1

Listings of Regulated Hazardous Substances

Hazardous Materials Listing
(49 CFR 172.101) — The labeling, packaging and transportation of these material are regulated by the U.S. Department of Transportation.

Toxic and Hazardous Substances Listing
(29 CFR 1910 Subpart Z) — Occupational exposure of these substances are controlled by the U.S. Department of Labor.

Listing of Hazardous Waste
(40 CFR 261) — The disposal of chemical wastes on this listing are regulated by the Environmental Protection Agency under the Resource Conservation and Recovery Act (RCRA).

Designation of Hazardous Substances
(40 CFR 116)—Chemicals which are hazardous to the environment are identified by the Environmental Protection Agency on this listing.

Available from: Federal Register or
U.S. Goverment Printing Office
Washington, D.C. 20402

A listing of the physical and chemical properties of twenty-nine commonly used hazardous substances in New York State is given in Table 1.2-3. This table represents common chemicals that are stored in bulk. Usage of these chemicals is from 1 million to 450 million pounds per year (not counting petroleum). The properties which are identified in this table include the following:

- The physical state at 20°C.
- The melting and boiling points.
- The specific gravity at 20°C or other specified temperatures.
- The solubility in water.
- The vapor pressure.
- The associated hazard (flammable, corrosive or toxic).
- The reactivity with common storage tank materials.

Knowledge of these various physical and chemical properties is important in determining the proper mode of storage of these substances. For example:

- The melting and boiling points of substances is useful in determining the appropriate range of storage temperatures.
- The solubility of the substance is helpful in determining whether the substance should be allowed to come in contact with water.

Table 1.2-2

Reports Describing Hazardous Materials

U.S. Dept. of Transportation Hazardous Materials Emergency Response Guidebook [1]:

- numerical and alphabetical indices of hazardous materials
- descriptions of health hazards and fire or explosion potential
- procedure to be followed in the event of fire, spill, leak or personnel exposure.
- isolation and evacuation distances for selected hazardous materials

U.S. Department of Transportation
Washington, D.C. 20590

National Fire Protection.Assn. Publication NFPA 49: Hazardous Chemicals Data [2]:

- degree of health hazard
- potential for reactivity
- flammability
- physical descriptions
- fire explosion hazard
- particular life hazards
- personal protection requirments during handling
- fire fighting phases

National Fire Protection Association
Batterymarch Park
Quincy, MA. 02269

U.S. EPA Hazardous Materials Spill Monitoring and Safety Handbook and Chemical Hazard Guide Parts A and B [3]:

Part A	Part B
- Safety consideration	- hazard priority number
- first aid procedures	- hazards
- protective equipment	- safety measures
- priority listing of hazardous material	- synonyms

National Technical Information Service
Springfield, VA. 22161
or
U.S. Environmental Protection Agency
Office of Research and development
Environmental Monitoring amd Support Laboratory
Las Vegas, NV. 89114

The Chemical Hazards Response Information System (CHRIS) Manuals [4]:

- Medical data (exposure hazard)
- flammability data (fire hazard)
- pollution data
- biological data
- physical properties
- chemical properties
- preventative and precautionarey initial
- response information

United States Coast Guard
U.S. Dept. of Transportaion
Washington, D.C. 20590

- The vapor pressure of the liquid substances is necessary to determine appropriate storage pressures (pressures at which significant vapor formation can be limited).
- The hazard associated with a particular substance is important in determining handling and storage protocols.
- How the substances react with various materials of construction is important in determining the mode of storage and the materials used in storage.

2. Relationships Between Temperature, Pressure and Volume Within a Storage Tank

In the handling and storage of hazardous liquids, it is important to note that most liquids expand and contract with changes in temperature. Variations in the temperature of the stored liquid can lead to changes in the volume of the stored liquid. In addition, variations in pressure can lead to changes in the volume of the storage tank itself. These volume variations become extremely important when one is attempting to detect small leaks from storage tanks.

The temperature of a liquid stored in a tank either above or below ground can vary throughout the year. The reasons for such variations include the following:

- The seasonal variations in ambient temperature.
- Changes in the weather (e.g., hot, sunny days vs. cold, rainy nights).
- Changes in pressure (compression) of the liquid.

An annual temperature profile for an underground tank is displayed in Figure 1.2-1. Although this profile was observed in an underground gasoline tank, it is typical of the types of variation that can be expected of most liquids which are stored underground.

Liquid temperatures can also vary throughout the storage tank itself. The reasons for such variation include the following:

- Variation in the surface temperature of aboveground tanks due to weather or exposure to the sun.
- Stratification of temperature in the ground surrounding an underground storage tank.
- The introduction of new liquid into a tank that has a different temperature than the liquid already stored in the tank [5,6].

Table 1.2-3

Physical and Chemical Properties of the Twenty-Nine Most Commonly Used Hazardous Substances in New York State

Substance	Physical State at 20°C	Melting Point C°	Boiling Point C°	Specific Gravity	Solubility[2] (mg/l) in H_2O	Vapor Pressure[3] (mm of Hq)	Hazard[4]	Material Compatibility: FRP Petroleum Tank	Material Compatibility: FRP Chemical Tank	Material Compatibility: Carbon Steel
1. Petroleum					Insoluble	NA	E, F	OK	—	OK
-Gasoline	Liquid	NA	60-199	0.132	NA	NA	E, F	OK	—	OK
-No. 2 Fuel Oil	Liquid	NA	NA	NA	515	28	E, F	—	OK	OK
2. Toluene	Liquid	-95	110.4	0.866 20/4	$2,860^{20}$	5	E	—	OK	8
3. Tetrachloro-ethane	Liquid	-44	146.5	1.58 25/4	1,000	74^{25}	E, F	—	—	7, 8
4. Methyl Chloride	Gas	-97	-23.7	0.918 20/4						
5. Trichloro-ethylene	Liquid	-73	87.1	1.45560 25/4	1,000	100^{32}	C	—	—	8
6. Tetrachloro-ethylene	Liquid	-23.25	121.20	1.6230 20/4	150	15.8^{22}	—	—	OK	8
7. Methylene Chloride (Di-chloromethane)	Liquid	-96.7	39.8	1.32	13,200-20,000	362.4	F	—	—	8
8. Phenols	Solid	43°	182	1.071 25/4	82,000	0.20^{25}	C, E	—	—	7, 8
9. Cresols	Liquid	10.9-35.5	191-203	1.048 20/4	25,000	1^{38}	C	—	—	8
10. Xylene	Liquid or Solid	25.4-75	203-225	NA	NA 60	NA $2,600^{25}$	NA C, E	— —	OK OK	NA NA
11. Vinyl Chloride	Gas	-160	-13.4	0.908 25/25	$1,780^{20}$	95.2	E, F	—	—	OK
12. Benzene	Liquid	5.51	80.093-80.094	0.8794	Very Slightly Insoluble	5.5 1^{22}	E, F C, E	— —	OK —	OK 8
13. Styrene	Liquid	-31	146	0.9074 20/4	NA	5^{25}	NA	—	—	OK
14. Chlorotoluene	Liquid	-43	179	1.1026 18/4						
15. P-Chlorobenzo-trifluoride	Liquid	-36	139.3	1.353 15.5/15.5	NA 448^{30}	NA $10^{22.2}$	NA F	— —	— —	NA 7, 8
16. Octyl Phenol	Solid	NA	280-283	0.941 24/4						
17. Chlorinated Benzenes	Liquid	-45	131.7	1.113 15.5/15.5	480-4,400 7,840	96 192	— —	— —	OK —	OK 8

Table 1.2-3 continued

18. Trichlorethane	Liquid	4-39	74	1.31	NA	NA	F[5]	—	OK	NA
19. Chloroform	Liquid	-63.5	61.26	1.49845[15]	60,000[15]	132.4 C		—	—	OK
20. Sevin	Solid	142	NA	1,232 20/20	Insoluble	10[54.8]	C	—	OK	OK
21. Hydroquinone	Solid	170.5	286.2	1,358 20/4						
22. P-Dichlorobenzene	Solid	53	173.4	1,4581 20.5/4	Insoluble	10[13.2]	E, F	—	—	OK
					60,000	134.8	C	—	—	OK
23. Pyridine	Liquid	-42	115.3	0.982 20/4	Infinitely	1[108.8]	C	OK	—	OK
24. Aniline	Liquid	-6.2	184.4	1.20 20/4	36,000[18]					
25. Diethylphthalate	Liquid	-40.5	296-302	1.110-1.21 20/20	35,000	71.2	E, F	—	—	OK
26. 2-Butanone (Methyl Ethyl Ketone)	Liquid	-86	79.6	0.805 20/4	Insoluble	200[13.5]	E	OK	—	NA
					800	100[23]	—	—	OK	8
27. Freon 113	Liquid	-35	47.6	1,576 20/4						
28. Carbon Tetrachloride	Liquid	-22.6	76.8	1,597	30	0.87[25]	C, E	OK	—	OK
29. Naphthalene	Solid	80.1	217.9	1,162 20/4						

Notes:

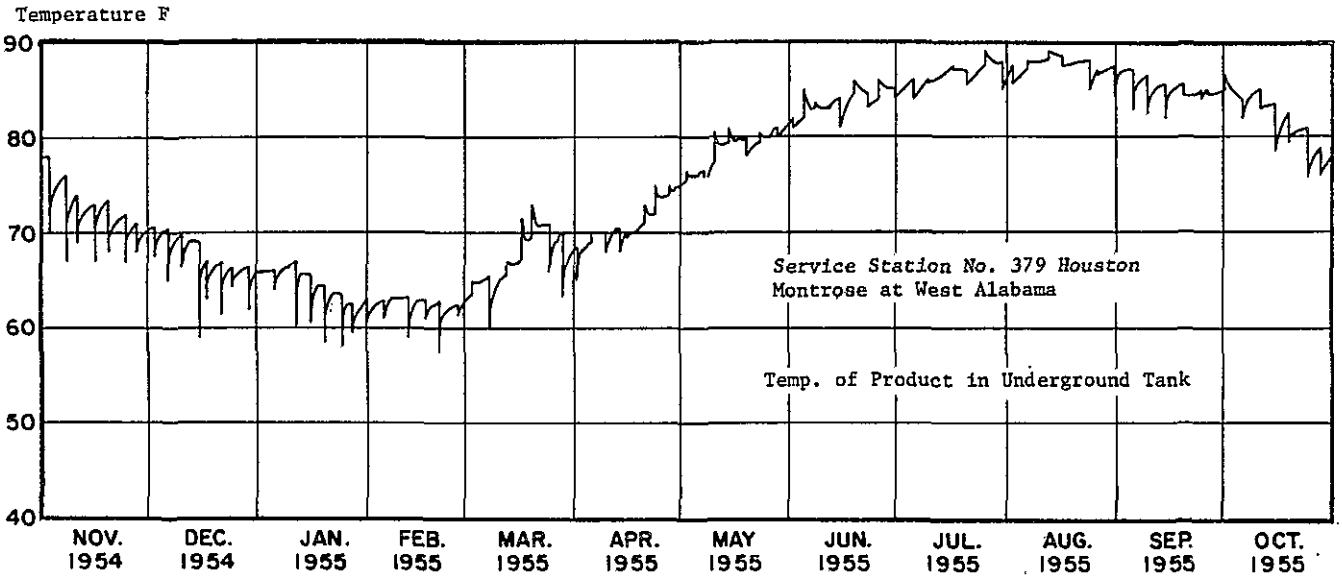
1. Specific gravity at 20° C or as otherwise stated. Where stated, numerator is temperature of substance, denominator i temperature of water.
2. Solubility at 25° C or as otherwise stated.
3. Vapor pressure at 20° C or as otherwise stated.
4. All listed substances are toxic to humans at some concentrations.
   E = Explosive
   F = Flammable (flashpoint of less than 80° F)
   C = Combustable (flashpoint of 80° F or higher)
5. Compound itself is not flammable but it is usually dissolved in a combustible liquid.
6. Not recommended.
7. Corrosive at high temperatures.
8. Corrosive at high concentrations.
9. Chemical compatibility may vary from what is shown in this table if special resins or other materials are used for tank construction. Check with the manufacturer for lab analyses of chemical compatibility and for other assurances that the tank you are using is warranteed for the chemical being stored.

NA = Not available

Sources: References 4, 11, 12, 15, 19, 20, 22

Figure 1.2-1

Typical Annual Tank Temperature Variation For an Underground Gasoline Tank



This graph shows temperature recordings for an entire year by combining the results of 52 weekly graphs. The vertical lines, either down or up show the immediate effect of the delivery on the tank temperature and the curving lines show the gradual return to underground temperatures.

The graph also shows a seasonal change of 30°F in underground temperatures occurring in south Texas. Much greater differences between summer and winter would exist in New York State.

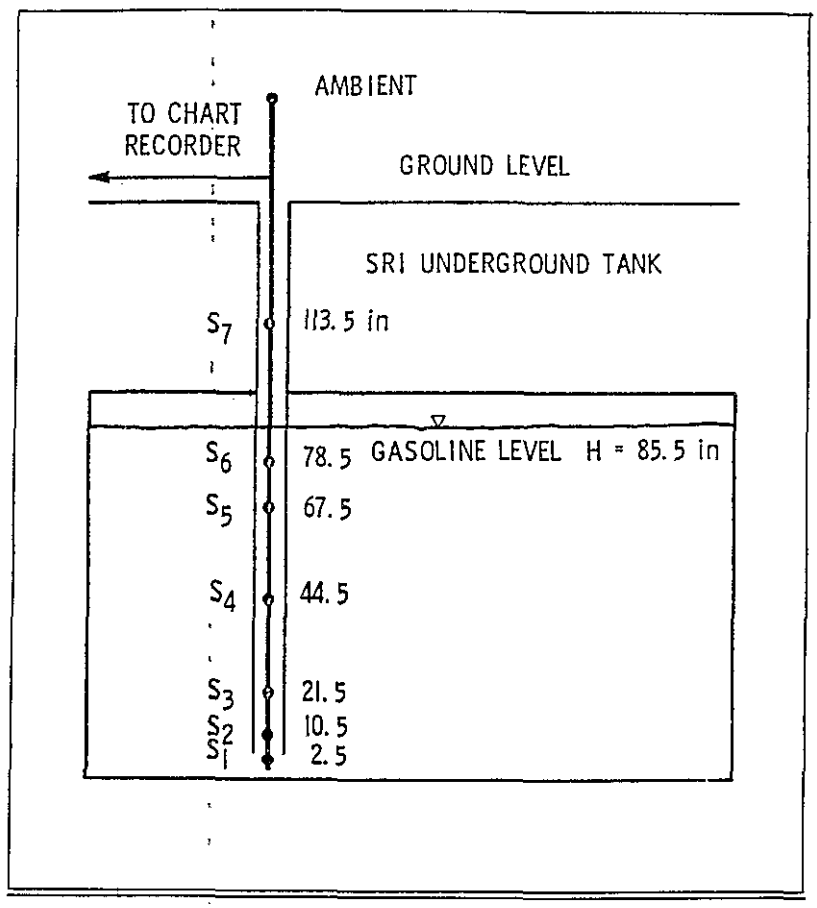
Source: Reference 21.

Figures 1.2-2, 1.2-3 and 1.2-4, taken from a Stanford Research Institute study on detection of small leaks, illustrate temperature variations throughout an underground gasoline tank [5]. Figure 1.2-2 shows the location of temperature sensors in the tank. Tank temperatures at these various sensor levels, as a function of time for a 24-hour period after tank filling, are displayed in Figure 1.2-3. As shown in this figure the tank temperature at each level differs and all these temperatures vary with time. The mean temperature variation, as a function of depth for this same tank over four different 24-hour periods, is illustrated in Figure 1.2-4. Again, as shown for each of the 24-hour periods, the liquid temperature can vary substantially throughout the tank.

Because liquids expand or contract as their temperature is raised or lowered, seasonal, day-to-day and tank-wide variations in temperature heavily affect the detection of small leaks. For example, in an 8-foot diameter, 8,000-gallon storage tank half-full of gasoline, a 1.2 gallon per day (0.05 gallon per hour) leak would cause only a 500 micro inch (0.0005 inches) height change in the gasoline level. A mean gasoline temperature change of only 0.012°C (0.022°F) would also result in a 500 micro inch height change of the gasoline level. Thus a 1.2 gallon per day leak could be hidden by a 0.012°C rise in mean liquid temperature [5].

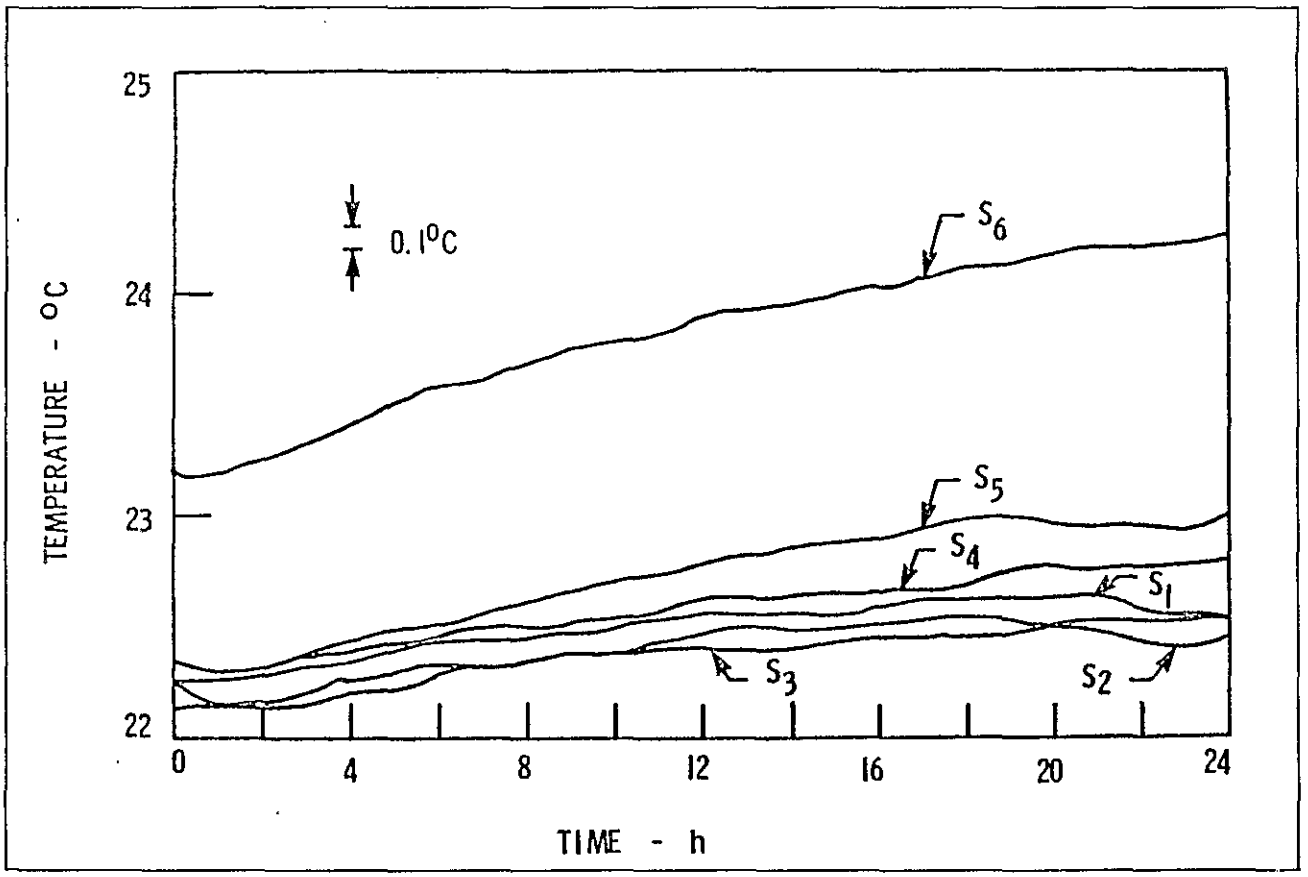
Internal tank pressure can also affect tank volume by leading to increases or decreases in the size of the tank. For example, the total forces exerted on the ends of tanks (assuming flat ends) of different diameters by different pressures are exhibited in Table 1.2-4. This table shows that a 3 pound per square inch (psi) pressure exerted on a tank's contents results in a force of over 10 tons on the ends of an 8-foot diameter tank [6]. This is sufficient force to cause the tank ends to bulge outward some small fraction of an inch, thus increasing the volume of a tank.

Figure 1.2-2
Location of Temperature Sensors In The SRI Tank



Source: Stanford Research Institute, "Measurement of Small Leaks in Underground Gasoline Storage Tanks Using Laser Interferometry," sponsored by the American Petroleum Institute, 1979.

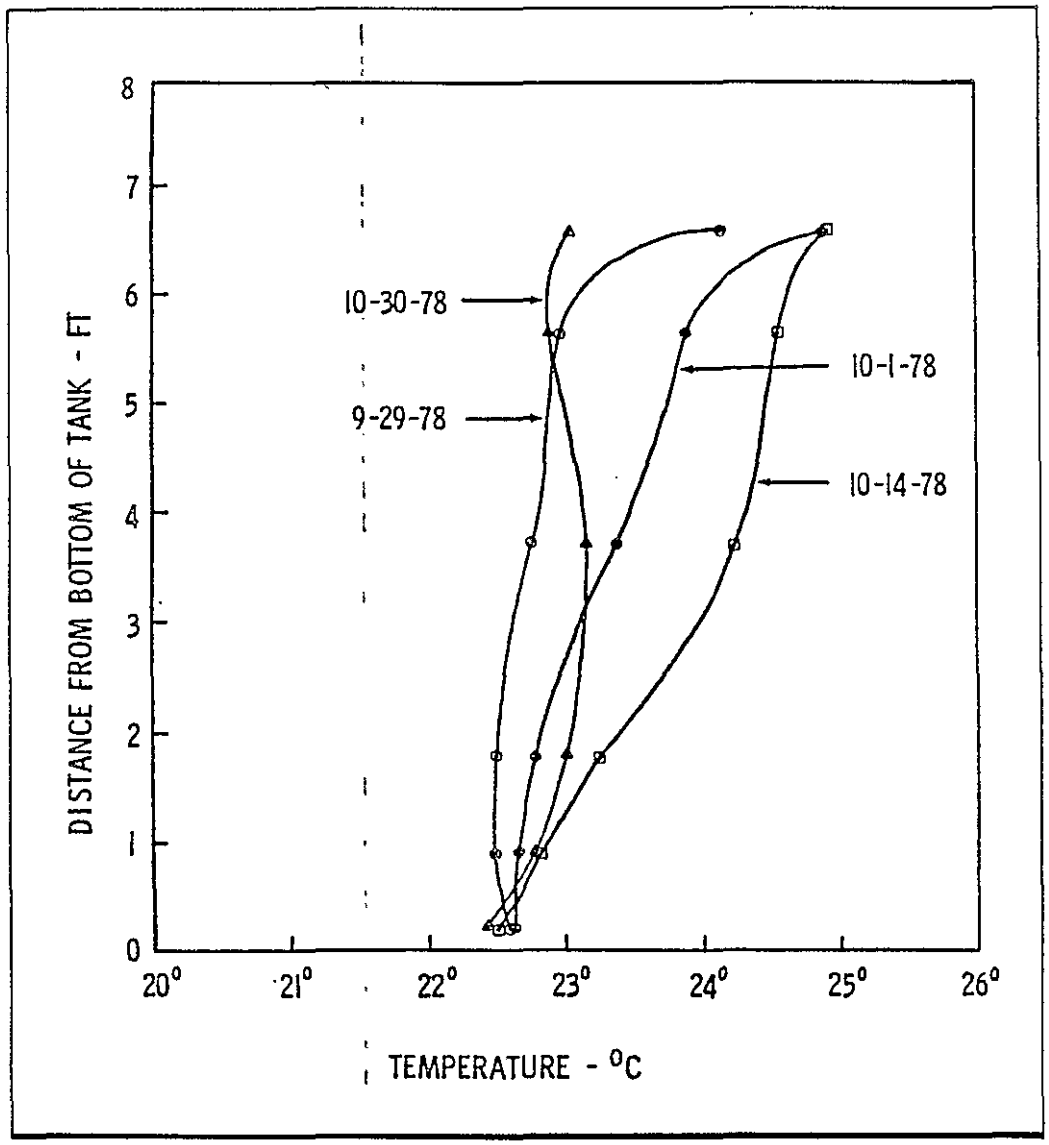
Figure 1.2-3
Tank Temperature at Various Heights
As a Function of Time for a 24-Hour Period
After Tank Fill-up



Source: Stanford Research Institute, "Measurement of Small Leaks in Underground Gasoline Storage Tanks Using Laser Interferometry," sponsored by the American Petroleum Institute, 1979.

Figure 1.2-4

Mean Temperature Distribution as a Function Of Depth for Four Different 24-Hour Periods



Source: Stanford Research Institute, "Measurement of Small Leaks in Underground Gasoline Storage Tanks Using Laser Interferometry," sponsored by the American Petroleum Institute, 1979.

Table 1.2-4

Total Force on Tank Ends Due to Internal Pressure

Tank Diameter	Total Force in Tons				
(inches)	1 psi	2 psi	3 psi	4 psi	5 psi
48	0.9	1.8	2.7	3.6	4.5
64	1.6	3.2	4.8	6.4	8.0
72	2.0	4.0	6.0	8.0	10.0
84	2.8	5.6	8.4	11.2	14.0
96	3.6	7.2	10.8	14.4	18.0

Source: Reference 6

The extent of tank bulging under pressure is dependent upon several factors, including tank diameter, tank age, the softness or wetness of the surrounding soil (for underground tanks), and past filling practice [6]. However, an 8-foot diameter tank could bulge enough to increase tank volume by 13 gallons or more [6].

These pressure effects become very important when one is attempting to detect small leaks using a method such as standpipe testing which places a pressure on the tank contents. For example, filling a 4-foot long standpipe on an 8-foot diameter gasoline tank buried three feet below grade puts an average pressure of 3.69 psi on the center of the tank [6]. This is sufficient to put more than 10 tons of force on the ends of the tank, and will lead to an increase in tank volume and a corresponding loss of volume in the standpipe. Thus, the detection of small leaks using a standpipe testing method becomes difficult.

C. STORAGE AND HANDLING PROTOCOLS

1. Storage and Handling Systems

Both aboveground and underground bulk storage systems should be composed of five basic components. These are:

- The product storage system (storage tanks).
- The product transfer (piping) system.
- An overfill prevention system.
- A spill containment and collection system.
- A leak detection system.

The basic methods and design considerations associated with these five components are summarized in Table 1.2-5 as a prelude to Parts II and III of this report. The advantages and disadvantages of the various materials of construction employed for product storage and transfer systems are summarized in Table 1.2-6.

2. Aboveground vs. Underground Storage

The choice of aboveground or underground tanks as an appropriate means of storage for a particular hazardous substance is dependent upon several factors, including the following:

- Type and amount of liquid to be stored.
- The availability of space (real estate) for storage.
- The level of product and tank accessibility required.
- The type of soil in the area.
- Groundwater levels in the area.
- Fire hazard considerations.

A comparison of the advanatages and disadvantages of aboveground and underground storage systems is presented in Table 1.2-7.

The reader should note that the storage of liquefied or compressed gases, such as liquefied natural gas, requires adherence to special design criteria as described in the following publications:

- API Standard 2510—The Design and Construction of Liquefied Petroleum Gas Installations at Marine Pipeline Terminals, Natural Gasoline Plants, Refineries and Tank Farms [7].
- NFPA Standard 58—Standard for the Storage and Handling of Liquefied Petroleum Gas [8].
- NFPA Standard 59—Standard for the Storage and Handling of Liquefied Petroleum Gas at Utility Gas Plants [9].

In addition, the American Society of Mechanical Engineers (ASME) has written the *A.S.M.E. Boiler and Pressure Vessel Code* [10], which contains rules for the design, fabrication and inspection of boilers and pressure vessels. This code consists of eleven sections as follows:

I	Power Boilers
II	Material Specifications
III	Nuclear Power Plant Components
IV	Heating Boilers
V	Nondestructive Examination
VI	Recommended Rules for Care and Operation of Heating Boilers
VII	Recommended Rules for Care of Power Boilers
VIII	Pressure Vessels, Division 1 Pressure Vessels, Division 2, Alternative Rules
IX	Welding Qualifications
X	Fibergalss-Reinforced Plastic Pressure Vessels

Table 1.2-5

Storage System Components — Methods, Materials, and Design Considerations

Product Storage	Product Transfer Piping & Accessories	Overfill Protection	Spill Containment	Leak Detection
-aboveground tanks -underground tanks -single-walled tanks -tank linings and coatings -tank wrappings -design considerations corrosion resistance chemical compatibility structural strength pressure relief foundation requirements safety factors -tank materials selection carbon steel stainless steel fiberglass-reinforced plastic (FRP) fiberglass/steel bonded tanks -coating and lining materials selection alkyds epoxies phenolics -wrappings vinyl polyethylene	-surface/subsurface piping -hoses -loading racks -design considerations corrosion resistance chemical compatibility structural strength pipe supports safety factors -materials selection carbon steel stainless steel fiberglass-reinforced plastic (FRP) polyvinyl chloride (PVC) polypropylene -check valves -emergency shutoff valves -coupling mates to prevent mixing of incompatible chemicals	-level control devices floats displacers gas bubblers hydrostatic head devices capacitance devices thermal conductivity devices ultrasonic devices optical devices nucleonic devices -automatic shutoff controls and flow diversion -high level alarms -liquid level gages -check valves -operating practices for *overfill protection* -dry disconnection hose valves -catchment basins	-impervious perimeter dikes, berms cutoff walls curbs aprons/slabs drainage ditches troughs -liners synthetic membranes asphalt, contrete -in-situ absorbing/neutralizing media for spill containment -spill collection systems -secondary containment *tanks (double-walled tanks)* -clay liners	-inventory control -visual inspection -interstitial monitoring of double walled tanks -soil/groundwater monitoring -tightness tests -structural tests

Table 1.2-6

General Properties of Materials Used for Storage Tanks and Piping

Structural Materials	Advantages	Disadvantages	Relative Cost
Carbon Steel	Compatible with petroleum products but not compatible with corrosive chemicals, such as mineral and oxidizing acids, without coatings. High structural strength.	Subject to attack by corrosive soils and corrosive chemicals such as mineral and oxidizing acids.	Low
Stainless steel	Material has better corrosion resistance than carbon steel and higher structural strength. There are more than 70 standard types of stainless steel and many special alloys.	Lower grade steels (i.e., martensitic steels) are not suitable for reducing acids such as HCl.	Medium to high, depending on grade of steel.
Fiberglass-reinforced plastic (FRP)	Compatible with petroleum and several chemical products.	Lacks the structural strength and impact resistance of steel tanks. Not compatible with some organic solvents.	Comparable to coated steel.
Polyvinyl chloride (PVC)	Excellent chemical resistance to acids, alkalis, and gasoline.	Plastics have low structural strength and are less resistant to mechanical abuse than steels. They are generally not suited for the storage or handling of organic solvents such as benzene, carbon tetrachloride and acetone.	Low
Concrete	Generally good resistance to chemical attack when exposed to dilute organic acids. Epoxy coatings are often applied to concrete to provide chemical resistance and decrease permeability.	Concrete is subject to cracking and spalling with changes in temperature such as during freeze/thaw cycles. Generally poor resistance to chemical attack.	High
Aluminum	Excellent resistance to atmospheric conditions and compatible with mineral and organic acids.	Pure aluminum has relatively low structural strength and as such is generally not used in the fabrication of tanks and pipes. Aluminum alloys are available but they are costly.	High
FRP/steel bonded tanks	Material has the combined advantage of the corrosion resistance of fiberglass and the structural strength of steel.	The main disadvantage of these tanks is their cost.	Medium
Linings and Coatings			
Alkyds	Alkyd-phenolics and alkyd-silicones have good weather-ability and good to excellent resistance to gasoline, non-halogenated organic solvents and alchohols. They may be applied to both the interior and exterior of tanks and pipes.	Not compatible with mineral acids, alkalis, chlorinated solvents, and organic acids.	Low

Table 1.2-6 continued

Epoxies	These materials include epoxy-amines, epoxy-esters and epoxy-phenolics. These materials have excellent weatherability and excellent chemical resistance to gasoline, non-halogenated organic solvents, alkalis and mineral acids. Epoxies may be applied to both interior and exterior of tanks and pipes.	Generally good to poor resistance to organic acids depending on the acid.	Low
Glass	Used for internal coatings. Very good chemical resistance.	High cost. Very fragile.	High
Phenolics	Excellent durability and excellent resistance to gasoline, non-halogenated organic solvents, and alcohols. Phenolic coatings may be applied to both interior and exterior of tanks and pipes.	Phenolic coatings generally exhibit poor resistance to alkalis, mineral acids, chlorinated solvents, and organic acids.	Low
Wrappings			
Vinyl	Good resistance to gasoline, non-halogenated solvents, alkalis and mineral acids. Vinyl coatings are usually applied as loose wrappings around tanks and pipes.	Not compatible with chlorinated solvents, and exhibits excellent to poor resistance to organic acids depending on the acid. Wrappings are usually not as effective as coatings because water often penetrates the space between the wrapping material and the tank.	Low
Polyethylene	Very good resistance to oxidizing acids, and some organic acids and alkalis. Polyethylene is usually applied as a loose wrapping around tanks and pipe.	Not compatible with gasoline and organic solvents. Wrappings are usually not as effective as coatings because water often penetrates the space between the wrapping material and the tank.	Low

Source: Reference 3.

Table 1.2-7

General Comparison of Aboveground and Underground Storage

Type of Storage	Advantages	Disadvantages
Aboveground	Accessible for equipment inspection and surveillance (leak detection).	Generally not aesthetically pleasing because equipment is visible.
	Allows for storage of much greater volumes in a single tank.	Requires large spill containment volume.
	Tanks accessible for cleanout and maintenance.	Subject to damage in flood area.
		Greater potential for vapor loss in atmospheric tanks due to temperature fluctuations because tank is exposed.
		Equipment is exposed to weathering.
		Greater exposure to fire.
Underground	Equipment out of sight; generally aesthetically pleasing; more efficient use of limited yard space.	Not accessible for inspection, surveillance, or easy maintenance.
	Accidental damage to equipment due to vehicular traffic (running into equipment) or similar causes is avoided.	One must be concerned with soil induced corrosion.
	Less subject to fire hazards and vandalism.	Potential for undetected leak and resultant groundwater contamination is much greater.
	Can be used at existing facilities located in flood plains if properly designed. (New facilities, whether aboveground or underground, may not be located in a flood plain under NYS regulation).	

Table 1.2-8

Capatibility Chart:
Chemicals vs. Structural Materials

Construction Material	Generally Incompatible with:
Steel	Mineral acids; nitric, hydrochloric, dilute sulfuric acids
Aluminum	Alkalies; potassium hydroxide, sodium hydroxide, mineral acids
Magnesium	Mineral acids
Lead	Acetic acid, nitric acid
Copper	Nitric acid, ammonia
Zinc	Hydrochloric acid, nitric acid
Tin	Organic acids, alkalies
Titanium	Sulfuric acid, hydrochloric acid
Fiberglass Reinforced plastics	Some organic solvents

Lining Materials	Generally Incompatible with:
Alkyds	Strong mineral acids, strong alkalies, alcohols, ketones, esters, aromatic hydrocarbons
Vinyls (poly-vinyl-chloride-PVC)	Ketones, esters, aromatic hydrocarbons
Chlorinated Rubbers	Organic solvents
Epoxy: (amine-cured, polyamide cured, or esters)	Oxidizing acids (nitric acid), ketones
Coal Tar Epoxy	Strong organic solvents
Latex	Oxidizing acids, ketones, esters
Polyesters	Oxidizing acids, strong alkalies, mineral acids, ketones, aromatic hydrocarbons
Silicones	Strong mineral acids, strong alkalies, alcohols, ketones, aromatic hydrocarbons

3. Chemical Compatibility

A primary concern in the handling and storage of hazardous liquids is the compatibility of these liquids with the storage system components. If, for example, a liquid is stored in a tank composed of a material which is incompatible with that liquid, accelerated and possibly very rapid deterioration of the tank could occur. This could result in a major leak or spill incident.

General information regarding the compatibility of various hazardous liquids with different materials of construction and lining materials is provided in Table 1.2-8. As shown in this table, steel is generally compatible with hydrocarbons, but is incompatible with most acids. In using Table 1.2-8 as a reference, the reader should note that when FRP is used as a material of construction, resins that are compatible with the material to be stored must be used. Other sources of information on material compatibility are listed in Table 1.2-9.

The compatibility of hazardous liquids with other types of liquids is also of concern. Liquids may come in contact with one another if, for example, a tank storing liquid A is not thoroughly cleaned before it is used to store liquid B. If these liquids were incompatible, a violent reaction could ensue with potentially destructive effects.

Table 1.2-9

References on Material and Chemical Compatibility

Chemical Engineering Handbook, Perry and Chilton [11]

Corrosion Data Survey, National Association of Corrosion Engineers [12]

"Beat Corrosion With a Rubber Hose," Gallagher, Chemical Engineering, September 8, 1980 [13]

"Guide for Protection of Concrete Against Chemical Attack by Means of Coatings and Other Corrosion-Resistant Materials," American Concrete Institute Committee 515 [14]

The Merck Index, Merck and Company [15]

A Method of Determining the Compatibility of Hazardous Wastes, U.S. EPA-600/1-80-076, April, 1980 [16]

The Chemical Hazards Response Information System, Chemical Data Handbook, U.S. Coast Guard, U.S. Department of Transportation [17]

References

1. U.S. Department of Transportation, *Hazardous Materials Emergency Response Guidebook*, USDOT P 5800.2, U.S. Department of Transportation, Washington, DC, 1980.

2. National Fire Protection Association, *Hazardous Chemicals Data*, NFPA 49, Batterymarch Park, Quincy, MA 02269, 1975.

3. U.S. Environmental Protection Agency, *Hazardous Materials Spill Monitoring and Safety Handbook and Chemical Hazard Guide, Parts A and B*, EPA-600/4-79-008a/b, PB295853 and PB295854, Office of Research and Development, U.S. Environmental Protection Agency, P.O. Box 15027, Las Vegas, Nevada 89114, January, 1979.

4. U.S. Department of Transportation, *Chemical Hazards Response Information System (CHRIS) Manuals*, U.S. Coast Guard, U.S. Department of Transportation, Washington, DC

5. Maresca, J.W., Evans, P.C., "Measurement of Small Leaks in Underground Gasoline Storage Tanks Using Laser Interferometry," SRI International, Menlo Park, CA 94025, October 31, 1979.

6. McLean, F.R., "Leak Seeking in Underground Tanks," Proceedings of the Forty-third Annual Fire Department Instructors Conference, March 30 – April 2, 1971, Kansas City, MO.

7. American Petroleum Institute, *The Design and Construction of Liquefied Petroleum Gas Installations at Marine Pipeline Terminals, Natural Gas Plants, Refineries and Tank Farms*, API Standard 2510, American Petroleum Institute, 2101 L Street, N.W., Washington, DC 20037.

8. National Fire Protection Association, *Standard for the Storage and Handling of Liquefied Petroleum Gas*, NFPA 58, Batterymarch Park, Quincy, MA 02269.

9. National Fire Protection Association, *Standard for the Storage and Handling of Liquefied Petroleum Gas at Utility Gas Plants*, NFPA 59, Batterymarch Park, Quincy, MA 02269.

10. American Society of Mechanical Engineers, *A.S.M.E. Boiler and Pressure Vessel Code*, American Society of Mechanical Engineers, 345 East 47 Street, New York, NY 10017.

11. Perry, R.H., Chilton, C.H., *Chemical Engineers' Handbook*, Fifth Edition, McGraw-Hill Book Company, 1221 Avenue of the Americas, New York, NY 10020, 1973.

12. Hamner, N.E., *Corrosion Data Survey*, Fifth Edition, National Association of Corrosion Engineers, 1440 South Creek, Houston, TX 77084, 1974.

13. Gallagher, R., "Beat Corrosion With Rubber Hose", *Chemical Engineering*, McGraw-Hill Book Company, 1221 Avenue of the Americas, New York, NY 10020, September 8, 1980.

14. American Concrete Institute Committee 515, *Guide for Protection of Concrete Against Chemical Attack by Means of Coatings and Other Corrosion-Resistant Materials.*

15. Windholy, M., Budauau, S., Stroumtsos, L.Y., Fertig, M.N., *The Merck Index, An Encyclopedia of Chemicals and Drugs*, Ninth Edition, Merck & Company, Inc., Rahway, NJ, 1976.

16. U.S. Environmental Protection Agency, *A Method for Determining the Compatibility of Hazardous Wastes*, EPA 600/2-80-076, U.S. Environmental Protection Agency, Municipal Environmental Research Laboratory, Cincinnati, OH 45268, April, 1980.

17. New York State Department of Environmental Conservation, *Properties of Top Ten Hazardous Liquids Used By Industry in New York State*, Division of Water, New York State Department of Environmental Conservation, 50 Wolf Road, Albany, NY 12233, October, 1980.

18. McAnaly, M.A., Dickerman, J.C., *Summary and Analysis of Data From Gasoline Temperature Survey Conducted at Service Stations by American Petroleum Institute*, API Publication No. 4278, Radian Corporation, 8500 Shoal Creek, Austin, TX, November 11, 1976.

19. Sax, Irving N., *Dangerous Properties of Industrial Materials*, Van Nostrand Reinhold Company, 135 W. 50 Street, New York, NY 10020, Fifth Edition, 1979.

20. U.S. Environmental Protection Agency, *Innovative and Alternate Technology Assessment Manual*, EPA 430/9-78-009, USEPA MERL, Cincinnati, OH, February, 1980.

References Continued

21. Heath Consultants, Inc., *Procedure Manual for the Operation of the Petro Tite Tank Tester*, Form 582 HPN 5124, Heath Consultants, Inc., 100 Tosca Drive, Stoughton, MA 02072.

22. Owens-Corning Fiberglas Corp., Fiberglas Tower, Toledo, OH 43659.

23. National Association of Corrosion Engineers, Recommended Practice RP-01-69, "Control of External Corrosion on Underground or Submerged Metallic Piping Systems," 2400 West Loop South, Houston, TX 77027.

Additional Information on Hazardous Chemicals

The following sources may be consulted for additional information:

A Comprehensive Treatise on Inorganic and Theoretical Chemistry, J.W. Mellor, John M. Wiley and Sons, Inc.

Accident Prevention Manual for Industrial Operations, National Safety Council.

American Insurance Association (Chemical Hazards Bulletins, Research Reports, Special Interest Bulletins).

Bureau of Mines, U.S. Department of the Interior.

Chemical and Engineering Dictionary, Chemical Publishing Company.

Condensed Chemical Dictionary, Reinhold Publishing Company.

Dangerous Properties of Industrial Materials, N. Irving Sax, Reinhold Publishing Corp.

Encyclopedia of Chemical Technology, Kirk and Othmer, Interscience Publishing Company.

Fire Officer's Guide to Dangerous Chemicals, Charles W. Bahme, NFPA.

Guide to Safety in the Chemical Laboratory, Manufacturing Chemists' Association.

Handbook of Chemistry, N.A. Lange, McGraw-Hill Book Company, Inc.

Handbook of Chemistry and Physics, The Chemical Rubber Company.

Handbook of Industrial Loss Prevention, Associated Factory Mutual Fire Insurance Companies.

Handbook of Laboratory Safety, The Chemical Rubber Company.

Industrial Hygiene and Toxicology, F.A. Patty, Interscience Publishers, Inc.

Industrial Safety, National Safety Congress, 1957.

Industrial Toxicology, L.T. Fairhall, William & Wilkins Company.

International Critical Tables, National Research Council, McGraw-Hill Book Company, Inc.

Manufacturing Chemists' Association, Inc. (Chemical Safety Data Sheets).

Matheson Gas Data Book, The Matheson Company.

McGraw-Hill Encyclopedia of Science and Technology.

National Fire Codes, National Fire Protection Association.

Safety in the Chemical Laboratory, Peters and Creyghton, Butterworths Scientific Publications.

Standard Methods of Chemical Analysis, F. Furman, Van Nostrand Company, Inc.

Thorpe's Dictionary of Applied Chemistry, John H. Wiley and Sons, Inc.

Underwriters' Laboratories, Inc.

U.S. Coast Guard Regulations.

U.S. Department of Transportation, Regulations for Transportation of Explosives and Other Dangerous Articles.

Part II
UNDERGROUND STORAGE SYSTEMS

INTRODUCTION

Part II of this report describes the components and concerns associated with underground storage facilites for hazardous liquids.

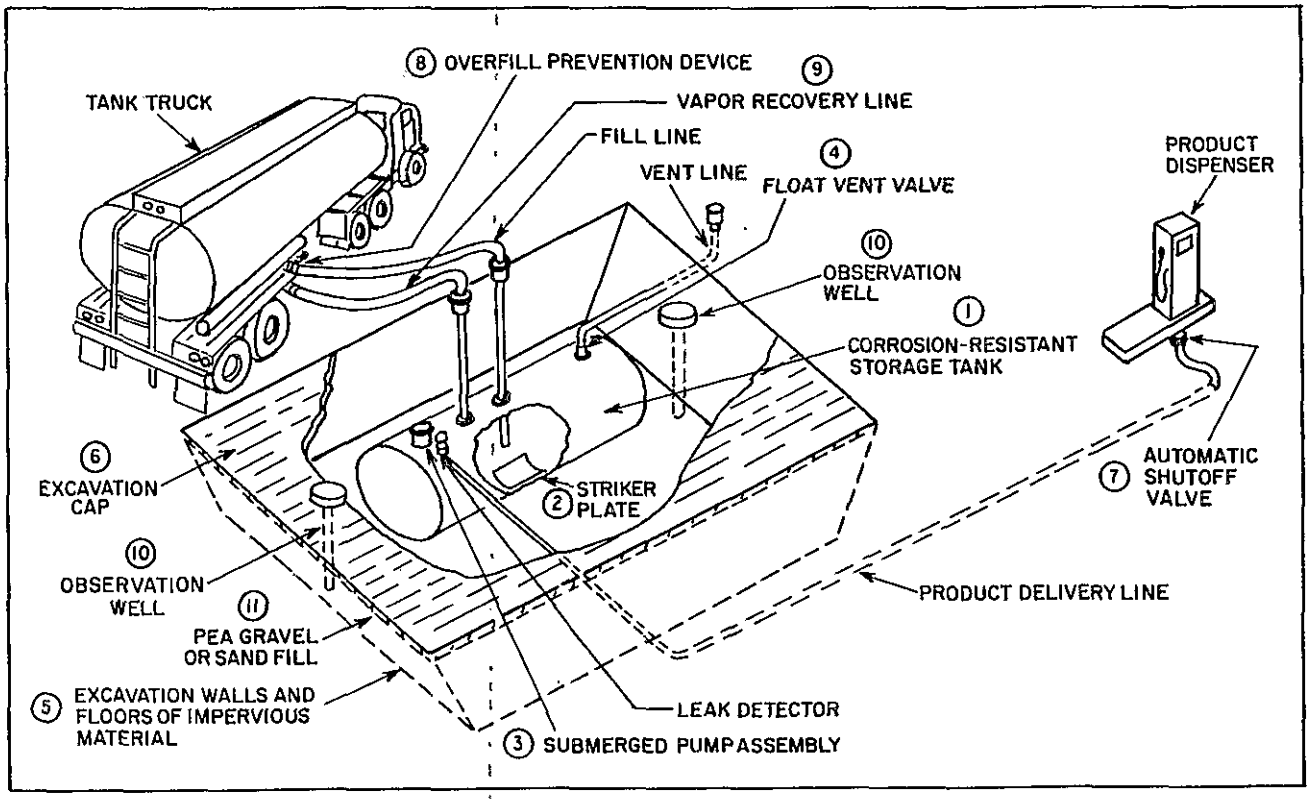
The basic principles shown in figure 2-1 are applicable to all underground storage systems. However, because chemicals are highly variable in the characteristics and the risks they present, underground storage may not always be an appropriate storage practice, or it may be appropriate for the design engineer to consider other practices not illustrated in this generalized drawing.

The items covered in detail in the following chapters include (1) the types of storage tanks available; (2) piping and pumping system components and their performance; (3) underground spill containment systems; (4) the types of overfill prevention systems and their performance; (5) leak monitoring and surveillance; (6) the testing and inspection of underground storage systems; and (7) the closure and abandonment of underground storage facilities.

A schematic diagram showing the key components of an underground storage system is presented in Figure 2-1.

Figure 2.1

Elements of an Underground Storage Tank Installation



Well designed underground storage systems usually contain the following:

1) corrosion resistant tank; 2) striker plate under tank fill line; 3) submerged pump with leak detector on product delivery line; 4) float vent valve in tank vent line; 5) excavation walls and floor of impervious material; 6) asphalt or concrete excavation cap; 7) automatic shutoff valve on delivery line at pump island; 8) overfill prevention device at fill line on tank truck; 9) vapor recovery in tank truck during filling operation; 10) observation wells located inside excavation boundaries; 11) pea gravel or sand fill for excavation.

These are all important aspects of a good underground storage system.

Part II

CHAPTER 1: UNDERGROUND STORAGE TANKS

A. INTRODUCTION

Several types of underground storage tanks or storage systems are available for use in today's market. These include the following:

- Bare steel tanks.
- Steel tanks with coatings.
- Cathodically protected steel tanks (galvanic protection).
- Cathodically protected steel tanks (impressed current protection).
- Fiberglass reinforced plastic (FRP) tanks.
- FRP/steel bonded tanks.
- Double containment systems, such as
  - Double-walled tanks,
  - Vaulted tank storage system, and
  - Impermeable liners.
- Relined tanks.
- Tanks which combine several design features such as cathodically protected double walled steel tanks or double walled steel tanks with a fiberglass bonded outer shell are available on custom order from many manufacturers.

Summaries of the characteristics and limitations of these various types of tanks and storage systems are presented in Table 2.1-1.

B. TANK LAYOUT

Idealized layouts for underground storage facilities are illustrated in Figures 2.1-1 and 2.1-2. The diagram of Figure 2.1-1 depicts a tank equipped with a suction pump while the illustration in Figure 2.1-2 is that of a tank equipped with a submerged pump. The discussion in chapter 2 explains these pumping systems in more detail.

It is highly desirable for the owner to prepare and keep at the storage site, a plot plan which shows the layout of the facility. The plot plan should show age of tanks, material of construction, depth and location of pipe galleries, chemical stored in tank and phone number and address of person to contact in case of an emergency.

The tank connections shown in Figures 2.1-1 and 2.1-2 include the following:

- A fill and gauge tube.
- A vent line, with a float vent valve installed at the vent line tank connection for overfill prevention.
- A manhole fitted over the fill and gauge tube to permit easy access to the tube.

In addition, Figure 2.1-2 shows a manhole over the pump manifold assembly to permit access for maintenance, and a leak detector mounted on the pump manifold, which detects leaks in the product supply line. Leak detectors are required by NFPA 30.

The utility and economics of providing a storage tank with a manhole are subject to debate. They add approximately $500 to the cost of a tank. A tank can be cut open and entered for inspection for about $700 and effectively resealed. However, all tanks may not require inspection in a normal life and only a small fraction may require re-entry.

Manholes have the advantage of allowing internal inspection of emptied tanks and are especially useful on fiberglass tanks where access for measuring diameter deflections is important. However, Manhole gaskets can leak, resulting in stormwater entry and can give a false reading during a leak test. Air pockets formed in the manhole area can interfere with leak testing, though this condition can be corrected with a properly placed bleeder valve.

All tanks, and especially FRP tanks, should be provided with a striker plate under the fill line. The striker plate is a heavy metal plate attached to the bottom of the tank which absorbs the shock of the dip stick when it is dropped into a tank to measure liquid level. It is becoming common practice to have striker plates under all tank openings.

Table 2.1-1

Characteristics of Underground Storage Tanks

Type	Description	Applications*	Types of Soil Suitable	Major Causes of Leaks	Relative Costs	Remarks (advantages and disadvantages)
Bare steel	Carbon steel	Compatible with fuels and a number of other chemical products. Not compatible with corrosive liquids such as acids.	Not compatible with corrosive soil.	Corrosion	Low	Fifty percent of the bare bare steel tanks leak after 15 years. Life expectancy is dependent on soil corrosivity and method of installation.
Coated/lined steel	Carbon steel with exterior coating and/ or interior lining.	Generally compatible with corrosive chemicals such as alkalis and organic and inorganic acids if internal lining is applied.	Generally compatible with corrosive soil if external coating is applied.	Corrosion due to defects in coating or lining.	Low	Coating/lining must be properly applied and free of defects (holidays). the effecttiveness of the coating/ lining will vary with the type of coating. Internal lining can increase life span of tanks.
Pre-engineered cathodically protected steel tanks-galvanic protection (e.g. Sti-P3 and B-10 tanks)	Steel tank with pre-engineered corrosion protection consisting of sacrificial anodes, protective coating and electrical isolation.	Compatible with gasoline, diesel fuel, kerosene, bunker oil and a number of other chemical products.	Can withstand corrosion in soils with resistivities greater than 2000 ohm-cm [26].	Internal corrosion	Medium	Life expectancy of these tanks is difficult to predict but the record for the fifteen years that the tank has been available is impressive.
Cathodically protected steel tanks-impressed current	Steel tanks to which a constant supply of electric current is applied.	Petroleum products and a number of other chemical products.	Will withstand highly corrosive soil if properly designed.	Internal corrosion	Medium	Good life expectancy if the cathodic protection is properly maintained.
Vaulted tank	Tanks are installed in concrete valults to provide secondary containment of leaks. Vaults sometimes have interior coatings and external polyethylene wrapper to prevent permeation through concrete.	Frequently used for secondary containment of highly hazardous chemicals.	Generally resistant to soil corrosion.	Low risk of leaks	High	Poorly designed concrete vaults are susceptible to cracking and chemical attack by salts and acids. Porosity of concrete is a problem.

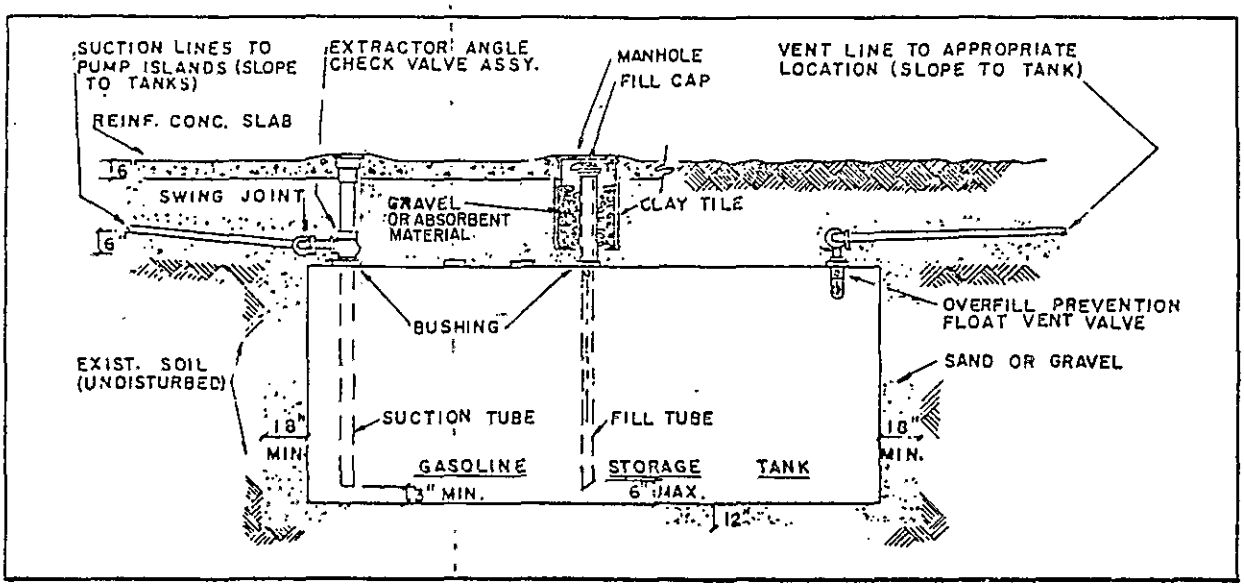
Table 2.1-1 continued

Impermeable liners	Involves the use of an impermeable liner as secondary containment in the tank excavation. Examples include membrane, clay, and bentonite liner.	See Part II, Chapter 4	See Part.II, Chapter 4	Low risk of leaks	Medium	Care must be taken to insure that lining material is compatible with stored material. Should include a leak detection system within the confines of the liner containment area.
Relined tanks	Existing steel tank relined with corrosion resistant material.	Petroleum products and corrosive chemicals. Used to extend the lifespan of underground tanks.	Bare steel tanks with interior liners will continue to corrode in corrosive soil.	Defects in lining	Low	Condition of the tank is a key consideration. It is important that the relining material be compatible with the material to be stored and that workmanship be according to the API standards.
Fiberglass reinforced plastic (FRP)	Plastic resins reinforced with glass fiber.	Petroleum and a number of other chemical products.	Suitable in highly corrosive soils.	Tank rupture	Medium	FRP tanks cannot withstand loads as does steel and may easily be damaged if dropped, mishandled or subjected to excessive loads because of improper installation.
FRP/steel	Outer FRP layer fused to an inner layer of steel by a polyester resin bond.	Petroleum products and a number of other chemical products.	Resistance to soil corrosion is comparable to that of fiberglass tanks.	Low risk of leaks. but tank is susceptible to internal corrosion.	Medium	Combines strength of steel with corrosion resistance of fiberglass.
Double-walled	Tank within a tank with a vacuum or pressurized space between the inner and outer walls. Currently manufactured doubled-walled tanks are composed of either steel (with coating and galvanic cathodic protection on outer wall) or FRP.	Applications are dependent upon the materials of construction. See descriptions of FRP and coated, galvanically protected steel tanks above.	Suitable in highly corrosive soils, depending on the materials of construction.	Low risk of leaks	High	Some models only available in capacities up to to 4000 gallons. These tanks usually include a built-in leak detection system located between the inner and outer walls.

* Refer to Table 1.2-8 and Appendix A for more inforamtion on chemical compatibility.

Figure 2.1-1

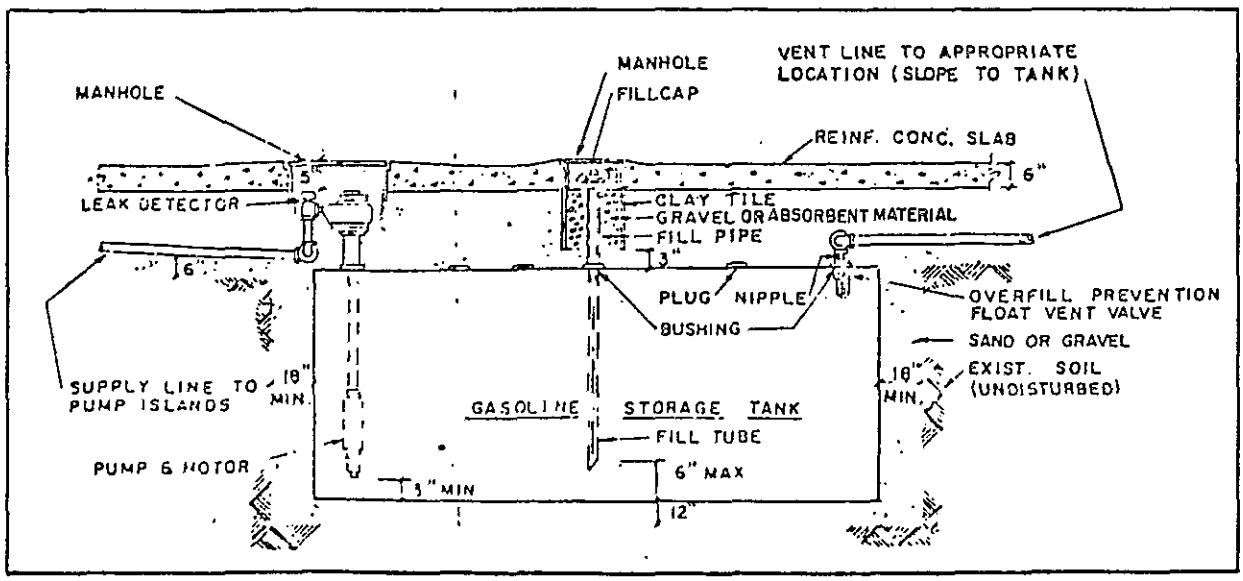
Tank Piping Details – Suction System



Source: API Publication 1615, *Installation of Underground Petroleum Storage Systems*, 1979.

Figure 2.1-2

Tank Piping Details – Submerged System



Source: API Publication 1615, *Installation of Underground Petroleum Storage Systems*, 1979.

C. TYPES OF UNDERGROUND STORAGE TANKS

1. Bare Steel Tanks

Bare steel tanks constructed of mild carbon steel may be used in non-corrosive soil environments to store non-corrosive materials, such as gasoline and other petroleum derivative products. The compatibility of steel with various petroleum and chemical products is discussed in Part I and Appendix B. The degree of environmental protection provided by bare steel tanks is minimal and consequently their use has declined in recent years.

Please note that many bare steel tanks have a thin surface coating to protect against rust. This is essentially a cosmetic coating, and should not be confused with more substantial corrosion protection coatings.

Design Standards. The capacities, dimensions and construction details for bare steel tanks generally follow established standards. These include the following:

Underwriter Laboratories (UL) Inc.:
- UL 58 – *Steel Underground Tanks for Flammable and combustible Liquids* [6].

National Fire Protection Association (NFPA):
- NFPA 30 – *flammable and combustible Liquids Code* [19].

American Petroleum Institute (API):
- API Publication 1602 – *Recommended Standard for Underground Gasoline Tanks* [21].
- API Publication 1611 – *Service Station Tankage Guide* [20].
- API Publication 1615 – *Installation of Underground Petroleum Storage Systems* [1].

American Society of Mechanical Engineers:
- ASME/Pressure Vessel Code, Section VIII/[14].

Of these standards, the Underwriters Laboratories standards are the most detailed in that they specify many of the tank design details. These include steel thickness, tank head design, bracing requirements for multi-compartment tanks, the sizes of vent connections, and tank marking and testing requirements.

The American Society of Mechanical Engineers Pressure Vessel Code may be used for storage tanks intended for industrial service.

The thicknesses of horizontal, atmospheric-type steel tanks of various capacities as recommended in UL 58 are shown in Table 2.1-2. This standard also recommends that the length of the tank be no more than six times its diameter [6]. As a source of reference, the capacity per foot of length for tanks having diameters of 24 to 144 inches is given in Table 2.1-3.

Installation of Underground Steel Tanks. Sources of information and recommendations of installation practices for underground storage tanks include API Publication 1615 [1], NFPA 30 [19] and the New York State Department of Environmental Conservation (NYSDEC) manual covering standards of practice for bulk storage of hazardous liquids [30]. Most manufacturers supply step-by-step procedures for tank installation and require that these steps be followed to validate the guarantees and warrantees.

The installation recommendations given in the API publication identify tank clearance, depth of excavation, and anchoring and backfilling requirements. Examples of the recommendations given in API Publication 1615 include the following:

- At least 6 inches and preferably 12 inches of well-compacted sand or gravel placed underneath the tank.
- A minimum tank clearance of 12 inches in all horizontal directions.
- In areas not subject to traffic, the cover depth should be a minimum of 24 inches, or not less than 12 inches plus a reinforced concrete slab not less than 4 inches in thickness.
- Where tanks are subject to traffic, cover depths should be a minimum of 36 inches, or not less than 18 inches of well-tamped material plus at least 6 inches of reinforced concrete or 8 inches of asphaltic concrete.

It should be noted that the burial depth of a tank is dependent upon several factors, including local regulations, the type of finished surface to be applied, soil conditions, topography, and suction pumping lift requirement [1].

The recommendations of NFPA 30 concur with those of API Publication 1615, with the addition that steel underground tanks shall be set on firm foundations and surrounded with at least 6 inches of noncorrosive inert material, such as clean sand or gravel, well-tamped in place [19].

The backfill for steel tanks is typically a clean, noncorrosive, porous material such as clean washed sand or gravel. Backfilling operations are very important to the life of the installation. It is important that the backfill be well compacted to avoid undue stresses on the tank. Application and compaction of the backfill in layers is often specified to chieve optimum compaction (eliminate voids in the backfill).

Table 2.1-2

Thickness of Steel Tanks

Capacity		Maximum* Diameter		Manufacturers Standard or Galvanized Sheet	Nominal Thickness			
					Uncoated		Galvanized	
U. S. Gallons	dm^3	Inches	m	Gage No.	Inches	mm	Inches	mm
Up to 285	Up to 1078	42	1.07	14	0.075	1.91	0.079	2.01
286 to 560	1082 to 2120	48	1.22	12	0.105	2.67	0.108	2.74
561 to 1100	2124 to 4164	64	1.63	10	0.135	3.43	0.138	3.51
1101 to 4000	4168 to 15142	84	2.13	7	0.179	4.55		
4001 to 12,000	15145 to 45425	126	3.20	1/4 inch	0.250	6.35		
12,001 to 20,000	45429 to 75708	144	3.66	5/16 inch	0.312	7.92		
20,001 to 50,000	75712 to 189270	144	3.66	3/8 inch	0.375	9.53		

* Length of tank shall be not greater than 6 times the diameter

Source: This material is based on and taken, with permission, from Underwriters Laboratories Inc. Standard for Safety for Steel Underground Tanks for Flammable and Combustible Liquids, UL 58, Copyright 1976 (by Underwriters Laboratories Inc.), copies of which may be purchased from Underwriters Laboratories, Inc., Publication Stock, 333 Pfingsten Road, Northbrook, Illinois 60062.

Note: UL shall not be responsible to anyone for the use of or reliance upon a UL Standard by anyone. UL shall not incur any obligation or liability for damages, including consequential damages, arising out of or in connection with the use, interpretation of, or reliance upon a UL Standard.

Table 2.1-3
Gallon Capacity per Foot of Length

Diameter in Inches	U.S. Gallons 1-foot Length	Diameter in Inches	U.S. Gallons 1-foot Length	Diameter in Inches	U.S. Gallons 1-foot Length
24	23.50	65	172.38	105	449.82
25	25.50	66	177.72	106	458.30
26	27.58	67	183.15	107	467.70
27	29.74	68	188.66	108	475.89
28	31.99	69	194.25	109	485.00
29	34.31	70	199.92	110	493.70
30	36.72	71	205.67	111	502.70
31	39.21	72	211.51	112	511.90
32	41.78	73	217.42	113	521.40
33	44.43	74	223.42	114	530.24
34	47.16	75	229.50	115	540.00
35	49.98	76	235.56	116	549.50
36	52.88	77	241.90	117	558.51
37	55.86	78	248.23	118	568.00
38	58.92	79	254.63	119	577.80
39	62.06	80	261.12	120	587.52
40	65.28	81	267.69	121	597.70
41	68.58	82	274.34	122	607.27
42	71.97	83	281.07	123	617.26
43	75.44	84	287.88	124	627.00
44	78.99	85	294.78	125	638.20
45	82.62	86	301.76	126	647.74
46	86.33	87	308.81	127	658.60
47	90.13	88	315.95	128	668.47
48	94.00	89	323.18	129	678.95
49	97.96	90	330.48	130	690.30
50	102.00	91	337.86	131	700.17
51	106.12	92	345.33	132	710.90
52	110.32	93	352.88	133	721.71
53	114.61	94	360.51	134	732.60
54	118.97	95	368.22	135	743.58
55	123.42	96	376.01	136	754.64
56	127.95	97	383.89	137	765.78
57	132.56	98	391.84	138	776.99
58	137.25	99	399.88	139	788.30
59	142.02	100	408.00	140	799.68
60	146.88	101	416.00	141	811.14
61	151.82	102	424.48	142	822.69
62	156.83	103	433.10	143	834.32
63	161.93	104	441.80	144	846.03
64	167.12				

Source: This material is based on and taken, with permission, from Underwriters Laboratories Inc. Standard for Safety for Steel Underground Tanks for Flammable and combustible Liquids, UL 58, copyright 1976 (by Underwriters Laboratories Inc.), copies of which may be purchased from Underwriters Laboratories, Inc., Publication Stock, 333 Pfingsten Road, Northbrook, Illinois 60062.
Note: UL shall not be responsible to anyone for the use of or reliance upon a UL Standard by anyone. UL shall not incur any obligation or liability for damages, including consequential damages, arising out of or in connection with the use, interpretation of, or reliance upon a UL Standard.

It is also recommended in API Publication 1615 that tanks be ballasted with the product as soon as possible after backfilling. Water ballast may be used as an alternative, but it is necessary to defer installation of submerged pumping units in the tank until after the water ballast is removed. If ballasting is necessary in order to prevent tank flotation (from a high water table or from rain), the product to be stored should be used as a first choice [1].

When a high water table is present, anchoring should be used to prevent tank flotation. A concrete slab is often used to anchor underground tanks as shown in Figure 2.1-3. When such a concrete slab is used, tanks should be separated from the slab by no less than 12 inches of compacted sand. Tanks should not be set directly on the concrete nor placed on hard or sharp material that could cause deformation or damage to the tank or tank coatings. Anchor straps should be installed so as not to damage the tank or tank coating. Material such as asbestos felt or pieces of rubber tire should be placed between the tank and the anchor straps to provide electrical isolation [1].

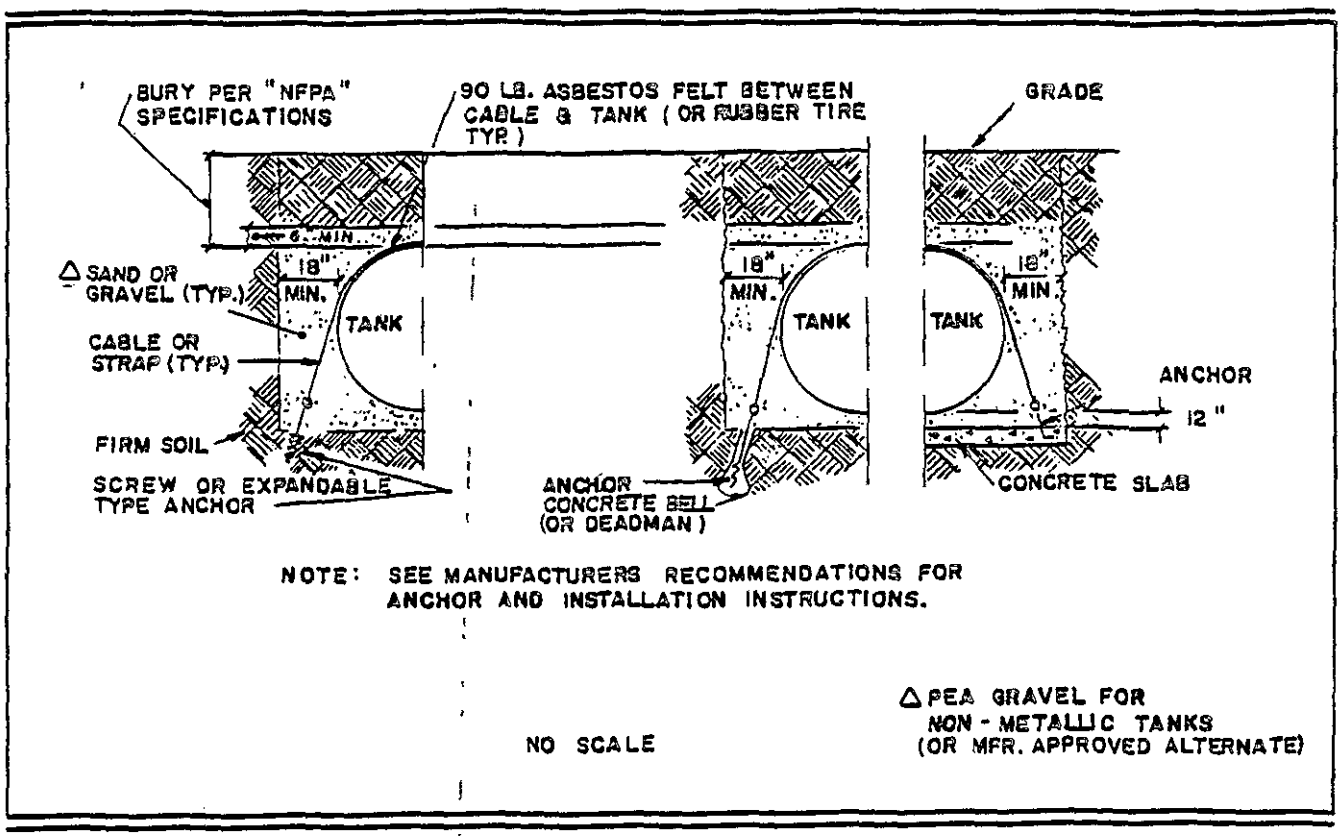
For complete information on the installation of underground steel tanks, the reader is directed to the NYSDEC standards of practice document, NFPA 30, API Publication 1615 and other sources, such as Occupational Safety and Health Administration regulations (29 CFR, Part 1910, Section 1910.106) [29] and specific manufacturer recommendations.

Characteristics of Carbon Steel. Carbon steel is the most common, most versatile and least costly metal used in industry. It is two-thirds the weight of lead and three times heavier than aluminum [14]. Carbon steel may be annealed (i.e. heated and then cooled) to make it stronger and more flexible, and galvanized (coated with zinc) to improve its corrosion resistance. The mechanical properties of carbon steel are strongly influenced by the carbon content.

Over the years, various types of carbon steel have been developed, for example, structural and pressure vessel steels. There are only minor metallurgical differences between these types of steel; the important differences are in the quality of the steel (resulting from adherence to tighter specifications).

Figure 2.1-3

Anchoring of Tanks Installed in High Groundwater Tables



Source: Reference 2

There are a number of standards and specifications for carbon steel in various forms, such as in the form of bars, pipe and plate. The American Society for Testing and Materials (ASTM) publishes specifications on many materials of construction including carbon steels. For detailed specifications and chemical analyses, references should be made to these ASTM standards. The American Iron and Steel Institute also issues specifications on a variety of carbon and alloy steels. The American Society of Mechanical Engineers, the American National Standards Institute, and the American Petroleum Institute are also active in the area [14]. For more information on these steel specifications and how they may be obtained, please refer to the list of steel specification references at the end of this chapter.

2. Coated Steel Tanks

Organic coatings may be applied to both the interior and exterior of underground steel tanks. Interior coatings are often called tank linings. In the case of shop-assembled tanks, coatings and linings are generally applied at the factory. The recommendations of the tank manufacturer should be followed when a coating is required since improper selection can lead to early failure and product contamination. When installing the tank, care must be exercised in order to avoid damage to the coating. The properties, compatabilities and costs of common organic coatings are given in Appendix C. Refer to Section D of this chapter for additional information on application of coatings and linings.

3. Cathodically Protected Steel Tanks — Galvanic Protection

As described in Part I, Chapter 1, Section C of this report, cathodic protection is used to reduce or eliminate corrosion of a metallic structure which is in contact with corrosive soil. This is accomplished by applying an electric current to the structure which is greater in strength and opposite in direction to the current that is causing corrosion.

The galvanic cathodic protection method employs sacrificial anodes, composed of materials such as magnesium or zinc, in electrical contact with the metal structure to be protected. These anodes are attached to the surface of the protected material (tank or pipe) in the soil or other electrolytic solution, and the required current is generated by corrosion of the sacrificial anode. A typical configuration for galvanic protection is shown in Figure 2.1-4.

The design of an adequate galvanic protection system requires making a measurement of the soil resistivity. If the amount of electric current required to protect the tank has been determined, the soil resistivity must be known in order to determine the type and size of anode(s) required to protect the tank. The life expectancy of the storage system is also important in determining the number and type of anodes required [22].

Magnesium anodes are the most common type of sacrificial anode, although zinc anodes may be used in soils with resistivities less than 1000 ohm-cm. Magnesium, because of its higher driving voltage, can be used quite effectively in soils with resistivities up to 5000 ohm-cm, and on well coated structures can often be used up to 10,000 ohm-cm or more [10, 12, 27].

In general, because of the low driving voltages of sacrificial anodes (1.1-1.6 volts) and the low electric currents generated (usually less than 100 milli-amperes per anode), it is desirable from both an economic and an engineering standpoint that galvanically protected tanks be coated. Bare tanks require a greater electric current, and hence a larger number of sacrifical anodes than coated tanks.

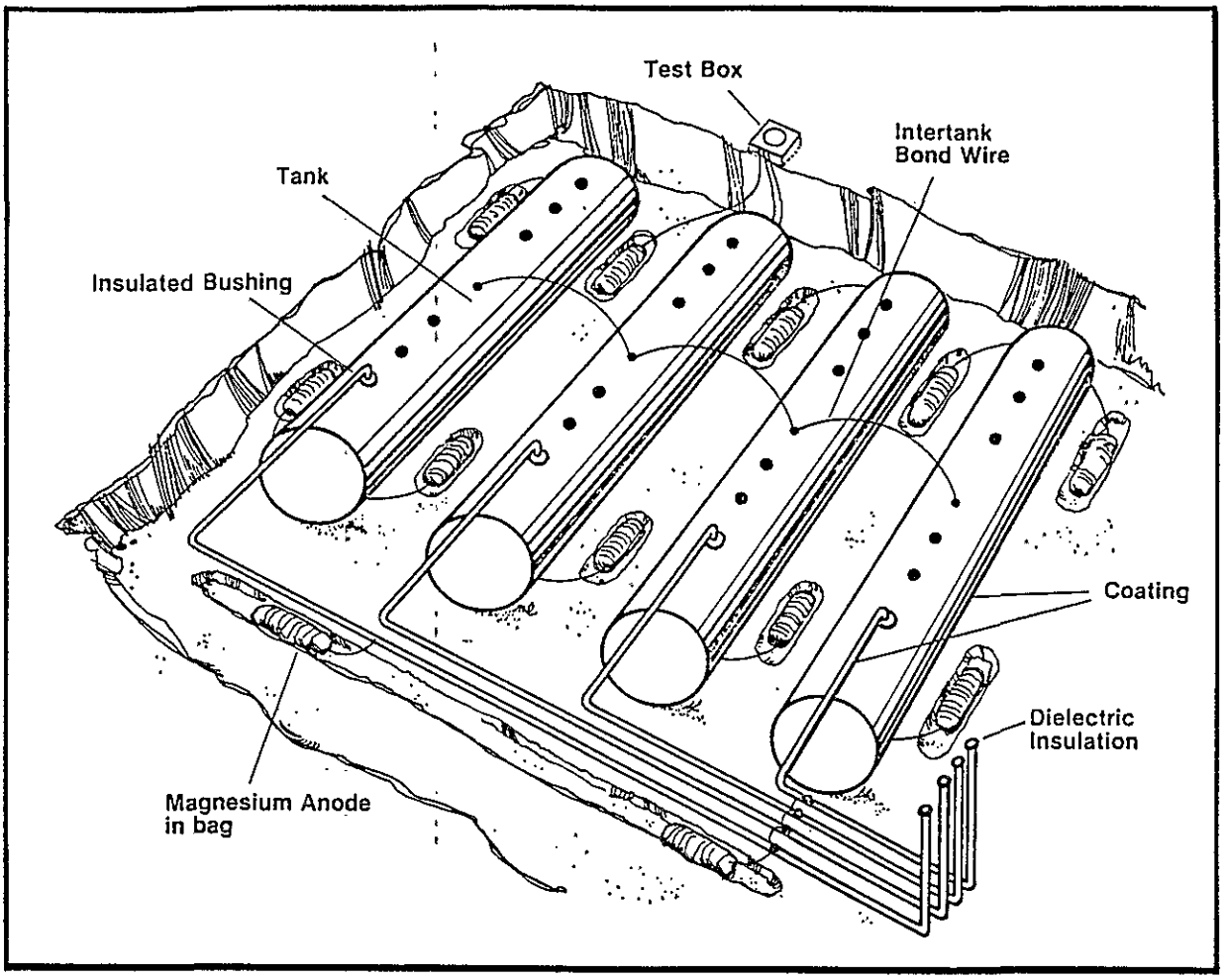
Periodic testing of cathodic protection is essential if the system is to function properly and provide long-term protection. The current from the anodes may fail because of anode deterioration or broken lead wires. Changes in underground conditions (e.g., installation of a water pipe) or coating deterioration can also change protective current requirements. Measurements of tank-to-soil potentials and anode output should be made at least once a year to ensure proper operation of the system [10].

In addition, care must be exercised during the installation of galvanic protection systems to ensure electrical continuity of the system. This means providing bonding wires between tanks when several tanks are installed and across flexible pipe joints, if such joints are used. Screwed piping should not be relied upon to provide electrical continuity.

Examples of pre-engineered, galvanically protected steel tanks include the Sti-P3 tank and the BT-10 tank. Both are standard steel tanks provided with three levels of corrosion protection: cathodic protection, a protective coating and electrical isolation. High-potential magnesium anodes are permanently attached to the heads of each tank to provide a flow of protective current. In the case of Sti-P3 tanks, the anodes are packaged in a special moisture-holding material which improves conductivity and current flow from the anodes. The second protective component in these systems is a coal-tar epoxy or urethane coating. Electrical isolation is the third component of these systems; this protects the tanks against stray currents that could otherwise reach them via piping connections. In those areas where internal corrosion may be a problem, optional construction may include striker plates, internal welding or internal zinc strips which serve as sacrificial anodes. If the product to be stored is not compatible with steel, then an internal lining of compatible material may be applied.

Figure 2.1-4

Magnesium Anode Cathodic Protection Typical Configuration



Source: *Suggested Ways to Meet Corrosion Protection Codes for Underground Tanks and Piping*, The Hinchman Company, Detroit, MI.

4. Cathodically Protected Steel Tanks (Impressed Currents)

The impressed current cathodic protection method employs direct current provided by an external source. This current is passed through the system by the use of non-sacrifical anodes composed of materials such as carbon, non-corrodible alloys, or platinum. These anodes are buried in the ground (in the case of underground structures) or otherwise suspended in the electrolyte and connected to the positive terminal of the external power supply. The tanks and other structures to be protected (e.g., pipes) are connected to the negative side of that power supply [27]. An impressed current system for underground tanks and piping is illustrated in Figure 2.1-5.

Impressed current cathodic protection systems are used extensively at service stations. These types of cathodic protection systems are particularly applicable for storage situations in highly corrosive soils. Because of the large power supply (electric current) provided by these systems, they can be used to protect bare as well as coated tanks [10].

A major advantage of impressed current is that short circuits can be overcome more easily than with sacrifical anode systems [10]. This facilitates installation, particularly when electrical continuity must be insured between two or more tanks. Major disadvantages of these systems are their high power consumption and the greater possibility of electrical interference on foreign structures [10].

As is the case with sacrificial anode systems, periodic testing of the cathodic protection is necessary to ensure proper protection. Current may fail because of rectifier malfunction or interruption of power. The system should be tested regularly in accordance with manufacturer's recommendations and adjusted as needed. At least once a year, tank-to-soil potential measurements should be made to check the adequacy of protection and determine if any rectifier adjustments are needed [10].

5. Fiberglass-Reinforced Plastic

Fiberglass-reinforced plastic (FRP) tanks are widely used for underground storage of flammable and combustible liquids. They are constructed of a plastic resin which provides chemical resistance, and a fiberglass material that gives the tank its structural strength. Insuring compatibility of the tank with the stored product is an important consideration since numerous resins and glass materials can be used in the fabrication of FRP tanks. Most fiberglass tanks are designed specifically for petroleum and its derivatives. However, fiberglass tanks suitable for storage of other chemicals have been developed. The tank manufacturer should be consulted on the selection of a resin which will be compatible with the product to be contained (see Table 1.2-3).

Two techniques are used to fabricate FRP tanks. One technique utilizes a centrifugal casting machine which allows the tank to be made in one continuous piece. The chopped fiberglass is sprayed on the interior of a revolving mold which forms the ribs, shell and hemispheres in one continuous piece. Two identical pieces can be fabricated by this technique and joined together in the middle to form the tank. The other fabrication technique consists of building the tank in alternating layers of resin and fiberglass. This type of FRP tank is usually more costly but is also stronger than the molded tank [13, 15, 29].

Design Standards. As with steel tanks, various standards have been developed by Underwriters Laboratories and the American Society of Testing and Materials for the design and construction of FRP storage tanks. For more information on accessing these standards, please refer to the tank design reference list at the end of this chapter.

In addition to the UL and ASTM standards, FRP tanks to be used in underground applications must adhere to requirements in the following National Fire Protection Association standards:

- NFPA 30: *Flammable and Combustible Liquids Code* [19].
- NFPA 31: *Standards for Installation of Oil Burning Equipment* [28].

Installation Requirements. The installation recommendations for FRP tanks, as listed in API Publication 1615, differ somewhat from those recommendations for steel tanks. Examples of the recommendations made in that publication for the underground installation of FRP tanks include the following:

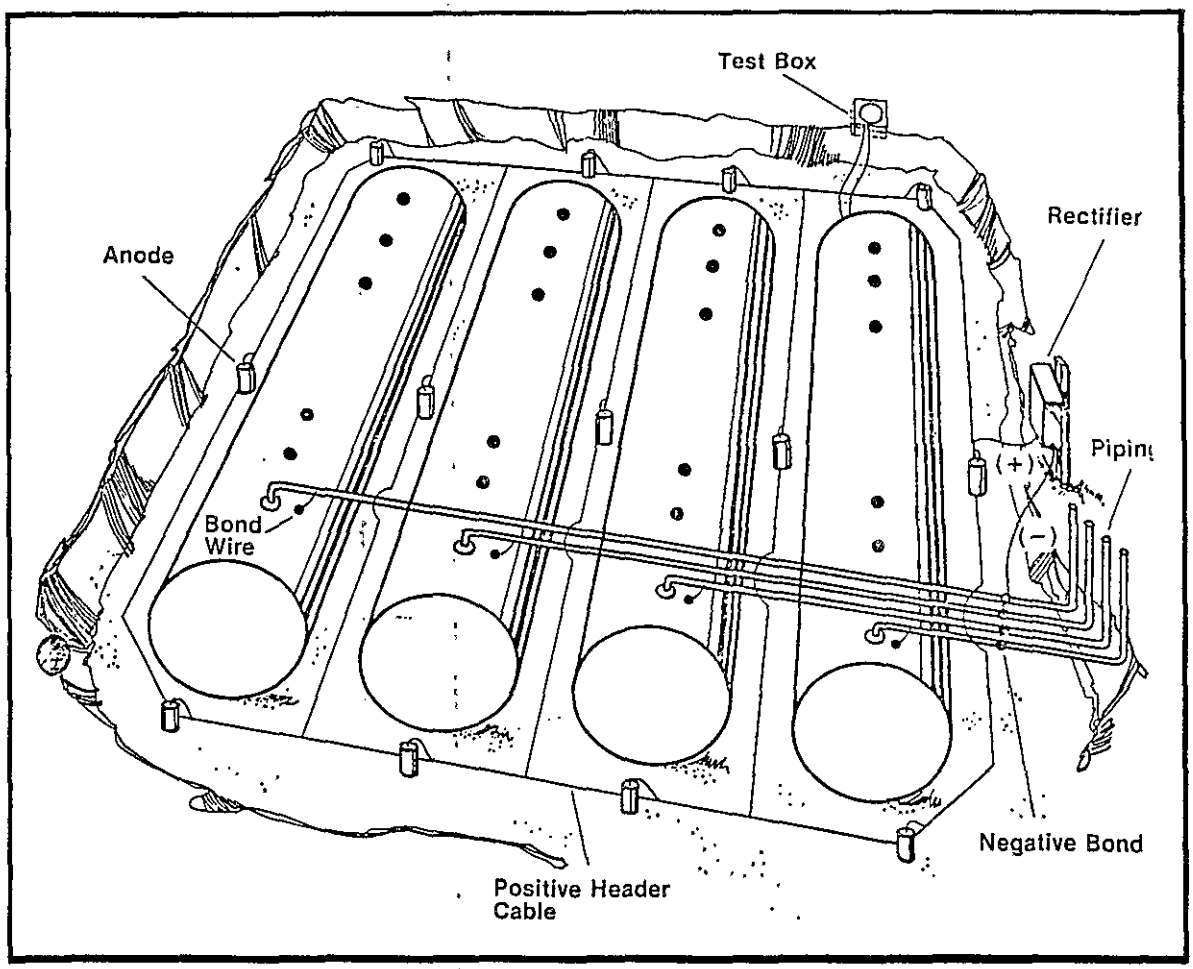
- The tank excavation should provide a minimum clearance in all horizontal directions of 18 inches.
- The excavation should be deep enough to provide at least 12 inches of backfill below the tank.
- A uniformly distributed backfill, which conforms to the tank manufacturer's specifications, must be used. Proper backfilling is essential to the performance of these tanks [1].

As is the case with steel tanks, proper anchoring and ballasting are important aspects of an FRP tank installation in an area of high ground water. Strict adherence to manufacturers installation recommendations and those of API Publication 1615 is important to insure the integrity of the storage facility.

Extreme care must be exercised in the installation of FRP tanks because they lack the structural strength to withstand the high stresses which may be induced during a difficult or improper installation [8]. For more complete information of FRP tank installation, refer to API Publication 1615, NFPA 30, the NYSDEC standards of practive document [30], and the literature of specific FRP tank manufacturers.

Figure 2.1-5

Impressed Current Cathodic Protection
Typical Configuration



Source: *Suggested Ways to Meet Corrosion Protection Codes for Underground Tanks and Piping*, The Hinchman Company, Detroit, MI.

6.FRP/Steel Bonded Tanks

FRP/steel tanks combine the corrosion resistance of fiberglass-reinforced plastic and the strength of steel. They are constructed of an outer layer of FRP fused to an inner layer of carbon steel via a polyester resin bond. FRP/steel tanks are protected against soil corrosion, but remain subject to internal decay from corrosive chemicals [7].

The steel inner structure on an FRP/steel tank provides structural support and serves to keep stresses evenly spread. FRP/steel tanks may be installed in accordance with NFPA 30 and API Publication 1615 guidelines (see sections on bare steel and FRP tanks). Saddles or "chock blocks", which interfere with the proper distribution of the load, should not be used, however. In addition, anchoring, as described in the discussion of steel tanks, should be used to prevent tank flotation from a high water table.

As is true with steel tanks, FRP/steel tanks are compatible with petroleum products, such as gasoline and diesel fuel, and other non-corrosive liquids.

7. Tanks of Other Materials

This group includes tanks made of such materials as stainless steel, aluminum and plastic. Although these materials have a higher resistance to corrosion than carbon steel, their use is overshadowed by that of steel, coated steel and FRP. Plastic tanks, including such materials as polyvinyl chloride (PVC) and polypropylene, are not widely used in underground installations because of their low structural strength, which makes them unable to withstand large structural loads. Aluminum tanks are not widely used because they also lack structural strength, and stainless steel tanks are not widely used because of their higher cost.

8. Double Containment Systems

Several methods of double containment for underground tanks are in use. These include the following.

- Double-walled tanks.
- Concrete vaults.
- Impermeable liners.

Double-walled tanks [4,23]. These tanks are essentially a tank within a tank (jacket) with a vacuum or pressurized space between the inner wall and outer wall. Leaks due to internal or external corrosion can be detected by loss of pressure or vacuum. Product or water detecting probes may also be inserted into interstitial space. Common materials of construction include coated steel and fiberglass. An inner liner may also be specified specified for steel tanks. Because double-walled tanks provide both two wall protection and monitoring of the interstitial (annular) space, they are well suited for storing highly toxic chemicals or for storing materials in sensitive environmental areas.

A double-walled fiberglass tank that is widely used in Europe is illustrated in Figure 2.1-6. This tank is constructed with inner and outer fiberglass shells supported by a concrete bearing wall in between. A built-in leak detection system monitors a vacuum drawn between the inner and outer shells. Products that may be stored in this tank include gasoline, diesel fuel, acid and caustic solutions, and other hazardous substances [4].

Another type of double-walled tank, manufactured in Canada, is fabricated of steel and includes a vacuum leak detection system between the inner and outer walls. This pre-engineered tank system also includes an external epoxy coating and sacrificial anodes to provide corrosion protection. This tank system is shown in Figure 2.1-7 [23].

More and more firms are producing double walled tanks, some with two walls of steel and an outer layer of bonded fiberglass, some with a complete outer shell of steel and epoxy coating, and others with just a double bottom to provide protection where corrosion is usually most severe. The high degree of environmental protection provided means that their usage will be more common in the near future.

Concrete vaults. Concrete vaults (also knows as concrete tanks) are generally used as secondary enclosures intended to contain any spills from the primary storage tank. Concrete vaults tend to crack with freezing and thawing, and are also susceptible to chemical attack by salts and acids. Coatings are often applied to the inside of concrete vaults to enhance their resistance to chemical attack (see Coating Compatibility Chart Appendix B).

Impermeable liners: Impermeable liners may also be used for secondary containment of underground spills. Examples of such liners include the following:

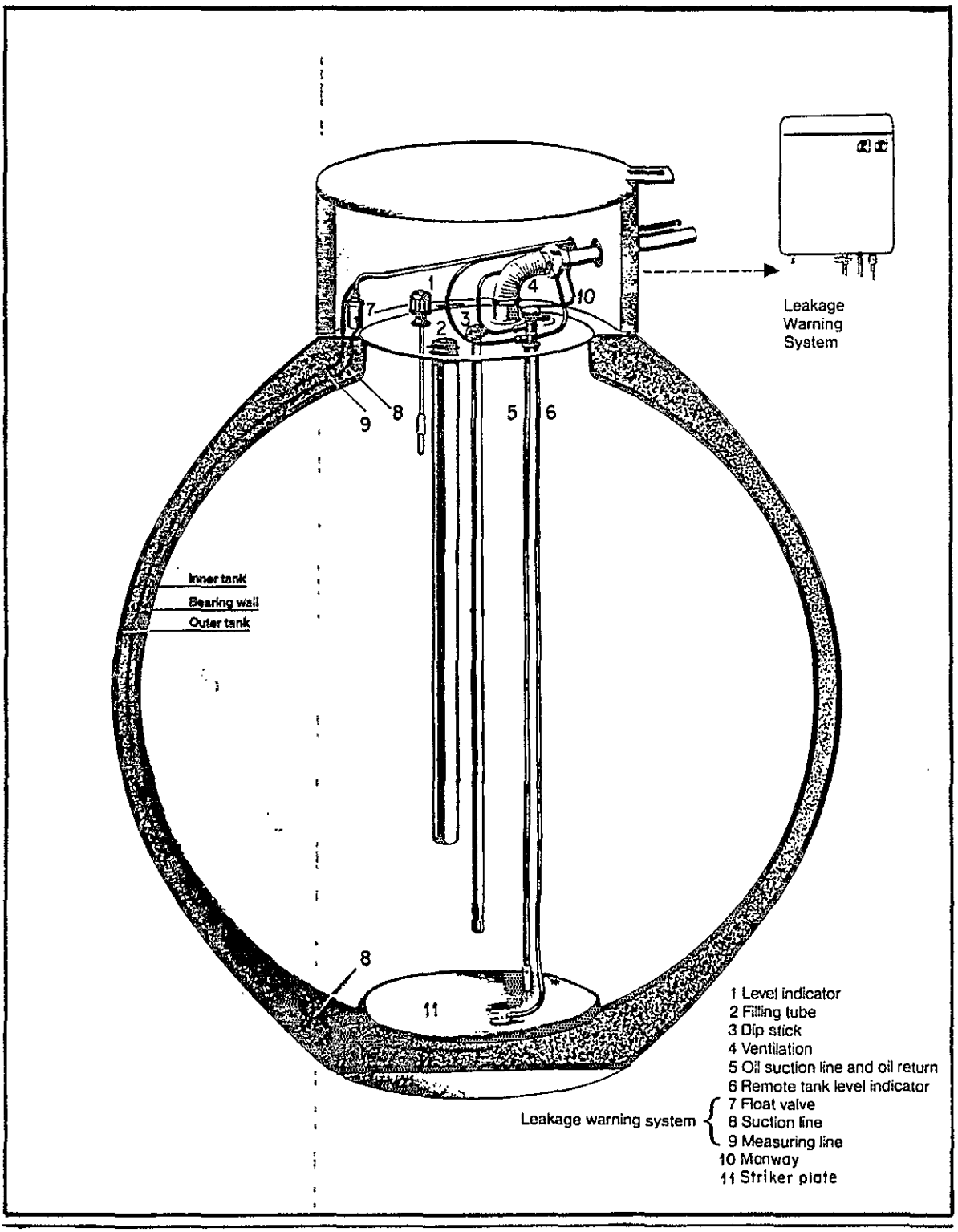
- Membrane liners.
- Clay liners.
- Bentonite (or similar material) liners.

In instances where impermeable liners of these types are used, care must be taken to insure that the lining material is compatible with the material being stored.

Impermeable liner systems should also include a leak detection system located within the confines of the enclosure formed by the liner. These types of systems are discussed in detail in Chapter 3 of this part of the report.

Figure 2.1-6

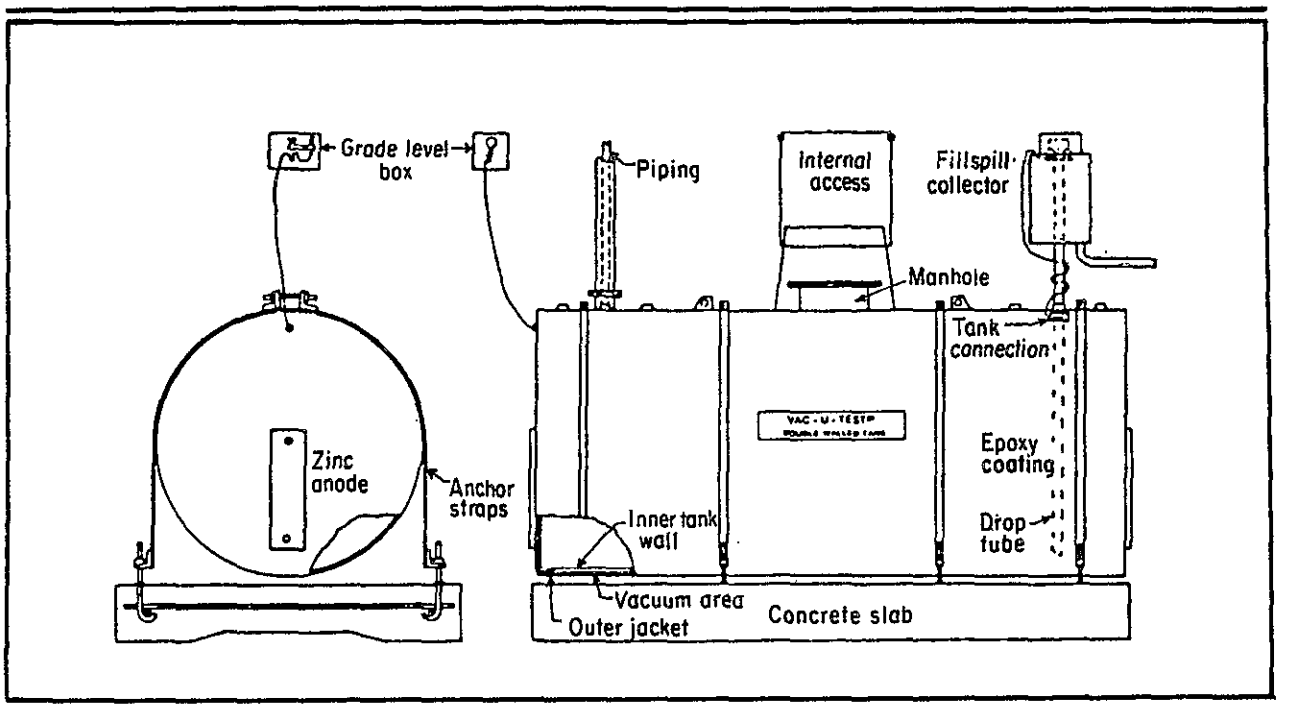
Fiberglass-Reinforced Plastic Double-Walled Tank With Built-In Leak Detection



Source: Betco Associates

Figure 2.1-7

Double Wall Steel Tank with Epoxy Coating and Sacrifical Zinc Anode



Model No.	Capacity Litres	Inside Diameter	Inside Length
1352	5 000	1 600	2 500
1353	10 000	2 000	3 185
1354	15 000	2 500	3 060
1355	25 000	2 500	5 100
1356	35 000	2 500	7 130
1357	50 000	2 500	10 200
1358	50 000	3 600	4 920
1359	75 000	3 000	7 080
1360	100 000	3 600	9 830
1361	125 000	3 600	12 290
1362	150 000	3 600	14 740

Source: Reference 23

9. Relined Tanks

In-place underground steel tanks may be relined internally provided the tank is not badly corroded. This is a widely used practice for extending the useful life of steel petroleum storage tanks. If consideration is being given to the relining of a tank which stores a non-petroleum product, the design engineer should secure assurances that the lining material is compatible with the product to be stored and check government regulations to see whether this practice is acceptable.

Interior relining is possible without unearthing the tank by entering it through a manhole. If the tank is not equipped with a manhole, one must be installed prior to relining the tank [18]. Before entering the tank, however, it must be completely emptied and freed of toxic or flammable vapors. Refer to the discussions in Part II, Chapter 7 and Part III, Chapter 7 for information on the emptying and degassing of tanks. Prior to relining, the existing lining must be completely removed and the tank must be properly prepared. Holes must be plugged and the surface must be sandblasted to etch a pattern for good bonding. Refer to the sections on the selection and application of coatings and linings for specific procedures and considerations. The combination of external cathodic protection with internal lining provides a reasonably low cost safeguard system for existing steel tanks and is useful as a repair technique for a leaking steel tank in generally good condition. The relining work should be done only by qualified specialists.

The following inset describes suitability factors for steel tank relining.

Tank Relining

A steel tank is not normally suitable for interior lining and should be removed or abandoned if it has one of the following:

- A split greater than 3 inches.
- A single hole greater than 1 inch diameter.
- More than 10 small perforations (none larger than ¼ inch diameter).

D. TANK COATINGS AND LININGS

Coatings are those corrosion- and chemical-resistant materials which are sprayed, brushed, or rolled onto the metal surface of a storage tank. Coatings serve one of two main purposes: (1) they protect the metal from attack by a corrosive liquid or environment, and (2) they protect the product from contamination by corrosion products. Coatings may also be applied to concrete vaults. When applied to the interior of a tank, coatings are often referred to as tank linings. Several factors affect the effectiveness and durability of tank linings and coatings. These include the following:

- Proper selection of the coating.
- Preparation of the tank surface.
- Proper application of the coating to the required thickness.
- Proper treatment (curing) of the coating.
- Testing and inspection of the applied coating.

Selection of coating. To insure the compatibility of the lining or coating, it is often necessary to consult with its manufacturer. As a reference tool, the properties of some commonly used linings and coatings are given in Appendix B.

Preparation of the Tank Surface. Steel, and for that matter any surface being coated, should be cleaned of all dirt, grease, moisture and loose powdery contaminants that might interfere with coating adhesion. The best method of steel surface preparation for most coating application scenarios consists of sandblasting all surfaces to be coated to SSPC-SP6 commercial blast. Sandblasting to commercial 6 produces a clean surface with a good profile for adhesion. This combination generally provides for maximum effectiveness of the chemical and physical forces of adhesion between the coating and the metal surface [16,17].

Surface preparation specifications may differ depending upon the type of application to be made, particularly in the case of retrofits and field oriented operations. Various specifications from the Steel Structures Painting Council are listed and described in Table 2.1-4 [16,32].

Coating Application. The following excerpt describes conventional coating and lining technology:

> "The coating system can be applied a number of ways including brushing, rollering and spraying. While brushing, and to a lesser degree rollering, have the advantage of working a coating into a rough or irregular surface, spraying is by far the most common application method.
>
> With conventional air spraying, air is used to atomize and propel the paint onto the surface being coated. The equipment is cheaper than airless equipment. The principal advantages of air spraying are the ability to partially trigger the gun to provide an air blow-down prior to paint application, and a finer atomization resulting in a smoother finish.

Airless spraying utilizes high pressure to hydraulically push paint through a small orifice. Upon going from high to low pressure the paint atomizes in a manner similar to water from a garden hose. The advantages of airless spraying are leading to its ever increasing use in industrial coating work. These include a thicker film with less chance of air entrapment, greater mobility for the painter because there is no air line, less turbulence in the spray pattern, and less chance of contamination with moisture and oils from improperly cleaned field compression equipment." [16]

Newer coating and lining application techniques include electrostatic spraying, powder coating, force drying and electron beam curing. Their advantages and disadvantages are summarized in Table 2.1-5.

Personnel safety is an important consideration in coating and lining application. In most instances, respirators should be worn as a minimum during application operations.

Table 2.1-4

Surface Peparation Specifications

Specification and subject		Purpose
SSPC-SP 1,	Solvent Cleaning	Removal of oil, grease, dirt, soil, salts, and contaminants by cleaning with solvent, vapor, alkali, emulsion or steam.
SSPC-SP 2,	Hand Tool Cleaning	Removal of loose rust, loose mill scale, and loose paint to degree specified, by hand chipping, scraping, sanding and wire brushing.
SSPC-SP 3,	Power Tool Cleaning	Removal of loose rust, loose mill scale, and loose paint to degree specified, by power tool chipping, descaling, sanding, wire brushing and grinding.
SSPC-SP 4,	Flame Cleaning of New Steel	Dehydrating and removal of rust, loose mill scale, and some tight mill scale by use of flame, followed by wire brushing.
SSPC-SP 5,	White Metal Blast Cleaning	Removal of all visible rust, mill scale, paint and foreign matter by blast cleaning by wheel or nozzle (dry or wet) using sand, grit or shot. (For very corrosive atmosphere where high cost of cleaning is warranted.)
SSPC-SP 10,	Near-White Blast Cleaning	Blast cleaning nearly to White Metal cleanliness, until at least 95% of each element of surface area is free of all visible residues. (For high humidity, chemical atmosphere, marine or other corrosive-environment.)
SSPC-SP 6,	Commercial Blast Cleaning	Blast cleaning until at least two-thirds of each element of surface area is free of all visible residues. (For rather severe conditions of exposure.)
SSPC-SP 7,	Brush-Off Blast Cleaning	Blast cleaning of all except tightly adhering residues of mill scale, rust and coatings, exposing numerous evenly distributed flecks of underlying metal.
SSPC-SP 8,	Pickling	Complete removal of rust and mill scale by acid pickling, duplex pickling or electrolytic pickling. May passify surface.

Source: Excerpted by special permissin for *Chemical Engineering*, December 4, 1972, Copyright (c) 1972, by McGraw-Hill, Inc., New York, N.Y. 10020.

Proper Treatment of the Coating. Proper treatment (curing) of the coating surface is an important step in the coating application procedure. There are numerous coatings available to protect steel and other metals with curing requirements varying from baking at temperatures on the order of 400°F to force drying at temperatures slightly above ambient. The proper curing or drying procedure for the various coating materials is specified in manufacturers' application instructions [17].

Testing and Inspection of the Applied Lining or Coating. After the coating is installed, it is the general practice to inspect its thickness and integrity. There are a variety of field instruments used to measure coating thickness and porosity after the coating has been applied and cured. These include dry gauges, such as the magnetic and semi-destructive scratch gauges, and the wet gauge known as the comb type gauge. Low voltage pinhole detectors (spark tests) may also be used to detect small imperfections in the coating. Other instruments that may be used include surface temperature thermometers; sling psychrometers, for calculating dewpoint and its relation to the surface being coated; surface profile comparators, for blast-cleaned steel surfaces; and moisture meters, for concrete and masonry surfaces [16].

Table 2.1-5

Latest Coating Techniques

Electrostatic Spraying—An electric charge is applied to the paint by the spray gun. The charged paint particles are attracted toward the grounded object being coated, depositing at points of maximum electrostatic attraction (thin areas). Can be combined with air and airless spray methods.

Advantages: Minimizes overspray, has "wrap-around" effect, edges and protruding irregularities receive heavier coatings.

Disadvantages: Requires electric source. electrostatic attraction diminishes as paint thickness increases; water base paints, or those using highly polar solvents or containing metallic pigments may be too conductive to be applied by electrostatic spray. The object being coated must be grounded and electrically conductive.

Powder Coating—Coating resins in powder form that are applied by electrostatic spray, fluidized bed or other methods. The coated object is heated, melting and sintering the powder to form a continuous coating.

Advantages: Insoluble resins can be applied such as polyethylene, polypropylene, nylon and fluorocarbons, as well as other thermoplastic resins. Either thick or thin coatings can be applied in one application. The object can be handled immediately upon cooling.

Disadvantages: Powdered materials present health and explosion hazard unless proper precautions are taken; expensive.

Force Drying—Heating of coated object after application to accelerate drying or rate of coating cure. Ventilation system prevents solvent escape into atmosphere. Dry time to topcoat or handle shortened. However, expensive to install and operate.

Electron Beam Curing—Recent innovation in which electrons are accelerated through a vacuum and directed toward object coated by conventional means with a coating capable of being crosslinked. The electron beam excites the reacting molecules, completing crosslinking and cure within seconds.

Advantages: Rapid handling and cure times, less solvents in paint.

Disadvantages: Cost; only a few coatings can be crosslinked at present (polyesters and acrylics); coatings in excess of seven mils cannot be cured.

Source: Excerpted by special permissin for *Chemical Engineering*, December 4, 1972, Copyright (c) 1972, by McGraw-Hill, Inc., New York, N.Y. 10020.

E. WRAPPINGS

Another method of corrosion protection involves the application of polyethylene as a loose wrapper around the tank. Wrappers act as exterior coatings which minimize the possibility of contact between the metal and the soil. Wrappers have the advantage that they are an inexpensive method of corrosion protection; however, the initial savings must be weighed against long-term economics and effectiveness. Wrappers are difficult to install properly and are frequently ineffective; they may actually trap moisture on the tank surface and thus lead to accelerated corrosion [10].

The life expectancy and performance of a wrapper depends upon several factors, including the following:

- Its incompatibility with the surrounding soil.
- Its incompatiblity with the liquid stored if the wrapper is exposed to that liquid.
- The wrapper thickness.
- The care taken to avoid tearing during its installation.

Some oil companies have reported extended tank lives attributable to polyethylene wrappers, but to date there is insufficient long-term experience to formulate a solid judgement regarding their effectiveness [10].

Information on Specifications for Tank Materials and Construction

Carbon Steel

American Society for Testing and Materials
1916 Race Street
Philadelphia, PA 19103

American Society of Mechanical Engineers
345 East 47th Street
New York, NY 10017

American National Standards Institute
1430 Broadway
New York, NY 10018
Information on standards and specifications of the Canadian Standards Association and the International Organization for Standardization may also be obtained from ANSI.

American Petroleum Institute
2101 L Street, N.W.
Washington, D.C. 20037

American Iron and Steel Institute
1000 Sixteenth Street, N.W.
Washington, D.C.

American Welding Society
2501 N.W. Seventh Street
Miami, FL 33125

National Association of Corrosion Engineers
1440 South Creek
Houston, TX 77084

Underwriters Laboratories, Inc.
333 Pfingsten Road
Northbrook, IL 60062

National Fire Protection Association
Batterymarch Park
Quincy, MA 02269

Steel Tank Institute
666 Dundee Road
Northbrook, Illinois 60062

Fiberglass-Reinforced Plastic

American Society for Testing and Materials
1916 Race Street
Philadelphia, PA 19103

Underwriters Laboratories, Inc.
333 Pfingsten Road
Northbrook, IL 60062

National Fire Protection Association
Batterymarch Park
Quincy, MA 02269

Tank Relining – Surface Preparation

Steel Structures Painting Council
4400 5th Avenue
Pittsburgh, PA 15213

References

1. American Petroleum Institute, *Installation of Underground Petroleum Storage Systems*, API Publication 1615, American Petroleum Institute, 2101 L Street N.W., Washington, D.C. 20037, November 1979.

2. Bixby, J.L., *Underground Steel Storage Tanks*. The Construction Specifier, The Construction Specifications Institute, Washington, D.C. 20036, October, 1973.

3. Fitzgerald, J.H., *Suggested Ways to Meet Protection Corrosion Codes for Underground Tanks and Piping*, The Hinchman Company, 1605 Mutual Building, Detroit, MI 48226, August 8, 1981.

4. Hasse Tank GmbH & Co., KG, *The Double Wall Self-Monitored Tank*, Betco Associates, P.O. Box 350, Closter, N.Y. 07624.

5. Owens-Corning Fiberglas Corp., *Fiberglas Tanks for Fuel Storage*, Pub. No. 3-PE-6312-L, Owens-Corning Fiberglas Corp., Non-Corrosive Products Division, Fiberglas Tower, Toledo, Ohio 43659, December 1980.

6. Underwriters Laboratories, Inc., *Steel Underground Tanks for Flammable and Combustible Liquids*, UL 58, Underwriters Laboratories, Inc., 333 Pfingsten Road, Northbrook, Illinois 60062, October 1976.

7. Anonymous, "Composite Tanks Fuse Fiberglass to Steel via Polyester Resin Bond," *Petroleum Marketer*, McKeand Publications, May-June 1979.

8. Anonymous, "Proper Installation is Vital to Long-Life of Fiberglass Tanks," *Petroleum Marketer*, McKeand Publications.

9. Anonymous, "Steel Tank Institute's 'Sti-P3' Tanks Combine Three-Way Protection," *Petroleum Marketer*, McKeand Publications, May-June 1973.

10. Fitzgerald, J.H., "Corrosion Control for Buried Services Station Tanks," Paper No. 52, The International Corrosion Forum Devoted Exclusively to the Protection and Performance of Materials, April 14-18, 1975, Toronto, Canada, National Association of Corrosion Engineers, Publications Department, 1440 South Creek, Houston, Texas 77084.

11. Standards of the Suffolk County Department of Health Services for the Administration of Article 12 (Toxic and Hazardous Materials Storage and Handling Control), of the Suffolk County Sanitary Code, County of Suffolk, Department of Health Services, Central Islip, N.Y. 11722 dated October 3, 1979.

12. Husock, B., *Corrosion Cathodic Protection and Common Sense*, Paper No. HC-3, Harco Corp., Cathodic Protection Division, 1055 West Smith Road, Medina, Ohio 44256.

13. Lifetime Fiberglass Tank Co., *Spec-Data Sheet 13P – Liquid and Gas Storage Tanks*, Lifetime Fiberglass Tank Co., 5000 Packing House Road, Denver, Colorado 80216, February 1981.

14. Perry, R.H., Chilton C. H., *Chemical Engineers; Handbook*, Fifth Ed, McGraw-Hill Book Co., 1221 Avenue of the Americas, New York, N.Y. 10020

15. Owens-Corning Fiberglas Corp., *Fiberglas Tanks for Liquid Chemicals*, Pub. No. 5-PE-6398-G, Owens-Corning Fiberglas Corp., Non-Corrosive Products Division, Fiberglas Tower, Toledo, Ohio 43659.

16. Tator, K.B., *Protective Coatings*, Chemical Engineering Deskbook Issue, McGraw-Hill Book Co., 1221 Avenue of the Americans, New York, N.Y., 10020, December 4, 1972.

17. Falck, S.B., *Process Tank Linings*, Chemical Engineering Deskbook Issue, McGraw-Hill Book Co., 1221 Avenue of the Americans, New York, N.Y., 10020, December 4, 1972.

18. Telephone conversation with Dick Hugo, Ceramic Coating Corp., Newport, KY., October 14, 1981.

19. National Fire Protection Association, *Flammable and Combustible Liquids Code*, NFPA 30, National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.

20. American Petroleum Institute *Service Station Tankage Guide*, API Publication 1611, American Petroleum Institute, 2101 L Street N.W., Washington, D.C. 20037.

References Continued

21. American Petroleum Institute *Recommended Standard for Underground Gasoline Tanks*, API Publication 1602, American Petroleum Institute, 2101 L Street N.W., Washington, D.C. 20037.

22. Rothman, P.S., *Cathodic Protection of Tanks and Underground Structures*, The Harco Corporation, Hatboro, PA 19040, 1978.

23. Clemmer Industries, Ltd., *Double-Walled Storage Tanks*, Clemmer Industries (1964) Ltd, 446 Albert Street, P.O. Box 130, Waterloo, Ontario N2J4A1, August, 1981.

24. J&T Ecology Corp., *Industrial-Chemical Storage Tanks*, JTEC-979, J&T Ecology Corp., 200 Lambert Avenue, Copiague, New York 11726.

25. Crown Rotational Molded products, *Crown Tanks for the Industrial-Chemical Industries*, Marked Tree, AR.

26. Steel Tank Institute, *Reliable, Low Cost, Long Life Design in Underground Steel Storage Tanks*, Publication 15.8 (d)/St, Steel Tank Institute, 666 Dundee Road, Northbrook, Illinois 60062.

27. Husock, B., *Fundamentals of Corrosion Protection*, Paper No HC-2, Harco Corporation, Cathodic Protection Division, 1055 West Smith Road, Medina, Ohio 44256.

28. National Fire Protection Association, *Standards for Installation of Oil Burning Equipment*, NFPA 31, National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.

29. Anonymous, "Denver's Lifetime Co. Constructs Fiberglass Tanks 'Like Giant *Pills*'", *Petroleum Marketer*, McKeand Publications, March/April 1980.

30. New York State Department of Environmental Conservation, *Standards of Practice for the Bulk Storage of Hazardous Liquids*, to be written.

31. Bethlehem Steel Corp., *BT-10 Specifications*, Bethlehem Steel Corp., Buffalo Tank Division; Frankfurst Avenue, Fairfield, Baltimore, MD 21226.

32. Steel Structure Painting Council, 4400 Fifth Ave., Pittsburgh, PA 15213.

33. PACE, *Underground Tank Systems;* Review of State of the Art and Guidelines. Report No. 82-3. PACE, 1202-275 Slater St., Ottawa, Can. KIP 5H9.

Part II

CHAPTER 2: UNDERGROUND PIPING SYSTEM

A. INTRODUCTION

The components of a piping system for an underground storage facility, as shown in Figure 2.2-1, include pipe, valves, pumps, and their associated connecting joints and fittings. These components represent a major potential source of leaks from underground storage facilities. Such leaks may occur due to: (1) corrosion; (2) physical breakage; or (3) loose connections attributable to wear or improper installation.

This chapter addresses the causes and methods of preventing product leaks in the piping system of an underground storage facility. The discussion focuses on the types of piping, pumps, connecting joints and fittings which are unique to underground (buried) service. Piping systems described here are typical of those found in the petroleum industry. Those components, which are usually located aboveground or in accessible locations, such as valves and large pumps, are discussed in Part III of this report.

B. CAUSES AND METHODS OF PREVENTING LEAKS

The major causes of leaks from the piping system are deterioration of piping system components and improper installation of these components. The deterioration of piping system components can occur for any one of several reasons: the most common of these, particularly in the case of metal components or parts, is corrosion, which has been discussed in detail in Part I. Other reasons included the following:

- Mechanical failure (physical breakage or rupture), such as the failure of valves or valve seals, pumps, or the gaskets in fittings.
- Cracks in piping or connecting joints. These could result from settlement or earth movement, vibration, or unrelieved stress concentrations.

Many leaks have also been traced to improper handling and installations practices, such as the following:

- *The improper connection of system components.*
- The improper installation of bedding and foundations for underground piping.
- Structural damage to piping, pumps, etc. during transportation and installation.
- Corrosion when impressed current cathodic protection is improperly bonded to the system.

Underground piping leaks can be prevented through the following:

- Proper design (selection of materials, component sizing, etc.)
- Proper installation.
- Proper testing.
- Timely replacement.

1. Proper Design

The design and selection of appropriate components for a particular piping system depends upon the intended use of those components. The items that must be considered include those listed in Table 2.2-1. In short, piping system concerns in underground applications focus on: (1) physical strength of the components; (2) ability to handle the required volumes (flow rates); and (3) ability to withstand such phenomena as internal and external corrosion, thermal loadings due to freezer-thaw cycles, and the physical loads caused by surges of liquid flow.

2. Piping System Installation

Faulty installation of pipe and pipe fittings is a major cause of leaks and spills at liquid storage facilities. The following is a list of important considerations during underground pipe installation:

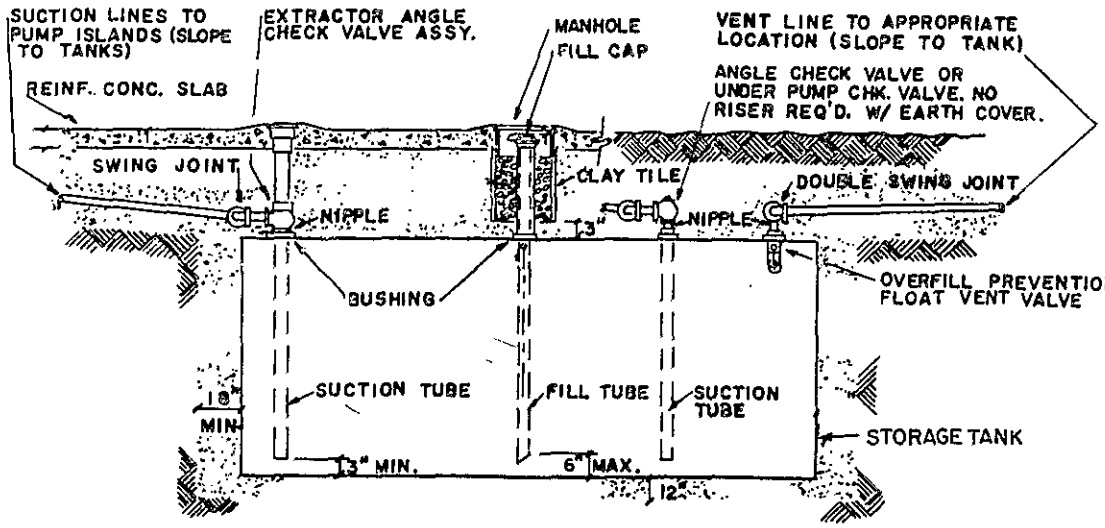
Table 2.2-1

Important Criteria in the Design of Piping System Components

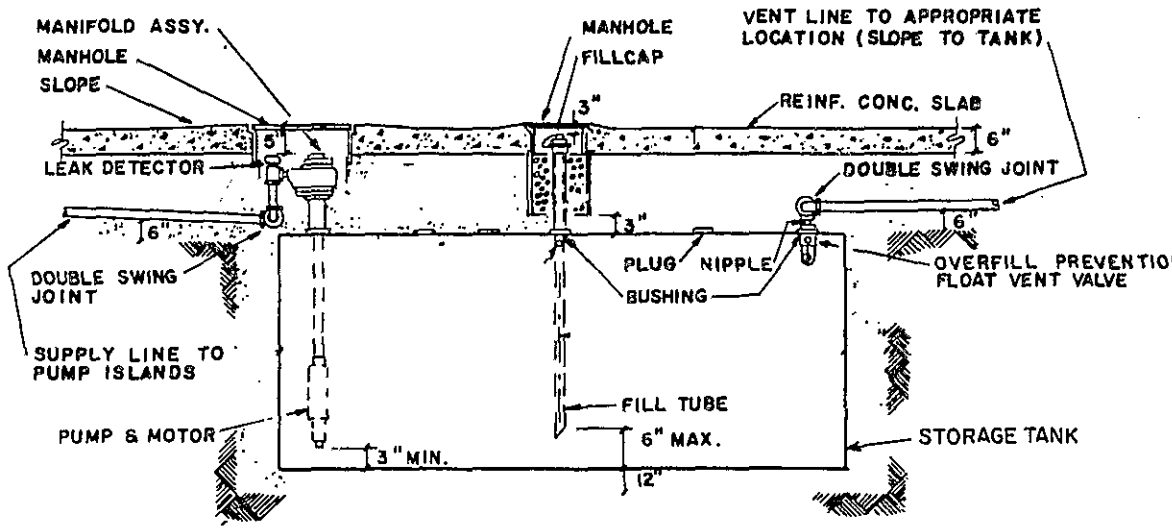
- The type of service (transporting liquid, vapor or slurry).
- The (corrosive) characteristics of the material to be transported, and the ability of piping system components to withstand that corrosion.
- The volume of material to be transported.
- The extent to which surges in flow are expected or likely.
- The characteristics of the soil or other atmosphere to which the piping system components are exposed.

Figure 2.2-1

Piping Systems for Underground Storage



SYSTEM WITH SUCTION PUMPING



SYSTEM WITH SUBMERGED PUMP

Source: API Publication 1615, *Installation of Underground Petroleum Storage Systems*, 1979.

- Product lines should be run in a single trench between the tank area and their destination. The same is true for underground vent lines. This will facilitate access to the piping system for repairs or replacement of components.
- Before any underground lines are laid, the trench or ditch for underground piping should receive a minimum 6 inch-deep bed of well-compacted non-corrosive (i.e., provides less corrosive environment than most native soils) material, such as clean, washed sand or gravel. All trenches should be wide enough to permit at least 6 inches of such protection around all underground lines. This applies to both metallic and nonmetallic underground piping. Bedding and the covering backfill should be of the same material. Providing bedding and covering in this manner serves two purposes: (1) it provides proper structural support for the pipe; and (2) it provides a less corrosive environment for metallic piping system components than most native soils.
- Piping should be arranged so that lines do not cross over underground tanks. This will minimize the possible creation of electrical connections between pipes and tanks which could accelerate corrosion. Pipe connections to tanks should be through insulated bushings.
- Underground product lines should have a minimum cover of 12 inches for adequate protection from the loads of surface traffic.
- Careful attention must be paid to the tightness of all joints and pipe fittings. Tightness should be tested (e.g. all joints and piping should be soap tested) before covering the pipe.
- The possible breakage of underground piping, or the loosening of pipe fittings resulting in product leaks, can be minimized through the use of swing joints. Swing joints, which are described later in this chapter, provide for movement at pipe connections without putting stress on the pipe. These types of joints should be installed in lines at the points where piping connects with underground tanks and where the piping ends at pump islands and vent risers. Fiberglass piping, which is inherently flexible, does not require swing joints if at least 4 feet of straight run is provided between any directional change exceeding 30 degrees.
- The actual location of pipe should be noted on as-built drawings, especially if there is a change from facility design drawings. Photographs of underground piping are also desirable as part of the permanent record of piping locations. Pipe location records of these types minimize the likelihood of pipe breakage accidents during future excavation at the storage facility.
- Product lines and vent lines should have a uniform slope toward the tank of not less than ⅛ inch per foot. This facilitates pipe drainage and avoids sags or traps in the line in which liquid can collect. Sloping is very important in insuring tight check valve and proper leak detection operation.

More information and direction on pipe installation practices can be found in API Publication 1615 [2].

3. Periodic Testing

Periodic testing of underground piping system components is also an important aspect of any leak/spill prevention program. Inasmuch as leaks in piping systems can occur in inaccessible (buried) pipe lengths and joints because of corrosion, thermal stresses and mechanical stresses, periodic testing is an important means of incuring safety and reliability.

Underground piping systems may be tested using the Kent-Moore Test as well as other types of tests. These testing techniques and their accuracy are described in Chapter 6 of this part of the report.

The required frequency of piping system testing will vary depending upon the severity of service, available historical data, and local regulatory requirements:

- Testing will be more frequent when high rates of internal or external corrosion are expected due to the nature of the stored products or the soil in which the piping system is buried.
- If the performance history of underground tanks or piping in the area indicate the likelihood of rapid deterioration of buried components, testing will be more frequent.
- The frequency of testing of underground tanks and piping may be mandated by law. OSHA regulations require submerged transfer pump piping tests at five year intervals.

4. Timely Replacement

Equally important in an adequate leak prevention program is the repair and/or replacement of deteriorated or damaged pipe prior to the occurrence of a leak or spill. Piping should always be of sufficient thickness and integrity to withstand normal working pressures due to fluid flow as well as the stresses caused by mechanical loading, hydraulic surge pressures, thermal expansion and contraction, and other conditions which can impose stresses on piping. When the pipe wall thickness or structural integrity of the pipe joints, connections, etc. approach a point at which these stresses cannot be withstood, that piping should be replaced.

Underground metallic piping at a storage facility should be replaced when metallic underground storage tanks are replaced to avoid accelerated corrosion in the new tanks; such accelerated corrosion could result from a reaction between the older pipe and the newer tank (see discussion of corrosion in Part I).

C. TYPES OF PIPING

There are a wide variety of types of piping commercially available. Those that are extensively used for underground applications include the following:

- Carbon steel.
- Stainless steel.
- Plastic.
- Fiberglass-reinforced plastic.
- Galvanized steel.
- Other composites, such as rubber-, plastic-, or epoxy-lined steel.

These types are typically used in sizes ranging from 1 to 4 inches in diameter, although larger pipe may be used in certain applications, such as at large bulk storage facilities. Data describing the chemical compatibility, and the advantages and disadvantages of the types of pipe listed above are summarized in Table 2.2-2.

In handling very hazardous or toxic liquids there are double walled pipes available. One type consists of an outer wall enclosing several pipes of smaller diameter. This whole ensemble is contained by a bulkhead at the end of each segment. The interstitial space of the outer wall is slightly pressurized with nitrogen. The inner pipes are filled with nitrogen at a higher pressure. With this configuration, pipe runs can be checked for leakage. A drop in pressure indicates leakage in the outer wall. A rise in pressure shows a leak in one of the inner pipes. See figure 2.2-2.

D. FITTINGS

Fittings are the connecting links of the piping system. This includes pieces of pipe that perform the following functions:

- Join two pieces of pipe, as do couplings and unions.
- change pipe direction, such as is the case with elbows and tees.
- Change pipe diameter, as do reducers.
- Terminate a pipeline, such as is the case with plugs and caps.
- Join two streams to form a third, as is the case with tees, wyes and crosses.
- Allow for pipeline directional flexibility, as do swing joints (or swivel joints) and expansion joints.

As stated earlier, fittings are frequent locations of piping system failure due to improper installation, mechanical stress, or wear. To insure proper operation, these components should be installed carefully and tested periodically.

E. EXPANSION JOINTS AND SWING JOINTS

Expansion joints and swing joints are used to add directional flexibility to pipelines, thereby preventing the building up of potentially destructive stresses. As shown in Figure 2.2-3, expansion joints typically consist of a flexible bellows jointed to pipe at each end. These types of joints can be designed for axial movement, lateral movement, or a combination of axial and lateral movement (see Figure 2.2-4). The most common types of expansion joints are rubber reinforced with steel rings and flexible corrugated metal bellows.

Expansion joints are used in piping systems for the following purposes:

- Prevent stresses. Piping systems expand and contract with temperature changes; an expansion joint compensates for this movement.
- Eliminate vibration and noise. Pumps, compressors, engines and pressure surges in pipe lines create vibration and objectionable noises.
- Compensate for misalignment. Piping and mechanical equipment often move out of normal alignment during operation due to wear, load stresses or settling of buildings and foundations.
- Reduce flange breakage. Undue stress caused by misalignment, vibration, expansion or contraction will break metal connecting flanges.

Note that there is a potential for leaks from expansion joints because the repeated flexing of the joint will eventually cause the joint to fail. To prevent this occurrence, the joint should be periodically tested (piping system tests) and, where accessible, inspected. They should not be used unless they are inspectable.

Swing joints or swivel joints are employed to provide rotational flexibility to a pipeline. As shown in Fig. 2.2-5, they may be designed to provide one, two, or three planes of rotation. These types of joints are used primarily to prevent torsional stresses in pipelines, thereby reducing the likelihood of flange or pipeline failure. Swivel joints, however, must be protected so that no dirt can enter the area of the bearing or bearing race.

F. UNDERGROUND PUMPS

The types of pumps used at underground storage facilities are typically submersible pumps or suction pumps. Suction pumps are located at grade, either directly above the storage tank or, as is the case in some dispensing operations, at some distance from the storage tank. Suction pumps may be either centrifugal, rotary or reciprocating pumps. The differences between these types of pumps and the concerns associated with their operation are addressed in Part III, Chapter 2, and in references such as the *Chemical Engineers' Handbook* [3].

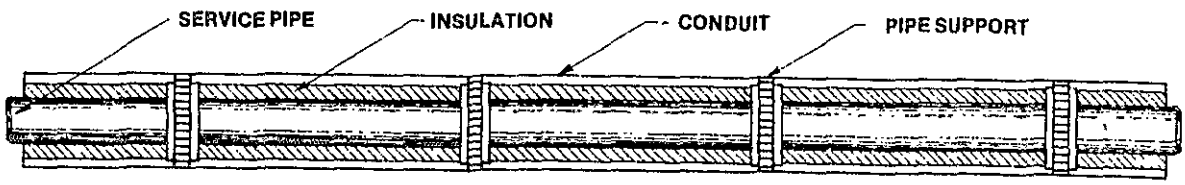
Table 2.2-2

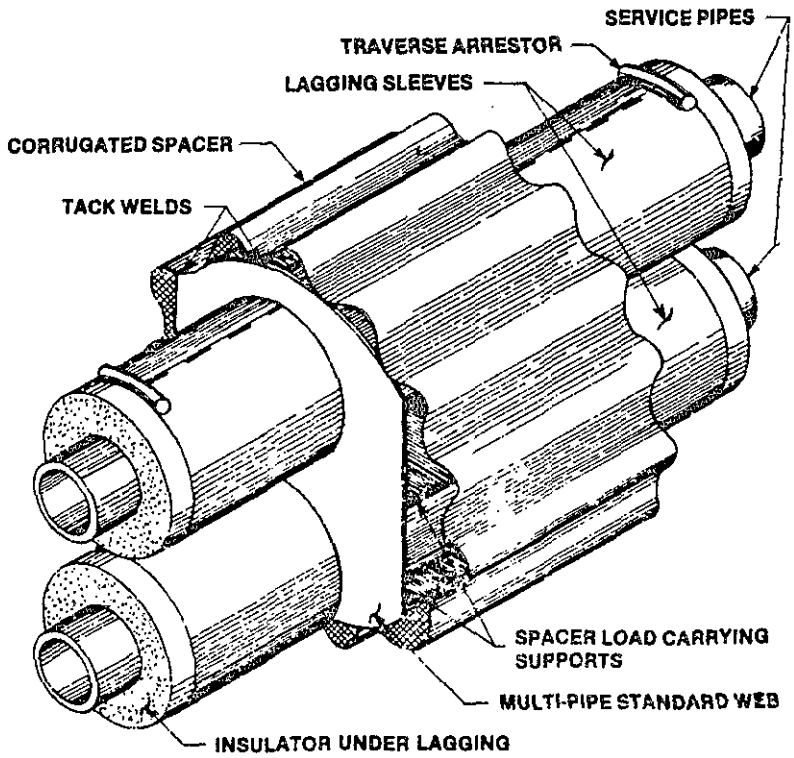
Characteristics of Piping Materials for Underground Service

Type of Pipe	Chemical Compatibility	Remarks
Carbon steel	Compatible with petroleum products but not compatible with corrosive chemicals such as acids without coatings.	Susceptible to corrosion if not coated, galvanized or cathodically protected.
		Relatively inexpensive.
		Galvanized steel is used extensively at service stations and other petroleum industry applications.
Stainless steel	Compatible with petroleun and corrosive chemicals, such as acids, depending on grade.	Used when product purity is of great concern.
		High relative costs.
		Primarily used for corrosion protection when coatings will not suffice (e.g. at high operating temperatures).
Cast iron	Resists corrosive attack by natural or neutral waters and neutral soils as well as atmospheric corrosion. Resistant to concentrated acids (nitric, sulfuric and phosphoric as well as alkaline and caustic solutions. Dilute acids and acid-salt solutions will attack this material.	Low relative cost.
		Provides more metal for less cost than steel piping systems.
		Brittle - has poor resistance to impact or shock.
		More widely used for non-hazardous service (e.g., water) than for hazardous chemicals service.
		Widely used for low pressure service where corrosion causes extensive loss of metal.
Plastic tube and pipe	Various plastics can be chosen for their resistance to specific chemicals. For example:	Free from internal and external corrosion.
		Do not cause galvanic corrosion when coupled to metallic material.
	Polyethylene pipe and tubing have excellent resistance to salts, sodium and ammonium hydroxides, and sulfuric, nitric and hydrochloric acids.	Allowable stresses and temperature limits are low.
		Low structrual strength when compared to steel.
	Polyvinyl chloride pipe and tubing have excellent resistance at room temperatures to salts, alcohol, gasoline, ammonium hydroxide, and sulfuric, acetic, nitric, and hydrochloric acids; may be damaged by ketones, aromatics and some chlorinated hydrocarbons.	Plastics are suitable for underground service when UL-approved for the product being carried by the pipe.
	Polypropylene pipe and tubing having excellent resistance to most common organic and mineral acids and their salts, strong and weak alkalies, and many organic chemicals.	
Plastic lined piping	Same as plastic tube and pipe above.	Combines the chemical resistance of the various plastics and the tensile and structural strength of steel.
Fiberglass and fiberglass-reinforced pipe	Compatible with a wide range of petroleum and chemical products. See chemical compatibility chart in Part II, Chapter 1.	Less structural strength than steel.
		High resistance to external and internal corrosion.
		Suitable for underground piping when UL approved for the product being carried.

Figure 2.2-2

Double Walled Pipe

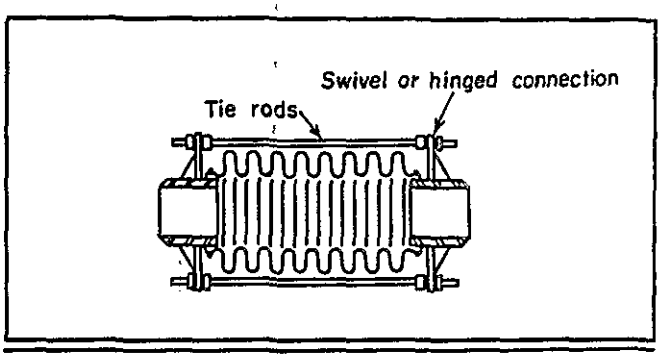




Source: Perma-Pipe, division of Midwesco, Inc.

Figure 2.2-3

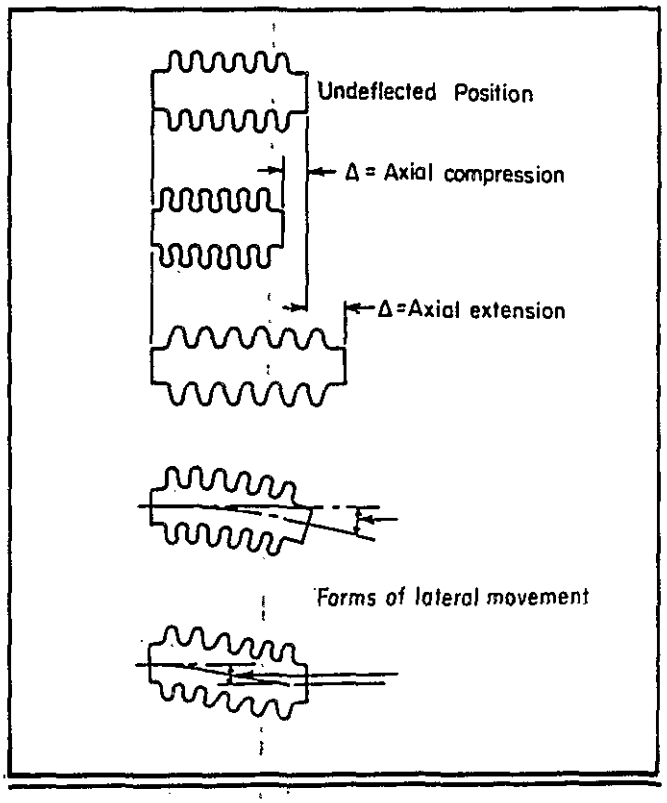
Diagram of a Universal-Type Expansion Joint



Source: From *Chemical Engineers' Handbook*, Perry, R.H. and Chilton, C.H., Copyright (c) 1973, McGraw-Hill, Inc. Used by special permissionof McGraw-Hill Book Company.

Figure 2.2-4

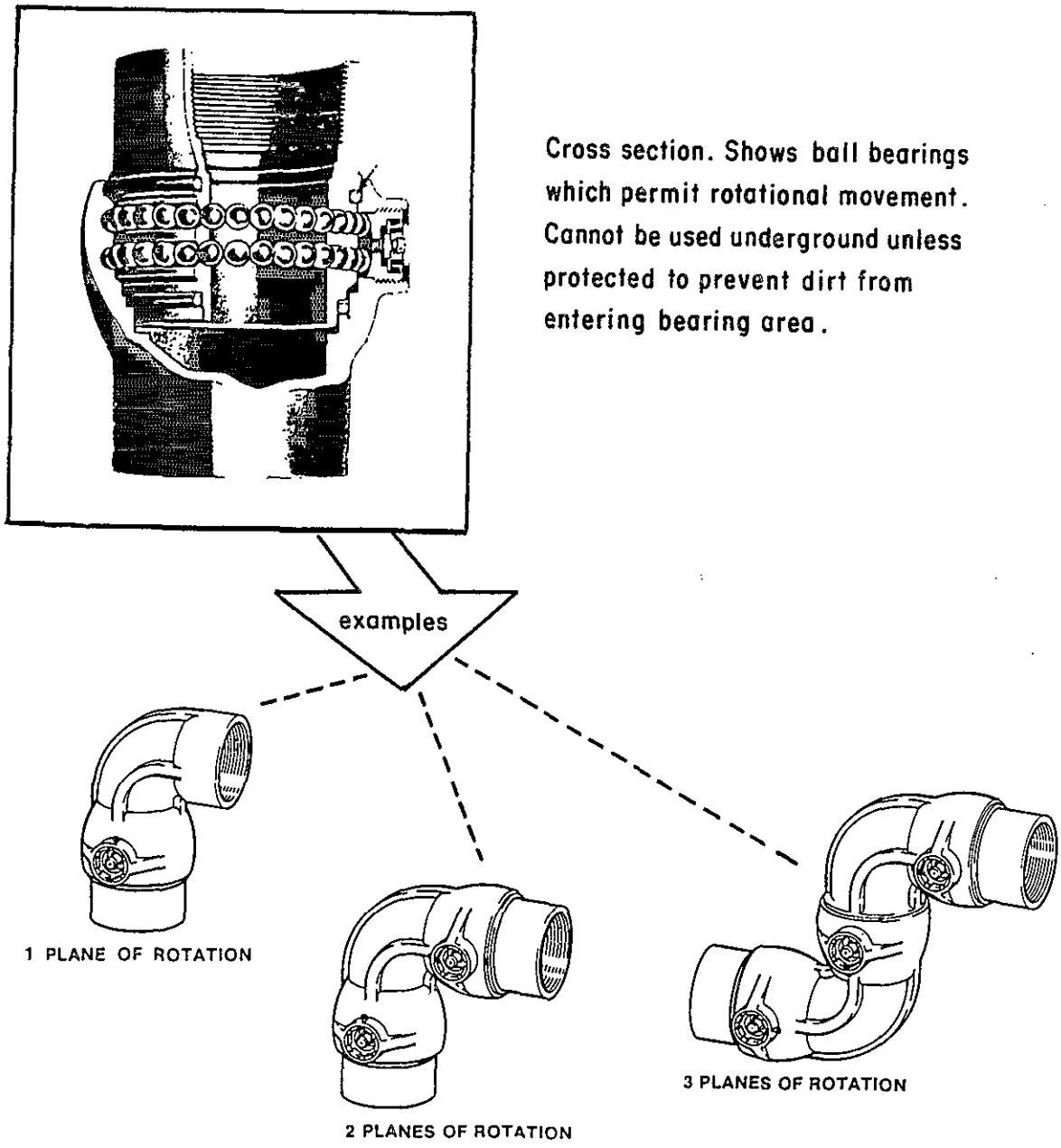
Action of the Bellows of an Expansion Joint



Source: From *Chemical Engineers' Handbook*, Perry, R.H. and Chilton, C.H., Copyright (c) 1973, McGraw-Hill, Inc. Used by special permissionof McGraw-Hill Book Company.

Figure 2.2-5

Swivel Joints



Source: *OPW Division/Dover Corp.*

The submersible pump (submerged transfer pump) system works on the principle of positive pressure to push the liquid from a low point to a high point. Unless there is a leak line detector in the system or the leak is large, loss of product will not be detected until considerable volume has been lost. A suction pump system works because of a vacuum at the high end which draws liquid from the low end. A large leak in the system would result in lack of suction and an immediate indication of trouble. A small leak would result in drainage of the pipe overnight and a lack of prime in the morning which would cause the system to be inoperative. A check valve under the product dispenser might hold enough product to reprime the pump but such a system should be discouraged because it would mask a line leak.

Submersible pumps are mounted inside the tank; they are centrifugal pumps closely coupled with an electric motor that can operate when submerged. These types of pumps may be commonly used in situations such as gasoline service stations.

When suction pumps are used, leaks in the pump delivery line that result in significant losses of product can be detected through a loss of pump suction, resulting in inefficient or poorer pump operation. When such a situation is encountered, operations should be halted until the source can be identified and corrective action taken.

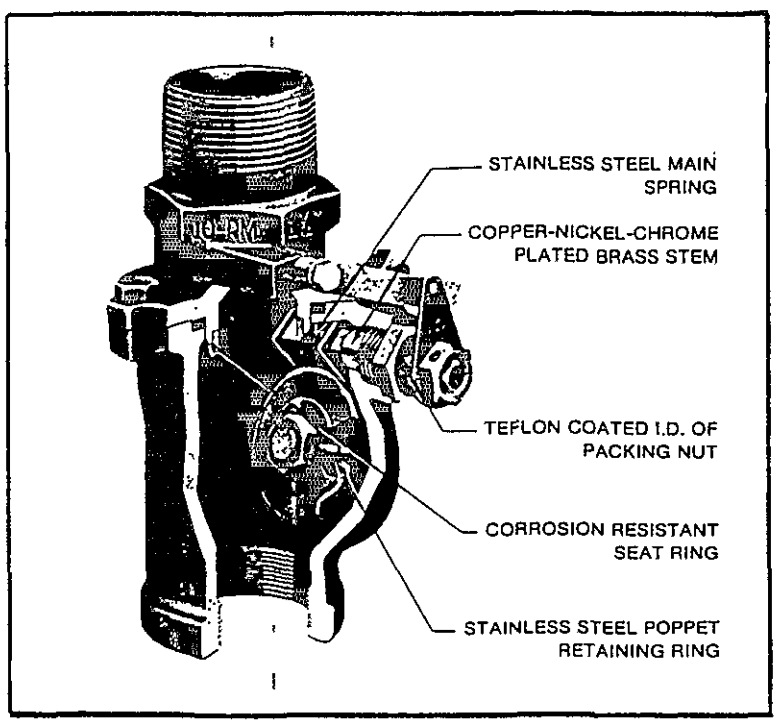
In the case of submerged pumping systems, leaks in the product delivery line can be detected through the use of product delivery line leak detectors. These devices are mounted immediately above the tank on the pump delivery line as shown in Figure 2.2-1; they are designed to detect losses of pressure in the product delivery that do not correspond to decreases in the discharge pressure of the submerged pump. Such a loss of pressure in the product delivery line indicates a loss of liquid in that line before it reaches the discharge point of the pipeline.

Another device recommended (actually required by NFPA 30) for use in submerged pumping systems or remote pumping systems, is a remote pump shut-off valve. In service stations these valves are located at the base of the dispensers. Should the dispenser be overturned, due to bumping or impact, the valve automatically closes, preventing extensive product spillage. These valves also contain a fusible link which closes the valve upon exposure to excessive heat or fire. A cross-section of a remote pump shut-off valve is shown in Figure 2.2-6.

Systems are also available that automatically shut off pipe flow in case of a drop in pressure or a difference of input compared to outflow.

Figure 2.2-6

Typical Remote Pump Shut-Off Valve



Source: *OPW Division/Dover Corp.*

References

1. American Petroleum Institute Underground Leak Survey results as reported by F.B. Killman to API Underground Leak Task Force, American Petroleum Institute, 2101 L Street, N.W. Washington, DC 20037, February 5, 1981.

2. American Petroleum Institute, *Installation of Underground Petroleum Storage Systems*, API Publication 1615, American Petroleum Institute, 2101 L Street N.W., Washington, DC 20037, 1979.

3. Perry, R.H., Chilton, C.H., *Chemical Engineers' Handbook*, Fifth Edition, Section 6, McGraw-Hill Book Company, 1221 Avenue of the Americas, New York, NY 10020, 1973.

4. Pace Company Consultants & Engineers, Inc., Spill Control Manual prepared under EPA Training Grant No. T-900-175-02-2 to the Department of Environmental Science and Engineering, Rice University, Houston, TX, February, 1975

5. American Petroleum Institute, *Guide for Inspection of Refinery Equipment, Chapter XI, Pipes, Valves and Fittings*, American Petroleum Institute, 2101 L Street, N.W., Washington, DC 20037, 1974

6. Baumeister, T., Avallone, E.A., Baumeister III, T., *Marks' Standard Handbook for Mechanical Engineers*, Eighth Edition, McGraw-Hill Book Company, 1221 Avenue of the Americas, New York, NY 10020, 1978.

7. Dover Corp., *OPW Swivel Joints: Ball Bearing Joints for Flexible Piping Systems*, Catalog SJ, Dover Corporation, OPW Division, P.O. Box 40240, Cincinnati, OH 45240, February, 1980.

8. Dover Corp., *OPW Engineered Service Station Products*, Catalog SSF, Dover Corporation, OPW Division, P.O. Box 40240, Cincinnati, OH 45240, July, 1981.

9. Perma-Pipe., div. of Midwesco, Inc., 7720 Lehigh Road, Nile, IL 60648.

Part II

CHAPTER 3: UNDERGROUND SPILL CONTAINMENT SYSTEMS

A. INTRODUCTION

1. Background

Underground spills or leaks can range in severity from a minor leak at a pipe joint or tank wall to a catastrophic tank rupture that spills the entire tank contents into the ground. The largest spills come from sizeable leaks that go undetected for years. Regardless of the severity of the incident, the resulting impacts in terms of soil and groundwater contamination are highly undesirable and should be avoided. The steps which can be taken to prevent long-term and widespread contamination of the soil and ground water include the following:

- Leak prevention and early detection practices such as good housekeeping, inventory control, and monitoring of the immediate storage area.
- Containment of the storage area.
- Removal of contaminated soil or groundwater before extensive spreading of the contaminant.

Good housekeeping is an important aspect of any leak prevention program. Many incidents occur due to carelessness and sloppy housekeeping, practices which should not be tolerated. Good housekeeping practices were addressed in Part I of this report.

Early warning leak detection practices such as inventory monitoring and tank excavation monitoring form the first line of defense against extensive soil and groundwater damage due to leaks. These techniques are discussed in detail in Chapter 5 of this part of the report.

Undergound spill or leak containment systems represent the second line of defense agaist propagation of soil or groundwater contamination. They can also act to enhance the effectiveness of early warning leak monitoring systems by confining the leak or spill until detection is possible.

The removal of contaminated soil and groundwater represent the last line of defense against widespread contamination. Practices such as extensive soil excavation for disposal, or the use of recovery wells to remove contaminated groundwater fall into this category and are drastic and relatively expensive steps. In addition, actions of this type are not always completely successful. For example, it may be impossible to remove all of a contaminant from a groundwater if it has spread extensively or become thoroughly mixed in the groundwater table. Recovery wells are discussed briefly in Part II, Chapter 5 of this report.

2. Containment Technology

The control technology used to contain underground spills and leaks consists of establishing a barrier around the storage tank so that any leaked liquid does not have a free path to escape from the storage area. The barrier materials used for containment include the following:

- Liners with low soil permeability (clay).
- Synthetic membrane liners.
- Soil sealants, such as soil cement or bentonites.
- Concrete vaults.
- Double-walled tanks.

It is important to include a liquid removal and monitoring system as part of secondary containment. The containment floor should be sloped to a sump from which a sample can be taken for analysis to determine if product is leaking from the tank. If the secondary containment does not have an impervious cover, accumulated rainwater which percolates to the liner should be removed by siphoning, pumping or via an underground drainage system. In fact some water will probably collect above the containment liner even with an impervious cover. Such water should be considered as contaminated and should receive proper treatment after being drained off.

Selection of the proper containment material for a particular application depends upon several factors, including:

- The type of material being stored.
- Local environmental conditions.
- Legislative requirements.

Type of Material Being Stored. Consideration of compatibility with the liquid being stored is important; the liner material must be able to maintain its integrity and impermeability when exposed to the stored product.

Local Environmental Conditions. The sensitivity of the environment in the vicinity of the storage facility can largely affect the level of environmental protection and hence the type of containment liner required. For example, in areas where the storage facility is located near or above an aquifer, greater care may be required in the selection and installation of the containment liner.

Legislative Requirements. In addition, local governments may be highly prescriptive and specific in terms of the type of containment barrier required. Such legislation requirements are often based upon local environmental conditions.

Containment systems will be effective only as long as they remain intact. Disruption of clay liners or soil sealants by tree roots, or the ripping of synthetic liners during handling are examples of incidents that can lead to ineffective leak or spill containment.

Table 2.3-1 presents a summary comparison of the various types of underground containment systems. Further details are provided in the remainder of this chapter.

B. CLAY LINERS

1. Chemical and Physical Properties [5,8,10]

Due to their general availability in many areas, clays are often considered the first alterntive for storage tank containment liners. Clays are relatively inexpensive liner materials that can be extremely effective for tank storage. These materials can also be effectively used as liners for pipe trenches.

Clays are complex minerals that have a wide range of compositions and properties. They are subject to changes in composition due to several factors, including the following:

- Weathering when exposed to air.
- Leaching of components when exposed to groundwater or other solutions.
- Ion exchange, or the replacement of ions in the clay with other ions of similar charge, when exposed to substances such as water containing acids, alkalis, or dissolved salts.
- Destabilization when exposed to some organic solvents.

Other factors that influence the performance of clay liners include: (1) compatibility with the stored product; (2) the thickness of the clay liner; (3) the shrink-swell potential of the clay; (4) the plasticity of the clay; and (5) the moisture content, density, and degree of compaction of the clay. The selection of a clay material for a particular liner application should be based upon tests for suitability by a soils engineer or a soils chemist.

2. Design and Installation Requirements [5,8]

Before installing a clay liner, it is necessary to first drain and stabilize the excavation. A bottom layer is then laid in place and compacted using a device such as a steel wheel roller. This bottom layer should be at least 6 inches deep; depths of 2 to 4 feet are not uncommon. When this bottom layer is more than 6 inches thick, it is usually the practice to apply it in stages to ensure proper compaction. The required degree of compaction depends upon the composition of the soil itself, its clay content, density, and moisture content. Once the bottom layer has been properly installed, the tank should then be installed in accordance with New York State standards and guidelines, and the excavation backfilled with more clay material to provide containment all around the tank. The installation of clay liners can be a complex operation requiring a trained contractor to ensure high levels of quality control.

C. SYNTHETIC MEMBRANE LINERS

1. Chemical and Physical Properties [5,8]

Synthetic membrane liners are polymeric materials, manufactured in sheet form, that can be spread over the tank excavation walls or floor to contain a leak or spill. As a class, these types of liners have several advantages and disadvantages. The advantages of synthetic membrane liners include the following:

- They can contain a wide variety of liquids with minimum loss through seepage.
- They have high resistance to bacterial deterioration.
- They have high resistance to chemical attack.
- They are relatively economical to install and maintain.
- They are readily installed for many applications.

In general, the disadvantages of synthetic membrane liners include the following:

- They are vulnerable to attack from ozone and ultraviolet light (sunlight) when compared to other types of liners.
- They have limited ability to withstand heavy loads.
- They are susceptible to laceration, abrasion, and puncture.
- They are prone to cracking at low temperatures, and stretching and distortion at very high temperatures.

The synthetic polymeric membranes that are most commonly used to contain chemical and petroleum products are polyvinyl chloride (PVC), polyethylene, chlorinated polyethylene (CPE), chlorosulphonated polyethylene (CSPE or hypalon), oil-resistant polyvinyl chloride (ORPVC), ethylene proylene diene monomer (EPDM), butyl rubber and neoprene. In addition, DuPont has developed a proprietary elasticized polyolefin called 3110. Table 2.3-2 presents a general summation of the advantages and disadvantages of thse synthetic materials, and Table 2.3-3 presents a summary of the compatibility of these substances with various types of hazardous materials. For more information on the chemical compatibility of synthetic membrane liners, please refer to references 5 and 8.

Table 2.3-1

Comparison of Underground Spill Containment Systems

Type of System	Advantages	Disadvantages	Relative Cost
Clay Liners	The least expensive liner if clay is available close to the site.	Subject to drying and cracking and thus must be protected with soil cover.	Low
	Use of clay is a well established practice and standard testing procedures are available.	Subject to leaching of components when exposed to groundwater or other solutions.	
		Subject to ion exchange when exposed to water containing acids, alkalis, or dissolved salts.	
		Subject to destabilization when exposed to some organic solvents.	
Polymeric Liners	Well established solution to problem of containing petroleum products.	Require subgrade preparation and sterilization to reduce risk of puncture.	Moderate to High
	Particularly good for temporary storage.	Must be protected from damage, particularly due to vehicular traffic.	
	High resistance to bacterial deterioration.	Must be protected from sunlight and ozone.	
		May be attacked by hydrocarbon solvents particularly those with high aromatic content.	
		Good oil resistance and good low temperature properties do not normally go hand in hand.	
Soil Cement	Good durability.	Subject to degradation due to frost heaving of subgrade.	Moderate
	Resistance to aging and weathering	In place soil usually used; permeability varies with the type of soil.	
Bentonite	Low permeability.	Untreated bentonite may deteriorate when exposed to contaminant.	Moderate
	Does not deteriorate with age.	Requires protective soil cover, typically 18 inches.	
	Self sealing.	Subject to destabilization when exposed to some organic solvent.	
Concrete Vaults	Good strength and durability.	Requires surface coating to insure impermeability.	High
		Subject to cracking when exposed to freeze/thaw cycles.	
Double Walled Tanks	Constructed of material (FPR or coated steel) which is resistant to the stored product and to external corrosion.	Some models only available in tank sizes up to 4,000 gallons.	High
	Includes leak detection system in tank design.		

2. Design and Installation Requirements [5,8]

In most instances, installation of the liner is as important to the overall success of the application as material selection. Liner installation is a relatively complicated task that should be performed by a qualified contractor, paying attention to important details such as the following:

- The base of the excavation should be compacted to prevent settling under the liner and tank after they are in use.
- The slope of the excavation should be stable to avoid collapse after the liner has been installed.
- The base and sidewall areas that will contact the membrance should be finely finished. All rocks, rubble and debris which could puncture the lining should be removed. Sand layers should be placed above and below the membrane to further prevent punctures and to facilitate underdrainage. Soi' sterilization with a herbicide may be considered in instances where vegetation may propagate, but the herbicide should not be applied indiscriminately.
- The liner should be carefully placed and seamed (bonded) in accordance with manufaturers' specifications. Table 2.3-4 summarizes the important considerations of synthetic liner installation.

Membrane liners are typically used in areas of high groundwater, although they can be employed in other instances. When the material to be stored is lighter than water, the liner is always installed around the sides of the excavation perimeter extending down beneath the groundwater level. For these types of chemicals, the groundwater acts as the bottom containment for any leak or spill. When the liquid to be stored is heavier than water, the liner is always installed under the tank along the excavation base as well as along the sidewalls to prevent the liquid from migrating outside the excavation area. With the liner under the tank, the bottom liner cover area should be drained before closure. An observation well to a low point of the membrane could be used to confirm liner integrity. The excavation should have an impervious cover to prevent flooding of the lined area. Figures 2.3-1 and 2.3-2 illustrate these types of applications.

Membrane liners can also be used as wrappers around underground storage tanks. Polyethylene wrappers have been used in such a manner to enclose steel tanks. Some success in tank leak prevention has been reported using such a technique. However, corrosion can occur under the wrapper if groundwater enters the space between the tank and wrapper through a tear or other imperfection. In addition, such a wrapper is not adequate for use with cathodic protection for steel tanks [9]. Further discussion of this tank protection technique has been included in Part II, Chapter 1.

Table 2.3-4

Considerations During Liner Placement

Use a qualified installation contractor having experience with membrane liner installation, preferably the generic type of liner being installed.

Plan and implement a quality control program which will help insure that the liner meets specification and the job is installed per specifications. Inspection should be documented for review and recordkeeping.

Installation should be done during dry, moderately warm weather if possible.

The excavation base and wall should be firm, smooth, and free of sharp rocks or debris.

D. SOIL SEALANTS

The types of soil sealants more commonly used for lining storage tank containment areas are soil cement and bentonites (clay materials). These types of sealants are discussed in detail below.

1. Soil Cement [5,8]

Chemical and Physical Characteristics. Soil cement is a compacted mixture of Portland cement, water, and selected in-place soils. The result is a low strength Portland cement concrete with greater stability than natural soils. The permeability of this mixture varies with the type of soil used. a more granular soil produces a more permeable soil cement.

Any soil can be treated with cement. However, there are some exceptions where cement should not be used:

- Highly organic soil retards cement hydration because of absorption of calcium ions.
- Clean well-graded gravels and crushed rock are sometimes unsuitable because of shrinkage problem.
- Clays can be unsuitable because of the difficulty of incorporating a fine cement powder into a wet, plastic clay and because soil properties are not significantly affected.
- Saline soils are unsuitable, but this can be overcome by increasing the cement content.

The aging and weathering characteristics of soil cements are good, especially when exposed to wet-dry and freeze-thaw cycles. Some degradation has been noted when this substance is exposed to highly acidic

Table 2.3-2

Comparison of Various Synthetic Polymeric Membranes

Liner Type	Advantages	Disadvantages	Relative Cost
Polyvinyl Chloride (PVC)	Good resistance to ozone and ultraviolet ligh when properly stabilized	Poor hydrocarbon resistance.	Low
	Good resistance to puncture.	*May deteriorate in presence of certain* chemicals and in contact with heat.	
	High tensile strength.		
Oil Resistant PVC	Improved resistance to aromatic hydrocarbon relative to standard grades of PVC.	Poor low temperature handling properties.	Moderate to High
Polyethylene[1]	Great resistance to bacteriological deterioration.	Poor puncture resistance.	Low
	Good tensile strength.	Poor tear strength.	
	Few restrictions on chemical exposure.	Susceptible to weathering and stress cracking.	
	Good low temperature characteristics.		
Chlorinated Polyethylene (CPE)	Excellent weatherability.	Limited range of tolerance for chemicals, oils and acids.	Moderate
	Good tensile and elongation strength.	Low recovery when subject to tensile stress.	
	Good resistance to ultraviolet light and ozone.		
	Excellent crack and impact resistance at low temperatures.		
	Moderate to good hydrocarbon resistance.		
Chlorosulfonated Polyethylene (CSPE or hypalon)	Good puncture resistance.	Low tensile strength.	Moderate
	Good resistance to microbiological attack.	Poor resistance to aromatic hydrocarbons.	
	Excellent resistance to low temperature cracking.		
	Excellent weather resistance.		
	Good resistance to ozone and ultraviolet light.		
	Flexible and resilient.		
Ethylene Propylene Diene Monomer	Good weathering characteristics.	Poor resistance to aromatic hydrocarbons.	Moderate
	Good temperature flexibility.	Low peel and shear strength.	
	Good heat resistance.		
	Resistant to mildew, mold, and fungus.		
	Excellent resistance to water vapor transmission.		
Butyl Rubber	Excellent resistance to water.	Poor resistance to hydrocarbons particularly petroleum solvents, aromatics, and halogenated solvents.	Moderate to high
	Excellent resistance to ultraviolet light and ozone.		
	High tolerance for temperature extremes.	Poor sealability.	
	Good tensile and shear strength.		
	Good resistance to puncture.		
	Ages well in general, but some compounds will crack on ozone exposure.		

Table 2.3-2 continued

Neoprene	Excellent aging and weathering characteristics. Overall good resistance to hydrocarbons, but shows some swell when exposed to aromatics and other cyclic hydrocarbons. Flexible and elastic over a wide range of temperatures.	Not heat or solvent sealable.	High
Elasticized Polyolefin (DuPont 3110)	Resistant to ultraviolet light; does not require earth cover. Good resistance to weathering and aging. Good resistance to ozone attack and soil microorganisms. Good resistance to hydrocarbons and will accomodate a broad range of solvents.	Relatively untested. Vunerable at low temperatures.	Moderate

NOTE 1 - Refers to low density polythylene. High density polyethylene is much less susceptible to puncture, tears, weathering and stress cracking.

Table 2.3-3

Chemical Compatibility of Membrane Liners with Hazardous Materials

Lining Material	Strong Acids	Strong Bases	Petroleum Products	Halogenated Solvents	Aromatic Solvents
Polyvinyl chloride (PVC)[1]	R	R	NR	NR	NR
Chlorinated Polyethylene (CPE)	R	R	NR	NR	NR
Chlorosulfonated Polyethylene (CSPE or Hypalon)	R	R	NR	NR	NR
Ethylene Propylene Diene Monomer (EPOM)	R	R	NR	NR	NR
Neoprene	R	R	R	NR	NR
Butyl Rubber	R	R	NR	NR	NR
Oil Resistant Polyvinyl Chloride (ORPVC)[1]	R	NR	R	NR	NR
Polyethylene	R	R	R	R	R

NOTES: 1. Not recommended if liner is exposed to the atmosphere due to extreme susceptibility to ultraviolet light and/or ozone

R = recommended

NR = not recommended

Source: References 1,2 and 4.

environments, but soil cements can resist moderate amounts of alkali, organic matter, and inorganic salts. One of the main deficiencies of soil cement as a liner material is its tendency to crack and shrink on drying. Severe cracking and detrioration may also result if the cement content of the mixture is too high.

Design and Installation. The details for construction, excavation base and wall preparation, and placing and curing of soil cement liners can be obtained from documents such as reference 5, 8 and 9, and from consulting engineers in this field. Some of the considerations and procedures are highlighted in Table 2.3-5.

Table 2.3-5

Highlights of Soil Cement Design and Installation

- Preparation of the base and walls is extremely important. The base and wall should be properly finished, and well moistened before placing the concrete to prevent the liner from drying too quickly.
- Concrete mixes should be plastic enough to consolidate well, but not stiff enough to slip on side slopes.
- Proper curing of the liner is important.

2. Bentonites [8,10]

Chemical and Physical Characteristics. Bentonites are naturally occurring inorganic swelling clays which are typically chemically treated, and are marketed under various trade names. Mixtures of soil and chemically treated bentonites may be used to line excavations for underground tanks and contain spills. When the bentonite is mixed with a sandy soil and saturated with water, the granular bentonite particles in the soil swell to fill the voids with a tough leather – like mastic, thereby forming an impermeable barrier. Bentonite can swell up to 15 times its dry bulk volume when used in such a manner. Untreated bentonites are generally not as effective when used as soil sealants and are more susceptible to degradation, particularly if the water used to wet the material during installation contains a high concentration of dissolved salts (i.e., hard water), acids, or alkalis. Bentonites are also subject to destabilization when exposed to some organic solvents.

Design and Installation Requirements. Before installing a bentonite liner, it is necessary to first drain and stabilize the excavation. The mixture of soil and bentonite is then used to line the bottom of the excavation. The mixture is typically wetted to saturation, and compacted using a wobble wheel or steel wheel roller [8]. The tank is then installed in accordance with New York State standards and guidelines and/or the manufacturer's recommendations, and the excavation is backfilled with more clay/soil mixture. When preparing the mixture, the manufacturer's recommendations should be

Figure 2.3-1
Synthetic Liner Installation for Storage of Lighter-Than-Water Liquids in Area of High Groundwater

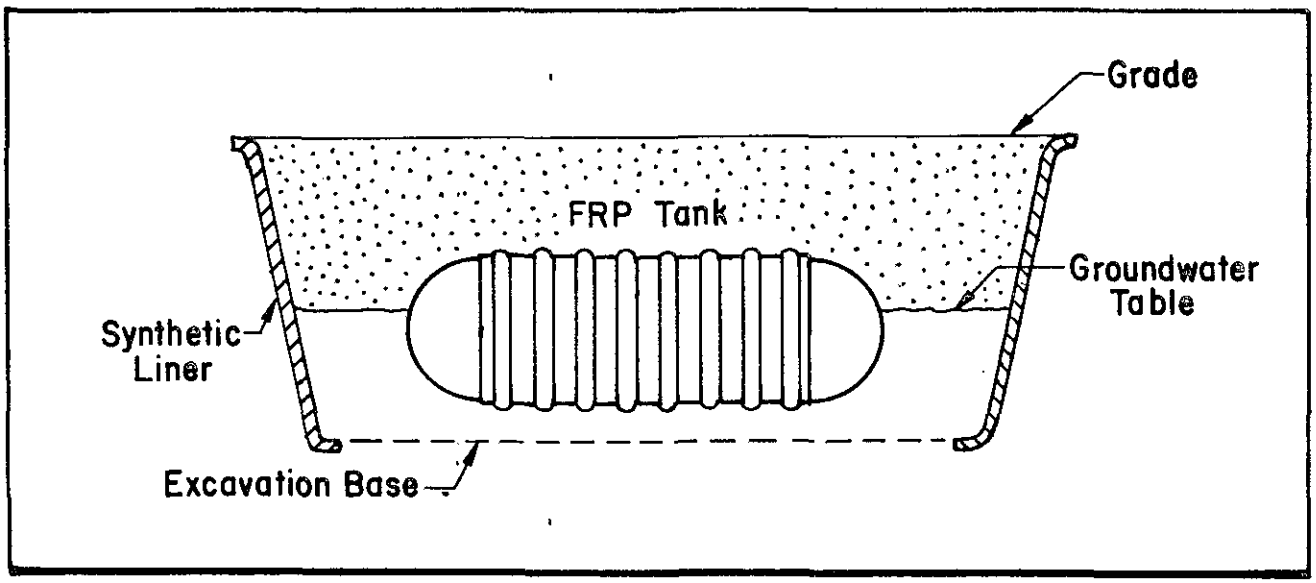
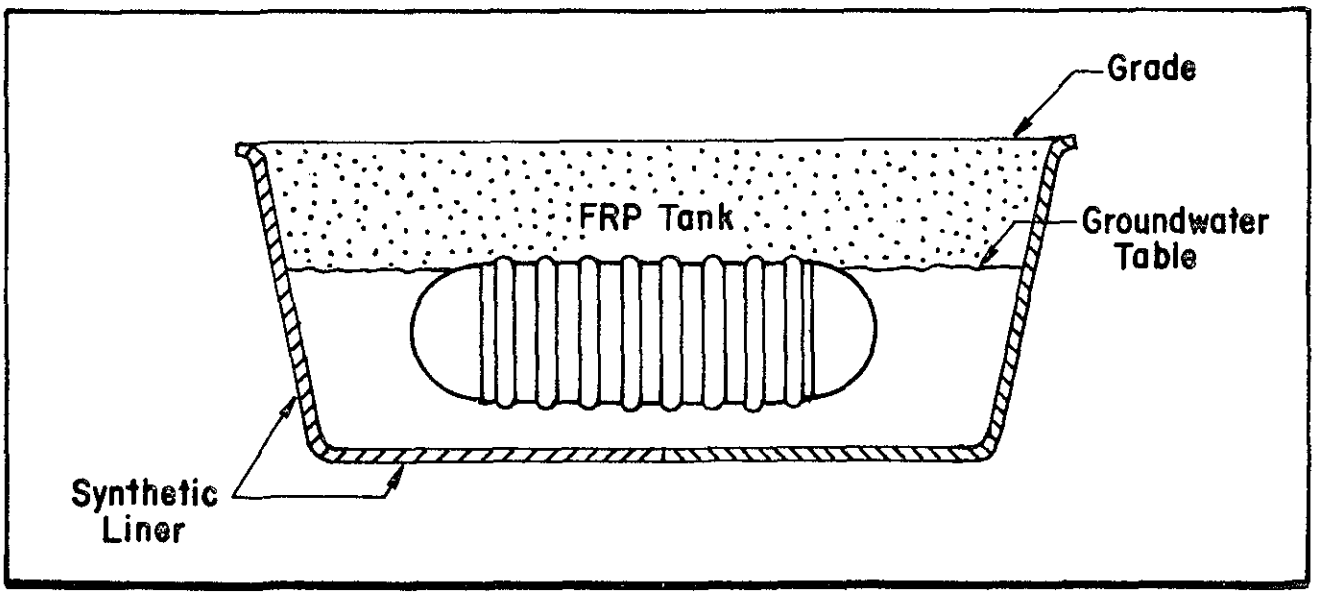


Figure 2.3-2

Synthetic Liner Installation for Storage of Heavier-Than-Water Liquids in Area of High Groundwater



followed as to the percent of the clay and soil, the amount and quality of water used for wetting, and the degree of compaction required. The mixture varies, but usually consists of one part bentonite and three parts clean uncontaminated soil.

E. CONCRETE VAULTS

Concrete vaults are secondary enclosures consisting of concrete walls and a concrete bottom slab upon which the tank is fastened. The vault system may include a cover.

The vaults may contain one, or more than a dozen tanks. Some vaults have an open interior so that tanks can be physically inspected while others are filled with a bedding of sand which provides structural support for the tanks. When the vaults are of open design, the interior tanks are supported structurally on cradles. Unusally the vault contains a sloped floor and a sump installed with a monitoring probe and a product recovery pump.

Concrete by itself is not an effective liquid barrier. Leaks through concrete occur in the vapor phase. Concrete will pass vapors of many chemicals after only a few days of exposure.

Coatings to make concrete impermeable are effective but there is no universal concrete coating for all chemicals, weather, and moisture conditions. Coatings will peel, crack or wear (in traffic areas) over time. In areas of wear, successive layers of coatings are color-coded, to show wear patterns.

A common practice is to put a vapor barrier around the outside of the vault. Concrete vaults must be carefully designed and constructed; otherwise joints may leak or the walls and floor may crack when exposed to freeze-thaw cycles for extended periods or if settling of the tanks occurs. Concrete vaults are mandatory in New York City for the underground storage of gasoline and other fuels.

F. DOUBLE-WALLED TANKS

Spill containment may also be provided with double-walled tanks. These tanks are essentially a tank within a tank and are described in Part II, Chapter 1 of this report.

References

1. Haxo, H.E., Haxo, R.S., White, R., *Liner Materials Exposed to Hazardous and Toxic Sludges, First Interim Report*, EPA-600/2-77-081, prepared by MATRECON, INC., Oakland, California, prepared for USEPA Municipal Environmental Research Laboratory, Cincinnati, Ohio 45268, June, 1977.

2. The Watersaver Company, *Membrane Linings*, Catalog No. GB78, The Watersaver Co., P.O. Box 16465, Denver, Colorado 80216.

3. Suffolk County Department of Health Services, *Design of Underground Gasoline and Oil Storage Facilities*, Standards of the Suffolk County Department of Health Services for the Administration of Article 12 (Toxic and Hazardous Materials Storage and Handling Control), of the Suffolk County Sanitary Code, Central Islip, New York 11722, dated October 3, 1979.

4. Perry, R.H., Chilton, C.H., *Chemical Engineer's*, Handbook, Chapter 23, Materials of Construction, Fifth Ed., McGraw-Hill Inc., 1221 Avenue of the Americas, New York, New York 10020, 1973.

5. U.S. Environmental Protection Agency, *Lining of Waste Impoundment and Disposal Facilities*, SW870, USEPA Municipal Environmental Research Laboratory, Cincinnati, Ohio 45268, September, 1980.

6. American Colloid Company, *Soil Sealants that Confine Oil and Chemical Leaks or Spills*, Brochure No. 290A, American Colloid Company, Environmental Products Division, 5100 Suffield Court, Skokie, Illinois 60077.

7. American Colloid Company, *Volclay Seepage Control Systems*, Brochure No. 229L, American Colloid Company, Environmental Products Division, 5100 Suffield Court, Skokie, Illinois 60077.

8. Petroleum Association for Conservation of the Canadian Environment, *State of the Art Review – Petroleum Product Containment Diking*, PACE Report No. 792, prepared for PACE by Golder Associates and James F. MacLaren Limited, Suite 400, 130 Albert Street, Ottawa, K1P564, Canada, March 1979.

9. Fitzgerald, J.H., "Corrosion Control for Buried Service Station Tanks," Paper No. 52, The International Corrosion Forum Devoted Exclusively to the Protection and Performance of Materials, April 14-18, 1975, Toronto, Canada, National Association of Corrosion Engineers, Publications Department, P.O. Box 1499, Houston, Texas 77001.

10. Jewett, M.A., Buyce, M.R., *A Review of Methods for Determining the Permeability Characteristics of Colorado Soils Exposed to Hazardous Waste*, prepared by Fred C. Hart Associates, Inc., prepared for U.S. Environmental Protection Agency, Region VIII, 1860 Lincoln Street, Denver, Colorado 80295, June, 1981.

Part II

CHAPTER 4: TRANSFER SPILL AND OVERFILL PREVENTION SYSTEMS FOR UNDERGROUND STORAGE TANKS

A. INTRODUCTION

Spills can occur at underground storage tank facilities because of tank overfilling and drainage from product transfer hoses. For example:

- It is common practice to unload products from vehicles into underground storage tanks without automatic means to prevent overfilling tanks. Without such protection, underground tanks can be overfilled with product which will rise through the vent lines until it attains a level equal to the product level inside the tank truck being unloaded.
- It is common practice to use quick disconnection couplings on the ends of discharge hoses rather than dry-break couplings which are heavier and more difficult to maneuver. With quick disconnect couplings, product remaining in the discharge hose is frequently spilled near the tank area. Beside the obvious dangers which can result from sloppy practices, the daily small spills seeping into the ground near the tank areas can accumulate into sizeable and hazardous volumes over a period of time.

To avoid situations such as these, it is good practice to equip underground tanks with overfill prevention systems and to equip transfer hoses with an automatic shut-off device which prevents backflow when the hose is disconnected. Adherence to good operating practices is also a prerequisite.

An ideal underground tank overfill prevention system would include the following basic elements: (1) a level sensing device that monitors and indicates the liquid level in the tank; (2) an alarm to alert the operator of an impending overfill condition; and (3) an automatic shut-off device that stops the flow of product when the tank is full.

Spills from transfer hoses can be prevented by using couplings equipped with spring loaded shut-off valves which stop flow automatically when the hose is disconnected and by using dry-disconnect couplings. Emergency shut-off valves may also be used to stop product flow, such as in the case of fire.

Devices for overfill and spill prevention add to the system cost, however. Underground tanks are not normally equipped with overfill prevention devices. Truck fleets generally are not equipped with dry disconnect couplings and there is some argument as to the reliability of such equipment on trucks.

The following text summarizes overfill and transfer spill prevention methods for underground storage systems.

It should be emphasized that the methods described are far more prevalent with aboveground systems (where a spill or overfill would be highly visible) than with underground systems. The evolving awareness of hazardous conditions that result from loss of product from an underground system and the financial accountability for site cleanup are changing the picture. The day of the deliveryman relying on a calibrated stick to determine available capacity in a buried tank may be passing.

B. OVERFILL PREVENTION SYSTEMS FOR UNDERGROUND STORAGE TANKS

1. Elements of an Overfill Prevention System.

Overfill protection is accomplished by measuring and controlling the level of liquid in a tank. A partial system may include only a gauge which indicates liquid height in the tank. A sophisticated system could include automatic flow control system and a backing audible high level alarm to warn the operator of emergency conditions.

The elements of a complete overfill prevention system are highlighted in table 2.4-1. These include the following:

- Sensors, which detect the level of liquid in the tank and indicate the liquid level through gauges or other types of indicators.
- High level alarms, which are activated to warn the operator of an impending overfill condition.
- Automatic shut-off devices of systems which prevent overfilling from occuring.

Table 2.4-1

Elements of a Good Overfill Prevention System

- Level sensing device.
- Level indicating device.
- High level alarm.
- Automatic shut-off control system.
- Interlocking of the unloading process and the overfill prevention system so that loading cannot take place if the overfill prevention system is inoperative.
- Bypass prevention so that the overfill prevention system cannot be overridden by the operator.

It may be desirable to interlock the unloading process with the overfill prevention system so that loading cannot take place unless the overfill prevention system is operative. A bypass prevention feature should also be included so that the overfill prevention system cannot be overridden by the operator.

Level Sensing Devices and Indicators. There are a variety of level sensing devices that have been marketed for detecting liquid levels in bulk storage tanks. These devices generally sense liquid characteristics, such as capacitance or thermal conductivity, or operate on such common principles as buoyancy, differential pressure, and hydrostatic head. Devices which operate based on these common priniciples are generally independent of product flow rate, pressure and temperature [13].

Indicators for underground tanks are typically remotely mounted (e.g., in a control room), although above-the-tank gauges may be employed in some cases. The devices are typically gauges, although more sophisticated electronic devices may be used in some overfill prevention systems.

High Level Alarms. Overfill alarms may be visual or audible instruments which are remotely mounted. Audible alarms may be the preferred type of alarm because they do not require visual monitoring. However, when several tanks are being monitored in the same control room, individual warning lights are generally provided for each tank. Ideally, an audible alarm would also be included in such systems to alert the operator that one of the tanks is overfilling.

Automatic Shut-off Controls. Automatic shut-off control systems interface with level sensing devices to: (1) prevent tank overfilling by shutting off the tank loading pump at a preset high level; (2) prevent damage to the tank unloading pump by shutting it off at low level; (3) operate various flow valves to control product flow. These control systems receive a signal from the level sensing device which is transmitted electrically or pneumatically to the control system. Pneumatic devices require a regulated supply of clean and dry instrument air, generally at 20 pounds per square inch (psi). Electric (or electronic) devices generally require 115V line voltage. Table 2.4-2 shows the characteristics of pneumatic and electronic controls.

2. Specific Level Sensing Devices.

The types of level sensing devices available for liquid level detecting in bulk storage tanks can be classified as follows:

- Float-actuated devices
- Displaced devices
- Hydrostatic head sensors
- Capacitance sensors
- Ultrasonic devices
- Optical devices
- Thermal conductivity sensors

Floated activated, capacitance, ultrasonic, optical, and thermal conductivity sensors can be readily used in underground tanks. Their applications are summarized in Table 2.4-3 and discussed below. The other types of sensors are used in aboveground storage systems and are discussed in Part II, Chapter 4 of this report.

Float-Actuated Devices. Float-actuated devices are characterized by a buoyant member which floats at the surface of the liquid. Float-actuated devices may be classified on the basis of the method used to couple the float motion to the indicating system. Examples of classifications include tape float guages and float vent valves.

A simple tape float gauge designed for use in underground gasoline tanks is shown in Figure 2.4-1. The device provides a local (above the tank) readout of both gasoline and water levels while prohibiting vapor loss.

Float vent valves are simple, inexpensive devices that are used to prevent overfilling of underground fuel tanks. These devices, which are shown in Figure 2.4-2, are installed in the tank's vent line. The float closes the vent line when high liquid level is attained, thus blocking the escape of air. This action causes the pressures inside the storage tank to equalize with the discharge head in the tank truck, thereby interrupting the flow of liquid.

Table 2.4-2

Characteristics of Pneumatic and Electronic Controls

Feature	Pneumatic	Electronic
Transmission distance	Limited to few hundred feet	Practically unlimited
Standard transmission signal	3-15 psi practically universal	Varies with manufacturer
Compatibility between instruments supplied by different manufacturers	No difficulty	Nonstandard signals require special consideration and may not be compatible
Control valve compatibility	Controller output operates control valve operator	Pneumatic operators with electropneumatic converters or electrohydraulic or electric motor operator required
Compatibility with digital computer or data logger	Pneumatic-to-electric converters required for all inputs	Easily arranged with minimum added equipment
Reliability	Superior if energized with clean dry air	Excellent under usual environmental conditions
Reaction to very low (freezing) temperatures	Inferior unless air supply is completely dry	Superior
Reaction to electrical interference (pickup)	No reaction possible	No reaction with the system if properly installed
Operation in hazardous locations (explosive atmosphere)	Completely safe	Intrinsically safe equipment availble equipment must be removed for most maintenance
Reaction to sudden failure of energy supply	Superior-capacity of system provides safety margin-backup inexpensive	Inferior-electrical failure may disrupt plant-backup expensive
Ease and cost of installation	Inferior	Superior
System compatibility	Fair-requires considerable auxilary equipment	Good-conditioning and auxilary equipment more compatible to systems approach
Instrument costs	Lower if installation costs are not considered	Higher-becomes competitive when total including installation is considered
Ease and cost of maintenance	Fair; procedures more readily mastered by people with minimim of training	Good-depends upon capability of personnel
Dynamic response	Slower but adequate for most situations	Excellent-frequently valve becomes limiting factor
Operation in corrosive atmosphere	Superior-air supply becomes a purge for most instruments	Inferior, unless special consideration is given and suitable steps taken
Performance of overall control systems	Excellent, if transmission distances are reasonable	Excellent-no restriction on transmission distance
Politics (the unmentioned factor that frequently pops up)	Generally regarded as acceptable but not the latest thing	Often regarded as the latest and most modern approach

Source: Reference 2

Table 2.4-3

Level Detection Devices for Underground Storage Tanks

Type	Monitor Liquid Level	Level Indication	Alarm and Shutoff Response [1]
Float Actuated Devices			
Tape float gauges	Yes	Gauge	Interfaces with electronic or pneumatic controls.
Float vent valves	No	None	Automatic Shut-off.
Capacitance devices	Yes	Gauge	Audible alarm and automatic shutoff electronic controls.
Thermal conductivity devices	Yes	Gauge	Audible alarm and automatic shutoff electronic controls.
Ultrasonic devices	Yes	Gauge	Audible alarm and automatic shutoff electronic controls.
Optical devices	Yes	Gauge	Audible alarm and automatic shutoff electronic controls.

The device also includes a pressure build-up relief bleed hole. Once flow from the tank truck has ceased due to pressure equalization, the storage tank fill line can be disconnected. Then, as vapor escapes through the float vent valve bleed hole, the liquid remaining in the fill line can drain into the tank. If dry disconnection couples are used, the liquid will be held in the transfer line until this draining can occur, thus preventing any spillage of product.

This device was developed as part of the Vapor Recovery Stage I system. Its purpose is to prevent product spillover into the vapor manifold, which might result in lead contamination of an unleaded gasoline grade. Its use as overfill protection has merit, but it is not used for that purpose generally.

The float vent valve must be installed in an "extractable tee" connection which permits removal of the float valve for tank testing. The Kent-Moore (Heath Petro-Tite Tank Tightness) Test cannot be run with the valve in place.

Float-actuated devices are made of a variety of materials, including aluminum, stainless steel and coated steel, depending upon the application [10]. They may be used in conjunction with pneumatic or electronic devices to operate valves, pumps, remote alarms or automatic shut-off systems.

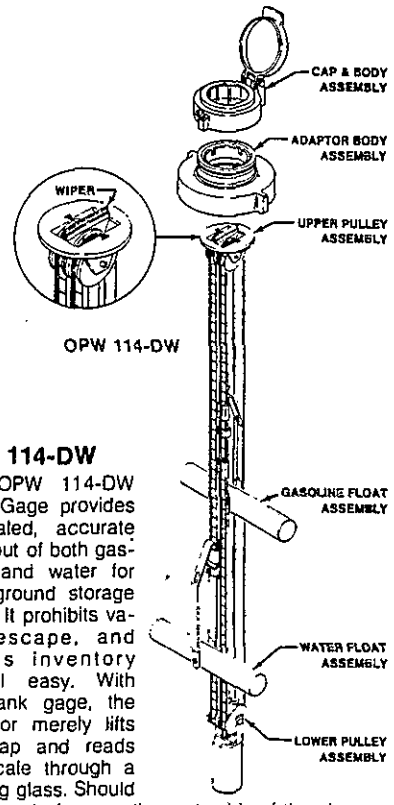
Capacitance Sensors [7]. Devices that operate based on the electrical conductivity of fluids may be used to monitor liquid level. A typical device consists of a rod electrode positioned vertically in a vessel, the other electrode usually being the metallic tank wall. The electrical capacitance between the electrodes is a measure of the height of the interface along the rod electrode. The rod is usually electrically insulated from the liquid in the tank by a coating of plastic.

Capacitance devices are suitable for use with a wide range of liquids, including the following: petroleum products, such as gasoline, diesel fuel, jet fuel and no. 6 fuel oil; acids; alkalis; solvents; and other hazardous liquids. They may be used in conjunction with electronic controls to operate pumps, valves, alarms or other external control systems.

Thermal Conductivity Sensor [18,19]. Devices which operate on the principle of thermal conductivity of fluids may be used to monitor liquid level. A typical device consists of two temperature-sensitive probes connected in a Wheatstone bridge (a type of electrical circuit configuration). When the probes are in air or gas, a maximum temperature differential exists between the active and reference sensors, which results in a great imbalance in the bridge circuit and a correspondingly high bridge voltage. When the probes are submerged in

Figure 2.4-1

Tape Float Gauge for Underground Storage Tank



OPW 114-DW

The OPW 114-DW Tank Gage provides a sealed, accurate read-out of both gasoline and water for underground storage tanks. It prohibits vapor escape, and makes inventory control easy. With this tank gage, the operator merely lifts the cap and reads the scale through a viewing glass. Should condensate form on the underside of the glass, a turn of the cap wipes it clean.

These tank gages are for use in 4" riser pipes, and are pre-assembled at the factory. One man can install the 114-DW tank gage by using the furnished instruction sheet as a guide.

Materials
Body: hard coat aluminum
Cap: hard coat aluminum
Gaskets: buna-N
Pulley: Acetal
Tape: steel with epoxy paint

OPW 114-SW

Similar to OPW 114-DW above, except it indicates product level only.

Source: OPW Division/Dover Corp.

a liquid, the temperature between the sensors is equalized and the bridge is brought more nearly into balance. The probes may be installed through the side wall of a tank or pipe, or assembled together on a self-supporting mounting and suspended through a top connection on the tank.

Thermal conductivity devices may be used to control level with great accuracy. They may be used with any liquid regardless of viscosity or density. They may also be used with immiscible liquids and slurries and in conjunction with electronic controls to operate pumps, valves, alarms or other external control systems.

Ultrasonic Sensors [16,17]. Devices which operate on the principle of sonic-wave propagation in fluids also may be used to monitor liquid level. These devices use a piezoelectric transmitter and receiver, separated by a short gap. When the gap is filled with liquid, ultrasonic energy is transmitted across the gap to a receiving element thereby indicating the liquid level. These devices may be used in conjuction with electronic controls to operate pumps, valves, alarms or other external control systems.

Another sonic technique used for level measurement is a sonar device. A pulsed sound wave, generated by a transmitting element, is reflected from the interface between the liquid and the vapor-gas mixture and returned to the receiver element. The level is measured in terms of the time required for the sound pulse to travel from the transmitter to the vapor/liquid interface and return.

Optical Sensor [9]. Devices which operate on the principle of light beam refraction in fluids may be used to monitor liquid level. An optical liquid level monitoring system consists of a sensor and an electronic control device. A specific electronic signal is generated and aimed at the tank mounted sensors. The sensors convert the electronic signal to a light pulse. This light pulse is transmitted into the tank by fiber optics, through a prism and out again via fiber optics. The light pulse is then converted to a specific electronic signal to indicate the liquid level. A distinct advantage of this type of system is that it is self-checking. Any interruption will sound the alarm, so if equipment is damaged or malfunctions the operator is alerted.

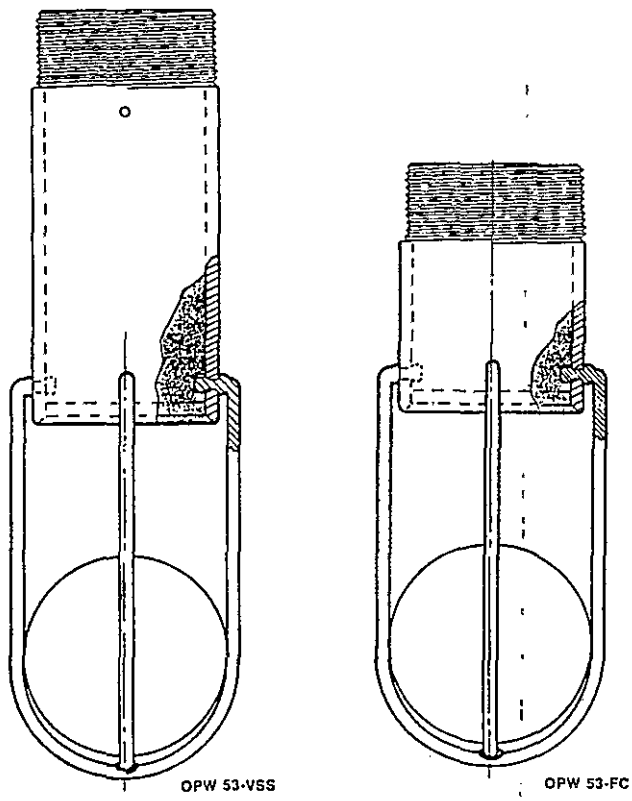
Figures 2.43 and 2.44 show typical applications of the optical liquid level sensing system for a tank truck and a bulk storage tank respectively. The sensor detects the level of liquid in the tank and sends a signal to the controller device (i.e. control monitor) which in turn activates the shut-off valve or the level alarm.

C. TRANSFER SPILL PREVENTION SYSTEMS

Spill prevention during transfer operations can be accomplished by using couplings equipped with spring loaded valves which automatically block flow when the hoses are disconnected. These include quick-disconnect couplings equipped with ball valves and dry-disconnect couplings. Emergency shut-off valves may also be provided in the product transfer line to stop flow in case of fire. Applications of these spill prevention devices are summarized in Table 2.4-4 and discussed below.

Figure 2.4-2

Float Vent Valves Used For Overfill Prevention



Source: OPW Division/Dover Corp.

1. Check Valves

Check valves are commonly used in the discharge piping of a pump or the fill line of a tank to prevent reversal of flow. Check valves are available in three basic designs: (1) swing check valves; (2) lift check valves; and tilting-disk check valves. They are available in a wide wariety of sizes and materials of construction to suit most applications. A more complete description of these devices can be found in Part II, Chapter 2 of this report.

2. Couplings

The use of tight couplings is essential to prevent spills when transferring hazardous products from one storage tank to another. Many types of couplings are available and their selection depends on temperature, pressure and the chemical properties of the material conveyed. The higher the temperature and/or pressure, the more securely the coupling must be attached. Also, the material being conveyed must not damage the coupling. The factor which determines the amount of pressure a coupling will withstand is generally the strength of the hose-coupling connection. If correctly applied (and at moderate working temperatures) bolt clamps will handle low pressure, bands will take low to medium pressures, and interlocking clamps and swaged or crimped ferrules will handle high pressures.

As mentioned earlier in this chapter, quick-disconnect couplings are commonly used because they are generally lighter and easier to handle than other types of couplings. However, precautions must be taken to prevent spill or loss of the product remaining in the transfer lines when these types of couplings are used. Quick-disconnect couplings equipped with ball valves and dry-disconnect couplings are used to minimize spills when the hoses are disconnected. Dry-disconnect couplings are the best type of coupling available in terms of product spill control. They are equipped with a spring loaded valve which is normally closed until the coupling is attached and the valve is manually opened with a lever. Figure 2.4-5 demonstrates the difference between the types of couplings.

Another good product transfer practice is the selective use of couplings and adapters to preclude the mixing of incompatible liquids. By carefully selecting couplings and adapters that are only compatible with each other, one can prevent undesired mixing of products.

Imbiber beads are useful for soaking up small spills, for example in the fill box. These beads absorb hydrocarbons and swell to many times their original size, but do **not** absorb water.

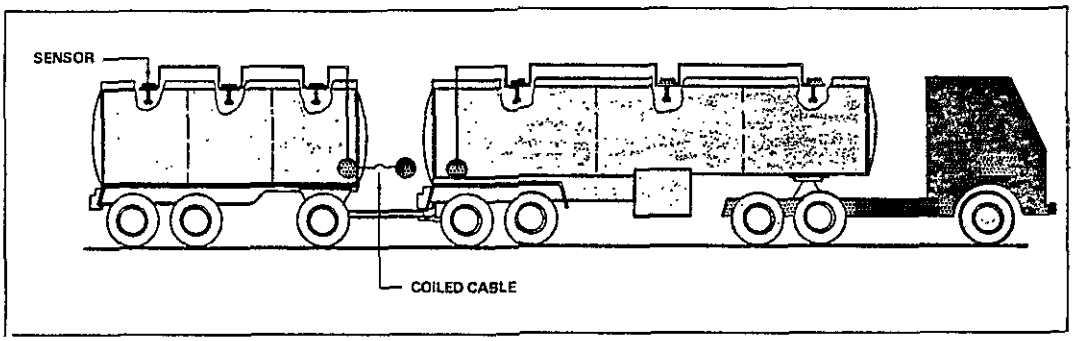
D. OPERATING PRACTICES FOR OVERFILL PROTECTION

Certain operating practices specified in Publication 385 of the National Fire Protection Association may be used to prevent overfilling of tanks [14]. Practices that are applicable to the transfer of any hazardous liquid include the following:

- Loading and unloading of tank vehicles shall be done in approved locations.
- The driver, operator, or attendant of any tank vehicle shall not remain in the vehicle and shall not leave the vehicle unattended during the loading or unloading process. The delivery hose, when attached to a tank vehicle, shall be considered to be a part of the tank vehicle. Some companies prefer to have their own trained personnel conduct all unloading operations so as to minimize the potential for human error. Whoever does the unloading must be cognizant of the potential problems and

Figure 2.4-3

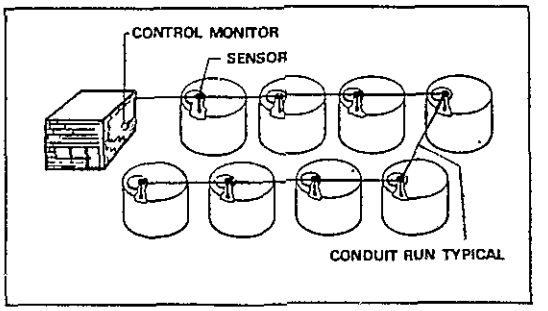
Optical Liquid Level Sensing System For Tank Truck



Source: OPW Division/Dover Corp.

Figure 2.4-4

Optical Liquid Level Sensing System For Bulk Storage System



Source: OPW Division/Dover Corp.

Table 2.4-4

Tranfer Spill Prevention Systems

System	Function	Spill Control	Applications
Ordinary quick-disconnect coupling	Product transfer	None	Tank vehicles and storage tanks.
Quick-disconnect coupling equipped with ball valve	Product transfer	Built-in valve reduces spills from disconnect hoses.	Tank vehicles and storage tanks.
Dry-disconnect coupling	Product transfer	No spills from disconnected hoses.	Tank vehicles and storage tanks.
Emergency shut-off valves	Flow control	A fusible metal link melts and closes the valve in case of fire or impact.	For use any place that, in the event of fire, it is important to stop flow.

dangers (overfilling, leaks, vapor or liquid explosions, fire, etc.), and must remain alert at all times. Human error is a major cause of transfer spill incidents, and in most instances spills could be avoided through proper personnel training and alert observation of all operations.

- When transferring Class I (flammable) liquids, motors of tank vehicles or motors of auxiliary or portable pumps shall be shut off during making and breaking hose connections. If loading or unloading is done without requiring the use of the motor of the tank vehicle, the motor shall be shut-off throughout the transfer operation of the liquid. These precautions should be taken to minimize the possibility of fire or explosion.
- No cargo tank (or compartment) containing volatile, flammable or combustible liquid may be fully loaded. Sufficient space (outage) must be provided to prevent leakage due to thermal expansion of the liquid transported. One percent is the minimum outage required.

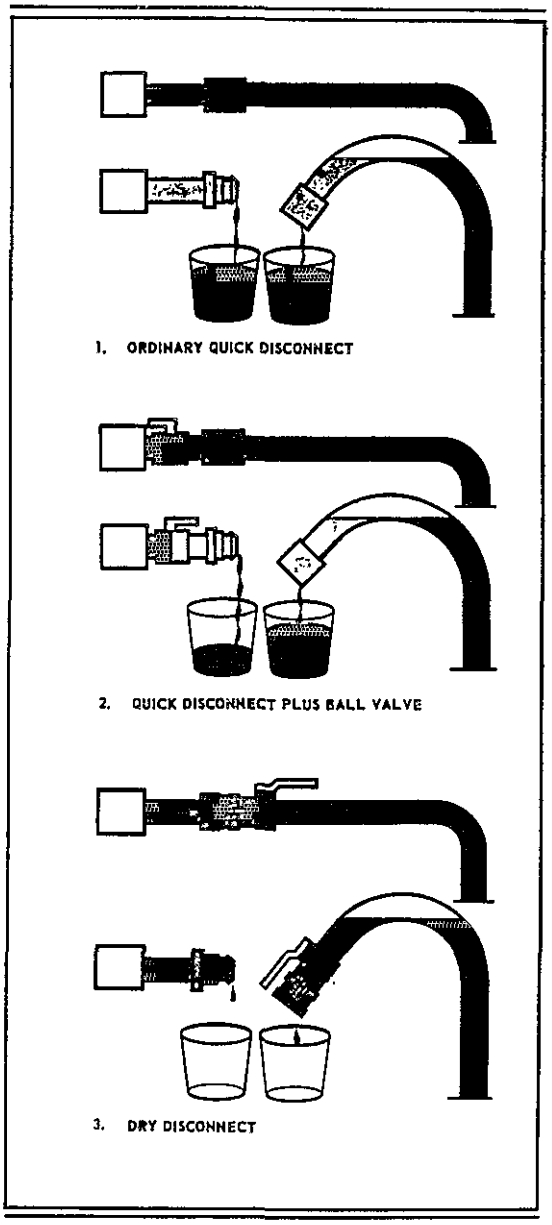
Please refer to NFPA-385 for more information on loading and unloading practices [14].

Other precautions which may be taken to prevent overfills and spills include the following:

- The use of labels, markings or color codes on hoses and special couplings that can be used only for transferring product to prevent accidental mixing of incompatible materials.
- Periodic inspection of hoses for leaks.
- Ensuring that the operator of any loading/unloading operation is properly trained and is aware of all potential problems. As stated earlier, a high percentage of transfer spills are caused by human error.

Figure 2.4-5

Types of Couplings



Source: OPW Division/Dover Corp.

References

1. Perry, R.H., Chilton, C.H., *Chemical Engineer's Handbook*, Chapter 22, McGraw-Hill Book Co., Fifth Edition, 1221 Avenue of the Americas, New York, New York 10020, 1973.

2. Anderson, N.A., *Instrumentation for Process Measurement and Control*, 2nd Edition, Chilton Book Co., 5601 Chestnut Street, Philadelphia, PA 19139, 1972.

3. Andermatten, R., *Overvill Protection System for Underground Storage Tanks of Hazardous Liquid Products*, 16 S. Lewis Place, Rockville Centre, N.Y. 11570, July 1, 1980.

4. Annual Report of The New York State Oil Spill Prevention, Control and Compensation Program, April 1, 1978 to March 31, 1979, New York State Department of Environmental Conservation, 50 Wolf Road, Albany, N.Y. 12233.

5. Annual Report of The New York State Oil Spill Prevention, Control and Compensation Program, April 1, 1979 to March 31, 1980, New York State Department of Environmental Conservation, 50 Wolf Road, Albany, N.Y. 12233.

6. Petrometer Corp., *Liquid Level Indicating and Control Systems*, Catalog No. 75, Petrometer Corp., P.O. Box 245, New Hyde Park, New York 10040.

7. Amprodux Inc., *Solid-State Electronic Bin and Tank Gauges, Level Alarms, and Level Control Instruments and Systems*, Catalog 15.10/AM, Amproduc, Inc., 150 West 28th Street, New York, N.Y. 10001.

8. Kodata, Inc., *Level Measuring System for Bulk Liquids or Solids*, Bulletin No. 8090-25, Kodata, Inc., 3621 McCart Street or P.O. Box 11528, Fort Worth, Texas 77610.

9. Dover Corp., *Optic Liquid Level Sensing System for Petroleum Transportation and Storage Applications*, Bulletin OLLS6-80, Dover Corp., OPW Division, 9393 Princeton-Glendale Road, P.O. Box 40240, Cincinnati, Ohio 45240, June, 1980.

10. Scully Electronic Systems, Inc., *New Scully-Moormann Development for Remote Readout Inventory control for Existing and new Moormann Liquid Gauges*, Scully Electronic Systems Inc., 70 Industrial Way, Wilmington, Mass 01887.

11. Dover Corp., *Service Station Vapor Recovery Products and Systems*, Catalog SVR, Dover Corp., OPW Division, 9393 Princeton-Glendale Road, P.O. Box 40240, Cincinnati, OH 45240, February, 1981.

12. Perry, R.H., Chilton, C.H., *Chemical Engineer's Handbook*, Section 6, McGraw-Hill Book Co., Fifth Edition, 1221 Avenue of the Americas, New York, New York 10020, 1973.

13. Emco Wheaton, Inc., *Fluid Handling Systems*, Catalog 7-8/73, Emco Wheaton, Inc., Chamberlain Blvd., Conneaut, Ohio 44030, Revised April, 1977.

14. NFPA 385, *Tank Vehciles for Flammable and Combustible Liquids*, National Fire Protection Association, Batterymarch Park, Quincy, MA. 02269, 1979.

15. Dover Corp., *OPW Kamvalok – Dry Disconnect Couplings*, Dover Corp., OPW Division, 9393 Princeton-Glendale Road, P.O. Box 40240, Cincinnati, OH 45240.

16. Envirotech Corp., *Sensall 880 Ultrasonic Non-Contact Continuous Level Transmitter*,, Catalogue B-8800, National Sonics, 250 Marcus Blvd., Hauppauge, NY 11787, March, 1981.

17. Envirotech Corp., *Sensall 880 Ultrasonic Non-Contact Continuous Level Transmitter*,, Catalogue B-800. National Sonics, 250 Marcus Blvd., Hauppauge, NY 11787, March, 1980.

18. Fluid Compnents, Inc., *Heat Actuated Liquid Level Controller Model 8-66*, Bulletin 8-66/1, Fluid Components, Inc., P.O. Box 1165, Canoga Park, California 91304.

19. Fluid Compnents, Inc., *Model FR72 Series Liquid Level Controller*, Bulletin FR72-LL/1, Fluid Components, Inc., P.O. Box 1165, Canoga Park, California 91304.

20. Dover Corp., *OPW Engineered Service Station Products*, Dover Corporation/OPW Division, 9393 Princeton-Glendale Road, P.O. Box 40240, Cincinnati, OH 45240.

Part II

CHAPTER 5: LEAK AND SPILL MONITORING FOR UNDERGROUND STORAGE

A. INTRODUCTION

Before any extensive discussion begins, a distinction must be made between system monitoring and system testing. Monitoring means either:

a) **Early warning leak detection systems** that provide continuous surveillance for leaks and spills.

b) **Area-wide surveillance methods** that may be used to investigate or pinpoint the source of a spill or leak.

Testing refers to special equipment and methods that are not part of normal operations. System testing is used to determine whether a tank or pipe system is leaking at a particular time. (Chap. II-6 discusses testing at length). Table 2.5-1 compares the various leak monitoring systems.

B. EARLY WARNING LEAK DETECTION SYSTEMS

Early warning leak detection systems typically provide continuous surveillance for the presence of a leak or spill. The types of early warning monitoring systems most widely used are the following:

- Inventory monitoring (also called inventory contol).
- Interstitial monitors in double-walled tanks.
- Systems that monitor the storage tank excavation. These types of systems include observation wells. U-tubes, and wire grids. The types of leak sensors used include:
  - thermal conductivity sensors;
  - electric resistance sensors; and
  - gas detectors.

1. Inventory Control

Early detection of leaks may be achieved by proper product accounting (i.e., recordkeeping), regular inspections of the visible parts of the product handling system, and prompt recognition of the conditions that indicate leaks in underground tanks and piping. Inventory monitoring is a technique that is widely applicable to any stored or transported product.

Evidence of leakage from buried tanks and pipelines can be gathered from inventory control records and from abnormal operation of pumping equipment. The following are some of the more obvious symptoms of such leaks:

- Loss of product in a tank during periods when product is not dispensed usually indicates a leaking tank, but might also indicate faulty accounting or metering of the product, theft, or extreme temperature change.
- An unaccountable increase in water in an underground tank may be caused by a leak in the tank if the ground surrounding it is saturated. Under such circumstances, water may leak into the tank instead of product leaking out. The increase in water may also be caused by a leaking gauge or fill cap, and these should be examined and made watertight, if necessary, before concluding that the tank is at fault.
- Increasing differences between the amount of product received and dispensed may indicate a meter calibration problem, theft, or a leak in tanks or piping.
- Where fill boxes are located remotely from the tanks, large differences appearing consistently between the amounts invoiced and the tank gauges after deliveries may indicate a leak in the remote fill line. In such event, the line should be tested.
- A hesitation in the delivery from a standard dispensing pump may indicate a leak in the suction piping, although such hesitation may also be caused by a leaking foot valve or, in warm weather, by vaporlock. Should this occur, the inventory control records may indicate whether the cause is mechanical or whether product is actually being lost.
- In a remote pumping system, meter spin without product delivery may indicate a leaking pipe.
- Gasoline odor in spaces below ground adjacent to the tank may be evidence of underground leaks, whether in the tank or piping. However, such odors may also be evidence of underground leaks, whether in the tank or piping. However, such odors may also be evidence of product spills during product delivery and tank filling.

Should the operator observe any of the foregoing symptoms, he should immediately notify those responsible for maintaining the equipment. He should not attempt to correct the condition himself, as the operation may involve some hazard and may require special equipment. Furthermore, in some locations, only specially licensed mechanics can work on storage equipment.

Table 2.5-1

Comparison of Various Leak Monitoring Techniques

Approach	Description	Applications	Substances Detected	Relative Cost	Advantages/Disadvantages
Inventory Control	A system based on product recordkeeping, regular inspections, and recognition of the conditions which indicate leaks.	Any storage tanks and buried pipelines.	Any product stored or transported.	Low	The technique is widely applicable to any product stored or transported in pipelines. However, it requires good bookkeeping, and will not detect small leaks.
Thermal Conductivity Sensors	Uses a probe that detects the presence of stored product by measuring thermal conductivity.	Can monitor groundwater or normally dry areas.	Any liquid.	Medium	Primary advantage is early detection which makes it possible for leaks and spills to be corrected before large volumes of material are discharged. Typically requires ¼ inch of product on groundwater to guarantee detection of product/water interface in wet (groundwater) applications [16].
Electric Resistivity Sensors	Consists of one or a series of sensor cables that deteriorate in the presence of the stored product, thereby indicating a leak.	Can monitor groundwater or normally dry areas.	Any liquid.	Medium	Primary advantage is the early detection of spills. Once a leak or spill is detected, the sensors must be replaced. Can detect small as well as large leaks.
Gas Detectors	Used to monitor the presence of hazardous gases in vapors in the soil.	Areas of highly permeable, dry soil, such as excavation backfill or other permeable soils, above groundwater table.	Highly volatile liquids, such as gasoline.	Medium	Once the contaminant is present and detected, gas detectors are no longer of use until contamination has been cleaned up.
Sampling	Grabbing soil or water samples from area for analysis.	Universal; primarily used to collect groundwater samples, as would be the case with tanks stored in high groundwater area.	Any substance	High	Highly accurate intermittent evaluation tool. However, does not provide continuous monitoring.
Interstitial Monitoring in Double-Walled Tanks	Monitors pressure level or vacuum in space between walls of a double-walled tank.	Double-walled tanks.	Pressure sensors monitor tank integrity and are applicable with any stored liquid. Fluid sensors monitor presence of any liquid in a normally dry area, and are also applicable with any stored liquid.	High	Accurate technique which is applicable with any double-walled tanks.

Table 2.5-1 continued

Groundwater Monitoring Wells (wet wells)	Wet wells are used to detect and determine the extent of contamination in groundwater tables.	Area-wide or local monitoring for groundwater contamination from underground storage tanks and pipelines. May be used for periodic sampling or may employ one of the sensors described above to detect leaks or spills.	Any hazardous liquids which can be detected by on-site instruments or laboratory analysis.	Medium to High	The type, number and location of wet wells depends upon the site's hydrogeology, the direction of groundwater flow and the type of spill containment and spill collection systems used.
Vapor (sniff) Wells	Vapor wells are used to detect and monitor the presence of hazardous gases and vapors in the soil.	Area-wide or local monitoring of the soil surrounding underground storage tanks and pipelines.	Many different combustible and non-combustible gases and vapors.	Low	The type, number and location of vapor wells depends upon the extent of the spill, the volatility of the product, and the soil characteristics. Vapor wells are subject to contamination from surface spills and cannot be used at contaminated sites.
Dyes and Tracers	Substances with a characteristic color or other characteristics (e.g., radioactive tracers) that can be used to trace the origin of a spill.	Area-wide monitoring of underground tanks and buried pipelines.	Dye itself is detected visually or with the use of instruments.	Low Medium	Dye or tracer could be low in cost, but the time required to perform a study could be great. Also may require the drilling of observation wells to trace the dye or other material. Radioactive tracers require a license and approval from the Nuclear Regulatory Commission or the U.S. Department of Labor. Therefore, they are generally discouraged.

There are a number of factors that limit the accuracy of inventory control as a leak detection method. These include the following:

- Product thermal expansion. Fluctuations in temperature can lead to expansion, contraction, evaporation and/or condensation of the stored product, thereby affecting inventory monitoring results. The relationship between temperature and storage volume is addressed in Part I of this report.
- Errors associated with faulty reading of dip stick measurements.
- Errors associated with resolution in meter readings. All meters have an associated level of error, typically on the order of 0.5% of the level of resolution of the meter.

Given these limitations in accuracy, even a carefully conductd inventory monitoring program can only detect leaks that are an appreciable fraction (typically 0.75%) of the stored volume. It should be emphasized that inventory control, conscientiously followed, is the first defense against leaks. Measuring the liquid level, (and the water level with a water finding paste) twice a day and comparing these levels with product deliveries and sales will indicate trends of product loss or water gain in a short time. Major oil companies require inventory records. Any unreported losses become the responsibility of the operator and reports of consistent product losses are followed by testing the suspected tank for leaks .

2. Interstitial Monitoring in Double-Walled Tanks

An early warning monitoring technique characteristic of double-walled tanks involves monitoring the space betwen the inner and outer walls of the tank, using either fluid sensors or pressure sensors. Pressure sensors would be used to monitor tanks that either have a vacuum drawn in the space between walls, or have that space pressurized. Failure of either the inner or outer wall is detected by loss of vacuum or pressure. Fluid sensors, on the other hand, would be located between the tank walls to detect the presence of a liquid due to failure of the inner wall (detecting stored product) or the outer wall (detecting water). (These systems may be applied at atmospheric pressures to vaulted tanks.)

3. Tank Excavation Monitoring Sensors

Tank excavation monitoring systems are aimed at detecting a spill or leak before the contamination spreads beyond the tank excavation or its immediate surroundings. The leak or spill sensing mechanisms that may be used in tank excavation monitoring systems include thermal conductivity sensors, electrical resistivity sensors, gas detectors and sample analysis.

Thermal Conductivity Sensors [1,2]. Thermal conductivity sensors detect changes in the thermal conductivity of their surrounding environment to determine if a leak or spill has occurred. These types of sensors can be used in wet or dry applications (i.e. areas of either low or high groundwater), and are particularly applicable for the detection of hydrocarbons such as gasoline, gasohol, fuel oils, alcohols, and trichloroethylene.

A system using a thermal conductivity sensor typically consists of an electronic control device that is connected by cable to a thermal conductivity probe. The probe is fitted with a sensor that determines if the monitored area is dry, wet with water, or wet with some other substance. The control device may be located up to 1,000 feet from the probe and can continuously indicate the site condition through indicator lights. A non-water liquid presence may also be indicated by an audible alarm, and recorded using a chart recorder. A relay contact that can activate external alarms, recovery pumps or other automatic controls can also be provided.

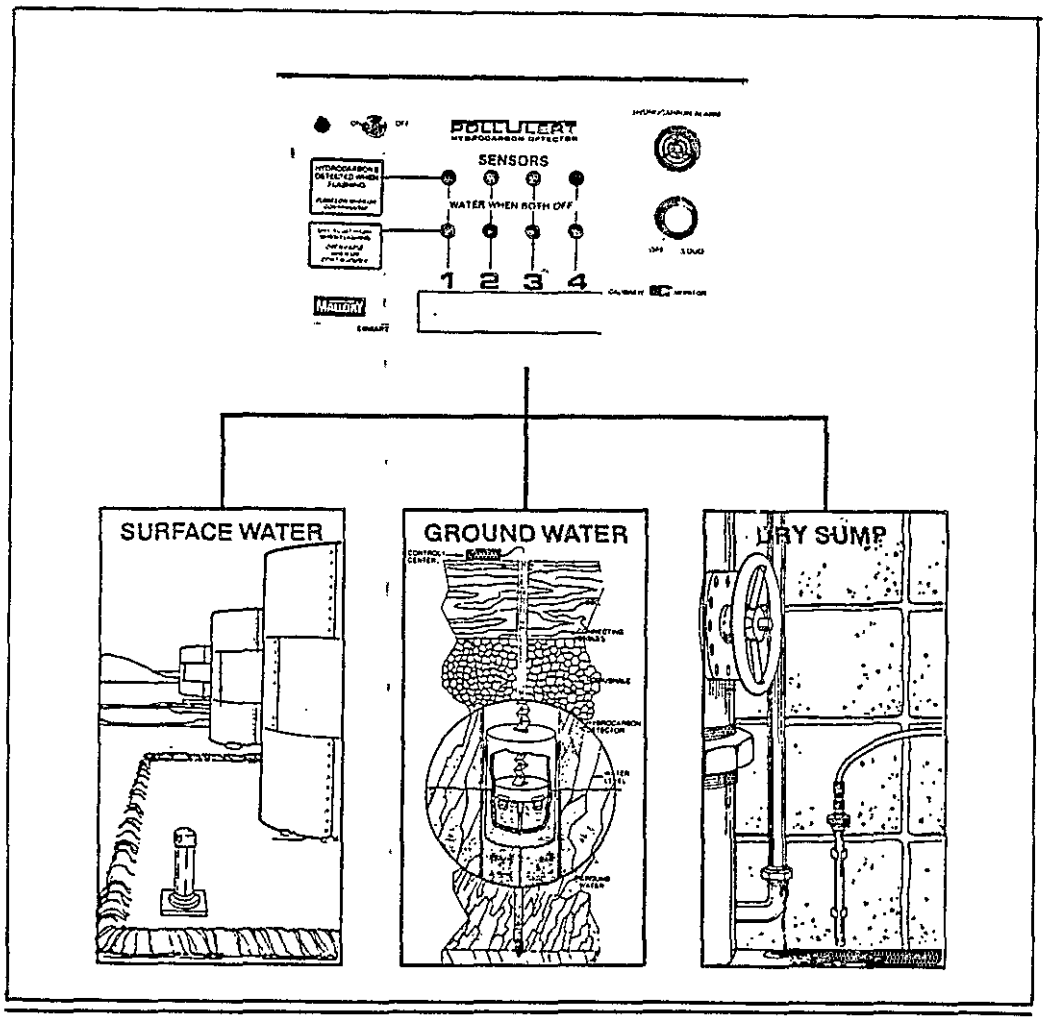
Figure 2.5-1 shows examples of thermal conductivity sensors installed in a diked area, a dry well or sump, and a wet well (in the groundwater table). When used to monitor a groundwater table, one sensor located in a monitoring well will only indicate the presence of contamination but not the extent of it. By using several sensors located at various levels the thickness of the contaminant layer may be ascertained.

Electrical Resistivity Sensors [3]. Systems employing this leak detection technique rely on the change in resistance in a wire due to exposure to the stored product to indicate the presence of leak or spill. The key to systems of this type is the use of wires or wire coatings that are highly susceptible to degradation when exposed to stored product. For example, bare steel wires may be used in acid storage areas or bare aluminum wires may be used in areas storing caustics. Correspondently, if the stored liquid is not corrosive to metals, the wires must be coated with a degradable material, such as rubber coatings in areas storing aromatic solvents. The wires in turn are connected to an electrical sensing device that passes a current through them to evaluate their electrical properties. Any degradation of the wire or its coating will result in a significant change in the circuit resistivity, thus indicating the existance of a product leak or spill.

Electrical resistivity sensors are applicable for either dry or wet (in groundwater) applications. Ambient temperature and soil moisture should have minimal effects on sensors of this type, particularly in applications involving coated wires. The drawbacks of these types of leak detection devices include the following:

Figure 2.5-1

Typical Applications of a Leak Monitoring System Based on Thermal Conductivity



Source: Reference 1

- Once a leak has been detected, the sensing wire must be replaced.
- They cannot be used in a previously contaminated well or soil unless the contamination has been removed. Otherwise they will rapidly deteriorate and require replacement.

The control units associated with electrical resistivity sensors can be designed to interface with audible alarms, visual alarms (e.g., indicator lights), control equipment such as pumps or valves, and computer controls. Occasional checks of systems of this type would be required to insure that the power supply and all controls are in working order.

Gas Detectors [4]. Gas detectors are available to detect a large number of combustible and non-combustible gases and vapors. These types of devices are generally applicable in areas of permeable soil or backfill, where gases and vapors are likely to migrate easily. Gas detectors are particularly applicable in instances where the stored product is highly volatile and the storage area (excavation) is relatively dry (free of groundwater).

There are a wide variety of both portable and permanent gas detection devices available that may be operated in conjunction with audible or visual alarm systems.

Sample Collection. Sample collection typically involves collecting samples from a well in the excavation area. Sample collection is an accurate but expensive method of leak detection that is particularly applicable in areas of high groundwater where direct groundwater contamination is of concern. Sample analysis can be performed using any of several techniques such as mass spectrometry and gas chromatography; therefore sample collection can be used to detect any stored product. However, sample collection is an intermittent as opposed to a continuous monitoring technique; sample cannot be collected 24 hours a day, 365 days a year. Therefore, sample collection may not be as desirable a monitoring technique as those described above.

4. Tank Excavation Monitoring Systems

There are several types of leak monitoring systems which may be employed using the leak sensors or detection techniques described above to detect leaks in or around underground tank storage areas. These system types include the following:

- Wire grids.
- Observation wells.
- U-tubes.

Table 2.5-2 summarizes the applicability of the types of leak sensors of detection techniques described above to these types of leak monitoring systems.

Wire Grids. This type of leak detection system employs electrical resistivity sensors in a wire grid located either within or just outside the containment region (e.g. just inside or outside the containment area synthetic liner). The wire grid is connected to a mini-computer that continuously monitors the electrical properties of each wire in the grid. If a leak occurs, the mini-computer can determine which wires in the grid have had their electrical properties altered, thereby identifying the location and extent of the leak. A drawback of this type of system is that is is susceptible to disabling by a spill. The insulation around the grid wire is dissolved, thereby registering a change in resistivity.

Observation Wells. Observation wells are most commonly used in areas of high groundwater, where the underground tank is likely to be anchored in the groundwater during normal operation. They may employ any of the types of leak sensors described above to provide continuous leak surveillance. An example of an observation well installation is shown in Figure 2.5-2.

Observation wells typically consist of a 4 inch diameter (schedule 40) PVC pipe driven into the tank excavation. The wells are constructed with a well screen long enough to provide a length of 5 feet or more above the water table, or to the well cap, and extending a minimum of 5 feet into the groundwater or 2 feet below the tank bottom, whichever is greater. Well screens typically have a slot size of 0.02 inches, and are extended to grade and covered with a water proof cap which is capable of being sealed.

U-tubes. A U-tube typically consists of a 4 inch diameter (schedule 40) PVC pipe installed as shown in Figure 2.5-3. The horizontal segment of the pipe is half-slotted (typical slot size – 0.06 inches), wrapped with a mesh cloth to prevent backfill infiltration, and sloped (pitched) toward the sump with a slope on the order of ¼ inch per foot. At the higher end of the pipe there is a 90 degree sweep to a vertical pipe that is extended to grade. At the other (lower) end of the hori-

Table 2.5-2

Applicability of Types of Leak Sensors in Tank Excavation Areas

Sensor Type	Sruveillance Method		
	Observation Wells	U-tubes	Wire Grids
Thermal Conductivity	X	X	
Electrical Resistivity	X	X	X
Gas Detectors	X	X	
Sample Collection and Analysis	X	X	

zontal pipe there is a tee connection with a vertical pipe; this vertical section is extended to grade, and extended 2 feet below the tee to act as a collection sump. All vertical pipe sections are unperforated, and the bottom of the sump is sealed so as to be leak proof. All openings to grade are provided watertight caps capable of being sealed.

The U-tube is a relatively new design that has not been extensively tested in the field. It appears to offer an economical method for monitoring and recovery of leaks and spills at underground installations. When the U-tube is installed without an underlying impervious liner it functions on the assumption that a leak will trickle downward along the exterior surface of the tank and drip off the very bottom directly into the U-tube. When installed with an underlying impervious liner, the U-tube will collect all liquids moving downward through the soil in the vicinity of the tank including rainwater. This provides positive assurance of collecting a leak from a tank but presents a problem with removal of rainwater which floods out the system.

U-tube monitoring systems, as shown in Figure 2.5-3, are most effective in areas of low groundwater, where it is unlikely that the tank will be exposed to groundwater during normal operation. However, U-tube installations can be used in conjunction with observation wells in areas where the groundwater table level is known to fluctuate to a level above the bottom of the storage excavation.

U-tubes may employ any of the leak detection devices discussed above to provide continuous surveillance of the storage installation.

C. AREA-WIDE SURVEILLANCE METHODS

Area-wide surveillance methods include the use of monitoring wells and the use of dyes or tracers. These methods are relied upon to investigate or pinpoint the source of a known leak or spill.

1. Dyes and Tracers

Dyes and tracers may be used as investiative tools to track down a source of groundwater contamination. The technique consists of injecting a strong dye or tracing material into a storage tank suspected of being the source of the contamination and monitoring the point where the contamination was first discovered for the appearance of the dye or tracer. A variety of dyes and tracers are available and include organic and fluorescent dyes, metallic tracers, ultraviolet tracers, and radioactive tracers. The use of dyes and tracers is governed by the prohibitions and limitations of the New York State DEC Ground Water Effluent Standards (Title 6, Official Compilation of Codes, Rules and Regulations, Part 703).

Rhodamine B is a fluorescent dye generally recomended for time-of-travel and dispersion measurements. Fluorescein and Rhodamine dyes are also typically used for groundwater applications. Pontacyl Pink is a good tracer dye, but is usually more costly than the others. In addition, detection of this dye requires a fluorometer [8].

Techniques that utilize radioactive tracers as detection elements may also be used to pinpoint the source of an underground spill. These techniques consist of injecting a small amount of a radioactive material such as tritium into the underground storage tank or pipeline and using a detection device to track its movement through the soil or groundwater [13]. However, there are a number of problems associated with the use of radioactive tracers including the following:

- A license or approval from the U.S. Department of Labor or the Nuclear Regulatory Commission will be required before such materials can be used.
- There are portential ecological and health hazards associated with the use of radioactive materials in this manner. Whatever materials are injected into a leaking tank will enter and remain in the environment, possibly generating a problem more serious than contamination of the environment with the stored product.

Monitoring techniques using dyes and tracers are often unsuccessful for several reasons:

- If only vapor is found at the discovery point, the dye or tracer may be useless [6].
- The dye or tracer may be absorbed by the soil or bleached by chemicals in the soil before it reaches the point of discovery [6].
- If underground flow is very slow, the site will have to be monitored for a long time to detect any leaked dye or tracer [6].
- The dye or tracer may contaminate underground water supplies [6]
- The dye or tracer may contaminate the product [6].

2. Monitoring Wells

Monitoring wells are typically employed as areal surveillance tools; they are used to investigate the movement of either a liquid or a gas in the ground.

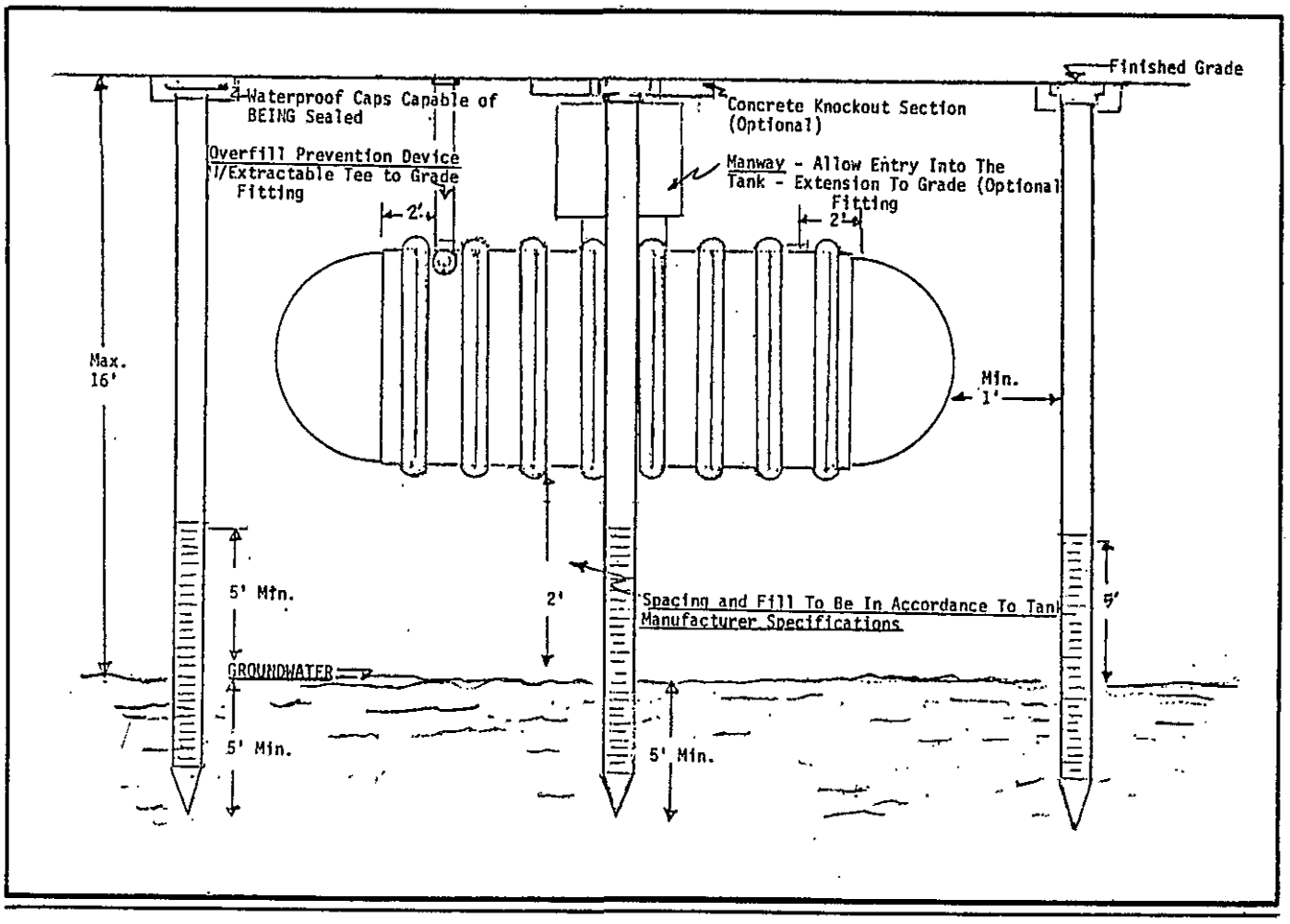
There are two basic types or categories of monitoring tht can be conducted using monitoring wells. These are:

- Detective monitoring, which establishes the presence or absence of contaminants and the need for further monitoring.
- Interpretative monitoring, which determines the extent of contamination.

Detective monitoring can be conducted using contaminant sensing devices such as those described earlier in this chapter. Interpretative monitoring, on the other hand, typically requires a sample collection and analysis.

Figure 2.5-2

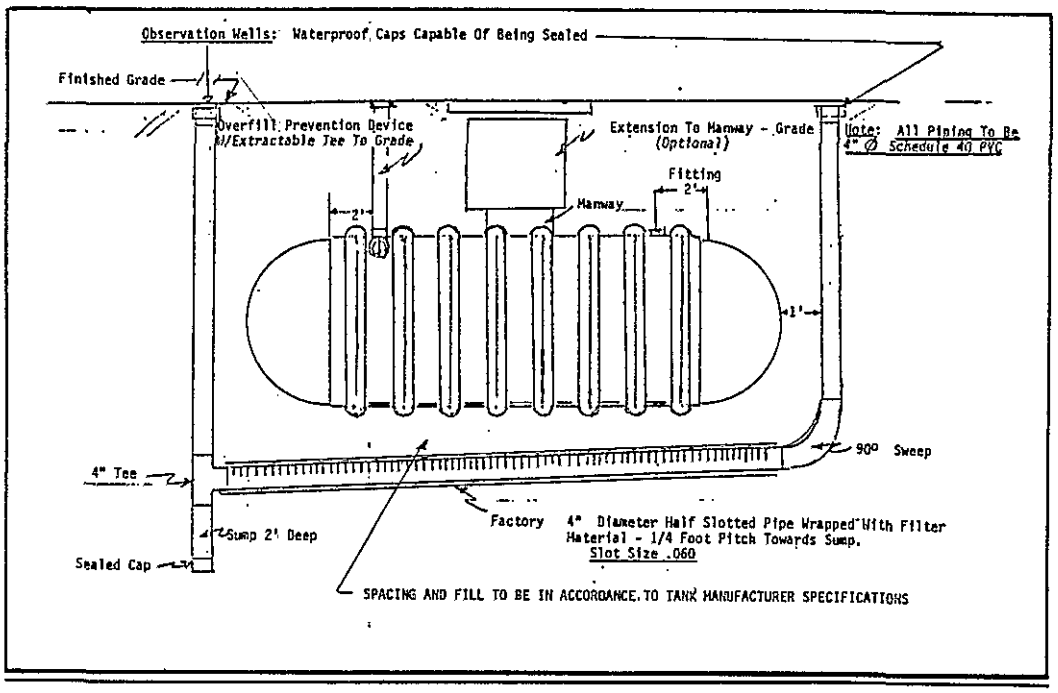
Examples of Observation Wells. Each Well Consists of 4" Perforated PVC Pipe, Driven at Least 2 Feet Below the Bottom of the Tank and at Least 5 Feet into the Groundwater



Source: James H. Pim, Suffolk Cty. (N.Y.) Dept. of Health Services

Figure 2.5-3

Example of a U-Tube Installation



Source: James H. Pim, Suffolk Cty (N.Y.) Dept. of Health Services

In the effective administration of a monitoring program using wells, it is important to have some understanding and appreciation of hydrogeology and its limiting influences on areal surveillance. Monitoring the movement of a contaminant in the soil or groundwater is completely different from monitoring a surface water or an air pollution plume; the main differences are the unpredictability and the difficulty and expense of obtaining representative data.

A listing of the type of data necessary to develop an adequate monitoring well program is given in Table 2.5-3. These data lead to the key item in deciding the location and depth of any monitoring wells that must be driven: a determination of the location and flow pattern of the groundwater and the contaminant.

The limitations of monitoring well techniques include the following:

- A monitoring well is used to sample a very small part (a point) of the soil or groundwater, thereby limiting its representativeness to the quality of the soil or groundwater in the immediate vicinity of the well.
- The extraction of samples from wells may be difficult due to the tightness of the geological formation or the depth to the groundwater.
- Determination of the groundwater flow rate and direction are prerequisites to determining the placement of groundwater monitoring wells. Drilling and measurements of the groundwater surface may be necessary.
- Groundwater flow rates are extremely slow (typically varying from one foot per day to much less), resulting in a correspondingly slow change in water quality at a particular well. This phenomenon could require data collection over long periods of time (months or years).

The attempt has been made here to emphasize the fact that the design and construction of a monitoring well program can be a complicated undertaking. For more detailed information see references 10, 11 and 12.

Vapor Wells. Vapor wells or sniff wells may be used to detect or monitor the presence of hazardous gases or vapors in unsaturated soil. That is, these types of wells may be used in permeable soils in the region above the groundwater table where vapors or gases are more likely to migrate.

Vapor wells typically employ gas detectors on permanent probes or portable gas sampling devices to monitor for gaseous contaminants. These types of devices will detect a large number of combustible and non-combustible gases and vapors. It should be noted that many contaminants have odors that can be manually detected, even at low concentrations. Gasoline, for example, can be detected by smell at concentrations as low as 0.1 *mg/l (of water)*.

Vapor wells are an advantageous means of detecting volatile soil contaminants before they are dissolved into the groundwater. However, their primary use is in indicating the presence of a contaminant. Once contamination has been detected, the vapors will remain present until cleanup; another monitoring technique (e.g. sample collection) will be required for further monitoring until that cleanup occurs.

A typical vapor well installation is shown in Figure 2.5-4.

Groundwater Monitoring Wells. Groundwater monitoring wells, or wet wells, may be used to detect or define the movement of a spilled or leaked substance in a groundwater table.

These types of wells are typically constructed of a PVC well casing that is screened or perforated in the region that is being sampled. The material used to fill the well borehole must be permeable to allow water to flow into the screened area of the casing. The well may be monitored using instruments such as the sensors described above, or samples may be collected manually for laboratory analysis.

There are various types of groundwater monitoring wells that may be used to detect and define groundwater contamination. These include the following:

- A well screened or open over a single vertical interval.
- A well cluster.
- A single well with multiple sample points.

These advantages and disadvantages of these configurations are summarized in Table 2.5-4 and described below.

Wells Screened Over a Single Interval. An example of a well screened over a single verticle interval is shown in Figure 2.5-5. This type of monitoring well configuration is routinely used to monitor groundwater contamination. However, a single well screened in such a manner is not effective in providing information on the vertical distribution of a contaminant.

Well Clusters. Investigators have used well clusters to define the vertical distribution of a contaminant in the groundwater. As shown in Figure 2.5-6, each cluster consists of a group of closely-spaced wells completed at different depths. From these wells, water samples that are representative of different levels in the groundwater table can be collected. Thus, careful placement of well clusters will allow delineation of both vertical and areal contaminant distribution. However, regardless of the selected depths of the wells in each cluster, there will remain unsampled regions through which contaminant may pass undetected.

Table 2.5-3

Types of Site Data Needed to Design an Appropriate Groundwater Monitoring Program

Geologic:

- surface geology (topography and type/depth of overburden)
- lithology of aquifer
- type of geology formation (local stratigraphy and structure)

Hydrogeologic:

- depth to water table
- water-table contours
- thickness of aquifer(s)
- relative hydraulic heads, if more than one aquifer
- annual precipitation
- aquifer permeability and porosity

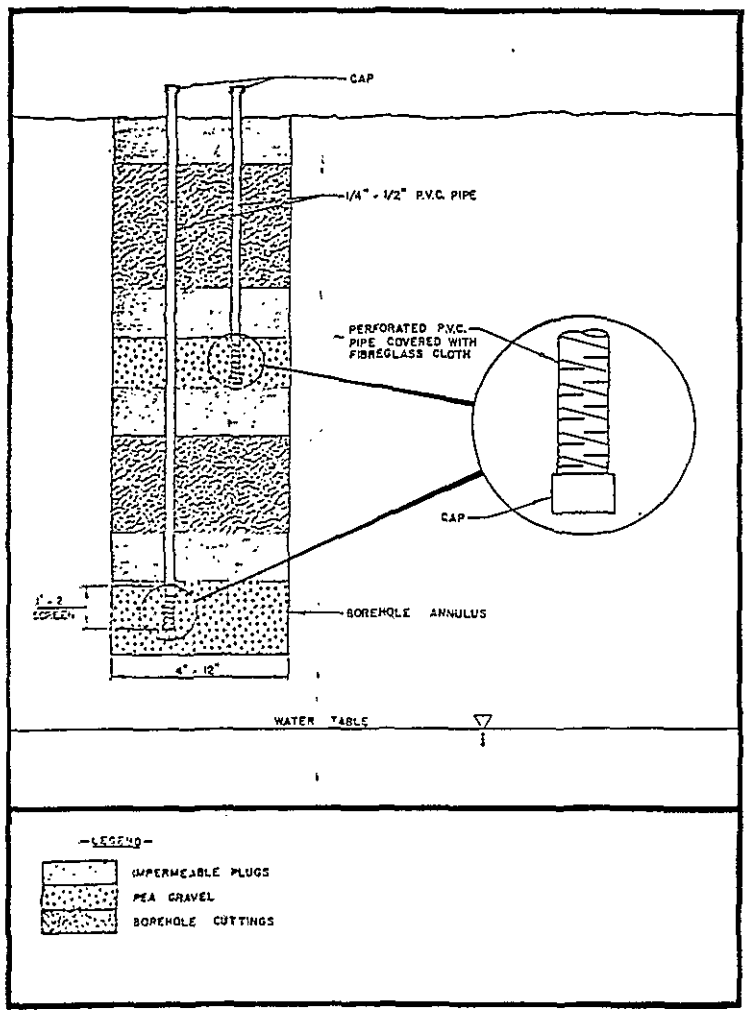
Geochemical:

- Background water quality
- chemistry of geologic formation
- presence of other sources of chemical or biological contamination.

Source: Reference 10

Figure 2.5-4

Typical Wells for Continuous Gas or Vapor Monitoring



Source: Reference 4

Table 2.5-4

Types of Groundwater Monitoring Wells

Type of Well	Advantages	Disadvantages
Well Screened or Open Over a Single Vertical Interval	Can provide composite groundwater samples if screen covers saturated thickness of groundwater table.	No information is given on the vertical spread of the contaminant.
		Improper completion depth can cause error in determining the spread of contamination.
		Screening over much of the aquifer thickness can contribute to vertical movement of contaminant.
		The contaminant may become diluted in the composite sample, resulting in lower-than-actual concentrations.
Well Clusters	Excellent vertical sampling made possible if sufficient number of wells are constructed.	If only a few wells are installed, large vertical sections of the aquifer are not sampled. Artificial constraint on data by completion depths.
	"Tried and true" methodology, accepted and used in most contamination studies where vertical sampling is required.	Small diameter wells can be used only for monitoring. They cannot be used in abatement schemes.
	Low cost if only a few wells per cluster are involved and if the drilling contractor has equipment suitable for installation of small-diameter wells (1-4 inches in diameter).	In small-diameter wells, development and sample collection become tedious and difficult if water is below suction lift.
Single Well-Multiple Sample Points (Nested Well)	Excellent information gained on vertical distribution of the contaminant.	Relatively expensive.
	If necessary, well diameter is large enough for use with pumping equipment.	Proper well construction and sampling procedures are critical to successful application.
	Sampling depths are limited only by the size and lift of the pump.	It is possible to skip large sections of the groundwater table and thereby miss the contamination plume.
	Rapid installation possible.	

Source: Reference 10.

Single Well – Multiple Sample Points. Another method used to provide sampling at multiple levels in the groundwater table is to use multiple sampling points in the same well. This type of monitoring well is called a nested well. An example of such a well is shown in Figure 2.5-7. This technique requires great care in construction of the well and isolation of the various sampling depths.

Another method has been recently developed by the Suffolk County, N.Y. Health Dept. It involves the use of a hollow stem auger to drill a sampling well which is first pumped and sampled at the deepest desired level. The screen is then withdrawn to the next sampling level, pumped and sampled again. The process is repeated until the top of the water table is reached. The well screen is usually set there. [17]

D. RECOVERY WELLS

Recovery wells may be used to recover oil or any other hazardous liquid that has been spilled and is floating on the groundwater table. Such wells are located so as to take advantage of natural gradients or induced gradients in the groundwater table in drawing out the contaminated water. Through judicious placement and operation of recovery equipment, the spill can be concentrated in one of a few recovery sites.

The factors that must be considered when establishing a recovery well program include:

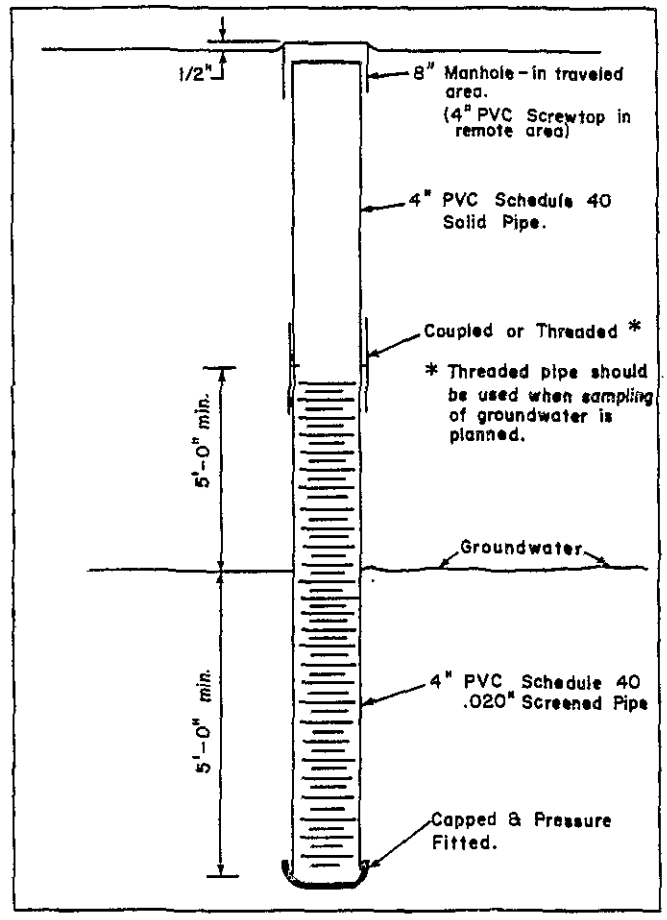
- The required pumping rate to recover product from the groundwater.
- The establishment of a well network that insures adequate coverage of the spill.
- The prevention of soil contamination during recovery operations.
- Existing environmental and public health standards which will be used to determine when spill recovery operations have been completed satisfactorily.
- The required depth of the recovery well.
- The geologic formation.
- The required well diameter.

The information required to adequately address these factors is generally obtained through separate pumping tests and through consultation with a hydrogeologist [7]. Typical single pump and two-pump recovery systems are shown in Figures 2.5-8 and 2.59 respectively.

E. EXAMPLES

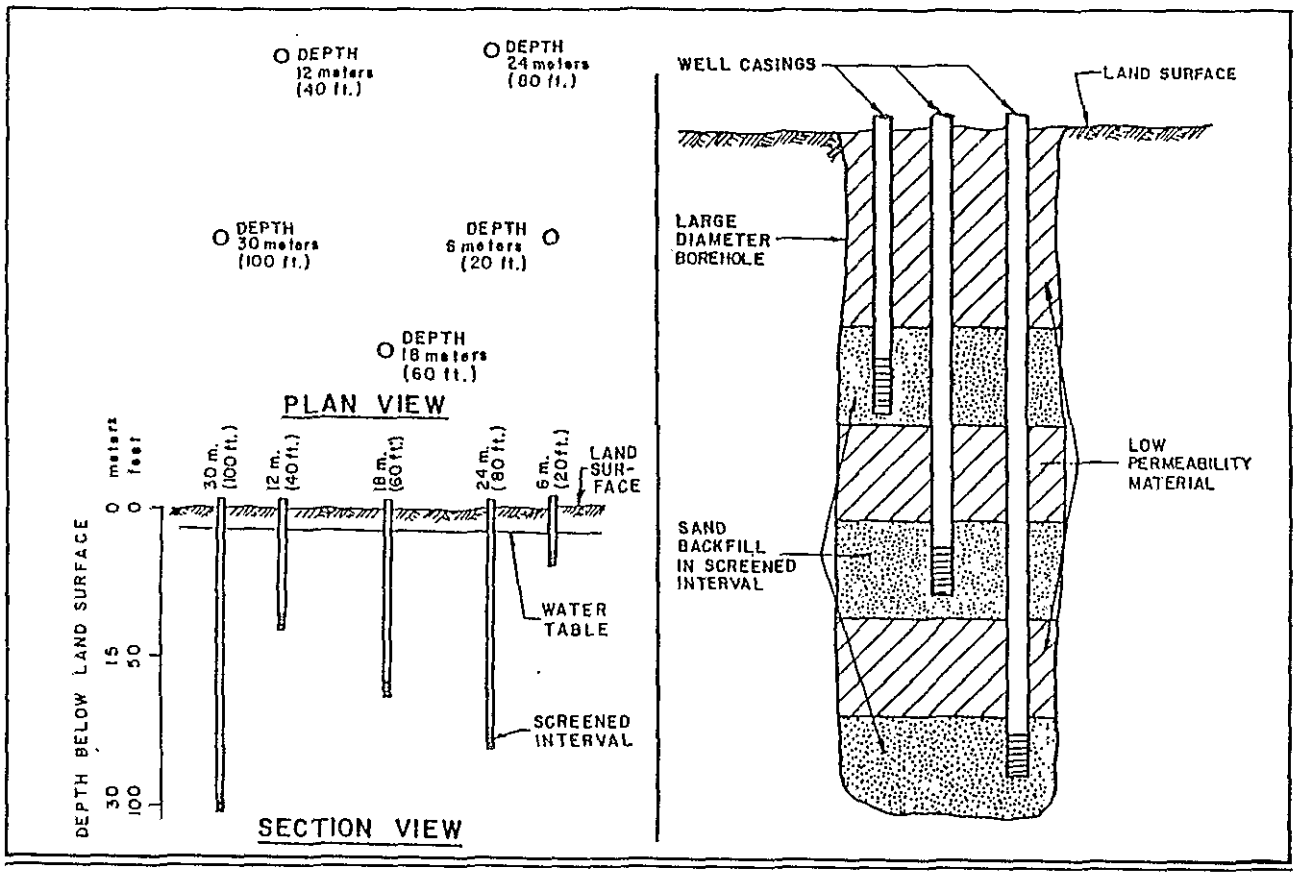
A partial list of manufacturers of leak detection systems and devices is presented in Table 2.5-5.

Figure 2.5-5
Typical Single Monitoring Wet Well



Source: Lawrence Peterec, P.E., New York State Department of Transportation, Oil Spill Prevention and Control Division.

Figure 2.5-6
Typical Wet Well Cluster



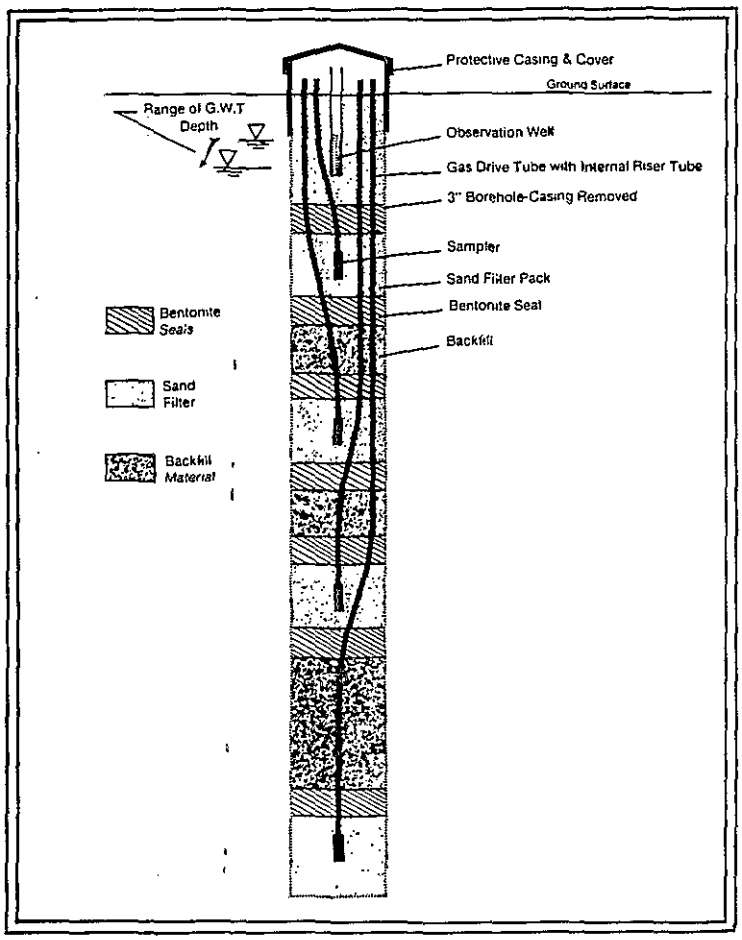
Source: Reference 10.

Table 2.5-5

Leak Detection System Manufacturers

Pollulert System	Pollullert System Mallory Components Group P.O. Box 706 Indianapolis, IN. 46206 (317) 261-1130
Leak-X Gas and Liquid Monitoring Systems	Leak-X Corporation 560 Sylvan Avenue Englewood Cliff, N.J. 07632 (201) 569-8989 (212) 822-6767
McTighe Hydro-carbon Detector	McTighe Industries, Inc. P.O. Box 370 Huntington, N.Y. 11743 (516) 549-0050

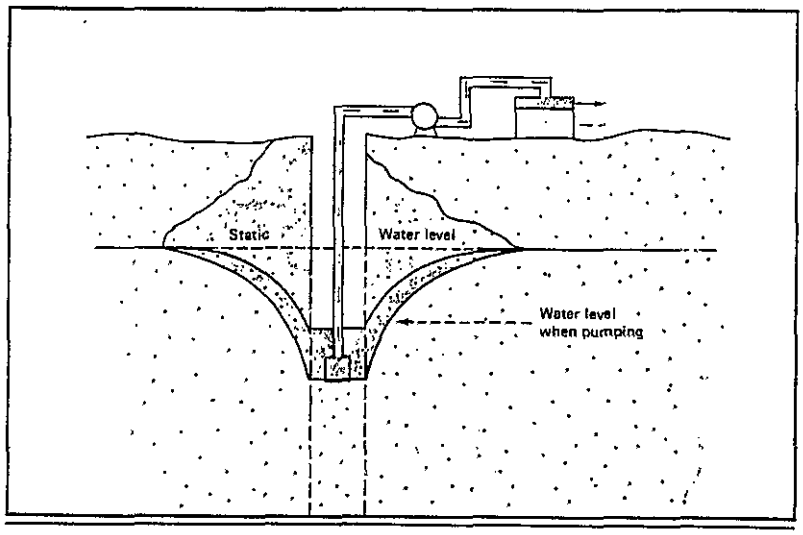
Figure 2.5-7
Schematic of a Typical Nested Monitoring Well System



Source: Reference 15.

Figure 2.5-8

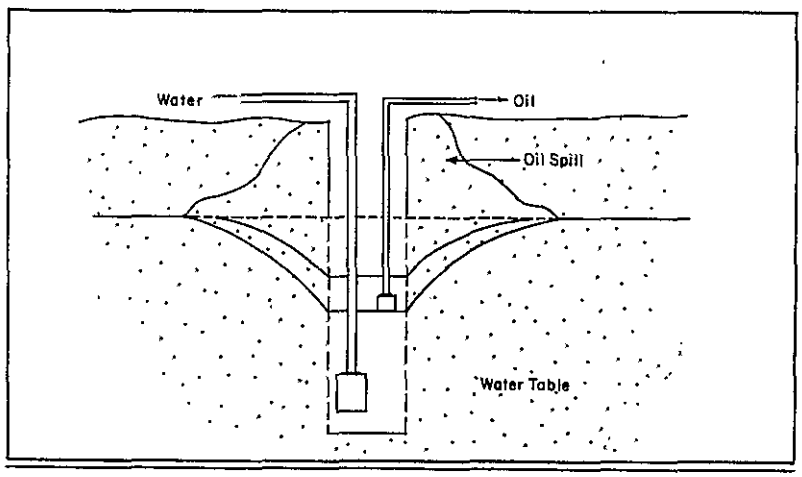
Typical Single-Pump Recovery System



Source: Reference 7.

Figure 2.5-9

Typical Two-Pump Recovery System



Source: Reference 7.

References

1. Emhart Industries, Inc., *Pollulert System*, Form No. P-100, Emhart Industries, Inc., Mallory Components Group, P.O. Box 706, Indianapolis, Indiana 46206, April, 1980.

2. Emhart Industries, Inc., *Mallory's New Pollulert System*, Form No. P-101, Emhart Industries, Inc., Mallory Components Group, P.O. Box 706, Indianapolis, Indiana 46206, April, 1980.

3. Leak-X Corp., *Leak Detection Cables*, Leak-X Corp., 560 Sylvan Avenue, Englewood Cliffs, N.Y. 07632.

4. Leak-X Corp., *Hazardous Leak Detector*, Leak-X Corp., 560 Sylvan Avenue, Englewood Cliffs, N.Y. 07632.

5. McTighe Industries, Inc., *McTighe Hydrocarbon Detector*, McTighe Industries, Inc., P.O. Box 370, Huntington, N.Y. 11743.

6. National Fire Protection Association, *Underground Leakage of Flammable and Combustible Liquids*, NFPA 329, National Fire Protection Association, Batterymarch Park, Quincy, MA 02269, 1977.

7. Pastrovich, T.L., Baradat, Y., Barthel, R., Chiarelli, A., Fussell, D.R., *Protection of Groundwater From Oil Pollution*, Prepared by CONCAWE's Water Pollution Special Task Force No. 11, CONCAWE, Den Haag, Netherlands, April, 1979.

8. Wilson, Jr., J.F., *Techniques of Water Resources Investigations of the United States Geological Survey, Chapter A12, Flourometric Procedures for Dye Tracing*, U.S. Department of the Interior, available from U.S. Government Printing Office, Washington, D.C.

9. American Petroleum Institute, *Recommended Practice for Bulk Liquid Stock Control at Retail Outlets*, API Publication 1621, American Petroleum Institute, 2101 L Street, N.W., Washington D.C. 20037, 1977.

10. Fenn, D., Cocozza, E., Isbister, J., Braids, O., Yare, B., Roux, P., *Procedures Manual for Ground Water Monitoring at Solid Waste Disposal Facilities*, EPA/530/SW-611, U.S. Environmental Protection Agency, 401 M Street, S.W., Washington D.C. 20460, August, 1977.

11. Edward E. Johnson, Inc., *Ground Water and Wells, A Reference Book for the Water-Well Industry*, Edward E. Johnson, Inc., St. Paul, Minnesota 55104, 1966.

12. Freeze, R.A., Cherry, J.A., *Groundwater*, Prentice-Hall, Inc., Englewood Cliffs, N.J. 07632, 1979.

13. Hasse Tank GmbH & Co., KG, *Hasse: The Double Wall, Self-Monitored Tank*, Betco Associates, P.O. Box 350, Closter, N.J. 07624.

14. Clemmer Industries, Ltd., *Double-Walled Storage Tanks*, Clemmer Industries (1964) Ltd, 446 Albert Street, P.O. Box 130, Waterloo, Ontario N2J4A1, August, 1981.

15. Cadwagan, R., Barvenick, M., "Monitoring Device Simplifies Sample Collection", *Water Well Journal*, National Water Well Association, 550 W. Wilson Bridge Road, Suite 135, Worthington, Ohio 43085, Vol XXXIV, No. 11, November, 1980.

16. Fluid Components, Inc., *Heat Actuated Liquid Level Controller, Model 8-66*, Bulletin 8-66/1, Fluid Components, Inc., P.O. Box 1165, Canoga Park, California 91304.

17. Pim, James, Suffolk County (N.Y.) Department of Health Services, personal correspondence regarding hollow stem auger well.

Part II

CHAPTER 6: TESTING AND INSPECTION OF UNDERGROUND STORAGE SYSTEMS

A. INTRODUCTION

Every business that handles bulk liquids is susceptible to inventory losses. Product losses result in an obvious monetary loss. However, when these losses are caused by leaks in underground tanks or piping, not only is money lost, but serious evironmental and safety hazards are often created. For instance, if an underground leak remains undetected, one or more of the following problems may develop:

- The leaking substance or its vapors can find their way into the basements of nearby buildings. If the substance is flammable or reactive, it may create a fire or explosion hazard.
- The leaking substance can seep into sewer systems, thus spreading the contamination to other areas, ofter far away from the source of the leak.
- The leaking substance or its vapors can seep into the groundwater, thus contaminating drinking water supplies.

Often the contamination caused by leaking underground tanks is not detected for months or even years, at which point it may have become widespread and very difficult and expensive to correct. It is therefore necessary to detect tank leaks early before they have a chance to spread and cause extensive damage. Regular testing and inspections of tank and piping are ways to insure that leaks are prevented, or detected early if they should occur.

> Historical Note: The technical difficulty inherent in determining tank tightness led to a target of 0.05 gallons per hour (1 gallon per day). If it could be determined that a tank was leaking more than 0.05 gph, it was a leaker. Less than 0.05 gph was beyond the scope of measurement ability and the tank was considered tight. Present technology is imprecise in detecting leaks smaller than 0.05 gph. This is the standard embedded in NFPA 329, Final Test (renamed Prescision Test).

B. TANK TESTING METHODS

As mentioned in Chapter 5, the term testing as used in this text refers to those tank or pipe leak detection methods that determine at a single point in time if a tank or pipe is either tight or leaking. These are to be distinguished from monitoring techniques, as discussed in Chapter 5, that provide either continuous surveillance for early leak detection, or area-wide surveillance to investigate the source of a leak or spill.

Tests to determine the tightness of underground storage tanks and piping should be conducted under the following conditions:

- As part of routine inspection and maintenance requirements.
- When there is a suspicion of leak because of stock inventory losses.
- When leak monitoring indicates ground contamination, but the actual cause is not determined from surface observation.
- When there is an accumulation of water in the tank.
- Upon completion of construction.

The tests that are usually performed consist of filling the tank with a fluid, usually water, or air until a certain pressure is reached, and observing if a loss of the fluid or pressure occurs due to an existing leak. Regardless of the testing procedure involved, it is important that underground tanks be tested in a condition as close as possible to normal operating conditions without uncovering the tanks. There are several reasons for this, including the following:

- Uncovering and exposing the tank can very easily cause a leak that did not previously exist and its discovery might imply the problem is solved when, in fact, it is not [6].
- Uncovering underground tanks or piping is costly and time consuming [6].
- Excessive pressures or tests using nonrepresentative liquids may indicate leaks where none existed, or conceal exisiting leaks [6].
- Inadvertent pressurization during testing may rupture the tank.

A number of testing methods may be used to detect leaks and at the same time ascertain the tightness of a tank and its associated piping. Each method has particular applications and limitations. The methods that apply to underground (buried) tanks include the following:

- Pneumatic (air) testing.
- Hydrostatic (standpipe) testing.
- The Kent-Moore test (Heath Petro-tite)
- The "Sunmark" leak detection test.
- Laser-beam leak detection.
- The J-tube manometer test.
- The Arco leak test.

In addition, certain tests using air, water, or instruments may be performed on the piping. These tests, which include suction piping testing and discharge line testing, are discussed in Section C of this chapter. The characteristics and accuracy of these various testing methods are summarized in Table 2.6-1, and discussed in the following text.

Table 2.6-1

Comparison of Various Leak Detection Tests for Underground Systems

Type of Test	Description	Applicability	Accuracy	Relative Cost	Remarks
Pneumatic test	Air or other gas is used to pressurize the system. A drop in pressure is indicative of a leak.	Underground tanks and piping systems	Pneumatic tests are often inconclusive.	Low	Air pressure tests are not recommended for tanks and piping systems containing flammable or combustible liquids. With air testing, there is also a serious danger of rupturing the tank.
Hydrostatic (standpipe) test	Water (or another liquid) is used to pressurize system. A drop in pressure is indicative of a leak.	Underground tanks and piping systems.	Hydrostatic tests are more sensitive than pneumatic tests.	Low	This procedure will be useful where it is desired to check the tightness of any underground storage tank and its connected piping for gross leaks. Does not compensate for thermal expansion or contraction of the stored liquid.
Kent-Moore test	Highly accurate type of hydrostatic test.	Underground tanks and piping systems.	0.05 gal/hr	High	Test is approved by the National Fire Protection Association (NFPA). Requires well trained operator. Requires several hours for completion of accurate test.
J-tube manumeter test	Manometer-type instrument that detects leaks by measuring small changes in product level.	Underground tanks.	Detects change in liquid level as small as 0.02 inches. Accuracy depends upon the time period over which the level charge is observed (leak of 0.02 inches over 1 hour is larger than leak of 0.02 inches over 10 hours in same tank.	Medium	Easy to transport, assemble and operate. Does not require a contractor crew to operate. Several tanks can be tested simultaneously. Tank, piping and dispenser openings need not be sealed
Sunmark leak tester	System operates on the principle of hydrostatic head and uses an analytical balance to measure small changes in liquid mass displacement.	Underground tanks and piping systems.	0.03 gal/hr	High	The time for the equipment to be set up and the test to be completed is at least 2 hours. Compensates for temperature and pressure.
Laser-beam leak tester	An experimental device for detecting leaks that operates on the principle of laser interferometry.	Underground storage tanks.	Threshold of detection has not yet been established.	Probably high when marketed	API has specified that it wants the device to be able to detect leaks as small as 0.05 gal/hr.
ARCO HTC leak tester	Systems use a float and light-sensing system to detect volume changes.	Underground storage tanks and their distribution lines.	Less than 0.05 gal/hr.	Medium	System works on tank 75% full. Therefore, it does not detect leaks in the upper 25% of the tank or in the fill line.

Table 2.6-1 continued

Suction piping test	Pump suction piping may be tested by pressuring with air or the liquid product in a similar way as tanks. A drop of pressure in excess of 5 psi per miniute is indicative of a leak.	Piping system	0.05 gal/hr	Low	Conditions such as pump cavitation and pump overspeed which are indicative of a leak in the suction piping should be observed prior to conducting the test. Above conditons may also be caused by a leaking check valve.
Discharge piping test	Pump discharge piping may be tested by pressurising with liquid product. A drop of pressure in excess of 5 psi per minute is indicative of a leak.	Piping system.	Test is inconclusive and will detect gross leaks only.	Low	Any pressure drop of less than 5 psi per minute may be caused by cooling or a small check valve leak.

1. Pneumatic Testing

Air pressure (pneumatic) tests can be performed when: (1) non-flammable liquids are stored; (2) water or other suitable liquid is unavailable; and (3) water in the tank may contaminate the product stored. Air testing should be avoided if the tank is badly corroded [3]. Low-pressure storage tanks as well as atmospheric tanks can be tested with this method except that low-pressure tanks are tested at slightly higher pressures (i.e. up to 15 psig.), depending upon their design [3].

The primary disadvantage of pneumatic tests is that they are not sensitive enough to detect slow leaks and their precision is limited by the readings of a stick gauge and the amount of product in the tank. Greater accuracy can be achieved, however, when the tank is full or nearly full. Air pressure varies greatly with temperature and also with the vapor pressure of the liquid stored in the tank. Pneumatic tests are extremely hazardous and their use should be discouraged. There has been a fatality from pneumatic testing: a faulty gauge led to overpressurization and explosion of a tank. NFPA 329 states that "pressure tests with air shall not be used on tanks." [8]

Another important drawback of the pneumatic testing method is that large amounts of product may be forced out of the tank during the test without detection. For example, a 6000 gallon tank half-full with product and pressurized to 5 psig with air would lose over 78 gallons of product before a 0.5 psi loss in pressure can be detected. Pneumatic tests are not capable of compensating for thermal expansion or contraction that may mask large leaks. They may even cause a leak by overpressurizing the tank. Air pressure is acceptable for piping tests, however, and it is routinely used at levels of 50 psig with no adverse effects on sound piping systems. OSHA regulations require air pressure testing of submerged transfer pump piping every five years at maximum operating pressure.

2. Hydrostatic (Standpipe) Testing [6]

Hydrostatic tests involve pressurization of a storage system by connecting a standpipe to a completely filled tank. An additional head is placed on the tank by filling the standpipe, generally to an elevation such that a pressure of 5 psi is exerted at the bottom of the tank. A leak is detected by observing a drop of the liquid level in the standpipe. The magnitude of the leak can be determined by measuring this level drop. Hydrostatic tests are more accurate than pneumatic tests, but they still contain several sources of error. The expansion of the tank due to the pressure exerted during the test produces an apparent loss of product. The magnitude of this apparent loss depends on the tank deflection and can be substantial. Table 2.6-2 shows the magnitude of this loss for varying deflections on a given size tank.

The procedure will be useful where it is desired to test an underground storage tank and its connected piping for gross leaks. It is not adequate for detecting slow leaks nor for determining that a tank system is tight.

Often water is substituted for the product stored in the tank. However, water is more viscous than many hazardous substances (gasoline, light oils, etc.), and thus will leak out at a slower rate. This will bias the measurement of the actual leak rate.

Hydrostatic tests do not compensate for thermal expansion or contraction of the test liquid as it exchanges heat with the tank and surrounding soils. If the test liquid is colder than the stored product, it will expand when heated and thereby raise the level in the standpipe. This will also bias the level measurements on which the test is based. For example, if the contents of 6000 gallon tank are warmed 2°F, there will be a 7.2 gallon increase in volume. If the hydrostatic test is run for 2 hours, a leak of almost 90 gal/day will not be detected because no change in liquid level will occur.

In situations where an underground storage tank can be removed from service for several days, a hydrostatic test in which the test liquid is allowed to reach thermal and mechanical equilibrium with the tank can be very sensitive in detecting small leaks. The ability to isolate and test a tank over a period of several days may be likely in an industrial storage situation, whereas it may be impractical in testing gasoline service station tanks. Increased accuracy is available from hydrostatic testing where a long time period can be employed to permit reaching equilibrium conditions.

3. The Heath Petro-Tite Tank and Line Testing Systems (Kent-Moore Test) [15,16]

The Kent-Moore test is essentially a hydrostatic test that compensates for temperature, pressure and viscosity variation. This enables leaks as small as 0.05 gal/hr to be readily detected. The Kent-Moore test consists of exerting a pressure head on the tank by means of a standpipe filled with the same liquid stored in the tank. This eliminates the error introduced by using a liquid of different viscosity. A pump is used to circulate the liquid in order to produce a uniform temperature throughout the tank. Using a thermal sensor, the temperature changes are precisely measured to account for expansion and contraction of the liquid. The volumetric measurements are then correspondingly adjusted for the changes in temperature. The Kent-Moore test includes a means of accurately measuring all product added or removed from the standpipe in order to maintain a constant head. By comparing the product added or drained with the volumetric changes anticipated due to temperature changes, it is possible to reliably detect a leak as small as 0.05 gal/hr.

For storage systems with submerged pumping, the Kent-Moore test must be run separately on the tank and

Table 2.6-2

Apparent Loss of Product Volume Due to Force On Tank Ends – In Gallons

END DEFLECTION IN INCHES

Tank Diameter	3/16	1/8	5/16	1/4	7/16	3/8	9/16	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4	1 1/2
48"	.488	.98	1.47	1.95	2.44	2.93	3.42								
				LINE "A"					LINE "B"						
64"	.872	1.74	2.61	3.48	4.35	5.22	6.10	6.97							
72"	1.101	2.20	3.31	4.41	5.51	6.62	7.72	8.82	11.01						
76"	1.227	2.46	3.68	4.91	6.12	7.36	8.60	9.81	12.27						
84"	1.50	3.00	4.50	6.00	7.50	9.00	10.50	12.00	15.00	18.00	21.00	24.00			
96"	1.957	3.91	5.87	7.82	9.77	11.75	13.70	15.65	19.57	23.50	27.40	31.30			
102"	2.21	4.42	6.63	8.85	11.06	13.30	15.50	17.70	22.20	26.60	31.00	35.40	39.80		
120"	3.06	6.12	9.18	12.25	15.30	18.38	21.40	24.50	30.60	36.70	42.80	49.00	55.12		
126"	3.37	6.75	10.12	13.00	16.85	20.3	23.8	27.0	33.75	40.5	47.2	54.0	60.7	67.50 Steel 3/16"	81.00 Steel 1/4"

"A" Probable limit of tank end deflection capacity increase.

"B" Limit of Maximum tank end deflection capacity increase.

Maximum Deflection Figures are Preliminary based on limited data from Tank Manufacturers and completely fluid soil conditions. Measurements were made with air pressure above ground.

Source: Reference 15

on the piping to give good results. On suction delivery storage sytems, the Kent-Moore test checks the entire system simultaneously.

The Kent-Moore test requires several hours for completion with accurate results. Generally, during he first few hours of such a test there is a drop in the standpipe level attributed to the tank expanding because of the increase in internal presure. This is compensated for by reducing the tank pressure after 2 hours to control tank expansion. It has been determined by experimentation and field testing that by reducing the tank pressure after 2 hours further tank expansion does not take place. The Kent-Moore test can usually be completed in one working day. However, it is a relatively difficult test which must be performed by a skilled technician.

Because of the extensive shut-down time requirements and the level of skill involved, the Kent-Moore test is relatively expensive to perform.

4. The J-Tube Manomenter Test [15,16]

The J-tube leak detector developed by the Ethyl Corporation and field-tested by Texaco is essentially a manometer-type instrument that is capable of measuring very small drops in product level caused by tank leakage. The J-tube consists of a large diameter leg and a small-diameter leg that cause a magnification of an liquid level change as shown in Figure 2.6-1a. The detector can be placed in a tank through a 3-inch or larger fill-pipe, and the valves can be operated while the detector is in the tank. When placed in the underground tank, the detector primes as shown in Figure 2.6-1c. If the liquid level in the tank drops during the test period, the indicator fluid will be displaced as shown in Figure 2.6-1d. The ratio of the change in the indicator level to the change in the liquid level of the tank is the magnification factor and a measure of the rate of leakage. The lower valve is closed and the reservoir valve is opened just before removing the detector from the tank. This locks the indicator fluid in place while the leak detector is removed from the tank and a reading obtained as shown in Figure 2.6-1e.

The J-tube leak detector will detect leaks that cause variations in tank product level as small as 0.02 inches [7]. For a one-hour test with the product level in the middle of an 8,000 gallon tank, a change of 0.02 inches reflects a leak rate of 2.12 gallons per hour. Accuracy is dependent on the time span of the test. If, in the example above, the time span had been for a period of 10 hours instead of one hour, the leak rate would be 0.212 gallons per hour.

Possible effects of temperature and tank-end deflection variables are reduced by careful adherence to the test procedure. Instructions on the use of the equipment state that 1°F change in product temperature during the test will negate the results. Therefore, tests conducted within 24 hours after delivery should be avoided because temperature sometimes varies within that period. When the leak test is begun 24 hours or more after a delivery, the temperature usually does not vary 1°F from the beginning to the end of the test.

Also, temperature has been found to be stable at various depths from the top to the bottom of the tank. Rejection of any test with a 1°F temperature change means that error due to temperature is kept within small limits. For example, the error in 4,000 gallons of gasoline would be less than 2.4 gallons, or in 2,000 gallons of gasoline would be less than 1.2 gallons.

Tank-end deflection is not regarded as a serious problem because no unusual pressure is applied to the tank and also because the tank has at least 24 hours to physically stabilize in the ground before the leak test starts.

Advantages of the Texaco J-tube leak detector are:

- It is relatively easy to transport, assemble and operate.
- It does not intensify existing leaks or create new leaks, since no hydraulic or air pressure is used.
- Accuracy is a function of the time span of the test. The euipment will measure major leaks in a short period of time and relatively minor leaks in a longer period of time.
- It does not require a contractor crew to operate and no tank truck delivery is requireu.
- Several tanks can be tested simultaneously.
- Underground tank, piping and dispenser openings need not be sealed.

One disadvantage of the J-tube leak detector is that it will not detect leaks above the product level in the storage tank.

While the J-tube leak detector was developed primarily for fuel storage tanks, it can be applied with other liquid products as well.

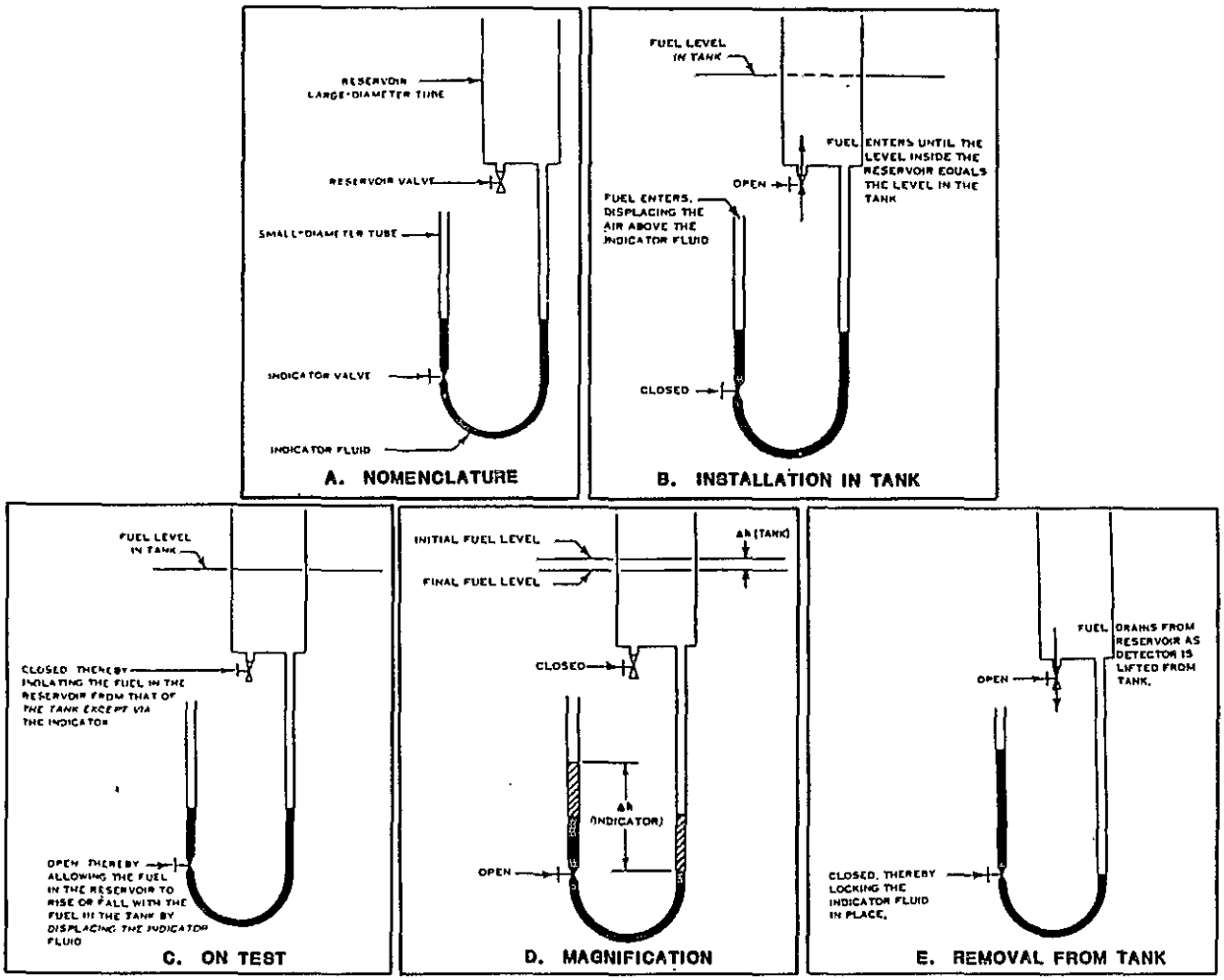
5. The Sunmark Leak Detection Test [8,9,10]

The Sunmark Industries Leak Lokator is an equipment system capable of detecting and measuring volume changes in underground storage systems. It was principally developed for use on gasoline storage tanks but could be used for other liquid storage systems as well. The equipment is capable of differentiating between piping leaks and tank leaks.

The basic equipment consists of a sensor, an analytical balance, and a chart recorder. The sensor is an open top, hollow tube filled with the liquid contained in the tank. It is suspended from the analytical balance and partially submerged in the tank liquid. As the liquid level in the tank changes, the buoyancy of the sensor also changes. This change of mass displacement measured by the analytical balance is an indication of volume changes within the tank. The chart recorder provides a graphical representation of volume change versus time.

Figure 2.6-1

J-Tube Underground Tank Leak Detector



Source: Reference 7.

The time for the equipment to be set up and a test completed on the typical service station fuel tank is about two hours. Once the equipment is set up, the actual test to determine a volume change (leak) takes about 15 to 20 minutes. The sensitivity of the test is greatest when the fluid level of the tank is at grade level, and least sensitive when it is near the center line of the tank. However, Sunmark claims it is possible to detect volume changes of 2 cc/minute (.03 gal/hr.) even at this level. When the tank is filled at or above grade level the sensitivity will be much greater than this.

The test currently compensates for temperature variations by means of a thermistor lowered to the center of the tank that measures temperature continuously during the test. Barometric pressure is also monitored continuously during the test and Sunmark claims than an air pocket equivalent to four gallons or less will have no significant effect on the result. The system is self-compensating for evaporation losses by the sensor. The sensor is filled with the fluid to be measured so that mass changes due to evaporation are proportionate between the tank and sensor.

End deflection problems associated with the Kent-Moore test are not considered for the Sunmark leak tester. Fluid levels need be brought only to the top of the tank and piping system for the Sunmark test to be started. Since it can be reasonably assumed that all tanks have been completely filled at some time previous, the volume changes associated with end deflection resulting from the unusually high head placed on the tank with the Kent-Moore test is not a factor.

Tanks of any size can be tested by the Sunmark system as long as an opening exists with a diameter of two inches or greater. A pemanent record of test results is provided by the chart recorder. The chart recorder notes the lapsed time in minutes versus the volume of liquid displaced either in or out of the tank in cubic centimeters. A vertical line on the chart indicates no change in volume and therefore a no leak condition. A leak out of the tank would be represented by a line with a positive slope and a leak into the tank, such as from a groundwater condition, would be represented by a line with a negative slope. The equipment is sensitive enough to be affected by vibrations from traffic or other causes. Although these vibrations affect the recorder significantly, they do not change the slope of the line being recorded and it is only the slope that is of interest in the application of this equipment.

6. Laser-Beam Leak Detection [12,13]

An experimental device for detecting leaks that operates on the principle of laser interferometry is currently being developed by SRI International, a California-based research and development company under contract to API. The device operates by aiming a laser beam down into the underground tank. Upon striking the liquid surface, the beam is reflected back to a detector which computes the liquid level in the tank. A change in the liquid level during the test is indicative of a leak in the tank. The tests performed to date on the device indicate that it is capable of detecting changes in liquid level in the order of microinches. However, the threshold of detection has not yet been established. The American Petroleum Institute, which is funding the development, has specified that it wants the device to be able to detect leaks as small as 0.05 gallons per hour in an instant [12].

7. The Arco Leak Test [18]

The Arco HTC Storage Tank Leak Tester uses a float and light-sensing system to detect volume changes in underground storage tanks and their distribution lines. The system can be used for any liquid whose density can be measured, and it is unaffectd by temperature changes that occur in the tank during the test. However, measurements can be taken only when the tank is inactive and contains between 70 and 82% of its volume (66-75% of liquid depth).

This leak tester consists of a float that is positioned at a particular depth in the tank and a detector that is usually attached to a support rod. The support rod is used to adjust the position of the detector and to allow insertion and extraction of the float from the tank.

In operation, the float is positioned at a calculated depth in the storage tank. This depth is a function only of the level of product in tank and the tank diameter. At this depth any changes in the liquid temperature occurring during the test do not affect the test results. This allows testing of tanks that are not at a constant temperature throughout the test period.

The detector assembly utilizes a light source/photocell system in which the light passes through a colored liquid (to the photocell). The amount of liquid in the light path changes in proportion to the volume of liquid gain or loss in the tank due to a leak. The change in light path causes a change in the amount of light seen by the photocell which is converted to a voltage and recorded on a strip chart recorder. These charts are later used to calculate the liquid volume change that occurred in the tank during the test period.

The process for testing storage tanks and their distribution lines with this system begins by inserting the tester into the tank. After the tester has been in the tank for one hour (to allow wave action to subside and all of the tester components to come into temperature equilibrium in the tank), leak testing can be started. The test procedure requires a calibration, followed by a one-hour test period followed by another calibration. This sequence is continued until two consecutive one-hour tests give the same calculated result. This can typically take four or five hours, although longer test periods are possible.

The unit is calibrated during each test by adding a known volume of liquid into the tank while the unit is in operation. This addition causes a change in the recorded voltage that is directly related to the volume added. This method of calibration corrects the results for tank size, volume present and equipment variables. Several calibrations are done during each tank test.

The primary drawback of this test procedure is that it must be conducted with the tank 66-76% full. Thus, it is not possible to detect leaks in the upper 25% of the tank.

C. PIPELINE TESTING PROCEDURES

The standards of NFPA 30 [11] require that all pipelines for underground storage systems shall be tested prior to being covered, enclosed or placed in use. These standards require either hydrostatic testing, pneumatic testing, or an approved equivalent. For more information, please refer to that code.
The following are descriptions of specific pipe testing procedures.

1. The Suction Piping Test [6]

If the pump used in moving the liquid is aboveground the supply pipe operates under a suction head and certain pumping characteristics indicate either a leaking check valve or a leaking pipe. If there is a leak, air will enter the pipe as liquid drains back into the tank through the check valve or through a pipe leak into the ground. The presence of air will be indicated by the action of the pump in the first few seconds of operation after an idle period. If the pump is equipped with a meter and cost/quantity display device such as is found in a gasoline service station, pumping of air is indicated by the display wheels skipping or jumping. Other indications of air in the suction line are:

- The pump is running but not pumping liquid.
- The pump seems to overspeed when first turned on and then slow down as it begins to pump liquid.
- A rattling sound in the pump and erratic liquid flow indicates air and liquid are mixed.

A common method of approximating the location of a leak in suction line is based on the quantity per foot that piping contains. A 1½ inch pipe, common to service stations, holds approximately 1 gallon per 10 feet, and, based on dispenser output, a rough estimate can be made as to a leak's location. For example, if a dispenser "sputters" after 30 seconds of operation.

Sample calculation:

$$30\,\text{sec} \times {}^{5\,\text{gal}}/_{60\,\text{sec}}\,(\text{dispensing rate}) \times {}^{10\,\text{ft}}/_{\text{gal}}\,(\text{pipe}) = 25\,\text{ft.}$$

Problem is approximately 25 ft. from the pump.

If any of the preceding conditions indicate a leak in the suction line, the check valve should be inspected first. Some check valves are located close to the pump inlet, others are mounted in the underground pipe just above the tank, and some may be on the end of the suction stub inside the tank. Some of those valves located in the pipe above the tank can be inspected and repaired from the surface of the ground through a special extractor mechanism installed with the valve. If not, or if the valve is inside the tank, it may be necessary to dig down to the tank to check the valve or disconnect and seal off the pipe for a pressure test.

Generally, digging down to the check valve or tank should be delayed until other more easily performed surface tests have failed to reveal the leak. If there is any doubt that the check valve seals tightly, repair it, replace it or seal it off. Then repeat the pumping test and if air is still entering the suction line, it may be assumed the pipe is leaking underground and it should be exposed for inspection. Dig carefully to avoid damage to the pipe that might make it impossible to verify whether a leak actually existed prior to uncovering.

If the pumps do not exhibit the symptoms of a leak as described above but there is still reason to suspect a pipe leak, or, if a complete system check has been performed and it is now necessary to isolate and check the piping system, individual pipe runs may be isolated and pressure tested.

2. Discharge Line Testing

Quite often pumps are located in the tank, or, on some rare occasions, just above the tank but remote from the dispensing devices. In such cases, the pipe to the dispensing equipment operates under pressure. A leak in this line will cause rapid loss of pressure after the pump is turned off. This can be checked in the following manner:

At the dispenser end of the pipe, close the emergency shutoff valve at the base of the dispensers or close any valve upstream of any hose to hold pressure at the dispenser end. The pump end can be sealed off by setting the check and relief valves in the head of the pump. The check valve is readily accessible in the manhole over the pump, and most are equipped with a screw or bolt supplied for the specific purpose of positively seating these valves for line checking. Install a pressure gauge in the line (a minimum of 3 inch dial with maximum 60 psi range should be used to clearly show gradations of 1 psi). Generally, the best location for the gauge is in the emergency shutoff valve under the dispenser where ¼ inch or other small size plugs are installed for this purpose. Start the pump, note the maximum pressure (generally 25 to 35 psi), seat the check valve, turn off the pump and observe any pressure drop. If the pressure drops more than 5 psi per minute, it indicates the probability of a leak in the line.

Repeat the test at least once to ensure against compression of entrained air. Any pressure drop less than 5 psi per minute is inconclusive as it may be caused by cooling or a small valve leak. Uncover the pipe for visual inspection if the test continues to indicate a leak.

The preceding test should not be considered conclusive. A change in temperature of the product may partially or completely mask a leak. A Kent-Moore test or other accurate testing technique is necessary to conclusively test piping integrity.

D. THE APPLICABILITY OF TANK TESTS TO THE ASSOCIATED PIPING

Small leaks (0.05 gph) in **suction** systems may be detected by the standard Petro-tite or Sunmark test. Since the tank is full and there is no impedance to flow out of the tank into the piping system, a leak will be detected.

The Arco test can be used to detect leaks in submerged turbine pump (STP) systems. After the normal tank test is run, the pump is turned on for 15-30 minutes. The tester will record any loss in product. Heath Petro-tite also makes a Kent-Moore type of tester to be used specifically on piping systems.

E. PHYSICAL INSPECTIONS

The purpose of physical inspections of underground tank systems is two-fold: (1) to detect existing leaks in the tank or its associated piping, and (2) to prevent sudden failure of the tank by performing certain tests that determine its tightness and structural strength. Physical inspections include the external as well as internal inspections that can be performed on underground storage tanks to detect leaks or determine their integrity. The following discussion addresses the various types of physical inspections which can be performed on underground storage systems.

1. Inspections Prior to Backfilling

The inspection of a storage tank system prior to backfilling is an important aspect of comprehensive tank installation procedure. Such physical inspections may range from soap tests, which involve soaping down a pressurized tank and checking for leaks (bubbles), to more detailed internal and external non-destructive tests such as ultrasonic tests, spark tests, and deflection measurements.

Deflection measurements can be performed internally on fiberglass tanks or any other flexible underground tank that depends on the strength of the underlying soil for structural support. Such measurements could be made to evaluate the structural strength and integrity of storage system components. Deflection can easily be measured prior to piping installation but might require excavation afterward. Guidelines for deflection are that ±1% of the diameter is allowable; anything over that is unacceptable, because it indicates residual stress from improper backfill.

Other testing techniques such as ultrasonic tests, acoustic emissions tests, spark tests and the use of radiation-type instruments may be used either internally or externally to inspect tanks prior to backfilling. These inspection techniques are described in greater detail in Part III, Chapter 6, of this report.

2. Internal Inspection of Installed Tanks

Unless underground tanks are contained in an accessible vault, external visual inspections are not possible without unearthing the tank. However, internal inspections may be performed if the tank is equipped with a manhole. The technique that may be used in such instances include ultrasonic tests and radiation-type tests. Spark tests may also be used in tanks that do not contain flammable or combustible materials. These inspection techniques are described in Part III, Chapter 6.

Internal tank inspection is inherently hazardous. The tank must be emptied of liquid, freed of gases, washed and cleaned prior to entering it. As an added precaution, a breathing apparatus and fire-resistant clothing should be worn when entering a tank that contained flammable material. [7].

3. Checking Tank Bottoms

Two tests for detecting large leaks in tank bottoms are discussed below. Failure to find a leak by these tests does not indicate that the tank is leak free, but if they do reveal a leak, a more conclusive test becomes unnecessary. These tests are as follows:

Checking the Tank Bottom Under the Fill Tube. Experience has shown that many tanks develop leaks in a narrow band along the bottom. This is because small amounts of water condense out of most liquids, and settle at the bottom of the tank to cause internal corrosion. This problem is often aggravated by gauge sticks hitting the bottom of the tank and causing localized corrosion and leaks under the fill pipe. "Washing" may also occur under the fill tube. Incoming liquid may be able to flush a thin film of corrosion off the steel, further exposing it to more corrosion.

To test for such leaks, it is necessary to make a probe by driving a finishing nail into the end of a gauge stick leaving about ¾ inch protruding. The gauge stick is then used to check for a hole in the tank bottom under the fill pipe by probing or "feeling" the bottom

with the nail head. This test test requires a little technique that is quickly learned and has been quite successful.

Checking for Leaks Along the Bottom of the Tank. Leaks along the bottom can be detected by a simple test of measuring a drop in liquid level. The test consists of adding water to the tank and gauging the level with finding paste. The test is not conclusive, but it will reveal the existence of large leaks in the tank bottom. The test can be used with petroleum and other lighter-than-water liquids. The test cannot be used however if the groundwater table is higher than the liquid level.

4. Checking for Water in Tanks

Another important inspection that may be performed regularly is to check for the presence of water in the tank. The water content of the tank can be determined when gauging the tank both during deliveries and inventory checks by using a water-finder paste smeared on the bottom portion of the gauge stick. An unaccountable increase in the water level may indicate a tank leak, especially if the increase occurs after a heavy rain. However, before concluding that the presence of water is due to a faulty tank, the fill cap, its seal, and other connections should be checked to insure that they are properly in place.

The presence of water may also be detected using a water detector. This device will sound an alarm when it comes into contact with the water layer inside the tank. The depth of the water layer can be accurately measured by raising the probe until the alarm stops [5].

If a significant amount of water is detected (i.e., above the pump suction pipe), the tank should be tested for leaks. The contaminated water should be pumped out and treated as required by local law or pumped into a tank truck for proper off-site disposal.

5. Inspection of Cathodic Protection Systems Checking for Water in Tanks

When the tank or associated piping is equipped with cathodic protection, inspection and maintenance of the cathodic protection system is essential if it is to function properly and provide long-term protection. In the case of impressed current systems, current may fail because of anode deterioration, broken lead wires, rectifier malfunction or interruption of power. Impressed current rectifiers should be checked monthly and adjusted as needed [4]. The output of rectifiers should be monitored with a voltage or current indicator. At least once a year, tank-to-soil potential measurements should be taken to check the adequacy of protection and determine if any rectifier adjustments are needed [4].

Galvanic anode systems need to be periodically tested also. Although there are no electrical components to maintain, measurements of tank-to-soil potential and anode outputs should be made at least annually [4]. So-called "maintenance free" galvanic systems are susceptible to the same failures as other galvanic systems (i.e., coating loss, broken wire and shorted insulators) [4].

On both types of systems a potential 0.85 volts tank-to-soil is considered to be adequate protection.

References

1. American Petroleum Institute, *Guide for Inspection of Refinery Equipment, Chapter II – Conditions Causing Deterioration or Failures*, American Petroleum Institute, 2101 L Street, N.W., Washington D.C. 20037, Second Ed., 1972.

2. American Petroleum Institute, *Guide for Inspection of Refinery Equipment, Chapter IV – Inspection Tools*, American Petroleum Institute, 2101 L Street, N.W., Washington D.C. 20037, Second Ed., 1972.

3. American Petroleum Institute, *Guide for Inspection of Refinery Equipment, Chapter XIII – Atmospheric and Low-Pressure Storage Tanks*, American Petroleum Institute, 2101 L Street, N.W., Washington D.C. 20037, Second Ed., 1973.

4. Fitzgerald, J.H., "Corrosion Control for Buried Service Station Tanks," Paper No. 52, The International Corrosion Forum Devoted Exclusively to the Portection and Performance of Materials, April 14-18, 1975, Toronto, Canada, National Association of Corrosion Engineers, Publications Department, 1440 South Creek, Houston, Texas 77084.

5. Scully Electronics Systems, *Technical Data Sheet on Scully WB100G Water Detector*, Scully Electronic Systems, Inc., Industrial Way, Wilmington, MA 01887.

6. National Fire Protection Association, *Underground Leakage of Flammable and Combustible Liquids*, NFPA 329, National Fire Protection Association, Batterymarch Park, Quincy, MA 02269, 1977.

7. Anonymous, "Field Tests Promising on Texaco Underground Tank Leak Detector," *Petroleum Marketer*, Sept.-Oct. 1978

8. Frick, R., *Preliminary Review – The Sunmark Leak Lokator*, New York State Department of Environmental Conservation Memorandum, NYSDEC, 50 Wolf Road, Albany, N.Y. 12233, Aug. 26, 1980.

9. Sunmark Industries, *The Sunmark Leak Lokator Technical Bulletin*, Sunmark Industries, P.O. Box 7368, Philadelphia, PA 19101.

10. Anonymous, "Sunmark Leak Lokator Meets NFPA Standards," *Petroleum Marketer*, Sept.-Oct., 1980.

11. National Fire Protection Association, *Flammable and Combustible Liquids Code*, NFPA 30, National Fire Protection Association, Batterymarch Park, Quincy, MA 02269, 1980.

12. Maresca, Jr., J.W., Evans, P.C., *Measurement of Small Leaks in Underground Gasoline Storage Tanks Using Laser Interferometry*, SRI International, Menlo Park, CA 94025, Oct. 31, 1979.

13. Anonymous, "Leak Detection: Still Top Priority," *Petroleum Marketer*, June 1980.

14. McLean, R.F., *A Test in Progress Using a Kent-Moore Tank Systems Tightness Tester – Model 1000*, paper sponsored by the American Petroleum Institute and presented at the 43rd Annual Fire Department Instructors Conference in Kansas City, MO, March 30-April 2, 1971.

15. Heath Consultants, Inc., *Procedure Manual for the operation of the Petro Tite Tank Tester*, Form #582 HPN 5124, Heath Consultants, Inc., 100 Tosca Drive, Stoughton, MA 02072.

16. Heath Consultants, Inc., *Procedure Manual for the operation of the Petro Tite Tank Tester*, Form #583 HPN 5254, Heath Consultants, Inc., 100 Tosca Drive, Stoughton, MA 02072.

17. Ethyl Corp., *"Ethyl" Tank Sentry (Underground Tank Leak Detector)*, Ethyl Corp., Petroleum Chemicals Division, 2 Houston Center, Suite 900, Houston, Texas 77002.

18. ARCO Petroleum Products Co., "HTC Service Station Tank Leak Tester", ARCO Petroleum Products Co., Harvey Technical Center, 400 East Sibley Blvd., Harvey, IL 60426.

19. National Association of Corrosion Engineers, NACE, 2400 West Loop South, Houston, Texas 77027.

20. Petroleum Association for Conservation of the Canadian Environment (PACE). Proceedings of the May 1982 Tank Testing Symposium held in Toronto, Canda. PACE 1202-275 Slater St., Ottawa, Can. K1P 5H9.

Part II

CHAPTER 7: TEMPORARY CLOSURE, ABANDONMENT AND REMOVAL OF UNDERGROUND TANKS

A. INTRODUCTION

The use of proper procedures for the temporary or permanent closure of underground storage tanks is important for several reasons:

- Product that is left in the bottom of the tank (e.g. below the withdrawal line) will eventually leak out, leading to potential environmental contamination and health hazard problems.
- Empty tanks left in place underground may be used for illegal storage or disposal of hazardous wastes.
- Improperly closed tanks may be accidently filled with a material that is incompatible with the previously stored material.
- Accidental intrusion into the abandoned tank site may occur. A classic example of such is children playing near an abandoned gasoline storage tank, where a casually discarded lit cigarette or match can lead to catastrophe.
- A tank may be reused in a sensitive application, such as for food product storage, without being properly cleaned and decontaminated.
- Tanks left empty may eventually collapse.
- An empty, forgotten tank could pose a long term threat, such as explosion, if site is excavated.

The options available for the temporary or permanent closure of an underground storage system are:

- Temporary closure: the tank and piping system are emptied and sealed so as to be "temporarily out of service".
- Abandonment in place: the tank and piping system are emptied and sealed and the tank is filled with an inert material.
- Removal for reuse or disposal: the tank and piping system are removed from the ground after being emptied.

The concerns associated with these closure options are presented in the box below. The steps involved in each of the closure options are summarized in Table 2.7-1 and discussed in the remainder of this chapter.

B. TEMPORARY CLOSURE

Underground storage tanks may be considered temporarily closed or "temporarily out of service" if: (1) they are idle and in sound condition, and will be returned to service; (2) they are awaiting abandonment in place; or (3) they are awaiting removal from the ground. These are typically tanks that are intended to be returned to service within two years or are scheduled for abandonment or removal within 90 days.

Temporary closure practices include procedures to:

- Remove product from the tank.
- Cap the lines leading into the tank.
- Secure the tank against tampering.

The product removal requirements can be met in several ways. The best practice in most instances is to pump out the residual product and fill the tank with water containing a corrosion inhibitor. This practice minimizes the possibility of a leak developing while the tank lies dormant. In addition, such a practice is necessary in instances where ballasting is required to keep the tank in place due to a high groundwater table. It should be noted, however, that when the tank is reactivated for service a problem exists with the proper disposal of a large volume of contaminated water. This can be transported away from the location by a licensed hauler only and must be disposed of in a manner which takes into consideration applicable regulations governing air and water pollution abatement.

In situations where water fill is not used and the stored product was non-flammable, all product should be removed from the tank. In the case of flammable liquids, a sufficient quantity (approximately 4 inches) of product should be left in the tank to ensure a saturated vapor space. This saturated vapor space is needed to reduce the possibility of vapor explosions.

Concerns Associated With the Closure of Underground Storage Systems

- Monitoring the physical integrity of tanks during temporary or permanent closure procedures.
- Ensuring that product spills do not occur.
- Ensuring that the possibility of explosions of product vapors or fires are minimized or eliminated.
- Ensuring that illegal or accidental access to the tank is not possible.
- Ensuring to the extent possible that projected future uses of the site and surrounding environs are not adversely affected.

Specific information on residual volume amounts to ensure saturated vapor space should be available from the liquid manufacturer.

Table 2.7-1

Closure, Abandonment and Removal of Underground Tanks

Closure Practice	Reason for Practice and Circumstances of Application	Typical Procedures	Relative Costs
Temporary Closure ("temporarily out of service")	For sound tanks intended to be returned to service within two years or scheduled for abandonment or removal within 90 days.	Remove product from tank. The best approach is to remove all product and fill the tank with water and a corrosion inhibitor. In lieu of this: (1) remove all non-flammable product; or (2) remove flammable product, leaving sufficient quantity (approx. 4 inches) to assure saturated vapor space in tank; or (3) empty tank and fill with a CO_2 atmosphere.	Relatively low costs.
	Provides for safeguards against tampering or accidental use until ultimate fate of tank is determined.	Use concrete cast in place to cap all fill and draw-off lines, and cut off power to tank pumps.	
		Leave any vent lines open.	
Abandoment in Place	Permanent closure technique which avoids cost of tank removal.	Remove all liquid possible from tank and piping systems.	Relative costs range from low to high.
	Application dependent upon tank age and salvage values and projected use of site after closure.	Remove or disconnect and plug all fill, gauge and product lines and cap.	
		Purge remaining product by filling tank with water.	
		Tank may be opened and filled with an inert solid like sand, or be pumped full with a grout mixture.	
Tank Removal	For tanks intended for junking or reuse.	Remove all liquid from tank and piping system.	Relatively high costs.
	May be required by local regulation or because of the projected future use of the site.	Remove all tank connections and temporarily plug all openings.	
		Purge tank of flammable vapors. The sequence should be repeated until vapors are no longer evident.	
		Remove tank from ground. Safeguard against tampering (Vapors must be periodically monitored until final disposition. Vapor may be released from sludge and scale and again reach explosive level).	

In instances where the future use of the tank is to be different from or incompatible with the cement use, product removal practices also include procedures to wash down and rinse the tank.

All fill lines, gauge lines and product lines leading to the tank should be capped during the temporary closure to prevent casual or accidental use. For example, a concrete cap can be poured over the fill line; this cap can later be tapped out with a hammer. In addition, all power servicing pumps that are conducted to or mounted in the tank should be turned off to prevent casual or accidental use. However, vent lines sould be left open in the case of flammable liquids to prevent the accumulation and pressurization (due to high temperatures) of explosive vapors.

In general, the temporarily closed tank should be secured against tampering. The use of locked caps or concrete caps on all plugged lines, and the isolation of the tank area through the use of locked fence are examples of precautions which should be taken.

C. PERMANENT CLOSURE

The determination of whether to abandon a tank in place or remove it for reuse or disposal is dependent upon several factors, such as the age and condition of the tank, its salvage value, and its potential for reuse. Governmental regulations may require tank removal. Other factors that are important include the following:

- Tank Location. The depth to which the tank is buried and the type of soil in which it is buried will affect the ease, and hence, the cost, of tank removal. The potential for damage to concrete or asphalt traffic surfaces and nearby utilities should also be considered.
- Projected Use of the Site After Closure. If site plans call for development that involves excavation or regrading to the level of the tank, it is very likely that the tank will have to be removed.
- The Cost and Availability of Labor and Equipment. Tank removal will require the use of heavy equipment and experienced labor. If the cost of this labor and equipment are prohibitive, abandonment in place may be the preferred option.
- The Proximity of Disposal Site. The proximity of the disposal site can also greatly affect the cost of tank removal. Tank transportation costs could be prohibitive, making abandonment in place the preferred option.
- Regulatory Requirements. Local laws or ordinances may require removal of the tank as part of any permanent closure procedures.

1. Abandonment in Place

Practices for abandonment in place, or on-site closure of underground tanks must include procedures for:

- Removing all product.
- Disconnecting all plumbing and controls.
- Filling the tank with an inert solid such as sand, gravel or concrete. This is important to prevent subsidence of the ground above the tank if and when the tank corrodes or otherwide deteriorates.
- Capping all fill lines, product lines, vent lines, etc. to prevent future entry into the tank.

More detailed information on on-site closure of underground tanks is available in NFPA 30 [1] and API Publication 1604 [2].

2. Removal of Tanks

Practices for removal of tanks must include procedures for:

- Removing all liquid product.
- Disconnecting and capping all plumbing and controls.
- Temporarily plugging all tank openings except .for a ⅛ inch hole for venting.
- Removing the tank from the ground.
- Freeing the tank of all flammable or toxic vapors.
- Transporting the tank from the site.

If the tank is to be disposed of, a sufficient number of holes should be made in it to render it unfit for further use. The reason for making holes in the tank is to discourage possible future use of it as a container for some edible products that would be contaminated by residual deposits of the material that was previously stored in the tank. Sources of more information on the disposal of storage tanks include NFPA 30 [1] and API Publication 1604 [2].

If the tank is to be reused, care should be taken to assure that the tank is properly cleaned and that the future use of the tank is compatible with the past use. For example, a tank that stored gasoline should not be used to store a product destined for human or animal consumption or a product that reacts adversely with gasoline. References for the proper cleaning and reuse of underground tanks include NFPA 327 [6] and API Publication 2015 [4].

References

1. National Fire Protection Association, *Flammable and Combustible Liquids Code*, NFPA 30, National Fire Protection Association, Batterymarch Park, Quincy, MA 02269, 1981.

2. American Petroleum Institute, *Recommended Practice for Abandonment or Removal of Used Underground Service Station Tanks*, API Bulletin 1604, American Petroleum Institute, 2101 L Street, N.W., Washington D.C. 20037, March 1981.

3. American Petroleum Institute, *Dismantling and Disposing of Steel from Tanks which have Contained Leaded Gasoline*, API Bulletin PSD 2202, American Petroleum Institute, 2101 L Street, N.W., Washington D.C. 20037, October 1975.

4. American Petroleum Institute, *Cleaning Petroleum Storage Tanks*, API Publication 2015, Second Ed., American Petroleum Institute, 2101 L Street, N.W., Washington D.C. 20037, November, 1976.

5. New York State Department of Environmental Conservation, *Bulk Storage of Hazardous Liquids – Five Proposed Regulatory Concepts*, Wastewater Bureau, New York State Dept. of Environmental Conservation, 50 Wolf Road, Albany, N.Y. 12233, November 1980.

6. National Fire Protection Association, *Cleaning Small Tanks and Containers*, NFPA No. 327, National Fire Protection Association, Batterymarch Park, Quincy, MA 02269, 1982.

7. National Institute for Occupational Safety and Health, U.S. Department of Health, Education and Welfare.

8. National Fire Protection Association, *Underground Leakage of Flamable and Combustible Liquids*, NFPA 329, National Fire Protection Association, Batterymarch Park, Quincy, MA 02269, 1977.

Part III

ABOVEGROUND STORAGE SYSTEMS

INTRODUCTION

Part III of this report describes aboveground storage facilities for hazardous liquids. The items covered in detail in the chapters which follow include:

- The types of storage tanks available and their applications.
- Piping and pumping system components and their performance.
- Spill containment systems.
- Overfill prevention systems and their applications.
- Leak detection through monitoring and inspection.
- Inspection of aboveground storage systems.
- The closure and abandonment of aboveground tanks.

Much of the information presented in Part II of this report applies to aboveground storage systems as well. In these instances, the reader is directed to the appropriate section of Part II for further detail. A schematic diagram showing the key components of a bulk storage facility is shown in Figure 3-1.

As was done in Part II, much of the detailed material presented is drawn from storage practices for petroleum products. Although the basic principles discussed are applicable to bulk storage of other hazardous substances, specific installations may differ because of differences in the characteristics of chemicals to be stored and site characteristics.

Figure 3

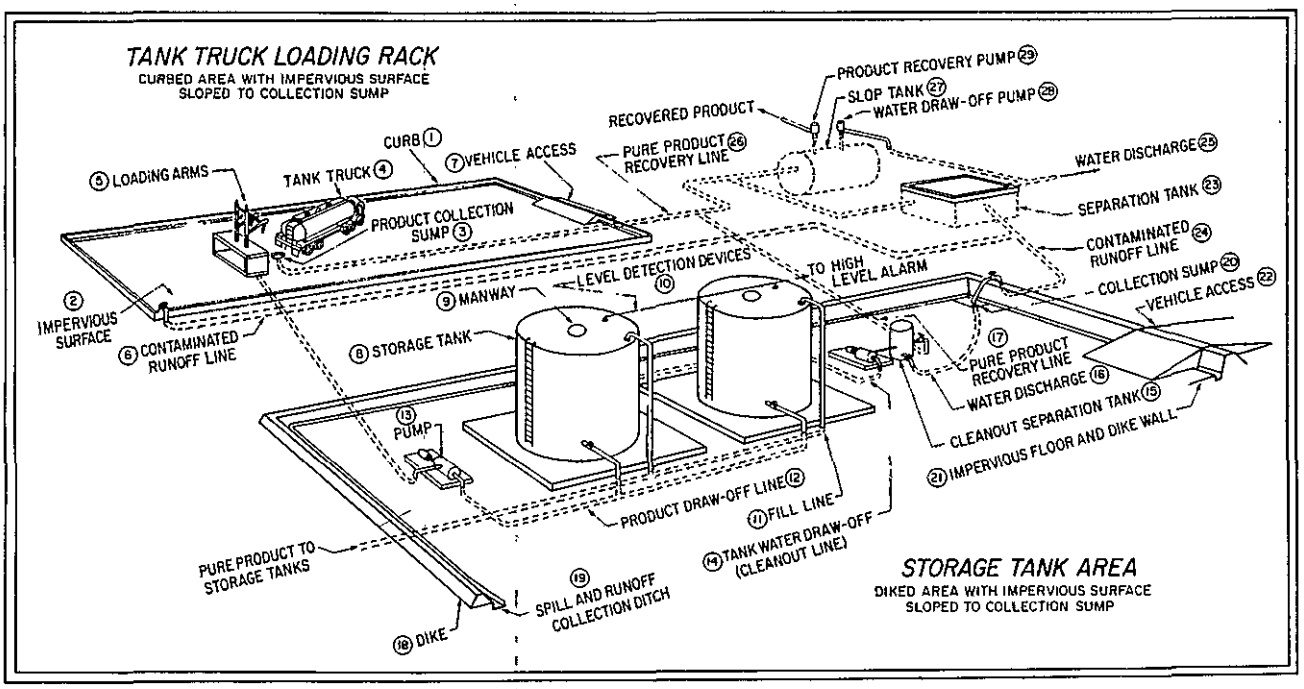
Selected Components of an Aboveground Storage Faciliy

This figure shows some of the components of an aboveground storage facility In this case, the product is assumed to be a petroleum derivative The product recovery system and contaminated runoff treatment system are therefore presented as a slop tank and a gravity separation tank respectively The items shown in the tank truck loading rack area include:
(1) curb and runoff collection ditch, (2) impervious surface, such as concrete sandwiched around an impermeable synthetic membrane, (3) a product collection sump for tank cleanout and rapidly recovered spills, (4) tank truck; (5) truck loading arms; (6) contaminated runoff conveyance line (to separation tank or other treatment system); and (7) vehicle access ramp.

The items shown in the storage tank area include.
(8) storage tanks, (9) manways, (10) level detection devices connected to a high level alarm, (11) fill lines, (12) product draw-off lines, (13) product pump for conveyance to loading area, (14) tank water draw-off (cleanout) lines directed to small separation tank, (15) separation tank for storage tank cleanout, (16) cleanout separation tank water discharge, (17) product recovery line from cleanout separation tank; (18) dike around storage area, (19) spill and runoff collection ditch, (20) collection sump, (21) impervious floor in storage area and on dike wall, (22) vehicle access ramp

Other items shown include the following.
(23) facility separation tank, (24) contaminated runoff line feeding separation tank, (25) separation tank water discharge line, (26) product recovery line leading to slop tank from loading rack area, (27) slop tank, (28) slop tank water draw-off pump, (29) slop tank product recovery pump

——— Please note that this figure is not drawn to scale ———



Part III
CHAPTER 1: ABOVEGROUND STORAGE TANKS

A. INTRODUCTION

Aboveground bulk storage tanks are used to store a multitude of chemical and petroleum products. The types of storage tanks commonly used fall into two broad categories:

- Atmospheric tanks.
- Low-pressure tanks.

Atmospheric tanks are those tanks that have been designed to operate at internal pressures in their gas and vapor spaces (area above the stored liquid) approximating atmospheric pressure. The Federal Occupational Safety and Health Administration defines atmospheric tank as follows:

> "Atmospheric tank shall mean a storage tank which has been designed to operate at pressures from atmospheric through 0.5 psig." [21]

In many instances atmospheric tanks are protected by pressure vacuum vents that maintain the pressure difference between the tank interior and the outside atmosphere at less than a few ounces per square inch [1]. Atmospheric tanks are used for the storage of low volatility materials. Crude oils, heavy oils, gas oils, furnace oils, naphtha, and gasoline are examples of substances that are commonly stored in atmospheric tanks.

Atmospheric tanks are usually constructed of carbon or alloy steel, or other metals for special services, and are either of welded or bolted construction, although many riveted tanks are still in service [1]. They may also be constructed of fiberglass-reinforced plastics (FRP) or a variety of olefin plastics such as polyvinyl chloride (PVC) and polyproplene. However, note that OSHA regulations prohibit the use of combustible materials of construction (e.g., FRP and plastics) for the storage of flammable and combustible liquids [10,21].

Low-Pressure storage tanks are those tanks that have been designed to operate at pressures in their gas or vapor spaces exceeding atmospheric pressure, but not exceeding 15 psig [1,21]. These tanks are normally constructed of steel and are usually welded, although some riveted tanks are still in service [1]. Low-pressure storage tanks are preferred over atmospheric storage tanks for the storage of liquids such as light crude oils, some gasoline blending stocks, light naphthas, pentane and other volatile chemicals because of the higher vapor pressures of these materials [1].

Numerous types of atmospheric and low-pressure tanks are available. These include, but are not limited to the following:

Atmospheric Tanks	Low-Pressure Tanks
Coned-roof tanks	Horizontal cylindrical tanks
Domed-roof tanks	Hemispheroidal tanks
Floating-roof tanks	Spheroidal tanks
Breather-roof tanks	Noded hemispheroidal tanks
Lifter-roof tanks	Noded spheroidal tanks

Figure 3.1-1 displays examples of various types of aboveground tanks. For more information on types of aboveground tanks, see references 1, 7, and 8.

The majority of the aboveground tanks used in the petroleum industry are of the atmospheric, fixed-roof type (e.g., coned-roof or domed-roof tanks) [7]. However, larger tanks of this type may be designed with internal floating roofs or steel pans. These internal floating roofs reduce the liquid surface exposed to evaporation to a minimum, thereby substantially decreasing potential vapor losses [7].

Aboveground bulk storage tanks are manufactured in a large variety of sizes and materials of construction. They may be of vertical or horizontal designs. Tanks that are less than 12 to 15 feet in diameter are generally shop-fabricated while those larger than 12 to 15 feet in diameter are field-erected [6,10,20]. Bulk storage tanks may include several compartments for storing differenct products or they may be double-walled with the outer shell acting as a secondary vessel to contain spills.

The materials commonly used in the construction of aboveground storage tanks include carbon steel, stainless steel, FRP and FRP-lined steel. Aluminum and concrete tanks are less common. The critical factors to consider in the choice of material for an aboveground storage tank include the following:

- Pressure service.
- Resistance to corrosion and chemical attack (compatibility with the stored liquid and the environment).
- Structural strength.
- Installation and foundation requirements.
- Maintenance requirements.

Some characteristics of materials used for aboveground storage tanks are summarized in Table 3.1-1.

B. TANK LAYOUT

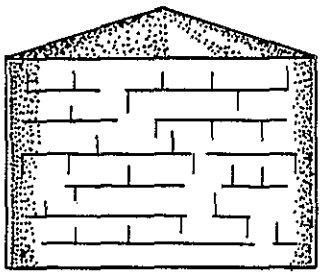
Regardless of their shape, size and material of construction, aboveground bulk storage tanks include the connections shown in Figure 3.1-2. These are:

- A fill connection.
- An outlet connection.
- A drain connection.
- A pipeline connection.
- A manway.
- An overflow connection.
- A vent connection.
- A level indicator connection.

The apparatus found on larger tanks also include platforms, ladders and stairways.

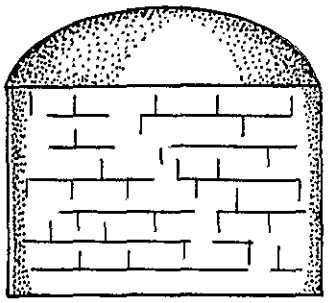
Figure 3.1-1

Types of Atmospheric and Low-Pressure Tanks



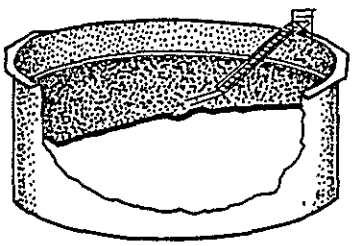
CONED ROOF TANK

- Simplest type of atmospheric tank
- Usually large, field-erected structure; can reach 300 feet in diameter and 64 feet in height
- Used for storage of liquids with low volatility



HEMISPHEROID TANK

- Low pressure tank
- Usually large, field-erected structure
- Used for storage of volatile liquids

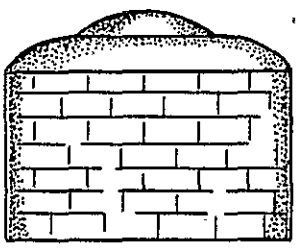


FLOATING ROOF TANK

- Atmospheric tank
- Usually large, field-erected structure
- Designed to reduce evaporation losses and increase protection from fire

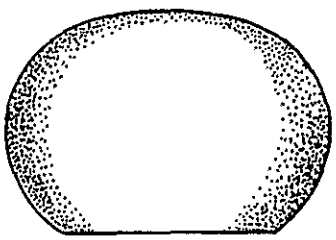
CYLINDRICAL TANK

- Low pressure tank
- Usually shop-erected and thus restricted to transportable sizes (e.g. 11-12 feet in diameter and 60 feet in length)



NODED HEMISPHEROID TANK

- Low pressure tank
- Usually field erected structure
- Used for storage of volatile liquids



SPHEROID TANK

- Low pressure tank
- Usually large, field-erected structure; can reach 90 feet in diameter
- Used for storage of volatile liquids under pressure

Table 3.1-1

Characteristics of Various Types of Aboveground Storage Tanks.

Type of Tank	Pressure Service	Resistance to Corrosive Attack	Protective Coatings and Linings	Relative Costs	Remarks
	(atm and/or pressure)	(chemical compatibility)			
Carbon steel (bolted)	Atmospheric	Compatible with petroleum products and caustic soda but not compatible with mineral and oxidizing acids such as dilute sulfuric acid and concentrated hydrochloric, phosphoric or nitric acids.	Coatings and linings may be applied for corrosion resistance to both the tank and its support foundation.	Low	Tanks may be horizontal or vertical and are generally large. Vertical tanks require concrete pads and horizontal tanks are generally mounted on steel or concrete saddles.
Carbon steel (welded)	Atmospheric and low pressure	Same as above.	Same as above.	Low	Smaller shop-assembled tanks are generally welded. Newer low-pressure tanks are welded.
Stainless steel	Atmospheric and low pressure	Better corrosion resistance than carbon steel, depending on grade.	Generally not used.	Medium to high depending on grade of steel.	Stainless steel is used in lieu of coatings when the temperature of the liquid store exceeds 200° F. Stainless steel is also used in storage situations where product purity is important, such as in the food industry.
Fiberglass-reinforced plastic	Atmospheric Low-pressure tanks available as special orders from some manufacturers.	Compatible with a wide range of organic and inorganic chemicals. See chemical compatibility chart in Part II, Chapter 1.	Not required.	Comparable to coated steel.	Fiberglass tanks have high corrosion resistance but, lack the structural strength, performance at elevated temperatures (above 200° F), or impact resistance of steel tanks. Available in capacities of 400-33,000 gallons. OSHA regulations prohibit the use of FRP for aboveground storage of flammable or combustible liquids.
Plastic	Atmospheric	Varies depending on the type of plastic. See discussions of Part II, Chapters 2 and 3.	Not applicable.	Low	Plastic materials include polyethylene, polypropylene, polyvinylchloride (PVC), and acrylonitrile butadiene styrene polymers (ABS). While these materials are used to manufacture portable and process tanks under 3000 gallons, they are generally not used for bulk storage tanks because of their low structural strength. OSHA regulations prohibit the use of plastic for aboveground storage of flammable or combustible liquids.

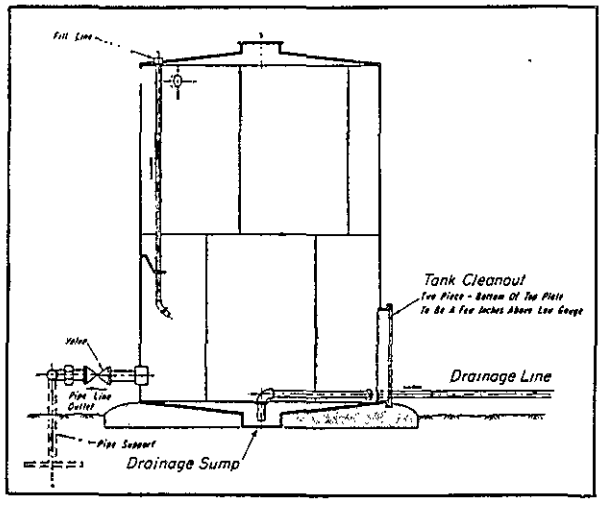
Table 3.1-1 continued

Concrete	Atmospheric	Subject to deterioration by corrosive chemicals.	Coatings may be applied for corrosion resistance to both interior and exterior of tank.	High	Concrete tanks are generally not used for the storage of petroleum and chemical products.
Aluminum	Atmospheric and low-pressure	High resistance to atmospheric conditions, industrial fumes and vapors, and fresh, brackish or salt water. Attacked by mineral acids, but can be used with concentrated nitric acid (above 82%) and sulfuric acid (99%). Cannot be used with strong caustic solutions. Compatible with most organic acids.	Coatings may be applied to both interior and exterior of tank for chemical resistance. Bonding coatings to aluminum is difficult.	Low	Aluminum tanks lack the structural strength of steel. Aluminum rapidly loses its structural strength at temperatures above 300° F. Aluminum retains its structural strength well at low temperatures; it can be used down to –420°F.

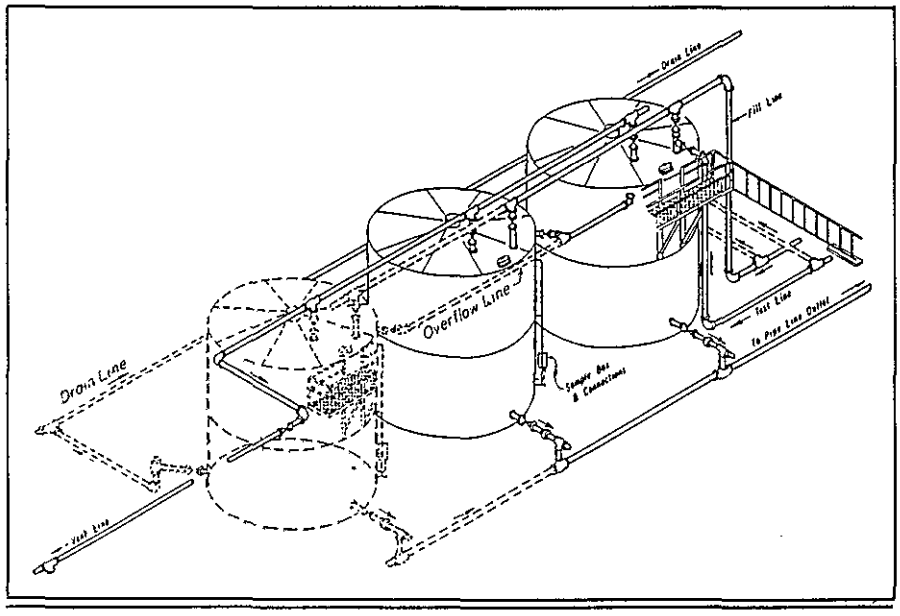
* Please refer to the discussion of storage protocol in Part I for more details on chemical compatibility.

Figure 3.1-2

Aboveground Tank Connections



a) Side view showing the fill connection, pipe line outlet connection, drain connection, drainage sump, and tank cleanout.



b) Perspective drawing showing the fill connection, pipe line outlet connection, drain connection, overflow connection, and vent connection.

Source: API RP 12Ra, *API Recommended Practices for Setting, Connecting, Maintenance and Operation of Lease Tanks*, 1981.

As shown in figure 3.1-2, the fill connection is typically located at the top of the tank, above the overflow connection. A drop tube running from the fill connection to the bottom of the tank is often included in the design. This feature is intended to prevent splashing [6].

The drain connection is typically the lowest piping connection in the tank, and is usually located in the tank wall 4-6 inches from the bottom of the tank. This 4-6 inch clearance between the connection and the tank edge is required by tank manufacturing standards and specifications, and varies depending upon the type of tank (e.g., atmospheric vs. low-pressure) [6,13,16, 18, 19].

The tank may also include a cleanout as shown in Figure 3.1-2. This connection permits physical access to the inside of the tank for complete drainage and/or sludge removal [6,16,17,18,19].

In some tanks, particularly large, field-erected tanks, a drainage sump may also be provided inside the tank. In these instances, the tank bottom is sloped toward the collection sump, and the drain line extends into the sump. This permits easier and more complete drainage of the tank prior to physical entry [6,19].

The pipe line connection or outlet connection is typically located opposite the drain line connection, at a slightly higher elevation [6,19]. The higher elevation and location of this connection limits the likelihood of entraining sludge or other product contaminants into the tank output.

As shown in Figure 3.1-2, the overflow connections are located below the fill connections, typically 6-12 inches below the top edge of the tank shell [6,19]. The overflow connection requires careful sizing. Tanks have been split open by overpressurization due to inadequate overflow vents. The vent connection is typically located on the roof of the tank, and is sized to handle the maximum air flow resulting from normal thermal effects and liquid movement into and out of the tank [6,19].

In most instances, storage tanks are also fitted with a manhole, typically 20-36 inches in diameter [13]. This manway is conveniently located at the side or top of the tank to permit easy accesss into the tank.

A level control probe connection may also be included in the tank design. This connection is typically located on the side or top of the tank, depending on the tank configuration and the type of level device used. See Chapter 6 of this part of the report for more details on these devices.

Many areas of New York State are adopting **vapor control systems** for gasoline, in order to reduce the level of ambient ozone in the air. The operating principle is that the space in an empty tank is filled with saturated vapor. When a delivery is made, that vapor is displaced by the incoming liquid. If these hydrocarbon vapors are expelled into the atmosphere, 1) they increase the ambient hydrocarbon level and, 2) the ozone level is raised due to reaction of the air with hydrocarbons.

When gasoline is delivered to a service station using vapor control, the vapor displaced is expelled into the tank truck. When the tanker is then reloaded, the vapor is displaced into a vapor control system. These systems are classified in six "design concept" categories.

1. Incineration or Flame Oxidation
2. Compression – Refrigeration – Condensation
3. Compression – Refrigeration – Absorption
4. Lean – Oil Absorption
5. Adsorption – Absorption
6. Refrigeration

Incineration or Flame Oxidation. The air-vapor mixture is displaced to a vapor holding tank. The mixture is then released to the oxidizer, where at critical levels it is mixed with propane as well as properly metered air stream and combusted.

Compression – Regrigeration – Condensation. The air-vapor mixture is compressed in a two-stage compressor with an inter-stage heat exchanger. The compressed hydrocarbons pass through a condenser where they are cooled and condensed. They are then returned, along with condensate from the heat exchanger, to the tank. Air is vented from the top of the condenser.

Compression – Regrigeration – Absorption. The air-vapor mixture is compressed and passed through a condenser where, as above, it is cooled and condensed. These now cooled and condensed vapors are contacted by chilled gasoline (either by a liquid bath system or by sprayers). The air is vented above the absorber.

Lean – Oil Absorption. The air-vapor mixture from the loading rack is displaced through the packed absorber column where it is absorbed by cascading lean gasoline. Lean gasoline is gasoline with the light hydrocarbon components evaporated off. The lean gasoline is used at atmospheric temperature and pressure. The stripped air-vapor mixture is vented from the top of the absorber.

Adsorption – Absorption. The air-vapor mixture enters the base of one of the two activated carbon-packed columns. As the mixture ascends through the column, the hydrocarbons are adsorbed into the carbon. When the first column is approaching its saturation level, the air-vapor mixture flow is transferred to the second carbon-packed column. The hydrocarbons collected in the first column are now desorbed from the carbon and absorbed into a gasoline bath column. The air is run back through the carbon and vented on top.

Refrigeration. Methylene chloride brine is pumped through finned tube sections of a vapor condenser at temperatures in the order of −90°F to −100°F. The air-vapor mixture is passed over the finned tubes. The moisture contained within the mixture condenses on the plate fins. Condensed hydrocarbons are collected at the bottom of the vapor condenser. These are then returned to the tank.

C. STORAGE TANK MATERIALS

1. Carbon Steel Tanks

Because of their strength and fire resistance, carbon steel tanks (also called mild steel) are widely used for the storage of chemical and petroleum products aboveground. It is used almost exclusively for tanks over 30,000 gallons. These tanks are considered compatible with a wide variety of liquids, including gasoline, kerosene, fuel oil, concentrated sulfuric acid, sodium hydroxide and methanol. (Refer to Appendix A Chemical Compatibility Chart of Materials and Table 1.2-8 for more information on chemical compatibility).

Several grades of carbon steel are manufactured; however, their chemical and physical properties do not vary significantly [8]. For additional information on the properties of carbon steel, refer to Part II, Chapter 2.

Corrosion is the primary cause of deterioration of steel storage tanks and accessories; therefore, corrosion protection and regular inspections are necessary to prevent premature failure.

External Corrosion. Atmospheric corrosion can occur on all external parts on an aboveground tank. This type of corrosion may range from negligible to severe, depending on the atmospheric conditions of the locality. For example, a sulfurous or acidic atmosphere can destroy protective coatings and increase the rate of corrosion. The external surfaces of a steel tank and its auxiliary equipment will corrode more rapidly if they are not protected with paint or other protective coatings, or with cathodic protection. Any depressions or pockets in which water can lie for long periods will be points of concentrated corrosion.

The type of steel tank and the construction details used can affect the location and extent of external corrosion. Riveted tanks, for example, offer many niches where concentrated corrosion may occur. Leaks at seams of riveted tanks often destroy paint films around the leaks. External corrosion may then take place. Soil corrosion also typically occurs at the grade line of tanks built partly below grade or where soil movement has raised the grade level to cover the lower portion of the tank shell [1].

External corrosion of steel tank bottoms can also be a serious problem. The materials used to form a pad under the bottom may contain chemical compounds that are corrosive. For example, cinders containing sulfur compounds become very corrosive under moist conditions. Faulty pad preparation with poor drainage may also precipitate corrosion by allowing water to remain in contact with the bottom. If a tank leaks corrosive material through the bottom, accumulation of the material can cause external corrosion of the tank bottom. For tanks that are supported above grade, improperly sealed foundation piers or saddles may allow moisture to accumulate between the tank and the supports and accelerate corrosion at such points [1].

Internal Corrosion. Internal corrosion of storage tanks depends on the contents of the tank and the construction material (i.e., type of steel). The most severe corrosion occurs in tanks used for storing corrosive (to steel) chemicals or petroleum products containing corrosive (to steel) compounds [1]. See Table 1.2-8 and Appendix B for more information on chemical compatibility.

Internal corrosion can occur in the tank vapor space or in the area covered by liquid. Corrosion in the vapor space of these tanks is most commonly caused by hydrogen sulfide vapor, water vapor, oxygen or any combination of the three. In the areas covered by the stored liquid, corrosion is most commonly caused by acid salts, hydrogen sulfide, or other sulfur compounds [1].

Other forms of internal corrosion found in carbon steel tanks are electrolytic corrosion, hydrogen blistering, caustic embrittlement, graphitic corrosion of cast iron parts, and dezincification of brass parts [1]. For additional information on the process of corrosion refer to the discussion in Part I.

Design and Construction of Aboveground Carbon Steel Tanks. Two basic types of fabrication techniques are presently used to construct carbon steel tanks; these are welding and bolting. Riveting was a commonly used technique some years ago, and many riveted aboveground tanks remain in service today [1]. Depending upon their size, steel tanks may be shop-fabricated or field-erected. The break point is usually determined by ease of transport; typically, tanks greater than 15 feet in diameter are field-erected.

The American Petroleum Institute (API) has developed a series of standards and specifications for the construction of carbon steel tanks. These standards and specifictions are listed, with brief descriptions, in Table 3.1-2 [6,13,16,17,18,19].

Underwriters Laboratories, Inc., has published the following tank standard: UL 142, *Steel Aboveground Tanks for Flammable and Combustible Liquids*. This document covers horizontal tanks up to 50,000 gallons, and vertical tanks up to 35 feet in height. Some of the recommendations of UL 142 regarding maximum diameter, maximum wall thickness, maximum tank height, etc., are presented in Tables 3.1-3, 3.1-4 and 3.1-5 [15].

The UL standards overlap the API standards, but include tanks that are smaller than those covered by the API standards. The Underwriters Laboratories standards

Table 3.1-2

Current Publications of the American Petroleum Institute Pertaining to Storage Tanks

Spec 12B: Specification for Bolted Tanks for Storage of Production Liquids.
Covers material, design, fabrication, and testing requirements for vertical, cylindrical, aboveground, closed and open top, bolted steel storage tanks in nominal capacities of 100 to 10,000 bbl (in standard sizes). Also includes appurtenance requirements.

Spec 12D: Specification for Field Welded Tanks for Storage of Production Liquids.
Covers material, design, fabrication, and testing requirements for vertical, cylindrical, aboveground, closed top, field welded steel storage tanks in nominal capacities of 500 to 10,000 bbl (in standard sizes).

Spec 12F: Specification for Shop Welded Tanks for Storage of Production Liquids.
Covers material, design, fabrication, and testing requirements for shop-fabricated vertical, cylindrical, aboveground closed top, shop-welded steel storage tanks in nominal capacities of 90 to 500 bbl (in standard sizes).

Std 620: Recommended Rules for Design and Construction of Large, Welded, Low-Pressure Storage Tanks.
These rules cover the design and construction of large, welded, field-assembled storage tanks used for petroleum intermediates and finished products operated at a gas pressure of 15 psig and less, down to an internal gas pressure close to atmospheric pressure, which are not now provided for in API Std 650.

Std 650: Welded Steel Tanks for Oil Storage.
This standard covers material, design, fabrication, erection, and testing requirements for vertical, cylindrical, aboveground, closed- and open-top, welded steel storage tanks, in various sizes and capacities, for internal pressures approximating atmospheric pressures. also includes an alternate basis for shell design, as well as one for calculating tank shell thickness.

Std 2000: Venting Atmospheric and Low-Pressure Storage Tanks.
This standard applies to the normal and emergency venting requirements for aboveground liquid petroleum storage tanks and aboveground and belowground refrigerated storage tanks designed to operate from ½ oz. per sq. in. vacuum through 15 psig pressure. The requirements of the standard do not apply to floating- or lifter-roof tanks.

RP 2003: Protection Against Ignitions Arising Out of Static, Lightning and Stray Currents.
Described in this publication are some of the conditions which have resulted in oil fires ignited by electrical sparks and arcs from so-called natural causes, as well as the methods which the petroleum industry currently is applying for the prevention of ignitions from these sources.

RP 2015: Cleaning Petroleum Storage Tanks.
A discussion of safe practices in tank cleaning — including use of suitable mechanical equipment and protective clothing, use of proper cleaning methods, elimination of potential ignition hazards, and provision for means of entrance and exit in an emergency. Combines and updates information contained in *Accident Prevention Manual No. 1: Cleaning Petroleum Storage Tanks — Section A, Crude Oil and Unfinished Products Tanks* and *Bull. 2016: Cleaning Tanks Used for Gasoline or Similar Low-Flash products.*

Std 2550: (ASTM D 1220-65)(75),† Measurement and Calibration of Upright Cylindrical Tanks, 1966 (ANSI Z11.197-1971) (Redesignated Chapter 2.2.2, API Manual of Petroleum Measurement Standards)
This standard describes the procedures for calibrating upright cylindrical tanks larger than a barrel or drum. It is presented in two parts: Part I outlines procedures for making necessary measurements to determine total and incremental tank volumes. Part II presents the recommended procedure for computing volumes. Sample calculations are included in an appendix.

Std 2555: (ASTM D 1406-65)(75),* Liquid Calibration of Tanks, 1966 (ANSI Z11.202-1971) (Redesignated Chapter 2.6, API Manual of Petroleum Measurement Standards)
This standard describes the standard procedure for calibrating tanks, or portions of tanks, larger than a barrel or drum by introducing or withdrawing measured quantities of liquid.

Guide for Inspection of Refinery Equipment, Chapter XIII, Atmospheric and Low-Pressure Storage Tanks.
This chapter covers the inspection of atmospheric storage tanks which have been designed to operate at pressures from atmospheric through 0.5 psig, and of low-pressure storage tanks which have been designed to operate at pressures above 0.5 psig through, but not over, 15 psig. Such details as reasons for inspection, frequency and time of inspection, methods of inspection and of repair, and records are some of the principal items included.

RP 12R1: Recommended Practice for Setting, Connecting, Maintenance and Operation of Lease Tanks.
A guide for new tank battery installations and a guide for revamping existing batteries if this is necessary for any reason.

*Joint standards for which ASTM has prime responsibility.
†Joint standards for which API has prime responsibility.

Source: API Specifications 12F, *API Specification for Shop Welded Tanks for Storage of Petroleum Liquids*, 1977.

are, however, not as detailed as those of API, and therefore put more responsibility on the designer [8].

Other sources of specifications and standards for the design and construction of aboveground steel tanks include the American Society of Mechanical Engineers (ASME), the American National Standards Institute (ANSI), the American Iron and Steel Institute (AISI), the American Society for Testing and Materials (ASTM), the National Fire Protection Association, (NFPA), and the American Welding Society (AWS). The addresses of these organizations are given at the end of Part II, Chapter 1 of this report. The reader should refer to these organizations, the API and UL standards described above, and specific manufacturers' data for more complete information on tank design and construction.

Table 3.1-3

Underwriters Laboratories Requirements for Metal Thickness of Horizontal Steel Tanks

Capacity, U.S. Gallons	Maximum Diameter, Inches	Thickness of Steel
550 or less	48	12 gauge (0.105 inches)
551 - 1100	64	10 gauge (0.135 inches)
1101 - 9000	76	7 gauge (0.179 inches)
1101 - 35000	144	¼ inch
35001 - 50000	144	⅜ inch

Source:
This material is based on and taken, with permission, from Underwriters Laboratories Inc. Standard for Safety for Steel Aboveground Tanks for Flammable and Combustible Liquids, UL 142, Copyright 1972 Steel (by Underwriters Laboratories Inc.), copies of which may be purchased from Underwriters Laboratories Inc, Publication Stock, 333 Pfingsten Road, Northbrook, Illinois 60062

Note:
UL shall not be responsible to anyone for the use of or reliance upon UL Standard by anyone. UL shall not incur any obligation or liability for damages, including consequential damages, arising out of or in connection with the use, interpretation of, or reliance upon a UL Standard.

Table 3.1-4

Underwriters Laboratories Requirements for Metal Thickness of Vertical Steel Tanks

Capacity U.S. Gallons	Thickness of Steel		
	Shell	Bottom	Top
1100 or less	12 gauge	12 gauge	12 gauge
Over 1100	7 gauge*	¼ inch	10 gauge

* For a tank more than 25 feet in height, all parts of the shell located more than 25 feet below the top edge of the shell shall not be less than 1/4 inch.

Source:
This material is based on and taken, with permission, from Underwriters Laboratories Inc. Standard for Safety for Steel Aboveground Tanks for Flammable and Combustible Liquids, UL 142, Copyright 1972 (by Underwriters Laboratories Inc.), copies of which may be purchased from Underwriters Laboratories Inc., Publication Stock, 333 Pfingsten Road, Northbrook, Illinois

Note:
UL shall not be responsible to anyone for the use of or reliance upon UL Standard by anyone. UL shall not incur any obligation or liability for damages, including consequential damages, arising out of or in connection with the use, interpretation of, or reliance upon a UL Standard

2. Stainless Steel Tanks

Stainless steel tanks are used primarily when product purity, and temperatures above 200°F are critical factors. For example, stainless steel tanks are widely used in the food processing industry. There is a variety of types of stainless steels, descriptions of which are detailed in the *Chemical Engineers' Handbook* [8].

Stainless steel materials normally exhibit excellent corrosion resistance to mild alkaline solutions, most petroleum products, and many chlorinated organics. These materials are not recommended for use with strong mineral acids, such as aqua regia, chloracetic acid, hydrochloric acid and sulfuric acid, whether strong or dilute. For more information on the compatibility of stainless steels with various chemicals, please refer to Appendix B.

Stainless steel tanks tend to be more costly than other alternatives, such as lined carbon steel [9]. However, commonly used linings degrade at temperatures above 150-200°F [5].

Table 3.1-5

Miscellaneous Requirements for Steel Tank Fabrication

- The overall length of a horizontal tank shall not be greater than six (6) times its diameter.
- The minimum diameter of a vertical tank shall not be less than one quarter of its height.
- The shell height of a vertical tank shall not be more than thirty five (35) feet.

Source:
This material is based on and taken, with permission, from Underwriters Laboratories Inc. Standard for Safety for Steel Aboveground Tanks for Flammable and Combustible Liquids, UL 142, Copyright 1972 Steel (by Underwriters Laboratories Inc.), copies of which may be purchased from Underwriters Laboratories Inc., Publication Stock, 333 Pfingsten Road, Northbrook Illinois 60062

Note:
UL shall not be responsible to anyone for the use of or reliance upon a UL Standard by anyone. UL shall not incur any obligation or liability for damages, including consequential damages, arising out of or connection with the use, interpretation of, or reliance upon a UL Standard.

3. Fiberglass-Reinforced Plastic

Aboveground fiberglass-reinforced plastic (FRP) tanks are widely used for the storage of liquid chemicals that are not combustible or flammable. The chemically inert properties of FRP enable it to handle a large number of corrosive chemicals safely. Some of the liquid chemicals commonly stored in FRP tanks are listed in Table 3.1-6 [10].

FRP tanks are manufactured in horizontal and vertical configurations in sizes ranging from 400 to 33,000 gallons [10]. Performance factors for various types of FRP tanks are shown in Table 3.1-7. These tanks are typically designed with a 25 pound per square foot (psf) snow load limit, and in some parts of New York State this may preclude their use. The snow load limit should therefore be ascertained from the tank manufacturer to insure that it is in accordance with Section A304-3 of the New York Building Code. For additional information on the characteristics and uses of FRP tanks, refer to the discussion in Part II, Chapter 1.

Table 3.1-6

Liquid Chemicals Commonly Stored in Aboveground Fiberglass Tanks

Acetic Acid	Lead Sulfate
Alum	Lime Slurry
Aluminum Chloride	Liquid Sugar
Aluminum Nitrate	Lithium Chloride
Aluminum Sulfate	Lithium Sulfate
Ammonium Chloride	Magnesium Carbonate
Ammonium Hydroxide	Magnesium Chloride
Ammonium Nitrate	Magnesium Nitrate
Ammonium Phosphate	Magnesium Sulfate
Ammonium Sulfate	Mercuric Chloride
Arsenic Acid	Nickel Chloride
Barium Carbonate	Nickel Nitrate
Barium Chloride	Nickel Sulfate
Brine	Nitric Acid
Calcium Carbonate	Nitrous Acid
Calcium Hydroxide	Paraffin
Calcium Hypochlorite	Peanut Oil
Calcium Sulfate	Phosphoric Acid
Citric Acid	Polyvinyl Chloride
Copper Acetate	Potassium Aluminum Sulfate
Copper Chloride	Potassium Bromide
Copper Nitrate	Potassium Carbonate
Copper Sulfate	Potassium Chloride
Ethyl Alcohol	Potassium Dichromate
Ethylene Glycol	Potassium Hydroxide
Ferric Chloride	Potassium Permanganate
Ferric Nitrate	Potassium Sulfate
Ferric Sulfate	Silver Nitrate
Ferrous Chloride	Sodium Chloride
Ferrous Sulfate	Sodium Hydroxide
Fluorosilicic Acid	Sodium Hypochlorite
Formaldehyde	Sulfuric Acid (dilute)
Glycerin	Vinegar
Glycol	Water
Hydrochloric Acid	Zinc Chloride
Hydrofluorosilicic Acid	Zinc Nitrate
Latex Emulsions	
Lead Acetate	

Source: Owens Corning Fiberglas Corp., Fiberglas Tanks for Liquid Chemicals, 1980

Table 3.1-7
Performance Factors for Various Types of Fiberglass Tanks

	Std. Vertical Tank	Std. Dish-bottom Tank	Horizontal Tank	Under-ground Tank
Stored material specific gravity upper limit	2.1	2.1	2.1	1.5
Storage temperature upper limit*	200°F.	180°F	150°F.	150°F.
Wind load limit when anchored	100 mph	100 mph	100 mph	N.A.
Concentrated top load limit	250# distributed over 16 sq. in.	250# distributed over 16 sq. in.	N.A.	**
Snow load limit	25 lbs. psf.	25 lbs. psf.	25 lbs. psf.	N.A.
Pressure	Standard design tanks must be vented. They are not designed for pressure applications.*			

*Non-insulated tanks only and only certain environments
**A concentrated surface load of 32,000 lbs. when properly installed

Source: Owens-Corning Fiberglas Corp., *Fiberglas Tanks for liquid Chemical,* 1980.

4. Plastic Tanks

Polyolefin plastics such as polyvinyl choride and polypropylene are used to manufacture storage tanks in capacities ranging from a few hundred to a few thousand gallons. They are particularly applicable for use as small (under 3000 gal.), portable storage tanks. However, as a rule, mechanical stress, elevated temperature, and extended exposure affect the service life of plastic tanks.

Plastics are compatible with a wide variety of chemical substances at ambient temperatures including dilute solutions of hydrchloric acid, nitric acid, and sulfuric acid; sodium hudroxide and other strong alkalies; and many organic chemicals. They are not recommended for use with concentrated mineral acids, aromatic hydrocarbons, and chlorinated hydrocarbons, and are not approved for the storage of flammable and combustible liquids.

Table 3.1-8 is a partial listing from a chemical compatibility chart for one specific type of polyolefin plastic. The purpose of the chart is to emphasize the fact that the compatibility between the plastic tank and the stored chemical can vary with type, concentration, and temperature of product stored.

5. Concrete and Aluminum Tanks

Concrete tanks are generally limited in their use for the storage of petroleum and hazardous chemicals. Concrete tanks have poor chemical resistance, and are generally costly to fabricate and install. They cannot be shop-fabricated except in relatively small sizes. They are considerably heavier than steel or fiberglass tanks of the same capacity and consequently require stronger foundations. However, lined concrete tanks are applicable for chemical storage in certain instances. For example, coatings have been applied to concrete tanks that are resistant to many organic and inorganic acids, alkalies, and salts. OSHA regulations have approved the use of unlined and lined concrete tanks with certain limitations:

> "Unlined concrete tanks may be used for storing flammable or combustible liquids having a specific gravity of 40° API or heavier [measurement of specific gravity]. Concrete tanks with special linings may be used for other services provided the design is in accordance with sound engineering practice." [21]

Table 3.1-8

Partial Chemical Compatibility Chart for One Type of Polyolefin Tank

S = Satisfactory U = Unsatisfactory M = Marginal N = Unknown

Some reagents are marked with an asterisk (*). Although cross-linked polyolefin is chemically resistant to these agents, excess temperatures and pressures can under certain conditions lead to stress cracking.

On reagents marked marginal, chemical attack will be recognized by a loss of physical properties of the container.

Reagent	70°F (21°C)	140°F (60°C)	Reagent	70°F (21°C)	140°F (60°C)
Acetic Acid* 1-10%	S	S	Hydrochloric Acid 10%	S	S
Acetic Acid* 10-60%	S	M	Hydrochloric Acid 30%	S	S
Acetic Acid* 80-100%	S	M	Hydrochloric Acid 35%	S	S
Acetone	S	M	Hydrochloric Acid Conc.	S	S
Ammonium Chloride Sat'd	S	S	Hydrogen Bromide 10%	S	S
Ammonium Fluoride 20%	S	S	Hydroquinone	S	S
Amyl Acetate	S	M	Lube Oil	S	M
Amyl Alcohol* 100%	S	S	Methyl Ethyl Ketone 100%	S	U
Amyl Chloride 100%	N	U	Methylene Chloride 100%	M	U
Aniline 100%	S	N	Nitric Acid 0-30%	S	S
Beer	S	S	Nitric Acid 30-50%	S	M
Benzene	S	M	Nitric Acid 70%	S	M
Calcium Carbonate Sat'd	S	S	Nitric Acid 95-98%	U	U
Calcium Chlorate Sat'd	S	S	Nitrobenzene 100%	U	U
Calcium Chloride Sat'd	S	S	Phenol 90%	S	U
Carbon Tetrachloride	M	U	Propyl Alcohol*	S	S
Carbonic Acid	S	S	Plating Solutions		
Chlorine Liquid	M	U	Brass*	S	S
Chlorobenzene	M	U	Cadmium*	S	S
Chloroform	M	U	Chromium	N	N
Chrome Alum Sat'd	S	S	Copper	S	S
Copper Nitrate Sat'd	S	S	Nickel*	S	S
Copper Sulfate Dilute	S	S	Potassium Carbonate	S	S
Copper Sulfate Sat'd	S	S	Potassium Nitrate Sat'd	S	S
Cychohexanol*	S	S	Potassium Perchlorate 10%	S	S
Cyclohexanone	M	U	Propyl Alcohol*	S	S
Detergents Synthetic*	S	S	Rayon Coagulating Bath*	S	S
Disodium Phosphate	S	S	Sodium Bisulfite Sat'd	S	S
Ethyl Acetate 100%	S	M	Sodium Borate	S	S
Ethyl Alcohol* 35%	S	S	Sodium Bromide Dilute Sol.	S	S
Ethyl Alcohol* 100%	S	S	Sodium Chloride Sat'd	S	S
Ethylene Chloride	N	U	Sodium Hypochlorite	S	S
Ferric Sulphate	S	S	Sodium Nitrate	S	S
Ferrous Chloride Sat'd	S	S	Sodium Sulfate	S	S
Formaldehyde* 40%	S	N	Tannic Acid* 10%	S	S
Fructose Sat'd	S	S	Tanning Extracts* Comm.	S	S
Fruit Pulp	S	S	Toluene - Under 50%	S	S
Gasoline*	S	U	Toluene - Over 50%	M	U
Gin	S	U	Trisodium Phosphate Sat'd	S	S
Glucose	S	U	Whiskey*	S	N
			Xylene	M	U

Aluminum tanks are also limited in use, primarily because of the material's low structural strength. However, aluminum does have high resistance to atmospheric conditions; fresh water, and certain hazardous chemicals such as concentrated nitric acid (above 82%) and sulfuric acid [8]. Thus, aluminum may be useful in certain situations.

D. COATINGS, LININGS AND CATHODIC PROTECTION

Coatings, linings, and cathodic protection may be applied for corrosion protection to aboveground as well as underground tanks. Factors that affect the effectiveness and durability of coatings and linings include the following: (1) compatibility of the lining with the product stored; (2) compatibility of the coating with the environmental conditions (e.g., climate, plant environment); (3) preparation of the tank metal surface; (4) application technique; (5) curing requirements; and (6) testing and inspection of the applied lining or coating. Refer to Part II, Chapter 1 for additional information on the application of coatings and linings.

The external surfaces of aboveground tanks may also be protected against corrosion with cathodic protection [1]. For additional information on cathodic protection systems, refer to Part II, Chapter 1.

References

1. American Petroleum Institute, *Guide for Inspection of Refinery Equipment*, Chapter XIII – Atmospheric and Low-Pressure Storage Tanks, Fourth Edition, American Petroleum Institute, 2101 L Street, N.W., Washington D.C. 20037, April, 1981.

2. A.O. Smith Harvestore Products, Inc. *Tank Systems for Water and Wastewater*, Publication AOSHPI IND. 000-379-001, A.O. Smith Harvestore Products, Inc., 550 W. Algonquin Road, Arlington Heights, Illinois 60005, 1981.

3. Sayers, J.A., *Brittle Materials*, Chemical Engineering, Deskbook Issue, McGraw-Hill, 1221 Avenue of the Americas, New York, N.Y. 10020, Dec. 4, 1972.

4. Flacke, S.B., *Process Tank Linings*, Chemical Engineering, Deskbook Issue, McGraw-Hill, 1221 Avenue of the Americas, New York, N.Y. 10020, Dec. 4, 1972.

5. Tator, K.B., *Protective Coatings*, Chemical Engineering, Deskbook Issue, McGraw-Hill, 1221 Avenue of the Americas, New York, N.Y. 10020, Dec. 4, 1972.

6. American Petroleum Institute, *API Specification for Shop Welded Tanks for Storage of Production Liquid*, API Specification 12F, Seventh Edition, American Petroleum Institute, Production Department, 211 N. Ervay, Suite 1700, Dallas, Texas 75201, January, 1977.

7. American Petroleum Institute, *Use of Internal Floating Covers and Covered Floating Roofs to Reduce Evaporation Loss*, API Publication 2519, American Petroleum Institute, 2101 L Street, N.W., Washington D.C. 20037, 1976.

8. Perry, R.H., Chilton C.H., *Chemical Engineers Handbook*, Fifth Ed., McGraw-Hill, 1221 Avenue of the Americas, New York, N.Y. 10020, 1973, Chapter 23.

9. Pitcher, J.H., *Trends in CPI Materials – Steels*, Chemical Engineering, Deskbook Issue, McGraw-Hill, 1221 Avenue of the Americas, New York, N.Y. 10020, Dec. 4, 1972.

10. Owens/Corning fiberglas, *Fiberglas Tanks for Liquid Chemicals*, Pub. No. 5-PE-63987-G, Owens-Corning Fiberglas Corp., Non-Corrosive Products Divison, Fiberglas Tower, Toledo, Ohio 43659, 1980.

11. *Composite Tanks Fuse Fiberglass To Steel Via Polyester Resin Bond*, Petroleum Marketer, McKeand Publication, May-June 1979.

12. Emco Wheaton, Inc., *Loading Arm Assemblies*, Catalog E-12/72, Emco Wheaton, Inc., Chamberlain Blvd., Conneaut, OH 44030.

References Continued

13. American Petroleum Institute, *Welded Steel Tanks for Oil Storage*, API Standard 650, Seventh Ed., American Petroleum Institute, 2101 L Street, N.W., Washington D.C. 20037, November, 1980.

14. J&T Ecology Corp., *Industrial-Chemical Storage Tanks*, JTEC-979, J&T Ecology Corp., 200 Lambert Avenue, Coprague, N.Y. 11726.

15. Underwriters Laboratory, Inc., *Steel Aboveground Tanks for Flammable and Combustible Liquids*, UL 142, Fourth Edition, Underwriters Laboratories, Inc., 333 Pfingsten Road, Northbrook Illinois 60062, December, 1972.

16. American Petroleum Institute, *Recommended Rules for Design and Construction of Large, Welded, Low Pressure Storage Tanks*, API Standard 620, American Petroleum Institute, 2101 L Street, N.W., Washington D.C. 20037, December, 1978.

17. American Petroleum Institute, *Cleaning Petroleum Storage Tanks*, API Publication 2015, Second Edition, American Petroleum Institute, 2101 L Street, N.W., Washington D.C. 20037, November, 1976.

18. American Petroleum Institute, *API Specification for Bolted Tanks for Storage of Production Liquids*, API Specification 12D, Twelfth Edition, American Petroleum Institute, Production Department, 211 N. Ervay, Suite 1700, Dallas, Texas 75201. January, 1977.

19. American Petroleum Institute, *API Specification for Field Welded Tanks for Storage of Production Liquids*, API Specificaion 12D, Eighth Edition, American Petroleum Institute, Production Department, 211 N. Ervay, Suite 1700, Dallas, Texas 75201. January, 1977.

20. American Petroleum Institute, *API Recommended Practices for Setting, Connecting, Maintenance and Operation of Lease Tanks*, API RP 12R1, Second Edition, American Petroleum Institute, Production Department, 211 N. Ervay, Suite 1700, Dallas, Texas 75201. February, 1981.

21. Occupational Safety and Health Administration, *OSHA Safety and Health Standards (29 CFR 1910)*, OSHA 2206, United States Department of Labor, available from U.S. Government Printing Office, Washington, D.C. 20402, Revised, June, 1981.

22. Atlas Minerals & Chemicals, Inc., *Atlas CT-30*, Data Sheet No. 30 PI (10-81), Atlas Minerals & Chemicals, Inc., Farmington Road, Mertztown, PA 19539.

Part III
CHAPTER 2: ABOVEGROUND PIPING SYSTEMS

A. INTRODUCTION

The components of the piping or liquid conveyance systems for aboveground bulk storage facilities include culverts or drainage ditches, pipes, valves pumps, and their associated connecting joints and fittings. These components represent a major potential source of leaks and spills due to corrosion, physical breakage or failure, or loose connections attributable to improper installation, wear, or misalignment.

In Part II, Chapter 2 of this report, the causes and methods of preventing product leaks and spills from underground piping systems were discussed. The chapter addresses leak and spill prevention in aboveground piping systems. The discussion focuses on the different types of piping systems, valves, and pumps found in aboveground facilities.

B. CAUSES AND METHODS OF PREVENTING LEAKS

The major causes of leaks and spills from piping systems have been discussed in detail in Part II, Chapter 2 of this report. These causes include improper installation of piping system components, and deterioration of these components due to corrosion, wear, or mechanical failure.

Leaks and spills from piping systems can be prevented through proper design and installation of piping systems, periodic testing and inspection of system components, and timely replacement of defective, damaged, or worn out parts.

1. Proper Design and Installation

As discussed in Part II, Chapter 2, piping systems must be designed and installed properly if they are to perform effectively. The design and selection of components for a piping system depend upon the intended service. The piping system components must have sufficient physical strength, they must be sufficiently large to handle the intended flow rates, and they must be able to withstand such phenomena as internal and external corrosion, thermal loadings due to freeze-thaw cycles, and the physical loads that result from surges of liquid flow.

Proper installation is an equally important requirement. All piping system components must be properly joined (i.e., with tight connections). They must also be properly supported through the use of anchors, hangers, or other supporting elements so that they can withstand the mechanical loads that are transmitted through piping systems during normal operation. These include weight loads, shock and vibration loads due to liquid flow, and temperature-induced loads, such as those due to thermal expansion or contraction of pipelines. Table 3.2-1 presents a list of important points that should be considered in the installation of piping system components.

2. Periodic Inspection

Periodic inspection of piping systems is an important aspect of any spill or leak prevention program. Inasmuch as leaks in piping systems may result from mechanical failure and the deterioration of equipment, periodic inspection is an important means of insuring facility safety and reliability.

There are many in-service inspection techniques available for accessible aboveground piping system components. These include visual inspection and thickness measurement techniques such as ultrasonic or radiographic analysis. Of these, visual inspections are made more easily because they do no require specialized equipment.

Visual Inspections. Visual inspection is the cheapest and the most common method of inspection for piping system leaks or spills. Frequent (e.g., weekly) visual inspection of piping system components should be made to detect evidence of existing or potential leak problems. Inspectors should search for evidence of pipe misalignment, excessive vibration, external corrosion, indications of pipe blockage, accumulations of liquids, or other signs of general physical damage.

Pipe Misalignment. Piping should be checked for misalignment. The following are some observations that may indicate misalignment:

- Pipe dislodged from its supports.
- Deformation of the wall of a vessel in the vicinity of the pipe attachments.
- Shifting of the base plate or shearing of the foundation bolts of mechanical equipment to which the piping is attached.
- Cracks in the connecting flanges or cases of pumps or turbines to which the piping is attached.

Excessive Vibration. If vibration or swaying is observed, inspection should be made for cracks in welds, particularly at points of restraint such as where piping is attached to equipment and in the vicinity of anchors. Additional support should be considered for poorly braced, small size piping and valves and for the main vibrating line to which they are attached. In cases of severe vibration, it may be advisable to have a competent consultant recommend the remedial action, particularly if specialized equipment may be required.

Table 3.2-1

Piping Installation and Leak Prevention

The following is a list of important points that should be considered in the installation of piping system components:

- Prepare proper supports for piping and other components, such as valves, so that pipline stresses are properly absorbed and are not transmitted to valves or other components.
- In locating valves, make sure they can be operated easily and safely, and are in a protected location so that projecting parts cannot be struck and damaged by passing traffic.
- Most valves work best when standing upright, with the stem pointing straight up. Any stem position from straight-up to horizontal is satisfactory, but still a compromise. Installing a valve with its stem down is not good practice. With a valve in this inverted position, the bonnet acts as a trap for sediment, which may cut and damage the stem. Upside down positioning for valves on liquid lines subject to freezing temperatures is bad because liquid trapped in the bonnet may freeze and rupture it.
- Ensure that all joints are properly connected. In the case of threaded joints, ensure that threaded ends are not damaged.
- Good piping practices require the proper identification of all lines, usually giving the purpose by tags, plates or painted colors. Operators should know the functions of every line and the location of critical valves, so that they can be operated quickly and properly in case of emergencies.

When laying out a line, it is important to consider the possibility of water hammer shock. Condensate or slugs of water in stream lines can be dangerous, rupturing joints, valves, or fittings and loosening anchors or supports. In liquid lines, the sudden stoppage of flow can cause water hammer and shock. Where quick opening or closing valves are installed, water hammer may result when the valve is opened or closed quickly. The resulting "backlash" or pressure surge causes pounding and vibration in the line. This can eventually weaken pipe joints in the system. Adequate air chambers or other cushioning devices--a vertical capped standpipe of adequate height for example--will tend to cushion the water hammer. These devices should be located upstream and not too far from the valve.

Proper installation practices for piping systems have been established and are published by various organizations such as the American Petroleum Institute (API) and the American Society for Testing and Materials (ASTM). These practices cover subjects such as welding of pipelines, testing of welds, pressure testing lines, etc. Good construction practice dictates that standards such as these be followed.

External Corrosion. Inspectors should look carefully for signs of external corrosion. Refer to the discussion of corrosion in Part I of this report for more information.

Indications of Blockage. A decrease in exit pressure or an increase in input pressure without an accompanying change in throughput is an indication of piping system blockage. The relative severity of the blockage will be indicated by the amount of pressure increase/decrease. If indications of blockage are encountered, steps should be taken to isolate and correct the problem before extensive damage results.

Accumulations of Liquids. Accumulations of leaked liquid that has seeped into the ground can usually be detected by discoloration of the earth. Evidence of such an accumulation is an indication that a leak has occurred, and steps should be taken to locate the leak source.

General Physical Damage. The inspector should also look for the following signs of general physical damage:

- Distortion of piping or pipe supporting elements.
- Movement or deterioration of concrete footings.
- Deterioration of foundation bolts.
- Broken or otherwise defective pipe anchors.

If such conditions are discovered, steps should be taken to find the cause, and correct the problem

Thickness Measurements. Ultrasonic inspection and radiographic inspection are more advanced methods of determining pipe thickness, which in turn is a method of determining the extent of piping deterioration. These and other inspection techniques are discussed in detail in Part III, Chapter 6 of this report.

3. Periodic Testing

Periodic testing is less important with aboveground piping systems than it is in the case of underground piping systems because aboveground systems are accessible for periodic inspection. However, testing can still be an important method of evaluating the performance of piping system components. Refer to Part III, Chapter 6 of this report for more discussion of testing techniques and tools.

4. Timely Replacement

As mentioned in the discussion of underground piping systems, timely repair and/or replacement of deteriorated or damaged piping system components is vital to an effective leak prevention program. Piping system components should always be of sufficient integrity to withstand normal operating loads. When this is not the case, these components should be repaired or replaced promptly to avoid spill/leak problems.

C. PIPING

1. Types of Piping Systems

There are three distinct types of liquid that must be handled in an aboveground storage facility. These are: (1) pure product; (2) a mixture of stormwater runoff and product (referred to as contaminated runoff); and (3) pure stormwater runoff (referred to as uncontaminated runoff). In the typical bulk storage facility these liquid streams are segregated, with separate piping or conveyance systems, for ease of handling.

Uncontaminated runoff conveyance systems handle the stormwater runoff from non-operating areas of the bulk storage facility such as plant and office roofs, roadways, sidewalks, and grassed areas. This runoff typically flows into storm sewers for offsite disposal.

Contaminated runoff conveyance systems handle the runoff from operating areas of the facility such as paved loading or unloading areas, pump and equipment areas, and storage tank (farm) areas. This runoff consists of stormwater, equipment wash-down water, and spilled product that drains from those operating areas. These streams are typically collected in impervious ditches or trenches and directed via piping to a product recovery operation.

Pure product piping systems handle only pure product, either during normal product transport operations (e.g. tank filling or draining) or during the cleanup of pure product spills.

2. Types of Piping

Because of the wide variety of applications for pipe, may types of pipe are commercially available for use in aboveground storage facilities, including the following:

- Ferrous metal pipe, such as carbon steel, stainless steel and cast iron.
- Non-ferrous metal pipe, such as aluminum, copper and copper alloys, nickel and nickel alloys and lead.
- Non-metallic pipe, such as coated or uncoated concrete, asbestos cement, plastic and fiberglass-reinforced plastic (FRP).
- Composite pipe, such as galvanized steel, and rubber- epoxy- or plastic-lined steel.

The types of pipe more commonly used to transport pure product are carbon steel, stainless steel, galvanized steel and steel lined with plastic or epoxy, although aluminum or other non-ferrous metals may be used in certain special applications. Concrete and asbestos cement pipe are commonly used to transport uncontaminated runoff. Coated (epoxy or glass) concrete is commonly used in drainage trenches to collect contami-

Table 3.2-2

Characteristics of Piping Materials

Type of Pipe	Chemical Compatibility	Application	Remarks
Carbon steel	Compatible with petroleum products but generally not compatible with acids without coatings.	Product transfer.	Susceptible to corrosion if not coated, galvanized or otherwise protected against internal and external corrosion. Relatively inexpensive.
Stainless steel	Compatible with petroleum and with acids depending on grade.	Primarily used for corrosion protection in product transfer applications when coated carbon steel will not suffice (e.g. at high operating temperatures).	Used when product purity is of great concern. High relative cost.
Cast iron	Resists corrosive attack by natural or neutral waters and soils as well as atmospheric corrosion. Resistant to concentrated acids (nitric, sulfuric and phosphoric) as well as alkaline and caustic solutions. Dilute acids and acid-salt solutions will attack this material.	More widely used for non-hazardous service (e.g. water) than for hazardous chemicals service.	Low relative cost. Provides more metal for less cost than steel piping systems.
Aluminum	Subject to attack by alkalies, traces of heavy-metal ions such as copper, nickel and mercury, and by prolonged contact with wet insulation.	Used in product transfer applications involving substances that cannot be handled by steel, such as organic acids.	Limited structural strength as compared to steel. However, aluminum does not retain its structural strength at low temperatures.
Nickel and nickel alloys	99% nickel, 0.06% carbon used for halogen acids at high temperatures. 99% nickel, 0.01% carbon used for fused caustic soda (sodium hydroxides).	Used for high temperature service up to 2000° F because of outstanding resistance to oxidation.	Useful for handling halogen acids at high temperatures, sodium chloride solutions, and caustic soda.
Lead and lead-lined steel	Useful for handling sulfuric acid at moderate temperatures.	Product transport for special applications such as in handling sulfuric acid.	Lead has limited structural strength. It is customary to lay lead pipe in steel angles or wood troughs.
Copper and copper alloys	Has high resistance to industrial and marine atmospheres, sea water, alkalies, and solvents. Oxidizing agents rapidly corrode copper. However, the alloys have somwhat different properties than commercial copper.	Copper tubing is widely used for piping in offices, laboratories, for steam tracing, and for pneumatic controls. Cupro-nickel is good in sea-water service. Bronze pipe generally performs well in hydro-carbon service.	Copper has excellent low-temperature properties.
Asbestos-cement	Smooth surface that does not corrode. Useful for solutions within a pH range of 4.5 to 14.	Used extensively for water systems (uncontaminated) runoff or stormwater).	Not used for product transfer.

Table 3.2-2 continued

Concrete	Subject to deterioration when exposed to acids.	Unlined, reinforced concrete is widely used as culvert, drain and sewer pipe. Lined concrete may be used to convey contaminated run-off when exposure to acids or other corrosive chemicals is likely.	May be lined with glass or epoxies for chemical use. Unlined concrete will leak.
Plastic tube and pipe	Various plastics can be chosen for their resistance to specified chemicals: — Polyethylene pipe and tubing have excellent resistance to salts, sodium and ammonium hydroxides, and sulfuric nitric and hydrochloric acids. — Polyvinyl chloride pipe and tubing have excellent resistance at room temperatures to salts, alcohol, gasoline, ammonium hydroxide, and sulfuric, acetic, nitric, and hydrochloric acids; may be damaged by ketones, aromatics and some chlorinated hydrocarbons. — Polypropylene pipe and tubing have excellent resistance to most common organic and mineral acids and their salts, strong and weak alkalies, and many organic chemicals.	For service with potentially corrosive material. limits are low. pared to steel. regulations.	Free from internal and external corrosion. Allowable stresses and temperature limits are low Low structural strength when compared to steel. Coefficients of thermal expansion are high. Sould be protected from fire exposure in accordance with OSHA regulations.
Plastic lined piping	See plastic pipe.	Widely applicable to handle corrosive chemicals.	Combines the chemical resistance of the various plastics and the tensile and structural strength of steel.
Fiberglass and fiberglass-reinforced pipe	Compatible with a wide range of petroleum and chemical products. See chemical compatibility chart in Part II, Chapter 2.	Widely applicable to handle corrosive chemicals, including acids, bases and hydrocarbon solvents.	Less structural strength then steel. High resistance to external and internal corrosion. Should be protected from fire exposure in accordance with OSHA regualtions.

nated runoff prior to pumping via metallic pipe to a treatment process. Data describing the circumstances of application, chemical compatiblity, advantages and disadvantages of the types of pipe listed above are presented in Table 3.2-2.

3. Hoses

Hoses are used at bulk storage facilities to transfer liquid during loading and unloading operations. They are preferred over piping in such cases because of their flexibility and ease of handling.

The following is a representative list of the materials of construction commonly used for hoses.

- Nylon
- Natural rubber
- Synthetic rubber
- Polyethylene
- Polyvinyl chloride (PVC)
- Polyurethane
- Polyester
- Steel wire
- Cotton braid
- Nylon braid

The most common type of construction is a combination of several of the above materials. For example, one type of hose has a PVC core, an open polyester braid, and a PVC cover. In choosing a hose material for a particular application, the responsible engineer should work carefully with the hose manufacturer to ensure that the proper material and design are being employed.

The major leak/spill problem associated with the use of hoses is the spilling or leaking of product when hoses are disconnected during loading and unloading operations. For example, it is currently common practice to use quick-disconnect couplings on the ends of discharge hoses during loading operations. However, quick-disconnect hoses do not seal the line against backflow when the hose is disconnected. Thus, product remaining in the hose will spill into the environment. This problem can be alleviated through the use of dry-disconnect couplings. Refer to the discussion of couplings in Part III, Chapter 4 for more information on this topic.

Other spill and leak problems associated with the use of hoses include the following:

- Improper connection and handling of hoses during filling operations. For example, the exit end of the hose is often an unthreaded nozzle that loosely fits into an inlet pipe. If the nozzle is removed from the inlet pipe during a delivery, a spill (possibly large) will result.
- Leaks at the joints between hoses and fittings.
- Rupture of the hose by internal pressure.
- Wearing of the hose by abrasion.

To prevent leaks and spills from these causes, the following practices are recommended:

- A trained operator should be present and alert during all product transfer operations.
- It should be confirmed that the hose pressure specification is adequate for the intended service.
- The hose should be pressure tested periodically.
- Guards should be provided on the hose for points of high abrasion.
- The hose should be inspected periodically for evidence of abrasion, cracks, etc.

Another common product transfer problem is the mixing of incompatible products. A good product transfer practice that can help in minimizing this problem is the selective use of couplings and adapters on transfer hoses. By carefully selecting couplings and adapters that are only compatible with each other, one can prevent the unloading or loading of product into the wrong tank.

4. Pipe Supporting Elements

Pipe supporting elements typically include anchors, guides, and hangers. These elements are designed to support the loads transmitted by piping to the attached equipment so as to prevent damage to the piping or other equipment. Pipe supporting elements are typically made of steel, although wrought iron and wood may also be used in certain situations. More information on pipe supporting elements is available in the *Chemical Engineers' Handbook* [1].

D. VALVES

1. Functions of Valves

The principal functions of valves are: stopping, starting, regulating, and controlling fluid flow in pipelines; preventing backflow in pipelines; regulating and relieving pressure in pipelines and tanks; and isolating piping or equipment for maintenance without interruping other connected units. These functions are highlighted in Table 3.2-3.

2. Types of Valves

Valves are composed of valve bodies and valve trim. Valve bodies are typically composed of metal, plastic or fiberglass-reinforced plastic. They can be cast, forged, machined from bar stock or built up by welding a combination of two or more forms of material.

Table 3.2-3

The Functions of Valves

Starting and Stopping Flow:	The service for which valves are most generally used. Gate valves are excellenty suited for such service.
Regulating or Throttling Flow:	Done most efficiently with globe and angle valves.
Preventing Back Flow:	Accomplished with check valves.
Regulatory Pressure:	Valves can be used to reduce pipeline pressure to a desired level and maintain it at that level.
Relieving Pressure:	Safety valves are used; these are spring-loaded valves that open automatically when the pressure exceeds the limit for which the valve is set.
Controlling Flow:	Control valves provide a continuously variable orifice to change and control the rate of flow through the valve.
Isolating Equipment:	Valves can be included in system design to isolate pipe sections or other components for easy servicing.

The term "valve trim" refers to the internal parts of a valve body assembly that come in contact with the fluid flowing through the valve. Various alloys and plastics are available for the valve parts such as seats, disks, and stems which must retain smooth finishes for successful operation.

The concerns associated with the selection of valve seat materials focuses on the following:

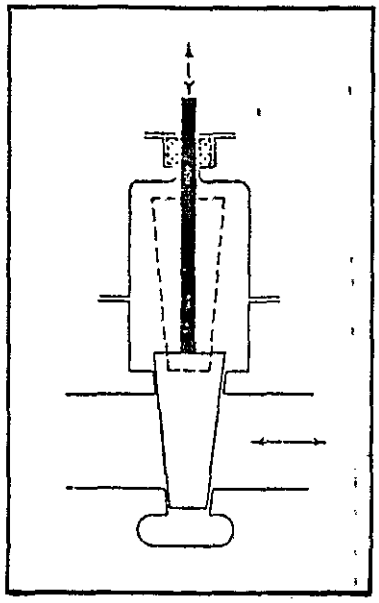
- Resistance to corrosion by the fluid handled.
- Resistance to oxidation at high temperatures.
- Resistance to erosion by suspended solids in the fluid.
- Maintenance of high strength at high temperatures.
- Prevention of galling (seizure at point of contact) by differences in material or material hardness.
- Avoidance of distortion.

The basic types of valves are gate valves, globe valves, angle valves, plug valves or plug cocks, ball valves, diaphragm valves, butterfly valves, check valves, and control valves. Diagrams of these types of valves are shown in Figures 3.2-1 through 3.2-4. Check valves and control valves are special types of valves which are further described below.

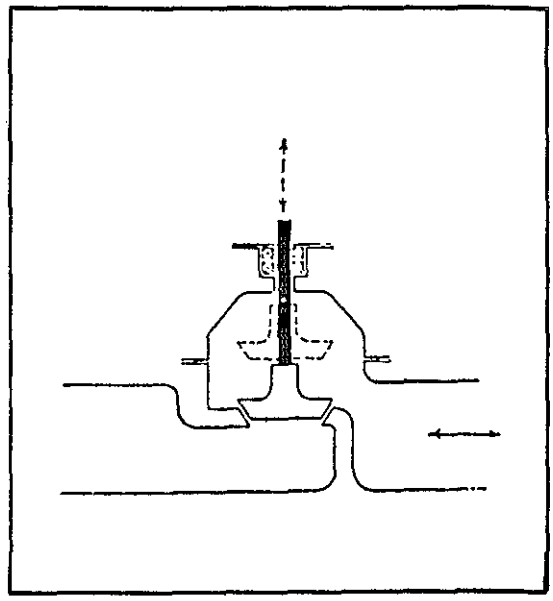
Check Valves. A check valve is used to automatically prevent back flow. The different types of check valves are swing check valves, piston check valves, ball check valves, and tilting-disk check valves. Piston and ball check valves are also referred to as lift check valves. Cross-sectional views of each type are shown in figure 3.2-3. These views portray the typical methods of preventing backflow.

Figure 3.2-1

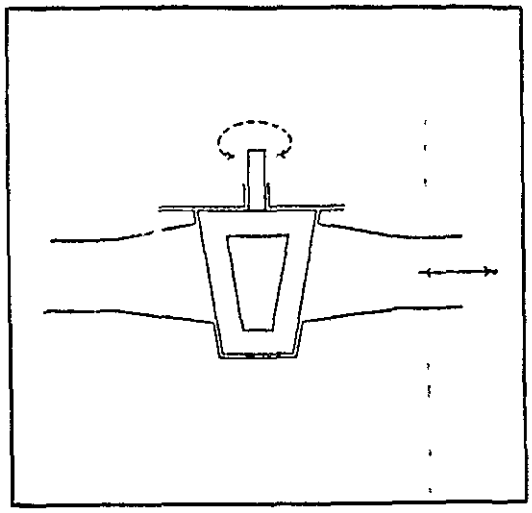
Types of Valves



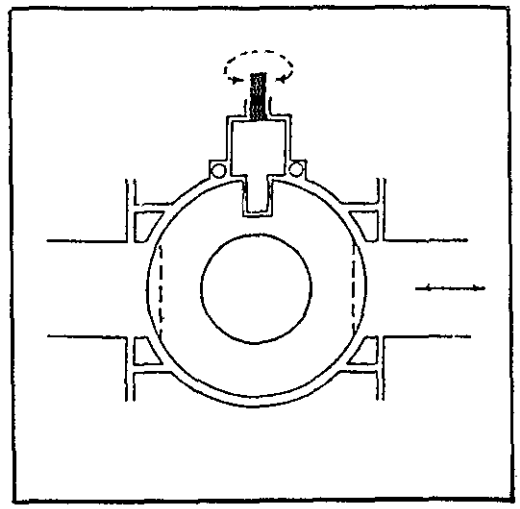
Gate Valve
Composed of a body containing a gate that interrupts flow



Globe Valve
Valve disk moves axially to rest against valve seat, blocking flow



Plug Cock
Composed of a tapererd plug with center hold that fits snugly into correspondingly shaped valve seat

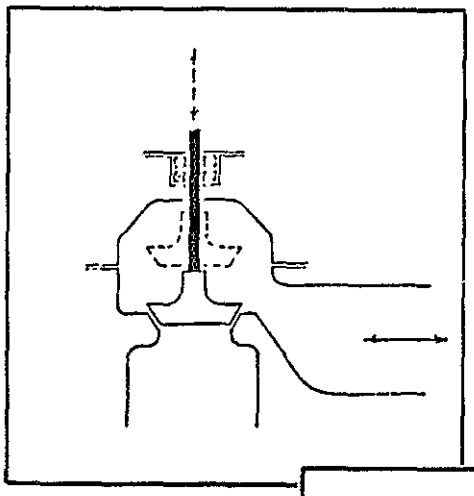


Ball Valve
Similar to plug cocks with exception that the plug is cylindrical.

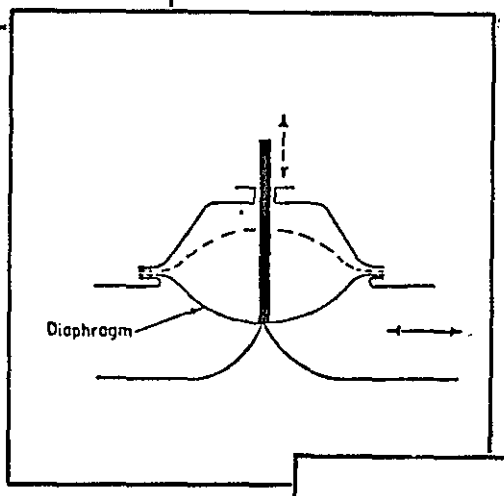
Source: Reference 4

Figure 3.2-2

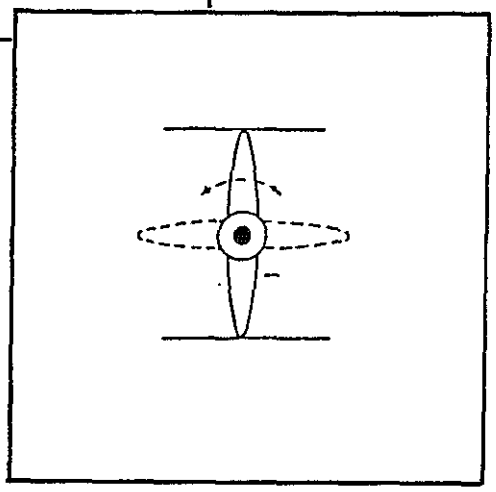
Types of Valves



Angle Valve
Similar to globe valve



Diaphragm Valve
Diaphragm functions as both closure mechanism and seal

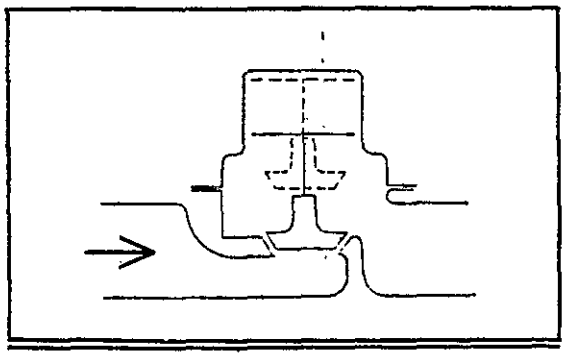


Butterfly Valve
A 90-degree turn of valve stem changes valve from completely closed to completely open

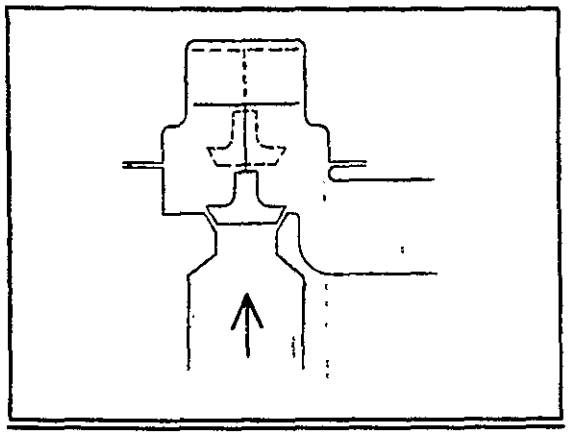
Source: Reference 4

Figure 3.2-3

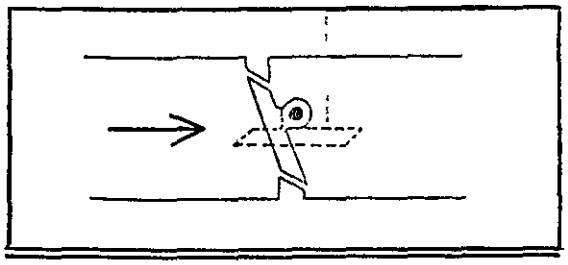
Check Valves Used To Prevent Backflow



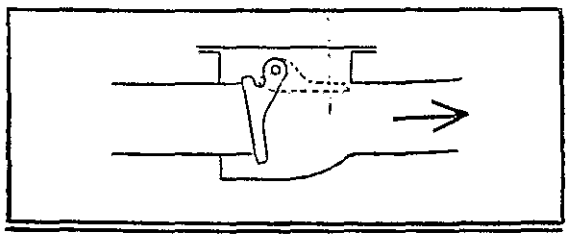
— Lift Check Valve, Globe



— Lift Check Valve, Angle



— Tilting-Disc Check Valve



— Swing Check Valve

Source: From *Chemical Engineers' Handbook*, Perry, R.H. and Chilton, C.H., Copyright (c) 1973, McGraw-Hill, Inc. Used by permission of McGraw Hill Book Company.

Control Valves. Control valves (see Figure 3.2-4) are typically the final elements in an automatic process control loop. The valve stem is moved up and down by an actuator that may be pneumatically, electrically or hydraulically powered. Pneumatic control is the most widely used method of process control.

Valve Maintenance. As is the case with other piping system components, valves must be inspected and tested periodically to insure proper operation. This includes dismantling at specified intervals to permit examination of all internal parts. Table 3.2-4 lists the problems that may be encountered with valves. For further information on the inspection and testing of valves, the reader is referred to API Standard 598, *Valve Inspection and Test* and to Chapter 6 of this part of this report.

E. PUMPS

1. Types of Pumps

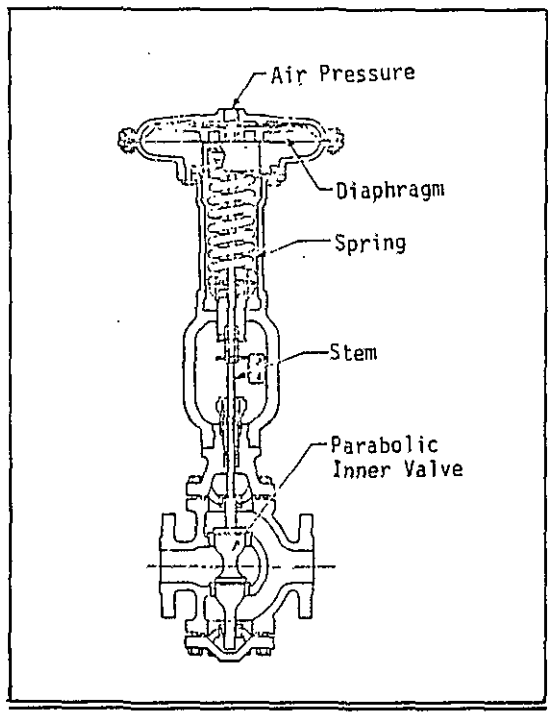
The basic function of pumps is to move liquids and slurries by imparting a velocity or pressure to those liquids. There are several different types of pumps available in today's market; however, they all have the following components in common:

- A casing or housing.
- A pumping mechanism that adds pressure or velocity to the fluid being moved.
- A power source.
- Seals that prevent or limit leaks of the pumped fluid from the pump housing or casing.

The three classes of pumps common in bulk storage facilities are centrifugal pumps, reciprocating pumps and rotary pumps. Each of these classes is further divided into a number of types. To select the correct pump for a particular service, several factors must be known; these include:

Figure 3.2-4

Typical Control Valve



Source: Reference 4

Table 3.2-4

Items to look for During Valve Maintenance

Improper Seating.
In some services, the valve seat will become filled with debris (sticks, stones, rags, screwdrives, etc.) and the valve will not seat when closed. Even though the stem appears to be down, the seal is not made.

Worn Trim.
Trim wears with time and hard service. Seats become damaged and worn and will not seal no matter how much pressure is applied to the valve handle.

Packing Leaks.
Over a period of time, packing will wear and cause a valve to leak at the packing gland. Normally this leaking is stopped by tightening the packing gland. However, there is a limit to how many times this can be done and eventually the packing must be replaced.

Broken Internals.
Internals such as the swing disc in a check valve, control valve spring, etc. can and do fail. These must be replaced.

- The properties of the liquid being transported, such as viscosity, volatility, etc.
- The required capacity, usually in gallons per minute (gpm or gal/min), and required range of capacity.
- The existing suction conditions (e.g., does a suction lift or suction pressure exist?)
- The discharge conditions.
- The type of service (continuous or intermittent).
- The type of power available to drive the pump.
- The pump location.

Most industries have developed pump standards for certain applications through experience. An example is API Standard 610, "Centrifugal Pumps for General Refinery Service." However, the size and type of pump best suited to a particular application can be determined only by an engineering study of the problem. Detailed descriptions of pump types are available in the *Chemical Engineers' Handbook* [1], and *Marks' Standard Handbook for Mechanical Engineers* [2].

2. Pump Seals

Pump shafts must be sealed from leaking since the shaft enters the pump casing and is connected to an impeller or piston. The failure of pump seals is a significant fource of leaks in piping systems and therefore proper selection and maintenance of pump seals is important.

The main classes of pump seals are mechanical seals and packing. Packing is the most common type of rotating shaft seal. If consists of fibers that are first woven, twisted or braided into strands, and then formed into coils, spirals or rings. To ensure initial lubrication and facilitate installation, the basic materials are often impregnated. In situations where lubrication of the packing cannot be sustained using some type of oil lubrication system, a small amount of leakage through the packing is essential to insure long packing life. A drip pan should be provided in such instances to contain the leakage.

Mechanical seals are widely used where leakage around the shaft is objectionable. They are also used in applications where packing cannot provide adequate leak protection. With mechanical seals, the sealing surfaces are perpendicular to the pump shaft. All mechanical seals contain four basic elements — a rotating seal ring, a stationary seal ring, a spring-loaded section for maintaining seal-face contact, and static seals. These components are shown in Figure 3.2-5.

Table 3.2-5 presents a comparison of the applications, advantages and disadvantages of packing and mechanical seals.

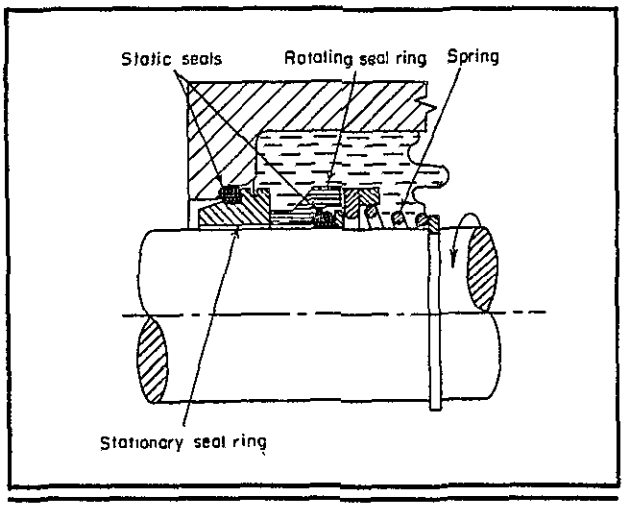
3. Spill and Leaks from Pumps

The following is a list of the major sources of leaks and spills from pumps:

- Leaking mechanical seals. Even though the purpose of mechanical seals is to eliminate leaking stuffing boxes, seals wear and will leak. Seals must be inspected frequently and leaking seals repaired or replaced.
- Leaking packed stuffing boxes. As the packing wears with pump operation, leaks will develop. These leaks are more frequent than those experienced with mechanical seals. The packing gland can be tightened to stop leaks. This must be done on a frequent basis until the packing is completely worn-out. Packing is then replaced and the process of alternating leaking and tightening resumes.
- Casing failure. Occasionally a pump casing will fail and the pumped material escapes. This can be largely eliminated if abrasive solids are pumped with a pump made of material that will withstand abrasion.
- Lubricating oil. Reciprocating pumps have lubricating oil systems for gear boxes, drive cylinders, piston rods, connecting rods, etc. There are leaks from maintenance filling of the lubricating oil system and from the stuffing boxes on the piston rod.

Periodic inspections of pumps is a necessary procedure in the bulk storage facility. It is often recommended that drip pans be installed under each pump, where possible, and that these drip pans be drained to a collection and/or treating system.

Figure 3.2-5
Mechanical Seal Components



Source: From *Chemical Engineers' Handbook*, Perry, R.H. and Chilton, C.H., Copyright (c) 1973, McGraw-Hill, Inc. Used by permission of McGraw-Hill Book Company.

Table 3.2-5

Comparison of Pump Seals

Seal Type	Materials of Construction	Advantages	Disadvantages
Packing	Flax Cotton Rubber Asbestos Jute Metallic braids Viscose rayon Leather Teflon Silicone Phenolic resins	Easy seal adjustment and replacement. Most equipment is designed so that disassembly of major pump components is not required to remove or add packing rings. Can be used in almost every class and type of pump.	Require constant lubrication, either with pump fluid or some other lubricant. Require frequent adjustment to compensate for wear. Often require leaking in small amounts to insure proper lubrication.
Mechanical Seals	Springs and other metallic components available in many alloys. Static seals composed of materials such as elastomers or teflon. Seal face materials include: - Carbon. - Ceramics. - Glass.	Effective elimination of leaks. Find their best application in situation where fluids are contained under substantial pressures. In these instances, their advantages over packing are: - Reduce friction-power loss. - Elimination of wear on shaft or shaft sleeve. - Negligible leakage over a long service life. - Freedom from periodic maintenance.	Are precision components that require careful handling and installation.

F. FITTINGS AND JOINTS

The types of fittings and joints used in piping systems and the problems associated with these components have been addressed in Part II, Chapter 2 of this report. Please refer to that chapter for details.

References

1. Perry, R.H., Chilton, C.H., *Chemical Engineers' Handbook*, Fifth Edition, McGraw-Hill Book Company, 1221 Avenue of the Americas, New York, NY 10020, 1973.

2. Baumeister, T., Avallone, E.A., Baumeister III, T., *Marks' Standard Handbook for Mechanical Engineers*, Eighth Edition, McGraw-Hill Book Company, 1221 Avenue of the Americas, New York, NY 10020, 1978.

3. American Petroleum Institute, *Guide for Inspection of Refinery Equipment, Chapter XI – Pipes, Valves, and Fittings*, American Petroleum Institute, 2101 L Street, N.W., Washington D.C. 20037, 1974.

4. Pace Company Consultants & Engineers, Inc., EPA Training Manual, prepared under EPA Training Grant No. T-900-175-02-2 to the Dept. of Environmental Science and Engineering, Rice University, Houston, TX, February, 1975.

Part III
CHAPTER 3: ABOVEGROUND SPILL CONTAINMENT SYSTEMS

A. INTRODUCTION

Spill containment and collection systems are an important part of the overall design of an aboveground bulk storage facility. In providing a means of preventing the free spread of escaped product, such systems serve the following purposes:

- Groundwater protection.
- Protection of the surrounding surface environment, including surface water and adjacent property.
- Product salvage.
- Fire protection in the case of flammable and combustible liquids.

The elements of a comprehensive spill containment and collection system include the following:

- Spill containment systems, such as dikes, impervious liners and underground barriers or cut-off walls.
- Spill collection systems, such as catchbasins, sumps, drip pans and collection troughs.
- Conveyance systems, such as sewer pipes, culverts and drainage ditches.

There are three types of runoff or spills that must be controlled at bulk storage facilities: (a) uncontaminated stormwater; (b) contaminated stormwater, which is a mixture of stormwater and product; and (c) pure product discharges and spills. Care must be taken to segregate these types of runoff because each will be handled and treated differently.

Uncontaminated stormwater is rainwater that falls on and flows over non-operating areas in the facility such as plant and office roofs, roadways, sidewalks and grassed areas. This runoff is typically collected in catch basins and directed to storm sewers for discharge to a municipal stormwater system, or directly to surface waters.

Contaminated stormwater is the runoff from operating areas such as paved loading or unloading areas, pump and equipment areas, and storage tank areas. It consists of rainwater, wash-down water and spilled product that drains from these operating areas. Contaminated stormwater is typically collected through catch basins and directed to a treatment facility for product recovery.

Pure product discharges include hose drainage, tank and equipment clean-out residues, and any spills that are collected prior to contamination with rainwater. These types of discharges are typically accumulated to be reprocesssed for recovery of clean product after a sufficient quantity is collected.

The schematic diagram of Figure 3.3-1 shows a bulk storage facility featuring segregation of the three types of runoff.

The type of spill control system used depends upon the area in which it is used, and on whether the system is intended to handle pure product, contaminated runoff, or uncontaminated runoff. The various types of containment and collection systems and their uses are summarized in table 3.3-1. The remainder of this chapter is devoted to a discussion of these system types and on-site spill cleanup procedures. Conveyance systems have been discussed in Chapter 2 of this part of the report.

B. DEGREES OF PERMEABILITY

The degree of permeability, or level of environmental protection provided by a spill containment or collection system should be sufficient to prevent loss of the stored liquid prior to cleanup. The discussion that follows focuses on the various levels of protection, surface materials used and factors that determine the type of material and level of protection employed.

1. Levels of Protection

The level of environmental protection provided by a spill containment surface can vary from minimal to extensive. Minimal protection, such as that provided by sandy soils, can be used in certain situations. An example of such an application would be a sandy soil surface used in a storage tank area housing heavy oil. The key in such instances is that the spill containment surface provides ample time for rapid collection and cleanup of any spilled material before significant damage to the environment is incurred.

A more stringent level of protection is that prescribed in the federal oil pollution prevention regulations governing Spill Prevention Control and Countermeasure (SPCC) Plans, which state that:

> ". . . Diked areas should be sufficiently impervious to contain spilled oil."

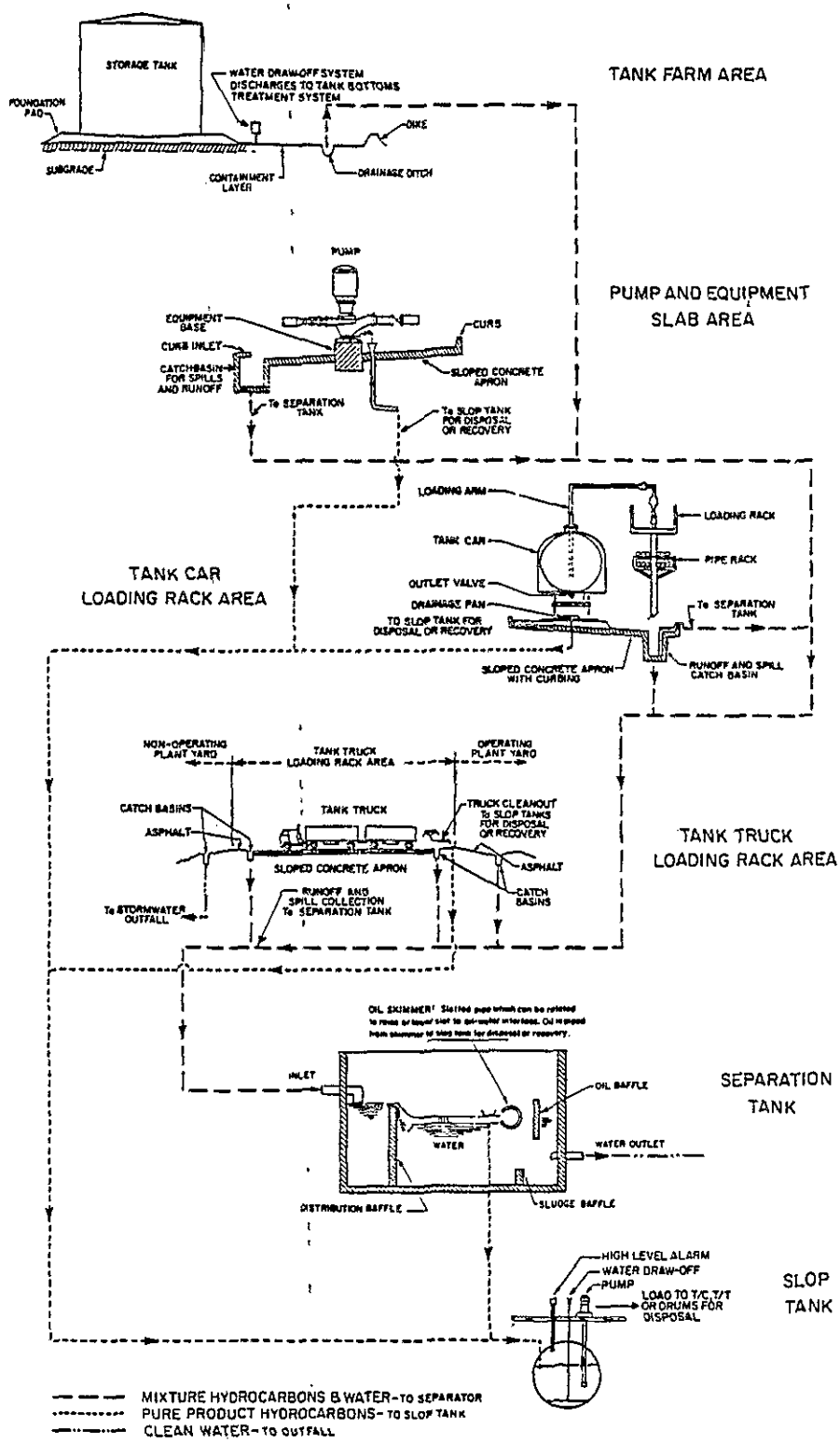
The use of the word sufficient makes this requirement subjective, but it implies a higher degree of impermeability than that described above, in that rapid spill cleanup is not a factor in determining the sufficiency of the containment surface.

A higher degree of protection can be achieved through the use of required performance criteria for containment surface permeability. An example of such a criteria is the New York State requirement for the level of impermeability of landfill liners:

> "Proposed landfills and modifications of existing landfills pursuant to Section 360.3 of this Part shall require a natural or artificial liner

Figure 3.3-1

Schematic Flow Diagram
Spill Catchment and Treatment System



Source: Reference 2

Table 3.3-1

Spill Containment and Collection Systems

Material	Source	Containment Systems	Collection Systems
Uncontaminated stormwater runoff	Non-operating areas such as plant and office roofs, roadways, sidewalks, and grassed areas.	Typically none.	Typically collected in drainage ditches and directed to storm sewers for discharge off site.
Contaminated runoff (mixture of product and stormwater)	Operating areas such as storage tank areas, loading and unloading areas, and pump equipment areas.	Containment in storage tank areas typically consists of diked impervious surface sloped to a collection ditch or sump. Containment in loading and unloading areas typically consists of a reinforced concrete apron surrounded by a concrete curb and sloped to a collection sump. Containment around pump equipment, etc., typically consists of concrete slab surrounded by a concrete curb and sloped to a collection sump. Containment in other operating areas of the plant consists of an impervious surface surrounded by curb or drainage ditch.	Collection systems consist of drainage ditches that direct flow to catchbasins or collection sumps for over-the-dike pumpout (in storage tank areas) or gravity drainage to a treatment facility.
Pure product	Hose drainage, tank and equipment clean up residues (without additives such as detergents, and quickly recovered spills.	Drip pans in loading and unloading areas and pump and equipment areas.	Collected separately from contaminated product and directed to a product recovery process such as a slop tank for oil recovery.

Table 3.3-2

Characteristics of Various Surface Materials

Surface Material	Advantages	Disadvantages	Relative Cost
Natural permeable soils	- Readily available at the site, requiring only compaction.	- Provides minimal environmental protection; useful by itself only in applications where a highly permeable surface can be tolerated.	Low
	- Useful as a cover over impermeable surfaces such as synthetic liners, clays, or bentonites to protect these surfaces from exposure to ozone, sunlight and vehicular traffic.		
Natural clays	- An inexpensive material if readily available.	- Subject to drying and cracking; must be protected with soil cover.	
	- Commonly used material; standard testing procedures are available.	- Subject to leaching of components when exposed to water or other solutions.	
	- High degree of impermeability can be attained; permeability will vary with thickness and degree of compaction.	- Subject to ion exchange when exposed to water containing acids, alkalis, or dissolved salts.	
		- Overcompaction can result in poor retention properties.	
Soil Cement	- *Good durability.*	- *In place soil usually used; permeability varies with the type of soil.*	Moderate
	- Resistant to aging and weathering.	- May not be applicable in the following soil situations: - highly organic soils - clays - saline soils - clean well-graded gravel or crushed rock.	
		- Subject to degradation due to frost heaving of subgrade.	
Bentonite	- *Low permeability.*	- Requires protective soil cover.	Moderate
	- Treated bentonites do not deteriorate with age.	- Untreated bentonites may deteriorate when exposed to contaminant.	

Table 3.3-2 continued

Asphalt	- Widely available. - Provides good water-proofing membrane, but does not provide a high degree of impermeability.	- Has poor resistance to hydrocarbons. - Application on frost-susceptible soils is questionable. - High temperature and long-term weather exposures may affect material properties.	Moderate
Concrete	- Easily applied to both rock and stable soil with good adherence. - Provides some degree of impermeability that can be enhanced with liners or coatings. - Good strength and durability. - Easily repaired	- If poorly designed, concrete is sus- to cracking when exposed to freeze/ thaw cycles, or if differential soil settlement occurs.	High
Synthetic Polymeric Membrane Liners	- High resistance to bacterical deterioration. - Specific polymers provide high degree of resistance to certain chemicals. - Provide high degree of impermeability to chemicals and water.	- Requires subgrade preparation and sterilization applied to earth to reduce the risk of puncture. - Must be protected from structural damage, particularly due to vehicular traffic. - May require protection from exposure to sunlight (ultraviolet light) and ozone. - Some polymers may be attacked by hydrocarbons solvents. - Good oil resistance and good low temperature properties do not normally go hand in hand.	Moderate to High

that restricts infiltration to the equivalent of five feet of soil at hydraulic conductivity of 10^{-5} cm/sec or less . . . ." [10]

2. Surface Materials

The materials that can be used for spill containment and collection surfaces include the following:

- Natural impermeable soils (clays).
- Soil additives, such as soil cement and bentonites.
- Synthetic polymeric membrane liners.
- Spray-on liners, such as concrete and asphalt.
- Poured-in-place liners of concrete or asphalt.

As mentioned in the previous section, natural permeable soils may also be used in a containment area. However, their application is limited to instances in which their lack of impermeability is not a major factor. The natural permeable soils used in a containment area are typically soils existing at or near the site.

The characteristics that are important in choosing a surface material for a particular application include the following:

- The degree of protection required (material permeability characteristics).
- Compatibility with the stored product.
- Structural integrity: ability to withstand weathering.
- Structural strength: ability to withstand normal operating loads.

The characteristics of the surface materials listed above are summarized in Table 3.3-2. Impermeable soils, soil additives, and synthetic membrane liners have been discussed in Part II, Chapter 3 of this report. Permeable soils, asphalt and concrete are discussed below.

Asphalt is a dark brown to black solid or semi-solid cementatious material; the primary constituents of asphalt are high flash point hydrocarbons that either occur naturally or are obtained as a residue of petroleum refining [11]. Asphaltic materials are widely available, and provide good waterproofing membranes. However, because of their hydrocarbon base they are susceptible to attack by hydrocarbon solvents. Therefore, they are not recommended for use in areas of frequent spills of that type.

Concrete mixtures consist of aggregate, cement, and additives to accelerate hardening. Sprayed concrete is easily applied to both rock and stable soil with good adherence. It forms a rigid, high strength surface with good long term stability and good hydrocarbon resistance. Sprayed concrete can be affected by freeze/thaw heave in frost susceptible soils; thermal and mechanical (vehicular traffic) stress may also affect performance. However, sprayed concrete is easily repaired.

3. Choosing a Surface Material

The choice of surface material and level of environmental protection for a particular spill containment and collection area will depend upon several factors, including the following:

- The type of material being stored.
- The speed with which spills are detected and cleaned up.
- The frequency of spills.
- Surrounding environmental conditions.
- Legislative requirements.

Type of Material Stored. The type of liquid being handled can determine to a great extent the degree of permeability required in all containment and collection surfaces. For example, heavy oil is very viscous, and therefore surfaces of sand or other graded (sloped) natural soils could be used, whereas the handling of gasoline would require more impermeable surfaces, such as concrete.

Frequency of Spills. The frequency (or likely frequency) of spills is another determining factor. Areas of the bulk storage facility where spills or leaks are more likely to occur, such as transfer areas (loading and unloading racks), would require more impermeable surfaces than other areas. For example, the surface of a transfer area handling jet fuels may consist of layers of concrete sandwiched around a synthetic liner, while a storage tank area handling the same liquids may have a spill containment surface of concrete or clay without the added protection.

Speed of Detection and Cleanup. The speed of spill collection and cleanup is also a factor in selecting surface materials. Surfaces in areas that are required to retain or hold a spill for relatively longer lengths of time will require more impermeable surfaces than those areas with much shorter spill retention times. Spill retention time is determined by such factors as:

- The design capacity of the facility's contaminated runoff collection and treatment systems.
- The frequency of inspection of the facility.
- The number, location and accuracy of leak/spill detection devices.

Surrounding Environmental Conditions. The sensitivity of the environment in the area of the bulk storage facility can be a major determinant in the level of environmental protection provided. In areas of high groundwater table or areas where the storage facility is located near or above an aquifer, surface impermeability is an extremely important requirement. Surface impermeability may be less important in areas where groundwater contamination is less of a threat due to hydrogeologic conditions.

Legislative Requirements. Degrees of permeability can also be required through legislation or regulatory action. The federal SPCC requirements and New York State landfill permeability requirements cited previously are examples of such regulations.

C. SPILL CONTAINMENT SYSTEMS

Spill containment systems consist of continuous surfaces that are surrounded by dikes, curbs, walls or berms. The purpose of these containment systems is to prevent a spill or leak of a hazardous liquid from leaving the area. To permit collection, containment surfaces are typically sloped to a sump, catchment basin, etc. Spills may then be collected in place, or conveyed to treatment, recovery or disposal via trenches, pipes or drainage ditches.

Typically the various areas of a bulk storage facility such as the storage tank area and the loading and unloading areas will have individual spill containment and collection systems. In addition, the entire bulk storage facility should be sloped inward to insure that no runoff or product spills are lost to the outside environment. The elements and designs of typical spill containment systems are discussed below.

1. Dike Systems

Aboveground tanks are typically enclosed by an impervious dike system designed to contain the spill in the immediate area of the tank. Diked areas for tank farms are designed to contain 110 percent of the capacity of the largest tank. In addition to providing emergency confinement of accidental spills, the dike also serves to hold contaminated runoff. After a storm or spill, the contaminated runoff or contained product is pumped over the dike to a treatment or recovery system. A typical dike system for a storage tank is shown in Figure 3.3-2.

Drainage of a diked area can be accomplished in one of two ways:

- A siphon may be used to draw the contaminated liquid over the dike as shown in Figure 3.3-3. This type of system is recommended for oil-water mixtures which tend to emulsify.
- A pumping system may be used to draw the contaminated liquid or product over the dike wall. With such a system, a permanent pump may be installed to transfer the contained liquid.

Gravity drains which pierce the dike should never be used. An open valve in the drain would be a route for loss of product after a spill.

Typical materials of construction for dikes include earth, masonry or reinforced concrete, with impermeable liners or cores composed of materials such as those listed in the previous section. Examples of types of earth dikes are shown in Figure 3.3-4.

The following is a listing of several important considerations in the design, construction and maintenance of diked areas:

- The diked volume should be sufficient to contain the entire storage volume which it surrounds plus the rainfall which could accumulate from a design (typically 50-year or 100-year) rainfall.
- The diked area should be impervious to the stored product to permit collection and cleanup of spills.
- The dike should be constructed with erosion-resistant and product-resistant materials.
- Vegetation growth should be controlled (prevented on earth dikes to prevent resulting damage to the impermeable coating or the dike itself.
- Breaches in the dike (through-the-dike pipes, etc.) should be prohibited. Ramps over the dike should be built for vehicle access.
- A program of diked area inspection and maintenance should be established and enforced.
- Dikes should be constructed with sufficient spacing around the tanks to meet fire codes and to allow the use of vehicles for cleanup.

2. Curbs

Curbed areas typically consisted of a reinforced concrete apron surrounded by a concrete curb as shown in Figure 3.3-5. This type of containment system is generally used in tank truck loading and unloading areas, tank car loading and unloading areas, and pump equipment areas. A spill collection system consisting of catch basins or a collection sump is usually included in curbed areas.

3. Slurry Trench Cut-Off Walls

A slurry trench wall or underground cut-off wall is a wall permanently embedded in the soil to reduce or "cut-off" the flow of groundwater. The expression slurry trench refers to the construction technique and not necessarily the end product. This type of spill containment system consists of an impervious concrete or bentonite wall that extends from the ground surface well into the groundwater table, as shown in Figure 3.3-6, or into an impervious stratum. The wall prevents the flow of spilled product away from the containment site, thus preventing a spill that has seeped into the soil from escaping. The cut-off wall application shown in Figure 3.3-6 is applicable only for oils or other materials that would float on the groundwater table.

Slurry trench walls are more commonly employed as a spill containment measure to confine a spill or leak after it has been discovered. However, they may be used as preventive measures in situations where a sensitive groundwater (aquifer) is located close to the bulk storage site in relatively permeable soils.

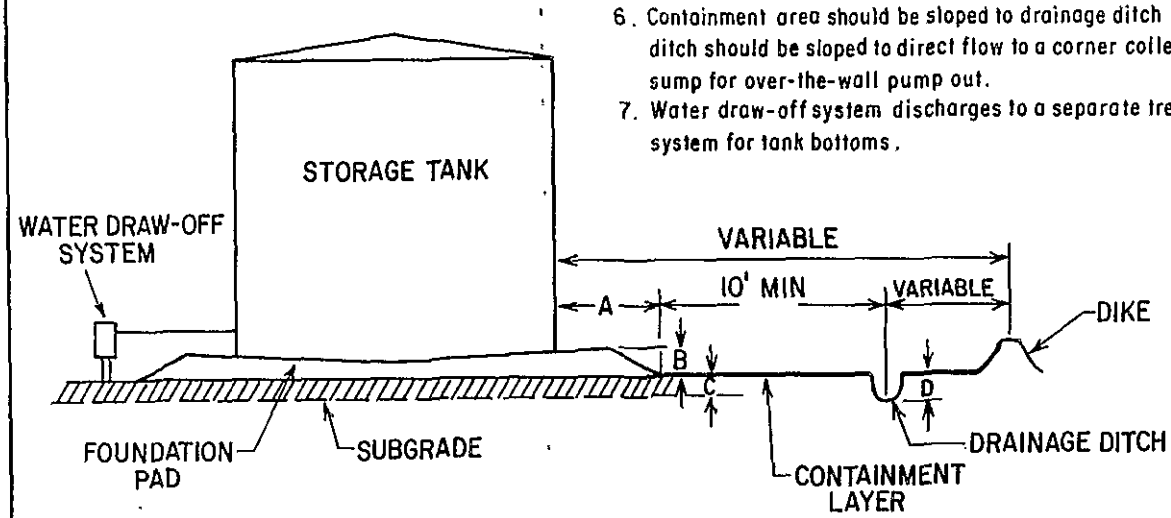
Very simply stated, slurry trench wall construction consists of excavating a trench about 3 feet wide to the desired depth, stabilizing or holding the sides of the trench up with a water-bentonite or water-leachate-ce-

Figure 3.3-2

Bulk Plant Layout

NOTES:

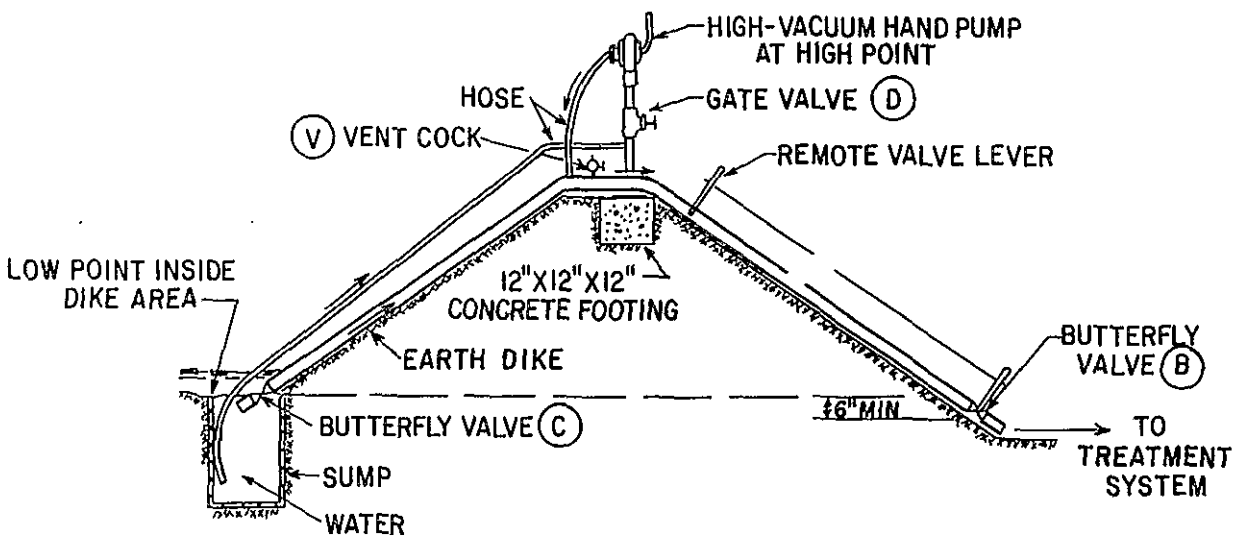
1. Dimension A is 1/25 of tank diameter plus one foot.
2. Dimension B is 1 1/2' minimum.
3. Dimension C is 1' minimum.
4. Dimension D is 1 1/2' minimum.
5. Containment volume must equal 110% of tank volume.
6. Containment area should be sloped to drainage ditch and ditch should be sloped to direct flow to a corner collection sump for over-the-wall pump out.
7. Water draw-off system discharges to a separate treatment system for tank bottoms.



Source: Reference 2

Figure 3.3-3

Dike and Siphon



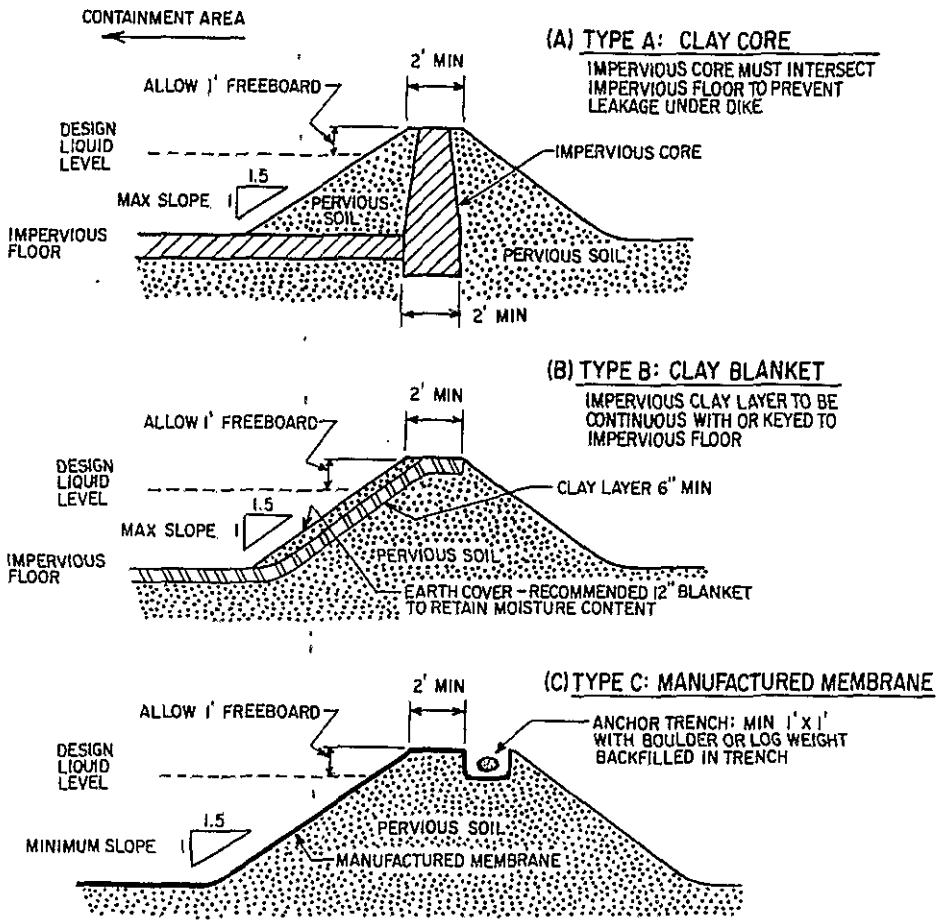
PIPE DRAINS, WITH OR WITHOUT VALVES DIRECTLY THROUGH DIKE WALL SHALL NOT BE USED

OPERATION OF SIPHON:
- CLOSE VALVE (B) & (C)
- OPEN VENT COCK (V) & GATE VALVE (D)
- PRIME SIPHON PIPE BY OPERATING PUMP; SUCKING WATER FROM INSIDE DIKED AREA TO BE DRAINED UNTIL WATER COMES OUT OF VENT COCK (V)
- CLOSE VENT COCK (V) & GATE VALVE (D)
- OPEN VALVE (B) & (C)
- BEFORE LEAVING, ATTENDANT MUST OPEN VENT COCK (V), GATE VALVE (D), DRAIN PIPING & PRIMING PUMP

Source: Reference 2

Figure 3.3-4

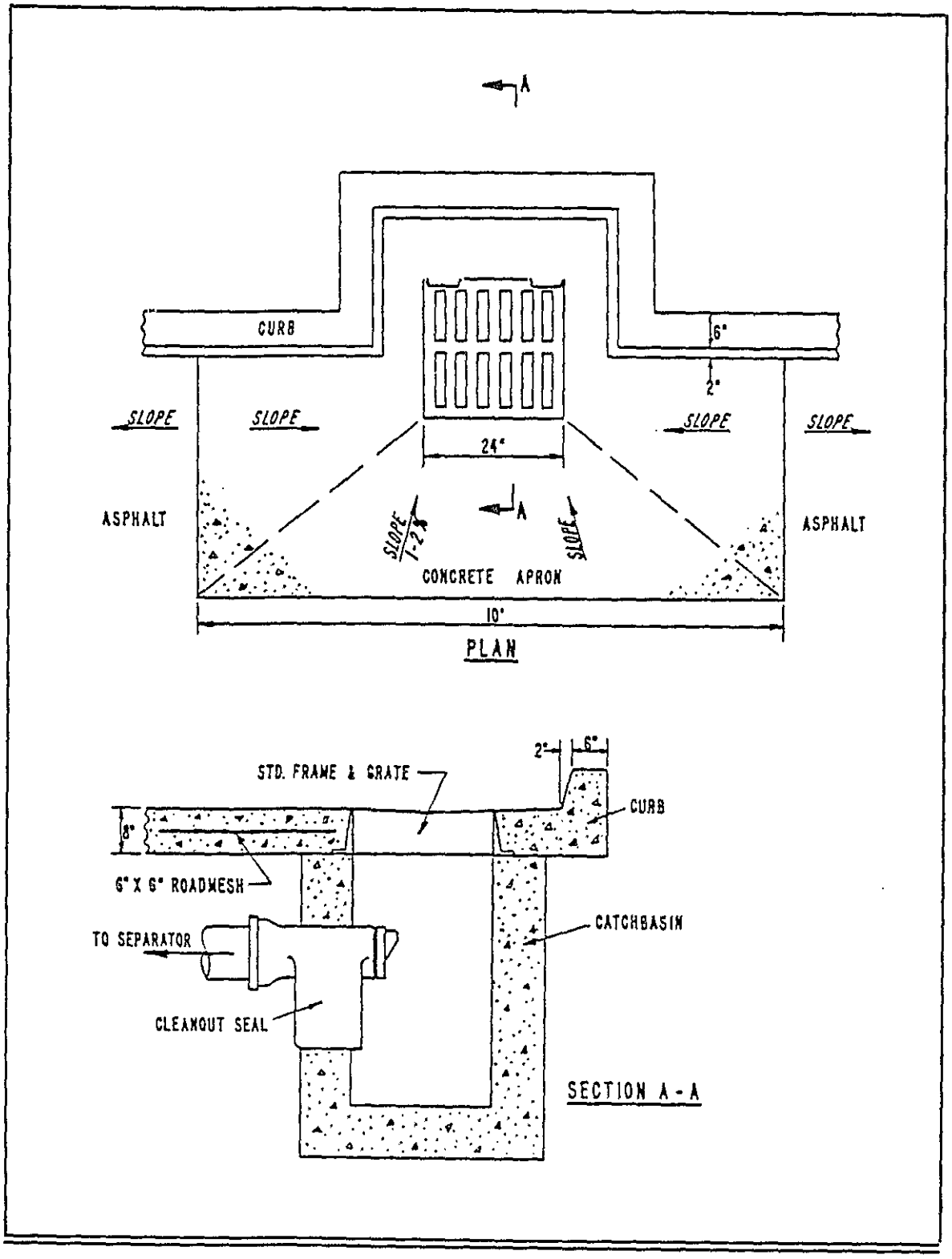
Typical Earth Dikes



Source: Reference 2

Figure 3.3-5

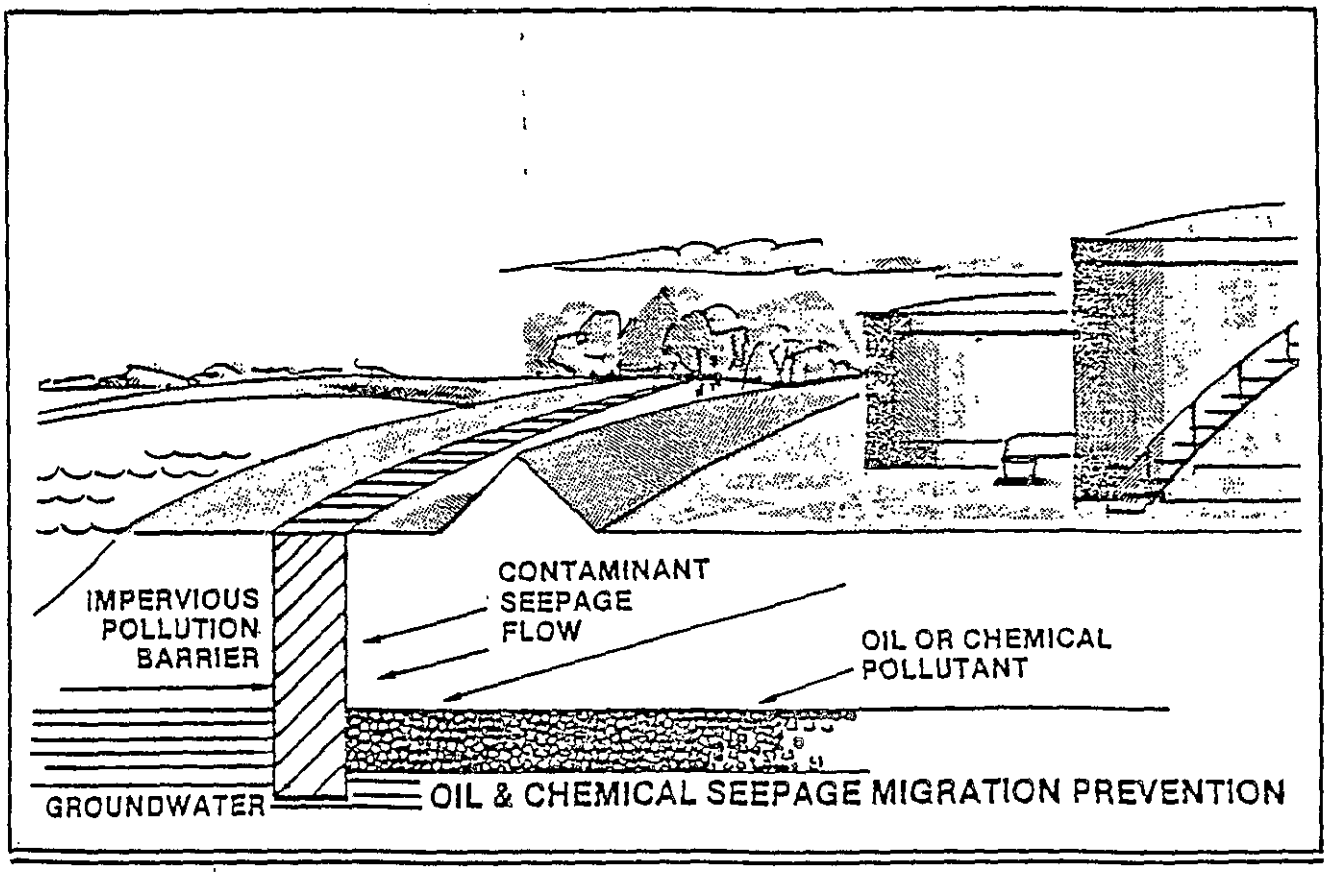
Typical Curbed Containment Area Drained Through Catch Basin



Source: Reference 2

Figure 3.3-6

Underground Barrier and Cut-Off Wall



Source: Reference 1

ment mixture, and possible backfilling the trench with concrete to form a wall. Extensive subsurface investigation and foundation engineering is often required in the design of these types of barriers [11].

4. Secondary Containment Tanks

Aboveground tanks storing hazardous materials may be placed inside secondary containment tanks designed to hold the product in case of rupture of the primary storage tank. These systems are often used at petroleum storage facilities and for secondary containment of acid and caustic storage. Secondary containment tanks are sized to hold the entire contents of the primary storage tank and are constructed of a material compatible with the product stored. Common materials of construction include coated carbon steel and concrete. For additional information on secondary containment tanks, refer to Chapter 1 of this part of the report.

D. SPILL COLLECTION SYSTEMS

Spill collection systems include trenches, gutters, collection troughs, catch basins, and collection sumps. Trenches, gutters and collection troughs are used as collection devices within the containment area. They collect and route spills and contaminated runoff to catch basins or collection sumps. Trenches, gutters and collection troughs are made of impervious materials that are compatible with the stored product. Catch basins and collection sumps are typically small underground concrete tanks connected by a network of drainage piping. These collection devices are located at low points within the containment area and collect minor spills and contaminated runoff for treatment and disposal. Catch basins are typically drained by gravity to a treatment system (e.g. an oil separator) via an underground pipe. Collection sumps are typically emptied by pumps or siphons. The over-the-dike siphon system shown earlier is a typical sump drainage device. Containments should be purposely designed to maximize product recovery and minimize contaminated residues resulting from a spill.

When designing a sump or catch basin, impermeability and compatibility of the surface material with the product stored are prime considerations. In some instances, it may be necessary to line the inside of the sump or catch basin with an appropriate coating material. Refer to the Compatibility of Coating Materials Chart in Appendix B. The drainage piping must also be compatible with the product stored to prevent premature deterioration. The number and location of catch basins or sumps is determined by the amount of spillage and runoff to be collected and the configuration of the containment area.

E. ON-SITE SPILL CLEANUP

On-site spill cleanup is aimed at the recovery of spilled product for reuse, if possible, or for disposal. Several techniques are available for on-site cleanup of spills, including the following:

- Direct suction pumping into tank trucks (large spills)
- The use of sorbents.
- Soil removal.
- Trenching and skimming.
- The use of recovery wells.
- On-site detoxification.
- The use of gelling agents.

Another technique that has received attention recently is the biodegradation of petroleum and other organic chemical spills.

The proper handling of spills of hazardous materials requires that certain materials and equipment be kept on site and, that a contingency plan outlining the steps to be taken to clean up a spill be prepared. A spill contingency plan typically includes: (1) a description of the steps that facility personnel must take to clean up the spill: (2) a list of plant personnel designated to respond to a spill emergency; (3) a list of the equipment kept on site for the purpose of cleaning spills; and (4) the names, addresses and telephone numbers of state and local emergency response agencies that may be called in, if needed, to assist in the cleanup operations. The promptness with which spills are detected and a response is made is important to minimize cleanup efforts.

1. Sorbents

Sorbents include spill scavengers and cleanup agents that absorb the spill. Based upon origin, sorbents may be divided into three classes:

- **Natural products,** which include straw, sawdust, clays and vermiculite
- **Modified natural products,** which include expanded perlite, charcoal, silicone coated sawdust, and surfactant-treated asbestos.
- **Synthetic products,** which include foam plastics and imbiber bead blankets.

When selecting a sorbent material, it is important to ensure that: (1) it is capable of absorbing the spilled material. and (2) it is chemically inert and will not react with the spilled material to form toxic or otherwise hazardous substances. The quantity of sorbent to be stored on site depends on the properties of the sorbent itself and the size of the potential spill to be cleaned up.

Imbiber Beads [5,6,7,8] Imbiber beads are a special type of sorbent material that deserve further discussion. Imbiber beads are small plastic spheres that will imbibe (absorb) a wide range of organic liquids (up to 27 times their own volume). During absorption, the spheres swell. The beads will not absorb water. There-

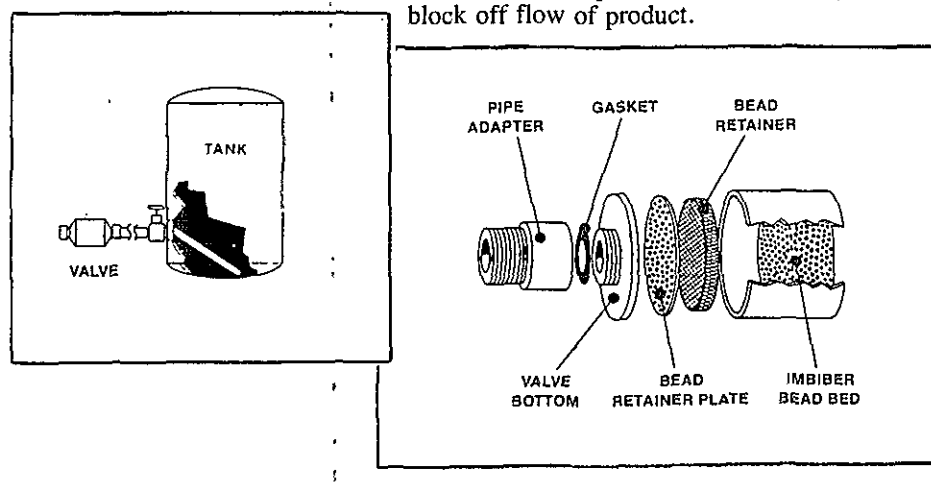
fore, water flowing through a bed of these beads will flow freely. If the water becomes mixed with gasoline or fuel oils, the beads absorb the contaiminant, swell to fill the void spaces between the beads and shut off all flow through the bed. Used, for instance, as a filter in a catch basin or sump as shown in Figure 3.3-7, the beads will not impede the flow of water unless a spill occurs. In the case of a spill, the beads will selectively imbibe the organic liquid, swell and shut off all flow to the drain. After the spill has been cleaned up, the bed of swollen beads must be removed, replaced and disposed of in a proper manner.

Figure 3.3-7

Imibiber Bead Applications

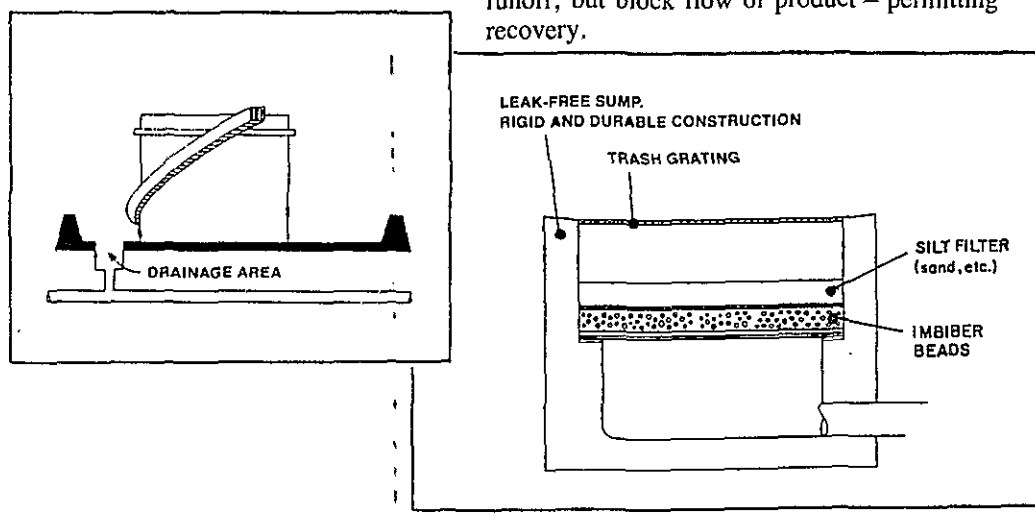
(A) *Storage tank water draw-off valve:*

Imbiber beads permit water drainage, but block off flow of product.



(B) Containment area drainage sump filter:

Imbiber beads permit drainage of water runoff, but block flow of product – permitting recovery.



Imbiber beads can be packed as loose beads, enclosed in packets for packaging dangerous liquids, or enclosed in blankets for spill cleanups. They are also packaged in canisters for use as valves in removing water from storage tanks: As shown in Figure 3-3.7 the canister is attached to the draw-off line and water is allowed to flow through. When the water/product interface reaches the beads, the spheres swell with product and shut off the flow. The line can then be closed off, and the imbiber bead canister replaced.

A list of materials that can be absorbed by imbiber beads is given in Table 3.3-3.

Table 3.3-3

Materials Absorbed by Imbiber Beads

Fuels:	Gasoline
	No. 1 Fuel Oil
	No. 2 Fuel Oil
	No. 3 Fuel Oil
	Jet Fuel
	Diesel Fuels
Chlorinated Solvents:	Carbon Tetrachloride
	Methyl Chloroform
	Trichlorobenzene
	Polychlorinated Biphenyls (PCB's)
Aromatic Solvents:	Benzene
	Toluene
	Xylene
	Ethylbenzene
	Cumene
	Styrene
	Methylnaphthalene
Polar Componds:	Methyl Isobutyl Keytone
	Tetrahydrofuran
	Ethyl Acrylate

Source: Reference 5

2. Soil Removal

Removal of contaminated soil is possible if the contaminant has penetrated only a few feet below the surface and high-capacity earth-movers are available. Soil that is excavated from a spill site should be properly disposed of. Soil excavation can be considered an initial, rapid response method for the removal of a contaminant before it reaches the water table. It may be possible and economical to aerate the soil in place where gasoline incursion is of low concentration. Air pollution guidelines should be checked before such a procedure, however. In all cases of soil removal, undermining of existing structures and damage to utilities should be avoided.

In cases of extremely toxic chemicals or sizeable spills that saturate the soil, treatment of the removed soil will be necessary.

3. Trenching and Skimming

In some instances, where a lighter-than-water substance has spilled or leaked and contaminated groundwater in a water table that is located near the surface, interceptors such as ditches, trenches, or pits can be used to control the flow of contaminated groundwater and recover the spilled product. Trenching and skimming may be used as the prime clean-up method or as a supplement to other methods.

Interceptor ditches deeper than 6 to 8 feet are usually impractical. The depth is basically limited by the type of excavation equipment available and the ability of the soil to support the walls of the excavation without collapsing. The ditch should extend at least 3 or 4 feet below the water table if the excavation is to be used as a withdrawal point. If the ditch is to be a collection point for skimming, its downstream wall is usually lined with an impermeable material such as polyethylene that blocks the flow of the contaminent on the water surface. Skimming must be continuous or the collected material will tend to move to the ends of the ditch and pass around the barrier.

Interceptor ditches need not be open ditches, as described in the following:

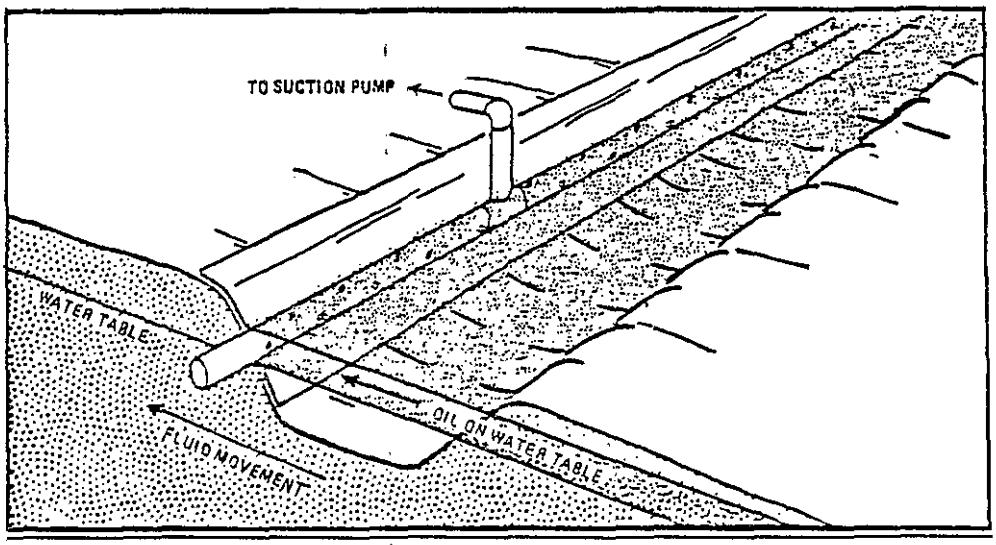
Backfilled Ditches. Ditches may contain permeable backfill. One approach is to lay a string of perforated culvert pipe in the bottom and backfill the ditch with porous material such as broken rock or gravel. Fluid enters the pipe through the perforations and can be removed through an opening left in the backfill. Back-filled trenches are difficult to construct and may not be effective. The pipe must be perforated only on the upstream side and located so that the perforations are precisely at the sufrace of the groundwater level. Fluctuations of groundwater level, which occur normally, tend to destroy the effectiveness of the drain before its need has passed.

Absorbent-Filled Ditches. Sometimes the interception ditch is filled with straw or other absorbent material. The absorbent is replaced periodically as it becomes saturated.

It must be noted that a trench is not a barrier to control subsurface movement of contaminated groundwater. The trench must either be skimmed continually or pumped sufficiently to make it a suitable collection point. A typical system for skimming the water surface in trenches or excavated pits is illustrated in Figure 3.3-8.

Figure 3.3-8

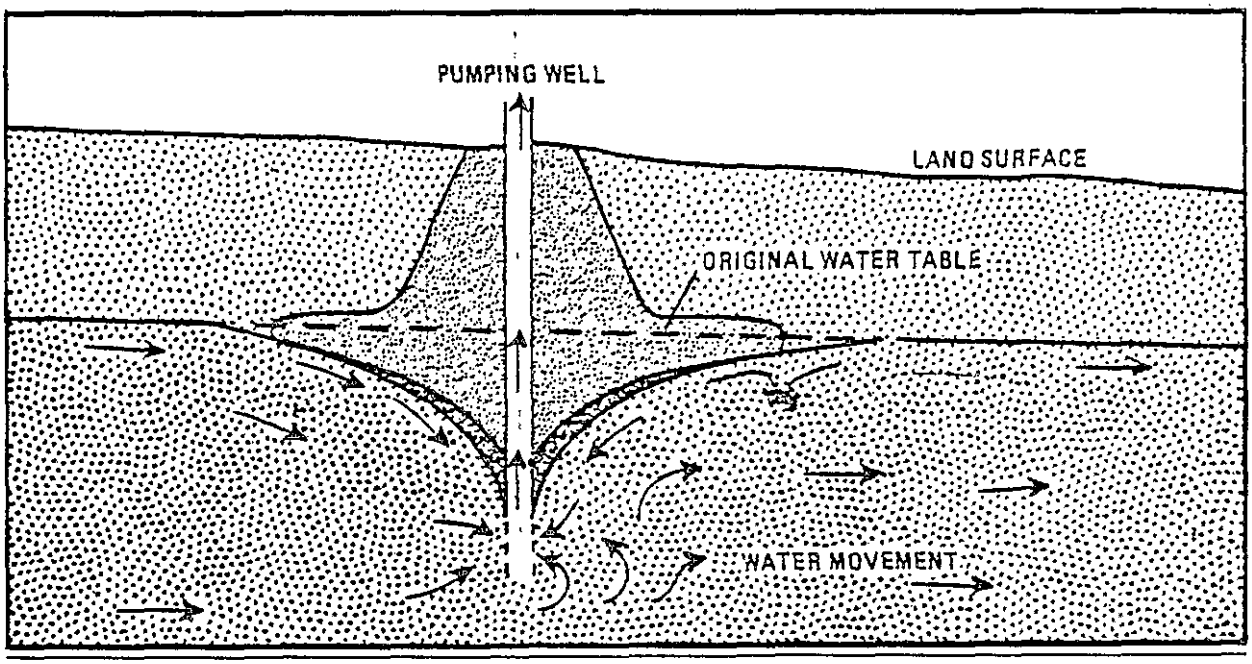
Spill Cleanup Using Inceptor Trench



Source: Reference 1

Figure 3.3-9

Spill Cleanup Using Pumping Well



Source: API Publication 4149, *The Migration of Petroleum Product in Soil and Ground Water*, 1972.

4. Recovery Wells

A pumping well, as shown in Figure 3.3-9, is used when the water table is too deep for the use of interceptors and ditches. This cleanup method is most efficient when the permeability of the aquifer is high and the depth of the aquifer is adequate to allow construction of a high-capacity well. In addition, vertical withdrawal wells can be effectively used in shallow aquifers when interceptor trenches will interfere with buildings, highways, tunnels, conduits and pipelines.

The product from the pumped well is separated from the groundwater by skimming or separation. It may also be necessary to aerate or carbon filter the separated water to remove dissolved materials.

This removal method establishes a depression in the water table sufficient to concentrate and prevent the further migration of a non-water soluble contaminant. A withdrawal well will work effectively where hydraulic conditions are such that pumping will depress the water table significantly. In this situation, the soil permeability and other hydrogeologic conditions allow a significant cone of depression of the water table. This causes the contaminated ground water to migrate toward the center of the depressed cone so it can be pumped to the surface. This method may be used with oil and other lighter-than-water chemical substances.

A standard procedure to determine the size and rate of development of cone is to drill several monitoring wells in straight lines adjacent to the pumping well. By observing the liquid level, the time and amount of drawdown can be determined as well as the further expansion of the depression cone. Pumping rates should be adjusted to maintain a cone large enough to contain only the contaminant.

The average cone of depression is shallow, but may be as deep as a few feet with a horizontal radius of as much as 1000 feet. If the water table is horizontal, a shallow depression normally will suffice to confine the floating contaminant. However, water tables are usually inclined and the cone must be deep enough to reverse the resulting gradient. The point at which the reversal occurs is the water table "divide". If the contaminant is to be contained effectively, the divide must lie beyond the contaminated area.

A series of small volume drawdown wells may be preferable to a single large volume drawdown well. The amount of water pumped should be limited as far as possible if disposal of dissolved contaminant will be a problem. If properly designed, the return of drawdown water to the affected area can increase the gradient toward or reduce the pumping rate at the drawdown well. This will promote flushing of the contaminated soil, ease water treatment loadings and reduce spreading of dissolved contaminants beyond the affected area.

5. On-Site Detoxification

At the present time, the most widely used cleanup techniques for land spills are excavation and hauling to a landfill or the flushing of the affected area with water (i.e., dilution of the spill). Flushing by fire departments is considered by many to be the best method of handling a spill in the view of safety. It is not. The appropriate solution, in most cases, is containment of the surface spill as quickly as possible and pick-up of the leaked product. Pick-up can be accomplished by suction pumping followed by sorption of the residue. Although these methods may be appropriate for some spills, other approaches may be needed when groundwater is threatened, when a large soil mass is contaminated or when no suitable disposal site is available. An alternative method is a mobile treatment system that will provide in-place detoxification of hazardous materials spilled on soil.

The objective of these techniques is to allow the spill to be cleaned up on-site. Containment is achieved by slurry trenching or injecting grouting material into the soil to seal the contaminated area. The isolated area is then chemically treated to achieve oxidation/reduction, neutralization, precipitation or polymerization of the spilled material.

The treatment system is generally mounted on a tractor-trailer. The grout and chemicals used are mixed in fiberglass tanks in alternate batches. The material is than transferred by positive displacement pumps to a feed tank. The vehicle is also equipped with an air compressor and a diesel-electric generator to operate the "air-hammer" that injects the treatment chemicals into the ground.

6. Gelling Agents

Application of a gelling agent to the contaminated area is an effective method of controlling spills of certain hazardous materials on relatively non-porous surfaces. Gelling agents interact with the hazardous material to form a gel that can be removed with earth-moving equipment. This immobilization prevents the spill from spreading and therefore minimizes contamination of soil and water.

Field tests have shown that the application of gelling agents is a practical solution for both small and large scale spills. Such systems can usually be operated with little training and can be built from readily available commercial equipment. The major drawback to this clean-up method is that gelling agents typically will not immobilize material at depths greater than 4 inches. There are various gelling agents available, each with different gel rates, application techniques and cost.

7. Biodegradation of Petroleum and Organic Chemical Spills

All natural soil, groundwater and surface water ecosystems include a group of organisms that are capable of biologically degrading complex organic molecules. These organisms are mostly microscopic, mainly bacteria and fungi. Although petroleum and organic chemicals are toxic to most plants and animals, some decomposing bacteria and fungi can use these substances as nutrients. For this reason, development of spill abatement technologies based on biodegradation is a promising field and has recently received much attention.

Although biodegradation is a natural process and will occur without any stimulation, its major drawback is that it normally proceeds very slowly in soil or groundwater systems. Thus, the technologies being developed to combat spills in these systems are directed toward speeding up biodegradation by ensuring a good supply of the materials that enhance the growth of bacterial and fungal populations. These materials, the most important of which are oxygen, nitrogen, phosphorus and water, are injected or allowed to percolate into the soil. However, it should be noted that the groundwater standards of New York State prohibit the discharge of nitrates as nitrogen into the groundwater in quantities exceeding 20 mg/1. On Long Island, the limitation of total nitrogen (as N) is 10 mg/1.

Although biodegradation is by no means a proven technique, it is already apparent that there are certain advantages and disadvantages. Advantages of the approach include:

- It can efficiently remove small concentrations of pollutants that would be difficult to separate by physical means.
- Water-soluble pollutants that are susceptible to biodegradation would be extremely difficult to remove by other clean-up techniques.
- Waste disposal is not a problem associated with this clean-up technology.
- In some cases, biodegradation may be a much faster process than other removal techniques.
- In groundwater contamination, the treatment moves with the contaminant plume.

Disadvantages include the following:

- Bacteria and fungi can create a viscous slime, which could plug up wells and soils and cut off the supply of oxygen, nutrients and moisture.
- Residues may create taste and odor problems.
- Even though the organisims involved are very small, in some geologic formations, with extremely small pore size, water and cell movement may be hindered.
- Continued injection of oxygen and nutrients may be ncecessary to sustain a high rate of degradation, expecially in groundwater systems.
- Where the pollutant is relatively concentrated, there may be relatively little surface area for the organisms to attach, and biodegradation may be slower than physical removal processes.
- In high density developed unsewered areas the bacteria may prefer the domestic sewage from seepage septic systems to the spilled materials as a source of food. This problem has occured in some areas.

In summary, biodegradation may not be the best technology to employ for all spills, but as more research is completed, it appears that it may be the best choice in some circumstances, and it is probably a valuable supplement to other clean-up techniques in others. Most of the information available on biodegradation relates to spills of petroleum products, but is certainly applicable for some other organic substances as well. It is conceivable that biodegradation techniques may be used in the future for combating spills of solutions of inorganic materials such an antimony, mercury, arsenic and selenium. These elements can all be reduced by bacteria to form gaseous complexes that would be mobile in the environment and could result in their liberation from contaminated soil or groundwater systems [1]. At any rate, currently existing technology for stimulating biodegradation of petroleum and organic chemicals is a valuable tool for ameliorating spills and should be considered as an alternative or supplement to other, more well-known, spill clean-up techniques [1].

References

1. U.S. Environmental Protection Agency, *A Guidance For Protection of Ground Water Resource From the Effects of Accidental Spills of Hydrocarbons and Other Hazardous Substances*, EPA-570/9-79-017, USEPA Office of Drinking Water, Ground Water Protection Branch, 401 M. Street, S.W., Washington, D.C. 20460, July, 1979.

2. Petroleum Association for Conservation of the Canadian Environment, *Bulk Plant Design Guidelines for Oil Spill Prevention and Control*, PACE Report No. 80-3, PACE Product Storage and Handling Committee, Suite 400, 130 Albert Street, Ottawa, K1P5G4, Canada, September, 1980.

3. U.S. Environmental Protection Agency, *Lining of Waste Impoundment and Disposal Facilities*, SW-870, USEPA Municipal Environmental Research Laboratory, Cincinnati, Ohio 45268, September, 1980.

4. Pace Company Consultants & Engineers, Inc., EPA Training Manual, prepared under EPA Training Grant No. T-900-175-02-2 to the Dept. of Environmental Science and Engineering, Rice University, Houston, Texas, February, 1975.

5. Dow Chemical U.S.A., *Imbiber Beads, Meeting Today's Needs by Controlling Organic Liquids*, Form No. 176-1328-77, Dow Chemical U.S.A., Functional Products and Systems Department, 2020 Dow Center, Midland, Michigan 48640.

6. Dow Chemical U.S.A., *Imbiber Beads Valves, Meeting Today's Needs To Remove Water From Organic Liquid Storage Tanks*, Form No. 176-1330-77, Dow Chemical U.S.A., Functional Products and Systems Department, 2020 Dow Center, Midland, Michigan 48640.

7. Dow Chemical U.S.A., *Imbiber Beads Valves, Meeting Today's Needs For Gravity Drainage From Diked Areas*, Form No. 176-1329-77, Dow Chemical U.S.A., Functional Products and Systems Department, 2020 Dow Center, Midland, Michigan 48640.

8. Dow Chemical U.S.A., *Imbiber Bead Packets and Blankets, Meeting Today's Needs to Clean Up Spills*, Form No. 176-1331-77, Dow Chemical U.S.A., Functional Products and Systems Department, 2020 Dow Center, Midland, Michigan 48640.

9. Code of Federal Regulations, "Oil Pollution Prevention", 40CFR Part 112, Office of the Federal Register, National Archives and REcords Service, available from U.S. Government Printing Office, Washington, D.C. 20402, revised as of July 1, 1979.

10. New York State Department of Environmental Conservation, *Solid Waste Management Facilities, Title 6 of the Official Compilation of Codes, Rules and Regulations*, 6 NYCRR Part 360, NYSDEC Division of Solid Wastes, 50 Wolf Road, Albany, N.Y. 12233, March 9, 1982.

11. Petroleum Association for Conservation of the Canadian Environment, *State of the Art Review – Petroleum Product Containment Dyking*, PACE Report No. 79-2, prepared for PACE by Golder Associates and James F. MacLaren Liited, Suite 400, 130 Albert Street, Ottawa, K1P5G4, Canada, March, 1980.

Part III

CHAPTER 4: TRANSFER SPILLS AND OVERFILL PREVENTION SYSTEMS FOR ABOVEGROUND STORAGE

A. INTRODUCTION

At aboveground bulk storage facilities, product transfers routinely take place in the storage tank area, as the tanks are filled, and in areas designated for the loading and unloading of tank cars or tank trucks. Transfer spills usually occur in one of the following manners:

- Product is spilled when transfer hoses are disconnected.
- Product is forced out of storage tank vent lines during tank filling operations.
- Storage tanks overflow during tank filling operations.
- Transfer lines or hoses leak or rupture while in use.
- Pumps break or leak.
- Tanks rupture from overpressurization.

Aside from a catastrophic event, such as the rupture of an unattended transfer hose while in use, transfer spills are generally small relative to the amount of liquid being handled. However, they can occur frequently enough to constitute a major source of product loss, damage to the environment, and hazard to the health of workers in the facility.

Transfer spills occur for the most part due to improper management and control of fluid transfer operations. They can be avoided or minimized through the implementation of transfer spill management systems and practices. The keys to transfer spill prevention are summarized in Table 3.4-1 and discussed in the remainder of this chapter.

B. OVERFILL PREVENTION SYSTEMS

The elements of a complete overfill prevention system for an aboveground storage tank are highlighted in the schematic diagram of Figure 3.4-1. These include:

- Level sensors and gauges to detect and indicate the liquid level in the tank.

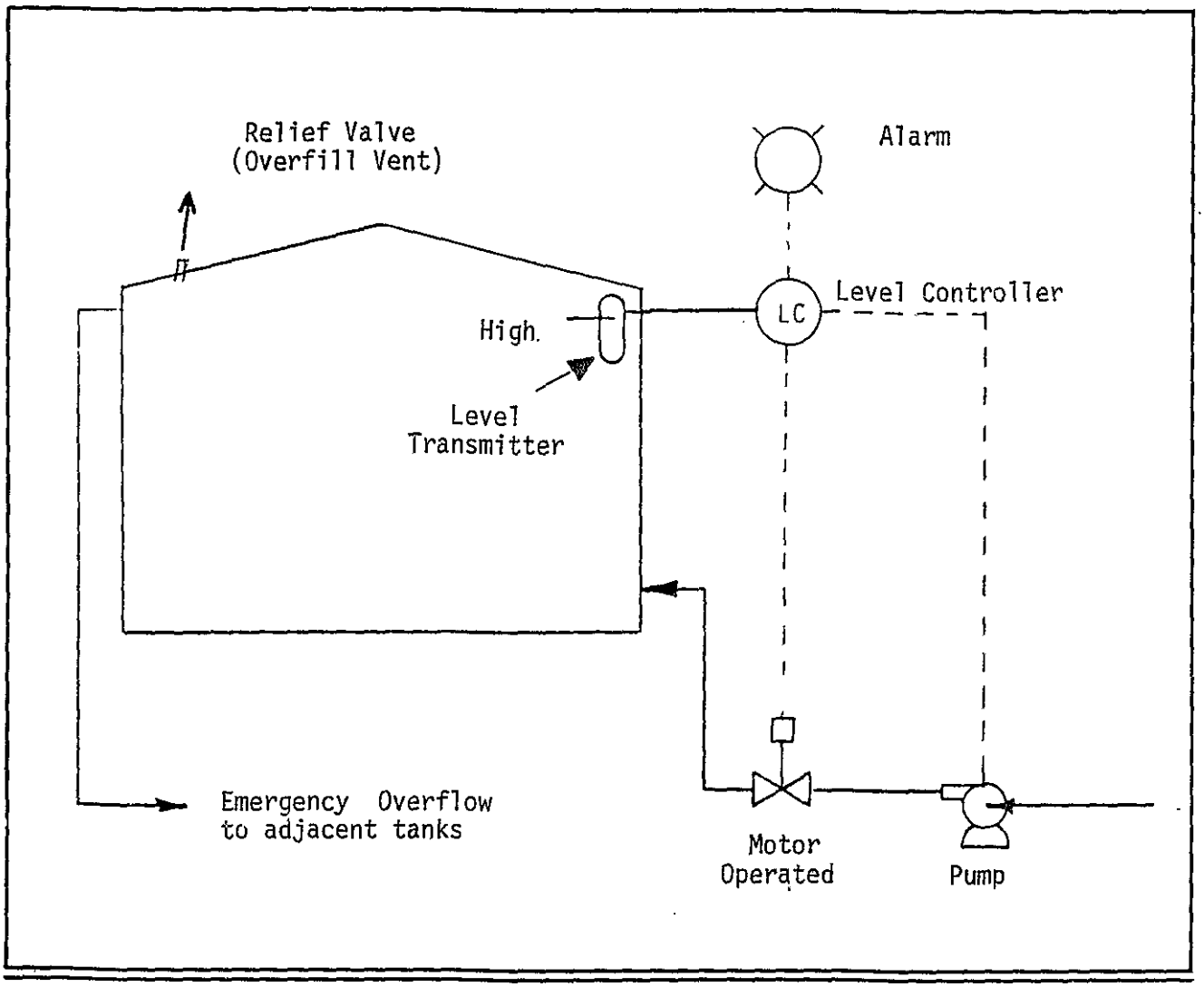
Table 3.4-1

Transfer Spills Are Prevented by Using the Following Equipment and Practices

- Install Overfill Prevention System
  - Level Sensor and Gauge
  - High Level Alarm
  - Automatic Shutdown of Valve and Pumps or Automatic Flow Dispersion
  - Emergency Overflow to Adjacent Tanks
- Use Dry Connect Couplings on Transfer Pipes/ Hoses
- Transfer Product at Established Stations Equipped with Curbing, Paving and Catchment Facilities
- Install Redundant Valves and Instrumentation
- Employ Proper Transfer Practices
- Conduct Regular Inspection and Maintenance of Spill Prevention Equipment

Figure 3.4-1

Elements of an Overfill Prevention System



Source: Reference 16

- High level alarms that are tripped to warn of an impending overfill situation.
- Automatic shutdown controls or automatic flow diversion controls that act to prevent tank overfilling.
- The capability for emergency overflow to adjacent tanks to collect overflowing product.

1. Level Sensors and Gauges

The level-sensing devices applicable to aboveground storage tanks include the following: (1) float-actuated devices; (2) displacer devices; (3) hydrostatic head devices; (4) capacitance devices; (5) thermal conductivity devices; (6) ultrasonic devices; and (7) optical devices.

Level-sensing devices may be top-mounted or side-mounted depending on the type of device and the location of the probe connection on the tank. As in the case of underground tanks, careful selection of the probe's materials of construction is necessary to ensure compatibility with the liquid in the tank.

Table 3.4-2 presents a comparison of these types of level-sensing devices, showing the types of gauges, alarms, and automatic controls with which they may be interfaced. Examples of capacitance, thermal conductivity, ultrasonic, and optical level-sensing devices were discussed in Part II, Chapter 4 of this report. The discussion below describes level-sensing devices that are applicable primarily in aboveground tanks, such as certain float-actuated, displacer, and hydrostatic (pressure) devices.

Float Systems. Float-actuated devices are characterized by a buoyant member that floats on the surface of the stored liquid. They are typically classified on the basis of the method used to couple the float motion to the indicating mechanism (gauge).

Chain or Tape Float Gauges. These devices consist of a float mechanically connected by a tape or a chain to a board or indicator dial as shown in Figure 3.4-2. They are commonly used in large atmospheric storage tanks because of their low cost and reliability. Their disadvantages include the potential for the following (1) getting out of alignment; (2) corrosion of the float material when improperly selected; and (3) jamming and freezing of the float linkage [7].

Lever and Shaft Float Gauges. As illustrated in Figure 3.4-3, this type of float gauge consists of a hollow metal sphere, sometimes filled with polyurethane foam and a lever attached to a rotary shaft that transmits the float motion to the outside of the vessel through a rotary seal. These devices are applicable to atmospheric as well as pressurized tanks. Careful selection of the float material is necessary to insure compatibility with the liquid.

Magnetically Coupled Floats. These devices consist of a permanent magnet attached to a pivoted mercury switch as shown in Figure 3.4-4. As the float rises following the liquid level, it raises the magnet attractor into the field of the magnet which in turn snaps against the non-magnetic barrier tube to tilt a mercury switch. When the liquid level falls, the float draws the magnet attractor below the magnetic field. The magnet swings out and tilts the mercury switch to the reverse position, causing actuation of the low level switch. The float and guide tube that come in contact with the measured liquid are available in a variety of materials for resistance to corrosion and chemical attack. Magnetically coupled float gauges may be used in conjunction with pneumatic and electronic controls to operate pumps, valves, alarms and other external systems.

Displacer Systems. Displacer-actuated devices use the buoyant force of a partially submerged displacer as a measure of liquid level. Vertical motion of the displacer is usually restrained by some elastic member whose motion or distortion is directly proportional to the buoyant force, and therefore to the level of the liquid. The range is limited to the length of the displacer. The coupling of float motion to the indicating mechanism is usually accomplished through the use of some type of packless mechanism, which frequently also constitutes the elastic restraining member. Accurate level measurement with displacement devices depends upon accurate knowledge of liquid and vapor densities. Displacer devices can be used in top cage mountings, or side mountings in vented (atmospheric), pressurized, or evacuated (vacuum) tanks.

Torque-tube Displacer. One of the most frequently used level-measuring devices is the torque-tube displacer, which is illustrated in Figure 3.4-5. The displacer is suspended on a displacer rod attached to a torque tube. This is fixed at its outer end, and supported on a knife-edge bearing at its inner end. The torque tube, in addition to being the elastic member, also constitutes a packless, presure-tight barrier. Inside the torque tube is a shaft that is fixed to the torque tube at its inner end. The rotation of the outer end of the shaft through a range of 5 to 10 degrees is porportional to the buoyant force exerted on the displacer by the stored liquid.

Magnetically Coupled Displacer. A displacer-actuated unit employing magnetic coupling is illustrated in Figure 3.4-6. Devices of this type commonly have a displacer constrained by a spring, and move a drive magnet enclosed in a protecting tube. Motion of the drive magnet is transmitted to the indicating mechanism by a magnetic follower outside the protecting tube. Devices of this type are almost always mounted in external displacer cages and require two tank connections, one above and one below the liquid level. They are compatible with both pneumatic and electronic controls.

Flexure-tube Displacer. A comparatively simple displacer device, as illustrated in Figure 3.4-7, consists of an elliptical or cylindrical float mounted on a short

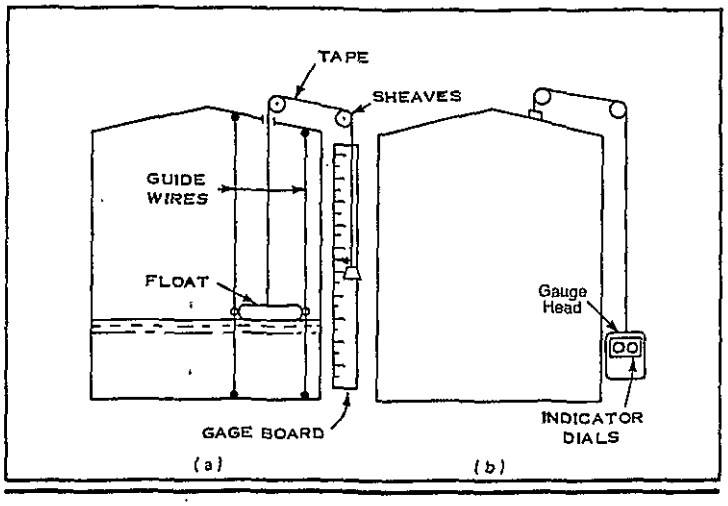
Table 3.4-2

Level Detection Devices for Overfill Prevention Systems for Aboveground Storage Tanks

Type of Device	Monitor Liquid Level	Level Indication	Alarm & Shutoff Response
Float Actuated Devices			
Tape or chain float gauges	Yes	Gauge	Interfaces with electronic or pneumatic controls.
Lever and shaft mechanisms	Yes	Gauge	Interfaces with electronic or pneumatic controls.
Magnetically-coupled floats	Yes	Gauge	Interfaces with electronic or pneumatic controls.
Displacer Devices			
Torque tube displacers	Yes	Gauge	Mechanical
Magnetically-coupled displacers	Yes	Gauge	Mechanical
Flexure-tube displacer	Yes	Gauge	Interfaces with electronic or pneumatic controls.
Pressure Devices			
Pressure gauge – open vessel	Yes	Gauge	Interfaces with electronic or pneumatic controls.
Bubble-tube systems (gas bubblers)	Yes	Gauge	Interfaces with electronic or pneumatic controls.
Head systems on pressurized tanks	Yes	Gauge	Interfaces with electronic or pneumatic controls.
Capacitance Devices	Yes	Gauge	Audible alarm & automatic shutoff; electronic controls.
Thermal Conductivity Devices	Yes	Gauge	Audible alarm & automatic shutoff; electronic controls.
Ultrasonic Devices	Yes	Gauge	Audible alarm & automatic shutoff; electronic controls.
Optical Devices	Yes	Gauge	Audible alarm & automatic shutoff; electronic controls.

Figure 3.4-2

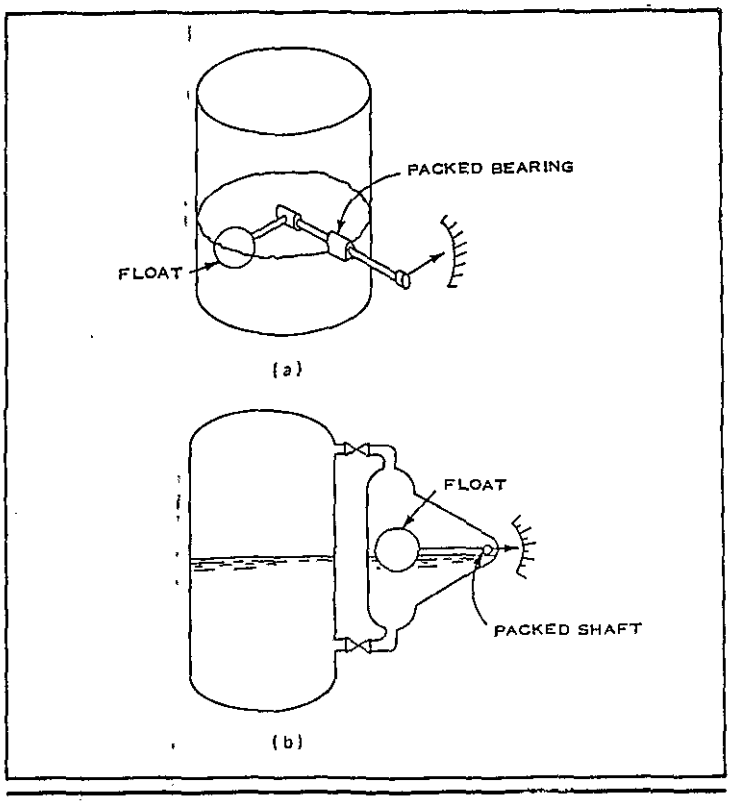
Chain and Tape Float Gauges Used For Level Control



Source: From *Chemical Engineers' Handbook,* Perry, R.H. and Chilton, C.H., Copyright (c) 1973, McGraw-Hill, Inc. Used by permission of McGraw-Hill Book Company.

Figure 3.4-3

Level and Shaft Float Gauges Used For Level Control



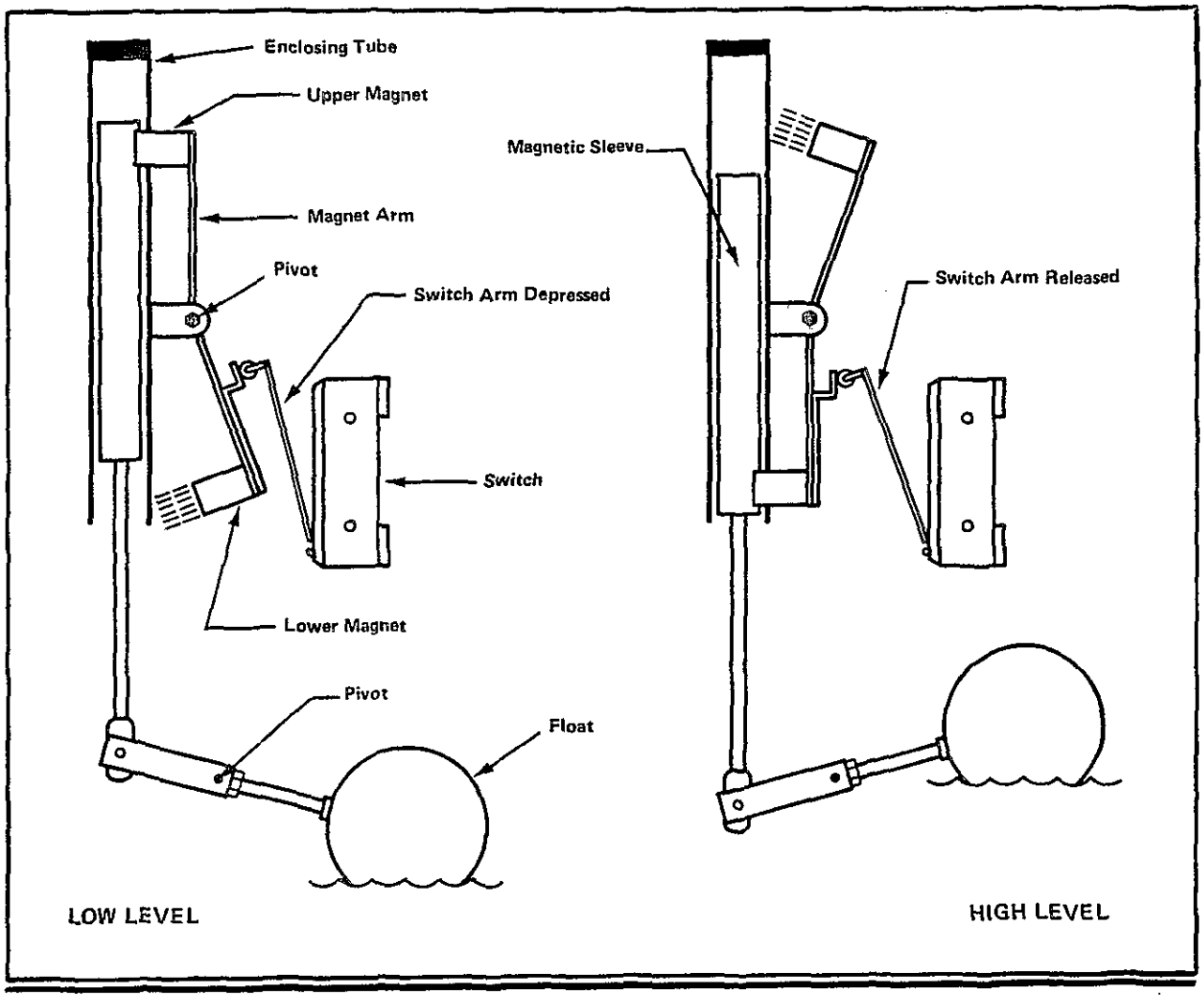
Source: From *Chemical Engineers' Handbook,* Perry, R.H. and Chilton, C.H., Copyright (c) 1973, McGraw-Hill, Inc. Used by permission of McGraw-Hill Book Company.

arm connected to the free end of a flexible tube, the fixed end of which is attached to a mounting flange. Motion of the float end of the tube is transmitted outside the float chamber by means of a rod extending out through the tube. These devices are side-mounted and are commonly used to actuate directly either an electrical level switch or a pneumtic pilot.

Hydrostatic Head (Pressure) Devices. A variety of devices utilize hydrostatic head as a measure of level. As in the case of displacer devices, accurate level measurement by hydrostatic head requires an accurate knowledge of the densities of both the liquid and the vapor-air misture inside the tank. The majority of these types of systems utilize standard pressure or differential pressure measuring devices. They are compatible with either pneumatic or electronic controls.

Figure 3.4-4

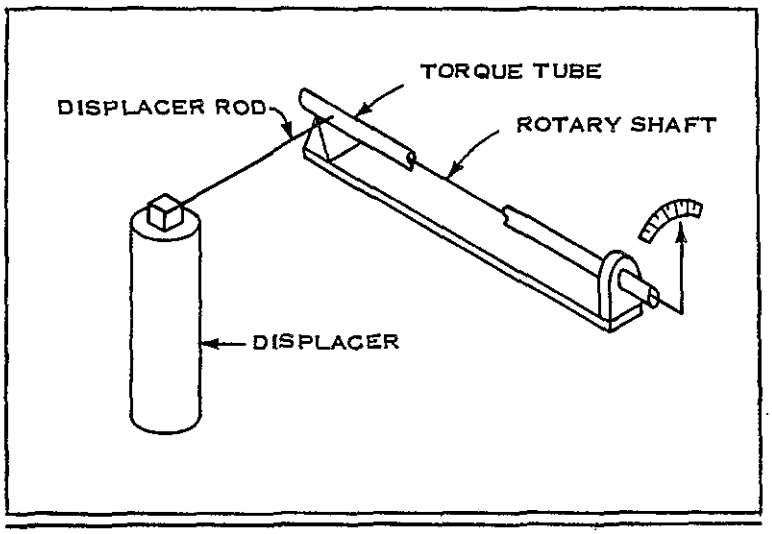
Magnetically Coupled Floats Used for Level Control



Source: Reference 15

Figure 3.4-5

Torque Tube Displacer Used for Level Control

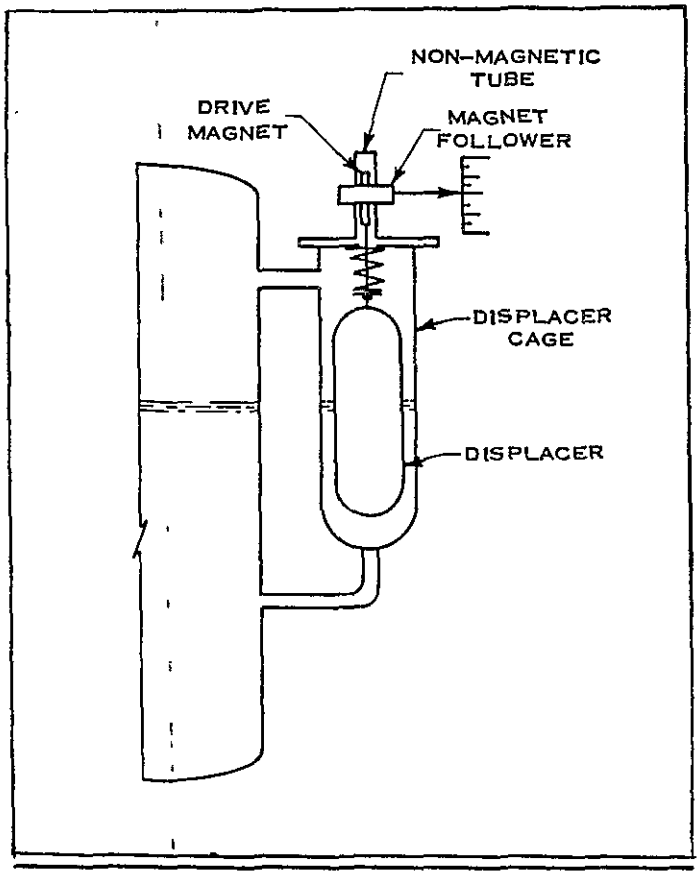


Source:

From *Chemical Engineers' Handbook,* Perry, R.H. and Chilton, C.H., Copyright (c) 1973, McGraw-Hill, Inc. Used by permission of McGraw-Hill Book Company.

Figure 3.4-6

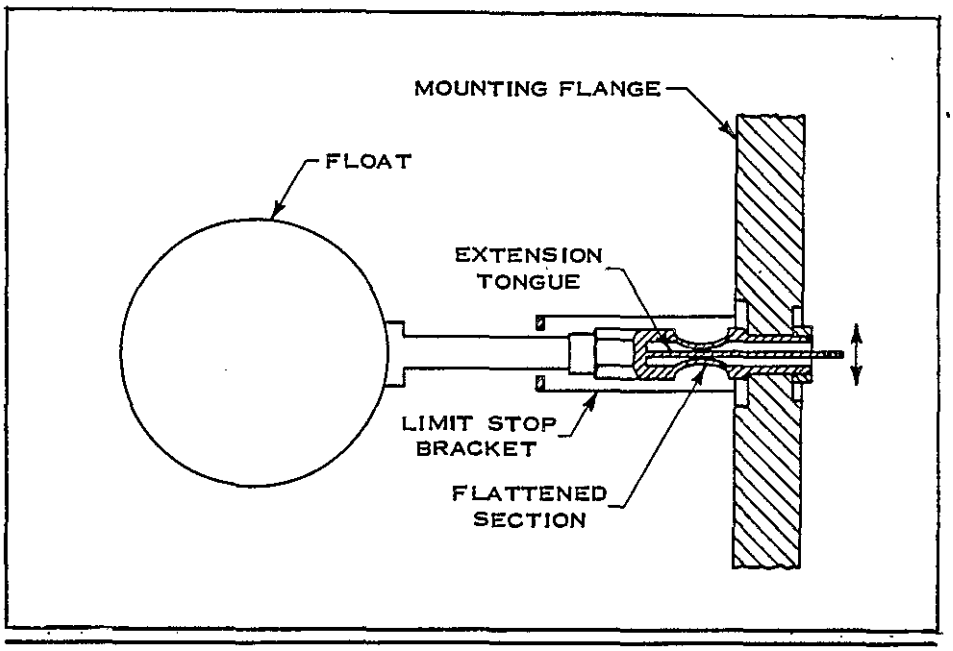
Magnetically Coupled Displacer Used for Level Control



Source: From *Chemical Engineers' Handbook,* Perry, R.H. and Chilton, C.H., Copyright (c) 1973, McGraw-Hill, Inc. Used by permission of McGraw-Hill Book Company.

Figure 3.4-7

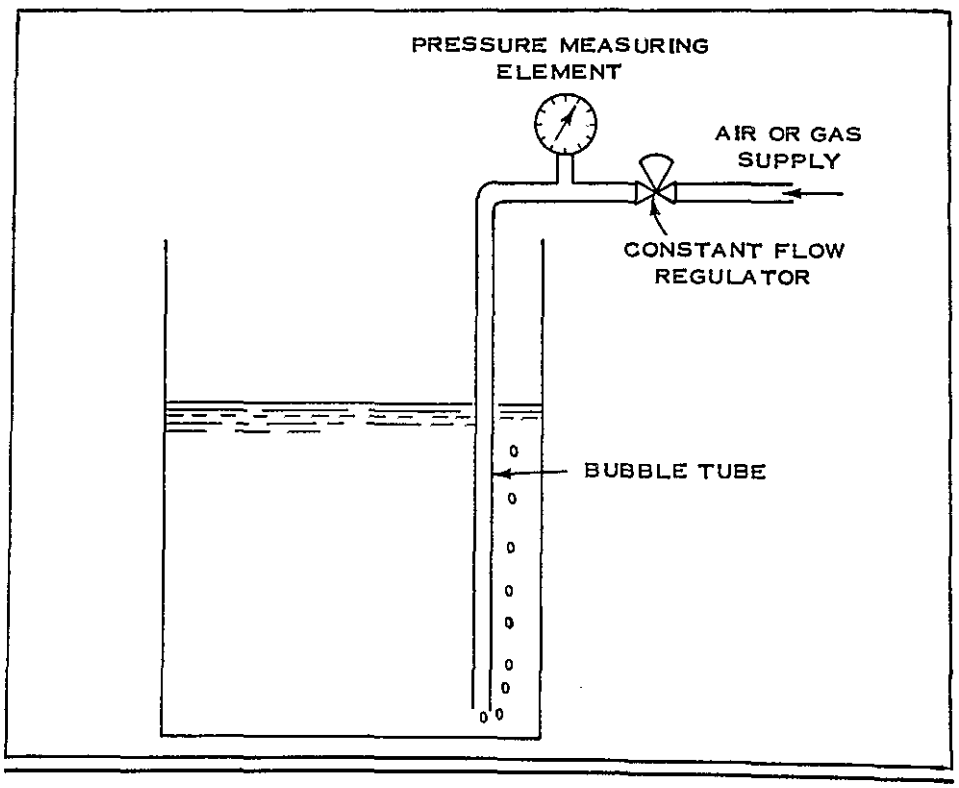
Flexure Tube Displacer Used for Level Control



Source: From *Chemical Engineers' Handbook*, Perry, R.H. and Chilton, C.H., Copyright (c) 1973, McGraw-Hill, Inc. Used by permission of McGraw-Hill Book Company.

Figure 3.4-8

Bubble Tube System Used for Level Control



Source: From *Chemical Engineers' Handbook*, Perry, R.H. and Chilton, C.H., Copyright (c) 1973, McGraw-Hill, Inc. Used by permission of McGraw-Hill Book Company.

Pressure Gauge Systems on Open Vessels. The simplest application of head level measurement is the measurement of liquid level in an open vessel. The pressure measuring element is located at or below the minimum operating level in the tank. Pressure piping between the vessel and the measuring element must be sloped upward toward the vessel in order to prevent errors due to entrapped air or other gases. A drain valve should be provided at the measuring element to allow sediment to be flushed from the piping. These types of level sensing devices are compatible with both pneumatic and electronic controls although electro-pneumatic converters may be required when electronic controls are used.

Bubble Tube Systems. Bubble tube systems consist of a tube inserted in the tank through which an air stream is maintained. The pressure required to keep the liquid out of the tube is proportional to the liquid level in the tank. The higher the liquid level, the higher the air pressure must be to keep the tube evacuated. A flow regulator is used to maintain a constant supply of air into the tube. A pressure indicator is located downstream of the flow regulator to measure the liquid level by measuring the pressure head exerted by the liquid. Bubble tube systems are particularly applicable to corrosive and viscous liquids, liquids subject to freezing and liquids containing entrained solids. They are generally used in conjunction with pneumatic controls but they may be used with electronic conrols if electo-pneumatic converters are provided. Bubble tube systems are usually more expensive than float or displacer systems since they require a constant supply of clean and dry instrument air. A bubble tube system is illustrated in Figure 3.4-8.

Head Systems on Pressurized Tanks. In pressurized vessels the measurement of liquid level by means of hydrostatic head differs from that in open vessels in that a differential pressure measurement is made. Applications of this technique may employ almost any of the conventional differential pressure measuring devices.

Careful attention to the details of the installation is important. The density and vapor pressure of the liquid must be known. Hydrostatic heads that are not pertinent to the desired measurement must be eliminiated or compensated for. The level above the lower tank connection (i.e., the discharge connection in the case of an aboveground tank and the fill connection in the case of an underground tank) is measured by the differential pressure across the measuring element. This measurement is accurate only if the following conditions are met: (1) compensation is made for any deviation of the density of the liquid; (2) the connection to the low-pressure side of the measuring element contains no liquid that has accumulated because of overflow or condensation; (3) the density of the air-vapor mixture above the liquid is either negligible or compensated for: and (4) the measuring element is located at the same elevation as the minimum level to be measured, or suitable compensation is made. Either pneumatic or electronic controls may be used with these devices.

2. High Level Alarms

A high level alarm should also be included in the overfill prevention system. This alarm may be an audible device such as a horn or a buzzer, or an indicator light. Alarms may be locally or remotely mounted. When several tanks are monitored simultaneously, it is often preferred to have both audible and visual alarms. In such case, one indicator light is provided for each tank, allowing the operator to know which tank is overfilling. The indicator light must be located so that it can be readily seen by the person responsible for control of the filling operation.

3. Automatic Shutown or Flow Diversion

An automatic control device is a third element in the overfill prevention system. Such a device must interface with the level-sensing device to perform one or more of the following functions:

- Prevent tank overfilling by shutting off the tank loading pump.
- Prevent damage to the tank unloading pump by shutting if off at low level.
- Operate various flow control valves and pumps to divert flow to another storage tank if an overfill situation occurs.

Controls can also be provided for loading a predetermined quantity of liquid. For example, a loading area at a tank truck loading station could be equipped with a level-sensing device and automatic control system which shuts off the flow of liquid when a predetermined level is reached in the tank truck. A loading area equipped with an automatic shutoff device is shown in Figure 3.4-9.

Automatic control devices are mechanical, electrical or penumatic in nature, although electrical and pneumatic controls are more common because they employ fewer moving parts and are more adaptable to remote operation. These types of controls have been discussed in Part II, Chapter 4 of this report.

4. Emergency Overflow to Adjacent Tank

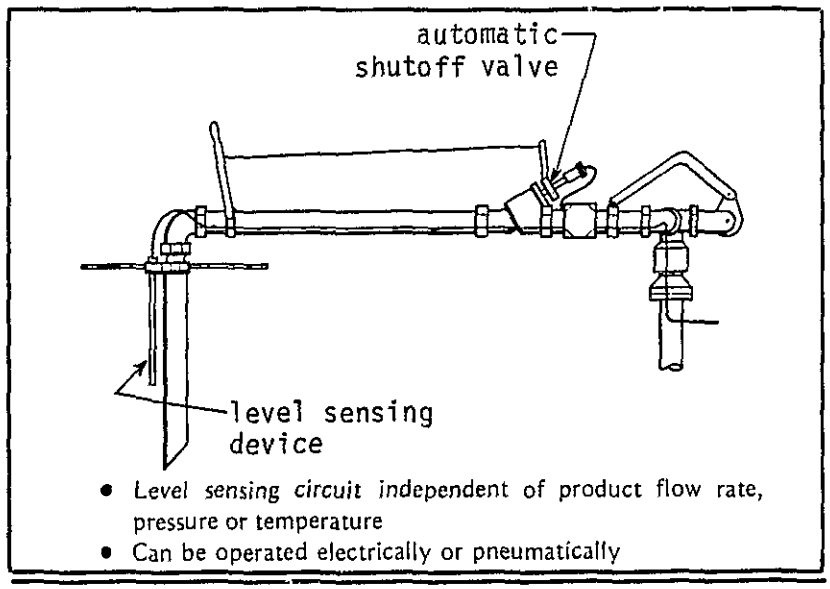
An emergency overflow system is the final safety step in a complete overfill prevention system. Such a system may be activated by the automatic control in the event that tank overfilling cannot be avoided through other means (e.g., pump shutdown). An emergency overflow system may also be available for manual operation should the automatic control system malfunction. Even if an emergency overflow to an adjacent tank is provided, a final overflow to the atmosphere must exist in case the entire system (tank and overflow tank) is filled to capacity. This overflow point must be visible.

5. Personal Monitoring of Systems

It should be kept in mind that no system is foolproof. The most reliable human being has his off moments and can forget a routine procedure. Devices tend to collect dust, dirt and paint chips that cause wheels to stick. Batteries wear out. Electrical connections vibrate loose. People trip over the inlet cord and never notice that the plug has left the socket. Murphy's law is sure to apply. Still, failure can be minimized when a reliable instrument system is monitored on a daily basis by a reliable person. Time requirements are small; dividends in reliability are large.

Figure 3.4-9

Loading Arm Equipped With Automatic Shutoff



Source: Emco Wheaton Inc., *Fluid Handling Systems*, Catalog Z-8/73, Emco Wheaton, Inc., Chamberlain Blvd., Conneaut, OH 44030, Revised April 1977.

C. DRY DISCONNECT COUPLINGS ON TRANSFER PIPES AND HOSES

The use of dry disconnect couplings on transfer pipes and hoses in lieu of quick disconnect couplings or other less reliable means of pipe and hose connection has been addressed in Part II, Chapter 4. Please refer to that chapter for details.

D. REDUNDANT VALVING AND INSTRUMENTATION

The use of redundant valving and instruments is an advisable practice in all product transfer operations. Valves and instruments can malfunction leading to catastrophic results in certain situations. This presence of redundant valves and instruments can be an inexpensive way to avoid spills in such instances. The primary valve controls should be near the observer's (delivery person's) point of observation. Direct communication should be maintained with the remote (secondary) valve control operator, during product delivery.

E. USE OF ESTABLISHED TRANSFER STATIONS

All product transfer operations should occur in designated transfer areas that are equipped with impervious surfaces, curbing and spill catchment facilities to contain and collect any product spills that may occur. These containment areas are addressed in Part III, Chapter 3 of this report.

F. PROPER TRANSFER PRACTICES

Human error is a major cause of spills or accidents during product transfer operations. To avoid or minimize transfer spill incidents, all operators should be properly trained in all loading and unloading operations. It is important that the operator be aware of all the potential problems and dangers associated with the transfer operations, and that he/she remain alert at all times. The following practices are applicable for hazardous liquid transfer operations:

- The driver, operator, or attendant of any tank vehicle must not remain in the vehicle and must not leave the vehicle unattended during the loading or unloading process. The delivery hose, when attached to a tank vehicle, is considered to be a part of the tank vehicle. The vehicle wheels should be blocked to prevent movement of the vehicle.
- To minimize the potential of fire or explosion when transferring Class I (flammable) liquids, motors of tank vehicles or motors of auxiliary or portable pumps must be shut off while making and breaking hose connections. If loading or unloading is done without requiring the use of the motor of the tank vehicle, the motor must be shut off throughout the transfer operation of the liquid.
- No cargo tank or compartment thereof used for the transportation of any volatile, flammable or combustible liquid can be loaded liquid full. Sufficient space (outage) must be provided in every case to prevent leakage from such tank or compartment by expansion of the contents due to rise in temperature in transit and must in no case be less than 1 percent.
- On special hoses and couplings designed to prevent accidental mixing of incompatible materials, labels, marking, or color codes should be used. The cargo should be clearly identified on a truck label.

Please refer to the discussion of Part II, Chapter 4, for more information on liquid transfer practices.

G. REGULAR INSPECTION AND MAINTENANCE

The final ingredient in a comprehensive transfer spill prevention effort is a regular inspection and maintenance program. All of the elements of the transfer spill prevention system should be inspected on a regular basis and repaired or replaced promptly when damage is detected. This includes:

- Hoses, piping, fitting, etc.
- Couplings.
- Curbs, containment surfaces and catchbasins.
- Loading area assemblies.
- Pumps and valves.
- All control instrumentation.
- All tanks, tank cars and tank trucks.

References

1. Perry, R.H., C.H., *Chemical Engineers' Handbook*, Section 22, McGraw-Hill Book Co., Fifth Edition, 1221 Avenue of the Americas, New York, NY 10020, 1973.

2. Anderson, N.A., *Instrumentation for Process Measurement and Control*, 2nd Edition, Chilton Book Co., 5601 Chestnut Street, Philadelphia, PA 19139, Chapters 5 & 9.

3. Andenmatten, R., *Overfill Protection System for Underground Storage Tanks of Hazardous Liquid Products*, 16 S. Lewis Place, Rockville Centre, NY 11570, July 1, 1980.

4. Annual Report of The New York State Oil Spill Prevention, Control and Compensation Program, April 1, 1978 to March 31, 1979, New York State Department of Enviornmental Conservation, 50 Wolf Road, Albany, NY 12233.

5. Annual Report of the New York State Oil Spill Prevention, Control and Compensation Program, April 1, 1979 to March 31, 1980, New York State Department of Environmental Conservation, 50 Wolf Road, Albany, NY 12233.

6. Petrometer Corp., *Liquid Level Indicating and Control Systems*, Catalog No. 75, Petrometer Corp., P.O. Box 245, New Hyde Park, NY 11040.

7. Amprodux, Inc., *Solid-State Electronic Bin and Tank Gauges, Level Alarms, and Level Control Instruments and Systems*, Catalog 15.10/AM, Amprodux, Inc., 150 W. 28th Street, New York, NY 10001.

8. Kodata, Inc., *Level Measuring System for Bulk Liquids or Solids*, Bulletin No. 8090-25, Kodata, Inc., 3621 McCart Street or P.O. Box 11528, Fort Worth, TX 76110.

9. Dover Corp., *Optic Liquid Level Sensing System for Petroleum Transportation and Storage Applications*, Bulletin OLLS 6-80, Dover Corp., OPW Division, 9393 Princeton-Glendale Road, P.O. Box 40240, Cincinnati, OH 45240, June, 1980.

10. Scully Electronics Systems, *New Scully-Moormann Development for Remote Readout Inventory Control for Existing and New Moormann Liquid-Level Gauges*, Scully Electronic Systems, Inc., 70 Industrial Way, Wilmington, MA 01887.

11. Dover Corp., *Service Station Vapor Recovery Products and Systems*, Catalog SVR, Dover Corp., OPW Division, 9393 Princeton-Glendale Road, P.O. Box 40240, Cincinnati, OH 45240, Feb., 1981.

12. Perry, R.H., Chilton, C.H., *Chemical Engineers' Handbook*, Section 6, McGraw-Hill Book Co., Fifth Edition, 1221 Avenue of the Americas, New York, NY 10020, 1973.

13. Emco Wheaton Inc., *Fluid Handling Systems*, Catalog Z-8/73, Emco Wheaton, Inc., Chamberlain Blvd., Conneaut, OH 44030, Revised April 1977.

14. National Fire Protection Association, *Tank Vehicles for Flammable and Combustible Liquids*, NFPA 385, National Fire Protection Association, Batterymarch Park, Quincy, MA 02269, 1979.

15. Magnetrol International Inc., *Magnetrol Liquid Level Controls*, Bulletin 44-117, Magnetrol International Inc., 5300 Belmont Road, Downers Grove, IL 60515.

16. Pace Company Consultants & Engineers, Inc., Spill Control Manual prepared under EPA Training Grant No. T-900-175-02-2 to the Department of Enviornmental Science and Engineering, Rice University, Houston, TX.

Part III

CHAPTER 5: LEAK MONITORING OF ABOVEGROUND TANKS

A. INTRODUCTION

The detection of leaks in aboveground tanks can be achieved by visual inspections and with the use of leak detection instruments. When large tank farms are involved, a combination of regular inspections, leak monitoring and a preventive maintenance program is used.

Visual inspection is the simplest method of leak detection, and is commonly used in small storage facilities. This method is most effective when:

- Regular inspections are scheduled and assigned to designated personnel.
- The method is used in conjunction with a regular maintenance program.

Visual inspection techniques and procedures are discussed in greater detail in the next chapter.

Inventory control may also be employed to identify the existence of leaks. This method is discussed in Part II, Chapter 6 of this report.

B. ABOVEGROUND LEAK DETECTION SYSTEMS

Many of the sensor types and practices that are employed to detect or monitor spills from underground storage facilities apply to aboveground facilities as well. These include the following:

- Thermal conductivity sensors.
- Electrical resistivity sensors.
- Sensors located to monitor the interstitial space of double-walled tanks.

The interstitial monitors in double-walled tanks are located to monitor fluid levels, or the loss of vacuum or pressure between the tank walls. Electrical resistivity and thermal conductivity sensors may be used in either of the following manners to provide continuous monitoring of aboveground storage facilities:

- Sensors may be placed in a collection sump or dry well within the containment area around aboveground tanks.
- Sensors may be located underneath tanks or piping to detect bottom leaks.

Sensors used in wet well (collection sump) applications may be anchored in the collection sump, or they may be mounted on a level detection float, thereby limiting their exposure to the surface of any collected runoff (stormwater, etc.). Sensors used in dry well applications may be mounted directly on the wall of the well. Figure 2.5-1 shows applications of thermal conductivity sensors in wet and dry well applications.

Leak monitoring sensors may also be placed in piping under tanks to detect leaks. An example of such an application is a wire grid system (using electrical resistivity sensors) under a tank that is used to monitor leaks that have seeped into the ground from a leak in the bottom of the tank. Such a system can be used to monitor large fuel tanks or other vertical aboveground tanks in instances where the bottom of the tank is not subject to visual inspections.

The types of sensors listed above and the associated advantages and disadvantages of each are described in detail in Part II, Chapter 5 of this report.

Part III

CHAPTER 6: INSPECTION AND MAINTENANCE OF ABOVEGROUND TANKS

A. INTRODUCTION

A program of regular inspection, either visual or using various instruments, to determine the integrity of the tank is essential to the early detection of leaks. The detail and frequency of these inspections should depend on the severity of the threat to life and property posed by the storage facility should an undetected leak or sudden spill occur. At a minimum, the program should consist of visual inspections at regular and frequent (e.g. weekly) intervals. In the case of large bulk storage facilities the inspection program should be coupled with a maintenance program and both should be incorporated into a written document. The following discusses the equipment and parts to be inspected, gives details on the methods and frequency of equipment inspections, and the corrective action that should be taken when an inspection deficiency is discovered.

B. VISUAL INPECTION OF TANKS

A visual inspection is the simplest way to detect corroded or broken equipment. Since corroded parts will eventually lead to the leakage and rupture of tanks the early detection and replacement of faulty equipment is necessary to prevent spills. Tanks and auxiliary equipment should be inspected externally and internally, but since they are usually in service, external inspections can be carried out more readily and frequently. A visual inspection typically includes the points outlined in Table 3.6-1. The inspection items include the tank itself as well as the associated equipment such as pipes, valves, fittings, heat exchangers, pumps, compressors, and instrumentation and controls.

In conducting a visual inspection, the inspector should be careful to note any design deficiences and improvements or needs that could help prevent a spill or leak. For example, an inlet nozzle placed too close to the wall of a tank storing sulfuric acid could lead to wahing away of the tank's protective ferrous sulfate film, resulting in accelerated tank deterioration.

Table 3.6-1

Tank Inspection Point Listing

I. Visual Inspection - Tank in Service

A. External Inspection

1. Ladders, Stairways, Platforms and Walkways
   - corroding bolts
   - cracked or spalled concrete pedestals
   - low spots where water can collect
2. Foundations
   - erosion
   - uneven settlement
   - cracks and spalling in concrete pads, base rings and piers
   - water seal between tank bottom and the foundation
   - distortion of anchor bolts
3. Pipe Connections
   - external corrosion
   - cracks and distortion
4. Protective Coatings
   - rust spots, blisters, and film lifting
5. Tank Walls
   - corrosion on the underside of tank bottoms
   - discoloration of paint surface
   - cracks at nozzle connections, in welded seams and metal ligament between rivets
   - cracks, buckles and bulges
6. Tank Roofs
   - malfunctioning of seal
   - blockage of water drains on roofs
   - general corrosion signs

B. Internal Inspection - Tank Out of Service

1. Tank Internal Preliminary Visual Inspection
   - roof and internal support
   - shell and bottom
   - vapor space
   - liquid level line
2. Roof and Structural Members
   - roof seals
   - roof corrosion
   - roof thickness

Table 3.6-1 continued

3. Tank Shell

- vapor space and liquid-level line
- cracking of plate joints
- cracking of nozzle connection joints
- bulges, holes or cracks of lining (if the inside shell is coated)

4. Tank Bottom

- corrosion pits
- spring seams
- rivets for tightness and corrosion
- depressions in the bottom areas around or under roof supports and pipe supports
- bottom thickness
- unevenness of the bottom

II. Visual Inspection of Pipes, Valves and Fitting

- loss of metal thickness
- pipe bends
- elbows
- tees
- orifice plates
- throttling valves
- other areas of flow restriction

III. Visual Inspection of Pumps and Compressors

- foundation cracks and uneven settling
- leaky pump seals
- missing anchor bolts
- excessive vibrations and noise
- deteriorating insulation
- accessible power shut-off switch
- filled lubricating oil reservoir
- odor and smoke
- excessive dirt
- excessive corrosion
- vibration level of pumps
- leaks and cracks of assembly bolts, gaskets, cover plates, and flanges

IV. Visual Inspection of Instruments, Control Equipment, and Electrical Systems

- check proper operation of equipment by qualified personnel
- according to manufacturer's recommended frequency and methodology

The following sections address the tank items that should be inspected.

1. External Inspection – Tank in Service

An external inspection should include the following components of the tank: ladders, stairways, platforms, walkways, foundations, anchor bolts, pipe connections, ground connections, protective coatings, insulation, tank walls, tank roofs, and valves.

Ladders, Stairways, Platforms and Walkways. Even though the failure of any of these equipment items would probably not cause leakage or rupture of a tank, they do pose significant safety hazards and are indicative of the overall condition of the tank facilities. Stairway or walkway failure may be imminent if the concrete pedestals are cracked and spalled. All bolts should be checked for corrosion at the contact points. Rust stains showing through paint are evidence of corrosion. Low points where water can collect should be examined carefully. The thickness of metals should be checked with calipers and equipment can be hammered to check integrity. All defects found should be marked with paint and recorded, and repair should proceed as soon as possible.

Foundations. Erosion and uneven settlement should be detected and corrected before serious damage occurs. Concrete pads, base rings, and piers should be examined for cracks and spalling. Such deterioration can be uncovered by scraping the suspected areas. The joint between the tank bottom and the concrete pad or base ring may have a seal for stopping water seepage and if so, it should be inspected for deterioration. Any wooden supports for tanks should be checked for rot by hammering. Metal loss in steel columns or piers can be checked by caliper readings that should be compared to the original thickness. Anchor bolts can be checked by visual inspection and hammering. Serious foundation settlement is usually indicated by distortion of anchor bolts, buckling of columns, and excessive concrete cracking.

Pipe Connections. The pipe connections to a tank should be inspected for external corrosion by visual examination, scraping and picking. Underground piping should be uncovered if severe soil corrosion is suspected. The pipe should be scraped and cleaned for visual inspection. In the event that the tank has settled excessively, special attention should be given to the piping connections that may have been loosened.

Protective Coatings. Rust spots, blisters and film lifting of the tank's protective coating can usually be detected by visual inspection or by scraping the film in suspected areas. Paint blisters usually occur on the roof and on the sunny side of the tank. Film lifting commonly occurs below seam leaks.

Tank Walls. External corrosion caused by corrosive elements in the soil can occur on the underside of tank bottoms. If any foreign material has collected around the bottom of the shell, or if the tank is below grade, the shell should be inspected at least a foot below grade at several locations. Visual inspection, picking, scraping and hammering are usually sufficient to locate corroded areas. When corrosion is found, thickness measurements should be taken at corroded points. This can be accomplished by ultrasonic, radiographic, or radiation-type instruments. The thickness measured externally should be compared with the thickness measured internally to locate the thinnest points and to determine the corrosion allowance left to safely operate the tank.

In addition to corrosion detection, the tank shell should be inspected for leaks, cracks, buckles and bulges. Leaks can be spotted by a discoloration of paint in the area below the leak, or by leak testing devices such as ultrasonic or vacuum devices. Cracks can be found at nozzle connections, in welded seams, and underneath rivets. Cracks, buckles and bulges can initially be spotted by visual inspection, and their extent can be more thoroughly determined by techniques such as the magnetic-particle, penetrant-dye or vacuum box methods.

All the external valves on the tank should be visually inspected to ensure that the seating surfaces are in good condition. If there are signs of corrosion, the thickness should be measured. In cold weather, water draw-off valves should be inspected closely to detect possible damage from freezing. Pressure vacuum vents and breather valves should also be inspected for plugging, tight seats and corrosion. All pressure gauges should be tested for accurate readings by using a deadweight tester or its equivalent.

Tank Roofs. Tank roofs should be inspected thoroughly by hammering, regardless of appearance, due to the strong posibility of corrosion. However, some safety measures should be taken before and during the inspection especially when the roof stability is questionable. Gas tests should be conducted prior to inspection of the roof as well as tests for structural stability. Safety measures during inspection should include wearing a safety belt. Water drains on roofs should be inspected frequently for blockage, since the accumulation of precipitation can cause a floating roof to sink and fixed roofs to fail or corrode more rapidly.

2. Internal Inspection – Tank Out of Service

Internal Preliminary Visual Inspection. As in the case of underground tanks, the safety aspects preceding an internal inspection are very important. The tank must be emptied of liquid, freed of gases, washed and cleaned. Adequate lighting and the necessary safety equipment should be specified. For safety reasons, the roof and internal supports should be inspected first, followed by the shell and the bottom. Ordinarily, the vapor space, the liquid level line, and the bottom are the areas most susceptible to corrosion. An inspector should pay special attention to these areas.

Roof and Structural Members. A visual inspection of the roof interior usually suffices. However, thickness measurements should be performed when corrosion is evident. Special attention should be given to interior roof seals.

Tank Shell. The shell should be examined visually for corrosion. The plate joints and nozzle connection joints should also be inspected for cracking. If any cracking is found, a more thorough investigation by magnetic-particle, penetrant-dye, or radiographic methods may be needed to determine its extent.

When the inside surfaces of a tank are lined with corrosion resistant material it is important to check for holes or cracks in the lining. When rubber, glass, organic or inorganic linings are used, the general condition of the surface is first inspected for mechanical damage. Holes in the lining can be evidenced by bulging, blistering or spalling. A thorough method of inspecting for leaks in such linings is to use a high-voltage, low-current electrode that is passed over the non-conductive lining while the other end of the circuit is attached to the steel of the tank. An electric arc will form between the brush electrode and the steel tank through any holes in the lining. Caution must be used to insure that the test voltage is not too high since an excessive voltage may cause damage to the lining surface.

Considerable care should be taken when working inside lined tanks to avoid mechanical damage to the lining. Glass-lined tanks, for example, are especially susceptible to severe damage that cannot be easily repaired. Glass-lined tanks should never be hammered on the inside or the outside in order to test their integrity.

Tank Bottoms. Tank bottoms should be hammered thoroughly to detect corrosion pits and sprung seams. The rivets should be checked at random for tightness and corrosion. The depressions in the bottom, the areas around or under roof supports and pipe-coil supports should also be checked for corrosion. Bottom thickness should be measured at various locations and recorded to ensure that a minimum thickness is maintained. Unevenness of the bottom may be caused by settling and should be checked visually.

C. VISUAL INSPECTION OF PIPES, VALVES, FITTINGS AND HOSES

Inspections of pipes, valves, and fittings are usually conducted to note any losses in metal thickness due to external or internal deterioration. These equipment parts are subject to erosion or wear due to the effects of high liquid turbulence or velocity. Leaks are particularly likely to occur around pipe bends, elbows, tees, and other restrictions, such as orifice plates and throttling valves. Loading or unloading hoses used as flexible connections between the vehicle and storage tank

are also subject to wear and tear. Damage to the hose is often caused by the tank vehicle running over it during loading and unloading operations.

Visual inspection techniques conducted while the tank is in operation include checking for: (1) leaks, (2) misalignment, (3) unsound piping supports, (4) vibration or swaying, (5) external corrosion, (6) accumulations of corrosive liquids, and (7) indications of pipe fouling. Thickness measurements can be made while the pipes are in operation utilizing ultrasonic or radiographic techniques.

If the tank is out of service, piping can be opened at various places by removing a valve or fitting or by springing the pipe apart at flanged locations to permit internal visual inspection. A flashlight or extension light is needed in most cases and a probe-type instrument, such as a borescope, or a mirror and light will permit a more detailed view. If corrosion or erosion conditions are noted visually for some parts, radiographic or ultrasonic techniques can be used to inspect the entire length of pipe, if inaccessible to visual examination.

Pressure tests for pipes may include a design test for newly installed systems and a leakage and tightness test for existing sytems. Various mediums used for pressure testing including water, steam, air, and carbon dioxide or other inert gases. These types of tests involve pressurizing a sealed length of pipe section or the piping system to determine the structural integrity. Leaks are detected through failure of the pipe to contain the pressurizing medium (steam, air, or inert gas). All seams should be soaped during pressurizing. A leak will be indicated by bubble formation.

Piping systems which can not be inspected visually are frequently pressure tested. They include:

- Underground and other inaccessible piping.
- Water and other nonhazardous utility lines.
- Complicated manifold systems.
- Small pipe and tubing systems.
- All systems after a chemical cleaning operation.

D. INSPECTION OF PUMPS AND COMPRESSORS

Mechanical wear is the predominant cause of deterioration of pumping and compression equipment, although erosion and corrosion are also responsible for an appreciable amount of deterioration. Other deteriorating factors include improper conditions, piping stresses, cavitation, and foundation deterioration.

Routine visual inspections of pumps and compressors to determine general conditions during operation should focus on the following danger signs:

- Foundation cracks and uneven settling.
- Leaky pump seals.
- Missing anchor bolts.
- Leaky piping connections.
- Excessive vibrations and noise.
- Deteriorating insulation.
- *Partially full or empty lubrication oil reservoir.*
- Missing safety equipment such as a pump coupling guard.
- A burning odor or smoke.
- Excessive dirt.
- Excessive corrosion.

Since vibration can rapidly deteriorate a pump or compressor, periodic examination of the vibration level should be made using an electronic vibration meter. Inspection of all assembly bolts, gaskets, cover plates, and flanges should be conducted to detect leaks and cracks as a result of vibration or abnormal operating conditions.

When a pump or compressor is taken out of service, the mechanical components should be checked for wear, clearance, deformation, corrosion, erosion, and any other changes detrimental to safe operation. Disassembly should be executed according to the manufacturer's recommendation.

E. VISUAL INSPECTION OF INSTRUMENTS, CONTROL EQUIPMENT AND ELECTRICAL SYSTEMS

Instruments and control equipment are classified according to the type of measurement or function performed. They include:

- Flow rate controls.
- Level controls.
- Temperature gauges.
- Pressure gauges.
- Control valves.
- Alarms and emergency shut-off devices.
- Analyzers.

The inspection of these instruments and controls includes checking transmission systems, power supplies, seals, purges, panels, and other associated equipment. In many cases, instruments and controls are inspected daily by the operator since they are an integral part of the daily operation of the facility. All instrumentation and control equipment should be thoroughly inspected and calibrated according to the manufacturers' recommended frequency and methodology.

Environmental conditions such as heat, moisture, chemical attack, and dirt are major reasons for deterioration of electrical systems. Insulation, enclosures, operating mechanisms, insulating and lubricating oils, protection relays, bearings, batteries, connectors, and rectifiers are items that should be inspected.

F. INSPECTION OF VAPOR CONTROL SYSTEMS

There are two main areas of concern with regard to the inspection of the vapor control systems described in Chapter 1 of this part of the report. The first is the inspection of pumps, compressors, and general plumbing which was covered in detail in the previous sections. The second is the inspection of the vapor holding tank if the system is so equipped. Most systems do employ the use of a vapor holding tank. Areas of inspection of the vapor holding tank include the following:

- The bladder height gauge, which should be checked for proper working condition.
- The pressure release valve, which should be checked for clear lines.
- The area between the bladder and shell should be checked with an explosimeter for detection of vapor leaks.
- The cycling schedule, which should be monitored to determine if the system is operating properly.

These first two of the items or areas are usually located on the roof of the holding tank.

If inspection encompasses loading time, fittings to the tank truck from loading racks should be inspected for proper fit. Inspection serves the purpose of ensuring that the system is operating safely and efficiently.

G. INSPECTION TOOLS AND ELECTROMECHANICAL EQUIPMENT

When visual inspection suggests that tools are needed for a more detailed inspection, simple hand tools may be used as an initial aid. Tools such as a scraper, digger or flange spreader are indispensible for visual inspection. Additional tools such as hammers, mirrors, magnifiers, magnets, and plumbing tools (e.g. levels or a plumb bob) are also helpful.

When the inspection requires more sophisticated equipment, there are many types of tools that can be readily purchased. The mechanical measuring tools include calipers, micrometers, scales, measuring tapes, and wire gauges. Useful electronic devices include ultrasonic and electromagnetic instruments, which provide nondestructive means of determining wall thickness.

In addition, there are chemical examination and destructive test methods that can be employed to evaluate storage system component performance. Destructive testing typically involves taking a sample of a tank or pipe wall, weld, etc. for detailed inspection and analysis, often under laboratory conditions.

Chemical examination can involve either of the following:

- Spot testing in the field, where the reaction of a storage system component to exposure to a specific chemical is usually evaluated.
- Laboratory analysis, where a sample taken from the storage facility is closely analyzed under laboratory conditions.

Destructive tests and chemical examination are useful in providing detailed performance data at either the macroscopic or the microscopic levels, depending upon the choice of examination technique.

The selection of a particular test method depends on the type of tank to be inspected, the extent of the inspection and the equipment available. Commonly used methods of inspecting aboveground tanks are discussed below.

1. Hammering

Hammering, or physical inspection or testing with a hammer, is worthy of some discussion. As an inspection tool, hammering reveals more than that disclosed solely by sound. Vibration, denting, and movement are also indicators of defects found with this method. So-called hammer testing, when employed by an inspector experienced in the art, offers a simple and effective tool for indicating that some discrepancies may exist and disclosing that others actually do exist. Such defects as areas of reduced thickness in walls of tubes, pipes, and pressure vessels; burned (oxidized) areas in tubes; cracks; loose joints; and intergranular cracking may be revealed.

It is difficult to explain how to make a hammer test. An inspector must sense what the hammering reveals; hence, a proficiency in the method can be gained only by actual experience. This experience can be accelerated by practicing on scrap pipe, tubes, plates, and other sections, where a comparison can be made of what is heard, felt and seen by hammering with the results of actual measuring. It should be recognized, however, that hammer testing of loose items will be different from the testing of items that are installed.

The accuracy of sounding with the hammer is dependent upon the ability to distinguish small differences in sound, coupled with the amount of rebound experienced when a blow is struck and the ability to translate these sounds and rebounds into metal soundness and thickness. Care must be taken in the hammer testing of equipment. This is true especially if hammer testing is permitted on in-service equipment. Normally a more accurate means than hammer testing, such as radiography or ultrasonics, should be used to determine metal thickness in the area around a leak or on areas suspected to be extremely thin.

Certain equipment should not be subjected to hammering as harm might result therefrom. In this classification are:

- Enameled, ceramic, or glass-lined pieces, where the lining may be injured.
- Equipment in caustic service, even though it has been stress-relieved. Stress-corrosion cracks have been found at hammer marks in such equipment, even when hammered from the outside.
- Brittle materials, such as cast iron; some high alloys of steel; and some nonferrous materials, such as brasses and bronzes. (Light tapping with a hammer may be permissible on some of these materials.)
- Other locations where hammering might result in stress corrosion or cracking.

2. Penetrant Dye Method

Penetrant dyes are often used to detect surface cracks in the outside of a tank that would not be revealed by a visual inspection. The penetrant dye is applied to a cleaned and dried surface by either brushing or spraying. After a few minutes of contact time the dye is cleaned off the surface. A chemical developer is then sprayed onto the surface to give a white appearance upon drying. Any dye remaining in cracks, holes, etc. stains the developer and exposes the extent and size of any defects.

3. Vacuum Box

The vacuum box is an open box in which the lips of the open side are covered with a sponge rubber gasket. The bottom of the box is made of glass. A vacuum gauge and air siphon connection are installed inside the box. The seam of the tank shell is first wetted with a soap solution, then the vacuum box is pressed tightly over the seam. The foam-rubber gasket forms a seal that allows a vacuum to be drawn inside the box by the air siphon. If any leak exists, bubbles will form inside the box and can be seen through the glass.

4. Ultrasonic Instruments

Ultarasonic instruments can be used to measure the tank's thickness and determine the location, size and nature of defects. They can be used while the tank is in operation as only the outside of the tank needs to be contacted. Two types of ultrasonic instruments, the resonance and the pulse type, are most commonly used for tanks. The pulse type instrument utilizes electric pulses and transforms them into pulses of ultrasonic waves. The waves travel through the metal until they reach a reflecting surface. The waves then are reflected back, converted to electrical pulses and show up on a time-base line of an oscilloscope. The instrument is calibrated by using a material of known thickness. Therefore, the time interval between the pulses correspond to a certain thickness.

There are two types of resonance-type ultrasonic instruments. In one of these, an electronic oscillator transmits electric energy of constant ultrasonic frequency to a crystal (transducer) which, in turn, converts this energy into mechanical pressure waves that travel through the material being measured in the direction of its thickness. The pressure waves travel at a constant velocity and are reflected at the opposite surface back to the crystal. Because velocity through a given material is constant, the time required for a wave to circumnavigate is a function of the distance traversed — in this case, equal to twice the thickness. Therefore, by measuring the time interval, the thickness can be determined.

In the other type of resonance device, a crystal (piezoelectric transducer) is applied to the surface of the wall to be measured, and an electronic circuit causes it to vibrate over a range of frequencies. When the vibrating frequency of the crystal matches the natural frequency of the vibration of the material being measured, a signal is fed through the circuits of the instrument and interpreted electronically as an indicated thickness. This indication is fed to an oscilloscope tube and emerges as a series of vertical lines across the face of the tube. These lines indicate thickness on a transparent plastic scale mounted directly on the face (front) of the oscilloscope tube.

A crew of two men operate this instrument: one is located at the tube; the other may be several hundred feet away, with the crystal and oscillator, on a tank or vessel.

5. Radiographic Tools

Radiography is used to detect flaws, such as cracks and voids, in opaque (solid) materials. In this method, the object to be inspected is placed between an electromagnetic ray source of realtively short wavelength and a photographic film. When the rays pass through the object, the absorption of rays by cracks or other voids is less than that of the solid material. After the film has been developed, the flaws will appear as darkened areas, approximating the size and shape of the flaws, while the remainder of the exposed object will appear lighter. Objects of uniform density and thickness, with no flaws, will produce pictures of a uniform shade.

Radiography may also be used for determining wall thickness, product build-up, blockage, and the condition of internal equipment such as trays, valve parts, thermowells, and the like.

The rays commonly used in storage system inspection are the X-ray and the gamma ray. The X-ray is produced in a tube within an X-ray machine; the gamma ray is produced from a radioactive material contained in a small capsule. The two rays are similar.

Special precautions must be taken where there is the possibility of exposure to X-rays or gamma rays. Radiography can only be conducted by qualified radiographers and assistant radiographers. Radiographers have successfully completed a course in Radiation Health Physics as prescribed by the Nuclear Regulatory Commission (NRC). Training and experience are required to correctly interpret the images produced on the radiographic film. The use of radioactive isotopes by a company must be licensed by the NRC.

6. Other Radiation-Type Instruments

In addition to the X-ray and gamma-ray instruments used to radiograph materials for defects, hand-portable gamma-ray instruments have been developed that are particularly adaptable to measuring piping and, to a lesser extent, vessel-wall thicknesses. These instruments contain a radioisotope; therefore, some caution is required. However, the amount of radioactive material is small, and there is no danger if simple precautions are taken.

The principle of the radiation-type instrument is as follows: Gamma rays are sent through the wall whose thickness is being analyzed and a count is taken of the rays that pass through. The rays that do not pass through are a function of the density and thickness of the wall. Because the density is a known constant, the thickness can be determined with an error of less than 3 percent.

Considerable experience is required to operate radiation-type instruments proficiently and safely. It is recommended that several persons be trained until proficient in the use and handling of these instruments, and that only these persons be used as operators. Radiation-type instruments are delicate and should not be used roughly.

7. Acoustic Emissions Testing [4,5]

The acoustic emissions testing technique employs piezoelectric transducers to monitor the acoustic emissions given off by a material during corrosion or disbonding. In effect, the technique involves "listening" to detect the presence of corrosion or other stressful situations (e.g., imminent structural failure) in a structure. Typically the area being inspected is heated to 160° – 180°F to accelerate any corrosive activity or worsen other stressful situations. The transducer is then held over the spot by thumb pressure and the accoustic emissions can be detected by instrumentation or heard by the operator if an audio monitor is used.

Acoustic emission technology is applicable in the following areas:

- The detection and location of flaws in structures.
- Leak detection and location.
- Corrosion detection and location.
- Real-time detection and location of flaws during welding operations.

H. FREQUENCY OF INSPECTIONS

Inspection intervals for a tank and its equipment are subject to the following factors:

- Results of previous visual/maintenance inspections.
- Availability of the equipment.
- Materials of construction, corrosion allowance, properties of the product stored, and corrosion rates.
- Potential risks of air or water pollution.
- Potential risk for personnel injury.

The results of previous visual maintenance checks can influence the inspection interval. An inspection that indicates that portions of the tank are in various stages of corrosion would warrant a shorter inspection interval, whereas, if previous inspections indicate little or no deterioration a longer inspection interval may be possible.

A more convenient and thorough inspection of a tank and its associated equipment can be accomplished when it is empty. Visual external inspections can be scheduled on a routine basis, usually weekly, whereas, internal inspection can take place when the tank is out-of-service due to reasons other than an internal inspection. However, if a tank is suspected to be rapidly corroding or leaking due to cracks or holes, it should be taken out of service for immediate inspection and repair. Additionally, if the tank's material of construction is being corroded rapidly by the stored product, the contents should be transferred to a corrosion-resistant tank.

Other specific factors relating to siting, such as the distance of the tank from surface and groundwater supplies, may justify an inspection schedule that is more or less frequent.

I. MAINTENANCE OF ABOVEGROUND TANKS

Preventive maintenance and routine repairs are required for safe and efficient operation. Maintenance procedures may include the following:

- Tank patching.
- Sand blasting for paint and rust removal.
- Recoating and relining.
- Replacement of valve packing.
- Replacement of gaskets for tank openings and flanges.
- Dike wall grading and stabilization.
- Repairs or replacement of tank insulation.
- Instrument maintenance and repair.
- Inside cleaning and scale removal.
- Pigging or cleaning of pipelines with a pig or scraper.
- Tank and accessories cleaning and rinsing before using the tank to store a different product.

References

1. American Petroleum Institute, *Guide for Inspection of Refinery Equipment, Chapter II – Conditions Causing Deterioration or Failures*, Second Ed., American Petroleum Institute, 2101 L Street, N.W., Washington, DC 20037, 1973.

2. American Petroleum Institute, *Guide for Inspection of Refinery Equipment, Chapter IV – Inspection Tools*, Second Ed., American Petroleum Institute, 2101 L Street, N.W., Washington, DC 20037, 1972.

3. American Petroleum Institute, *Guide for Inspection of Refinery Equipment, Chapter XIII – Atmospheric and Low-Pressure Storage Tanks*, Third Ed., American Petroleum Institute, 2101 L Street, N.W., Washington, DC 20037, 1972.

4. Acoustic Emission Technology Corp., "The Sign of a Good Panel is Silence", *Aviation*, Aviation Engineering and Maintenance, 2065 Martin Avenue, Suite 104, Santa Clara, CA 95050, April, 1979.

5. Acoustic Emission Technology Corp., *AEI, Acoustic Emission Technology Corp.: Originators of Real-Time Source Location Systems*, Acoustic Emission Technology Corp., 18125 Tribute Road, Sacramento, CA 95815, February, 1980.

Part III

CHAPTER 7: TEMPORARY CLOSURE, ABANDONMENT AND REMOVAL OF ABOVEGROUND TANKS

A. INTRODUCTION

As is the case with underground storage system components, the options available for the temporary or permanent closure of aboveground storage tanks are temporary closure at the site, abandonment at the site, or removal for disposal or reuse offsite. The reasons for using these practices, circumstances of application, typical procedures and relative costs are summarized in Table 3.7-1.

It cannot be overemphasized that the selection of proper procedure for the closure of aboveground storage tanks is important to prevent spills, leaks, fires, explosions and other releases of toxic or hazardous substance such as vapors to the environment. As stated in Part II, tank closure concerns must focus on such items as tank integrity, tank safety and security of the facilities. Concerns of particular importance for aboveground storage tanks are tank decontamination and tank dismantling.

B. TANK DECONTAMINATION

The decontamination of a tank is important in any temporary or permanent tank closure scenario. This is particularly true in the case of tanks which are being closed on-site, because these tanks remain visible and accessible to the public. The concerns in tank decontamination should focus on procedures to do the following:

- Remove all liquid product from the tank.
- Close off all piping to prevent re-entry of vapor or liquids into the tank.
- Free the tank of any vapors to the extent possible.
- Remove all sludge or other residues from the tank.
- Thoroughly clean the tank walls, floor and roof.

Vapor-freeing of the tank is necessary to remove any potential ignition or personnel exposure hazards. Depending upon the type of tank (e.g., fixed-roof atmospheric, floating-roof atmospheric, pressurized, etc.), the vapors may be displaced by mechanical ventilation, steam ventilation, or natural ventilation.

Sludge may be removed by various methods or by a combination of methods, depending on the construction of the tank and the number and size of shell openings. Possibly the simplest method is to wash, brush, or sweep the sludge into piles and shovel it into buckets or wheel barrows to remove it from the tank; sweep and wash down the tank with a water-hose stream; and remove remaining moisture from the tank by using an absorbent such as sawdust, spent clay or rags. While removing sludge by such methods, care must be taken to minimize the release of vapors from the sludge.

If the tank has floor-level cleanout manways, most of the sludge may be removed by flushing it from the tank with a high-pressure water stream. If such openings do not exist, pumps of the self priming type, or steam or water operated ejectors may be used. Any method of removing residual material from the tank that minimizes the time men must spend within the tank contributes to the safety of the tank-cleaning operations.

In all flushing operations, a large volume of contaminated water will be generated. This water cannot be discharged to a storm sewer or emptied onto the ground surface unless treated to remove the contaminants. Manual methods of sludge removal may be employed with flammable solvents or oils being used for the cleanup. The cleanup solvents or oils can be disposed by incineration.

Vacuum tank trucks also provide a fast and efficient method for removing and hauling sludge from tanks being cleaned. Where such equipment is used, the area of operation must be proved to be vapor-free and the truck should be located upwind from the tank and outside the path of probable vapor travel. In the area of discharge of sludge from the tank truck, vapor travel and sources of ignition must be considered.

In any tank cleaning operation, concern must focus on worker safety. Without proper safeguards and procedures, injury or property damage may result from one or more of the following:

- Explosion or fire.
- Oxygen deficiency.
- The presence of toxic liquids, vapors or dusts that are dangerous to breathe.
- Physical hazards such as slipping, tripping or falling objects.

For more information on the procedures involved in tank cleaning, the degree of hazard associated with these operations, and the precautionary steps that should be taken, please refer to the sources listed in Table 3.7-2 [1,2,5,6,7,8].

Table 3.7-1

Closure, Abandonment and Removal of Aboveground Tanks

Closure Practice	Reason for Practice and Circumstances of Application	Typical Procedures	Relative Costs/ Remarks
Temporary Closure (*temporarily out* of service")	For sound tanks intended to be *returned to service within two* years, or scheduled for abandonment or removal within 90 days.	Remove product from the tank. For inflammable liquids remove all product. For flammable liquids, leave sufficient residual quantity to assure saturated vapor space. Check with the manufacturer or other chemical data information source to determine the required residual volume. Thorough washing and rinsing *of tank may be required if it is to be* for a different product or one that is incompatible with the initially stored product.	Relatively low costs.
	Provides for safeguard against tampering or accidental use until the ultimate fate of the tank is determined.	Cap all fill and draw-off lines as close to the tank as possible to prevent flow of vapor or product back into the tank. Cut off power to the tank pumps.	
		Leave any vent lines open if flammable product remains in the tank.	
		Anchor tank to prevent flotation if located in a flood plain. (Ideally, in such a location, the tank should be anchored during use as well.)	
Abandonment in Place	*Permanent closure technique* that avoids the cost of tank removal.	Remove all liquid possible from the tank and piping system.	Relative costs range from low to high. For safety reasons abandonment in place *should be* considered less desirable than removal of the tank.
	Use of this method is dependent upon the tank age and salvage value and the projected use of the site after closure.	Disconnect and cap all fill, gauge, vent and product lines.	
	Local regulations may prohibit the use of this method.	Free the tank of all flammable or toxic vapors.	
		Remove all sludge or other tank residues.	
		Thoroughly clean the inside of the tank.	
		Secure entranceways to prevent casual or accidental entry into tank.	
		Anchor tank to prevent flotation if located in a flood plain. An inert material such as sand or gravel could be used to provide the necessary ballast in such an instance.	
Tank Removal	For tanks intended for junking (to recover salvage value) or reuse offsite.	Remove all liquid from the tank and piping system.	Relatively high costs.
	May be required by local regulation or because of the projected future use of the site.	Disconnect and cap all fill, gauge, vent and product lines.	For safety reasons, tank removal is more desirable than abandonment in place.
		Free the tank of all flammable or toxic vapors.	
		Remove all sludge or other tank residues.	Tank dismantling from the outside *is perferred, when* possible, to limit worker exposure hazards.
		Thoroughly clean the outside of the tank.	
		Dismantle the tank if necessary.	

C. TANK DISMANTLING

The safe removal of aboveground tanks often requires dismantling of the tank because of its size. Methods for the safe dismantling of petroleum storage tanks are described in API PSD-2202 [3]. These methods, which apply to tanks storing other liquids as well, are summarized in the following discussion.

The dismantling of a tank will dislodge accumulated scale and rust, resulting in abnormal amounts of dust. This is especially true during cold-cutting or sandblasting operations and is the principal reason why dismantling from the outside is more desirable. The dust can be reduced by application of water spray.

If dismantling is done inside the tank, excess scale or rust should be removed with a chipping hammer before cutting. During chipping and cold-cutting operations, respirators should be worn. Positive pressure air-supplied equipment should be worn during flame-cutting operations inside the tank, unless an area of at least 6-inches on each side of the cutting line has been previously cleaned to bare metal. Sandblasting or power wire-brushing are methods that will clean metal sufficiently for flame cutting. A respirator should be worn while sandblasting if the exterior of the tank has been primed or painted with lead-base paint. Similarly, a tank which had contained leaded gasoline will retain lead compounds in the scale. A respirator should be worn when performing any scale removal operations in such a tank.

Certain disposal precautions are also recommended in API PSD-2202 for steel tanks. If the steel is to be permanently discarded, such as by burying, no cleaning is needed except for removal of heavy scale deposits that might create dust in handling or transporting. If the steel is to be sold for scrap and possible remelting, sandblasting to remove heavy scale is recommended. For additional details on tank cleaning, dismantling and disposal precautions, refer to API PSD-2202 [3] and API Publication 2015 [1].

Table 3.7-2

Reference for Tank Cleaning Operations

API-2015
Cleaning Petroleum Storage Tanks

API-2015A
A Guide for Controling the Lead Hazard Associated with Tank Entry and Cleaning.

API PSD-2202
Dismantling and Disposing of Steel from Tanks which have Contained Leaded Gasoline.

API PSD-2207
Preparing Tank Bottoms for Hot Work.

ANSI-Z28.2
Standard Practice for Rispiratory Protection.

API Pub. 2013
Cleaning Mobile Tanks in Flammable or Combustible Liquid Service.

NFPA 325M
Fire Hazard Properties of Flammable Liquids, Gases and Volatile Solids.

NIOSH, criteria for a recommended standard, Working in Confined Spaces. DHEW 80-106.

These publications may be obtained from the following addresses:

API Publications: American Petroleum Institute
2101 L Street, N.W.
Washington, DC 20037
(202) 457-7173

ANSI Publications: American National Standards Institute,
Inc. 1430 Broadway
New York, N.Y. 10018
(212) 868-1220

NFPA Publications: National Fire Protection Association
Batterymarch Park
Quincy, MA. 02269
(617) 328-9230

NIOSH Publications: National Institute for Occupational
Safety and Health
Public Health Service
Center for Disease Control
National Institute for Occupational Safety and Health

References

1. American Petroleum Institute, *Cleaning Petroleum Storage Tanks*, API Publication 2015, Second Ed., 2101 L Street, N.W., Washington, DC 20037, November, 1976.

2. American Petroleum Institute, *A Guide for Controlling the Lead Hazard Associated with Tank Cleaning and Entry*, API Publication 2015A, First Ed., 2101 L Street, N.W., Washington, DC 20037, May, 1975.

3. American Petroleum Institute, *Dismantling and Disposing of Steel from Tanks which have Contained Leaded Gasoline*, API Bulletin PSD 2202, 2101 L Street, N.W., Washington, DC 20037, October, 1975.

4. American Petroleum Institute, *Preparing Tank Bottoms for Hot Work*, API Publication PSD-2207, 2101 L Street, N.W., Washington, DC 20037.

5. American National Standards Institute, *Standard Practice for Respiratory Protection*, ANSI Publication Z28.2, 1430 Broadway, New York, N.Y. 10018.

6. American Petroleum Institute, *Cleaning Mobile Tanks in Flammable or Combustible Liquid Service*, API Publication 2013, Fifth Edition, 2101 L Street, N.W., Washington, DC 20037, October, 1975.

7. National Fire Protection Association, *Fire Hazard Properties of Flammable Liquids, Gases and Volatile Solids*, NFPA 325M, Batterymarck Park, Quincy, MA, 02269, 1977.

8. American Petroleum Institute, *Recommended Practice for Abandonment or Removal of Used Underground Service Station Tanks*, API Bulletin 1604, 2101 L Street, N.W., Washington, DC 20037, March, 1981.

Appendix A
CHEMICAL AND PHYSICAL PROPERTIES OF HAZARDOUS SUBSTANCES

DEFINITIONS

The data presented in this appendix present classifications for various solid, liquid and gaseous materials that are considered hazardous compounds. These data were taken, for the most part, from the U.S. EPA's *NPDES Best Management Practices Guidance Document* [1].

Table A-1 presents the various classifications used. These classifications are described in detail in the following discussion.

1. Human Poisons

All substances poisonous to humans are ranked as Class A or Class B poisons by the U.S. Department of Transportation, and are defined as follows:

Class A. A poisonous gas or liquid that, when mixed with air in small amounts is dangerous to life.

Class B. A substance, liquid or solid, known to be so toxic to man as to constitute a hazard to health during transporatation or presumed to be toxic to man because it falls within any one of the following categories when tested with laboratory animals:

Oral toxicity: a single dose of 50 mg or less per kilogram of body weight when administered orally produces death within 48 hr in half or more than half of a group of 10 or more white laboratory rats weighing 200 to 300 g.

Toxicity on inhalation: continuous inhalation for 1 hr or less at a concentration of 2 mg or less per liter of vapor, mist, or dust produces death within 48 hr in half or more than half of a group of 10 or more white laboratory rats weighing 200 to 300 g.

Table A-1. Chemical Group Classification

Liquids	Solids	Gases
HP - Human poisons	HP - Human poisons	HP - Human poisons
Fl - Flammables	Fl - Flammables	Fl - Flammables
C - Corrosives	C - Corrosives	C - Corrosives
R - Reactives	R - Reactives	R - Reactives
V - Volatiles	BT - Amenable to BWT*	A- Highly toxic to aquatic life
F - Floaters	B - Biodegradeables	
BT - Amenable to BWT*	S - Solubles	
B - Biodegradeables	A - Highly toxic to aquatic life	
A- Highly toxic to aquatic life		

* Biological waste treatment.

Toxicity by skin absorption: when administered by continuous contact with the bare skin for 24 hr or less produces death within 48 hr in half or more than half of a group of 10 or more rabbits tested at a dosage of 200 mg or less per kilogram of body weight.

2. Flammables

Flammables are any liquids that have a flash point below 100°F (38°C). Any solid liable to spontaneous ignition in air, including solids that react with air or the moisture in air to produce extremely flammable products; and any solid liable to ignition in air by friction or slight heating, including solids that react with air or the moisture in air to produce flammable products.

3. Corrosives

Corrosives are defined as any substance that significantly chemically attacks common metals or metal alloys, including ferrous metals. (This definition and the designations of specific chemicals as corrosive are from the Rice report. Rice utilized designations provided by the U.S. Department of Transportation where available. USDOT defines a corrosive material as a "liquid or solid that causes visible destruction or irreversible alterations in human skin tissue at the site of contact, or in the case of leakage from its packaging, a liquid that has a severe corrosion rate on steel"; and "a liquid is considered to have a severe corrosion rate if its corrosion rate exceeds 0.250 inches per year on steel (SAE 1020) at a test temperature of 130°F.)

4. Volatiles

All chemicals with vapor pressures greater than 1.3 x 10^3 Pa (10 mm Hg) at 10°C are defined as volatiles.

5. Floaters

Floaters are all materials that will float on the surface of water in a spill situation and all chemicals with solubilities of less than 1% and specific gravities of less than 1.0.

6. Reactives

Reactive materials are defined as those materials which in themselves or in contact with water are readily capable of detonation or of explosive decomposition or explosive reaction at normal temperatures and pressures and as those materials which are sensitive to mechanical or localized thermal shock at normal temperatures and pressures.

7. Solubles

Solubles are solids with solubilities in water of greater than 0.1% or 1000 ppm.

8. Solids or Liquids Amenable to Biological Treatment

These compounds are defined as those which, while not necessarily biodegradable, are amenable to biological waste treatment in that they can be accepted into biological waste treatment systems without causing adverse impact on treatment of the pollutants normally present. Compounds in this classification group would have to be fed to biological treatment process.

9. Biodegradables

Compounds that can be degraded by microorganisms to normal biological end products, such as carbon dioxide and water, are considered to be biodegradeable. Biochemical oxidation requires an acclimated seed of microorganisms and dilution of the chemical compounds to levels that will not be toxic or inhibitory to the microorganisms.

10. Compounds Highly Toxic to Aquatic Life

Compounds that have an LC_{50} (concentration of material that is lethal to one-half of the test population of aquatic animals upon continuous exposure for 96 hr or less) of less than 1 mg/liter are considered to be highly toxic to aquatic life and include all compounds classified as X and A by EPA Classification of hazardous substances.

CLASSIFICATIONS

The toxic and hazardous substances classified as solids, liquids, or gases, as well as their chemical and physical characteristics, are given in Tables A-2, A-3, and A-4 respectively. The physical state of the particular substance is based on the pure chemical form in the absence of information on its use at a particular plant. Some of the compounds listed as solids and gases may in reality exist in solutions with solvents and/or water. These compounds are identified in Tables A-3 and A-4 and may be listed under more than one physical state classification. Examples are phosphoric acid, sodium hydroxide and formaldehyde. In the absence of data several compounds were grouped in the same categories as the chemical family. Assumed groupings are so noted in the tables.

Table A-2. Liquid Group Classification[a]

Liquid	Poisonous to Humans	Flammable	Corrosive	Reactive	Volatile	Floater	Amenable to Biological Treatment	Biodegradeable	Highly Toxic to Aquatic Life
Acetaldehyde	-	X	-	-	X	-	X	X	-
Acetic acid	-	-	X	-	-	-	X	X	-
Acetic anhydride	-	-	X	X	-	-	X	X	-
Acetone cyanohydrin	X	-	-	-	-	-	X	X	X
Acetyl bromide	-	-	X	X	-	-	X	X	-
Acetyl chloride	-	X	-	X	X	-	X	X	-
Acrolein	X	X	-	X	X	-	X	X	X
Acrylonitrile	-	X	-	-	X	-	X	X	-
Allyl alcohol	X	X	-	-	X	-	X	X	-
Allyl chloride	X	X	-	-	X	X	X	X	-
Ammonium hydroxide	-	-	X	-	-	-	X	-	-
Amyl acetate	-	X	-	-	-	X	X	X	-
Aniline	X	-	-	-	-	-	X	X	-
Benzene	-	X	-	-	X	X	X	X	-
Benzonitrile	-	-	-	-	-	-	X	X	-
Benzoyl chloride	-	-	X	X	-	-	X	X	-
Benzyl chloride	-	-	X	-	-	-	X	X	-
Bis(chloromethyl) ether	X	-	-	-	X	-	X	X	ND
Bis (2-chloroisopropyl) ether	-	-	-	-	X	-	X[b]	X[b]	ND
Bis (2-chloroethoxy) methane	-[b]	-[b]	-[b]	-[b]	X[b]	-[b]	X	X	ND
Bis (2-chloroethyl) ether	X	-	-	-	X	-	X	X	ND
Bis (2-ethylhexy) phthalate	X	-	-	-	X	X	-	-	ND
Bromoform (tribromomethane)	-	-	-	-	-	-	-	-	ND

Liquid	Poisonous to Humans	Flammable	Corrosive	Reactive	Volatile	Floater	Amenable to Biological Treatment	Biodegradeable	Highly Toxic to Aquatic Life
Butyl acetate	-	X	-	-	-	X	X	X	-
Butylamine	-	X	-	-	X	-	X	X	-
Butyl benzyl phthalate	-	-	-	-	-	-	X	X	-
Butyric acid	-	-	X	-	-	-	X	X	-
Carbon disulfide	-	X	-	-	X	-	-	-	-
Carbon tetrachloride	-	-	-	-	X	-	-	-	-
Chlordane	-	-	-	-	-	-	-	-	X
Chlorobenzene	-	X	-	-	-	-	X	X	-
Chlorodibromomethane	-	-	-	-	X	-	-	-	ND
Chloroethane	X	X	-	-	X	X	X	X	ND
2-Chloroethyl vinyl ether	-	X	-	-	X	-	X	X	ND
Chloroform	-	-	-	-	X	-	X	-	ND
2-Chlorophenol	X	-	-	-	-	-	X	X	-
4-Chlorophenyl phenyl ether	X[b]	-[b]	-[b]	-[b]	X[b]	-[b]	-	-	-
Chlorosulfonic acid	-	-	X	X	-	-	X	X	ND
Crotonaldehyde	X	X	X	-	X	X	X	X	-
Cyclohexane	-	X	-	-	X	X	X	X	X
Diazinon	-	-	-	-	-	-	-	-	ND
1,2-Dichlorobenzene	-	-	-	-	-	-	X	X	-
1,3-Dichlorobenzene	-	-	-	-	-	-	X	X	-
Dichlorobromomethane	-[b]	-[b]	-[b]	-[b]	-[b]	-	-	-	ND
1,1-Dichloroethane	-	X	-	-	X	-	X	X	ND
1,2-Dichloroethane	-	X	-	-	X	-	X	X	-
1,1-Dichloroethylene (vinylidene chloride)	-	X	-	-	X	-	-	-	ND
1,2-Dichloropropane	-	X	-	-	X	-	X	X	-
2,2-Dichloropropionic acid	-	-	X	-	-	-	-	-	ND

Liquid	Poisonous to Humans	Flammable	Corrosive	Reactive	Volatile	Floater	Amenable to Biological Treatment	Biodegradeable	Highly Toxic to Aquatic Life
1,3-Dichloropropylene	X	X	-	-	X	-	X	X	-
Dichlorovos	-	-	X	-	-	-	-	-	X
Diethylamine	-	X	X	-	X	X	X	X	ND
Diethyl phthalate	-	-	-	-	X	-	X	X	ND
Dimethyl phthalate	-	-	-	-	X	-	X	X	ND
Di-n-butyl phthalate	X	-	-	-	X	-	X	X	ND
Di-n-octyl phthalate	-	-	-	-	X	-	X	X	ND
Disulfoton	X	-	-	-	-	-	-	-	ND
Dodecylbenzenesulfonic acid	-	-	X	-	-	-	X	X	ND
Endrin aldehyde	-	-	-	-	-	-	-[b]	-[b]	X
Epichlorohydrin	X	X	X	-	-	-	X	X	-
Ethion	-	-	-	-	-	-	-	-	X
Ethylbenzene	-	X	-	-	X	X	X	X	-
Ethylene dibromide	X	-	X	-	X	-	X	X	-
Ethylenediamine	-	X	-	-	-	-	X	X	-
Formic acid	-	-	X	-	-	-	X	X	-
Furfural	-	-	X	-	-	-	X	X	-
Hexachlorobutadiene	-	-	-	-	-	-	X	-	ND
Hydrochloric acid	-	-	X	-	-	-	X	-	-
Hydrofluoric acid	-	-	X	-	-	-	X	-	-
Isophorone	-	-	-	-	-	X	X	X	ND
Isoprene	-	X	-	-	X	X	X	X	-
Malathion	-	-	-	-	-	-	-	-	X
Methylene chloride (dichloromethane)	-	-	-	-	X	-	-	-	ND
Methyl methacrylate	-	X	-	-	X	X	X	X	-
Mevinphos	X	-	X	-	-	-	-	-	X
Naphthenic acid	-	-	X	-	-	-	X	X	-
Nitric acid	-	-	X	-	-	-	X	-	-

Liquid	Poisonous to Humans	Flammable	Corrosive	Reactive	Volatile	Floater	Amenable to Biological Treatment	Biodegradeable	Highly Toxic to Aquatic Life
Nitrobenzene	X	-	-	-	-	-	X	X	
N-nitrosodimethylamine	-	-	-	-	X	-	-	-	ND
N-nitrosodi-n-propylamine	-[b]	-[b]	-[b]	-[b]	X[b]	-[b]	-	-	ND
Parathion	X	-	-	-	-	-	X	X	X
Phosphorous oxychloride	-	-	X	X	-	-	X	X	-
Phosphorous trichloride	-	-	X	X	X	-	X	-	-
Polychlorinated biphenyls (PCBS)	-	-	-	-	-	-	-	-	X
Propionic acid	-	-	X	-	-	-	X	X	-
Propionic anhydride	-	-	X	X	-	-	X	X	-
Propylene oxide	-	X	-	-	X	-	X	X	ND
Quinoline	-	-	-	-	-	-	-	-	-
Styrene	-	X	-	-	X	X	X	X	-
Sulfuric acid	-	-	X	-	-	-	X	-	-
Sulfur monochloride	-	-	X	X	-	-	X	-	-
2,4,5-Trichlorophenoxy acetic acid with amines	-	X	-	-	X	-	-	-	-
1,1,2-Tetrachloroethane	-	-	X	X	X	-	-	-	ND
Tetrachloroethylene	-	-	-	-	X	-	-	-	ND
Tetraethyl pyrophosphate	X	-	-	X	-	-	-	-	ND
Toluene	-	X	-	-	X	X	X	X	-
1,2-trans-Dichloroethylene	-	-	-	-	X	-	X	X	ND
1,2,4-Trichlorobenzene	-	-	-	-	-	-	X	X	ND
1,1,1-Trichloroethane	-	-	-	-	X	-	X	X	ND
1,1,2-Trichloroethane	-	-	-	-	X	-	X	X	-
Trichloroethylene	-	-	-	-	X		X	X	ND
Triethylamine	-	X	X	-	X	X	X	X	-
Vinyl acetate	-	X	-	-	-	X	X	X	-

Liquid	Poisonous to Humans	Flammable	Corrosive	Reactive	Volatile	Floater	Amenable to Biological Treatment	Biodegradeable	Highly Toxic to Aquatic Life
Vinyl chloride (chloroethylene)[b]	-	X	-	-	X	X	X	X	ND
Xylene	-	X	-	-	-	X	X	X	-

Table A-3. Solids Group Classification[a]

Solid	Poisonous to Humans	Flammable	Corrosive	Soluble	Amenable to Biological Treatment	Reactive	Biodegradeable	Highly Toxic to Aquatic Life
Acenaphthylene	-	-	-	-	-	-	-	-
Acenapthene	-	X	-	-	-	-	-	ND
Adipic acid	-	-	X	X	X	-	X	-
Aldrin	X	-	-	X	-	-	-	X
Aluminum sulfate	-	-	-	X	X	-	-	-
Ammonium acetate	-	-	-	X	X	-	X	-
Ammonium benzoate	-	-	-	X	X	-	X	-
Ammonium bicarbonate	-	-	-	X	X	-	-	-
Ammonium bifluoride	-	-	-	X	X	-	-	-
Ammonium bisulfite	-	-	-	X	X	-	-	-
Ammonium carbamate	-	-	-	X	X	-	X	-
Ammonium carbonate	-	-	-	X	X	-	-	-
Ammonium chloride	-	-	-	X	X	-	-	-
Ammonium citrate dibasic	-	-	-	X	X	-	X	-
Ammonium fluoborate	-	-	-	X	X[b]	-	-	-
Ammonium fluoride	-	-	-	X	X	-	-	-
Ammonium oxalate	-	-	-	X	X	-	X	-
Ammonium silicofluoride	-	-	-	X	X[b]	-	-	-
Ammonium sulfamate	-	-	-	X	X	-	X	-

Solid	Poisonous to Humans	Flammable	Corrosive	Soluble	Amenable to Biological Treatment	Reactive	Biodegradeable	Highly Toxic to Aquatic Life
Ammonium sulfide[c]	-	X	-	X	X	-	-	-
Ammonium sulfite	-	-	-	X	X	-	-	-
Ammonium tartrate	-	-	-	X	X	-	X	-
Ammonium thiocyanate	-	-	-	X	X	-	X	-
Ammonium thiosulfate	-	-	-	X	X	-	-	-
Anthracene	-	-	-	-	-	-	-	ND
Antimony	X	-	-	-	-	X	-	-
Arsenic	X	-	-	-	-	-	-	-
Asbestos	-	-	-	-	ND	ND	ND	ND
1,2-Benzanthracene	-[b]	-	-	-	-	-	-	ND
Benzidine	-	-	-	X	X	-	X	ND
3,4-Benzofluoranthene	-	-	-	-	-	-	-	ND
11,12-Benzofluoranthene	-	-	-	-	-	-	-	ND
Benzoic acid	-	-	-	-	X	-	X	-
3,4-Benzopyrene	-	-	-	-	-	-	-	ND
1,12-Benzoperylene	-	-	-	-	-	-	-	ND
Beryllium	X	-	-	-	-	-	-	ND
a-BHC (hexachlorocyclohexane)	X	-	-	-	X	-	X	X
B-BHC (hexachlorocyclohexane)	X	-	-	-	X	-	X	X
-BHC (hexachlorocyclohexane)	X	-	-	-	X	-	X	X
4-Bromophenyl phenyl ether	-	-	-	-	-	-	-	ND
Cadmium	-	-	-	-	-	-	-	-
Cadmium carbide	-	X	-	X	-	X	-	-
Cadmium dodecylbenzenesulfonate	-	-	-	X	X[b]	-	X[b]	-
Cadmium hydroxide[c]	-	-	-	X	X	-	-	-
Cadmium hypochlorite	-	-	X	X	X	-	-	-
Calcium oxide	-	-	-	X	X	X	-	-

Solid	Poisonous to Humans	Flammable	Corrosive	Soluble	Amenable to Biological Treatment	Reactive	Biodegradeable	Highly Toxic to Aquatic Life
Captan	-	-	-	X	-	-	-	X
Carbaryl	-	-	-	-	-	-	-	-
Carbofuran	ND	ND	ND	ND	ND	ND	ND	X
2-Chloronapthalene	-	-	-	-	X	-	X	ND
Chromium	-	-	-	-	-	-	-	-
Chrysene	-[b]	-[b]	-[b]	-	-	-[b]	-	ND
Cobaltous bromide	-	-	-	X	-	-	-	-
Cobaltous formate	-	-	-	X	-	-	-	-
Cobaltous sulfamate	-	-	-	X	-	-	-	-
Coumaphos	X	-	-	-	-[b]	-	-[b]	X
Copper	-	-	-	X	X	-	-	X
Cresol	X	-	-	-	X	-	X	ND
Cyanide	X	-	-	-	X	X	X	X
1,4-Dichlorobenzene	-	-	-	-	X	-	X	-
2,4-Dichlorophenoxy acetic acid	-	-	-	X	-	-	-	-
2,4-Dichlorophenoxy acetic acid esters	-	-	-	X	-	-	-	-
4,4'-DDD	X	-	-	-	-[b]	-	-[b]	X[b]
4,4'-DDE	X	-	-	-	-[b]	-	-[b]	X[b]
DDT	X[b]	-	-	X	-	-	-	X
1,2,5,6-Dibenzanthracene	-[b]	-[b]	-[b]	-[b]	-	-[b]	-	ND
Dicamba	-	-	-	X	-	-	-	-
Dichlorbenil	-	-	-	X	-	-	-	-
Dichlone	-	-	-	X	-	-	-	X
3,3'-Dichlorobenzidine	-	-	-	-	X	-	X	ND
2,4-Dichlorophenol	-	-	-	-	X	-	X	ND
Dieldrin	X	-	-	X	-	-	-	X
2,4-Dimethylphenol	-	-	-	-	X	-	X	ND
Dinitrobenzene	-	-	-	X	-	-	-	-

Solid	Poisonous to Humans	Flammable	Corrosive	Soluble	Amenable to Biological Treatment	Reactive	Biodegradeable	Highly Toxic to Aquatic Life
4,6-Dinitro-o-cresol	X	-	-	-	X	-	X	ND
2,4-Dinitrophenol	-	-	-	-	X	X	X	ND
2,4-Dinitrotoluene	-[b]	-	-	-	X	-	X	-
2,6-Dinitrotoluene	-[b]	-[b]	-[b]	-[b]	X	-[b]	X	-
1,2-Diphenylhydrazine	-[b]	-[b]	-[b]	-[b]	-	-[b]	-	ND
Diquat	-	-	-	X	-	-	-	-
Diuron	-	-	-	X	-	-	-	-
Chlorpyrifos	-	-	-	X	-	-	-	ND
Endosulfan sulfate	-	-	-	X	-	-	-	X
a-Endosulfan	-	-	-	X	-	-	-	X
B-Endosulfan	-	-	-	X	-	-	-	X
Endrin	-	-	-	X	-	-	-	X
EDTA	-	-	-	-	X[b]	-	X[b]	-
Ferric ammonium citrate	-	-	-	X	X	-	X	-
Ferric ammonium oxalate	-	-	-	-	X	-	X	-
Ferric chloride[c]	-	-	X	X	X	-	-	-
Ferric fluoride	-	-	-	X	X	-	-	-
Ferric nitrate	-	-	-	X	X	-	-	-
Ferric sulfate	-	-	-	X	X	-	-	-
Ferrous ammonium sulfate	-	-	-	X	X	-	-	-
Ferrous chloride	-	-	-	X	X	-	-	-
Ferrous sulfate	-	-	-	X	X	-	-	-
Fluoranthene	-	-	-	-	-	-	-	ND
Fluorene	-	-	-	-	-	-	-	ND
Fumaric acid	-	-	X	X	X	-	X	-
Guthion	-	-	-	X	X	-	X	X
Heptachlor	X	-	-	X	-	-	-	X
Heptachlor epoxide	X	-	-	-	-[b]	-	-[b]	ND
Hexachlorobenzene	-	-	-	-	-	-	-	ND

Solid	Poisonous to Humans	Flammable	Corrosive	Soluble	Amenable to Biological Treatment	Reactive	Biodegradeable	Highly Toxic to Aquatic Life
Hexachlorocyclopentadiene	-	-	-	-	X	-	-	X
Hexachloroethane	-	-	-	-	-	-	-	ND
Indeno (1,2,3-c,d) pyrene	-[b]	-[b]	-[b]	-[b]	-	-[b]	-	ND
Isopropanolamine dodecylbenzenesulfonate	-	-	-	X	X[b]	-	X[b]	ND
Kelthane	-	-	-	-	X	-	X	-
Kepone	X	-	-	-	-	-	-	X
lead	-	-	-	-	-	X	-	-
Lindane	-	-	-	X	-	-	-	X
Maleic acid	-	-	-	X	X	-	X	-
Maleic anhydride	-	-	-	X	X	X	X	-
Mercaptodimethur	X	ND	ND	-	X	-	X	X
Mercury	X	-	-	-	-	X	-	X
Methoxychlor	-	-	-	X	-	-	-	X
Methyl parathion	X	-	-	X	X	-	X	X
Naled	-	-	X	X	-	X	-	X
Napthalene	-	-	-	-	X	-	X	-
Nickel	-	-	-	-	-	-	-	-
2-Nitrophenol	X	-	-	X	X	-	X	-
4-Nitrophenol	X	-	-	X	X	-	X	-
N-nitrosodiphenylamine	X	-	-	-	-	-	-	ND
Nitrotoluene	X	-	-	-	X	X	X	ND
Parachlorometa cresol	-	-	-	X	X	-	X	ND
Paraformaldehyde	-	-	-	X	X	X	X	-
Phenanthrene	-	-	-	-	X	-	X	ND
Pentachlorophenol	X	-	-	-	-	-	-	X
Phenol[c]	X	-	-	X	X	-	X	-
Phosphoric acid[c]	-	-	X	X	X	-	-	-
Phosphorus	-	X	-	-	X	-	-	-

Solid	Poisonous to Humans	Flammable	Corrosive	Soluble	Amenable to Biological Treatment	Reactive	Biodegradeable	Highly Toxic to Aquatic Life
Phosphorus pentasulfide	-	X	-	X	X	-	X	-
Potassium hydroxide[c]	-	-	-	X	X	-	-	-
Potassium permanganate	-	-	-	X	X	-	-	-
Propargite	ND	ND	ND	-	ND	ND	-	ND
Pyrene	-[b]	-[b]	-[b]	X	-[b]	-	-[b]	ND
Pyrenthins	-	-	-	X	-	-	-	-
Resorcinol	-	-	-	X	-	-	-	-
Selenium	-	-	-	-	-	-	-	-
Silver	-	-	-	-	ND	-	-	X
Sodium	-	X	-	X	X	X	-	-
Sodium bifluoride	-	-	-	X	X	-	-	-
Sodium bisulfite	-	-	-	X	X	-	-	-
Sodium dodecylbenzene-sulfonate	-	-	-	X	X[b]	-	X[b]	-
Sodium fluoride	-	-	-	X	X	-	-	-
Sodium hydrosulfide	-	-	-	X	X	-	-	-
Sodium hydroxide[c]	-	-	-	X	X	-	-	-
Sodium hypochlorite[c]	-	-	-	X	X	-	-	-
Sodium methylate	-	-	-	X	X	X	X	-
Sodium nitrite	-	-	-	X	X	-	-	-
Sodium phosphate dibasic	-	-	-	X	X	-	-	-
Sodium phosphate tribasic	-	-	-	X	X	-	-	-
Strychnine	X	-	-	-	-	-	-	X
Thallium	X	-	-	X	ND	X	ND	-
2,3,7,8-tetrachloro-dibenzo-p-dioxin (TCDD)	X	-	-	-	-	-	-	ND
Toxaphene	-	-	-	X	-	-	-	X
Trichlorfon	-	-	-	X	-	-	-	X
2,4,6-trichlorophenol	-	-	-	-	X	-	X	X

Solid	Poisonous to Humans	Flammable	Corrosive	Soluble	Amenable to Biological Treatment	Reactive	Biodegradeable	Highly Toxic to Aquatic Life
2,4,5-Trichlorophenoxy acetic acid	X	-	-	-	-	-	-	-
2,4,5-Trichlorophenoxy acetic acid, esters	-	-	-	-	-	-	-	-
2-(2,4,5-Trichlorophenoxy) propanoic acid	-	-	X	-	-[b]	-	-[b]	X
2-(2,4,5-Trichlorophenoxy) propanoic acid esters	-	-	X	-	-	-	-	X
2,4,5-Trichlorophenoxy acetic acid, sodium salt	-	-	-	X	-	-	-	X
Triethanolamine dodecyl-benzenesulfonate	-	-	-	X	X[b]	-	X[b]	-
Uranyl acetate (radioactive)	-	-	-	X	-	-	-	-
Uranyl nitrate (radioactive)	-	-	-	X	-	-	-	-
Vanadium pentoxide	-	-	-	X	-	-	-	-
Vamadul sulfate	-	-	-	X	-	-	-	-
Xyleneol	-	-	-	X	X	-	X	-
Zectran (Mexacarbate)	X	-	-	X	-[b]	-	-[b]	-
Zinc	-	-	-	X	X	X	-	-
Zirconium nitrate	-	-	-	X	-	-	-	-
Zirconium potassium fluoride	-	-	-	X	-	-	-	-
Zirconium sulfate	-	-	-	X	-	-	-	-
Zirconium tetrachloride	-	-	X	X	-	X	-	-

[a]X denotes chemical is in this category. - denotes chemical is not in this category.
ND denotes no data available.
[b]Assumed values, based on chemical groups of similar type substances.
[c]Normally exists in liquid solution.

Table A-4. Gases Group Classification[a]

Gas	Poisonous to Humans	Flammable	Corrosive	Reactive	Highly Toxic to Aquatic Life
Ammonia	-	-	X	-	-
Chlorine	X	-	-	-	X
Cyanogen chloride	X	X	-	-	X
Dichlorodifluoromethane	-	-	-	-	-
Dimethylamine	-	X	X	-	-
Formaldehyde[b]	-	X	-	X	-
Hydrogen sulfide	X	X	-	-	-
Methyl bromide	X	-	-	-	-
Methyl chloride	-	X	-	-	-
Methyl mercaptan	-	X	X	-	-
Monomethylamine	-	X	X	-	-
Monoethylamine	-	X	X	-	-
Nitrogen dioxide	X	-	-	X	-
Phosgene	X	-	-	X	-
Trichlorofluoromethane	-	-	-	-	-
Trimethylamine	-	X	X	-	-

[a]X denotes chemical is in this category, - denotes chemical is not in this category, ND denotes no data available

[b]Normally exists in liquid solution.

Appendix B
COMPATIBILITY CHART FOR FLUIDS, SEALS, AND METALS

Appendix B:

CHEMICAL–MATERIALS COMPATIBILITY

The following chart presents compatibility data for several common materials of construction, including: steel, stainless steel, and aluminum. Other excellent sources of information include the following:

1. Hamner, Norman, E., *Corrosion Data Survey*, Fifth Edition
   includes: A comprehensive compilation of corrosion data for metals and non-metals.
   available from: National Association of Corrosion Engineers
   1440 South Creek
   Houston, Texas 77084
   (713)492-0535

2. Gallagher, Raymond, "Beat Corrosion With A Rubber Hose"
   published in: *Chemical Engineering*, Sept. 8, 1980, pages 105-118,
   includes: Comprehensive information on the compatibility of various hose materials with a wide range of chemicals.
   available from: McGraw-Hill Book Company
   1221 Avenue of the Americas
   New York, N.Y. 10020
   (212)997-1221
   or
   Mr. Raymond Gallagher
   The Gates Rubber Company
   999 South Broadway
   Denver, Colorado 80217
   (303)744-4041

3. Perry, R.H., Chilton, C.H., *Chemical Engineers' Handbook*
   includes: A series of tables presenting corrosion resistance (chemical compatibility) data for several ferrous and non-ferrous metals, plastics, and natural and synthetic rubbers.
   available from: McGraw-Hill Book Company
   1221 Avenue of the Americas
   New York, N.Y. 10020
   (212)997-1221

COMPATABILITY CHART FOR FLUIDS, SEALS AND METALS

Resistance of Metals & Gasket Materials to Various Compounds

CODE: G = Good; F = Fair; P = Poor

FLUID	METAL					SEAL MATERIAL				
	ALUMINUM	BRONZE	IRON	STEEL	ST. STEEL	BUNA	BUTYL	NEOPRENE	TEFLON	VITON
Acetaldehyde	G	P	G	G	G	P	G	P	G	
Acetate Solvents - Crude	G	F	F	F	G	P	P	G	G	
Acetate Solvents - Pure	G	G	G	G	G	P		G	G	
Acetic Acid - Pure	G	G	P	P	G	F	F	F	G	
Acetic Anyhydride	G	P	F	P	G	G	G	G	G	
Acetic - Glacial	G	G	P	P	G	G	G	G	G	P
Acetone	G	G	G	G	G	P	G	F	G	P
Acetyl Acetone	G	G	G	G	G	P	P	P	G	
Acetyl Chloride	F	F	F	G	G				G	
Acrylonitrile	G	G	G	G	G	P	F	G	G	
Aliphatic Hydrocarbons	G	G	G	G	G	G	P	G	G	G
Aluminum Chloride	F	F	P	P	F	G	G	G	G	
Aluminum Nitrate	G		P	P	G	G	G	G	G	
Aluminum Sulphate	G	F	P	P	G	G	G	G	G	
Ammonium Hydroxide	F	P	G	G	G	G	G	G	G	
Ammonium Liquors	F	P	G	G	G				G	
Ammonium Nitrate	G	P	G	G	G	G	G	G	G	
Ammonia, Anhydrous	G	P	G	G	G	G	G	G	G	
Ammonia, Aqua	F	P	G	G	G	F	G		G	
Amyl Alcohol	G	G	G	G	G	G	G	G	G	G
Anthracene	G	G	G	G	G				G	
Aromatic Hydrocarbons	G	G	G	G	G	G	F	F	G	G
Asphalt	G	G	G	G	G	F	P	F	G	
Aviation Gasoline	G	G	G	G	G	G		G	G	G
Beer - Beer Wort	G	G	F	F	G	P	G	G	G	G
Benzene - Benzol	G	G	G	G	G	P	F	P	G	F
Benzyl Alcohol	G	G	P	P	G	P	G	G	G	G
Benzyl Chloride	P	P	P	P	G	P	G	P	G	
Brines		G					G		G	
Butadiene	G	G	G	G	G	G			G	G
Butane	G	G	G	G	G	G	P	G	G	G
Butyl Acetate	G	G	G	G	G	P	F	F	G	
Butyl Alcohol - Butanol	G	G	G	G	G	G	G	G	G	G
Butyl Ether	G	G			G	F		P	G	
Butylene	G	G	G	G	G	G			G	G
Calcium Hydroxide	F	G	G	G	G	G	G	G	G	G
Calcium Nitrate	F	G	G	G	G	G		G	G	G
Carbitol Solvent	G	G				G	G	G	G	G
Carbolic Acid - Phenol	G	G	P	P	G	P	P	P	G	
Carbon Disulphide	G	F	G	G	G	P	P		G	G
Carbon Tetrachloride	F	G	F	G	G	F	P	F	G	
Carbonic Acid	G	P	P	P	G	F	G	G	G	
Castor Oil	G	G	F	F	G	G	G	G	G	G
China Wood Oil - (Tung Oil)	G	G	F	F	G	G		G	G	G
Chloroacetone	P	G		G				G	G	
Chloroethane		G			G	P		P	G	
Chloroform	G	G	G	G	G	P	P	P	G	
Chlorobenzene	G	G	G	G	G	P	P	P	G	
Chlorine - Dry	F	F	G	G	G	F	F	F	G	
Chlorine Gas	F	G	G	G	G				G	
Chloromethane	G	G	F	F	G	P		P	G	
Citric Acid	G	F	P	P	G	G	F	G	G	G
Corn Oils	G	G	G	G	G	G	G	F	G	G
Cotton Seed Oil	G	G	G	G	G	G	G	G	G	G
Creosol	G	G	G	G	G	P	P	G	G	
Creosote, Crude	G	F	G	G	G	G	P	F	G	G
Cresylic Acid	G	G	G	G	G	G	P	P	G	G
Cumene	F	G	F	F	G			G	G	
Cutting Oils	G	G	G	G	G	G			G	G

FLUID	METAL					SEAL MATERIAL				
	ALUMINUM	BRONZE	IRON	STEEL	ST. STEEL	BUNA	BUTYL	NEOPRENE	TEFLON	VITON
Cyclohexane	G	G	G	G	G	G	P	G	G	G
Cyclohexanol	G	G	G	G	G	G		G	G	G
Cyclohexanone	G	G	P	G	G	P	F	P	G	
Detergent Oils			G	G	G	G		G	G	G
Diacetone Alcohol	G	G	G	G	G	P	G	F	G	
Dichlorobenzene	G	G	P	P	G	P	P	P	G	G
Dichloro Ethane	G	G		G	G	F			G	
Dichloro Ethylene	G	G	G	G	G	P	P	P	G	
Diesel Oil	G	G	G	G	G	G			G	G
Diethyl Ether	G	G	G	G	G	F		G	G	
Diethyl Phthalate		G	G	G	G	P		P	G	
Diethylene Glycol	G	G	G	G	G	G		G	G	G
Ethyl Acetate	G	G	G	G	G	P	F	F	G	
Ethyl Alcohol	G	G	G	G	G	G	G	G	G	G
Ethyl Benzene	G	G	F	F	G	P	P	P	G	
Ethyl Benzoate	G	G	G	G	G	G	P	P	G	G
Ethyl Chloride	G	G	G	G	G	G	G	G	G	G
Ethyl Ether	G	G	G	G	G	F	F	F	G	
Ethylene Chloride	G	G	P	G	G				G	
Ethylene Glycol	G	G	G	G	G	G	G	G	G	G
Ethylene Oxide	G	F	G	G	G	F		P	G	
Fatty Acids	G	F	P	P	G	G	F	F	G	G
Foods	G				G				G	
Formaldehyde	G	G	F	F	G	G	G	G	G	G
Formic Acid	G	F	P	P	G	P	G	P	G	
Freon, Dry	G	G	G	G	G	G	F	P	G	G
Fuel Oil	G	G	G	G	G	G	P	G	G	G
Gas, Natural - Manufactured	G	G	G	G	G	G	P	P	G	G
Gasolene, Sour	G	F	F	F	G	G	P	G	G	G
Gasolene, Motor	G	G	G	G	G	G	P	G	G	G
Gasolene, Aromatic	G	G	G	G	G	F	P	P	G	
Gasolene, Aviation	G	G	G	G	G	F	P	P	G	G
Glycerine - Glycerol	G	G	G	G	G	G	G	G	G	G
Grease	G	G	G	G	G	G	F	G	G	G
Heptane	G	G	G	G	G	G		G	G	G
Hexane	G	G	G	G	G	G	P	G	G	G
Hexanol - Hexyl Alcohol	G	G	G	G	G	G		G	G	G
Hi-Boiling Naptha		G			G				G	G
Hi Flash Naptha		G			G				G	G
Hydraulic Oil		G			G	G	G	F	G	G
Hydrochloric Acid, 150°	P	P	P	P	P	G	G	G	G	G
Hydrogen Peroxide	G	P	P	P	G	G	G	G	G	G
Hydrogen Sulphide, Wet	G	F	G	G	G	F	G	F	G	
Isoctane	G	G	G	G	G	G	P	G	G	G
Isopentane		G			G	G			G	G
Isopropyl Acetate	G	G	G	G	G	P	G	P	G	
Isopropyl Alcohol	G	G	F	G	G	F	G	F	G	G
Isopropyl Ether	G	G	G	G	G	G	P	F	G	G
Jet Fuel - JP 4 - JP 5	G	G	G	G	G	G	P	F	G	G
Kerosene	G	G	G	G	G	G	P	G	G	G
Lacquer Solvent	G	F	F	F	G	P	P	P	G	
Lactic Acid	G	F	P	P	G	F	F	F	G	

Emco Wheaton Inc., *Loading Arm Assemblies*, Catalog E-12/72, EMCO Wheaton Inc., Chamberlain Blvd., Conneaut, OH 44030, Revised Sept. 1974.

COMPATABILITY CHART FOR FLUIDS, SEALS AND METALS

FLUID	METAL					SEAL MATERIAL				
	ALUMINUM	BRONZE	IRON	STEEL	ST. STEEL	BUNA	BUTYL	NEOPRENE	TEFLON	VITON
Lard - Lard Oil	G	G	G		G	G	F	G	G	G
Linseed Oil	G	G	G	G	G	G	G	G	G	G
Lube Oil	G	G	G	G	G	G	P	G	G	G
Methyl Alcohol - Methanol	G	G	G	G	G	G	G	G	G	G
Methyl Amyl Alcohol	G	G			G	F		P	G	
Methyl Amyl Acetate	G	G			G	P		P	G	
Methyl Acetate	G	G	G	G	G	P		P	G	
Methyl Chloride	P	P	P	P	G	F	F	P	G	
Methyl Ether	G	G			G	F		P	G	
Methyl Ethyl Keytone	G	G	G	G	G	P	F	P	G	P
Methyl Isobutyl Keytone	G	G	G	G	G	P	F	P	G	P
Methyl Propyl Keytone	G	G	G	G	G	P		P	G	P
Methylene Chloride	P	G	G	G	G	P		P	G	
Milk	G	P	P	P	G	G	G	G	G	G
Mineral Oils	G	G	G	G	G	G	F	F	G	G
Molasses	G	G	G	G	G	G		G	G	G
Naptha	G	G	G	G	G	G	P	P	G	G
Napthalene	G	G	G	G	G	P	P	P	G	
Naptha Solvents	G	G	G	G	G	G	P	P	G	G
Natural Gas	G	G	G	G	G	G	P	G	G	G
Nitric Acid - (Conc)	P	P	P	P	G	P	P	P	G	
Nitric Acid, Crude	P	P	P	P	G	P	P	P	G	
Nitric Acid, Diluted	P	P	P	P	G	P	G	P	G	
Nitrobenzene	G	G	G	G	G	P	G	P	G	
Nitroethane	G	G	G	G	G	P	G	P	G	
Nitromethane	G	G	G	G	G	P	G	P	G	
Nitropropane	G	G	G	G	G	P	G	F	G	
Nitrogen Fertilizers	G		G	G	G	G		G	G	G
Octyl Alcohol	G	G			G	F		G	G	G
Olive Oil	G	G			G			G	G	G
Oleic Acid	G	F	F	F	G	F	G	G	G	
Organic Phosphates	G	F	F	F	G	P	G	P	G	
Palm Oil	G	G	F	F	G			G	G	
Paraffin Oil	G		G	G	G			G	G	
Peanut Oil	G	G	F	F	G			G	G	
Pentane	G	G	G	G	G	G		G	G	G
Perchlorethylene	G	G	G	G	G				G	
Petroleum Ether	G	G	G	G	G	G	F	P	G	G
Petroleum Naptha	G	G	G	G	G	G		P	G	G
Petroleum Oils	G	G	G	G	G	G	P	G	G	G
Petroleum Spirits	G	G	G	G	G	G		P	G	G
Phenol	G	F	F	F	G	P	G	F	G	
Phosphoric Acid, Crude	P	P	F	F	G	F	G	F	G	
Phosphoric Acid, Pure 45%	P	P	P	P	G	F	G	F	G	
Pine Oil	G	G			G	F	P	F	G	
Potassium Hydroxide	P	P	F	G	G	F	G	G	G	
Propylene	G	G	G	G	G	P	P	P	G	
Propane	G	G	G	G	G	G	P	G	G	G
Propionic Acid	G	G	P	P	G	F	F	F	G	
Propyl Alcohol Propanol	G	G	G	G	G	G	G	G	G	G
Propylene Glycol	G	G		G	G	G	G		G	G
Propylene Oxide	G	G	G	G	G				G	

FLUID	METAL					SEAL MATERIAL				
	ALUMINUM	BRONZE	IRON	STEEL	ST. STEEL	BUNA	BUTYL	NEOPRENE	TEFLON	VITON
Rapeseed Oil	G	G			G			G	G	
Sewage	G		G		G	G	F	F	G	G
Skydrol		G			G	G			G	G
Sodium Bicarbonate	G	G	F	F	G	G	G	G	G	G
Sodium Bisulphite	F	F	P	P	G	G	G	G	G	G
Sodium Carbonate	F	F	G	G	G	G	G	G	G	G
Sodium Chloride	F	F	G	G	G	G	G	G	G	G
Sodium Cyanide	P	P	G	G	G	G	G	G	G	G
Sodium Hydroxide	P	P	G	G	G	F	G	F	G	
Sodium Hypochlorite	P	P	P	P	G	F	F	F	G	
Sodium Metaphosphate	P	P	P	P	G	G	G	F	G	G
Sodium Nitrate	G	F	G	G	G	G	G	F	G	G
Sodium Perborate	G	F	F	G	G	G	G	G	G	G
Sodium Peroxide	G	F	F	F	G	F	G	F	G	
Sodium Phosphate, Mono-Basic	G	F	F	F	G	G	G	G	G	G
Sodium Phosphate, Di-Basic	F	F	F	F	G	G	G	G	G	G
Sodium Phosphate, Tri-Basic	P	P	G	G	G	G	G	G	G	G
Sodium Silicate	P	F	G	G	G	G	G	G	G	G
Sodium Sulphate	G	G	G	G	G	G	G	G	G	G
Sodium Sulphide	P	P	G	G	G	G	G	G	G	G
Sodium Thiosulphate	G	F	F	F	G	G	G	G	G	G
Soya Bean Oil	G	G	F	F	G	G	G	G	G	G
Stoddard Solvent	G	G	G	G	G	G	P	F	G	G
Styrene	G	G	G	G	G	P	P	P	G	
Sugar	G	G			G		G	G	G	
Sulphur, Dry	G	P	G	G	G	F	F	F	G	
Sulphur, Chloride	P	P	F	F	F	F	P	F	G	
Sulphuric Acid - 10% Cold	P	P	P	P	G	G	G	G	G	G
Sulphuric Acid - 10% Hot	P	P	P	P	F	G	G	G	G	G
Sulphuric Acid - 10-75% Cold	P	P	P	P	F	F	G	F	G	
Sulphuric Acid - 10-75% Hot	P	P	P	P	F	F	G	F	G	
Sulphuric Acid - 75-95% Cold	P	P	G	G	G	F	G	F	G	
Sulphuric Acid Fuming	P	P	G	G	F	P	P	P	G	
Sulphuric Acid Fuming Hot	P	P	G	G	F	P	P	P	G	
Synthetic Lubricants		G			G	F	P	F	G	G
Tar	G	G	G	G	G	G	P	G	G	G
Tetraethyl Lead		G			G				G	
Toluene - Toluol	G	G	G	G	G	G	P	G	G	G
Trichlorethylene	G	G	G	G	G	P	P	P	G	
Tung Oil	G	G	F	F	G	G	G	G	G	G
Turbine Oil					G	G		G	G	G
Turpentine	G	F	F	F	G	G	P	F	G	G
Varnish	G	G	F	F	G	G	P	G	G	G
Varsol	G	G	G	G	G				G	
Vegetable Oils	G	G	G	G	G	G	G	G	G	G
Water, Fresh	G	F	G	G	G	G	G	G	G	G
Water, Sea	F	F	F	F	G			G	G	
Xylene - Xylol	G	G	G	G	G	P	P	P	G	

Appendix C
PROPERTIES OF PRINCIPAL COATING RESINS

References

1. Tator, K.B., *Protective Coatings*, Chemical Engineering Deskbook Issue, McGraw-Hill, 1221 Avenue of the Americas, New York, N.Y. 10020, December 4, 1972.
2. U.S. Environmental Protection Agency, *NPDES Best Management Practices Guidance Document*, EPA-600/9-79-045, USEPA Industrial Environmental Research Laboratory, Cincinnati, OH, December, 1979.

PROPERTIES OF PRINCIPAL COATING RESINS

	Description	Performance	Limitations	Comments
Alkyds	Esterification of polyhydric alcohol (glycerol) and a polybasic acid (phthalic acid), modified with a drying oil. Hardens by solvent evaporation and oxidation	Good resistance to atmospheric weathering and moderate chemical fumes; not resistant to chemical splash and spillage. Long oil alkyds have good penetration although are slow drying. Short oil alkyds are fast drying. Temperature resistant to 225 F.	Not chemically resistant; not suitable for application over alkaline surfaces such as fresh concrete.	Long oil alkyds make excellent primers for rusted and pitted steel and wooden surfaces. Corrosion resistance is adequate for mild chemical fumes that predominate in many industrial areas. Used as interior and exterior industrial and marine finishes. Cost: $4.00 to $8.00/gal.
Vinyls	Polyvinyl chloride—polyvinyl acetate copolymer dissolved in strong polar solvent, generally a ketone. Coating hardens by solvent evaporation.	Insoluble in oils, greases, aliphatic hydrocarbons and alcohols. Resistant to water and salt solutions. Not attacked at room temperature by inorganic acids and alkalis. Fire resistant; good abrasion resistance.	Strong polar solvents redissolve the vinyl. Initial adhesion poor. Relatively low thickness per cost (1.5–2.0 mils). Some types will not adhere to bare steel without primer. Pinholes in dried film more prevalent than other types.	Tough and flexible; low toxicity; tasteless; colorless; fire resistant. Used in potable water tanks and sanitary equipment; widely used industrial coating. Cost: $6.00 to $9.00/gal.
Chlorinated rubbers	Formed by adding chlorine to unsaturated isoprene units. Resin is dissolved in aromatic hydrocarbons, esters and ketones. Hardens by solvent evaporation.	Low moisture permeability and excellent resistance to water. Resistant to strong acids, alkalis, bleaches, soaps and detergents, mineral oils, mold and mildew. Good abrasion resistance.	Redissolved in strong solvents. Degarded by heat (200 F. dry and 140 F. wet) and ultraviolet light, but can be stabilized to improve these properties. May be difficult to spray, especially in hot weather.	Fire resistant; odorless; tasteless and non-toxic. Quick drying and excellent adhesion to concrete and steel. Used in concrete and masonry paints, swimming pool coatings, industrial coatings, marine finishes. Cost: $6.50 to $9.50/gal.
Epoxy, amine cured	Reaction of active hydrogens of aliphatic amines with epoxy groups of bisphenol-A epichlorhydrin resin. Coating hardens by solvent evaporation and cures by cross linking. Amine adduct epoxies consist of partially prepolymerized coatings to which the remainder of the amine is added prior to application to complete the cross linking.	Excellent resistance to alkalis, most organic and inorganic acids, water and aqueous salt solutions. Solvent resistance and resistance to oxidizing agents is good as long as not continually wetted. Amine adducts have slightly less chemical and moisture resistance.	Harder and less flexible than other epoxies and intolerant of moisture during application. Coating will chalk on exposure to ultraviolet light. Strong solvents may lift coatings. Temperature resistance: 225 F. dry, 190 F. wet. Will not cure below 40 F.; should be topcoated within 72 hr. to avoid intercoat delamination. Maximum properties require about seven days cure.	Good chemical and weather resistance. Best chemical resistance of epoxy family. Excellent adhesion to steel and concrete. Widely used in maintenance coatings and tank linings. Cost: $9.00 to $13.00/gal.
Epoxy, polyamide cured	Reactive polyamide resins (condensation products of dimerized fatty acids with polyamines) combined with epoxide groups in the epoxy resin. Coating hardens by solvent evaporation but cures by cross linking.	Superior to straight epoxies for water resistance. Excellent adhesion, gloss, hardness impact and abrasion resistance. More flexible and tough than amine epoxies. Chemical resistance slightly less than straight epoxies. Temperature resistance: 225 F. dry; 150 F. wet.	Cross linking does not occur below 40 F. Maximum resistances generally require seven days cure at 70 F.	Easier to apply and topcoat, more flexible and better moisture resistance than straight epoxies. Excellent adhesion over steel and concrete. A widely used industrial and marine maintenance coating. Some formulations can be applied to wet or underwater surfaces. Cost: $7.00 to $12.00/gal.
Epoxy ester	Formed by reaction between epoxy resin and unsaturated fatty acids (commonly linseed and soya oils). Coating hardens by solvent evaporation and oxidation.	Least resistant of epoxy family. Good weather resistance; chemical resistance better than alkyds and usually sufficient to resist normal atmospheric corrosive attack.	Not resistant to strong chemical fumes, splash or spillage. Temperature resistance 225 F. dry.	A high quality oil base coating, good compatibility with most other coating types. Easy to apply. Used widely for atmospheric resistance in chemical environments on structural steel, tank exteriors, etc.

PROPERTIES OF PRINCIPAL COATING RESINS [2]

	Description	Performance	Limitations	Comments
Epoxy, coal tar	Coal tar mixed with epoxy resin and cured using either an amine or a polyamide. Coating hardens and cures by cross linking.	Excellent resistance to salt and fresh water immersion. Very good acid and alkali resistance. Solvent resistance is good, although immersion in strong solvents may leech the coal tar.	Embrittles on exposure to cold or ultraviolet light. Cold weather abrasion resistance is poor. Should be topcoated within 48 hr. to avoid intercoat adhesion problems. Will not cure below 50 F. Black or dark colors only. Temperature resistance 225 F. dry, 150 F. wet.	Good water resistance. Thicknesses to 10 mils per coat. Can be applied to bare steel or concrete without a primer. Low cost per unit coverage. Cost: $6.50 to $8.50/gal.
Latex	Latex resins (generally styrene-butadiene, polyvinyl acetate, acrylic or blends) are emulsified in a water vehicle. After application the water evaporates and the resin particles coalesce and sinter to form the coating.	Resistant to water, mild chemical fumes and weathering. Good alkali resistance. Latexes are compatible with most generic coating types, either as an undercoat or topcoat.	Must be stored above freezing. Does not penetrate chalky surfaces. Exterior weather and chemical resistance not as good as solvent or oil base coatings.	Ease of application and cleanup. No toxic solvents. Good concrete and masonry sealers because breathing film allows passage of water vapor. Used as interior and exterior coatings. Cost: $5.00 to $8.00/gal.
Polyesters	An unsaturated polyester (resulting from esterification reaction between polyhydric alcohol and polybasic acid) is further reacted with diallyl phthalate to cross link and harden.	Excellent resistance to acids, organic solvents and water, as well as abrasion and abuse resistance.	Hard and inflexible. Very short pot life. Swelled and softened by strong alkalis. Minimum thickness of 6 mil required for cure.	Inert, tile-like appearance. Good adhesive and cohesive strength. High film build per coat (10 mils). Used in maintenance coatings and linings for tanks and process equipment. Cost: $9.00 to $13.00/gal.
Silicone	Composed of the siloxane bond with various organic side chains.	As heat resistant coating, requires catalyzation and baking. With aluminum pigments can withstand 1,000 F.; with ceramic frits up to 1,400 F. As a water repellant, resinous silicones in hydrocarbon solvents are used on masonry. Water soluble alkaline silicone in water are used on limestone and concrete.	Heat resistant silicones have moderate chemical fume resistance at lower temperatures.	Can be combined with other coating types to improve properties such as heat and moisture resistance. Water repellants are clear, breathing and durable. Used as stack coatings and above grade water repellants. Cost: $5.00 to $8.00/gal.
Zinc rich	Inorganic type consists of zinc dust in binder such as a silicate. Can be post or self cure, and can harden either by curing compound, water evaporation or hydrolyzation. Organic form used vehicles such as epoxies, phenoxies or chlorinated rubber. Hardens by chemical cross linking or solvent evaporation.	Resistant to weathering and mild chemical fume environments. Zinc in the coating is attacked when pH is below 6 or above 10.5. Inorganic type is resistant to abrasion and temperatures up to 700 F.	Requires clean steel surfaces. More difficult to apply than conventional coatings. Topcoating may be difficult especially with inorganics. Must be topcoated in severe corrosion environments.	Eliminates pitting corrosion. Despite limitations, widely used as industrial and marine primer. In mild environments can be used as one coat system. Cost: $8.00 to $18.00/gal.
Fire retardant	Flame retardant use nonflammable resins and plasticizers with compounds (such as bromates) that generate non-flammable gases. Intumescent coatings bubble and swell upon heating, thus insulating substrate from the fire.	Can reduce surface flammability or initial heat effects of fire but should be used only with conventional fire protection methods. Properties are generally better the thicker the coating.	May not be as chemically resistant as same type non-fire retardant coating. Generally provide only a few minutes delay. Some intumescent coatings are water sensitive and will not retain full properties after prolonged exposure to weather.	Used to reduce flame spread on combustible materials and to initially insulate structural steel from heat of fire. Cost: $6.50 to $9.00/gal.

Source:
Excerpted by special permission from *Chemical Engineering*, December 4, 1972, copyright (c) 1972, by McGraw-Hill, Inc., New York, N.Y. 10020

APPENDIX D

Glossary

GLOSSARY

Aboveground. Refers to storage tanks in which 100% of the tank volume is above final ground elevation.

Acoustic Emissions. Acoustic emissions are internally generated sounds produced by a material when placed under stress. With appropriate sensing equipment, this phenomenon can be effectively used for early warning and immediate response to hazardous spills developing from ruptures and leaks in a tank or pipe.

Anode. A metal electrode from which electric current leaves the surface and enters a solution (electrolyte). This electrical chemical action causes destructive alteration or eating away of the metal, typically through the process of oxidation.

Aquifer Sensitivity. Refers to the liklihood of, and degree to which groundwater resources may be contaminated at a particular site or area.

Asphalts. Black, solid or semisolid bitumens which occur in nature or are obtained as residues during petroleum refining.

Atmospheric Tank. A storage tank which has been designed to operate at pressures from atmosphere through 0.5psig.

Barrel. Strictly speaking, a statistical measure equalling 42 U.S. gallons. Actual barrels (or drums) used by oil companies, hold 55 gallons.

Bioconcentration. A process by which living organisms concentrate an element or compound to levels in excess of those in the surrounding environment.

Biodegradation. A process by which microbial organisms are capable of transforming or altering the structure of chemicals introduced into the environment through enzymatic action.

Bottom Loading. A method for loading liquid into a tank truck from ground level with a dry disconnect type fitting which usually incorporates a system designed to provide overflow protection. This type of loading operation eliminates the need for visual inspection of the inside of the tank during loading.

Bulk Storage. Materials stored in large quantities which are usually dispensed in smaller units for use or consumption. Warehousing of 55 gallon drums, underground tanks at gas stations and petroleum/chemical storage tank farms are examples of bulk storage facilities.

Bulk Storage Plant. A terminal where flammable or liquid or hazardous substances are received by tank vessel, pipe lines, tank car, tank vehicle, and are stored or blended in bulk for the purpose of distributing such liquids by tank vessel, pipe line, tank car, tank vehicle, or container.

Bunker "C" Oils. A general term used to indicate a heavy fuel oil.

Bunker Fuel. A general term for heavy oils used as fuel on ships and in industry. It often refers to No. 5 and No. 6 fuel oils.

Cathodic Protection. An electrical process for preventing corrosion on a wide variety of metallic structures which are in electrolytes such as soil or water. It operates by passing direct current continuously from electrodes which are installed in the electrolyte to the structure protected. The typical cathodic protection installation consists of a buried steel tank which becomes the cathode, and a separate "sacrifical" anode, which usually consists of a bar, rod, or wire of metal. The anode is literally consumed as electrical current passes from it through the electrolyte to the cathode (steel tank).

Coatings. Corrosion and chemical resistant materials which are sprayed, brushed, or rolled onto the metal surface of a storage tank. Coatings serve one of two main purposes: (1) they protect the metal from attack by a corrosive liquid or environment. (2) they protect the product from contamination by corrosion products.

Collection System. A series of components that collect stormwater, waste or spills. Collection systems are used at tank farms to collect spills through a network of pipes, channels, sewers, culverts, etc., necessary to transport the flow from collection points to slop tanks, retention areas, treatment facilities or outfall.

Combustible Liquid. Any liquid having a flashpoint at or above 100°F and below 200°F.

Containment. The prevention of the spreading of oil or other hazardous materials by the placing of booms or physical barriers and the use of absorbents, gelling or herding agents or other materials to mitigate the effects of the spill.

Containment System. A structure having an impervious surface (concrete, asphalt, membrane, etc.) surrounded by curbs, gutters, dikes, etc. The purpose is to prevent any flow from leaving the immediate area.

Corrosion. The deterioration of a material, usually a metal such as steel resulting from a flow of electricity from a metal (anode) to a positively charged material (cathode) through an electrolyte. This electrochemical action causes destructive alteration or eating away of the metal anode where positively charged atoms of metal detach themselves from the solid surface and enter into solution while the corresponding negative charges, in the form of electrons, are left behind in the metal.

Corrosive Material. Any liquid that causes destruction of human skin tissue or that has a severe corrosion rate on steel, aluminum or other metallic or non-metallic substance.

Crude Oil. Raw, liquid petroleum as it is extracted from the earth. Crude oil is found in many forms, each needing different handling and refining techniques. It might be thick as tar or nearly as thin as water. Its color can vary from yellow to green to reddish to black. Crude oil can be "sweet" (with low sulfur content) or "sour" (high sulfur content).

Demulsibility. The resistance of an oil to emulsification or the ability of an oil to separate from any water with which it is mixed. The better the demulsibility rating, the more quickly the oil separates from water.

Discharge. Includes, but is not limited to, any spilling, leaking, pumping, pouring, emitting, emptying or dumping except those activities duly permitted by any local, state or federal agency.

Dispersing Agents. Chemical agents or compounds which emulsify, disperse or solubilize oil into the water column or act to further the surface spreading of oil slicks in order to facilitate dispersal of the oil into the water column.

Electrical Insulation. A non-conductive material used for preventing corrosion caused by dissimilar metals; for example, by using insulating couplings to connect copper pipe and fittings to steel pipe.

Electrolyte. A chemical substance either a liquid, paste or gas which facilitates the flow of electrons in an electric field. Soil and groundwater adjacent to and in contact with a buried steel tank act as an electrolyte with respect to the electrochemical process of corrosion.

Electrolytic Corrosion. Corrosion as a result of direct current from outside sources entering and then leaving a particular metal structure by way of an electrolyte. Where current enters the structure, that structure is usually unaffected or is provided some degree of protection. Where the current leaves the structure, corrosion occurs. In underground work, this type of corrosion is often referred to as stray current corrosion and is a result of currents entering the ground from sources of direct current such as street railways or DC machinery.

Emulsion. A mechanical mixture of two liquids which do not naturally mix as oil and water. Water-in-oil emulsions have the water as the internal phase and oil as the external. Oil-in-water emulsions have water as the external phase and the internal phase is oil.

Etiologic Agent. A viable micro-organism or its toxin which causes or may cause human disease.

Flammable Liquid. Any liquid having a flash point below 100°F as determined by prescribed testing procedures.

Flammable Solid. Any solid material other than explosives which is liable to cause fires through friction, adsorption of moisture, spontaneous chemical changes, retained heat from manufacturing or processing, or which can be ignited readily and when ignited burns so vigorously and persistently that it creates a serious transportation hazard.

Flash Point. The lowest temperature at which substances give off sufficient vapor to form a mixture which will ignite, under standard conditions.

Fuel Oil Grade. Numerical ratings ranging from 1 to 6. The lower the grade number, the thinner the oil is and the more easily it evaporates. A high number indicates a relatively thick, heavy oil. No. 1 and 2 fuel oils are usually used in domestic heaters, and the others are used by industry and ships. No. 5 and 6 oils are solids which must be liquefied by heating. Kerosene, coal oil, and range oil are all No. 1 oil. No. 3 fuel oil is no longer used as a standard term.

Galvanic Anode. A metal which because of its relative position in the galvanic series, provides sacrificial protection to metal or metals that are more noble in the series, when coupled with an electrolyte.

Galvanic Corrosion. Self-generated corrosion which results when dissimilar metals placed in the soil electrolyte produce electrical currents. Corrosion occurs at the anodic surface where current leaves the metal to enter the soil electrolyte.

Gas (or natural gas). Simply speaking, petroleum in a gaseous state. Natural gas should not be confused with motor gasoline, which must ordinarily be refined from crude oil.

Holiday. A "bare spot" in a coating where there was little or no coating applied.

LeGrand Rating System. A procedure to evaluate the potential for groundwater contamination at a specific site under consideration for the storage of a hazardous substance. Evaluation factors include physical site characteristics, groundwater data, and the hazard potential of the substance that may be stored on the site.

Lethal Concentration Fifty (LC_{50}). A calculated concentration which, when administered by the respiratory route, is expected to kill 50 percent of a population of experimental animals during an exposure of 4 hours. Ambient concentration is expressed in milligrams per liter.

Liner. Corrosion and chemical resistant materials which are sprayed, brushed, or applied to the interior of a tank to protect the metal from attack from a corrosive liquid or environment, and to protect the product from contamination by corrosion products.

LNG. Liquid natual gas.

LPG. Liquified petroleum gas, such as propane or butane, commonly know as bottled gas.

Median Threshold Limit (96HRTLM). The concentration of a material at which it is lethal to 50 percent of the test population over a 96 hour exposure period. Ambient concentration is expressed in milligrams per liter.

NFPA. Refers to the National Fire Protection Association and its codes and generally accepted standards.

Oil. Refers to oil in any form including gasoline, crude oil, fuel oil, diesel oil, lubricating oil, oil refuse, sludge, and any other petroleum related product.

Oil Film. A slick thinner than .0001 inch which may be classified as follows:

Standard Term	Gallons Of Oil Per Sq. Mile	Appearance
"barely visible"	25	barely visible under most favorable light conditions
"silvery"	50	visible as a silvery sheen on surface water
"slightly colored"	100	first trace of color may be observed
"brightly colored"	200	bright bands of color are visible
"dull"	700	color begins to turn dull brown
"dark"	1300	much darker brown

Operator. The person or persons in responsible charge of the day-to-day operation and maintenance of a storage facility.

Outage. Space left in a product container to allow for expansion during temperature changes it may undergo during shipment and use. Measurement of space not occupied.

Oxidizing Agents. Substances which may increase corrosion acting as an electron acceptor to remove the film of hydrogen at a cathode; or in higher concentrations, substances such as nitric acid, which can form invisible protective films that reduce corrosive action.

pH. Term used to express the apparent acidity or alkalinity of aqueous solutions; values below 7 indicate acid solutions and values above 7 indicate alkaline solutions.

Phytotoxicity. Ability to cause poisonous or toxic reactions in plants.

Poison. A substance causing illness or death when ingested, inhaled or absorbed through the skin.

Pour Point. The lowest temperature at which a substance will flow or can be poured under specified conditions of test.

Pyroforic Liquid. Any liquid having a flash point below 100°C as determined by certain tests (highly flammable).

Resistivity. A unit measure of the electrical resistance of the soil. It is defined as the resistance of a unit cube, usually a one centimeter cube, to the passage of electrical current and is expressed in resistance-length units, usually ohm-centimeters (ohm-cm). Soil resistivity has a major influence on corrosivity by effecting the rate at which current passes from a metal surface into the soil, or from the soil into the metal. In general, corrosivity increases with decreasing soil resistivity. The USDA Soil Conservation Service categorizes soil corrosivity as high if resistivity (ohm-cm) is less than 2,000, as normally is the case in poorly drained clay soils; and low corrosivity if resistivity (ohm-cm) is greater than 10,000, as is typical of well-drained gravel.

Sacrificial Protection. Reduction or prevention of corrosion of a metal in an electrolyte by galvanically coupling it to a more anodic metal which literally is consumed; hence sacrificial.

Saturation Zone. That portion of the lithosphere in which the functional interstices of permeable rocks are saturated with water under hydrostatic pressure.

Sinking Agents. Chemicals or other agents that can physically sink oil below the water surface.

Sheen. An iridescent appearance on the surface of water.

Sodium Bentonite Soil Treatment. A substance having a molecular structure that allows it to absorb many times its own weight of substance, swelling enormously in the process...in most cases up to 10-16 times its dry bulk volume...to form an impermeable gel barrier. In most sodium bentonites, the swelling ability is long lasting and reversible. It can be dried and reswelled an infinite number of times. When mixed with soil around a storage tank and wetted, the sodium bentonite swells, pressing against the soil particles and filling the voids between the particles. The swelling action forms a tight seal around pipes and other equipment that protrude from a tank, eliminating difficult installation and sealing probems.

Solubility. The property of a chemical to dissolve or pass into solution. Solubility in water refers to the pounds of a chemical that will dissolve in 100 pounds of pure water. Solubility usually increases when the temperature increases.

Specific Gravity. The ratio of the weight of a given volume of the material at 4°C (or some stated temperature) to the weight of an equal volume of distilled water.

Storage Facility. Refers to warehouses, yards, tanks, containers, pipes and equipment for storing and handling hazardous materials.

Storm Runoff. A flow containing only water and no hydrocarbons.

STP. Submerged transfer pump.

Stray Current Corrosion. Corrosion resulting from direct current flow through paths other than the extended circuit. Service stations, for example built near cathodic protection rectifiers, factories or shops using D.C., or electrified (P.C.) railways or transit systems may experience stray current corrosion.

Stiker Plate. A 12" x 12" steel plate welded at bottom interior or tank under the fill opening so the dip stick is not always making a clean spot to enhance corrosion at that spot.

Surfactant. Chemical agents used to reduce the interfacial energy between gasoline and water, and to minimize the viscosity of gasoline – water emulsions so as to enhance and accelerate the recovery of gasoline spilled underground.

Unsaturated Zone. That portion of the lithosphere in which the functional interstices of permeable rock or earth are not (except temporarily) filled with water under hydrostatic pressure; that is, the water in the interstices is held by capillarity.

Unstable (Reactive) Liquid. A liquid in the pure state or as commercially produced or transported will vigorously polymerize, decompose, condense, or will become self-reactive under conditions of shock, pressure or temperature.

Vapor Pressure. A measure of a liquid's propensity to evaporate or give off flammable vapors. The higher the vapor pressure the more volatile the liquid and usually, the more readily the liquid gives off vapors.

Vapor Recovery System. A system designed to capture and retain, without processing, vapors displaced during filling operations at service stations, bulk storage plants, or terminals. The basic function of a vapor recovery system is to prevent vapors from being released into the atmosphere by diverting the vapor back into the transport tank through a closed circuit system. During the drop, vapor which already is present, and additional vapor generated by the drop being displaced by volume, is forced to the top of the tank and out through the vent line (or a special vapor return pipe), then diverted to the transport tank where it replaces the liquid being emptied from the transport tank.

Viscosity. The property of liquids which causes them to resist instantaneous change of shape, or instantaneous rearrangement of their parts, due to internal friction caused by molecular attraction. The resistance which the particles of a liquid offer to a force tending to move them in relation to each other. Viscosity of oils is usually expressed as the number of seconds at a definite temperature required for a standard quantity of oil to flow through a standard apparatus.

Viscous. Thick, resistant to flow, having a high viscosity.

Volatilization. Vaporizing or evaporating quickly. Volatilization rate is a function of turbulence, temperature and vapor pressure of the liquid.

65. New York State Department of Environmental Conservation. Criteria and Guidance for Underground Storage of Petroleum (Draft), Albany, New York, August 1983

Stephen Fagundes

DEC
PUBLICATION

Criteria and Guidance for Underground Storage of Petroleum

DRAFT

NOTE

This report contains references to the "Bulk Storage Code." As of July 1983, New York State has a Bulk Storage Law, which manadates such a Code. **References to the Code are for discussion purposes only.** Formal enactment of this Code is about two years away.

August 1983

New York State/Department of Environmental Conservation

SW-P58 (8/83)

K. Harder

MANUALS IN NEW YORK STATE'S BULK STORAGE PROGRAM

This Manual on Recommendations and Guidelines for Storing Hazardous Substances provides information on the proper installation and storage methods for underground storage facilities housing petroleum products. The manual brings together recommended practices and guidelines for: (1) the design of storage tanks and piping systems; (2) the installation of underground storage systems; (3) secondary containment; (4) leak detection; (5) overfill protection and transfer spill prevention; (6) storage system testing; (7) storage tank rehabilitation; and (8) the closure of underground storage systems. The aim of this manual is to assist the storage system owner in preventing leaks and spills of hazardous liquids.

The State-of-the-Art Review Manual compiles much of the latest information on the equipment available for storing and handling hazardous liquids. Included are data on tanks, hoses, overfill prevention devices, piping, valves, and pumps. Important information is also provided on the field practices and equipment available for leak detection and spill cleanup.

The Model Local Ordinance for Storage of Hazardous Substances provides suggested wording and format for local ordinances to regulate the storage of hazardous materials. Alternatives to fit specific needs are presented.

The Siting Manual presents information and procedures to assist local officials in preventing leaks and spills of hazardous substances in sensitive environments. Discussed are: types of hazards, causes of leaks and spills, site evaluation procedures, and practices for spill prevention and mitigation.

These manuals are available from:

Bureau of Water Resources
NYS Department of Environmental Conservation
50 Wolf Road
Albany, NY 12233
Telephone 518 457-4351

Preface

This Manual presents a series of guidelines and recommended practices for the underground storage of petroleum and petroleum derivative liquids. The purpose of this document is to encourage the use of technology and practices which would prevent leaks and spills from underground storage systems by presenting what the New York State Department of Environmental Conservation regards as proper storage practices.

Because these hazardous liquids vary widely in their characteristics and in the manner in which they should be stored, this Manual can serve only as a guide. Each liquid requires its own specific storage design. It is the responsibility of the owner of a storage facility to seek the assistance of a professional engineer who has the skills to design a storage system which can be used safely and which provides the necessary measures for environmental protection.

The mention of trade names or commercial products in this manual does not constitute endorsement or recommendation for use by the Department of Environmental Conservation.

ACKNOWLEDGEMENTS

This Manual was prepared by the Bureau of Water Resources in cooperation with the consulting engineers:

Fred C. Hart Associates
530 Fifth Avenue
New York, New York 10036

The project managers wish to thank the many people who contributed to this report, particularly those individuals on the review committee who have provided very valuable insights, comments and suggestions.

TABLE OF CONTENTS

Item	Page
Preface	i
Acknowledgements	ii
Table of Contents	iii
List of Figures	vi
List of Tables	vii
Introduction	I-1
A. The Relationship Between the Bulk Storage Code, Manufacturer Recommendations, and This Recommended Practices Manual	I-1
B. The Approach of This Manual	I-2
Chapter One: Underground Tanks	1-1
A. Introduction	1-1
B. General Requirements for All Tanks	1-2
C. Design Recommendations - Cathodically Protected Steel Tanks	1-4
D. Design Recommendations - Fiberglass-Reinforced Plastic Tanks	1-16
E. Steel Tanks Which Are Clad With Fiberglass-Reinforced Plastic	1-18
F. Double-Walled Tanks	1-19
References	1-22
Chapter Two: Pipe, Fittings, and Pumping Systems	2-1
A. Introduction	2-1
B. Pipe Materials	2-1
C. Fittings	2-9
D. Pumps	2-11
E. Hoses	2-14
References	2-17

Chapter Three: Recommended Installation Practices For Underground Storage Facilities. 3-1

A. Introduction 3-1

B. Planning and Desiging the Facility 3-2

C. Site Preparation 3-6

D. Preinstallation Testing and Inspection 3-11

E. Care in Handling 3-11

F. Bedding and Backfilling 3-11

G. Pavement Openings 3-18

H. Cover and Pavement 3-19

I. Testing and Inspection 3-19

J. Installation of Piping Systems 3-23

References. 3-29

Chapter Four: Secondary Containment Systems 4-1

A. Introduction 4-1

B. Double-Walled Tanks 4-2

C. Vaults 4-2

D. Cutoff Barriers and Containment Liners 4-4

E. Sites With Impervious Soils 4-11

F. Liner Material and Installation Practices 4-13

References 4-19

Chapter Five: Storage Tank Rehabilitation 5-1

A. General Safety Precautions 5-1

B. Rehabilitation of Steel Tanks 5-5

C. Rehabilitation of FRP Tanks 5-11

References 5-13

Chapter Six: Recommended Practices for Tank Closure and Abandonment. 6-1

A. Introduction 6-1

B. Temporary Closure 6-1

C. Permanent Closure 6-3

References 6-13

Chapter Seven: Leak Detection Systems 7-1

A. Introduction 7-1

B. Interstitial Monitoring in Double-Walled Tanks 7-2

C. In-Tank Testing Equipment 7-3

D. Excavation Monitoring Systems 7-3

E. Inventory Monitoring 7-13

References 7-15

Chapter Eight: Tightness Testing for Storage Systems 8-1

A. Introduction 8-1

B. Inspections of Underground Tanks 8-1

C. Final or Precision Tests 8-5

D. Pipeline Tests 8-8

References 8-11

Chapter Nine: Overfill Protection and Transfer Spill Prevention. 9-1

A. Overfill Protection Systems 9-1

B. Transfer Spill Prevention Systems 9-5

C. Operating Practices 9-7

References 9-8

List of Figures

Figure Name		Page
1-1	Features of a Pre-engineered Underground Storage Tank	1-5
1-2	Anode Installation on Pre-engineered Tanks	1-10
1-3	Anode Holders and Installation of Anodes	1-11
1-4	Electrical Isolation Using a Companion Nylon Flange	1-14
1-5	Electrical Isolation Using a Flange Insulation Kit	1-15
1-6	Double-Walled Tank With Bonded Fiberglass Coating	1-20
2-1	Diagram of an Underground Piping System	2-2
2-2	A Galvanic Cathodic Protection System	2-5
2-3	An Impressed Current Cathodic Protection System	2-6
2-4	Double-Walled Pipe	2-10
2-5	The Pipeline Leak Detector	2-13
2-6	An Emergency Shutoff Valve	2-15
3-1	Dimensions for Underground Tank Installations	3-7
3-2	Size of Pea Gravel and Crushed Stone Recommended for Bedding and Backfill Material	3-13
3-3	Wet Hole Tank Installation	3-16
3-4	Tank Piping Details - Suction System	3-20
3-5	Tank Piping Details - Submerged System	3-21
3-6	Minimum Dimensions for Piping Installations	3-25
4-1	Diagram of a Secondary Containment Vault	4-5
4-2	A Cutoff Barrier Used for Secondary Containment in an Area of High Groundwater	4-7
4-3	An Excavation Liner Used for Secondary Containment in an Area of Low Groundwater	4-9
4-4	A Trough Liner System in an Area of Low Groundwater	4-10
4-5	Containment in Native Impermeable Soils	4-12

List of Figures
(Continued)

Table		Page
5-1	Types of Tank Ventilation Equipment	5-4
5-2	Installation of a Tank Cover Plate	5-10
7-1	A Typical In-Tank Testing System	7-4
7-2	Example of a U-Tube Installation	7-5
7-3	Examples of Observation Wells	7-8
7-4	Example of a Vapor Well	7-10
7-5	Diagram of a Collection Sump	7-11
9-1	Float Vent Valves	9-4
9-2	Types of Couplings	9-6

List of Tables

Table		Page
I-1	Organizations Providing Specifications and Other Information	I-3
1-1	Thickness of Steel Tanks	1-7
1-2	Sacrificial Anode Requirements	1-9
2-1	Considerations in Piping System Design	2-3
3-1	Planning and Design Considerations for Installing Underground Storage Facilities	3-3
3-2	Classes of Soil Corrosivity	3-5
3-3	Recommended Dimensions for Underground Tank Installations	3-8
5-1	Sources of Information on Safe Tank Rehabilitation Procedures	5-2
6-1	Important Considerations in Storage Tank Closure	6-2
6-2	References for Tank Cleaning Operations	6-11
8-1	Apparent Loss of Product Volume Due to Force on Tank Ends - In Gallons	8-7
8-2	Tank Testing Schedule	8-9
9-1	Level Detection Devices for Underground Storage Tanks	9-2

INTRODUCTION

A. The Relationship Between the Bulk Storage Code, Manufacturer Recommendations, and This Recommended Practices Manual

The adequacy of the initial design and installation of underground storage systems for petroleum and derivative liquids is perhaps the most important factor in minimizing potential environmental hazards due to spills or leaks of these liquids. This applies not only to storage tanks, but to the tank appurtances, other storage system components, and storage system maintenance practices.

1. The Bulk Storage Code

To ensure the proper design, installation, operation, and maintenance of these underground storage systems, the New York State Department of Environmental Conservation (hereafter referred to as the Department or DEC) has adopted a Bulk Storage Code. This Code is recorded in the New York State Rules and Regulations (6 NYCRR 612), and must be followed for all underground petroleum and petroleum derivative storage installations.

2. This Recommeded Practices Manual

The purpose of this report is to present Department recommendations and guidelines for meeting the requirements of the Bulk Storage Code. The items covered include the following:

- Underground storage tanks and piping systems.
- Installation practices.
- Containment and recovery systems.
- Storage system rehabilitation.
- Storage system closure and abandonment.
- Overfill prevention.
- Transfer spill prevention.
- Leak detection and tightness testing.

The recommendations which follow should guide all underground storage installations. They are consistent with generally accepted practices, and the recommendations of tank manufacturers. If these recommended practices are implemented, they will greatly reduce the likelihood of a major spill or leak incident. However, this guidance should be considered subordinate to the Bulk Storage Code, and to site-specific engineering practices which may be required for an individual facility.

3. Manufacturers' Recommended Practices

Proper installation is so crucial to the leak-free operation of a storage facility that major tank manufacturers warrant their tanks against failure only if they are installed and used in accordance with manufacturer instructions. For this reason, tanks should be installed in strict accord with manufacturers' recommendations.

B. The Approach of This Manual

This manual is intended for the use of owners of petroleum storage facilities, and others in government and the private sector who are concerned with minimizing the risks of leaks and spills to the environment. It is written for the layman as well as the engineer so that they may jointly consider and select appropriate bulk storage and handling practices for leak and spill prevention.

> The practices and guidelines recommended in this manual pertain to the storage of petroleum and derivative liquids, but many of the principles, performance criteria and recommended practices presented apply to the storage of other hazardous liquids as well.

The recommendations and guidelines presented herein focus on the level of performance necessary to prevent leaks and spills and protect the environment. Where appropriate, the standards and recommendations of organizations such as Underwriters' Laboratories (UL), the National Fire Protection Association (NFPA), the American National Standards Institute (ANSI), the American

Society of Testing and Materials (ASTM), the American Society of Mechanical Engineers (ASME), and the American Petroleum Institute (API) have been referenced. Reference is also made throughout the report to the Technology Assessment Manual which was prepared as part of the New York State Bulk Storage Program. The reader may wish to refer to the specific documents highlighted throughout this report for more detailed information. Table I-1 provides a list of organizations whose specifications and/or reports may be of interest.

TABLE I-1

Organizations Providing Specifications and Other Information

ANSI	American National Standards Institute, Inc. 1430 Broadway, New York, New York 10018 (212) 354-3473
API	American Petroleum Institute 2101 L Street N.W., Washington, D.C. 20037 (202) 457-7000
ASME	The American Society of Mechanical Engineers 345 East 47th Street, New York, New York 10017 (212) 705-7703
ASNT	American Society for Nondestructive Testing 3200 Riverside Drive, Columbus, Ohio 43221 (614) 488-7921
ASTM	American Society for Testing and Materials 1916 Race Street, Philadelphia, Pennsylvania 19103 (215) 299-5400
AWWA	American Water Works Association 6666 W. Quincy Avenue, Denver, Colorado 80235 (303) 794-7711
AWS	American Welding Society 2501 N.W. 7th Street, Miami, Florida 33125 (305) 642-7090
CDA	Copper Development Association 405 Lexington Avenue, New York, New York 10017 (212) 953-7300
NBS	Federal Specification: Superintendent of Documents United States Government Printing Office, Washington, D.C. 20402 (202) 541-3000
MSS	Manufacturers Standardization Society of the Valve and Fittings Industry 5203 Leesburg Pike, Falls Church, Virginia 22041 (703) 998-7996
NACE	National Association of Corrosion Engineers P.O. Box 986, Katy, Texas 77450 (713) 492-0535

Table I-1 (cont)

NFPA	National Fire Protection Association Batterymarch Park, Quincy, Massachusetts 02269 (617) 328-9290
PFI	Pipe Fabrication Institute 1326 Freeport Road, Pittsburgh, Pennsylvania 15238 (412) 782-1624
PPI	Plastics Pipe Institute 250 Park Avenue, New York, New York 10017 (212) 687-2675
SAE	Society of Automotive Engineers 400 Commonwealth Drive, Warrendale, Pennsylvania 15096 (412) 776-4841
UL	Underwriters Laboratories 333 Pfingsten Road, Northbrook, Illinois 60062 (312) 272-8800
STI	Steel Tank Institute 666 Dundee Road, Suite 705, Northbrook, Illinois 60062 (312) 498-1980

CHAPTER 1:

UNDERGROUND TANKS

A. Introduction

The importance of selecting the proper material for underground storage tanks cannot be overemphasized. Factors which must be taken into account include the following:

- Corrosion resistance.
- Chemical compatibility with the stored product.
- Structural strength.
- Foundation (support requirements).

In the past, bare steel (or carbon steel) tanks have been widely used for underground storage of gasoline and other petroleum products. These steel tanks are structurally strong, require relatively little in the way of foundation support other than uniform backfill, and are compatible with a wide range of liquids. However, carbon steel tanks are particularly susceptible to corrosion, especially when installed in highly corrosive soils or in groundwater. Approximately 50% of the bare steel tanks installed are leaking by the time they are 15 years old. For this reason, unprotected (bare) steel tanks should not be used for underground storage.

The types of tanks which are suitable for underground petroleum storage include the following:

- Cathodically protected steel tanks.
- Fiberglass-reinforced plastic tanks.
- Steel tanks which are clad with fiberglass-reinforced plastic.
- Double-walled steel or fiberglass-reinforced plastic tanks.

Recommended practices for the design and construction of these types of tanks listed above are given in the remainder of this chapter.

All new underground storage tanks should be made of fiberglass-reinforced plastic, steel clad with fiberglass-reinforced plastic, or coated steel which is cathodically protected. (6NYCRR 610.8(c).) These types of tanks, together with double-walled vessels, are the only types of tanks which should be used for underground petroleum storage in New York. Bare steel tanks are unsuitable for use as underground storage vessels.

B. General Requirements for All Tanks

All storage tanks installed underground in New York State should include the following features:

- Proper labeling.
- Wear (striker) plates beneath fill openings.
- Factory pressure tests for tightness.
- Manholes.

The following discussion addresses each of those features in more detail.

1. Tank Labeling

In New York, each tank should have a label of permanent construction affixed at its fill port which contains information on the manufacturer, tank capacity, date of manufacture, and standards of construction. This information is useful if a tank warrantee claim becomes necessary, when property or management changes, or in the investigation of tanks for leakage.

In addition, it is desirable that each tank be marked in a prominent place (e.g., on the tank head or end) with important handling, safety, manufacturing, and installation instructions. This marking should also be of a permanent nature.

2. Wear Plates

All tanks should have a ¼ inch thick steel wear plate (striker plate) centered under each opening. This plate should be rolled to the contours of the tank, bonded or seam welded in place, and have an area of at least 575 square inches. These wear plates provide valuable protection against punctures from dip sticks and "blast erosion" which occurs under the fill tube.

3. Factory Pressure Tests

To assure tightness of all welds, seams, and fittings, tanks should be factory tested at 5 psig*, in accordance with UL standards and procedures, and guaranteed by the manufacturer to be tight. If the tank is compartmentalized, each section of the tank should be separately tested for leakage and repaired if necessary.

4. Manholes

Although it is possible to retrofit a tank with manhole, it is best to use a tank which has a factory-installed manhole. This allows the owner to inspect the tank for soundness after installation or to enter the tank later to clean sludge from the bottom, internally inspect the tank for soundness, and make necessary repairs. Manholes also allow the manufacturer of steel tanks to enter the tank during fabrication to join seams with double welded butt joints. These joints are stronger than lap welds, and less susceptible to corrosion.

Manholes should be located above the highest normal liquid level of the tank, and should be of the bolted cover type. Manhole cover joints should be sealed with a gasket material which is compatible with the tank contents. The gasket should not be less than 1/8 inch thick.

---

* FRP tanks with diameters above 10 ft. should be pressurized to 3 psig for tightness tests.

Manholes may pose management problems for the owner. Manhole gaskets may lose their seal and leak, or air pockets may form in the manhole chamber. Either situation will present a problem when a tank is tested for a leak. However, such problems can be resolved by using new gaskets and installing an air release valve at the top of the manhole.

C. Design Recommendations - Cathodically Protected Steel Tanks

A suitable cathodically protected steel tank, regardless of size, should be designed in accordance with Underwriter Laboratory Standard 58 [1], or the American Society of Mechanical Engineers (ASME) Code for pressure vessels [2]. A corrosion protection system should include these four measures of control:

- Cathodic protection via sacrificial galvanic anodes or anodes energized by impressed current.
- Monitoring to track the effectiveness of the cathodic protection system.
- A tough exterior epoxy coating which measures at least 10-15 mils in thickness.
- Electrical isolation of the tank from the piping system and other underground metallic structures.

To assure complete protection, it is essential that all of the above features are present. Figure 1-1 illustrates these tank construction features.

1. Steel Tank Design

The fabrication and design requirements of Underwriters' Laboratory are specified in UL 58, entitled Standards for Steel Underground Tanks for Flammable and Combustible Liquids [1]. The requirements of ASME are delineated in the ASME Pressure Vessel Code, Section VIII, Division 1, Boiler and Pressure Vessel Code [2].

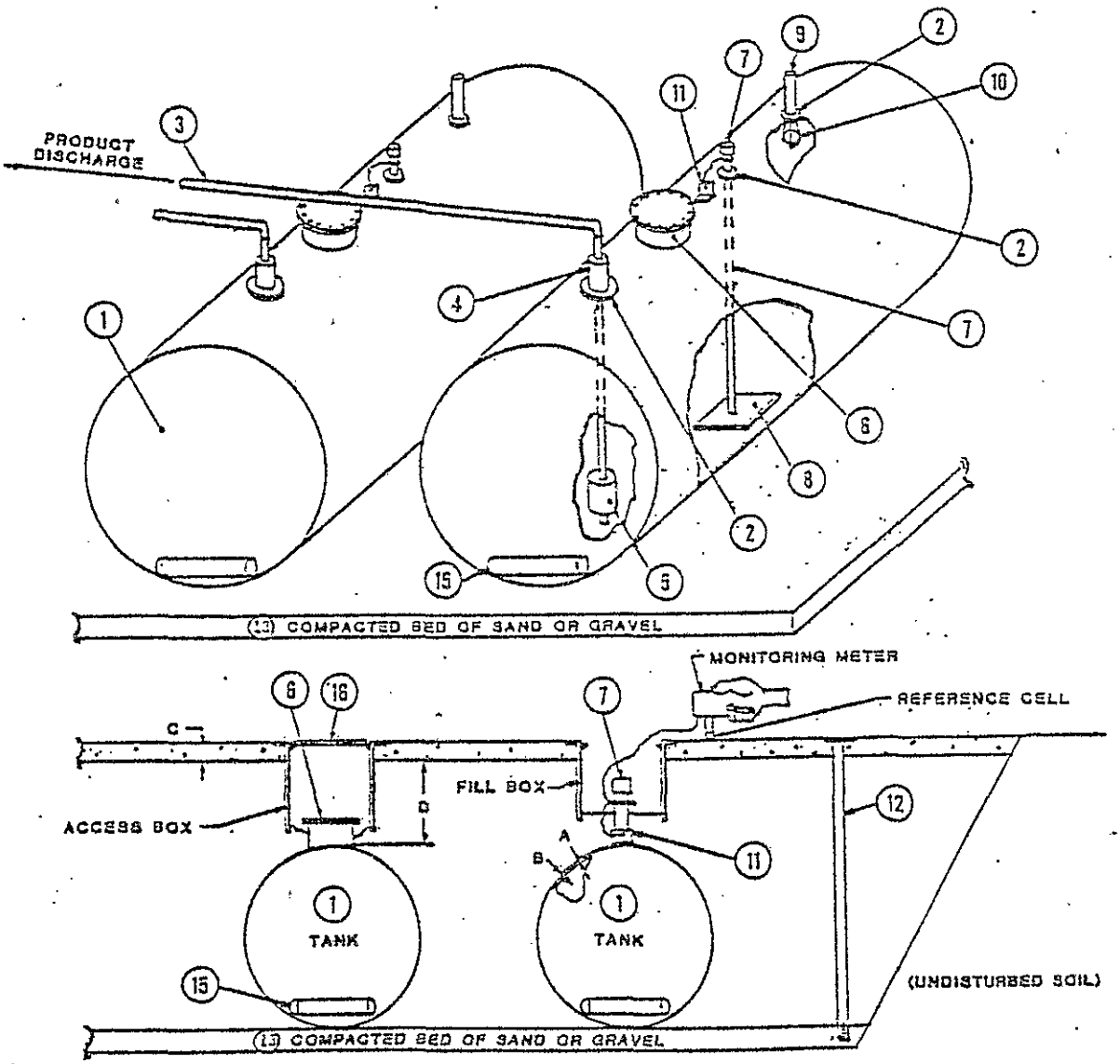
UL Standard 58 requires that the length of the tank not be greater than six times the diameter. Table 1-1 shows the minimum thickness required by

FIGURE 1-1

PRE-ENGINEERED UNDERGROUND STORAGE TANK

This figure shows the components typically found in a pre-engineered (sacrificial anode cathodic protection) underground storage tank installation. These components include the following:

(1) cathodically-protected, epoxy coated steel tank; (2) dielectric bushings providing electrical insulation between tank and all connecting lines; (3) product delivery line; (4) leak detector on product delivery line; (5) submerged product delivery pump; (6) access manway; (7) fill pipe; (8) striker plate below fill pipe; (9) vent line; (10) float vent valve in vent line for over-fill protection; (11) Cathodic Monitoring System; (12) leak observation well inside the excavation; (13) compacted bed of sand or gravel (same material as backfill); (14) sand or gravel backfill; (15) sacrificial anodes; (16) waterproof, tamper-proof lids on fill lines and manways.



Notes:

A. Inner wall ½" steel
B. Coal-tar epoxy set to rigid manufacturers specifications
C. 8" minimum thickness
D. 24" minimum distance

Underwriters' Laboratory for tanks up to 50,000 gallons in capacity. Note that for small tanks (below 1,100 gallons in capacity), UL allows the use of galvanized steel for cathodic protection. UL indicates that such tanks may have shell thickness as thin as 10-14 mils. Although these tanks are structurally satisfactory and acceptable for aboveground use, the Department recommends that small tanks of these designs not be used underground. The zinc coating of galvanized steel and the light weight steel shell do not provide the long-term protection and corrosion allowances that are necessary for unmonitored small underground tanks. The Department recommends that the shell of any underground steel tank have a minimum thickness of at least 7 gauge (0.18 inch), with a ¼ inch tank shell (if available) being preferable. The extra shell thickness provides the corrosion allowances and longer life expectancies which are comparable to those of a larger tank.

The joints of the tank may be butt welded or lap welded, according to UL or ASME standards, although double welded butt joints, as discussed earlier, are stronger than lap joints and less susceptible to corrosion.

2. Cathodic Protection

Cathodic protection is used to minimize corrosion of the tank which is exposed to corrosive conditions. This protection is achieved by applying an electric current to the structure which is greater in strength and opposite in direction to the flow of current which causes corrosion. For example, if steel is exposed to corrosive soil, it would normally emit a current and corrode over time. When a sacrificial anode is connected to the tank electrically (via wires), it produces a stronger current that flows to the tank and the anode, not the tank, corrodes.

Corrosion protection should be provided by using either an impressed current system which incorporates DC current and an energized anode to deliver current to the tank, or a galvanic anode which relies on the electromotive difference between a sacrificial metal and the tank to provide a protective flow of current to the tank. Regardless of which method is used, a negative voltage of at least -.85 volts, as measured by a copper-copper sulfate reference half cell, is usually sufficient to provide corrosion protection.

TABLE 1-1

Thickness Of Steel Tanks
Recommended By Underwriters Laboratory

Capacity		Maximum* Diameter		Manufacturers Standard or Galvanized Sheet	Nominal Thickness			
					Uncoated		Galvanized**	
U.S. Gallons	dm^3	Inches	m	Gauge No.	Inches	mm	Inches	mm
Up to 285	Up to 1078	42	1.07	14 **	0.075	1.91	0.079	2.01
286 to 560	1082 to 2120	48	1.22	12 **	0.105	2.67	0.108	2.74
561 to 1100	2124 to 4164	64	1.63	10 **	0.135	3.43	0.138	3.51
1101 to 4000	4168 to 15142	84	2.13	7	0.179	4.55		
4001 to 12,000	15145 to 45425	126	3.20	¼ inch	0.250	6.35		
12,001 to 20,000	45429 to 75708	144	3.66	5/16 inch	0.312	7.92		
20,001 to 50,000	75712 to 189270	144	3.66	3/8 inch	0.375	9.53		

Source:
This material is based on and taken, with permission, frdm Underwriters Laboratories Inc. Standard for Safety for Steel Underground Tanks for Flammable and Combustible Liquids, UL 58, Copyright 1976 (by Underwriters Laboratories Inc.), copies of which may be purchased from Underwriters Laboratories, Inc., Publication Stock, 333 Pfingsten Road, Northbrook, Illinois 60062.

Note:
UL shall not be responsible to anyone for the use of or reliance upon a UL Standard by anyone. UL shall not incur any obligation or liability for damages, including consequential damages, arising out of or in connection with the use, interpretation of, or reliance upon a UL Standard.

* Length of tank shall be not greater than six times the diameter.

** The use of galvanized steel and shell thicknesses less than 7 gauge are not recommended by the Department of Environmental Conservation.

Impressed Current Systems. Impressed current cathodic protection systems require the use of a rectifier, which converts AC current to DC current, and a high silicon cast iron sacrificial anode (or graphite anode, if the soil environment is saline). Although the impressed current system is effective in almost any corrosive environment, such systems are expensive and have been known to disrupt nearby communication circuits. Because of their complexity, they should only be installed by a qualified corrosion engineer.

Galvanic Systems. Pre-engineered galvanic cathodic protection systems provide an economical and effective means of corrosion protection. The best of these systems use high potential magnesium anodes which provide a strong natural flow of protective current to the tank. Table 1-2 shows the weight and number of magnesium anodes to be used for various size tanks. These anodes should be carefully installed on the outside of the tank and electrically connected with a lead wire to the tank, as shown in Figures 1-2 and 1-3.

If a tank which relies on galvanic protection is used, the flow of electrical current from the anode to the tank should be monitored at least semi-annually. Systems for continuous or intermittent monitoring are available commercially.

Galvanic protection for internal surfaces of the tank may be provided by installing zinc strips which act as sacrificial anodes in a manner similar to the exterior magnesium anodes. The Department recommends internal cathodic protection, particularly for petroleum products that contain ethanol or methanol.

As with impressed current systems, a galvanic system should only be designed by a qualified corrosion engineer.

3. Coating

Active cathodic protection as discussed above should be supplemented by the passive protection of a tough exterior coating.

TABLE 1-2

Sacrificial Anode Requirements

Surface Tank Area Sq. Ft.	Number of Anodes Required: Each Head	Shell Anodes	Total Tank	Anode Weight, pounds: Each Anode	Total Per Tank	Dow Galvomag Anode Type (1
50-175	1		2	9	18	9D3
175-350	1		2	17	34	17D3
350-515	1		2	24	48	24D4
515-780	1		2	32	64	32D5
780-1000	1		2	48	96	48D5
1000-1280	2		4	32	128	32D5
1280-1600(2)	1		2	32	64	32D5
	1		2	48	96 160	48D5
1600-1900(2)	2		4	48	192	48D5
1900-2200(2)	1	2	4	32	128	32D5
	1		2	48	96 224	48D5
2200-2500(2)	1		2	32	64	32D5
	1	2	4	48	192 256	48D5
2500-2875(2)	2	2	6	48	288	48D5

Notes

1. If size recommended is not available, use next larger size.

2. If tank length is over 35 feet, place anodes on heads and shell. Design assumes that tank of this size will have to be loaded, unloaded, and otherwise handles with a crane so that no rolling of tank will be necessary.

FIGURE 1-2

ANODE INSTALLATION

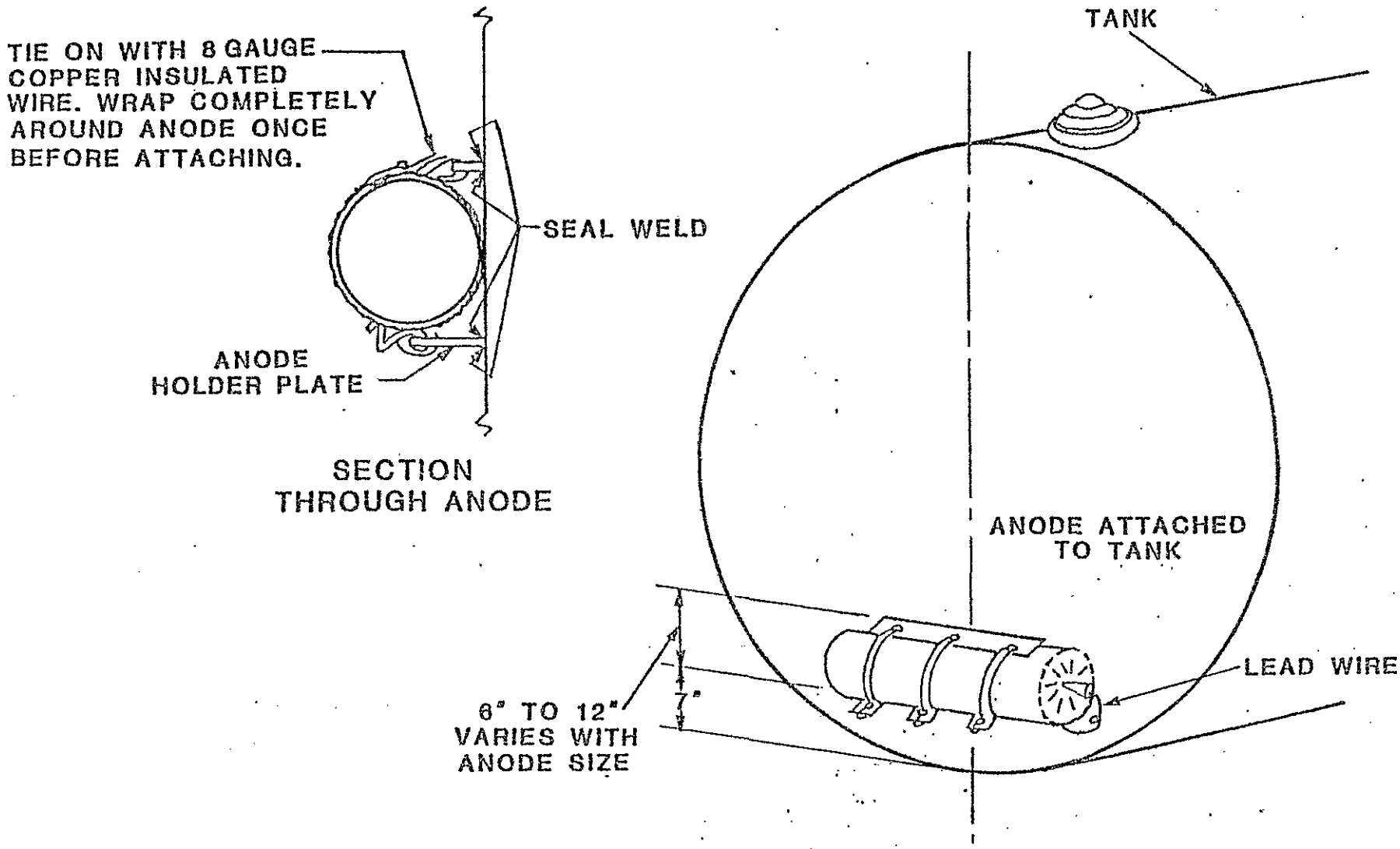
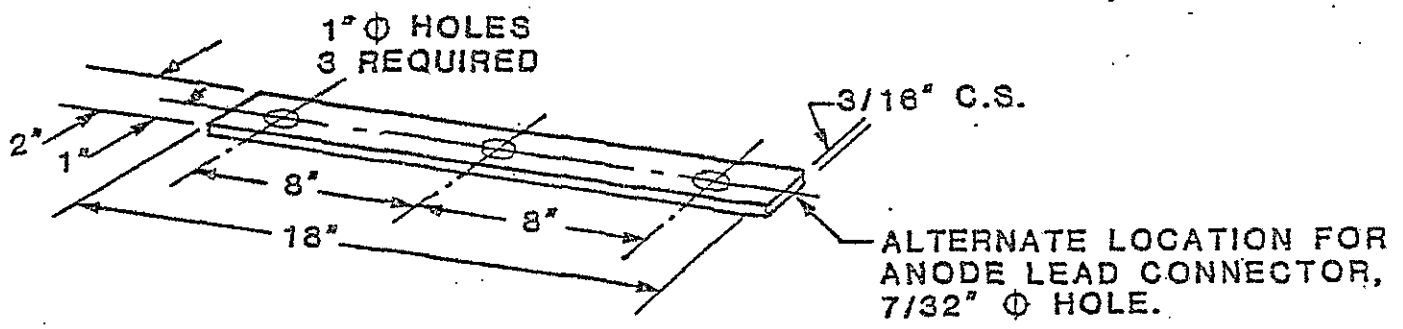
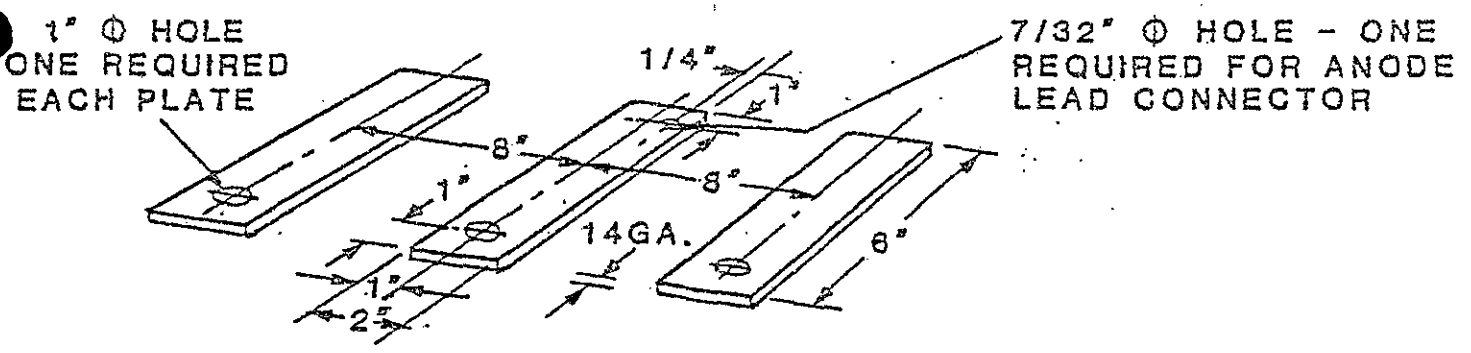


FIGURE 1-3

ANODE HOLDER DETAILS AND INSTALLATION



TOP ANODE HOLDER PLATE
ONE REQUIRED ON EACH END



BOTTOM ANODE HOLDER PLATES
REQUIRED ON EACH END

Notes:

(1) The hole locations and size of top anode holder plates and the number of bottom anode holder plates may be changed (but not the basic design or attachment) to use 2 bottom plates for 9 lb., 3 for 17, 24 and 32 lb. and 4 for 48 lb. anodes.

(2) For shell mounted anodes use two top anode holder plates and no bottom anode holder plates.

(3) Where two anodes are required for each head, two top anode holder plates are to be spaced above one set of bottom anode holder plates. Bottom anode shall be installed in the usual manner; top anode shall be installed in a manner similar to shell anodes.

The coating should be factory applied to the entire exterior surface of the tank after anode holders and all bushings and plugs have been installed and, immediately after sandblasting. Sandblasting should be completed in accordance with the Steel Structure Painting Council Specification No. 6, Commerical Blast Cleaning. The coating material should be a coal tar epoxy coating, equal to one of the following:

- Tarset Standard No. 7001, produced by Porter Coatings, Division of Porter Paint Company
- Plas-Chem Chem-Master 2203, produced by Plas-Chem Coatings, Eagle Picher Industries, Inc.
- Koppers 300M, producted by Koppers, Inc.
- Corrocote II (Instant Setting) by Madison Chemical Industries, Inc.

The thickness of the coating on the tank shell should be 13 mils wet (10 mils minimum when dry); the thickness of the coating on the tank head and within 48 inches of shell-mounted anodes should be 22 mils wet (15 mils minimum when dry). For proper curing, the coating must be applied at temperatures greater than 50°F. Heat may be introduced into the tank to ensure proper coating at low ambient temperatures. Moisture must not touch the tank exterior or coating until the coating is thoroughly cured.

The finished coating should be inspected by the fabricator using a non-destructive magnetic film gauge tester. However, it is recommended that a wet film thickness gauge be used frequently while applying the coating to ensure proper application thickness.

Coverage of the anode holders and other tank appurtenances should be carefully checked to insure that the coating has the proper film thickness on all surfaces and edges.

The coated tank should be handled with care to minimize damage to the coating during loading, unloading, or installation activities. Padding between trucks and tanks, and on chains or wire rope, is recommended. The repair of any coating surface which is damaged by mishandling should be in

strict accord with manufacturers' recommendations and should conform to the above specifications for minimum thickness.

Internal corrosion can be mitigated by using a coating on the inside of the tank in lieu of the sacrificial zinc anodes which were recommended above. This provides an extra measure of protection which is recommended by the Department for products containing ethanol or methanol.

4. Electrical Isolation

All cathodically protected tanks should be equipped with fittings for electrically insulating the tank from piping. These fittings may be nylon bushings, bolted flanges with companion nylon flanges, commercially available flange insulation kits, or an equivalent system.

If nylon bushings are used, they should be properly tightened by the manufacturer so that they will not have to be removed or further tightened in the field. The nylon material must be able to withstand exposure to the material to be stored without swelling and/or degradation. If there is any question as to the compatibility of the nylon bushings with the stored material, bushings made of a compatible material or flanged openings with chemically compatible gaskets should be used. An alternate method of electrically insulating the tank using bolted flanges and nylon companion flanges is shown in Figure 1-4.

Another method of electrically isolating openings is to use commercially available flange insulation kits. As shown in Figure 1-5, these kits consist of a gasket, sleeves for bolts, and washers; all of these are composed of dielectric material. Flange insulation must be shipped installed in the tank with suitable threaded companion flanges so the flange isolation will not be disturbed in the field. It is recommended that the installation of flange insulation kits be such that the bolts will be grounded to the tank and, therefore, cathodically protected, but isolated from the companion flange.

FIGURE 1-4

ELECTRICAL ISOLATION USING A NYLON COMPANION FLANGE (WITH NYLON OF THE SAME SPECIFICATION AS THE BUSHING).

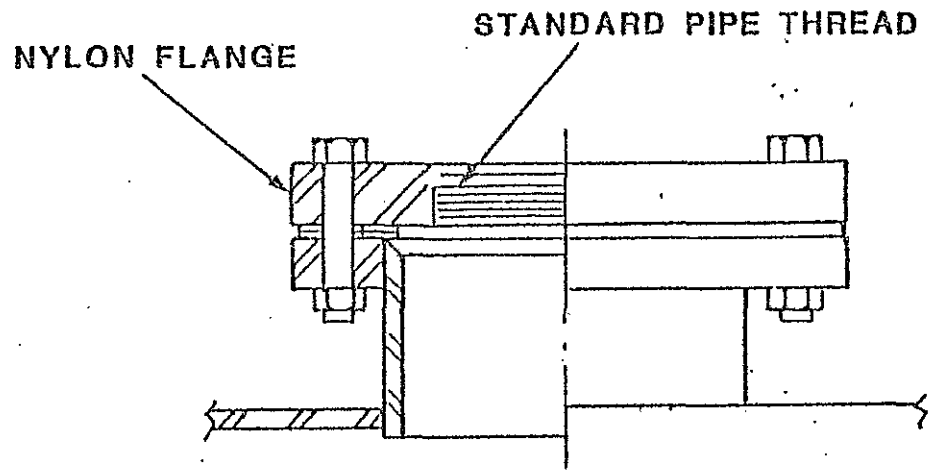
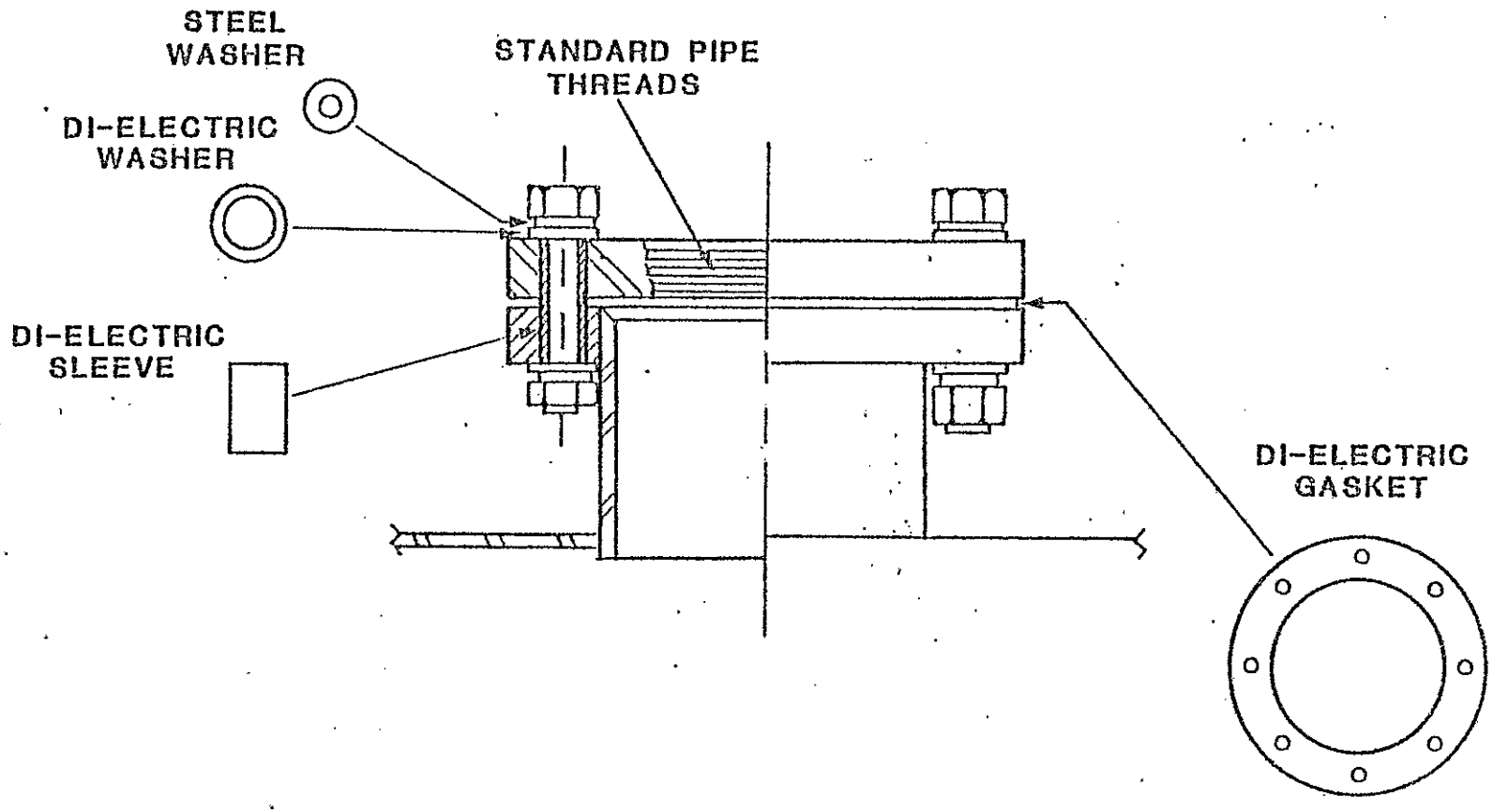


FIGURE 1-5

ELECTRICAL ISOLATION USING A FLANGE INSULATION KIT



D. Design Recommendations - Fiberglass-Reinforced Plastic Tanks

Fiberglass-reinforced plastic (FRP) tanks are manufactured by a highly specialized industry. These tanks must be designed and fabricated by engineers with expertise in the strength of fiberglass materials, material compatibility, and underground tank installation. For this reason, only FRP tanks constructed by a reputable manufacturer should be used.

The following recommendations cover spherical or horizontal cylindrical atmospheric-type tanks of fiberglass-reinforced plastic construction which are intended for underground storage of petroleum.

1. FRP Tank Design

FRP tanks should be UL listed and designed in accordance with Underwriters' Laboratory Standard 1316, Standard for Glass-Fiber-Reinforced Plastic Underground Storage Tanks [3], or Underwriters' Laboratory of Canada, Standard ULC-S615-1977, Standard for Reinforced Plastic Underground Tanks for Petroleum Products [4]. These standards set forth requirements for structural strength, criteria for chemical compatibility of tank material with product stored, and surrounding soil, and test methods for quality control. Usually the wall thickness of an underground FRP tank is 0.22 inches, although a thicker wall may be necessary for large tanks or tanks storing products with a specific gravity greater than 1.5.

Some FRP tanks have incorporated reinforcing ribs in their design. These ribs provide the additional structural strength that is necessary for tank integrity in those cases. These ribs are designed to withstand both the internal stresses from the stored product, and the external backfill, hydrostatic and buoyancy forces. The ribs are also often designed to accept the hold down straps used to ballast the tank when flotation is a possibility.

An FRP tank should be equipped with lifting lugs that are attached to the tank or can be attached to a fitting on the tank. Tanks with a capacity of 1,000 gallons or less may be equipped with only one lifting lug. The precise method of handling and lifting the tank should be prescribed by the

manufacturer and these instructions should be carefully adhered to by the installer.

2. Compatibility of Materials

Many resins are available for use in FRP tanks, and each has its own characteristics of performance. Some resins dissolve, soften, or become brittle in acidic or saline soil environments. Others will lose structural strength when exposed to certain chemicals. Gasahol (a gasoline-ethanol blend) has been known to cause FRP tank failure particularly at mixtures of 15 to 20% ethanol. Methanol and other gasoline additives are known to be incompatible with certain resins. Manufacturers of tanks carrying a UL label are required to perform immersion tests to prove material durability and chemical compatibility. Underwriters' Laboratories in turn certifies only that the tank is compatible with certain chemicals.

In selecting an FRP tank, it is therefore of utmost importance that the tank manufacturer be notified of the exact chemical composition of the product to be stored. The manufacturer should then bear the responsibility for selecting the proper tank and providing the owner with a written assurance of chemical compatibility. Under no circumstances should products be switched from tank to tank unless the manufacturer provides assurances that the new product is compatible with the tank.

Because the resins used for FRP construction have changed over time, it is imprudent to reuse a FRP tank of unknown origin and age unless the prior use of the tank is known and the tank manufacturer is consulted on the compatibility of the tank resin with the new product to be stored.

3. Installation of FRP Tanks

Fiberglass tanks have more exacting handling requirements than do steel tanks and they acquire most of their support strength from the backfill. For this reason, following the manufacturer's installation instructions and having the manufacturer's representative present to inspect the installation is of critical importance. Chapter 3 discusses in detail the recommended practices for installing FRP tanks.

E. Steel Tanks Which Are Clad With Fiberglass-Reinforced Plastic

Steel tanks which are clad with fiberglass (often referred to as composite tanks) consist of a basic steel tank as prescribed under Section C of this Chapter, which has an outer layer of fiberglass resin reinforcement with a thickness of 100 mils bonded to the steel shell. Underwriters' Laboratories has a specific listing for composite tanks, but no official standard has been promulgated. Specific designs are considered on a case-by-case basis. These tanks, when fabricated by a reputable manufacturer, provide a storage vessel which is both strong and resistant to external corrosion. They may also be custom manufactured with an internal fiberglass layer to provide protection from internal corrosion, or constructed in a two wall design.

1. Electrical Insulation

As with any steel tank, the composite tank should have nonconductive bushings, gaskets or washers at all piping connections to assure that the tank is electrically insulated from the piping system.

2. Coating

The fiberglass coating must be applied under strict quality control. The tank must be sandblasted free of rust and scale using the Steel Structures Painting Council specifications for commercial blast cleaning, SSPC-SP-6. Following sandblasting and vacuuming, the coating should be immediately applied to the surface under moisture-free conditions.

After curing, the coating should be inspected for air pockets, blisters, pinholes and electrostatically tested with 10,000 volts for coating short circuits.

The coating must have bonding qualities and a coefficient of thermal expansion which are compatible with steel so that stress due to temperature changes will not be detrimental to the soundness of the coating and the permanent bond between the coating and the steel. The coating must be of

sufficient density and strength to form a hard impermeable shell which will not crack, wick, wear, soften or separate. It must also be capable of containing the product under normal service conditions in the event that the steel wall should leak.

As with FRP tank designs, the resins used in the coating of a composite tank should be noncorrosive in underground soil environments and compatible with petroleum, petroleum additives, and petroleum derivative liquids.

F. Double-Walled Tanks

Tanks of double-walled design with continuous monitoring of the annular (interstitial) space provide the best overall protection against leakage. Because monitoring of tank integrity and secondary containment are an inherent and intergral features of their design, double-walled tanks may be more economical than single-walled tanks with a monitoring well and containment liner installed separately in the excavation.

> Double-walled tanks provide the best protection against leaks. The Department recommends that these types of tanks be used on all new installations.

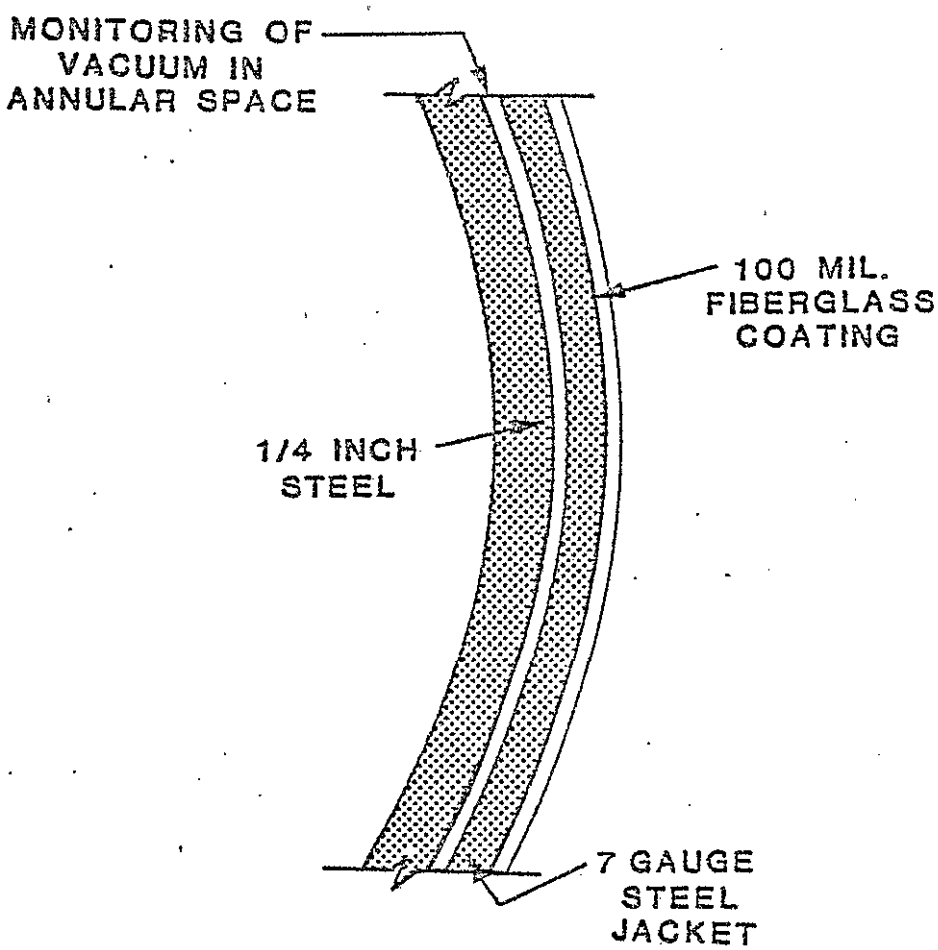
Double-walled tanks should have an outer jacket which covers at least the bottom two-thirds (2/3) of the tank. The jacket should cover all straight and girth seams of the inner wall. There should be no penetrations of any kind through the jacket to the tank except the top entry fittings required for monitoring the interstitial space. Figure 1-6 details the construction of a double-walled tank.

The double-walled tank is most effectively monitored by applying a pressure or vacuum to the interstitial space and checking for pressure of vacuum loss.

A double-walled tank should incorporate all of the recommended practices for single walled tanks identified in Sections B through F of this

FIGURE 1-6

DOUBLE-WALLED STEEL TANK WITH BONDED FIBERGLASS COATING



CROSS SECTIONAL VIEW
(DRAWN TO APPROXIMATE SCALE)

chapter. If a double-walled cathodically protected tank is used, it should consist of a standard tank with an outer (second) wall made of steel with a minimum thickness of 7 gauge (0.18 inch). This outer wall should be covered by an epoxy coating or equivalent as discussed in Section C. If a double-walled fiberglass tank is used, all requirements for structural strength discussed in Section D should be addressed.

A double-walled steel/fiberglass composite tank should consist of a standard tank with a 7 gauge outer jacket covered by the fiberglass coating discussed in Section E.

In the case of all double-walled tanks of steel construction, provisions should be made to eliminate potentially corrosive water vapor from the annular (interstitial) space of the tank.

Double-walled tanks provide the following advantages:

- The highest level of containment technology.
- Product monitoring of the interstitial space to detect leaks.
- Secondary containment of the stored product, and prevention of its release into the environment.
- Tightness testing is usually not necessary in the event that groundwater contamination from an unknown source is discovered.
- They can be used in environmentally sensitive areas.
- They lead to lower environmental risks and inherently lower insurance costs.

References

1. Underwriters Laboratories, Inc., Steel Underground Tanks for Flammable and Combustible Liquids, UL 58, Underwriters' Laborartories, Inc., 333 Pfingsten Road, Northbrook, Illinois, October, 1976.

2. American Society of Mechanical Engineers, ASME Pressure Vessel Code, Section VIII, Division 1, Boiler and Pressure Vessel Code, American Society of Mechanical Engineers, 345 East 47th Street, New York, NY 10017.

3. Underwriters' Laboratories, Inc., Standard for Glass-Fiber-Reinforced Plastic Underground Storage Tanks, UL 1316, Underwriters' Laboratories, Inc., 333 Pfingsten Road, Northbrook, Illinois 60062, _____ 19__.

4. Underwriters' Laboratories of Canada, Inc., Standard for Reinforced Plastics Underground Tanks for Petroleum Storage, ULC-S615-1977, Underwriters' Laboratories of Canada, Inc., 7 Crouse Road, Scarborough, Ontario, March, 1977.

5. New York State Department of Environmental Conservation, Technology for the Storage of Hazardous Liquids, A State-of-the-Art Review, New York State Department of Environmental Conservation, 50 Wolf Road, Albany, NY 12233, January, 1983.

CHAPTER 2:

PIPE, FITTINGS, AND PUMPING SYSTEMS

A. Introduction

Piping and pumping systems perform the function of delivering stored product from underground storage tanks to aboveground dispensers without leakage. Figure 2-1 illustrates piping and pumping systems which are typical of a fuel service station. This chapter will briefly discuss the elements of piping and pumping systems and recommend specific components.

B. Pipe Materials

> New underground pipes at a storage facility should always be protected against corrosion. The two most common materials that meet this criteria are fiberglass-reinforced plastic and cathodically-protected galvanized steel pipe.

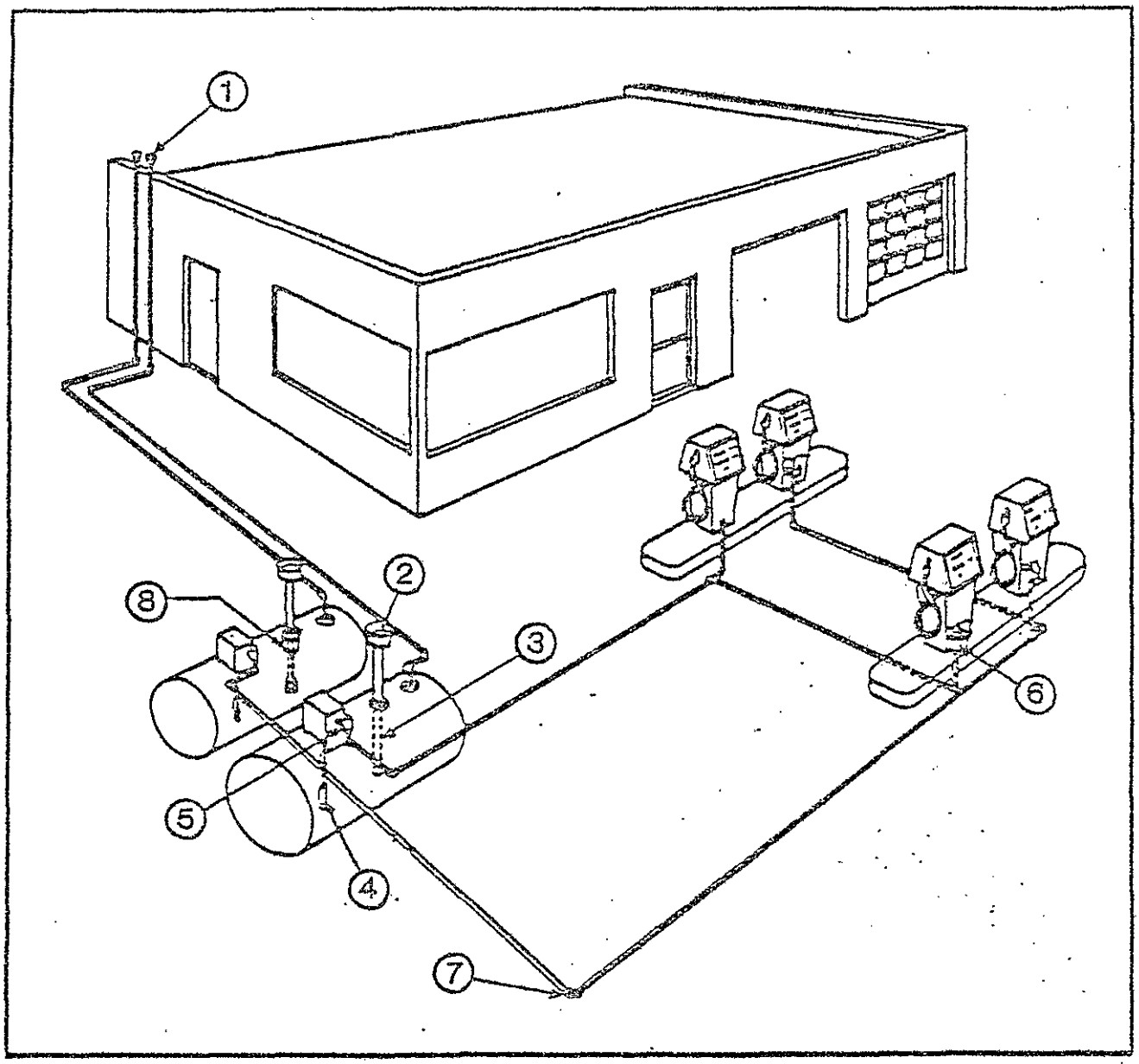
Piping failure is a significant cause of underground leakage. According to a leak survey conducted by the American Petroleum Institute, piping failure accounted for fully 1/3 of all reported leaks at underground storage facilities [1]. The principle causes of piping failures are as follows:

- Corrosion.
- Settlement of backfill.
- Frost heave.
- Traffic loadings on poorly protected piping.
- Stresses resulting from changes in temperature.

Some of the general considerations associated with the design of piping systems are highlighted in Table 2-1. The principle remedies for these problems are corrosion protection, proper design by professional engineers, and installation by experienced and qualified installers.

FIGURE 2-1

ELEMENTS OF AN UNDERGROUND PIPING SYSTEM



A TYPICAL PIPING SYSTEM AT AN UNDERGROUND STORAGE FACILITY, SHOWING THE FOLLOWING ITEMS:

1. STORAGE TANK VENT
2. TANK FILL CAP AND DROP TUBE ADAPTER
3. TANK DROP TUBE
4. SUBMERGED TRANSFER PUMP
5. PIPELINE LEAK DETECTOR
6. EMERGENCY SHUTOFF VALVE
7. SWING JOINT AT A CHANGE OF DIRECTION
8. EXTRACTOR ASSEMBLY (FOOT VALVE)

Table 2-1

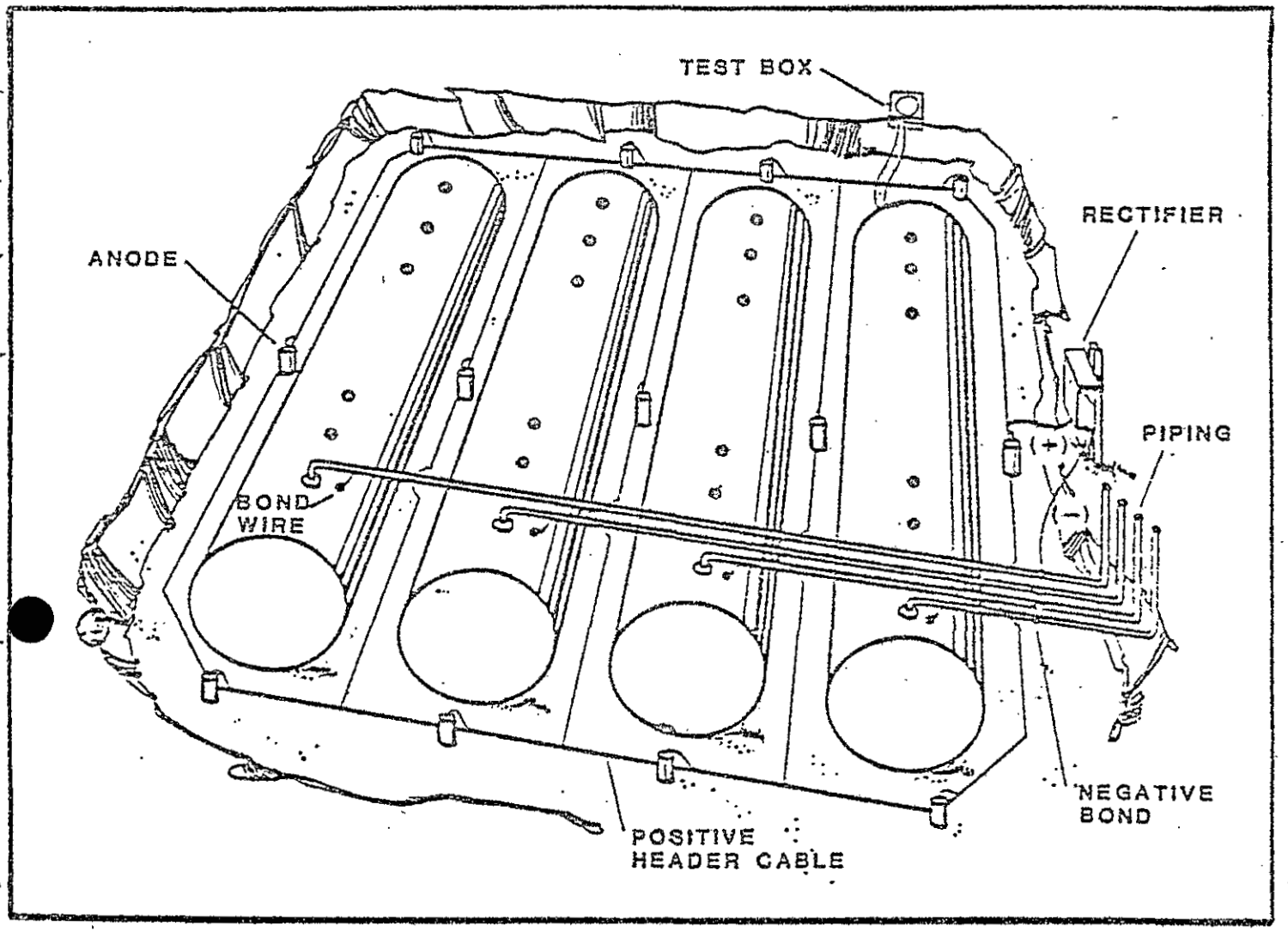
Considerations in Piping System Design

The following are some general considerations to be evaluated when selecting and applying materials in piping:

- The corrosive characteristics of the material to be transported, and the ability of the piping system components to withstand that corrosion.
- The characteristics of the external atmosphere (soil, water, etc.) to which the piping system components are exposed.
- Force loadings due to dynamic effects (fluid flow) and weight considerations.
- The susceptibility of the piping material to crevice corrosion in threaded joints, in socket welded joints, and in other stagnant, confined areas.
- The possibility of adverse electrolytic effects if the metal is subject to contact with a dissimilar metal, including older metals of the same type.
- The compatibility of lubricants or sealants used on threads with the fluid handled.
- The suitability of packing, seals, and O-rings for the fluid service, including possible effects of or on the fluid handled.
- The compatibility of materials such as cements, solvents, solders, and brazing with the fluid being transported.

FIGURE 2-3

AN IMPRESSED CURRENT CATHODIC PROTECTION SYSTEM CONFIGURATION



SOURCE: Suggested Ways to Meet Corrosion Protection Codes for Underground Tanks and Piping; The Hinchman Company, Detroit, MI.

There are several types of piping materials available which will provide protection against leakage. The materials recommended for use by the Department include cathodically protected steel, fiberglass-reinforced plastic (FRP), and stainless steel. Double-walled pipe is also recognized by the Department as a reliable means of conveying liquids.

1. Cathodically Protected Steel Pipe

In instances where steel is the preferred piping material, the Department recommends the use of cathodically protected, galvanized steel pipe. Steel pipe alone has excellent strength, but is susceptible to corrosion. Zinc galvanizing gives some corrosion protection to the pipe, but this protective coating is often scraped off or scratched during handling, pipefitting, and installation operations. Therefore, galvanizing alone does not provide adequate corrosion protection.

To provide adequate protection from corrosive elements, either galvanic or impressed current cathodic protection should be used. The galvanic cathodic protection method employs sacrificial anodes made of magnesium or zinc. These anodes are installed in electrical contact with the piping via bonding wires. The corrosion of these anodes creates electrolytic cells, generating a weak electric current that protects the pipe from corrosion. Figure 2-2 shows a layout of a galvanic, or sacrifical anode, cathodic protection system.

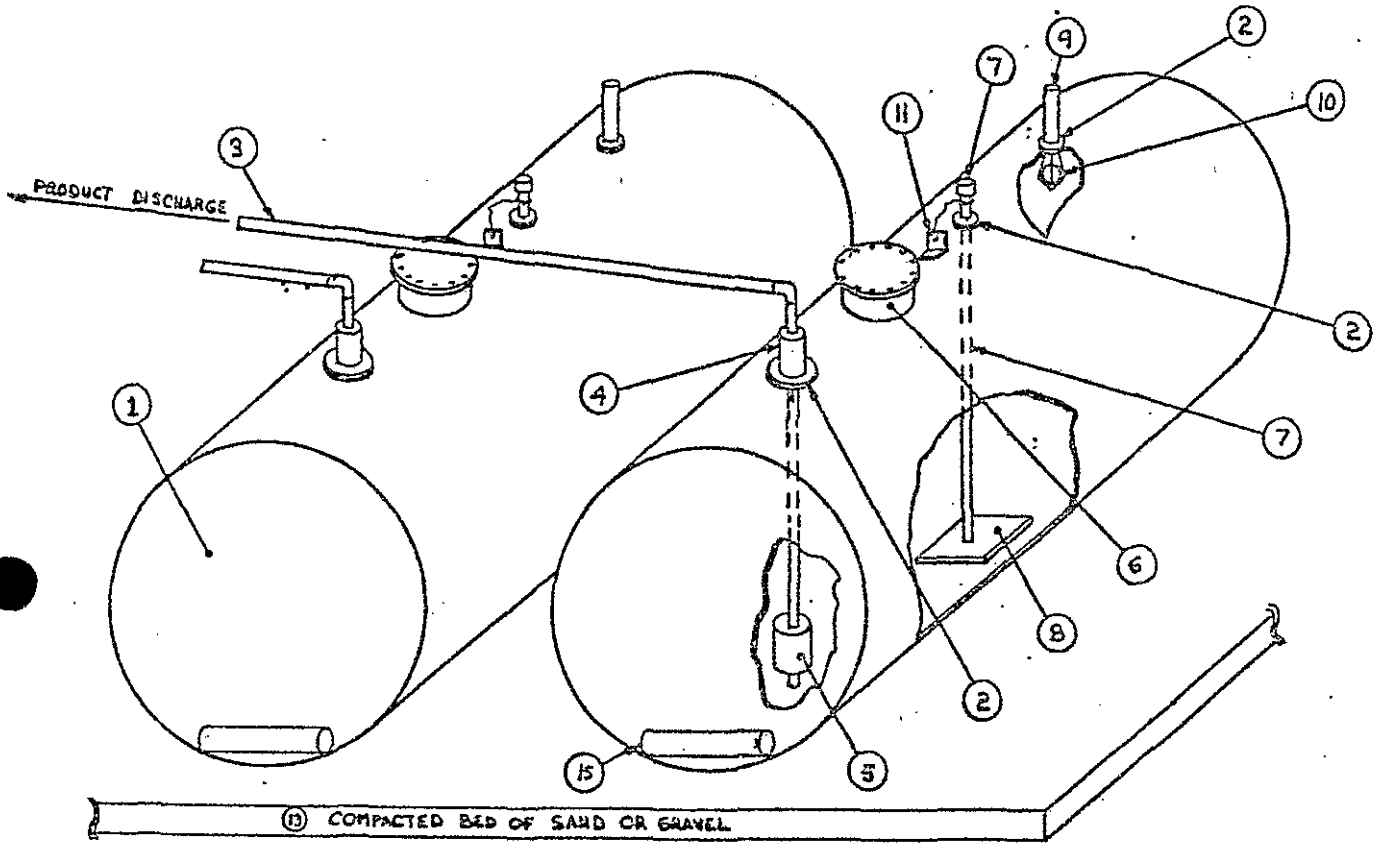
The impressed current cathodic protection method employs D.C. current provided from an external source. This current is passed through the system by the use of non-sacrificial anodes composed of materials such as carbon, non-corrodible alloys, or platinum. These anodes are buried in the ground (to protect underground piping), or otherwise suspended in the electrolyte, and electrically connected to the positive terminal of the external power supply. The piping is then connected to the negative side of that power supply. The resulting flow of current prevents corrosion of the pipe. The layout of a typical impressed current cathodic protection system is shown in Figure 2-3.

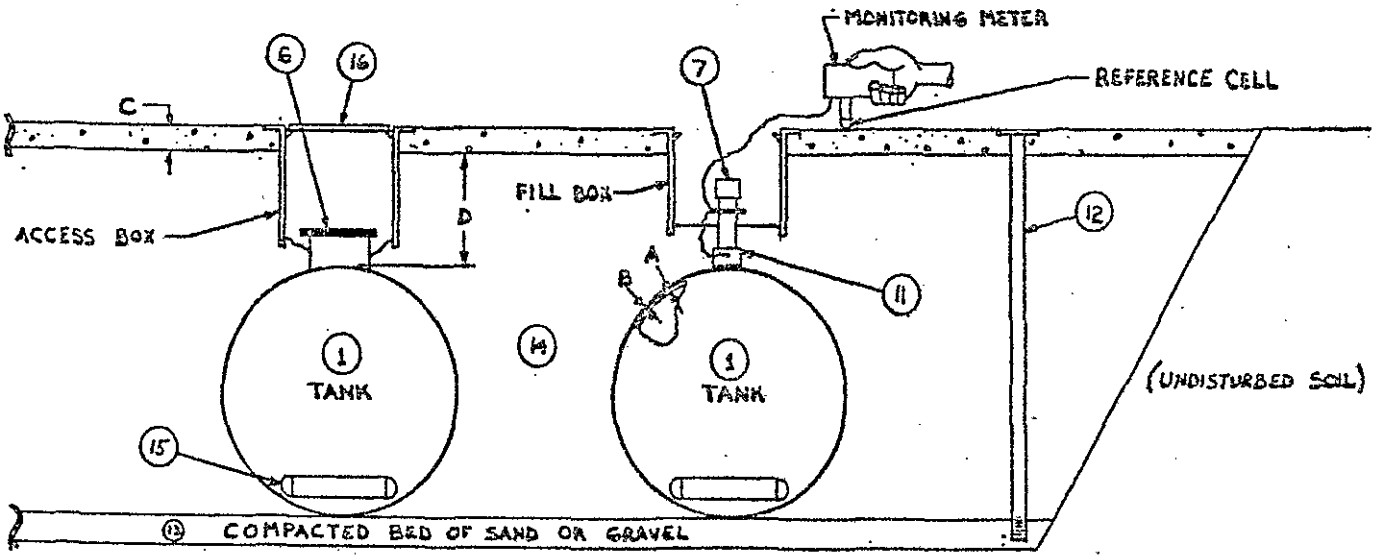
Figure 2-2

Pre-engineered Underground Storage Tank

This figure shows the components typically found in a pre-engineered (sacrificial anode cathodic protection) underground storage tank installation. These components include the following:

(1) cathodically-protected, epoxy coated steel tank; (2) dielectric bushings providing electrical insulation between tank and all connecting lines; (3) product delivery line; (4) leak detector on product delivery line; (5) submerged product delivery pump; (6) access manway; (7) fill pipe; (8) striker plate below fill pipe; (9) vent line; (10) float vent valve in vent line for over-fill protection; (11) Cathodic Monitoring System; (12) leak observation well inside the excavation; (13) compacted bed of sand or gravel (same material as backfill); (14) sand or gravel backfill; (15) sacrificial anodes; (16) waterproof, tamper-proof lids on fill lines and manways.





NOTES

A. INNER WALL ¼" STEEL
B. COAL-TAR EPOXY SET TO RIGID MANUFACTURERS SPECIFICATIONS
C. 8" MINIMUM THICKNESS
D. 24" MINIMUM DISTANCE

In either type of cathodic protection system, the determination of the appropriate size, location, and spacing of the anodes requires engineering expertise; such expertise and guidance are available from organizations such as the National Association of Corrosion Engineers.

use old IP

As an additional method of corrosion protection, some steel piping systems have a corrosion-resistant coating composed of a material such as coal-tar epoxy. Such a coating may be brushed or sprayed on, and has excellent hardness, durability, adhesion, and chemical resistance properties.

> In underground installations, it is important to remember that new steel pipe is anodic to old steel pipe. That is, if new steel pipe is connected to old steel pipe, the new pipe will corrode much faster than it would under normal circumstances.

Electrical isolation is also an important consideration in the use of steel piping. All such piping should be isolated from dissimilar metals to avoid accelerated corrosion. In addition, care should be taken to ensure that new steel piping is not installed in connection with or in close proximity to old steel structures such as storage tanks or piping. In such instances, the old steel acts as a dissimilar metal and, as highlighted in the inset above, acts to accelerate corrosion of the newer steel.

2. <u>Fiberglass-Reinforced Plastic Pipe</u>

FRP pipe has a distinct advantage over steel pipe in that it is inherently corrosion resistant, and thus provides excellent protection against leaks when installed correctly. It is also flexible enough to account for minor misalignment and earth movement. No swing joints are required except for very short pipe runs, or sharp turns. As a result, this material has found increasing acceptance for bulk storage applications in recent years.

However, FRP pipe has lower structural strength than steel pipe. It therefore requires fully-compacted bedding and extra caution in handling and

installation. The recommended installation practices for this material are addressed in Chapter 3, Section F of this report.

FRP pipe and steel pipe are now considered to have the same installed cost. The cost of the fiberglass material is much higher than the cost of steel, but this is counterbalanced by lower handling and pipefitting costs.

Underwriters Laboratories has a listing of FRP pipe which is approved for underground petroleum products service. This listing is particularly appropriate for service station applications, and should be consulted if one is considering the use of this piping material.

3. Stainless Steel Pipe

Stainless steel pipe is also suitable for underground use. It is well known for its corrosion resistance, and its industrial use is growing. The main drawback of stainless steel is its cost. Its installed cost is approximately three times that of galvanized steel or FRP pipe. However, the added expense may be warranted where highly hazardous liquids are stored, or in environmentally sensitive areas.

Schedule 10, Type 304 stainless steel is satisfactory in highly corrosive soil environments and is the most common kind of stainless steel pipe for service station-type, low pressure (20-40 psi) applications. Schedule 10 pipe has a thinner wall thickness than Schedule 40, but is of sufficient thickness for welded joints. Where screwed fittings must be used, a transition to Schedule 40 stainless pipe must be made.

Stainless steel pipe has the important advantages of being able to be installed without coatings or cathodic protection. However, it does require the same high quality bedding that the other materials require.

4. Double-Walled Pipe

For situations involving the piping of very hazardous or toxic liquids, or in instances where the environment would be severly impacted by leakage, double-walled piping is endorsed as an acceptable choice.

Figure 2-4 illustrates one type of double-walled pipe. The outer wall encloses the inner pipe, which is supported at regular intervals. This ensemble is contained by a bulkhead at the end of each segment. The interstitial space between the inner and outer walls is slightly pressurized with nitrogen. This pressure is monitored. A drop in pressure indicates leakage in the outer wall, while a rise in pressure indicates that there is leakage from the inner pipe. This manufacturer coats its products with coal tar epoxy or FRP in a manner similar to that described for tank coatings in Chapter 1.

At this time, the use of double-walled pipes for underground petroleum products piping is something of a rarity in New York. The Department makes no specific recommendations as to material selections or wall thicknesses. However, corrosion protection is still of paramount concern, and the manufacturer's recommendations on this subject should be closely followed.

C. Fittings

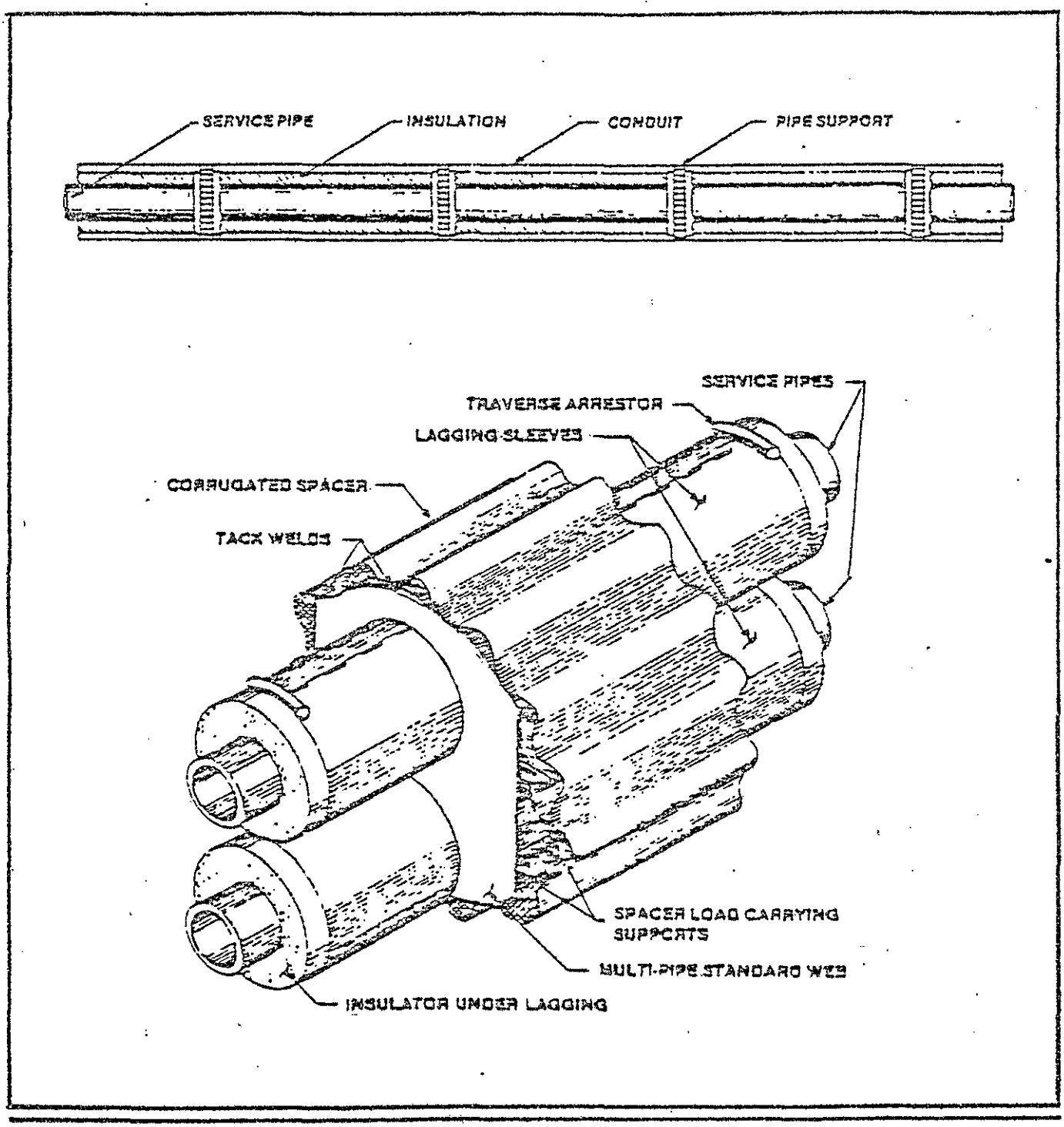
Connections between pipe lengths and at the tank are a frequent source of leaks. This section will describe fittings by material type since there are few fitting elements common to all types of pipe materials.

When pipe is screwed together, thread lubricant (pipe dope) is necessary to ensure that the pipe and fitting are mated to the proper depth, to ensure that a tight seal has been made, and to provide some degree of protection against the crevice corrosion that can occur at joints. Where threads are joined, the union of two metals with just slightly different properties results in a galvanic cell which will corrode if not protected. Thread lubricant gives limited cathodic protection to joints. The practice of welding galvanized pipe fittings is uncommon and is an unsuitable practice for underground piping systems.

In addition to the usual elbows and couplings, swing joints should be used at all changes in direction. This is necessary to relieve stress on the pipe from such causes as frost action, temperature changes, and traffic loadings. Expansion joints have been used in the past for this purpose, but

FIGURE 2-4

DOUBLE WALLED PIPE



SOURCE: PERMA-PIPE, DIVISION OF MIDWESCO, INC.

age and repeated flexing will eventually cause them to fail. Expansion joints should only be used aboveground.

Where metallic piping is attached to metallic storage tanks, dielectric bushings are highly recommended. This practice prevents any stray electrical currents picked up by the pipe from being conducted to the tanks. These bushings are normally made from either nylon or teflon.

FRP joints are glued, except where transitions to pumps and emergency shutoff valves are made. Chapter 3 of this report details the concerns of fiberglass joint make-up.

Relatively thin-walled (Schedule 10) stainless steel pipe may be used for low pressure piping. The joints for this Schedule 10 piping are welded. Welding stainless steel is an operation requiring considerable skill and attention to detail. Where screwed connection are required, such as for the pump connection, a transition to Schedule 40 pipe must be made. The Schedule 40 pipe has sufficient thickness to allow for pipe threads to be cut.

The joining methods for double-walled pipe include flanges, welding, and resin-gluing. The exact method depends on the specific type of pipe chosen. Manufacturers' specifications should be consulted for more detailed information.

D. Pumps

Under normal operation, pumps are not a major source of leakage. In fact, in some instances the pumping system of a bulk storage facility can be used to monitor the piping system for leaking. The following discussion will address the basic principles of the common types of pumping systems, and describe their utility as leak detection devices.

> The two most common types of pumping systems, remote pumping systems and suction pumping systems, are both acceptable for service at bulk storage facilities.

1. Remote Pumping Systems

Remote pumping systems employ submerged transfer pump (STPs) to transport the stored liquid from the tank to product dispensers. These pumps are typically centrifugal pumps which are rated intrinsically safe (explosion proof) and are immersed in the product storage tank. They pressurize the product delivery line, imparting a "positive head", or positive pressure, to the product to deliver it to aboveground and often remote dispensers.

Remote pumping systems are generally more energy-efficient than suction pumping systems. They also have an advantage in that one pump can service several dispensers, whereas suction pumps can only serve one dispenser per pump.

The drawback to this type of system is that a submerged transfer pump cannot differentiate between product dispensing and leakage in the delivery line. A leak or crack in a pipe may go undetected for some time because, unlike suction pumping systems, there is no interference with product flow. In addition, since the pipeline is operating under a positive head, losses tend to be rapid. For this reason, the Bulk Storage Code states that "... new facilities employing a remote pumping system must be equipped with a pipeline leak detector on the discharge side of the pump [3]." These leak detectors should be capable of interrupting product flow if there is a drop in pressure in the delivery line. Figure 2-5 describes the operation of a leak detector of this type.

> The Department recommends that all remote pumping systems in use be retrofitted with a pipeline leak detector to avoid large scale leaks. These detectors are inexpensive and, in most cases, easily installed.

2. Suction Pumping Systems

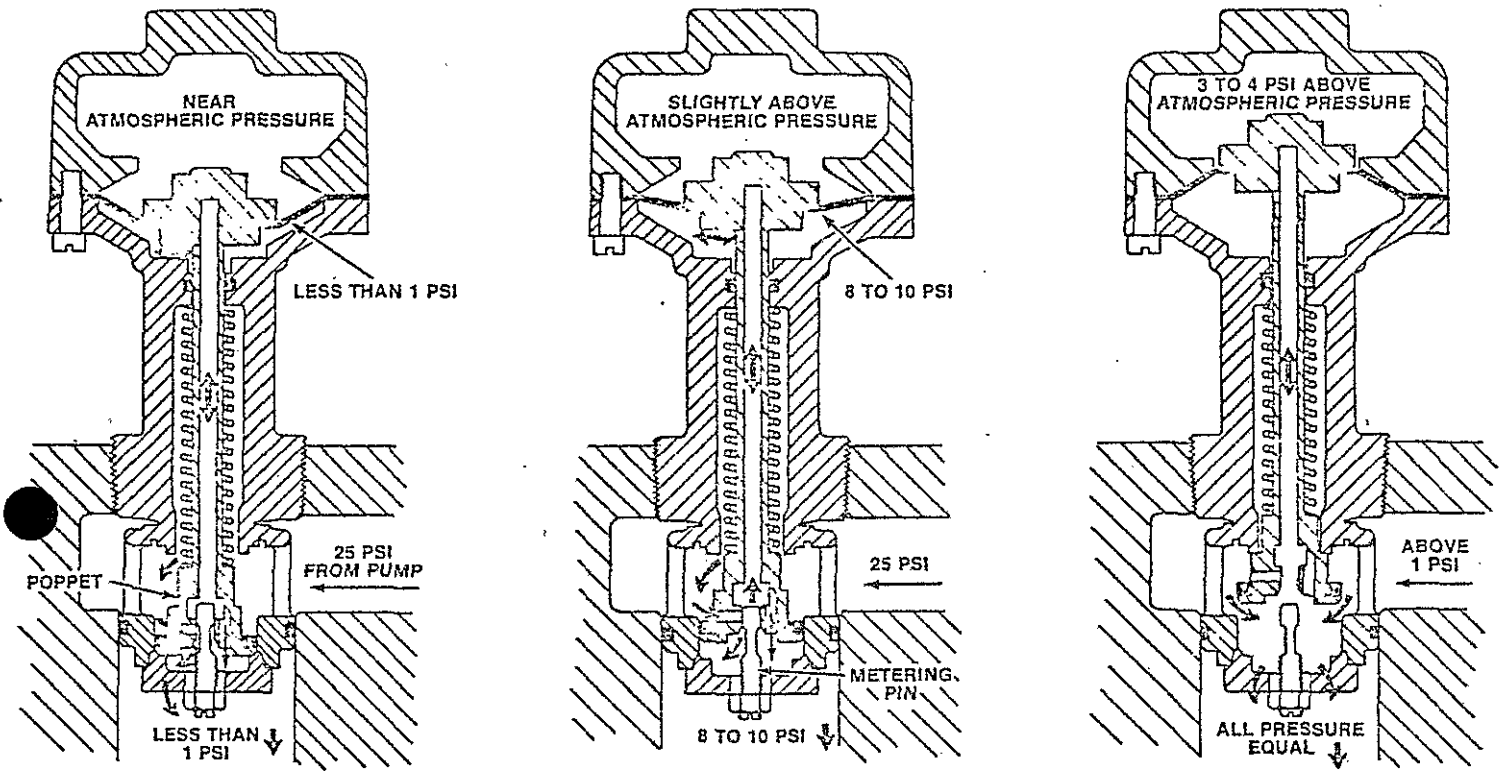
Suction pumping systems employ pumps located at the dispersion units to "suck" liquid out of the storage tanks. This type of pumping system has

Figure 2-5
Pipeline Leak Detector

The Red Jacket leak detector is a pressure sensing, diaphragm operated valve designed to indicate a leak in the piping between the leak detector and dispenser.

When the submerged pump is turned on, a controlled amount of product (three gallons per hour) is metered through the leak detector into the piping system. If a leak is present which equals or exceeds this amount, as much product escapes from the system as is metered in through the leak detector. Under this condition pressure cannot build up in the piping system. When a nozzle is opened a poppet in the leak detector moves to a position which restricts the flow to approximately 3 GPM. This is the indication to the operator that a leak is present.

If there are no leaks, pressure rapidly builds in the system forcing the leak detector to open to the full-flow position. In a system with no leaks it takes only two seconds for a complete test. No further line testing takes place until the line pressure drops below 1 PSI.



1. **THE "TRIP" OR RELAXED POSITION.** Under normal operating conditions, it is assumed that the lines are filled with gasoline which is essentially non-compressible. When the system pressure is less than 1 PSI, the diaphragm and poppet are in their "down" or "tripped" position. The position of the valve "poppet" is such as to allow approximately 3 GPM flow into the delivery line, through a bypass opening in the leak detector valve poppet, when the submersible pump starts. Since the system is full, pressure builds instantly and the poppet moves to the leak sensing position, assuming there is no leak present.
2. **LEAK SENSING POSITION.** As the pressure builds to approximately 8 to 10 PSI (Instantly), the diaphragm has moved the "poppet" to such a position as to almost stop the flow into the piping through the leak detector valve poppet. In this position, all the flow must then travel around the metering pin which limits it to approximately 3 GPH rate. If a simultaneous loss from the system equals or exceeds this amount, the line pressure will not build beyond this point and the valve will remain in the leak sensing position with the main flow blocked. If there is an attempt to dispense while the valve is in this position, the line pressure will drop, the diaphragm will respond, and the poppet will return to position 1 where approximately 3 GPM will flow to the dispensers. Leaks smaller than 3 GPH will be indicated by the Leak Detector taking longer than two seconds to open completely. If there is no leakage in the system, the small flow around the metering pin increases the line pressure to 10 PSI in approximately two seconds at which point the diaphragm will snap the poppet to position 3. This all takes place in less time than it takes the dealer to reset the dispenser, walk to the car, remove the gas tank cap, insert and open the nozzle.
3. **NON-LEAK POSITION.** This position allows full flow. The poppet will remain in this position as long as the system pressure remains above 1 PSI. At less than 1 PSI the "poppet" will return to position 1.

decreased in popularity in recent years as STPs have become more sophisticated.

From an environmental standpoint, suction pumps have a built-in safety check. If there is a break in the line and product leaks out, the pump will experience a loss of prime and will sputter and hesitate or not work at all. However, to be effective as a leak detection method, the only check valve in the line must be at the tank. The Bulk Storage Code states that "a facility employing a suction pumping system must not be equipped with a check valve such as a union check valve except at the tank end of the piping system [3]."

3. Emergency Shutoff Valves

The terminus of any type of pumping system should be an emergency shutoff valve such as the type shown in Figure 2-6. These valves, also referred to as impact valves, are mandated by Chapter 7 of NFPA 30, The Flammable and Combustible Liquids Code [4]. They are typically located at the base of the dispensing unit as shown in Figure 2-6, and shut off product flow in the event that the dispersing pedestal is knocked over or exposed to fire.

4. Leaks from Pumping Systems

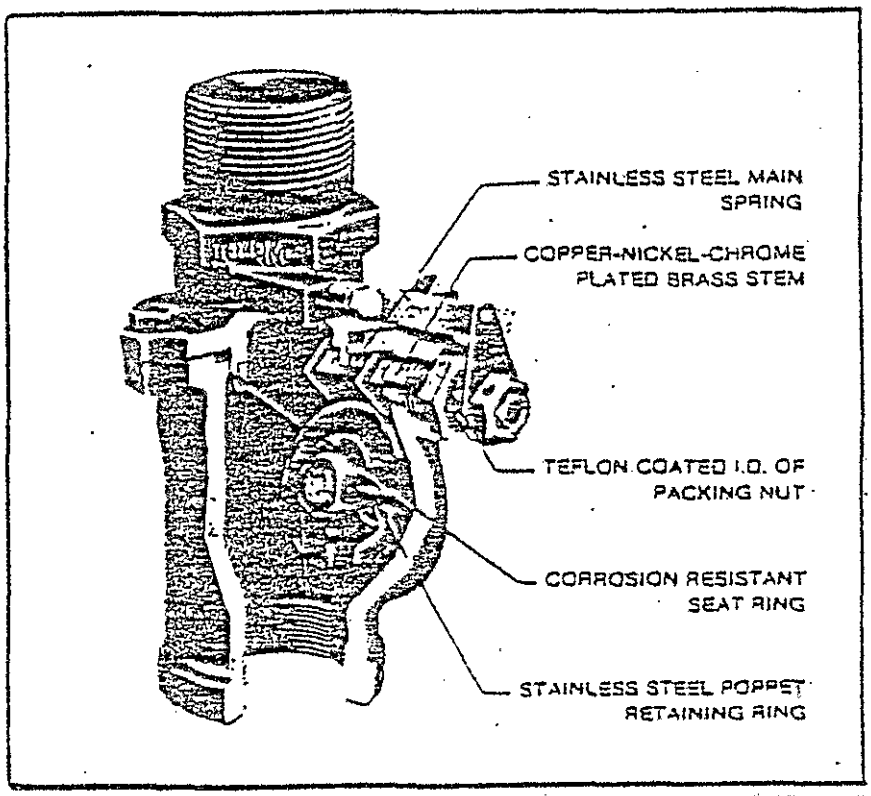
Although pumps do not represent a major source of spills or leaks, incidents resulting from leaking pump seals, pump casing failures, and losses of lubricating oil have been known to occur, particularly in the case of suction pumps or remote pumps which are mounted above (as opposed to in) the storage tanks. As a result, periodic inspections of pumps are necessary in a bulk storage facility; the Department recommends that such inspections be conducted on ~~an annual~~ a monthly basis, ~~as a minimum~~.

E. Hoses

Hoses are generally used at bulk storage facilities to transfer liquid during loading and unloading operations. ~~They are preferred over piping in such cases because of their flexibility and ease of handling.~~

FIGURE 2-6

A REMOTE PUMP
EMERGENCY SHUTOFF VALVE



SOURCE: OPW DIVISION/DOVER CORP.

Same ¶

There are a wide variety of materials currently used in the construction of hoses. As a general rule, the Department recommends that any hose used for liquid transfer at bulk storage facilities be UL listed for the intended service.

The major causes of leaks and spills associated with hoses include improper connection and handling of hoses during liquid transfer operations, leaks at joints or fittings, rupture of the hose due to internal pressure, and abrasive wear of hoses.

To prevent leaks and spills from these causes, the following practices are recommended:

- A trained operator should be present and alert during all liquid transfer operations.
- It should be confirmed that the hose pressure specification is adequate for the intended service.
- Hose guards should be provided for areas of high abrasion.
- The hose should be inspected periodically for evidence of abrasion, cracks, or other signs of wear.

References

1. American Petroleum Institute, Underground Leak Survey Results as reported by F.B. Killmar to API Underground Leak Tank Force, American Petroleum Institute, 2101 L Street, N.W. Washington, D.C. 20037, February, 1981.

2. New York State Department of Environmental Conservation, Technology for the Storage of Hazardous Liquids, A State-of-the-Art Review, New York State Department of Environmental Conservation, 50 Wolf road, Albany, N.Y. 12233, February, 1983.

3. The Bulk Storage Code.

4. National Fire Protection Association, Flammable and Combustible Liquids Code, NFPA 30, National Fire Protection Association, Batterymarch Park, Quincy, MA 02269, 1981.

5. Emco Wheaton Inc., Service Station Products, Catalog A - 12/72, Emco Wheaton, Inc., Chamberlain Blvd., Conneaut, Ohio 44030, December, 1982.

6. Perma-Pipe, div. of Midwesco, Inc. 7720 Lehigh Road, Nile, IL 60648.

7. Red Jacket Pumps, A Marley Pump Company, PO Box 3888, Davenport, Iowa 52808.

8. The Hinchman Company, Suggested Ways to Meet Corrosion Protection Codes For Underground Tanks and Piping, Job Number 1079-4542, The Hinchman Company, Corrosion Engineers, 1605 Mutual Building, Detroit Michigan 48226, April 8, 1981.

CHAPTER 3
RECOMMENDED INSTALLATION PRACTICES FOR UNDERGROUND STORAGE FACILITIES

Proper installation is an important factor in preventing leaks from underground bulk storage facilities.

A. Introduction

Many leaks are traced to mishandling of storage tanks and equipment prior to installation or to poor installation practices. The most common installation mistakes include the following:

- Damage to the protective coatings of steel tanks.
- Structural damage to tank materials during transportation and installation.
- The use of corrosive backfill materials.
- Poor foundations, the lack of bedding, or improper compaction of backfill.
- Poor anchoring of tanks in high groundwater areas.

Poor installation of tanks can lead to tank settling, tank floatation, or deflection of the tank walls; any of these can result in damage to the tank or piping. Failure to properly level a tank during installation can lead to the creation of air pockets in the tank during its use, ~~thus~~ preventing accurate measurement of inventory losses and tank leaks. Damage to coatings, or the use of poor or improper backfill material, can lead to accelerated corrosion of underground steel tanks.

Proper installation is so crucial that major tank manufacturers warrant their tanks against failure only if they are installed and used in accordance with manufacturer's instructions. For this reason, tanks should be installed in strict accord with manufacturer's recommendations.

The DEC recommendations which follow should guide all tank installations. They are consistent with generally accepted practices and the recommendations of tank manufacturers. If this guidance is followed, installation related tank and piping failures should not occur. This guidance should be considered subordinate to the Bulk Storage Code and to site-specific engineering practices which may be required for an individual facility.

Other Installation Information

Owens Corning Fiberglass Corporation has prepared a tank installation techniques manual which discusses solutions to some of the more common problems a contractor, inspector or engineer might face during installation of underground vessels [4]. Although its primary focus is on fiberglass tanks, the principles and guidelines are applicable to steel tanks as well.

B. Planning And Designing the Facility

Many storage problems are due to poor site conditions, or improper layout and design. These topics are covered in the American Petroleum Institute (API) Publication 1615, Installation of Underground Petroleum Storage Systems [2] which is an excellent guide for engineers, marketers and contractors in the design of underground gasoline service station systems. Table 3-1 summarizes the major planning and design concerns presented in API Publication 1615. Copies of this document are available from API at the address given in the introduction of this manual.

The actual location and orientation of all tanks and piping system components should be noted on as-built drawings, especially if there is a change from original drawings. Photographs are also desirable to convey a physical idea of the location of underground equipment. Copies of all drawings, photographs, and plans should be maintained at the site for the life of the facility.

Table 3-1

Planning and Design Considerations for Installing Underground Storage Facilities

Site Conditions

Soil Characteristics - Clays, wet soils, cinders and acid soils are highly corrosive and can significantly affect the rate of corrosion of metal tanks and piping. See Table 3-2 for classes of soil corrosivity.

Depth to Groundwater - Tanks installed in areas of high groundwater or in floodways must be properly anchored. Tanks placed in water-filled excavations require ballasting and special installation.

Land Use at the Site - Sites which contain abandoned pipes and tanks, agricultural drainage tiles, or landfill materials pose special installation problems. New metal parts may become anodic to old tanks and pipes. Fill may be highly corrosive. Agricultural drainage tiles or old storm drains may breach secondary containment barriers. Old buried tanks which were not properly filled when they were abandoned may collapse and cause foundation problems for newly installed tanks and pipes. In addition, stray electric currents from nearby underground power lines or from improperly constructed electric systems may cause problems of accelerated corrosion.

Layout

Tank Fill Openings - Tank fill openings should be located to minimize manuvering during truck deliveries and so that delivery trucks are not blocking driveways or located on public right-of-ways.

Maps of Facilities - As-built drawings should be prepared so that underground electrical circuits, pipes and tanks can be readily located.

Design Considerations

Bimetallic and Galvanic Cells - Dissimilar metals in proximity to each other can cause problems with corrosion. A bronze check valve joined to a steel pipe, a copper water line crossing the property, an electric service grounded to water service, or weld metal which is different from the parent metal are all potential causes of corrosion. For similar reasons, new steel tanks should not be installed next to old steel tanks.

Initial Costs vs. Operating Costs - Frequently a higher initial capital outlay can mean lower operating costs over the long run.

Table 3-1 (Continued)

Planning and Design Considerations for Installing Underground Storage Facilities

Selection of Materials/Equipment - The choice of tank, whether steel or fiberglass, the dimensions of the tank, and the type of pump system may be determined by such factors as rock conditions, pumping lift requirements, or other site conditions described above.

Traffic - The type and amount of traffic above tanks and pipe galleries affect the physical loads on underground facilities and therefore must be considered in the design.

Venting - Each tank should be vented to prevent the buildup of excessive pressure or the blowback of vapor or liquid at the fill opening when the tank is being filled.

Table 3-2

Classes of Soil Corrosivity

Soil Corrosivity	Soil Characteristics	Resistivity (Ohm-centimeters)
Very low	Well Drained Gravel	10,000
Low	Well Drained Sand & Gravel	5,000-10,000
Medium	Poorly Drained Sand & Gravel	2,000-5,000
High	Poorly Drained Fine Sand and Silt	1,000-2,000
Very High	Poorly Drained Clay	Less than 1,000

C. Site Preparation

1. Location of the Excavation

Underground tanks must be located outside the prism of bearing pressure of structural footings so as not to receive foundation loads. To avoid footing pressures, undermining the foundations of existing structures, and other construction problems, tanks should, wherever possible, be located no closer than 10 feet to a building.

2. Excavation Size

In stable soils where shoring is not required to maintain a vertical wall from top to bottom, the excavation should be large enough for the tank plus a minimum clearance of 24 inches between adjacent tanks and between the tank sides and ends and the banks of the hole. This is large enough to allow tamping of backfill and to properly cushion the tank.

In unstable soils such as muck, peat or dry sand, a hole equal to 1 1/2 the diameter of tank being installed is usually necessary. Unstable soils are defined as those soils which have either less than 750 lbs/sq.ft. cohesion as calculated from an unconfined compression test, or an ultimate bearing capacity of less than 3,500 lbs/sq.ft.

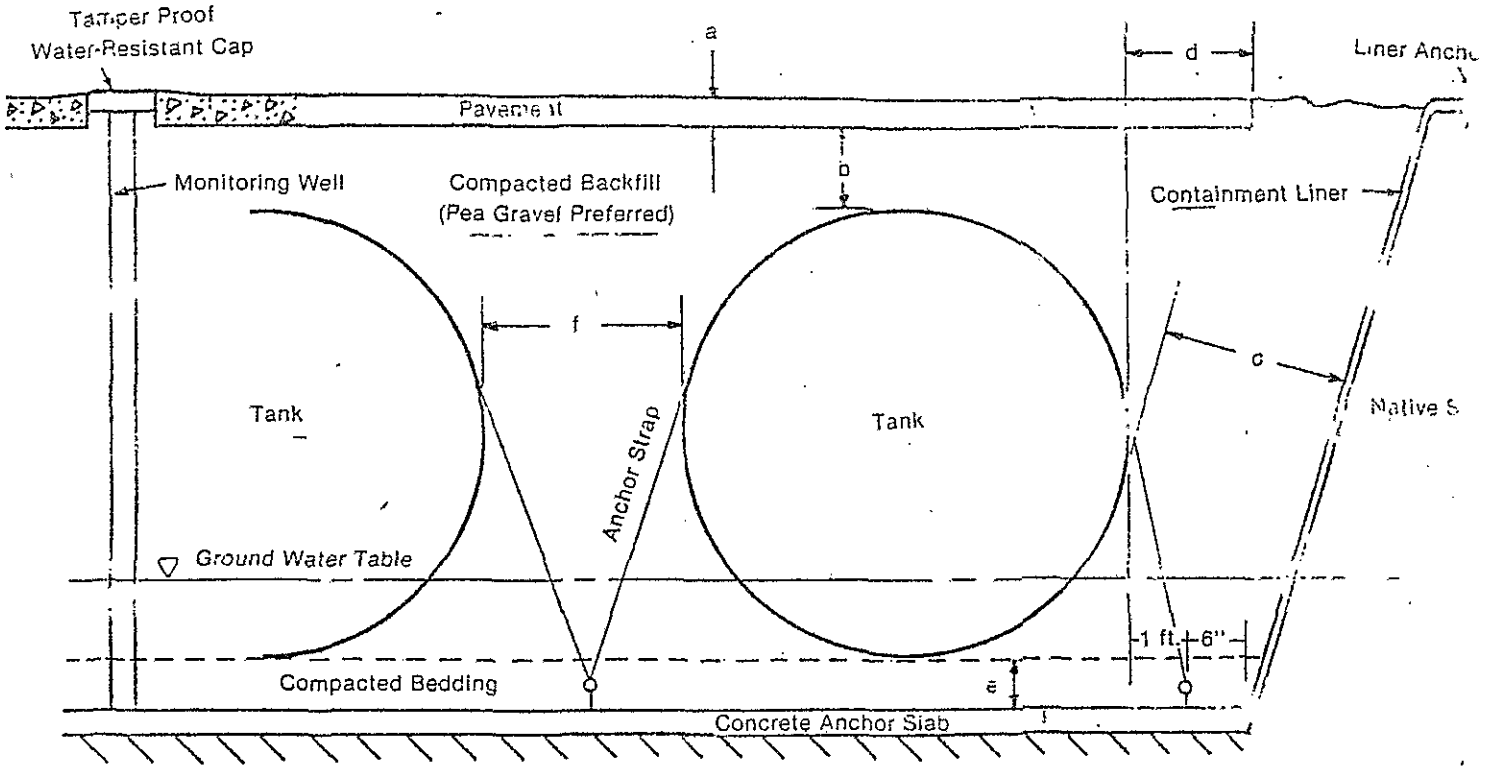
If the excavation is oversized it should be backfilled with materials specified in Section F of this chapter, Bedding and Backfill.

3. Excavation Depth

Figure 3-1 and Table 3.3 show the minimum depth of cover and thickness of bedding required for underground tanks. The excavation depth is normally equal to these minimum depths plus 1 tank diameter. For atmospheric tanks of steel construction, tanks may be buried deeper but in no case should the

Dimensions for Underground Tank Installation

Fig 3-1



Key

a-pavement thickness
b-depth of compacted backfill cover
c-distance between tank and excavation wall
d-pavement extension
e-depth of bedding
f-distance between adjacent tanks

Table 3-3
Recommended Dimensions for Underground Tank Installations

TYPE OF TANK	MINIMUM REQUIREMENT*
All Tanks	
Pavement Extensions(d)	12 inches
Distance Between Adjacent Tanks(f)	24 inches
Distance Between Tank and Bank of Excavation(c)	24 inches
Thickness of Compacted Bedding(e)	12 inches
Steel Tanks	
With Traffic Loads	
Reinforced Concrete Pavement(a)	6 inches
Plus Compacted Backfill Cover(b)	18 inches
or	
Asphaltic Concrete Pavement(a)	8 inches
Plus Compacted Backfill Cover(b)	18 inches
Without Traffic Loads	
Reinforced Concrete Pavement(a)	4 inches
Plus Compacted Backfill Cover(b)	12 inches

TYPE OF TANK	MINIMUM REQUIREMENT*
Fiberglass Reinforced Plastic Tanks (20,000 Gallons and Under)	
Maximum Burial Depth(b)	84 inches
With Traffic Load	
Reinforced Concrete Pavement(a)	6 inches
Plus Compacted Backfill Cover(b)	18 inches**
or	
Asphaltic Concrete Pavement(a)	6 inches
Plus Compacted Backfill Cover(b)	30 inches**
Without Traffic Loads	
Reinforced Concrete Pavement(a)	4 inches
Plus Compacted Backfill Cover(b)	12 inches**
Fiberglass Reinforced Plastic Tanks (Over 20,000 gallons)	
Maximum Burial Depth(b)	84 inches
With Traffic Loads	
Reinforced Concrete Pavement(a)	6 inches
Plus Compacted Backfill Cover (b)	36 inches
or	
Asphaltic Concrete Pavement(a)	6 inches
Plus Compacted Backfill Cover(b)	42 inches
Without Traffic Loads	
Reinforced Concrete Pavement(a)	6 inches
Plus Compacted Backfill Cover(b)	24 inches

Unless Otherwise Noted

***In Wet Hole Installations, the Minimum Depth of Compacted Cover Is 36 Inches*

PAGE 3-8 DELETED

PAGE 3-9 DELETED

burial depth be such that the static head imposed on the bottom of the tank exceeds 10 psig with the fill pipe or vent pipes filled with liquid. Also, if the depth of cover is greater than the tank diameter, the tank manufacturer should be consulted to determine if reinforcement is required.

Atmospheric tanks of fiberglass reinforced plastic construction may also be buried deeper but the depth of cover must not exceed 84 inches (7 feet) over the top of the tank.

4. Dewatering the Excavation

In areas of high groundwater or where surface runoff leads to accumulations of water in the excavation during installation, site dewatering may be necessary.

There are three methods for dealing with water accumulation in an excavation: (1) water can be allowed to flow into an excavation and pumped out from sumps or ditches; (2) the water table can be lowered prior to excavating, using either wells, wellpoints or ejectors; or (3) cutoff walls of slurry or grout can be installed. Any one or a combination of these three methods can be used to effectively dewater a site.

There are a number of factors which influence the choice of a dewatering procedure. Aside from the cost, these factors include the following:

- The nature of the soil.
- The areal groundwater hydrology.
- The size and depth of the excavation.
- The proposed method of excavation and, if necessary, wall support.
- The proximity of existing structures.
- The construction schedule or required duration of dewatering operations.

The bulk of this information can be ~~accumulated~~ obtained through test borings, and analyses of the hydrogeology of the area.

Construction Dewatering, A Guide to Theory and Practice, by J.P. Powers [1] is a good source of background information on site dewatering. In practice, if dewatering is required, an experienced professional engineer, geologist, or hydrogeologist should be consulted.

D. Preinstallation Testing and Inspection

The Department requires that all tanks be tested prior to shipment. Once the tank has been delivered to the site, it is recommended that the tank be cleaned free of dirt clods, visually inspected, and pressure tested aboveground at the site prior to installation. The test usually consists of pressurizing the tank to 5 psi, soaping all joints, seams and fittings, and monitoring for pressure drop and bubbles.

E. Care in Handling

Although tanks are designed to withstand normal handling and to provide secure storage of its product, they must not be dropped, handled with sharp objects, dragged or rolled. The protective coatings of steel tanks or the shells of fiberglass tanks can be damaged with mishandling. If the tank coating or shell is damaged, it must be repaired in accordance with manufacturer instructions.

The proper way of moving a tank is by lifting it, using lifting lugs installed by the manufacturer. ~~Do not use~~ Slings, cables or chains should never be used around the tank.

F. Bedding and Backfilling

1. Secondary Containment and Recovery System

The Department requires that all new underground installations include a secondary containment system, a monitoring well and a well for recovering lost product. The design and installation of these systems are discussed in Chapter 4 (Secondary Containment) and Chapter 7 (Leak Detection).

2. Bedding and Backfill Materials

Fiberglass Tanks. Fiberglass reinforced plastic (FRP) underground tanks receive as much as 90% of their structural support from the backfill and bedding used. The selection of backfill material is therefore an important aspect of the installation.

FRP tanks should be installed using bedding and backfill of either pea gravel or stone/gravel crushings. If pea gravel is used it must be a clean naturally rounded aggregate with a mix of particle sizes with diameters not less than 1/8 of an inch or more than 3/4 of an inch. If stone/gravel crushings are used, they should be washed and free flowing, with angular particle sizes not less than 1/8 of an inch nor more than 1/2 of an inch. Figure 3-2 shows the size of pea gravel and crushed stone recommended for bedding and backfilling underground tanks and pipes. Pea gravel and crushed stone compact readily when placed in the excavation; this property makes them highly suitable as foundation materials.

All backfill material must meet the requirements of ASTM-33, Paragraph 9.1 for quality and soundness. No materials should have particles passing a #8 sieve. In freezing conditions, the materials must be dry and free of ice and snow. Under no circumstances will backfill with frozen lumps be acceptable. When they melt, these lumps can create voids in the backfill.

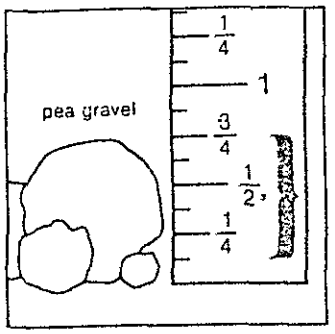
The supplier should be required to certify that the backfill and bedding material meets these specifications. If acceptable material is not available, the tank manufacturer or a professional engineer should be contacted for information on the use of light weight aggregate cement slurry or other alternative materials and the proper installation procedures for each.

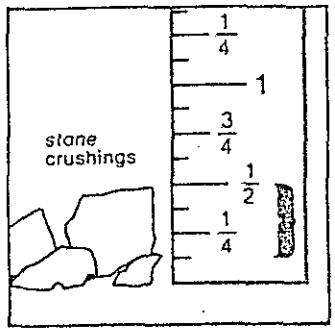
Steel Tanks. Although steel tanks are less dependent on backfill material for structural support than FRP tanks, the use of good materials and adherence to sound engineering practices are essential for proper steel tank installation. Pea gravel or crushed stone/gravel as specified for fiberglass tanks is preferred but a uniform clean sand or self-compacting gravel which is free of rocks, clay, loam, or cinders is acceptable.

Figure 3-2

Size of Pea Gravel and Crushed Stone Recommended for Bedding and Backfill Material

Bed and Backfill





Gravel

A clean naturally rounded aggregate with a mix of particle sizes not less than 1/8" or more than 3/4" is required. This material is commonly called pea gravel.

Stone or Gravel Crushings

Washed stone or gravel crushings with angular particle size not less than 1/8" or more than 1/2" are required.

Note: All backfill materials must meet ASTM C-33 paragraph 9.1 for quality and soundness. No backfill should have particles passing a #8 sieve.

In freezing conditions backfill must be dry and free of ice

Note: You should require your backfill supplier to certify that the backfill meets this specification.

If your backfill does not meet the above requirements alternate materials may be used under the following conditions.

1. Only on 4' through 10' diameter tanks
2. Particle size shall be a mix and can not exceed 1/2" with no particles passing a #200 sieve. The material must be free of organic materials, silt, dirt, or clay. The material must also meet the ASTM specification for hardness referenced above
3. The material must be mechanically compacted in 12" lifts to achieve a 90% relative density to support the tank.
4. Verification of the 90% relative density must be furnished to the owner in writing.

Figure 3-2 shows the size of pea gravel and crushed stone recommended for bedding and backfilling underground tanks and pipes. Pea gravel and crushed stone compact readily when placed in the excavation which make them highly suited as a foundation material.

3. Dry Hole Installation

Once the secondary containment barrier and a 12 inch (minimum) compacted bedding is installed, the tank should be carefully placed on the bed and checked again to insure that it is free of dirt clods.

> An underground tank should not be placed directly on a concrete slab, timbers, beams or cradles.

The tank should then be leveled and 12 inches of backfill placed along the bottom of the tank by hand shoveling and tamping to ensure that the tank is fully and evenly supported. A board and long handled probe can be used to penetrate backfill and move it to fill any voids. It is particularly important to work voids free at the ribs and caps of fiberglass tanks. One way of checking to see if voids have been removed is to enter the tank through the manway and to lightly tap the shell wall with a wooden screwdriver handle from side to side in the backfill area. Voids can be found by a distinct hollow sound.

If the tank is a cathodically protected steel tank, the anode lead-wire attachment to the tank should be checked at this point to assure that this connection has not been damaged. Where damaged, the connection must be repaired in strict accordance with manufacturer's specifications.

> Leveling the tank, and hand placement and compaction of fill along the bottom edges of the tank are important steps for proper installation.

If the tank is a large (diameter 12 feet or larger) FRP tank, anchoring in strict accord with manufacturer's requirements is necessary.

Once the first backfill lift has been properly placed, successive 12 inch lifts can be similarly installed up to the sub-grade level for the slab. Placement and tamping of the soil in lifts will prevent flattening of

the bottom of the tank and allows the tank to hold the cylindrical or spherical shape necessary for maximum strength.

Hand placement and compaction to 95% Standard Procter is especially important for the bed, the first two lifts, and the last two lifts between the top of the tank and cover slab.

If the backfill is brought to the top of the tank, but further backfilling of the excavation is delayed, it may be necessary to add water to the tank as ballast. This will prevent flotation should the site become flooded before the final cap is installed. Do not ballast the tank with water until the backfill is even with the top of the tank.

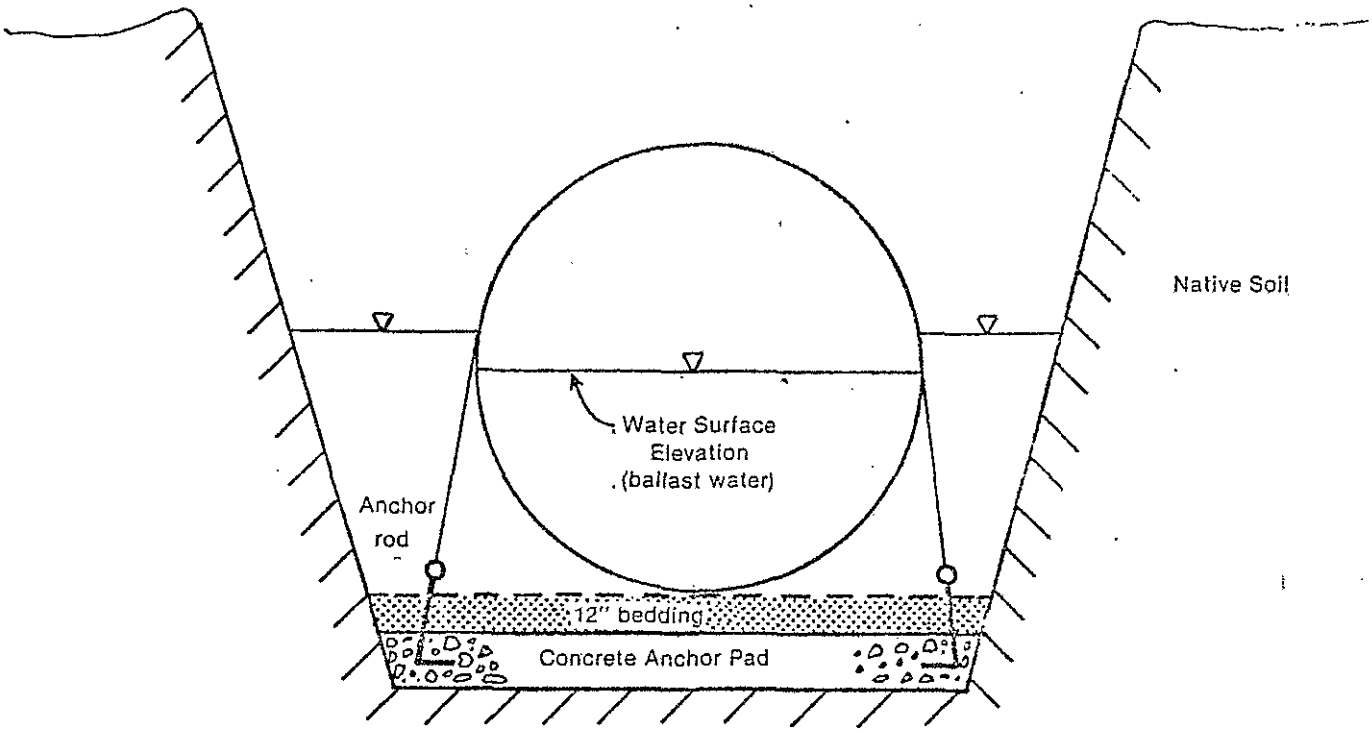
4. Wet Hole Installation

Tank installations in high groundwater areas, or where the hole may fill with water, are much more complex than dry hole installations. Although the requirements for bedding, leveling and compaction of backfill are the same as for dry hole situations, the tank must usually be ballasted with water during installation and anchored to prevent flotation. Many tanks and connecting pipes have been placed into service only to be later damaged by high groundwater levels. Although fiberglass tanks are particularly susceptible to flotation damage, even steel tanks can be damaged.

First of all, the water level in the excavation should be maintained at the lowest practical level. The dewatering methods discussed in Section C of this chapter are usually successful.

If the water level in the excavation cannot be lowered, ballast must be added to the tanks. This is accomplished by partially filling the tank with water until it settles gently on the prepared bed. The ballast level must never exceed the water level in the hole. Ballasting with petroleum or product is dangerous and not recommended. Figure 3-3 shows the concerns associated with a wet hole installation.

Figure 3-3
Tank Ballasting



If the water level in the hole cannot be lowered, tanks will need ballasting. Ballast water in tanks must never exceed water levels in the hole during installation.

5. Weighting and Anchoring

> Anchoring or weighting of a tank is usually necessary to protect against flotation in high groundwater areas.

Weighting or anchoring the tank is required under any circumstances where the ground may become saturated with water, such as in flood plains, groundwater aquifers, wetlands or in tight soils where rainfall and runoff cannot be successfully diverted from the site. Because of their additional weight, steel tanks are less susceptible to flotation than fiberglass tanks and smaller tanks are less buoyant than larger tanks. If there is any question on whether or not weighting or anchoring is necessary, estimates of expected groundwater levels and calculations of bouyant forces should be made by a professional engineer. Buoyancy tables for fiberglass tanks are available in the Owens-Corning Fiberglas Underground Tank Installation Techniques Manual. Tank manufacturers should be consulted for buoyancy information on steel tanks.

All FRP tanks over 12 feet in diameter must be anchored, whether installed in a wet site or not.

Weighting the Tank. Weighting the tank is accomplished by burying the tank deeper and/or by adding a thicker surface (cover) slab. The weight of the overburden holds the tank down. Sometimes buoyancy is counteracted by a concrete weight collar installed at the upper 1/3 level of the tank. This is called mid-anchoring and requires special installation procedures which should be conducted under the supervision of the tank manufacturer or field engineer.

Anchoring the Tank. Anchoring involves strapping the tank to a reinforced concrete anchor pad buried underneath 12 inches or more of bedding, or strapping it to reinforced concrete deadmen layed along each side and parallel to the tank. The weight of the concrete and the overburden on top

of the slab or deadmen provides the necessary hold-down force. The size of the concrete reinforcement bars, the size of the slab or deadmen, positioning, and strapping requirements depend on the size of the installation and the soil conditions. They must be designed in accordance with accepted engineering practices and installed in accordance with manufacturer's recommendations. At a minimum, anchor slabs should be 8 inches thick and extend 18 inches beyond the ends of the tank and the vertical tangent line of the tank. Deadmen should be a minimum of 12 inches beyond the vertical tangent line of the tank. Deadmen should be a minimum of 12 inches by 12 inches and extend 12 inches beyond the ends and vertical tangent line of the tank.

Anchor bolts should be imbedded in the slab and coated with epoxy to prevent corrosion.

Anchor Straps. The positioning of anchor straps is one of the most important steps in anchoring a tank. The straps must be uniformly tight and spaced so that the load will be evenly distributed. On fiberglass tanks all anchor points in the bottom of the tank excavation should be spaced a distance equal to the tank diameter plus 1 foot from the point in the bedding directly under the center line of the tank. Straps must be aligned on the ribs designated by the manufacturer, not between them.

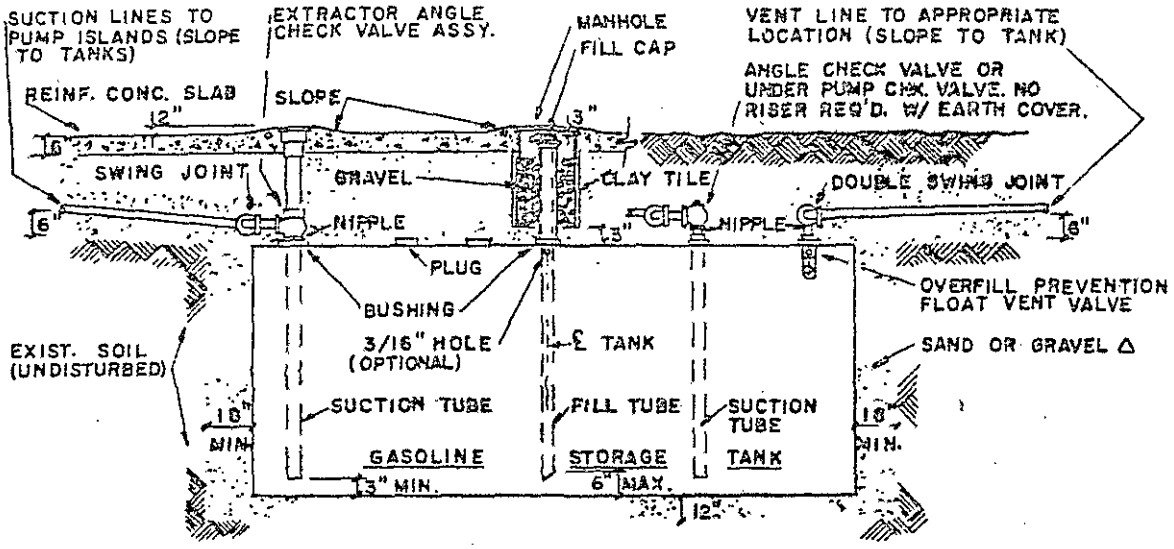
On steel tanks, straps must be separated from the tank by a pad made of inert material. The pad which is usually 2 inches wide, prevents scratches in the coating and electrically isolates the tank from the straps and anchor. Neoprene or asphalt-impregnated expansion joint material is normally used.

G. Pavement Openings

Any part of the excavation which has an opening or fitting that is connected to the tank must be protected from traffic and the infiltration or collection of water from precipitation. This protection must extend the full thickness of the pavement.

FIGURE 3-4

TANK PIPING DETAILS - SUCTION SYSTEM



PIPING DETAILS FOR TANKS — UNDER CONCRETE

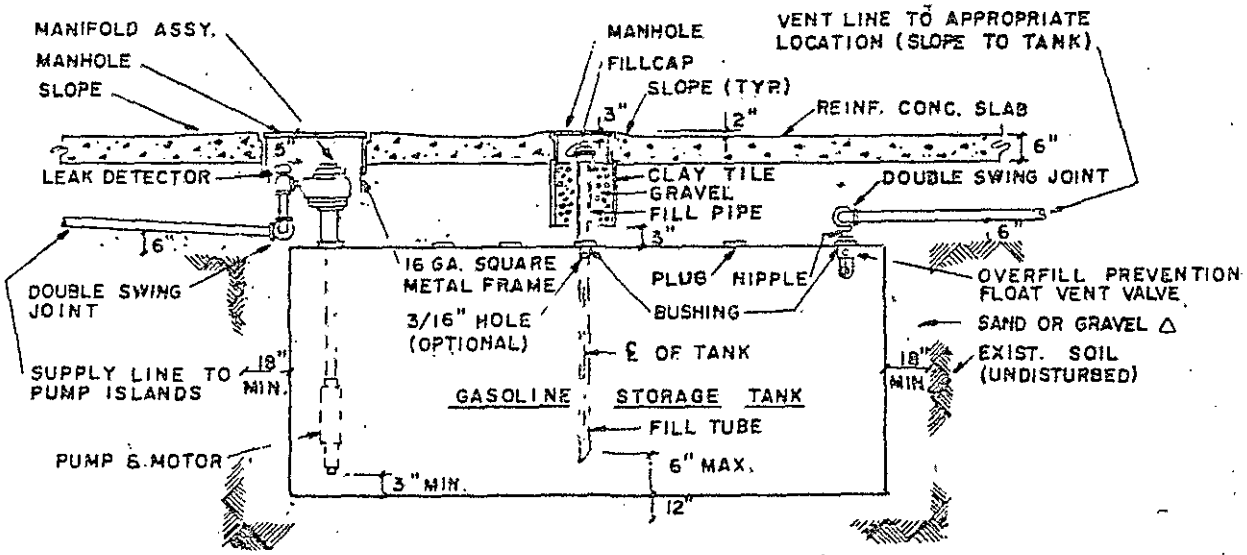
△ PEA GRAVEL FOR NON-METALLIC TANKS (OR MFR. APPROVED ALTERNATE)

NO SCALE

NOTE: ELIMINATE CONC. SLAB IN NON-TRAFFIC AREAS & CONSTRUCT CONC. PADS (ONLY) AROUND MANHOLES. THE EXTR. ANGLE CHECK RISER IS NOT REQ'D. W/ EARTH COVER.

FIGURE 3-5

TANK PIPING DETAILS - SUBMERGED SYSTEM



PIPING DETAILS FOR TANKS — UNDER CONCRETE

△ PEA GRAVEL FOR NON-METALLIC TANKS (OR MFR. APPROVED ALTERNATE)

NO SCALE

NOTE: ELIMINATE CONC. SLAB IN NON-TRAFFIC AREAS & CONSTRUCT CONC. PADS (ONLY) AROUND M.H.'S.

All fittings or accessways which extend through pavement openings must be raised at least two (2) inches above grade (the pavement surface), and the pavement must slope upward to the edge of this opening, as shown in Figures 3-4 and 3-5. This prevents the drainage of precipitation into the tank or tank excavation.

In many instances, there are cavities under pavement openings for functions such as pump access or imbiber bead pockets. The walls of these cavities are typically composed of materials such as square metal framing, clay tiles, or a section of culvert pipe. In any such situation, the cavity wall must never touch the underground storage tank. A minimum gap of three (3) inches must be maintained between the tank and the bottom of the cavity wall to prevent abrasion of the tank or coatings. (See Figures 3-4 and 3-5 for illustrations.)

H. Cover and Pavement

The final step of construction is to place a compacted backfill cover, a 10 mil (minimum thickness) polyethylene water barrier, and a concrete or asphalt slab over the tank. The cover material should be the same material as that used for backfilling and must be placed at a depth as prescribed in Table 3-3.

The concrete or asphalt slab thickness is also specified in Table 3-3. The slab and polyethylene underlayment are recommended even if traffic loads are not anticipated. They provide a factor of safety against tank flotation, prevent water from entering the excavation, and safeguard against vehicle and equipment traffic which may accidentally pass over the installation. (It is anticipated that some time in the 25 year lifetime of a storage facility, traffic will pass over the installation.)

I. Testing and Inspection

Since damage can occur at any stage of construction, it is desirable to make an inspection and perform a tightness test if the tank is dropped or accidentally damaged. This way the damage can be repaired before expensive additional work is completed. As a minimum, a tightness test and inspection

PAGE 3-20 DELETED

PAGE 3-21 DELETED

should be performed before installation as discussed earlier, and again either after installation but prior to backfilling, or at the conclusion of construction (after paving and all pipes and pumps have been installed).

1. Tightness Tests

If the test is conducted prior to backfilling, the usual method is to soap all fittings, seams and dents and inspect for bubbling when the tank is pressurized to 5 psi. Large fiberglass tanks (over 25,000 gallons capacity) should be pressured to 3 psi. Air gauges should be monitored for 30 minutes to observe pressure losses. Tank manways and the end caps of fiberglass tanks should not be approached while under pressure.

If the test is conducted after installation and product has not been put in the tank, the tank may be pressurized with air as above and monitored for pressure loss. This is the only time that the tank may be safely air pressure tested.

Double-walled tanks can be readily checked for tightness by monitoring the annular space between the inner and outer wall by vacuum or pressure.

2. Inspection

Measuring the inside dimensions of the tank for roundness is recommended for checking on the quality of the installation. Measurements can be done by entering the tank if a manhole exists or by measuring tank diameter at the fill tube prior to and after backfilling. If the tank is entered, Federal OSHA safety codes should be strictly followed.

If a manhole does not exist in the tank, the diameter can be checked at the fill tube riser. Making a tank diameter measurement at the riser is not a problem as long as the drop tube is not in place. All that is necessary to measure the distance from the tank bottom to top of riser with a dipstick and then measure the distance from top of tank to top of riser by driving a nail in the dipstick, catching the nail underneath the lip of the riser fitting and reading the measurement difference on the dipstick.

Measurements of tank roundness are particularly important on fiberglass tanks, which depend on the surrounding soil for structural support. Excessive deflection indicates residual stress on the tank which may cause cracking or may cause the suction line to penetrate the bottom of the tank. If deflections exceed the values shown in the following chart the tank manufacturer should be contacted before proceeding further with the installation.

Tank Diameter	Maximum Deflection
6'	5/8"
8'	1 1/4"
10'	1 1/2"
12'	1 1/2"

Fiberglass tank manufacturers will not warrant a tank against failure unless these criteria and other manufacturer's installation requirements are followed.

J. Installation of Piping Systems

Proper installation of piping system components is as important as proper installation of the storage tank. For example, in the API Leak Survey [7], fully 1/3 of all leaks detected from underground storage facilities were in the piping systems. Adherence to proper material selection and installation procedures could have prevented most of those leaks.

1. General Considerations

Regardless of the type of pipe selected for a particular application, there are a large number of considerations which are common to any piping system installation. These include the design criteria presented in Section B and Table 3-1 of this chapter. Other considerations which apply specifically to piping include the following:

- Piping should be located in a single trench. This will facilitate access to the pipe in case of a problem, and concentrate the piping so that future excavation at the site can be done safely.

- Piping should be sloped a minimum of 1/8 inch per foot toward the tank so that lines can be drained, and so there is no accumulation and blockage of product vent lines.

- Vent piping should extend at least 12 feet vertically aboveground and be a minimum of 2 feet higher than adjacent buildings. The use of rain caps is endorsed.

Figure 3-6 presents recommended minimum clearance dimensions for back-filled piping trenches.

2. Galvanized Steel Pipe Installation

Galvanized steel pipe has become an industry standard because of its low cost. Installers are intimately familiar with installation techniques and generally are quite proficient. The Department recommends that good piping installation practices, such as those found in API Bulletin 1615 [2], be followed. Such recommended procedures include the following:

- Piping Location. Piping should be located so that it does not cross over underground tanks. Further, installed pipes should not pass close to water lines. This practice will reduce the possibility of conducting stray electrical currents to the tank.

- The Use of Swing Joints. Double swing joints should be used at all changes of direction, and at the end of each line. These joints help reduce stresses that can loosen or crack pipes. Stresses can arise from settlement, temperature change, and misalignment.

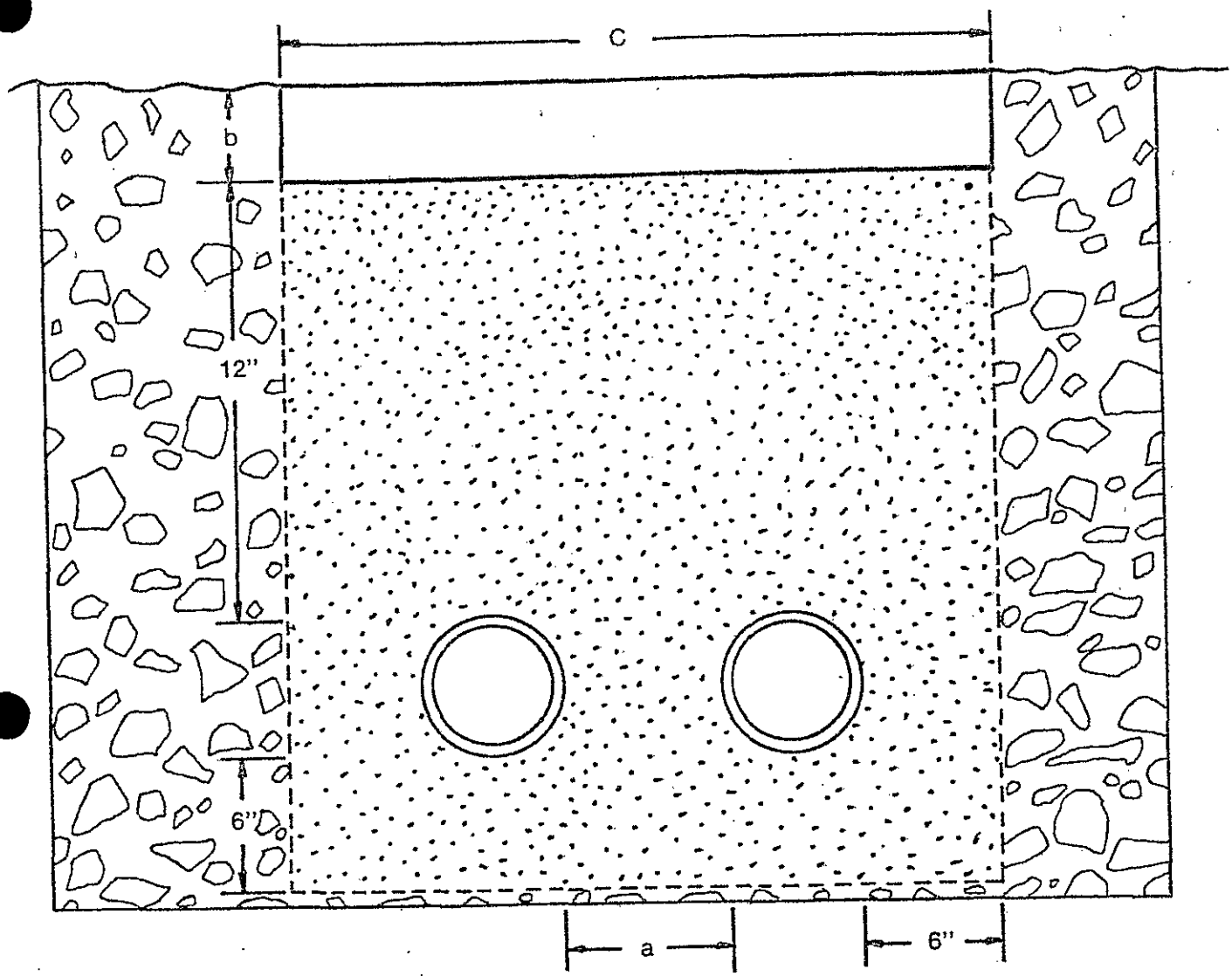
- Pipe Fittings. Pipes should be joined using standard 150 lb. malleable iron fittings. Care should be taken to protect threads from damage and dirt. Thread lubricant (pipe dope) which is compatible with the product to be stored should be used.

- Corrosion Protection. Cathodic protection is usually achieved through the use of either:

  a) a sacrificial anode system which creates a galvanic cell conducting a protective electrical current towards the piping; or
  b) an impressed current system which sends a current supplied by the electrical utilities through a non-sacrificial anode to the tank.

Figure 3-6

Minimum Dimensions for Piping Installation



NOTE:
Dimension a. twice the diameter of the pipe, but at least 4 inches.
b. pavement tickness, 4" of reinforced concrete or 6 inches of asphaltic concrete
c. pavement width is at least equal to excavation width.

Further information on cathodic protection can be found in the Department document Technology for the Storage of Hazardous Liquids, A State-of-the-Art Review [6]. Both types of systems should be professionally designed, but in either case, the pipes should be coated against corrosion in addition to being galvanized. When the piping has been lead tested and proven tight, all joints must be coated and wrapped.

3. Fiberglass-Reinforced Plastic (FRP) Pipe Installation

The corrosion resistant properties of FRP pipe are similar to those of FRP tanks. However, there are some important points to be made regarding installation.

Pipefitting. FRP pipe is normally joined with adhesive, but other methods are available, including thread, adhesive and mechanical joints. The manufacturers' installation manuals provide the most detailed advice on joining methods. Important points to be remembered include the following:

- Both the pipe itself and particularly the ends must be protected from dirt and damage until joint makeup.
- All joint surfaces must be meticulously cleaned.

Joint curing temperatures are critical. A temperature of at least 60°F must be maintained for the full cure time. If there is any likelihood that this temperature will not be maintained, auxiliary heat should be used.

Thermal Expansion. FRP pipe is inherently flexible and does not require swing joints if at least 4 feet of straight run is provided between directional changes. Otherwise, swing joints must be used. Where long straight runs encounter fixed end constraints, expansion loops may be used. The size of the expansion loop is a function of the length of the run.

Inspection. It is recommended that one person be responsible for piping inspection. Evidence of damage includes localized color differences called "star crazes". Potential joint failures can be identified by the following:

- Joint Back-out. During assembly of a bell and spigot joint, a bead of adhesive is normally found at the edge of the bell. If the joint backs out before the adhesive is set up, the bead will no longer be next to the bell.

- Cocked Joint. If a joint is misaligned, or "cocked", there will usually be a gap between the bell and spigot on one side. The opposite side will typically have no gap.

- Improperly Cured Joint. If the adhesive bead is soft and flexible when checked with a knife after the cure cycle, the adhesive is faulty.

4. Stainless Steel Pipe

The common perception of stainless steel pipe is that it is astronomically expensive. In fact, the installed cost is approximately double that of ordinary galvanized steel. The Department feels that this cost can be justified in light of the increased corrosion resistance and longer life-span, particularly in sensitive environmental areas.

Stainless pipe has the important advantage of being able to be installed without wrapping, coating, or anodes.

The Department recommends the use of Schedule 10, Type 304 stainless steel where joints are to be welded, and Schedule 40, Type 304 stainless steel where joints are to be screwed. The backfill and general requirements are the same as for other pipe materials.

5. Testing

Air pressure testing of piping is recommended only for low pressure service, such as filling stations. The recommended procedure is as follows:

- Isolate the piping system at both ends.

- Soap all joints.

- Gradually pressurize to 150% of working pressure or at least 50 psi. The gauge used should have a full scale reading of no more than twice the test pressure (e.g., if the test pressure is 50 psi, the gauge should be no more than 100 psi full scale).

- Inspect for bubble formation; monitor for pressure drop for an hour.
- No tightening or repairs should be attempted while the system is pressurized.
- Wrap or coat joints in preparation for backfilling operations.

REFERENCES

1. Powers, J.P., Construction Dewatering, A Guide to Theory and Practice Wiley-Interscience Division, John Wiley and Sons, Inc., 605 Third Avenue, New York, NY, Copyright (c) 1981.

2. American Petroleum Institute, Installation of Underground Petroleum Storage Systems, API Publication 1615, American Petroleum Institute 2101 L Street, N.W. Washington, DC 20037, November, 1979.

3. Steel Tank Institute, Specification for sti-p, System of Corrosion Protection of Underground Steel Storage Tanks, Steel Tank Institute, 666 Dundee Road, Suite 705, Northbrook, Illinois 60062, May 15, 1980.

4. Owens-Corning Fiberglas, Owens-Corning Fiberglas Underground Tank Installation Techniques Manual, Publication No. 3-PE-9632, Owens-Corning Fiberglas Corporation, Non-Corrosive Products Division, Fiberglas Tower, Toledo, Ohio 43659, May, 1981.

5. Xerxes Fiberglass, Inc., Century Fiberglass Tanks Installation Instructions, Publication No. CT 4-80-01, Xerxes Fiberglass, Inc., 34250 Mills Road, Avon, Ohio 44011.

6. New York State Department of Environmental Conservation, Technology for the Storage of Hazardous Liquids, A State-of-the-Art-Review, Bureau of Water Resources, Division of Water, New York State Department of Environmental Conservation, 50 Wolf Road, Albany, New York 12233, January 1983.

7. American Petroleum Institute, Underground Leak Survey results as reported by F.B. Killmar to API Underground Leak Task Force, American Petroleum Institute, 2101 L Street, Northwest, Washington, D.C. 20037, February 5, 1981.

8. Ciba-Geigy Pipe Systems, Inc., Piping Specifications and Installation Practices, Ciba-Geigy, Inc., 11999 Katy Freeway, Houston, TX 77079.

9. A.O. Smith-Inland, Inc., General Installation Instructions, Manual No. 9474, A.O. Smith-Inland, Inc., Reinforced Plastics Div., 825 Lehigh Avenue, P.O. Box 193, Union, NJ 07083.

CHAPTER 4

SECONDARY CONTAINMENT SYSTEMS

All new underground storage systems should include a secondary containment structure which collects and contains a spill or leak, and should include provisions for removing spilled or leaked material from the excavation.

A. *Introduction*

Underground spill or leak containment systems represent an important line of defense for protecting groundwater quality. They can also act to enhance the effectiveness of leak detection systems in tank excavations by concentrating the contaminant and channeling it to a monitoring sensor, and by confining a leak or spill until removal of the liquid is possible.

Containment systems work by establishing a barrier around the storage tank(s) so that leaked liquid does not have a free path to escape from the storage excavation. The Department recommends that this be accomplished through the use of one of the following: (1) double-walled tanks; (2) tank vaults; (3) cutoff barriers or containment liners; or (4) sites with highly impervious soils.

A secondary containment system would be inadequate without provisions for monitoring the containment area and removing leaked or spilled product. Recommended practices for monitoring and removal are addressed in Chapter 7 of this manual.

The selection of the best containment system for a particular storage application is dependent upon several factors, including the following:

- The type and quantity of material stored.
- The level of environmental protection needed.

- Groundwater levels.
- Soil conditions, especially soil permeability.

For more information on secondary containment options, refer to the Department manual entitled Technology for The Storage of Hazardous Liquids, A State-of-the-Art Review [1].

The remainder of this chapter presents Department recommendations for the design and installation of secondary containment systems using double-walled tanks, vaults, cutoff barriers, and containment liners, and in areas with naturally-occurring impervious soils.

B. Double-Walled Tanks

Double-walled tanks incorporate all of the fundamental requirements for leak prevention, including a secure storage vessel, secondary containment via the outer wall, and monitoring of the interstitial space to check on the integrity of both the inner and outer walls. Such tanks, when built in accordance with the recommended practices for double-walled tank construction discussed in Chapter 1, provide not only an efficient means of achieving secondary containment, but also a high degree of overall environmental protection.

C. Vaults

A vault is a secondary enclosure which houses the storage tank, contains any leaks ~~which might occur~~ from the tank, and provides protection ~~to the tank~~ from corrosive soils. They may contain one, or more than a dozen storage tanks. Some vaults have an open interior so that tanks can be entered through a manhole and physically inspected and repaired, while others are filled with a bedding of sand or other acceptable backfill material which provides structural support for the tank.

In the case of open vaults, at least 24 inches of clearance should be left between the tanks and the vault walls to permit access for inspection. Tanks should be supported on cradles and properly anchored, with padding

between the cradle and the tank. The cradling must be consistent with acceptable engineering practices.

If the storage tank is bedded in fill material, the bedding must consist of at least 12 inches of compacted backfill, and there must be at least 24 inches of clearance between the tank and the vault sidewalls to allow for proper compaction of the backfill material.

Reinforced concrete is the most common construction material used for vaults. If concrete is used, the reinforcing bars (rebars) should be epoxy coated to resist corrosion.

Concrete vaults should be continuous structures which are impervious to water and the stored product. The best construction method is to pour the walls and floor continuously. The vault cover can be added afterwards. The floor of the vault should be constructed with a slope (typically greater than or equal to 1/8 inch per foot) which channels any leaked or spilled product to collection trenches and a sump.

The collection sump in a vault must be equipped with a leak detection sensor and a recovery pump to remove accumulated liquid. The pipe to the recovery pump should be at least 4 inches in diameter. The leak detection system installed in the vault must meet Department recommendations for such systems as presented in Chapter 7 of this manual.

Concrete used alone does not provide an effective liquid barrier; leaks through concrete can occur in the vapor phase after only limited exposure times. Therefore, it is important to have a continuous structure with chemical-resistant water stops where joints are necessary. In addition, the walls of the concrete vault must be covered with an internal chemical-resistant coating to prevent liquids and vapors from entering or leaving the vault.

Vaults should contain no drain connections or other entries except top entry manholes and other top openings for filling and emptying the storage tank, monitoring or inspecting the vault interior, and recovering any leaked

or spilled product which has collected in the vault. These openings all require waterproof seals.

The structural design of an underground vault will depend on the size of the vault, the amount and type of overhead vehicular traffic, and foundation conditions. They should be designed in accordance with acceptable engineering practices.

Figure 4-1 shows a diagram of a typical secondary containment vault. Such vaults are occasionally used for petroleum storage but more commonly used in extremely sensitive environmental areas where toxic materials are being stored.

Vaults are generally unsuitable in areas of high groundwater. If a vault is installed in such an area, there is a strong likelihood that long-term deterioration or chemical decay of the vault materials will lead to the eventual flooding of the inner chamber, resulting in the additional expense of continuous dewatering of the vault.

D. Cutoff Barriers And Containment Liners

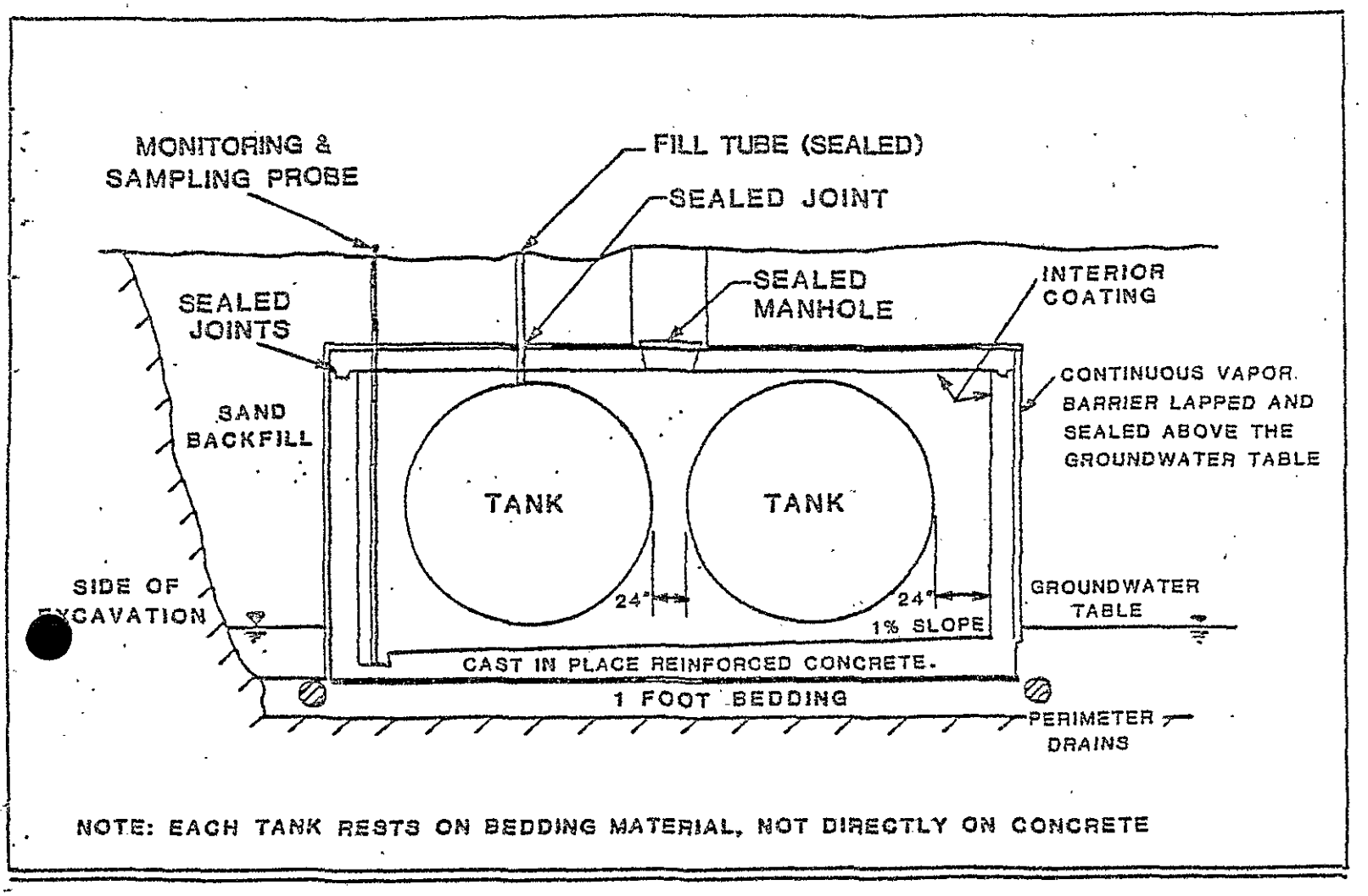
Cutoff barriers and containment liners (which include excavation liners, trough liners and containment bags) function by providing relatively impermeable surfaces which prevent the flow of leaked or spilled product away from the excavation. These types of systems are typically installed in or around the tank excavation prior to tank installation and backfilling. The choice of a containment scenario depends upon whether the storage installation is in an area of high or low groundwater. The selection of a containment material is dependent upon several factors which are discussed in detail later in this section.

1. Cutoff Barriers

In situations where the stored product is lighter than (floats on) water, and is not soluble or miscible in water, and the known low level of the groundwater table is above the bottom of the storage excavation, cutoff

FIGURE 4-1

DIAGRAM OF A SECONDARY CONTAINMENT VAULT



barriers may be used for secondary containment. In this type of system, the groundwater actually acts as the bottom of the containment. The cutoff barrier prevents lateral movement of the product out of the containment area. This concentrates the spill or leak and greatly enhances detectability. The cutoff barrier should encompass the entire perimeter (side walls) of the excavation, and should extend five feet above the high groundwater level (or to the top of excavation) and five feet below the low groundwater level or to the ~~bottom of the storage tank(s),~~ slab or excavation bottom, whichever is lower. This cutoff barrier must be impervious to and chemically compatible with (i.e., resistant to) the stored product, and be free of any holes, cracks, tears, punctures, or other means by which leaked product could escape from the site. Figure 4-2 shows a diagram of a cutoff barrier used in a high groundwater area.

Cutoff barriers are typically constructed of soil cement, bentonite, or a soil/bentonite slurry. However, it is possible to construct barriers of synthetic membranes or clays. These materials are discussed in Section F of this chapter.

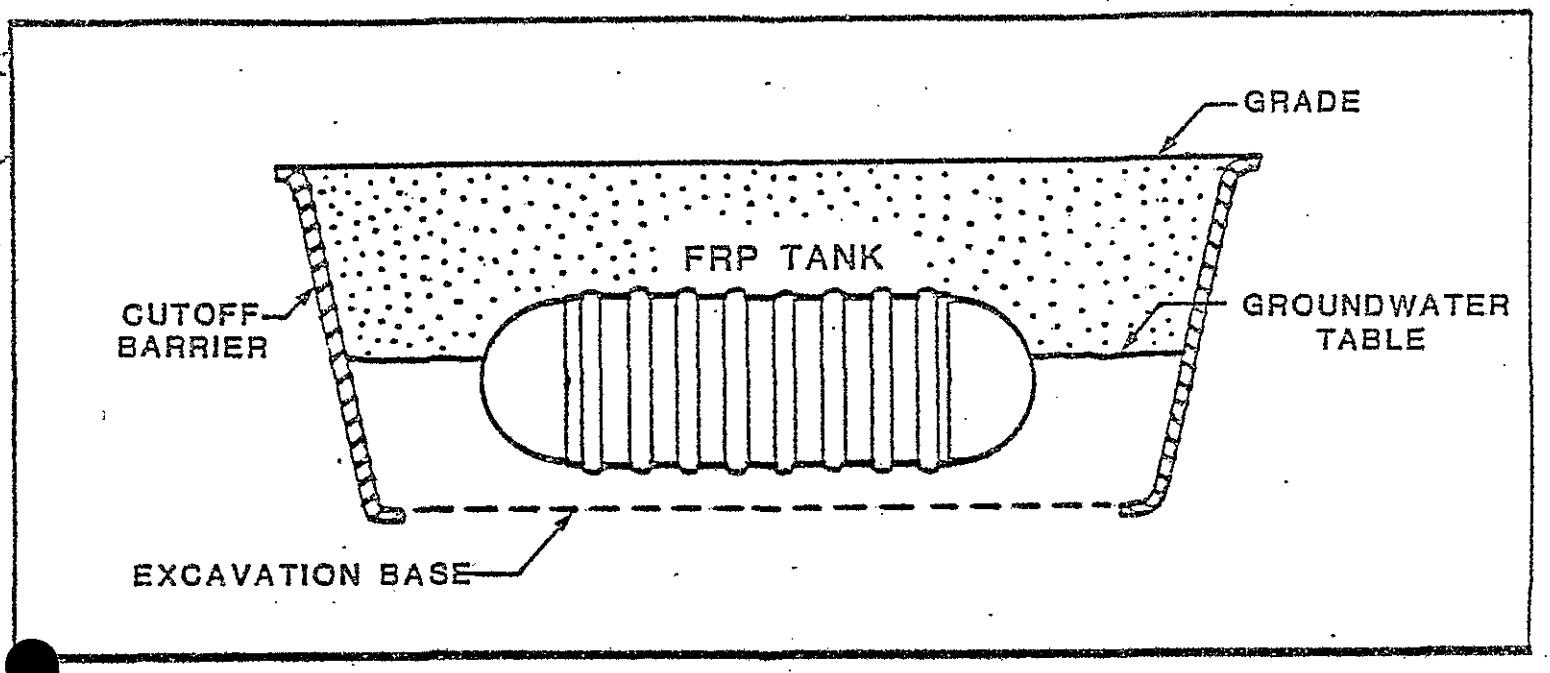
2. Excavation Liners

Continuous containment liners, or excavation liners, are suitable for secondary containment in areas of either low or high groundwater. This type of liner is installed along the perimeter (sidewalls) and bottom of the excavation before the tank foundation and tank are installed and backfilling is initiated; the intention of the liner is to catch and permit recovery of any product which is spilled or leaked at the site. The liner must be impervious to and chemically compatible with both water and the stored product, and it must be free of any holes, cracks, tears, punctures, or other means by which leaked product could escape from the site. The bottom of the excavation must be sloped with a minimum slope of ¼ inch per linear foot to a dry well or collection sump where any water or leaked product will drain to facilitate detection and allow for periodic removal.

In addition, the excavation must have a watertight cover which extends at least one (1) foot beyond each side and end of the excavation. This

FIGURE 4-2

SCHEMATIC OF A CUTOFF BARRIER USED FOR SECONDARY CONTAINMENT IN AN AREA OF HIGH GROUNDWATER



cover can be constructed of asphalt, reinforced concrete, or a similar material which provides the required protection from traffic, and should be sloped to drainways leading away from the storage excavation. The only openings in this cover should be those openings required for access to the tanks and any leak detection equipment, and these openings shall be provided with watertight caps.

If an excavation liner is to be installed in an area of high groundwater, that area must be dewatered until the liner, the storage tank and piping, and the backfill have been installed. In such an installation, the excavation backfill will apply pressure from its weight which will more than offset the pressure or buoyant force exerted by groundwater once dewatering has been terminated. In short, the weight of the backfill helps ensure the integrity of the excavation liner.

A properly designed and installed excavation liner should enable the operator to monitor the entire tank battery from one monitoring well. The drawback of this system is that it sacrifices the ability to distinguish exactly which tank is leaking in a multi-tank storage facility because the entire excavation drains to a common sump.

Excavation liners can be constructed of synthetic membranes, bentonite, clay, or soil cement. The selection of the appropriate material depends upon the chemical characteristics of the stored product and the site-specific economics of these various materials. The characteristics of these storage materials are described in Section F of this chapter.

Figure 4-3 shows a diagram of secondary containment using an excavation liner in an area of low groundwater.

3. Trough Liners

In areas where the high groundwater level is below the bottom of the tank, a sloped, trough shaped liner can be installed under each tank as shown in Figure 4-4. The trough liner may be used with a single monitoring and recovery well at the sump hole of each trough, or with a U-tube leak detection system in each trough.

In addition, the excavation must have a watertight cover which extends at least one (1) foot beyond each side and end of the excavation. This cover can be asphalt, reinforced concrete, or other material which is sloped to drainways leading away from the storage excavation. The only openings in this cover should be those openings required for access to the tanks and any leak detection equipment; and these openings shall be provided with watertight caps.

The excavation liner enables the operator to monitor the entire tank battery from one monitoring wall. The drawback of this system is that it sacrifices the ability to distinguish exactly which tank is leaking since all of the tanks drain to a common sump.

Figure 4-3 shows a diagram of secondary containment using an excavation liner in an area of low groundwater.

3. Trough Liners

In areas where groundwater is below the bottom of the tank, a sloped, trough shaped liner can be installed under each tank as shown in Figure 4-4. The trough liner may be used with a single monitoring and recovery well at the sump hole or with a U-tube leak detection system.

The design and installation criteria (slope of liner, requirements for watertight cover, need for periodical removal of sumpage, etc.) are same as discussed above for excavation liner.

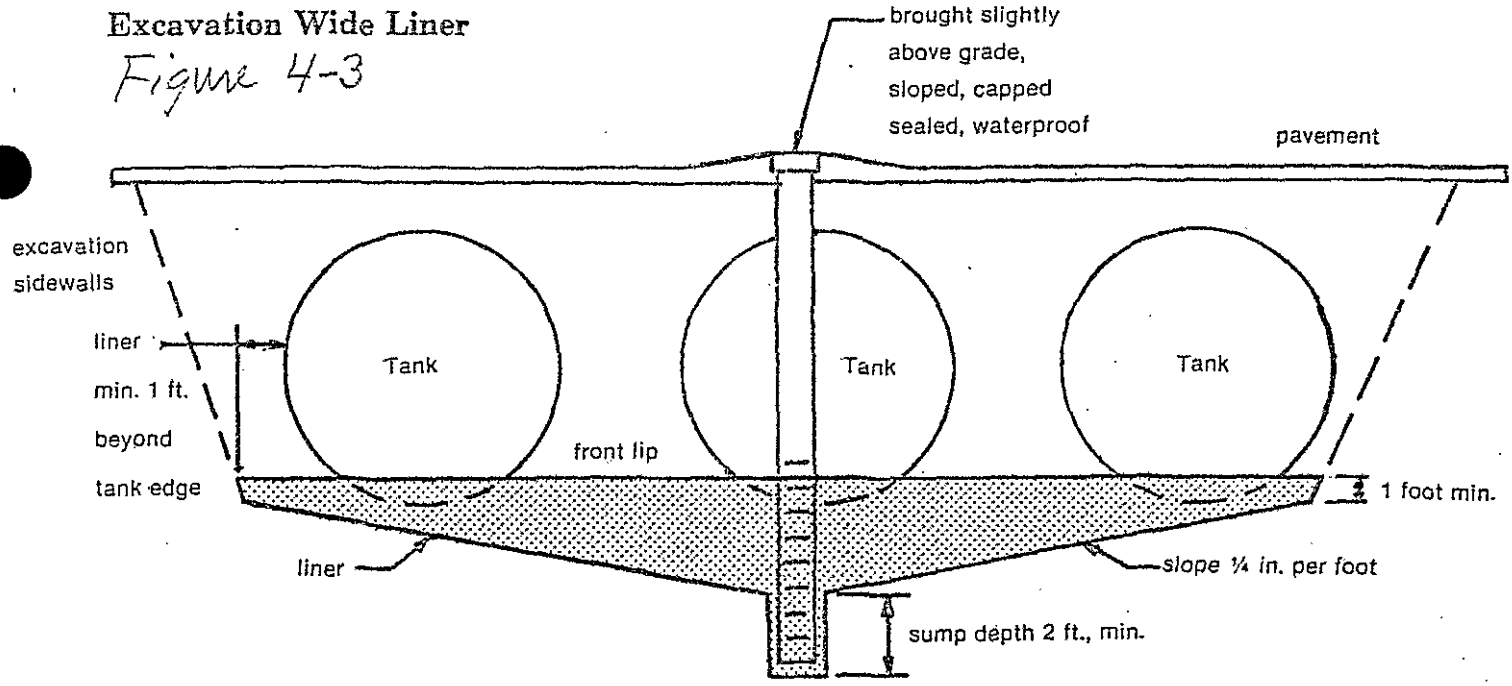
This system is similar to the excavation liner system except that each tank has its own trough and monitoring well and therefore can be checked separately for leakage.

4. Bag Containment

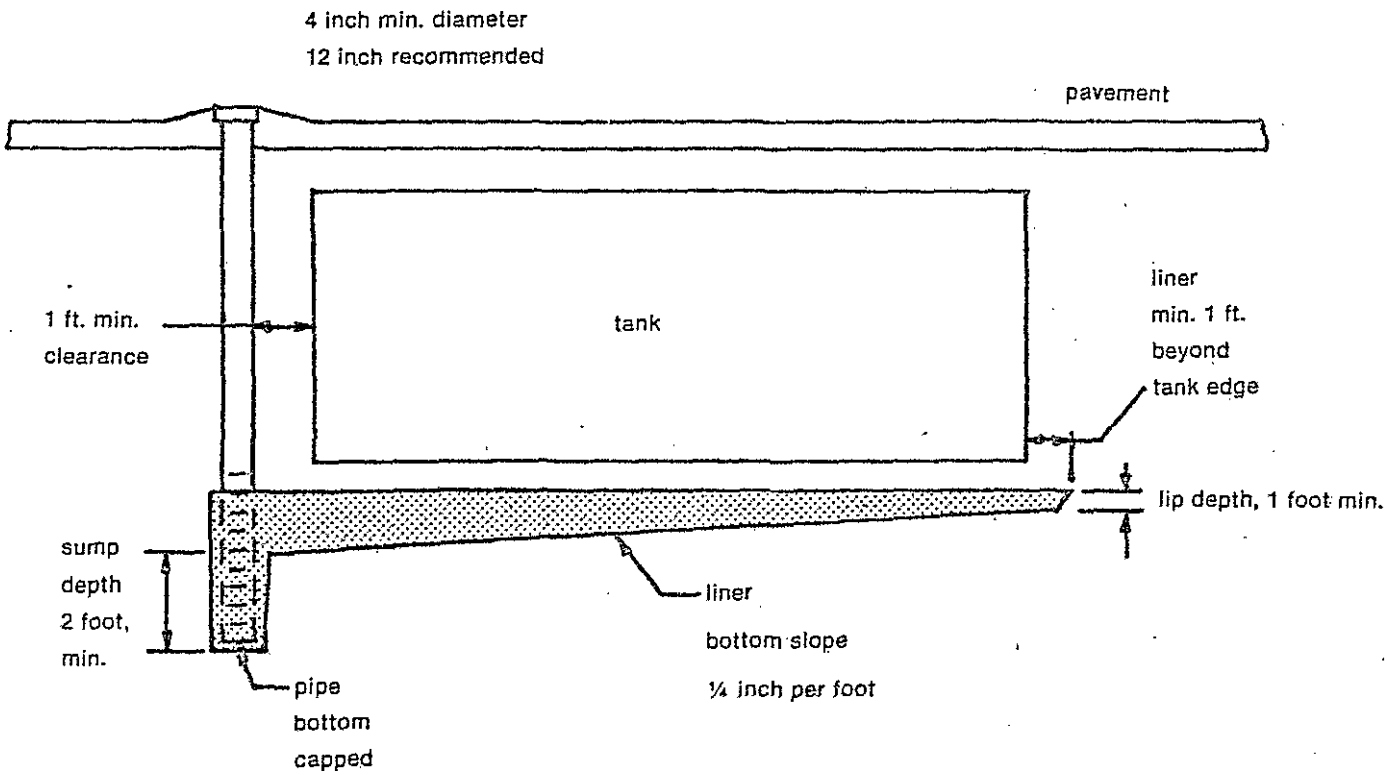
Tank bags as shown in Figure 4-5, can be used in any groundwater situation. The tube shaped bags are loosely fitted over the tank and sealed at the end and where tank appurtenances and monitoring probe are attached. The bag will not be completely waterproof, but should the entire bag fill with water, there will be little buoyant force involved.

Excavation Wide Liner

Figure 4-3



End View



Side View

The design and installation criteria for a trough liner (e.g., the slope of the liner, requirements for watertight covers over openings in the storage area, the need for periodic removal of sumpage, etc.) are the same as those presented above for excavation liners. This type of ~~containment~~ containment system is similar to the excavation liner system with the exception that each tank has its own trough and monitoring well. In such an arrangement, the source of a leak in a multi-tank storage facility can be more readily identified.

In a storage system with trough liners, care must be taken to ensure that the floor of the multi-tank storage facility presents a continuous barrier to the loss of stored product. In essence, this type of system is an excavation liner with individual troughs and monitoring and recovery wells for each storage tank.

E. Sites With Impervious Soils

If the native soils of a particular site have very low permeability they can form a natural barrier to the migration of leaked petroleum products, and be used as a containment material. Therefore, if in-site field permeability tests and other geological investigations show that soils are impermeable and areawide in extent, and there are no outcroppings of bedrock or other conduits for the escape of leaked product, no additional containment lining is required. Possible exceptions to this include the storage of highly toxic material and/or storage in environmentally sensitive areas.

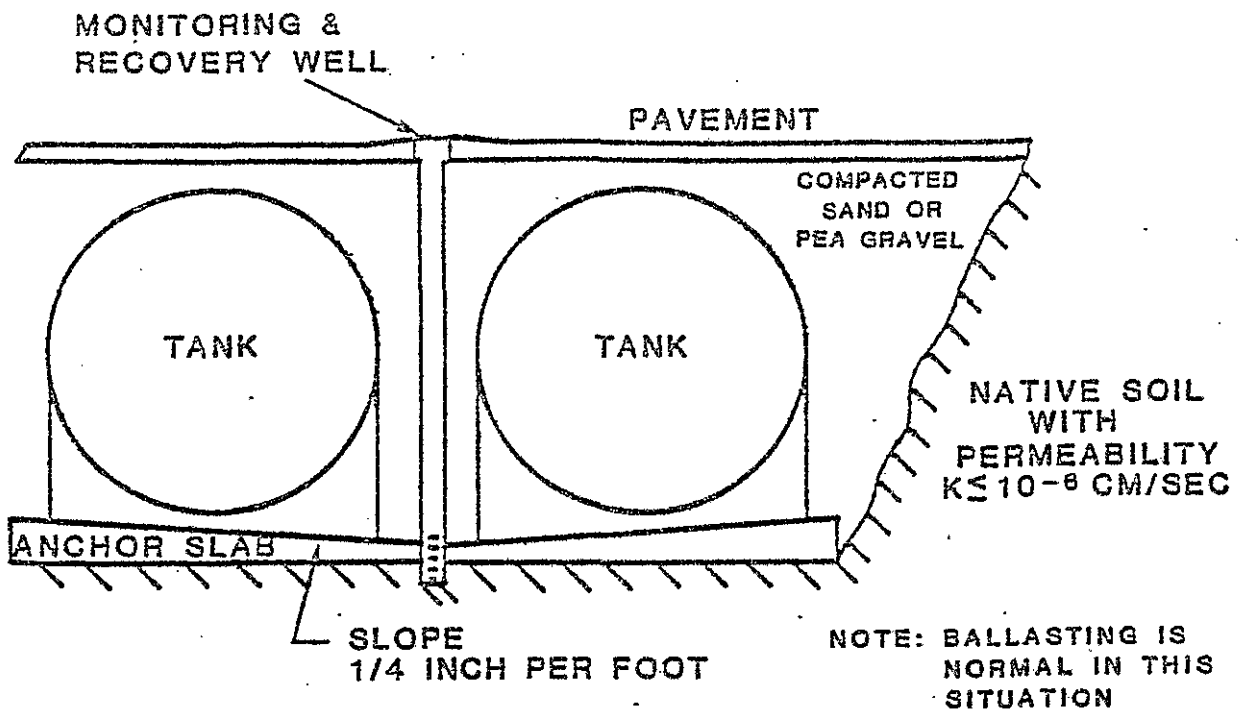
Permeability Guidelines

1) 0.035 inch/day ($1X10^{-6}$ cm/sec) for facilities located within recharge areas designated "sole source aquifers".
2) 0.35 inch/day ($1X10^{-5}$ cm/sec) for facilities located elsewhere in the state.

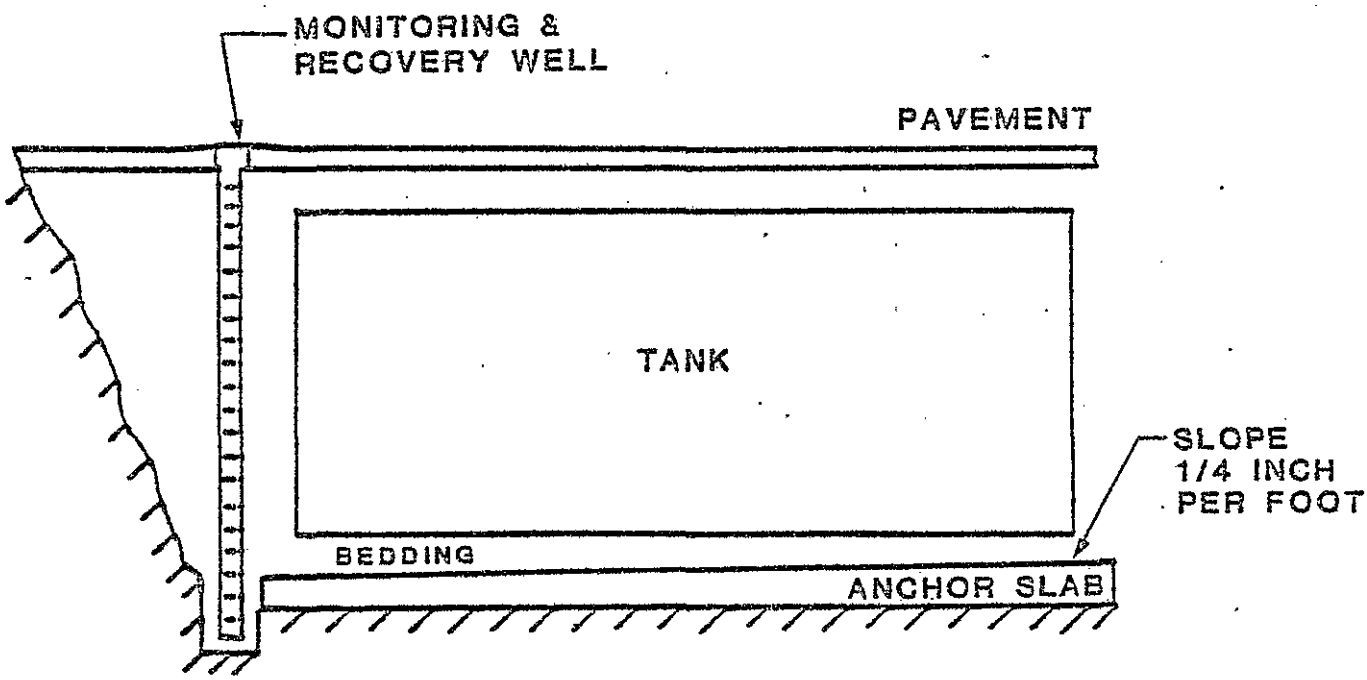
Because any excavation will tend to fill ~~the~~ with water during ~~exposure to weather~~ wet periods, certain construction steps are necessary in a storage facility in soils of this type. These include: (1) the installation of a watertight cover over the tanks for draining surface water away from the excavation; and (2) the installation of a well which will serve as both a monitoring well and recovery well. Figure 4-5 shows the construction details for a typical installation in impermeable soils.

FIGURE 4-5

CONTAINMENT IN NATIVE IMPERMEABLE SOILS



END VIEW



SIDE VIEW

F. Liner Material and Installation Practices

The materials which are satisfactory for the construction of cutoff barriers or containment liners include the following:

- Clay.
- Synthetic membrane liners.
- Concrete.
- Soil sealants, such as soil cement or bentonites.

The properties and installation requirements of these materials are discussed briefly below. More information on these materials is available in the Department manual entitled Technology for the Storage of Hazardous Liquids, A State-of-the-Art Review [1]. ~~and the references cited therein.~~

1. Clay Liners

Due to its general availability in many areas and relatively low cost, clay is often considered the first choice for a secondary containment liner. If the clay has a permeability rate of 1×10^{-6} cm/sec or lower and is installed properly, a clay liner will provide a suitable barrier against migration of a groundwater contaminant. The factors which influence the performance of clay liners include the following:

- Compatability with the stored product, particularly in the case of certain organic liquids
- Thickness of the clay.
- The shrink-swell potential of the clay.
- The plasticity of the clay.
- The moisture content, density, and degree of compaction of the clay.
- The angle of the excavation sidewalls.

It should be noted that some organic liquids degrade the mineral structure of clays and thus act to increase their permeability. This may be true

of some petroleum products. It is therefore important that the selection of a clay material for a particular application be based upon tests and investigations by an experienced soils chemist or soils engineer.

Before installing a clay liner, it is necessary to first drain and stabilize the excavation. After drainage, the liner is then laid in place and properly compacted at optimum moisture level. The layer of clay should be at least 6 inches deep and compacted to 95% of Standard Proctor. If the soils engineer recommends a clay liner that is more than 6 inches thick, it should be applied in layers no greater than 6 inches to ensure proper compaction. The installation of clay liners is a complex operation and requires the supervision of a field engineer and a trained contractor to ensure high levels of quality control.

2. Synthetic Membranes

Synthetic membrane lines are ~~typically~~ polymeric materials which are manufactured in sheet form. Two criteria are critical for successful liner applications. The first of these is chemical compatibility. The choice of liner materials which can successfully withstand long-term exposure to petroleum and petroleum derivations is limited. The second important criteria is proper installation. Liners must be installed so there are no pressure points where the liner can tear or be punctured.

As a class, synthetic membrane liners have several advantages and disadvantages. Their advantages include the following:

- There are a wide variety of liner materials, each with individual qualities for specific applications.
- They have a good resistance to bacterial deterioration.
- They are relatively economical to install~~, and maintain.~~
- They can be used in many containment designs.

In general, the disadvantages of synthetic membrane liners include the following:

- They may be vulnerable to attack from some chemicals, ozone and ultraviolet light (sunlight) when compared to other lining materials.

- They have a limited ability to withstand heavy loads.

- They are difficult to properly install and are susceptible to laceration, abrasion, and puncture.

- They are prone to cracking at low temperatures, and stretching and distortion at very high temperatures.

The most suitable liners for petroleum storage are high density polyethylene, oil resistant polyvinyl chloride, and neoprene. However, there is much research being done in this area, and new products with better chemical resistance to petroleum and petroleum derivatives are ~~likely to be~~ being developed. ~~in the future.~~

The manufacturers of specific synthetic membranes should be consulted on material selection and should provide the storage facility owner with written assurances that the selected material, under long-term exposure, is compatible with the product to be stored and suitable for use in underground soil environments.

The proper installation of a membrane liner is as important to the overall success of the application as material selection. Liner installation is a relatively complicated task that should be performed by a qualified contractor, with attention given to important details such as the following:

- The base of the excavation should be compacted to prevent settling under the liner and tank after they are in use.

- The slopes of the excavation walls and floor should be stable to avoid collapse after the liner has been installed.

- The base and sidewall areas that will contact the membrane should be finely finished. All rocks, rubble and debris which could puncture the lining should be removed. Sand layers should be placed above and below the membrane to further prevent punctures and to facilitate underdrainage.

- The liner should be carefully placed and seamed (bonded) in accordance with manufacturers' specifications.

Considerations During Synthetic Liner Placement

Use a qualified installation contractor having experience with membrane liner installation, preferably the generic type of liner being installed.

Plan and implement a quality control program which will help ensure that the liner meets specifications. Inspections should be documented for review and recordkeeping.

Installation should be done during dry, moderately warm weather if possible.

The excavation base and wall should be firm, smooth, and free of sharp rocks or debris.

3. Concrete

Concrete, if sprayed with a chemically resistant coating, is sufficiently impermeable to be used as a leak or spill containment material. A 6 inch slab constructed with an inexpensive 2500 psi concrete mix is adequate for this purpose.

A concrete pad properly sloped to collect a leak or spill can serve not only as a containment structure but also as foundation and anchor for the tank.

4. Soil Sealants

Bentonites are excellent soil sealants when properly designed and when installed under the supervision of an experienced engineer.

Bentonites are naturally occurring inorganic swelling clays which are usually chemical treated. They are marketed under various trade names. Mixtures of soil and chemically treated bentonites may be used to line

excavations for underground tanks and contain spills. When the bentonite is mixed with a sandy soil and saturated with water, the granular bentonite particles in the soil swell to fill the voids, thereby forming an impermeable barrier.

Before installing a bentonite liner, it is necessary to first drain and stabilize the excavation. The mixture of soil and bentonite is then used to line the walls and bottom of the excavation. The mixture is typically wetted to saturation, and compacted using a wobble wheel or steel wheel roller. When preparing the bentonite mixture, the manufacturer's recommendations should be followed as to the percent of the clay and soil, the amount and quality of water used for wetting, and the degree of compaction required.

Recent research has shown that the impervious qualities of bentonites may degrade upon exposure to certain organic solvents. Therefore it is imperative that an experienced soils chemist or soils engineer be involved during the liner material selection process to ensure that product containment will be sufficient.

5. Soil Cement

Soil cement is a compacted mixture of Portland cement, water and selected in-place soils. The result is a low strength concrete with greater stability than natural soils. The permeability of this mixture varies with the type of soil used -- a more granular soil produces a more permeable soil cement.

Soil cement is a suitable lining material for underground liners in some instances. However, caution should be used under the following conditions:

- Highly organic soil retards cement hydration because of absorption of calcum ions.
- Clean, well-graded gravels and crushed rock are sometimes unsuitable because of shrinking problems.

- Clays can be unsuitable because of the difficulty of mixing a fine cement powder into a wet, cohesive clay, and because the clay's properties are not significantly changed.

- Saline soils require a much larger cement content.

In general, soil cements are more permeable, but less expensive, than bentonites, clays or synthetic membranes.

Highlights of Soil Cement Design and Installation

- Preparation of the base walls is extremely important. The base wall should be properly finished, and well moistened before placing the concrete to prevent the liner from drying too quickly.

- Concrete mixes should be plastic enough to consolidate well, but not stiff enough to slip on slide slopes.

- Proper curing of the liner is important.

References

1. New York State Department of Environmental Conservation, Technology for the Storage of Hazardous Liquids, A State-of-the Art Review, New York State Department of Environmental Conservation, Division of Water, Bureau of Water Resources, 50 Wolf Road, Albany, New York 12233, January 1983.

2. Petroleum Association for Conservation of the Canadian Environmental (PACE) Report No. 79-2 State of the Art Review: Petroleum Product Containment Diking, PACE, Suite 400, 130 Albert Street, Ottawa, Ontario K1P5G4.

3. U.S. Environmental Protection Agency, Lining of Waste Impoundment and Disposal Facilities, SW870, USEPA Municipal Environmental Research Laboratory, Cincinnati, Ohio 45268, September, 1980.

4. Jewett, M.A., Buyce, M.R., A Review of Methods for Determining the Permeability Characteristics of Colorado Soils Exposed to Hazardous Waste, prepared by Fred C. Hart Associates, Inc., prepared for U.S. Environmental Protection Agency, Region VIII, 1860 Lincoln Street, Denver, Colorado 80295, June, 1981

CHAPTER 5:

STORAGE TANK REHABILITATION

> Under certain conditions, a used underground storage tank may be rehabilitated by installing an interior lining as prescribed in the Bulk Storage Code, and pursuant to manufacturers' specifications.

This chapter presents recommended practices and guidelines for the interior lining, or rehabilitation, of steel and fiberglass-reinforced plastic (FRP) underground storage tanks. The interior lining of tanks can be an effective means of tank repair which can extend the usable life of a tank.

The activities associated with the rehabilitation of underground storage tanks include: (1) freeing the tank of all hazardous liquids and vapors; (2) cleaning the interior surface of the tank and preparing it for coating; (3) plugging or patching holes in the tank; (4) relining the tank interior; and (5) closing and sealing the tank. These activities are discussed below, with guidelines and recommendations given for repairing steel and FRP storage tanks. Table 5-1 lists sources of technical assistance for safely carrying out these activities. In addition, the American Petroleum Institute has recently published recommended practices for tank relining [8].

A. General Safety Precautions

Personnel and general public safety are critical considerations during any procedures that involve opening and entering a tank that contained hazardous liquids. The following subsections descibe safety precautions which the Department recognizes as prudent and necessary for the rehabilitation of underground storage tanks.

Table 5-1

Sources of Information on Safe Tank Rehabilitation Procedures

API Publication 2015, Cleaning Petroleum Storage Tanks, Second E., 1976.

API Publication 2015A, Guide for Controlling the Lead Hazard Associated With Tank Entry and Cleaning, 1975.

API R.P. 2003, Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents, Third Ed., 1974.

NFPA 327, Cleaning Small Tanks and Containers.

NIOSH, Criteria for a Recommended Standard, Working in Confined Spaces. Dept. of Health, Education and Welfare. DHEW 80-106.

1. Preparations for Opening the Tank

Proper procedures for preparing the tank for opening and entry are essential to ensure the safety of all persons involved in the tank rehabilitation process. As such, the following are important:

- Controlling Sources of Ignition: All sources of ignition must be removed from the area surrounding the tank and vapor vents. All open flames and spark-producing equipment within the vapor exposure area must be shut down, and all electrical equipment used in the area must be explosion proof.

- Removal of Liquid Product: As much product and sediment or sludge as possible must be removed from the tank. Hand pumps should be used to remove residual product which is below the level of the product pump.

- Removal of Flammable Vapors: The tank must be thoroughly purged of flammable vapors. Figure 5-1 shows several common types of tank ventilation ~~equipment~~ configurations.

- Testing Vapor Concentrations: After the tank has been vapor-freed, the flammability of the vapor remaining in the tank should be tested. Tank opening and entry operations should occur only after the vapor concentration is below 20% of the lower explosive limit (LEL).

Guidelines for these activities can be found in API Publication 2015, Cleaning Petroleum Storage Tanks [2].

2. Opening the Tank

If no manway or hatch exists, a hole with the minimum dimensions of 18" x 18" (22" x 22" maximum) can be cut in the tank top (steel) or tank end cap (FRP). The tank must be cut using an explosion-proof (such as air driven) saber saw or snipper using lubricating oil to reduce friction, heat and possible sparks. Prior to the final cut, the section must be supported to prevent its falling into the tank.

After the hole is cut, the tank vapors must again be tested to verify that the tank is still safe. The readings should be lower than 20% LEL.

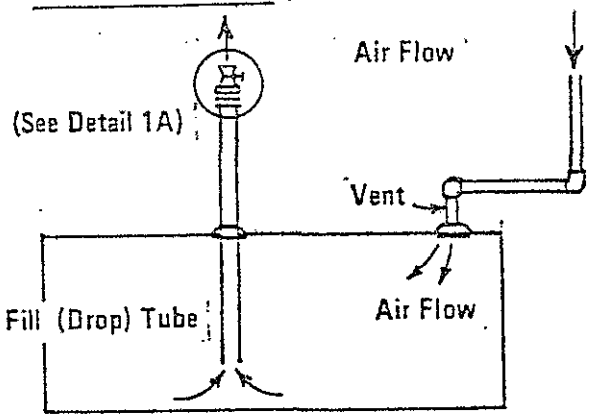
~~PAGE 14~~ Figure 5-1

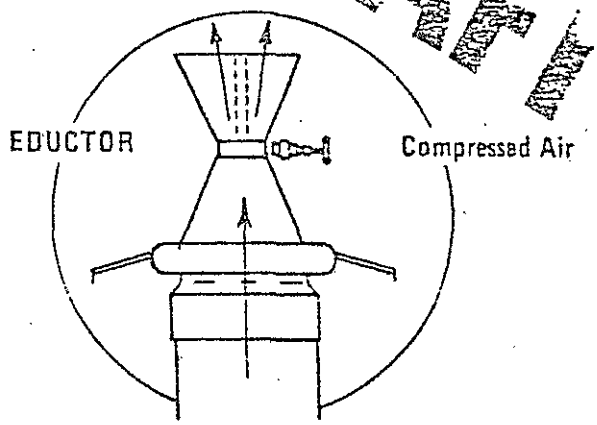
INTERIOR LINING OF STEEL UNDERGROUND STORAGE TANKS

DRAFT

TYPES OF TANK VENTILATION AIR MOVERS

EDUCTOR TYPE

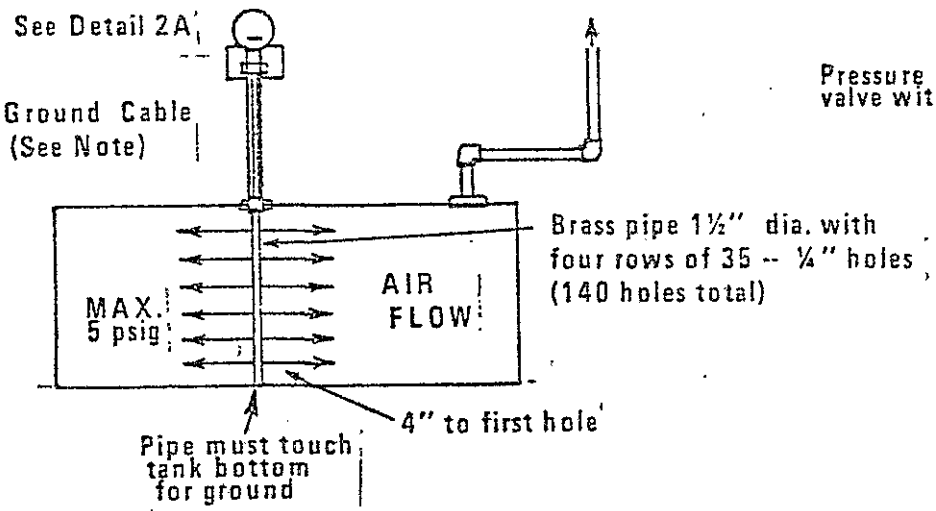


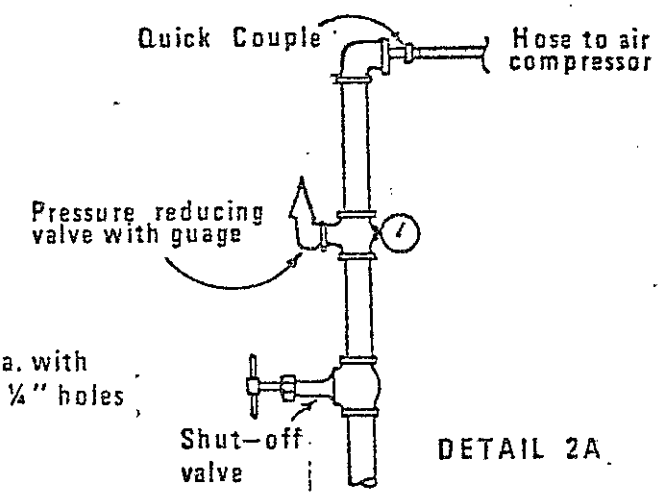


DETAIL 1A

FIGURE 1

DIFFUSED AIR BLOWER





DETAIL 2A

NOTE: Ground cable brazed to pipe must be clamped to fill pipe. Use 12 gauge ground wire from fill pipe to water pipe or ground rod.

FIGURE 2

LOW PRESSURE AIR BLOWER

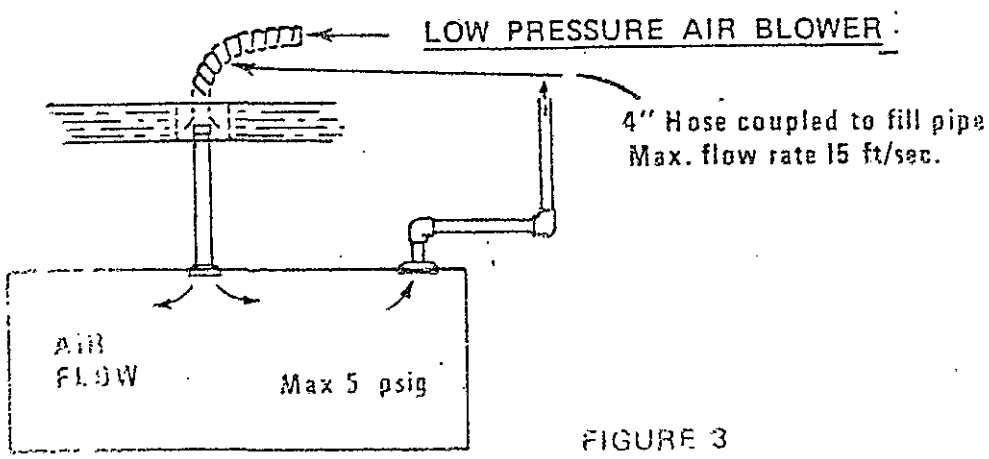


FIGURE 3

3. Tank Entry

Persons entering an underground tank for rehabilitation activities should be equipped with positive air displacement equipment with full face-mask at all times. Such persons should also wear a safety harness which is connected to a safety line held by an attendant outside the tank. The clothing worn by any personnel entering a tank should consist of the following:

- Cotton or other non-static producing fabric that covers the arms, legs, torso, and head.
- Oil, water and chemical resistent boots.
- Oil, water and chemical resistant gloves.

It is important that vapor freeing and tank ventilation operations continue while personnel are in the tank. If the tank is perforated, product or fumes that have leaked out may re-enter the tank through the perforations.

B. Rehabilitation of Steel Tanks

1. Conditions for Rehabilitation

A steel tank may be relined, or rehabilitated, only if it meets the conditions given in the box below. If the tank does not meet these structural requirements, it is unlikely that rehabilitation operations will be successful. If these structural requirements cannot be met, the tank's service life is over. It cannot be relined or reused.

A steel tank may be relined or rehabilitated only if it meets the following structural conditions:

- It has a minimum shell thickness of 0.18 inch (7 gauge).
- It has no open seam or split longer than 3 inches.
- It has less than ten (10) holes with none larger than one-half inch in diameter.
- It meets all the standards of the lining manufacturer for structural soundness.

A tank which fails to meet these requirements must be removed or abandoned except as provided by the Bulk Storage Code [1].

To determine adherence to these requirements, the interior surface of the tank must be tapped by a ballpeen hammer to investigate for soundness. Weak areas, holes, and seams must be ballpeen hammered to obtain structurally sound edges. Holes and seams must be reamed until the edges of the opening are a minimum of one-eighth (1/8) inch thick.

2. Preparation of the Tank Interior

Preparation of the tank interior includes procedures for sludge removal, if necessary, inspection of the tank surface, sandblasting of the tank surface, plugging of any perforations, and installation of striker plates.

Sludge Removal. Sludge which has accumulated in the tank constitutes a hazardous waste. It must be collected, placed in a tightly sealed container, and disposed of in accordance with Part 360 of the New York State Code of Regulations. Care should be taken during sludge removal operations to avoid causes of sparks or sources of ignitions.

Surface Inspections. After any sludge has been removed, the tank interior surface should be carefully reinspected to ensure that the tank meets the structural requirements for rehabilitation given above.

Sandblasting. The entire internal surface of the tank must be sandblasted completely free of rust, scale, and other foreign matter in accordance with the Steel Structures Painting Council Specification SPCC-SP 5-63 (S.S.S.a3) (White Metal Blast Cleaning). A White Metal Finish is defined as a surface with a gray-white uniform metallic color, slightly roughened to form a suitable surface for coatings. Following sandblasting, the entire surface must be brushed and vacuumed such that the surface is free of all moisture, oil, grease, dirt, visible mill scale, rust, corrosion products, oxides, paint, or other foreign matter.

Temporary plugging of all holes and splits in the tank may be necessary prior to sandblasting to preclude re-entry of product liquids or vapors during the sandblasting operations. Temporary repairs can be made with non-corrosive plugs made of teflon or nylon for holes, and hydraulic cement for seams or splits.

Permanent Plugging. After sandblasting, all perforations and open or split seams should be permanently repaired as follows:

- All perforations must be plugged with boiler plugs made of non-corrosive plastic. These boiler plugs must be covered with a laminate of resin and fiberglass cloth which overlaps all sides of the plug by at least two (2) inches.

- Open seams may be plugged with hydraulic cement. Seams repaired in this manner must be covered with either a laminate of resin and fiberglass or a steel plate which is bonded in place. The plate should have a thickness of 7 gauge (0.18 inch) or more and must extend beyond all sides of the hole or split by six (6) inches. A laminate of resin and fiberglass cloth must cover the plate with a minimum overlap of two (2) inches.

Installation of Striker Plates. Prior to the application of an interior coating, striker plates, if not present and in satisfactory condition, should be installed under all tank access openings, such as the fill and gauging tubes. These striker plates are necessary to prevent or limit future damage to the tank, such as that which could be caused by dipsticking.

Each striker plate should be a one-quarter (¼) inch steel plate rolled to the contour of the tank with minimum dimensions of twenty (20) inches by twenty (20) inches. This plate size will help reduce both dipstick damage and blast erosion from product delivery. Each plate must be bonded to the tank and must be covered with a laminate of resin and fiberglass cloth.

3. The Interior Tank Lining

> The coating which is used to line the interior of the tank must maintain a permanent bond to the tank, and must form a hard impermeable shell which will not crack, wear, soften, or separate from the tank surface for a period of at least ten (10) years.

The material which is used to coat the interior surface of the tank must be guaranteed to last for a minimum of ten (10) years. This material must maintain a permanent bond with the steel surface of the tank, and it must be of sufficient thickness, density, and strength to form a hard, impermeable surface which will not crack, wear, or soften.

The Department does not specify minimum thicknesses in this manual because the minimum thickness requirements will vary with the coating material chosen. However, the coating material must be chemically compatible with the stored product. It must also have a coefficient of thermal expansion which is compatible with steel so that stress due to temperature changes will not be destructive to the coating or the coating-to-steel bond.

> The coating material must be applied in strict accordance with manufacturer's specifications.

The coating material must also be applied as soon as possible after the tank surface has been cleaned and sandblasted, so as to avoid accumulations of dirt, grit, rust, or moisture. The Department recommends that not more than eight (8) hours elapse between surface preparation and application of the coating.

After application, the new lining must be tested for the presence of air pockets and pinholes. The Department recommends that an Elcometer Thickness Gauge or equivalent be used to check the coating thickness, and a Barcol Hardness Tester or equivalent be used to assure compliance with manufacturer's specifications for hardness. An electronic spark tester or equally effective device should be used to detect the presence of any holidays (holes or other defects) in the coating.

4. Closing the Tank

After the interior of the tank has been coated, all manways or accessways which have been used to enter the tank must be closed and sealed properly to prevent future losses of product or product vapors. To accomplish this, the Department recommends the procedures described in the following paragraphs, and illustrated in Figure 5-2.

If the tank had a manhole, the manhole cover gasket must be replaced with a new one before resealing.

If an opening had to be cut to enter the tank, this opening should be sealed using these procedures:

- A 1/4 inch thick steel cover plate, rolled to the contour of the tank, must be made to overlap the hole at least two inches on each side.
- The cover should be used as a template to locate 3/4 inch diameter holes on five inch centers, one inch from the edge of the cover.
- The cover plate should be sandblasted to the standard set forth above. Both sides and the entire inside surface must be coated with coating material to act as a gasket.
- Before the coating on the cover cures, the cover must be fastened to the tank using 1/2 inch (minimum) diameter bolts. The bolt shafts are to be placed through the holes from the inside of the tank and held in place by spring clips, then fastened with lock washers and nuts which have been dipped in a seam sealer.
- After being bolted to the tank, the cover plate and surrounding tank surface must be properly sandblasted, coated with coating material, and allowed to cure before backfilling the tank excavation.

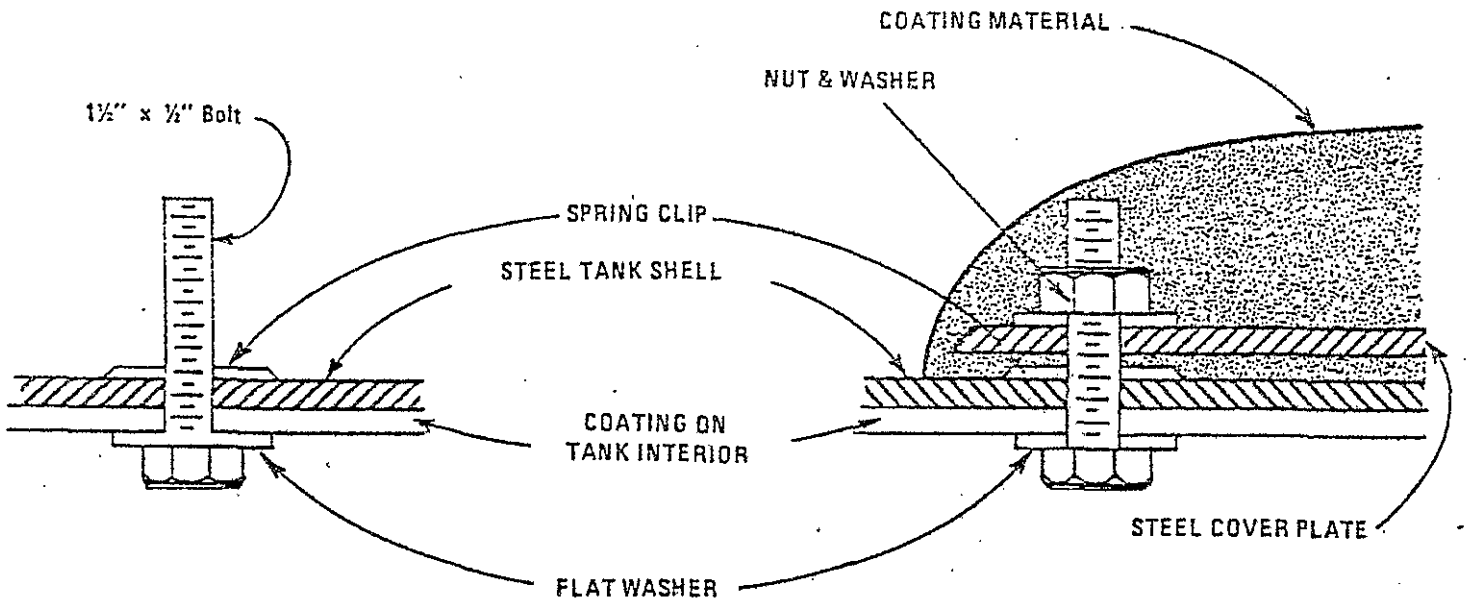
~~PAGE 15~~ Figure 5-2

INTERIOR LINING OF STEEL
UNDERGROUND STORAGE TANKS

DRAFT

Figure 4

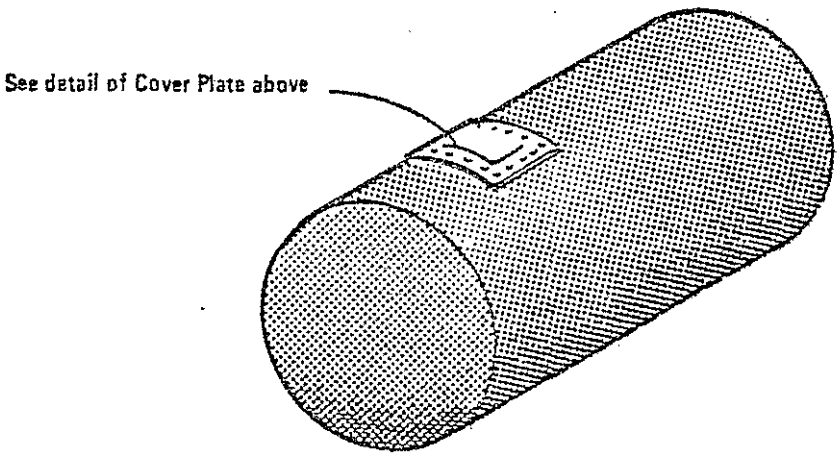
INSTALLATION OF TANK COVER PLATE



WITH BOLT IN PLACE PRIOR TO COVER INSTALLATION

WITH COVER BOLTED IN PLACE

CROSS SECTION



5. Tightness Testing

Once the tank has been coated and closed, and before backfilling has occurred, the tank should be pressure tested to insure that all plugging, patching, coating, and sealing procedures have been effective. The Department recommends that the tank be soaped and pressure tested at a pressure of 5 psig for a minimum period of one hour to ensure tank integrity.

> A Precision Test is the best method to certify to the tank owner that the storage tank is liquid tight when it is placed back in service (see Chapter 8).

C. Rehabilitation of FRP Tanks

> The repair of FRP tanks must be conducted by experienced field personnel in strict accordance with manufacturers' specifications and guidelines.

1. Conditions for Rehabilitation

The primary criteria typically used to determine whether an FRP tank should be repaired or replaced is economics. One should compare the cost of time and materials for repair to the cost of purchasing and installing a replacement tank. In some cases, the cost of repair may be greater than the cost of replacement.

There may also be some instances in which the structural damage to a tank is so great that repair is not feasible or practical (as well as prohibitively expensive). In such instances, replacement of the tank is the only path to continued operation. Before rehabilitation of an FRP tank is attempted, the tank manufacturer should be consulted to determine if repair operations will result in a tank that continues to meet Department standards.

2. Repair Procedures

The repair or rehabilitation of fiberglass-reinforced plastic tanks typically involves patching holes or cracks in the tank shell or end caps, or repairing or replacing crushed or cracked ribs. In any activity of this type, close adherence to manufacturer's specifications is a necessity. The Owens-Corning Fiberglas Corp. Field Service Manual [7] is an excellent reference on this subject.

The repair of cracks or holes in the shell or end cap of a FRP tank involves the following steps:

1. Surface Preparation. The surface which is to be repaired must be cleaned and roughened so that bonding with new resin material will be facilitated. Typically, the damaged surface is ground or sanded to give it a rough surface, and then solvent cleaned to remove all dust and other foreign matter.

2. Patching the Damage. The crack or hole must be covered, patched, or bridged with an approved material, such as a resin-impregnated fiberglass mat. The objective is to cover the damaged area effectively with a material that can be adequately bonded to the tank.

3. Curing the Patch. The patch or mat used to cover the damaged area is allowed to cure to bond itself to the tank. After this step, the repair is basically complete.

In preparing the surface and patching the damaged area, it is typical to extend the area of repair beyond the area of damage. For example, in repairing small (less than 4 inches in diameter) holes in FRP tanks, Owens-Corning Fiberglas Corporation directs their repair teams to grind (roughen) the surface at least 6 inches beyond the damaged area in all directions, and to ensure that the patch that is used extends 4 inches beyond all sides of the damage [7].

The repair of damaged ribs requires similar steps, with the exception that the patch or replacement piece used must be in the original shape of the rib. This ensures that the repaired rib will supply proper structural support for the tank when it is under operational loads.

References

1. The Bulk Storage Code.

2. American Petroleum Institute, Cleaning Petroleum Storage Tanks, API Publication 2015, American Petroleum Institute, 2101 L Street, N.W., Washington, D.C. 20037, November 1976.

3. American Petroleum Institute, A Guide for Controlling the Lead Hazard Associated with Tank Cleaning and Entry, API Publication 2015A, First Ed., American Petroleum Institute, 2101 L Street, N.W., Washington, D.C. 20037, May 1975.

4. National Fire Protection Asociation, Cleaning Small Tanks and Containers, NFPA No. 327, National Fire Protection Association, Batterymarch Park, Quincy, MA 02269, 1975.

5. American Petroleum Institute, Cleaning Mobile Tanks in Flammable or Combustible Liquid Service, API Publication 2013, Fifth Edition, American Petroleum Institute, 2101 L Street, N.W., Washington, D.C. 20037, October 1975.

6. New York State Department of Environmental Conservation, Technology for Storage of Hazardous Liquids, A State-of-the-Art Review, New York State Department of Environmental Conservation, 50 Wolf Road, Albany, New York 12233.

7. Owens-Corning Fiberglas Corp., Field Service Manual, Bulletin 1, Owens-Corning Fiberglas Corp., Non-Corrosive Products Division, Fiberglas Tower, Toledo, Ohio 43659, October 1975.

8. American Petroleum Institute, Recommended Practice for the Interior Lining of Existing Steel Underground Storage Tanks, API Publication 1631, American Petroleum Institute, 2101 L Street, N.W., Washington, D.C. 20037, 1983.

CHAPTER 6:

RECOMMENDED PRACTICES FOR TANK CLOSURE AND ABANDONMENT

The use of proper procedures for the temporary or permanent closure of underground storage tanks is important to prevent environmental contamination and to insure the future safety of the site.

A. Introduction

Table 6-1 lists some of the environmental and safety concerns that are associated with the proper closure of underground storage facilities. The options available for temporary or permanent closure of such storage systems are as follows:

- Temporary closure: the tank and piping system are emptied and sealed so as to be "temporarily out of service."
- Abandonment in place: the tank and piping system are emptied and sealed, and the tank is filled with an inert material.
- Removal for reuse or disposal: the tank and piping systems are removed from the ground after being emptied.

The remainder of this chapter further describes these alternatives and presents recommended practices for each.

B. Temporary Closure

1. General Description

Underground storage tanks may be considered temporarily closed or "temporarily out of service" if: (1) they are idle and in sound condition, and will be returned to service; (2) they are awaiting abandonment in place; or (3) they are awaiting removal from the ground. These are tanks that are intended to be returned to service within two years or are scheduled for abandonment or removal within 90 days.

Table 6-1

Important Considerations in Storage Tank Closure

- Product that is left in the bottom of the tank (e.g., below the withdrawal line) will eventually leak out, leading to potential environmental contamination and health hazard problems.

- Empty tanks left in place underground may be used for illegal storage or disposal of hazardous wastes.

- Improperly closed tanks may be accidently filled with a material that is incompatible with the previously storage material.

- Accidental intrusion into the abandoned tank site may occur. A classic example of such is children playing near an abandoned gasoline storage tank, where a casually discarded lit cigarette or match can lead to catastrophe.

- A tank may be accidentally reused in a sensitive application, such as for food product storage, without being properly cleaned and decontaminated.

- Tanks left empty in the ground may eventually collapse, causing ground subsidence.

- An empty, forgotten tank could pose a long-term threat, such as a threat of explosion, if the site is excavated.

2. Recommended Practices

The Department recommends that any temporary closure of an underground storage system include the following steps:

1. Remove all product from the tank and piping system, leaving sufficient quantity in the tank (a minimum of 4 inches, a maximum of 6 inches) to assure a rich, non-explosive vapor mixture.
2. Use concrete cast in place to cap all fill and draw-off lines.
3. Leave the vent lines open.
4. Cut off the power to all tank pumps and dispensers.
5. Secure the storage area against tampering. Isolation of the storage area through the use of a locked fence is recommended where practical.

In lieu of leaving standing product in the tank to insure a non-explosive vapor atmosphere, one may fill the tank completely with a water solution containing a rust and corrosion inhibitor (to prevent rusting or corrosion of steel tanks). This practice would serve the same purpose of removing all fire and explosion hazards while preventing corrosion or rusting of steel tanks during temporary closure. However, one should be aware that if the tank is leaking at all, this water may be lost during the storage period.

C. Permanent Closure

1. General Discussion

The determination of whether to abandon a tank in place or remove it for reuse or disposal is dependent upon several factors, such as the age and condition of the tank, its salvage value, and its potential for reuse. Governmental regulations may require tank removal. Other factors that are important include the following:

- Tank Location. The depth to which the tank is buried and the type of soil in which it is buried will affect the ease, and hence, the cost, of tank removal. The potential for damage to concrete or asphalt traffic surfaces and nearby utilities should also be considered.

- Projected Use of the Site After Closure. If site plans call for development that involves excavation or regrading to the level of the tank, it is very likely that the tank will have to be removed.

- *The Cost and Availability of Labor and Equipment.* Tank removal will require the use of heavy equipment and experienced labor. If the cost of this labor and equipment is prohibitive, abandonment in place may be the preferred option.

- The Proximity of the Disposal Site. The proximity of the disposal site can also greatly affect the cost of tank removal. Tank transportation costs could be prohibitive, making abandonment in place the preferred option. Tanks which have contained leaded gasoline are considered a hazardous waste and must be disposed of accordingly.

- Regulatory Requirements. Local laws or ordinances may require removal of the tank as part of any permanent closure procedures.

- The Presence of Other Tanks. The presence of other tanks still in use in the same excavation could affect the decision. If, for example, the tank which is to be closed is adjacent to an FRP tank, it should be abandoned in place to prevent structural damage to the remaining FRP tank. See Section 7 below for more information.

> The New York State Bulk Storage Code requires that any new steel tank installation include cathodic protection and an exterior corrosion-resistant coating. Therefore, unprotected (bare) steel tank cannot be salvaged and reused in underground applications.

2. Abandonment in Place

Underground storage tanks may be effectively and safely abandoned in place through the following sequence of procedures:

1. Remove all liquid which can be pumped out of the tank and piping system. A hand pump or suction pump will be required to remove the bottom four inches of liquid from the tank.

2. Remove, or disconnect and plug all but one of the tank's fill, gauge, and product delivery lines. The remaining accessway will be used to add water to the tank.

3. Since petroleum products will float on water, the tank should be filled to overflowing with water and purged of any remaining product. When the floating residual product reaches the fill opening, suspend the filling operation, remove the floating product and the remaining water, and dispose of it properly (in accordance with Part 360 of the New York State Code of Regulations). Alternatively, tanks that are equipped with drop tubes need only be filled to a water depth of 1 foot (which should be sufficient to permit removal of residual product) before being pumped out.

   Flammable vapors will be expelled through the tank vent and remaining fill openings during this water-filling process. Purged product may also flow out of the tank opening if the tank is overfilled. Therefore, the entire operation should be considered hazardous, and precautions should be taken to prevent vapor ignition.

4. Dig down to the tank top at all fill and gauge openings and at connected lines.

5. Disconnect, empty, and cap all piping. Be particularly careful to avoid spilling product from the piping into the excavation.

6. Fill the tank with a solid, inert material such as sand, a combination of sand and earth, a concrete slurry, or grout. This fill material can be introducted into the tank through the manway (if one exists), the opening that was used to add and remove water (if large enough), or a hole punched in the tank top using a backhoe or other equipment. This operation should be considered hazardous, and precautions should be taken to prevent vapor ignition.

7. Disconnect and cap all vent lines.

8. Cover the tank with backfill material and grade.

Underground tanks being abandoned in place must be filled to prevent the subsidence that would accompany tank collapse. Sand is an ideal fill material because it will readily flow into the tank and it is generally available. Any type of sand is suitable as long as it is free of rocks which might prevent leveling out in the tank. The sand may be introduced into the tank in dry form as long as it flows in freely and, when the cone nears the top of the tank, can be washed into the tank with a nominal amount of water and puddled to cause it to flow to the ends of the tank. The use of extensive amounts of water should be avoided in this instance as the tank might be filled with water before it is filled with sand.

A combination of sand and earth can also be used to fill the tank as follows: (a) fill the tank with sand to approximately 80 percent of capacity; and (b) pour a free-flowing mud consisting of soil and water into the tank opening and puddle until the tank is full.

Concrete or grout slurries can also be used to fill tanks which are being abandoned in place. Depending upon site economics, such as the availability and proximity of materials and labor requirements, these options may be somewhat more expensive than using sand or earth fill. However, they will eliminate the need for puddling to ensure that the tank is completely full, and as such may be attractive alternatives in some instances. If one of these options is used, the tank drop tube must be removed before the tank can be pumped full of the slurry.

Detailed records should be maintained during all storage facility closure procedures. These records should include, at a minimum, the following information:

- The date of the closure operation.
- The as-abandoned location of the tank and piping which remain in the ground.
- The amount of product removed and the method of disposal (or use) of that product.
- The amount of water used (for product removal) and the method of (treatment and) disposal of that water.

The location of tanks abandoned in place should also be noted on the property deed.

3. Removal of Underground Tanks

The safe removal of underground tanks from storage facilities can be accomplished through the following procedural steps:

1. Remove all liquid from the tank. It will be necessary to use a suction pump or hand pump to remove the bottom few inches of product.

2. Remove the fill tube from the tank if one is present.

3. Disconnect the fill, gauge, vent and product delivery lines from the tank. Cap or plug the open ends of all lines. Remove all liquid from the delivery lines, using care not to spill any liquid into the excavation.

4. Remove all flammable or otherwise hazardous vapors from the tank using one of the following methods. Note that the use of any of these methods will result in the release of vapors to the surrounding environment. Hence safety precautions with regard to the handling of hazardous (especially flammable or explosive) vapors should be observed.

   (a) If the stored product will float on water, if water is available, and if there is a suitable means for disposing of wastewater, the tank may be overflowed with water to expel any remaining product and vapors. Any remaining product should be pumped out as the tank fills. Care should be taken to avoid spillage of product and exposure to product vapors if a flammability or toxicity hazard exists. Once all product and vapor have been removed from the tank, the contaminated water should be removed and disposed of in accordance with applicable state and local regulations. All tank openings should then be capped or plugged.

   (b) An alternate method would be to ventilate the tank with air, using a small gas exhauster (eductor) operated with compressed air (as from a portable compressor or other suitable means). The flow of air through an opening near one end of the tank and the discharge of the vapor-air mixture out an opening near the opposite end of the tank will remove any vapor present. The vapor concentration in the tank can be checked with a gas concentration indicator during the operation. When the tank is gas-free, cap or plug all tank openings. Note that any air hoses used during this procedure must be grounded to prevent static discharges.

   (c) Another method involves the use of solid carbon dioxide (dry ice) to purge flammable vapors and render the remaining tank gases inert. Dry ice should be introduced into the tank in the amount of 1.5 pounds per 100 gallons of tank capacity; the dry ice should be crushed and distributed evenly over the tank area to assure rapid sublimation. After all the dry ice has vaporized, all tank openings should be capped or plugged.

5. Remove excavation backfill to uncover the tops of the tank and any product lines.

6. The tank may now be uncovered and removed from the excavation.

Before the tank is moved from the site, be certain that all holes are plugged or capped. Use screwed (boiler) plugs to plug any corrosion leak holes. One plug should have a 1/8 in. vent hole to prevent the tank from being subjected to an excessive pressure differential caused by critical temperature changes.

Tanks should be removed from the premises as promptly as possible after these procedures have been completed, for the atmosphere in the tank will not remain gas-free indefinitely. If a tank remains at the site overnight, or longer, additional vapor may be released from liquid held in the scale or sediment in the tank. The vapor space should again be tested and the ventilation process repeated if necessary.

Extreme care must be taken in the offsite transportation of tanks which contained flammable vapors. All holes in the tank must be plugged and the tank positioned on the truck so that the plug having a 1/8" vent hole is located at the uppermost portion of the tank. All transportation regulations concerning hazardous materials must be followed.

Detailed records should be maintained during these operations. These records should include, at a minimum, the date of the operation, the methods of product and vapor purging, and the amounts of product removed and the method of disposal of any waste liquids.

4. Junking of Tanks

When tanks are no longer fit for the storage of flammable liquids or are considered junk, they should be disposed of. Whether sold to a junk or scrap dealer or discarded to an acceptable facility, sufficient holes should be made in tanks to render them unfit for further use.

When a tank is gas-freed it should be punctured with a pickax, chisel, or other heavy, sharp object; or many large holes may be drilled into it. When a tank is not gas-free it should be filled with water until overflowing and punctured, as above, while full of water.

As an added precaution, regardless of condition, the tank should be labeled in legible letters with the following information:

"Tank Has Contained Flammable Liquids
Not Gas-Free
Not Suitable for Food or Drinking Water"

Prior to the junking of tanks, the latest applicable waste disposal regulations should be checked to determine if special attention or preparation is required.

5. Reuse of Storage Tanks

Any storage tank that is reused for in underground storage facility must meet the requirements of the Bulk Storage Code for a new tank installed in such a facility. If the owner cannot guarantee a minimum tank life of 15 years, the tank should not be reused.

At a minimum, any tank which is to be reused must undergo a thorough internal cleaning and careful inspection of both the interior and exterior surfaces. Tank cleaning procedures will include water-filling of the tank to remove all residual liquid, and manual removal of any product sludge, rust, and scale that remains after the water and product have been pumped out.

In any tank cleaning operation, concern must focus on worker safety. Without proper safeguards and procedures, injury or property damage may result from one or more of the following:

- Explosion or fire.
- Oxygen deficiency.
- The presence of toxic liquids, vapors or dusts that are dangerous to breathe.
- Physical hazards such as slipping, tripping or falling objects.

For more information on the procedures involved in tank cleaning, the degree of hazard associated with these operations, and the precuationary steps that should be taken, please refer to the sources listed in Table 6-2.

The goal of any tank inspection is to determine if the tank has sufficient integrity to be put back into service. The internal and external surfaces must be thoroughly inspected to determine if any pinholes or evidence of structured damage are present. All seams should be carefully inspected for cracks or other signs of wear or decay. The thickness of the tank wall should also be checked to ensure that it meets or exceeds the requirements of the Bulk Storage Code.

The Department recommends that acoustical or ultrasonic testing equipment be used to inspect storage tanks for structural flaws. Spark testing equipment should also be used when coatings are present to detect pinholes or holidays in the coatings. More information on these types of equipment is available in the Department publication Technology for the Storage of Hazardous Liquids, A State-Of-The-Art Review [4].

In some situations, relining may be required to bring the tank in compliance with Department standards for reuse. Chapter 5 addresses tank rehabilitation in detail.

6. Storing Tanks for Reuse or Disposal

Used tanks that have been gas-freed cannot be guaranteed to remain gas-free because of the potential for the retention of liquid product (which may eventually vaporize) in crevices and under scale. It is therefore important that tanks stored for reuse or disposal be handled with caution. The recommended procedures for storing used tanks are listed below.

Tanks should be stored and secured where they can be safeguarded, usually on the locked premises of a tank user familiar with the hazards, or at another location where the general public will not have access. An open, fenced yard area, apart from other facilities, is desirable.

Table 6-2

References for Tank Cleaning Operations

API-2015
Cleaning Petroleum Storage Tanks

API-2015A
A Guide for Controlling the Lead Hazard Associated with Tank Entry and Cleaning.

ANSI-Z28.2
Standard Practice for Respiratory Protection.

API Pub. 2013
Cleaning Mobil Tanks in Flammable or Combustible Liquid Service.

NFPA 327
Cleaning Small Tanks and Containers.

NIOSH, criteria for a recommended standard, Working in Confined Space. DHEW 80-106.

These publications may be obtained from the following organizations:

API Publications:	American Petroleum Institute 2101 L Street, N.W. Washington, DC 20037 (202) 457-7173
ANSI Publications:	American National Standards Institute, Inc. 1430 Broadway New York, N.Y. 10018 (212) 868-1220
NFPA Publications:	National Fire Protection Association Batterymarch Park Quincy, MA. 02269 (617) 328-9230
NIOSH Publications:	National Institute for Occupational Safety and Health Public Health Service Center for Disease Control National Institute for Occupational Safety and Health

Before storing tanks, it is desirable to have them gas-freed via steaming or mechanical ventilation. If such facilities for gas-freeing are unavailable, tanks may be overflowed with water to expel vapors, and then drained.

Tanks will also become gas-free by natural ventilation if stored off the ground with all openings down and open for a protracted period. During this period of natural breathing caused by temperature change, the vapors may be within their flammable limits. To assure safe operations, the condition of the tanks should be indicated by a label or sign and they should be protected from unauthorized personnel during this period.

Any gas-freeing operations may release scale or sludge containing hazardous materials. Such scale or sludge must be carefully handled, and must be disposed of in accordance with applicable federal, state and local requirements.

Gas-free tanks may be safely stored with unplugged openings, but plugging of all openings is recommended to keep tank interiors clean.

In any of the foregoing cases where all tank openings are to be tightly plugged, screwed plugs should be used, and one plug should have a 1/8 in. vent hole to prevent the tank from being subjected to an excessive pressure differential caused by critical temperature changes.

The former contents and present vapor state of each tank, if known, or the gas-freeing treatment and date should be indicated by an appropriate label on the tank.

7. Abandoning Steel Tanks Adjacent to FRP Tanks

If the permanent closure of a steel tank which is adjacent to an FRP tank is necessary, this steel tank should be abandoned in place. This is necessary to prevent structural damage to the fiberglass-reinforced plastic tank due to the loss of lateral support. Improper abandonment or removal of the steel tank in this instance could lead to settlement, which would probably cause a failure in the FRP tank.

References

1. American Petroleum Institute, Recommended Practice for Abandonment or Removal of Used Underground Service Tanks, API Publication 1604, American Petroleum Institute, 2101 L Street, N.W., Washington, D.C. 20037, March, 1981.

2. American Petroleum Institute, Cleaning Petroleum Storage Tanks, API Publication 2015, American Petroleum Institute, 2101 L Street, N.W., Washington, D.C. 20037, November, 1976.

3. National Fire Protection Association, Cleaning Small Tanks and Containers, NFPA No. 327, National Fire Protection Association, Batterymarch Park, Quincy, MA 02269, 1975.

4. New York State Department of Environmental Conservation, Technology for Storage of Hazardous Liquids, A State-of-the-Art Review, New York State Department of Environmental Conservation, 50 Wolf Road, Albany, New York 12233.

5. American Petroleum Institute, Cleaning Mobile Tanks in Flammable or Combustible Liquid Service, API Publication 2013, Fifth Edition, 2101 L Street, N.W., Washington, DC 20037, October, 1975.

6. American Petroleum Institute, A Guide for Controlling the Lead Hazard Associated with Tank Cleaning and Entry, API Publication 2015A, First Ed., 2101 L Street, N.W., Washington, DC 20037, May, 1975.

7. American National Standards Institute, Standard Practice for Respiratory Protection, ANSI Publication Z28.2, 1430 Broadway, New York, N.Y. 10018.

CHAPTER 7

LEAK DETECTION SYSTEMS

Leak detection systems and inventory monitoring practices that provide continuous surveillance for leaks and spills are an important requirement in underground bulk storage installations.

A. Introduction

Surveillance for a leak or spill from an underground storage tank is an extremely important require of any bulk storage installation. This is best accomplished with a leak detection system. The purpose of the detection system is to inform the operator that a leak has occurred before the leak can become a significant environmental health or safety problem.

The recommendations which follow focus on the types and operation of leak detection equipment, and represent minimum objectives for owners and operators of bulk storage facilities.

The types of leak detection systems which may be employed include the following:

- Interstitial monitors of double-walled tanks.
- In-tank testing equipment.
- Systems which monitor the excavation, such as U-tubes, vapor wells, observation or liquid sensing wells, and collection sumps equipped with sensors.

Leak detection is important at all underground storage facilities. Even a small pinhole leak, if undetected over a long period, can cause serious environmental contamination. A leak as small as 0.2 gallons per hour will result in a discharge of 1,750 gallons per year.

In addition to the use of leak detection systems, tank operators should monitor their storage inventories daily and maintain detailed records of these inventory control results.

B. Interstitial Monitoring in Double-Walled Tanks

Systems which monitor the interstitial space between the walls of double-walled tanks using either pressure sensors or fluid sensors represent the best mode of continuous leak surveillance available. In such systems, a leak can be detected due to failure of only one of the two walls of the tank. Thus, the operator can be made aware of the leak before stored product has left the tank and entered the environment.

In interstitial leak monitoring systems, pressure sensors would be used to monitor tanks that either have a vacuum drawn in the space between the tank walls, or have that space pressurized. Failure of either the inner or outer wall is detected by loss of vacuum or pressure. Such systems are applicable in either wet or dry hole installations.

Fluid sensors, on the other hand, would be located between the tank walls to detect the presence of liquid due to failure of the inner wall (detecting an outflow of product) or the outer wall (detecting an inflow of water). Such systems are more applicable in wet hole installations where failure of the outer wall will result in the presence of a fluid in the interstitial space. Because failure of the outer wall can go undetected if fluid sensors are used in dry hole installations, such an application is not recommended if pressure sensors can be used instead.

In the case of either type of interstitial monitoring system, it is important that the tank be constructed to allow for free movement of fluids or gases in the space between the tank walls so that a leak anywhere in the tank can activate strategically located sensors.

C. In-Tank Testing Equipment

In-tank testing equipment, as shown in Figure 7-1, can be an effective method of leak detection. Such a system usually consists of a probe permanently mounted inside the tank which continuously monitors the levels of product and water in the tank. To assure that a small continuous leak does not go undetected, such a system should be capable of detecting any leak greater than two-tenths (0.2) gallons per hour, or roughly five (5) gallons per day, of water flow into the tank or product flow out of the tank. An example of such a system is highlighted in the box insert below.

In-Tank Sensing Equipment

The TLS-150 gasoline tank level sensing system by Veeder-Root can identify inventory losses and accurately track fuel dispensing and deliveries [2]. When in its inventory monitoring mode, this system continuously monitors the tank and provides an hourly printout of inventory changes. In addition, this leak detection system can provide an instantaneous tank inventory report which includes the following: (1) date and time; (2) level of product; (3) volume of product; (4) temperature of the product; and (5) the height of the water level in the tank.

D. Excavation Monitoring Systems

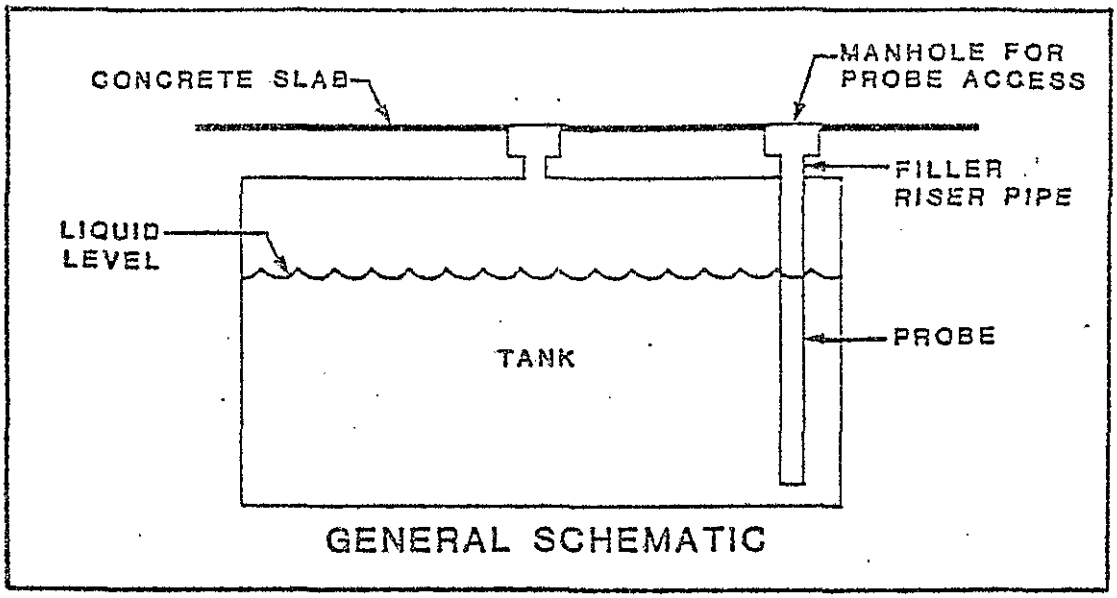
Surveillance systems which monitor for product which has leaked into the excavation can be effective under many circumstances. These include U-tubes, vapor wells, observation or liquid sensing wells, and collection sumps equipped with leak sensors. The leak detector chosen for a particular storage system depends upon the nature of the product and the hydrogeologic conditions of the excavation site.

1. U-tubes

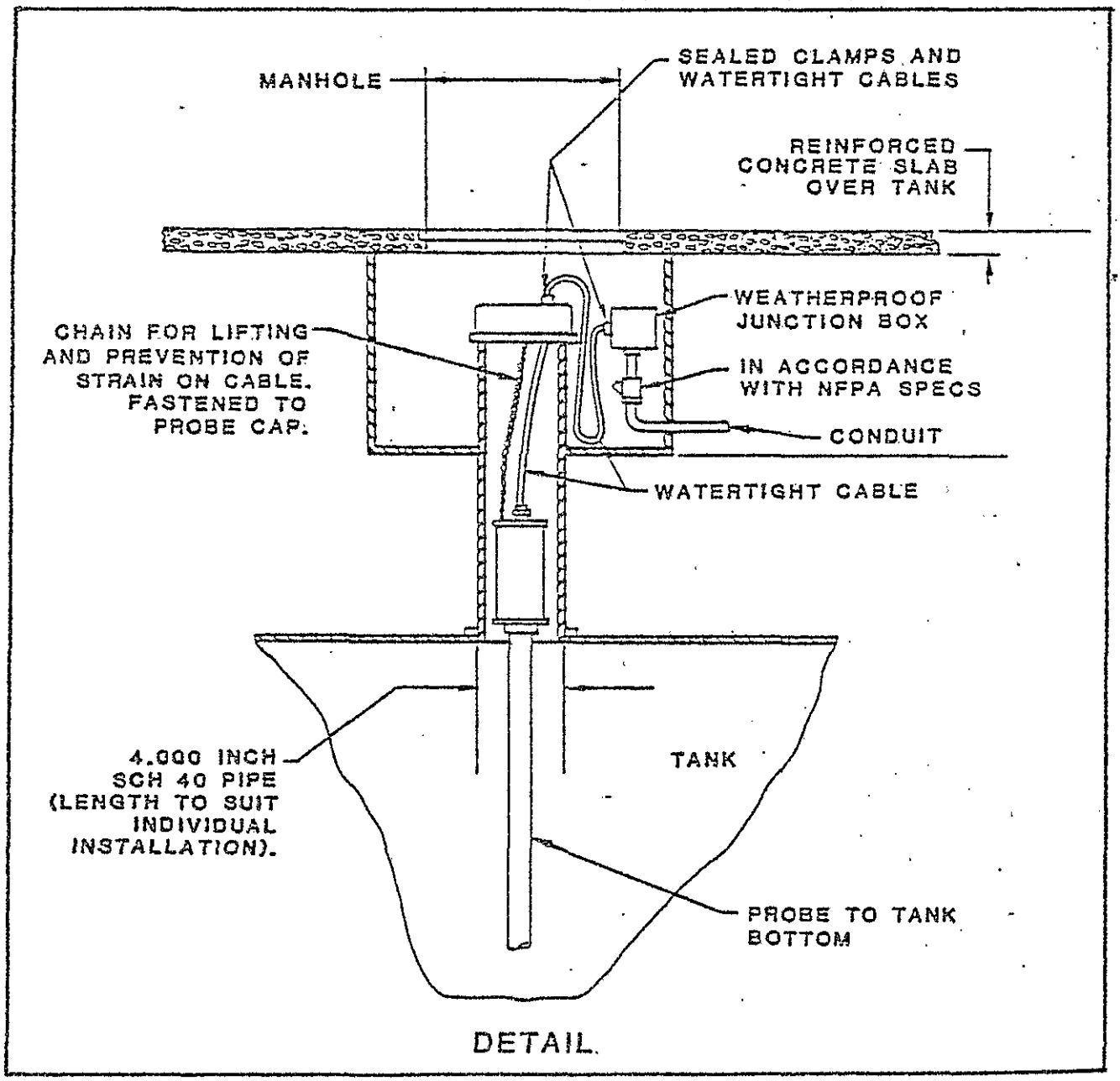
A U-tube consists of a 4 inch diameter (Schedule 40) PVC pipe installed as shown in Figure 7-2. The horizontal segment of the pipe is half-slotted (typical slot size - 0.06 inches), wrapped with a mesh cloth to prevent

FIGURE 7-1

A TYPICAL IN-TANK TESTING SYSTEM



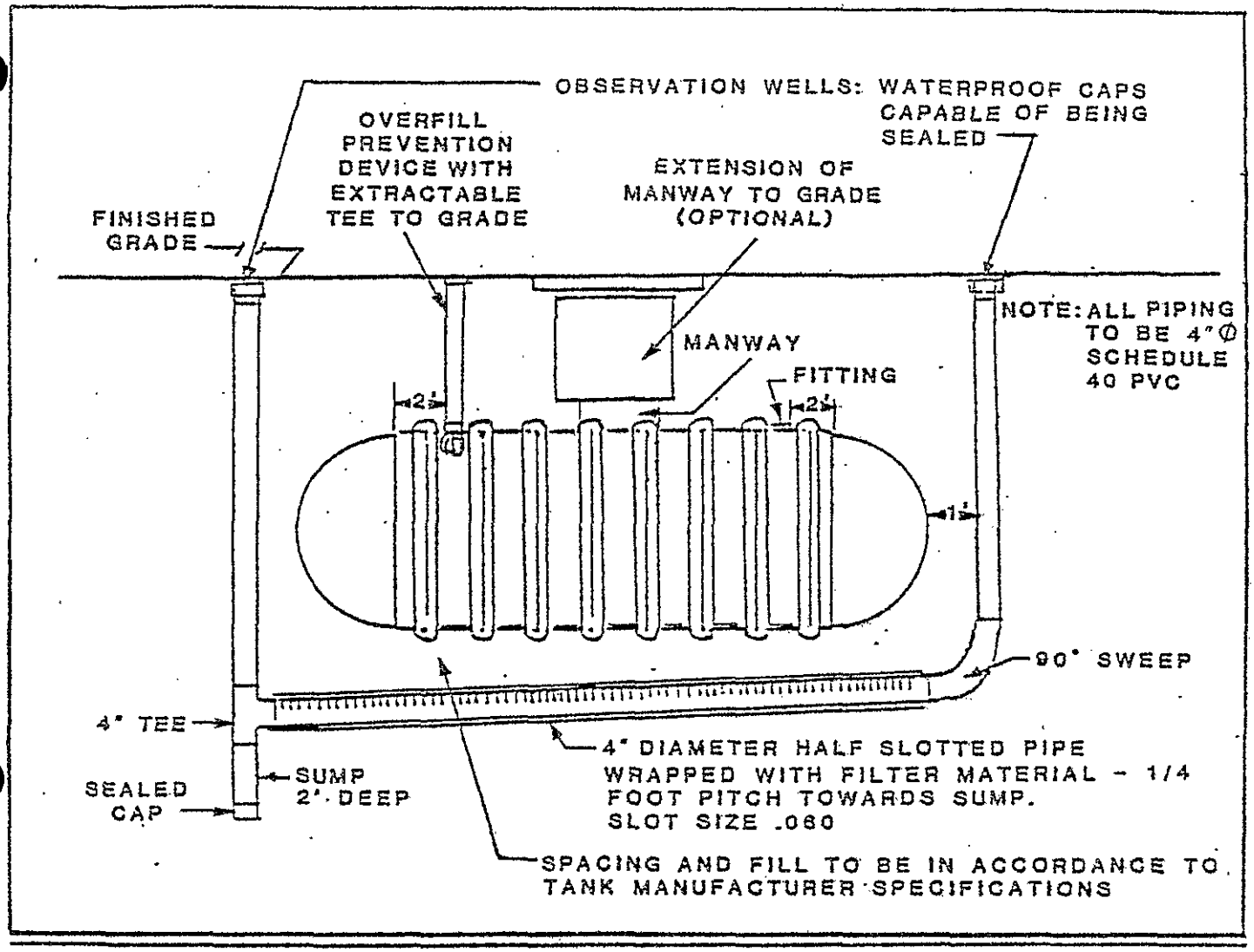
GENERAL SCHEMATIC



DETAIL.

FIGURE 7-2

EXAMPLE OF A U-TUBE INSTALLATION



backfill infiltration, and sloped (pitched) toward the sump with a slope on the order of 1/4 inch per foot. At the higher end of the pipe there is a 90 degree sweep to a vertical pipe that is extended to grade. At the lower end of the horizontal pipe there is a tee connection with a vertical pipe; this vertical section is extended to grade, and extended 2 feet below the tee to act as a collection sump. All vertical pipe sections are unperforated, and the bottom of the sump is sealed to be leak proof. All openings to grade are provided with watertight caps capable of being sealed.

These tubes may be installed under each tank in an excavation, or centrally located in the excavation. In either case, the excavation bottom must be sloped slightly (a minimum of 1/4 inch per foot) toward the U-tube to permit collection of any leaked material.

The collection sump of the U-tube must be equipped with a removable sensing device which is capable of detecting 1/8-inch of standing product or a 1/8 inch layer of product on water. This sensing device must be installed so as to activate an alarm which is strategically located aboveground. Leak sensing devices are discussed further in Section 5 below.

If the vertical section of the U-tube is designed as described above and shown in Figure 7-2, leaked or spilled product can be readily recovered from the collection sump using standard equipment such as a 3 3/8-inch submersible pump. Construction of the vertical section in this manner also permits easy sampling of leaked material to pinpoint the source of a leak. This may be necessary in situations where two or more similar products are stored, such as in an excavation housing both leaded and unleaded gasoline.

U-tubes can be used only in situations where the excavation is above the high level mark of the groundwater table (dry hole installations), the excavation has been provided with an impervious secondary containment layer on its walls and floor, and the installation is covered with a waterproof cap. In such cases, any leaked material will eventually find its way to the U-tube's collection sump, where it can be detected without water interference.

2. Observation Wells

Observation wells may be used to monitor for leaks from underground tank installations in areas of high groundwater, where the tank is likely to be anchored in the groundwater at least occassionally during normal operation. A diagram of an observation well installation is shown in Figure 7-3.

An observation well, or liquid product sensing well, consists of, at a minimum, a 4 inch diameter (Schedule 40) PVC pipe placed in the tank excavation. The wells are constructed with a well screen long enough to provide a length of 5 feet or more above the water table, or to the well cap, and extending a minimum of 5 feet into the groundwater or 2 feet below the tank bottom, whichever is greater. Well screens typically have a slot size of 0.02 inches, and are extended to grade and covered with a water proof cap which is capable of being sealed.

As is true of the vertical section of the U-tube, if observation wells are constructed as described above and shown in Figure 7-3, they can be used for leak sensing, direct sampling, and product (and contaminated groundwater) recovery. When leak sensors are used, they must be capable of detecting a 1/8-inch layer of the stored product on the groundwater surface, and they must activate a strategically located aboveground alarm when that product is detected.

The selection of the number and location of observation wells in a particular storage system is dependent upon the local hydrogeology, including parameters such as the groundwater flow direction. The Department recommends that any installation using observation wells employ at least two (2) wells in each excavation.

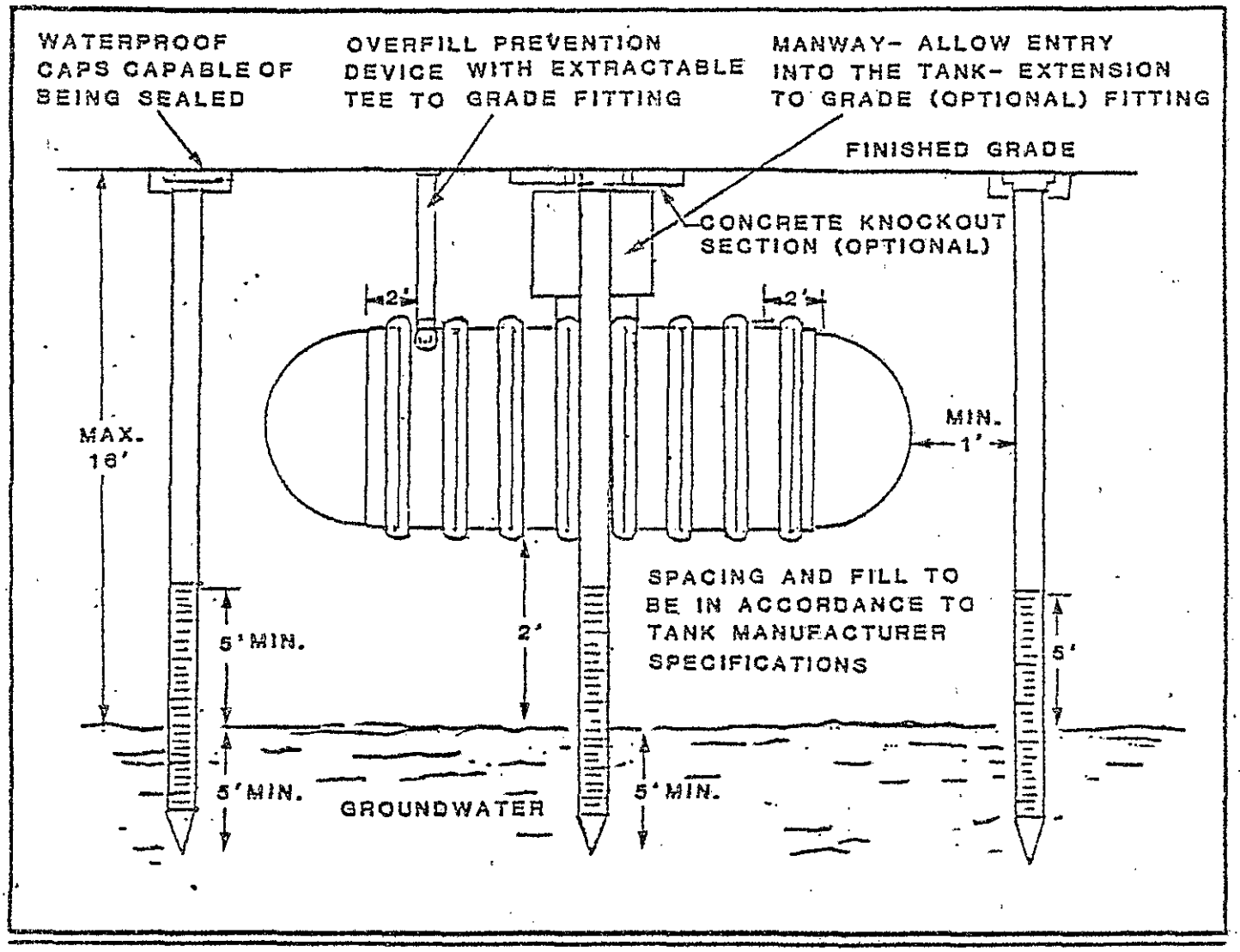
3. Vapor Wells

A vapor well is similar to an observation well with the exception that it is intended for the monitoring of vapors or odors from underground storage systems. Such a well consists of a 4 inch diameter (Schedule 40) PVC

FIGURE 7-3

EXAMPLES OF OBSERVATION WELLS

EACH WELL CONSISTS OF 4" PERFORATED PVC PIPE, DRIVEN AT LEAST 2 FEET BELOW THE BOTTOM OF THE TANK AND AT LEAST 5 FEET INTO THE GROUNDWATER



pipe installed in the excavation within 5 feet of the tank. In dry installations, these wells extend to the containment liner on the floor of the excavation. In wet installations they extend into the groundwater.

The well screens in vapor wells should have a slot size of 0.02 inches. In dry hole installations, the screened opening should extend from the containment volume floor to a height of at least 4 feet. In wet hole installations, the well screen must be long enough to provide a length of 5 feet or more above the water table and should extend a minimum of 5 feet into the water table or 2 feet below the tank bottom, whichever is greater.

Vapor wells can be used only at uncontaminated sites. Once product vapors have entered the well, they will remain there until their source has been removed (the leak has been pinpointed and repaired) and the well has been purged free of residual vapors. If the well cannot be purged, the vapor well must be either retrofitted with an alternate means of sensing leaked product, or abandoned. A diagram of a typical vapor well is given in Figure 7-4.

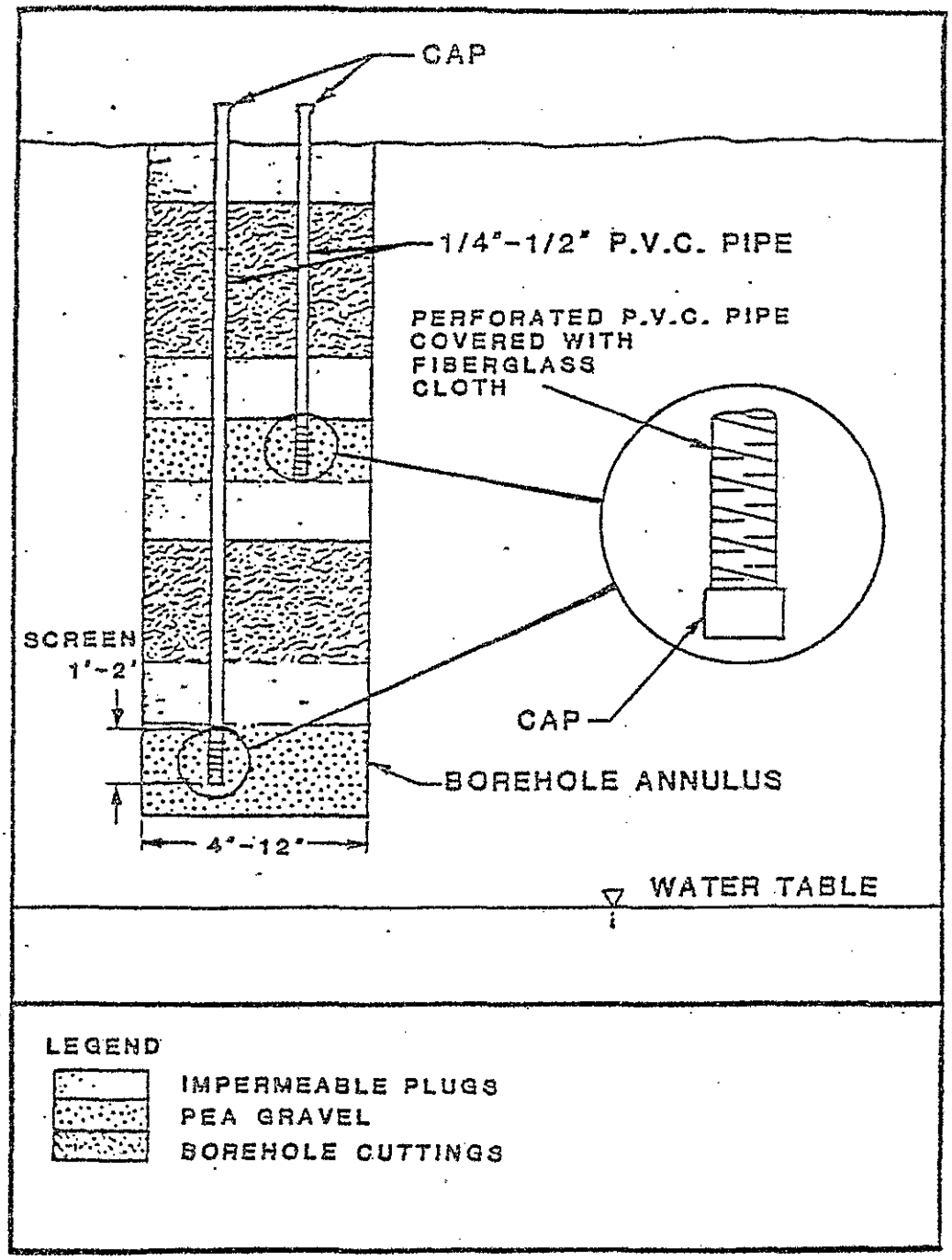
4. Collection Sumps

Collection sumps can be used in dry hole installations as a collection mechanism which aids in leak detection. ~~A diagram of this type of system is shown in Figure 7-5.~~

In this type of system, the floor of the storage excavation (or secondary containment volume) is sloped at a rate greater than or equal to 1/8 inch per foot to a collection sump. This sump shall be at least 2 feet deep and shall be extended to grade via, at a minimum, a 4 inch diameter (Schedule 40) PVC pipe, and covered with a waterproof cap. This extension is essentially an observation well which is screened in the region of the sump. ~~(see Figure 7-5).~~ The sump ~~shall~~ should be equipped with a removable leak detection sensor which is capable of detecting 1/8 inches of standing product, and activates a strategically located aboveground alarm when that product is present. If constructed as described above and shown in Figure 7-5, the sump and well can also be used for leak sampling and for the recovery of leaked or spilled product.

FIGURE 7-4

TYPICAL WELLS FOR CONTINUOUS GAS OR VAPOR MONITORING



PAGE 7-11 DELETED

5. Leak Sensors

The types of sensors suitable for monitoring leaks from underground petroleum storage facilities include the following:

- Thermal Conductivity Sensors: These types of sensors detect changes in the thermal conductivity of their environment to determine if a leak has occurred. They may be used in either wet or dry installations, and are particularly applicable for the detection of hydrocarbons.

- Electrical Resistivity Sensors: These sensors rely on changes in the resistance of a wire due to exposure to the stored product. They are applicable for either wet or dry installations.

- Gas Detectors: These types of sensors are generally applicable in areas of permeable soil or backfill, and are particularly applicable in instances where the stored product is highly volatile and the excavation is dry (free of groundwater).

Another option in the case of U-tubes, observation wells, and collection sumps is direct sampling. While more accurate, this option is much more expensive than the use of sensors, and as such is only employed in instances where it is necessary to pinpoint the source of a leak (e.g., in an instance where tanks containing similar but different products, such as leaded and unleaded gasolines, are located in the same excavation).

When thermal conductivity and electrical resistivity sensors are used, the level of accuracy is important. Such sensors must be able to detect 1/8-inches of standing product, or a 1/8 inch layer of product on the ground water surface.

More information on the advantages and drawbacks of the various types of sensors described above is available in the Department manual Technology for the Storage of Hazardous Liquids, A State-of-the-Art Review [3].

E. Inventory Monitoring

Detection of leaks is facilitated by proper product accounting (record-keeping), regular inspections of the visible parts of the product handling system, and prompt recognition of the conditions that indicate leaks in underground tanks and piping. Inventory monitoring is a technique that is widely applicable to any stored or transported product.

Evidence of leakage from buried tanks and pipelines can be gathered from inventory control records and from abnormal operation of pumping equipment. The following are some of the the more obvious symptoms of such leaks:

- Loss of product in a tank during periods when product is not dispensed usually indicates a leaking tank, but might also indicate faulty accounting or metering of the product, theft, or extreme temperature change.

- An unaccountable increase in water in an underground tank may be caused by a leak in the tank if the ground surrounding it is saturated. Under such circumstances, water may leak into the tank instead of product leaking out. The increase in water may also be caused by a leaking gauge or fill cap, and these should be examined and made watertight, if necessary, before concluding that the tank is at fault.

- Increasing differences between the amount of product received and dispensed may indicate a meter calibration problem, theft, or a leak in tanks or piping.

- Where fill boxes are located remotely from the tanks, differences appearing consistently between the amounts invoiced and the tank gauges after deliveries may indicate a leak in the remote fill line. In such event, the line should be tested.

- A hesitation in the delivery from a suction pump may indicate a leak in the suction piping, although such hesitation may also be caused by a leaking foot valve or, in warm weather, by vaporlock. Should this occur, the inventory control records may indicate whether the cause is mechanical or whether product is actually being lost.

- In a remote pumping system, pump operation without product delivery may indicate a leaking pipe.

The Department recommends that any bulk storage inventory monitoring program include measurements of the following items:

- The level of product in each tank.
- The level of water in each tank.
- Product sales.
- Deliveries to and draw-off from each tank.

These items should be measured and recorded at least once per day, and daily records should be maintained of gains or losses based upon these measurements. These records should be maintained and kept on the premises for at least 5 years.

Inventory control measurements may be made by gauge, gauge stick, or by readout from an automatic gauging system such as the Veeder Root system described in Section C above. Guidance on tank gauging is available in API Publication 1621, Recommended Practice for Bulk Liquid Stock Control at Retail Outlets [4], and from the New York State Association of Service Stations [5].

Whatever inventory monitoring system is used, that system should be capable of detecting a change (usually an increase) in the tank water level exceeding 1 inch on a day with no delivery, or apparent product losses exceeding one of the following:

- 0.75% of product stored.
- 7.5 gallons per 1000 gallons delivered.

References

1. New York State, Bulk Storage Code, Part 612.

2. Veeder Root, TLS-150 Tank Level Sensor System, Brochure No. 14-150, Veeder Root, Petroleum Products Division, 70 Sargeant Street, Hartford, Ct. 06102, 1983.

3. New York State Department of Environmental Conservation, Technology for the Storage of Hazardous Liquids, A State-of-the-Art Review, New York State Department of Environmental Conservation, Division of Water, Bureau of Water Resources, 50 wolf Road, Albany, New York 12233, January, 1983.

4. American Petroleum Institute, Recommended Practice Bulk Liquid Stock Control at Retail Outlets, API Publication 1621, American Petroleum Institute, 2101 L Street, N.W., Washington, D.C. 20037, 1977.

5. New York State Association of Service Stations, 8 Elk Street, Albany, NY 12210.

CHAPTER 8:
TIGHTNESS TESTING FOR STORAGE SYSTEMS

Storage system tightness tests must be performed on a regular basis, and must incorporate equipment and procedures which have been approved by the Department.

A. Introduction

In many instances, the contamination caused by leaking underground storage tanks or piping has gone undetected for months or even years, at which point it has become widespread, and very difficult and expensive to correct. Such situations should be avoided. Regular testing and inspection of underground tanks and piping provide for early detection should such leaks occur. This chapter presents recommended practices and guidelines for inspection (or preliminary testing) and final testing of underground storage systems.

B. Inspections of Underground Tanks

The inspection techniques which are recommended and described in this section are essentially screening techniques (often called preliminary tests) which can be used to develop a gross determination of the tightness and integrity of underground storage system components. The purpose of these techniques or tests is two-fold: (1) to detect existing leaks in the tank or its associated piping; and (2) to avoid sudden failure of the tank while in service by performing tests to determine tightness and integrity. These inspection techniques include the following:

- Inspections prior to backfilling.
- Checking tank bottoms.
- Checking for water in tanks.
- Inspection of cathodic protection systems.

1. Inspections Prior to Backfilling

The inspection of a storage tank system prior to backfilling is an essential component of a comprehensive storage system installation procedure. The inspection of an FRP tank installation should include, at a minimum, soap tests of tanks in place prior to backfilling. Soap tests involve applying a soap solution to the external surface of the tank, pressurizing it to a pressure of 3 or 5 psig, and inspecting the tank closely for bubbles which would indicate air leaks. The choice of the test pressure level is dependent upon the size of the tank as delineated in Chapter 1. The tank should be capable of maintaining the test pressure for at least one hour.

The inspection of a steel underground tank prior to backfilling should include, at a minimum, soap tests of the tank in place, spark tests of the exposed external coating, and inspections of the cathodic protection system to ensure proper connection (wiring) and operation.

2. Checking Tank Bottoms

Experience has shown that many steel tanks develop leaks in a narrow band along the bottom. This often occurs because small amounts of water condense out of the stored liquid and settle at the bottom of the tank. This phenomenon can result in internal corrosion of the tank.

This internal corrosion will often be aggravated under the tank's fill tube or gauge hole as protective rust is removed by liquid flow against the tank bottom or the impact and movement of the gauge stick, either of which could lead to localized corrosion. Liquid flow through fill tubes and the action of gauge sticks can also lead to localized wear in fiberglass-reinforced plastic tanks, ultimately resulting in leaks.

The Department recommends that preliminary tests or inspections be conducted at least twice per year using the techniques outlined below to test for the presence of large leaks in the bottoms of underground storage tanks. Due to other variables which are discussed later, these preliminary

tests are only useful in detecting the presence of large leaks. The failure to find a leak using these techniques does not indicate that a tank is completely leak-free, but if they do reveal a leak, a more conclusive (and more expensive) test becomes unnecessary.

Checking Under Tank Openings. The Department recommends that tank owners and operators inspect the areas under the openings of their underground tanks, such as the areas under the fill and gauge tanks. A relatively easy method of testing for large leaks in these areas is to construct a probe by driving a finishing nail into the end of a gauge stick, leaving about 3/4 inch protruding. This gauge stick can then be used to check for a failure in the tank bottom under the fill and gauge tubes by probing or "feeling" the tank bottom with the nail head. This test requires a technique that is quickly learned, and it can be successful in identifying large leaks.

Checking the Remainder of the Tank Bottoms. The bottom of the full length of the storage tank can be checked for large leaks by adding water and measuring for a decrease in water level over time. This technique is described in detail in the National Fire Protection Association's Standard NFPA 329, Underground Leakage of Flammable and Combustible Liquids [2]. This inspection technique will work only if it is practical for the stored liquid to come in contact with water, and if the liquid level in the tank is sufficiently higher than the groundwater table to overcome the hydrostatic pressure of the groundwater.

3. Checking for Water in Tanks

If continuous monitoring of the water level in the tank of a given storage system is not used, then the tank should be checked regularly for the presence of water and the level of that water. For example, the water content of the tank can be determined when gauging the tank, both during deliveries and inventory checks, by using a water-finder paste smeared on the bottom portion of the gauge stick. An unaccountable increase in the water level may indicate a tank leak, especially if the increase occurs after a heavy rain. However, before concluding that the presence of water

is due to a faulty tank, the fill cap, its seal, and other connections should be checked to ensure that they are performing properly.

If a test of this type or a continuous water monitor indicates that a significant amount of water is present (e.g., above the pump or pump suction pipe), the tank should be tested for leaks using a more definitive (final) test.

4. Inspection of Cathodic Protection Systems

When a steel tank and/or associated piping is equipped with cathodic protection, inspection and maintenance of the cathodic protection system is essential to ensure long-term effectiveness. In the case of an impressed current system, the flow of current may fail because of anode deterioration, broken lead wires, rectifier malfunction or interruption of power. Impressed current rectifiers should be checked monthly and adjusted as needed [4]. The output of rectifiers should be monitored with a voltage or current indicator. At least once a year, tank-to-soil potential measurements must be taken to check the adequacy of protection and determine if any rectifier adjustments are needed [4].

The cathodic protection system must produce a structure-to-soil voltage of at least -0.85 volts as measured on the tank at the most distant point from the anode by a copper-copper sulfate reference half-cell (or equivalent half-cell reference). The -0.85 voltage must be monitored annually and mantained for the life of the tank. If the structure-to-soil potential is less negative than -0.85 volts, the cathodic protection must be restored to that level, or the tank must be tested for tightness annually.

Galvanic cathodic protection systems are also susceptible to system failure, due to such phenomena as the loss of tank or pipe coatings, broken wires, and short-circuited electric insulators. In these types of cathodic protection systems, measurements of tank-to-soil potential and anode output should be made semi-annually.

C. Final or Precision Tests

> The Department will approve only tightness tests which are a "precision test" or "final test", as defined by the National Fire Protection Association in NFPA 329, Underground Leakage of Flammable and Combustible Liquids [1].

Any final test technique which is used to determine the tightness of an underground storage system must first be approved by the Department. The test must be able to determine conclusively whether or not an underground storage tank is leaking. This means that the test must be capable of accurately detecting a tank or piping leak as small as 0.05 gallons per hour (gph), adjusted for all variables, such as the following:

- The presence of vapor pockets.
- Thermal expansion or contraction of the product.
- Temperature stratification in the tank.
- Evaporation.
- Pressure variations in the tank.
- The deflection of tank ends.

All of these variables can affect the volume of liquid in the tank, and can therefore act to distort leak measurements as discussed below.

1. The Effect of Temperature

Liquids expand with an increase in temperature and contract with a decrease in temperature. For example, a temperature increase of only 0.02°F is one hour in a 6000 gallon tank would cause a volumetric change of 0.072 gallons, which exceeds the 0.05 gph leak rate that is considered to indicate a leak. If such a temperature change was not accounted for during a tightness test, a leak could be masked by thermal expansion, or thermal contraction could lead to a leak indication where no leak exists.

Another temperature effect that must be recognized and accounted for is temperature stratification or layering. For example, temperature may vary with depth in an underground tank, particularly in a case where cool product has been added to warm product that is already in the tank.

2. The Effect of Pressure

With most final or precision tightness tests, measuring very small volumetric changes in a storage tank requires the filling of that tank to a point above grade where volumetric measuring equipment can be used. This increase in height of liquid increases the pressure inside the tank over the normal operating pressure.

For example, in a 6 ft. diameter tank, the average pressure on the end or "head" of a tank full of typical gasoline is .98 pounds per square inch. If the tank is buried 3 ft. below grade (as is typical for most gasoline tanks), the average pressure on the head will increase to approximately 2.95 pounds per square inch (psi) when the fill pipe and standpipe are filled to 3 ft. above grade for a tightness test. The increase of approximately 1.95 psi in pressure exerts an additional force on the ends or "heads" of the tank of about 8,000 pounds.

This increase in pressure can result in deflection of the heads or ends of the tanks. Under normal, unrestrained conditions, such as might occur if the tank were aboveground and its ends were not supported, it is possible to calculate the exact increase in volume associated with a given pressure. However, when tanks are located underground, they are subject to variations in support from the surrounding soil, and it is not possible to predict how much movement will take place. Very solid soil may provide close to full support, but normally soils will consolidate to some degree, particularly if they are wet, thereby allowing tank expansion and end deflection.

Extensive tests have shown that significant volumetric increases will occur when increases in pressure of this type take place during a tightness test. Table 8-1 shows the apparent loss of product due to varying degrees of tank end deflection. It is important that any final or precision test that is used take this phenomena into account to avoid erroneous results.

TABLE 8-1

Apparent Loss Of Product Volume Due to Force on Tank Ends - In Gallons

Tank Diameter (inches)	Outward Deflection at Center of Head in Inches											
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	5/8	3/4	7/8	1
48	.49	.98	1.47	1.95	2.44	2.93	3.42					
64	.87	1.74	2.61	3.48	4.35	5.22	6.10	6.97				
72	1.10	2.20	3.31	4.41	5.51	6.62	7.72	8.82	11.0			
84	1.50	3.00	4.50	6.00	7.50	9.00	10.50	12.00	15.0	18.0	21.0	
96	1.96	3.91	5.87	7.82	9.77	11.75	13.70	15.65	19.6	23.5	27.4	31.3
102	2.21	4.42	6.65	8.25	11.06	13.30	15.50	17.70	22.6	26.6	31.0	35.4
120	3.06	6.12	9.18	12.25	15.30	18.40	21.40	24.50	30.6	36.7	42.8	49.0

Source: NFPA 329, Underground Leakage of Flammable and Combustible Liquids, [2].

3. Final Test Frequency and Recordkeeping

A "precision" or "final" test should be conducted according to the schedule presented in Table 8-2. This schedule is a simplified version of the requirements of the Bulk Storage Code, and should be used as a rule-of-thumb reference only. The Bulk Storage Code also requires reporting test results to the Department within 30 days on forms designed for that purpose.

The tank owner/operator should keep test results on the premises permanently, but records should be kept for at least five years.

4. Types of Final Tests

There are several types of tank testing procedures currently in use that meet the Department's criteria for a final or precision test. Some of these techniques also apply to detecting leaks in pipelines. For more information, please refer to the Department document entitled Technology for the Storage of Hazardous Liquids, A State-of-the-Art Review [3].

D. Pipeline Tests

Recommendations for pipeline testing before the pipline has been placed in service are given in Chapter 3 of this manual.

Pipelines should be tested whenever precision testing is done on tanks, since the equipment will already be on hand.

Leaks in pressure piping can largely be eliminated by the use of pipeline leak detectors, as long as they are operating property. These detectors should be tested for proper operation at least semi-annually.

Pipeline leak detectors have an internal hydraulic circuit which tests the delivery line for a drop in pressure each time the dispenser is used. If the line pressure has dropped, the detector will shut off product flow. This detector action is automatic and requires no decision on the part of the dispenser user. Pipeline leak detectors are discussed in greater detail in Chapter 2 of this manual.

TABLE 8-2

Tank Testing Schedule

Category A: Unprotected steel tanks -- test 10 years after installation, and yearly thereafter.

Category B: Corrosion resistant tanks installed prior to the enactment of the Bulk Storage Code -- test 15 years after installation and yearly thereafter, unless the system has a leak monitoring system installed. Leak testing can be waived for systems with monitoring.

Category C: Tanks installed according to the Bulk Storage Code with one of the monitoring systems described in Chapter 7 of this manual -- no testing is required.

Common Corrosion Resistant Tanks

FRP tanks
Cathodically protected steel tanks
FRP-clad steel tanks
Double-walled tanks

Common Monitoring Systems

Monitoring Well, preferably one with product sensor -- suitable for retrofit

Double-walled tank system

Monitoring of secondary containment using one of the following types of containment:

- A vault.
- An excavation liner.
- A trough liner.
- A "bagged" tank.

Leaks in suction systems become evident in the course of normal operations. It needs emphasis that, as stated in the Bulk Storage Code, "A facility employing a suction pumping system must not be equipped with a check valve, such as a union check valve, except at the tank end of the piping system." [1] These check valves can mask the loss of prime experienced when a suction line develops a leak.

REFERENCES

1. The Bulk Storage Code

2. National Fire Protection Association, Underground Leakage of Flammable and Combustible Liquids, NFPA 329, National Fire Protection Association, Batterymarch Park, Quincy, MA 02269, 1977.

3. New York State Department of Environmental Conservation, Technology for the Storage of Hazardous Liquids, A State-of-the-Art Review, New York State Department of Environmental Conservation, 50 Wolf Road, Albany, NY 12233, 1983.

4. Fitzgerald, J.H., "Corrosion Control for Buried Service Station Tanks," Paper No. 52, The International Corrosion Forum Devoted Exclusively to the Protection and Performance of Materials, April 14-18, 1975, Toronto, Canada, National Association of Corrosion Engineers, Publications Department, 1440 South Creek, Houston, TX 77084.

5. National Fire Protection Association, Flammable and Combustible Liquids Code, NFPA 30, National Fire Protection Association, Batterymarch Park, Quincy, MA 02269, 1980.

CHAPTER 9:

OVERFILL PROTECTION AND TRANSFER SPILL PREVENTION

The recommended practice for prevention of overfilling and transfer spills is the use of automatic systems which shut off the delivery of product when there is an impending overfill, and the use of dry-disconnect couplings to prevent transfer spills.

A. Overfill Prevention Systems

Overfilling and product transfer spills are the most common sources of spillage in underground bulk storage facilities. It is common practice to fill storage tanks without an automatic means to prevent overfilling. Without such protection, it is just a matter of time before an overfill incident or product spill occurs. To avoid these types of accidents, it is necessary that tank owners install and use overfill prevention systems.

The best overfill prevention systems contain the following elements:

- A high level alarm, which warns the operator of an impending overfill condition
- An automatic shutoff device which prevents overfilling from occurring
- Interlocking of the unloading process and the overfill prevention system so that tank loading cannot take place if the overfill system is inoperative
- Bypass prevention so that the overfill prevention system cannot be overridden.

The level gauge should be accurate to within one-half (±½) inch, and should be easily visible to the operator in the control room. Audible alarms or individual visual alarms such as indicator lights are also needed to pinpoint the impending overfill situation. These alarms should be mounted so that they can easily be heard and/or seen by the control operator during filling operations. Table 9-1 lists various types of control gauges.

TABLE 9-1

Level Detection Devices for Underground Storage Tanks

Type	Monitors Liquid Level	Type of Level Indication	Alarm and Shutoff Reponse
Float Actuated Devices			
Tape float gauges	Yes	Gauge	Interfaces with electronic or pneumatic controls.
Float vent valves	No	None	Automatic Shut-off
Capacitance devices	Yes	Gauge	Audible alarm and automatic shut-off electronic controls.
Thermal conductivity devices	Yes	Gauge	Audible alarm and automatic shutoff electronic controls.
Ultrasonic devices	Yes	Gauge	Audible alarm and automatic shutoff electronic controls.
Optical devices	Yes	Gauge	Audible alarm and automatic shutoff electronic controls.

The concept of having separate and distinct levels of indication, alarm, and shutoff provides a versatile system of response to the overfill threat. Although it might seem that such a sophisticated system is prohibitively expensive, it is certainly warranted in most situations.

Recognizing that the best overfill prevention system may be prohibitively expensive for many underground storage facilities, the following are the minimally recommendable systems for overfill prevention at underground storage tanks.

MINIMAL REQUIREMENTS FOR OVERFILL PREVENTION SYSTEMS

On tanks which are filled by gravity flow from the product delivery vehicle, the vent line must be equipped with a float vent valve or similar device.

On tanks which receive product under pressure from the product delivery vehicle, the tank must be equipped with a combined audible/visual high level alarm mounted in a location that is both visible and audible to the delivery vehicle operator.

Float vent valves are simple devices, as shown in Figure 9-1. When installed properly (in the tank vent line), the float will block the vent line when a high liquid level is attained, thereby preventing the escape of air from the tank. This action causes the pressure inside the storage tank to equalize with the discharge head in the delivery vehicle, thereby interrupting the flow of liquid.

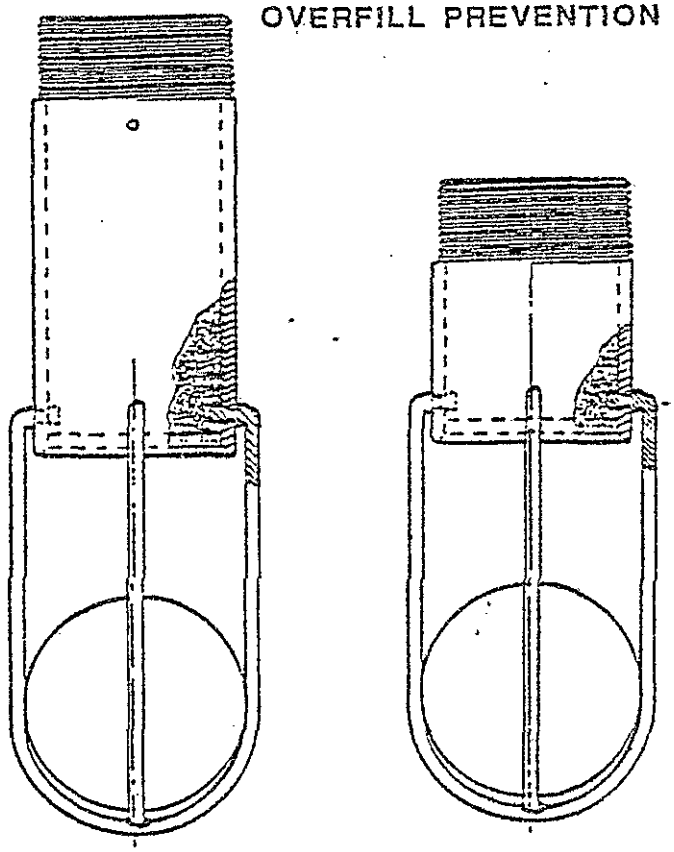
This device also includes a pressure relief bleed hole. Once ~~flow from the delivery vehicle has ceased due to pressure equalization~~ the overflow condition is recognized, the delivery truck fill valve ~~can be~~ is shut. Then, as vapor escapes through the float vent valve bleed hole, the liquid remaining in the fill line can drain into the storage tank.

Float vent valves must be installed in a extractable tee connection which is extended to grade. This permits easy removal of the float vent valve when the tank is to be tested for leaks. These valves are normally

FIGURE 9-1

FLOAT VENT VALVES

FLOAT VENT VALVES USED FOR OVERFILL PREVENTION



OPW 53-VSS OPW 53-FC

SOURCE: OPW DIVISION/DOVER CORP.

installed in conjunction with vapor recovery equipment. Retrofitting is rarely a problem.

B. Transfer Spill Prevention Systems

> All liquid transfer equipment (hoses, piping) must contain valves which close automatically and provide a dry disconnection when transfer hoses or pipes are disconnected. Such valves must be located on both the discharge and receiving ends of the transfer coupling [1].

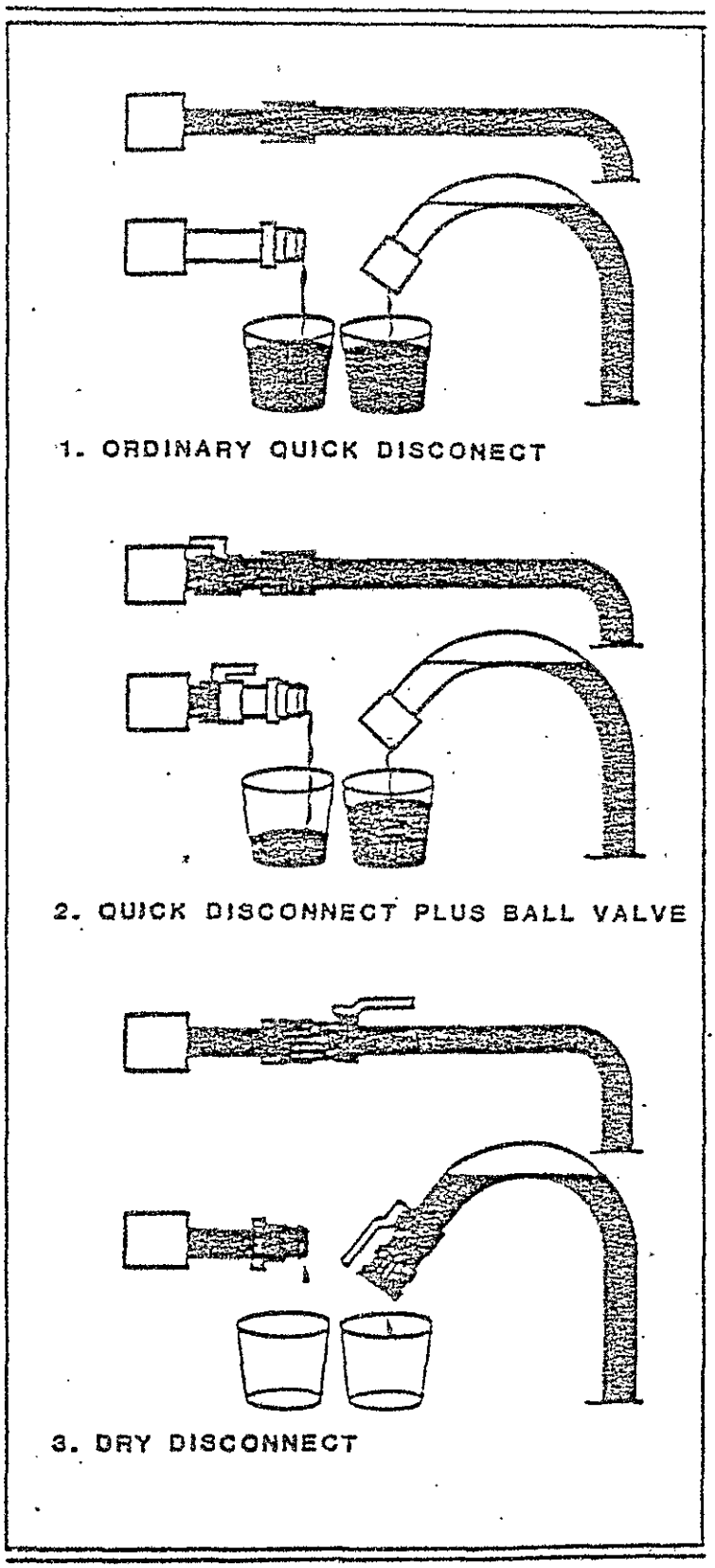
The use of tight couplings is essential to prevent spills when transferring hazardous liquids. Many types of couplings are available. However, the Department recognizes that dry-disconnect couplings are the best type of coupling available in terms of product spill control, and recommends them for use in all product transfer operations. Dry-disconnect couplings are equipped with a spring loaded valve which is normally closed until the coupling is attached and the valve is manually opened with a lever. The difference between the performance of dry-disconnect couplings and that of other types of quick-disconnect couplings is discussed in further detail in the Department manual entitled Technology for the Storage of Hazardous Liquids, A State-of-the Art Review [2]. Figure 9-2 shows this difference pictorially.

In some metropolitan areas of New York State, vapor recovery systems have been mandated and are being installed. There are three types of systems in use, and two of the three are compatible with the use of dry-disconnect couplings. The coaxial vapor recovery system combines the product delivery return lines into one coupling. Dry-disconnect couplings are not available for this system at the present time. The other two systems use separate fill and vapor return lines which would not preclude the installation of dry-disconnect couplings.

To prevent product mixing, color coding of product types is recommended. Also, the use of different couplings for different product types

FIGURE 9-2

TYPES OF COUPLINGS



SOURCE: OPW DIVISION/DOVER CORP.

can prevent product mixing. A system can thus be devised whereby a product delivery hose simply cannot be connected to the wrong tank.

C. Operating Practices

Certain operating practices are recommended to prevent overfilling of tanks and to limit the likelihood of transfer spills. These include the following:

- Loading and unloading of vehicles should be done only in approved locations.
- The driver, operator, or attendant of any delivery vehicle should not leave the vehicle unattended during the loading or unloading process. The delivery hose, when attached to the vehicle, should be considered to be a part of that vehicle.
- When transferring flammable liquids, motors of delivery vehicles and motors of auxiliary or portable pumps should be shut off during the making or breaking of hose connections. If loading or unloading does not require the use of the delivery vehicle's motor, the motor should be shut off throughout the liquid transfer operation.
- Labels, markings, or color codes should be used on all couplings and hoses to prevent accidental mixing of incompatible liquids.
- All transfer hoses should be inspected periodically for leaks.
- Any operator of a loading or unloading operation should be properly trained and should be aware of of all potential problems.

References

1. The Bulk Storage Code

2. New York State Department of Environmental Conservation, Technology for the Storage of Hazardous Liquids, A State-Of-The-Art Review, New York State Department of Environmental Conservation, 50 Wolf Road, Albany, New York, 12233, January, 1983.

3. National Fire Protection Association, Tank Vehicles for Flammable and Combustible Liquids, NFPA 385, National Fire Protection Association, Batterymarch Park, Quercy, MA 02269, 1979.

4. Dover Corp., OPW Engineered Service Station Products, Dover Corporation/OPW Division, 9393 Princeton-Glendale Road, P.O. Box 40240, Cincinnati, OH 45240.

5. Dover Corp., OPW Kamvalok Dry-Disconnect Couplins, Dover Corporation/OPW Division, 9393 Princeton-Glendale Road, P.O. Box 40240, Cincinnati, OH 45240.

66. New York State Department of Environmental Conservation. Recommended Practices for Underground Storage of Petroleum, Albany, New York, May 1984

Recommended Practices for

UNDERGROUND STORAGE OF PETROLEUM

Received DTS
OCT 15 1984

Received DTS
OCT 15 1984

New York State
Department of Environmental Conservation

MANUALS IN NEW YORK STATE'S BULK STORAGE PROGRAM

This manual contains the Department's recommended practices for underground petroleum storage. Guidance includes: (1) the design of tanks and piping systems; (2) the installation of underground storage systems; (3) secondary containment; (4) leak detection; (5) overfill protection and transfer spill prevention; (6) storage system tightness testing; (7) storage tank rehabilitation; and (8) the closure of underground storage facilities. This manual is intended for engineers, inspectors and owners who are designing or upgrading their underground facilities for leak and spill prevention.

Much of the latest information on the equipment available for storing and handling hazardous liquids may be found in **Technology for the Storage of Hazardous Liquids - A State-of-the-Art Review.** It includes data on tanks, hoses, overfill prevention devices, piping, valves and pumps. It also contains important information on field practices and the equipment available for leak detection and spill cleanup.

The Siting Manual for Storing Hazardous Substances presents information and procedures which will aid with land use decisions on the storage of hazardous substances in sensitive environments. It discusses the types of hazards, causes of leaks and spills, site evaluation procedures, and practices for spill prevention and mitigation.

The final report on bulk storage entitled, **Administrative and Legal Options for Storing Hazardous Substances: A Guide for Local Officials,** reviews the available administrative and legal options which municipalities can use to prevent spills and leaks of hazardous substances. It also suggests the wording for a local law which would control bulk storage.

These manuals are available from:

New York State Department of Environmental Conservation
Division of Water
Bureau of Water Resources
50 Wolf Road, Rm. 328
Albany, New York 12233
Telephone No.: (518) 457-4352

Preparation of this manual was financed by a grant from the U.S. Environmental Protection Agency under Section 208 of the Federal Water Pollution Control Act.

PREFACE

This Manual presents a series of guidelines and recommended practices for the underground storage of petroleum and petroleum derivative liquids. The purpose of this document is to encourage the use of technology and practices which would prevent leaks and spills from underground storage systems by presenting what the New York State Department of Environmental Conservation regards as proper storage practices.

Because petroleum products vary widely in their characteristics and in the manner in which they should be stored, this Manual can serve only as a guide. Each liquid requires its own specific storage design. It is the responsibility of the owner of a storage facility to seek the assistance of a professional engineer who has the skills to design a storage system which can be used safely and which provides the necessary measures for environmental protection.

The mention of trade names or commercial products in this manual does not constitute endorsement or recommendation for use by the Department of Environmental Conservation.

ACKNOWLEDGEMENTS

This Manual was prepared by the Department of Environmental Conservation, Division of Water, with assistance of consulting engineers:

Fred C. Hart Associates
530 Fifth Avenue
New York, New York 10036

The Department wishes to thank Fred C. Hart Associates for their assistance with the project and the many agencies and individuals who reviewed early drafts of this report and offered comments on methods for leak and spill prevention at underground petroleum storage facilities.

TABLE OF CONTENTS

Page

Preface i

Acknowledgements ii

Table of Contents iii

List of Figures v

List of Tables vi

Introduction 1
- A. The Relationship Between the Bulk Storage Code, Manufacturer Recommendations, and This Recommended Practices Manual 1
- B. The Approach of This Manual 1

Chapter One: Underground Tanks 3
- A. Introduction 3
- B. General Requirements for All Tanks 3
- C. Design Recommendations - Cathodically Protected Steel Tanks 4
- D. Design Recommendations - Fiberglass-Reinforced Plastic Tanks 12
- E. Steel Tanks Which Are Clad With Fiberglass-Reinforced Plastic 12
- F. Double-Walled Tanks 15
- References 16

Chapter Two: Pipe, Fittings, and Pumping Systems 17
- A. Introduction 17
- B. Pipe Materials 17
- C. Fittings 21
- D. Pumps 21
- E. Hoses 23
- References 26

Chapter Three: Recommended Installation Practices For Underground Storage Facilities 27
- A. Introduction 27
- B. Planning and Desiging the Facility 27
- C. Site Preparation 29
- D. Preinstallation Testing and Inspection 31
- E. Care in Handling 31
- F. Bedding and Backfilling 31
- G. Pavement Openings 35
- H. Cover and Pavement 35
- I. Testing and Inspection 35
- J. Installation of Piping Systems 37
- References 40

Chapter Four: Secondary Containment Systems 41
- A. Introduction 41
- B. Double-Walled Tanks 41
- C. Vaults 41
- D. Cutoff Barriers and Containment Liners 42
- E. Sites With Impervious Soils 45
- F. Liner Material and Installation Practices 45
- References 51

Chapter Five: Storage Tank Rehabilitation 52
A. General Safety Precautions 52
B. Rehabilitation of Steel Tanks 54
C. Vaults 57
References 58

Chapter Six: Recommended Practices for Tank Closure and Abandonment 59
A. Introduction 59
B. Temporary Closure 59
C. Permanent Closure 60
References 64

Chapter Seven: Leak Detection Systems 65
A. Introduction 65
B. Inventory Monitoring 65
C. Interstitial Monitoring in Double-Walled Tanks 67
D. In-Tank Testing Equipment 67
E. Excavation Monitoring Systems 67
References 73

Chapter Eight: Tightness Testing for Storage Systems 74
A. Introduction 74
B. Inspections of Underground Tanks 74
C. Final or Precision Tests 75
D. Pipeline Tests 76
References 79
Chapter Nine: Overfill Protection and Transfer Spill Prevention 80
A. Overfill Protection Systems 80
B. Transfer Spill Prevention Systems 80
C. Operating Practices 83
References 86

LIST OF FIGURES

Figure	Name	Page
1-1	Features of a Pre-engineered Underground Storage Tank	5
1-2	Anode Installation on Pre-engineered Tanks	9
1-3	Anode Holders and Installation of Anodes	10
1-4	Electrical Isolation Using a Companion Nylon Flange	11
1-5	Electrical Isolation Using a Flange Insulation Kit	13
1-6	Double-Walled Tank With Bonded Fiberglass Coating	14
2-1	Diagram of an Underground Piping System	18
2-2	An Impressed Current Cathodic Protection System	20
2-3	Double-Walled Pipe	22
2-4	The Pipeline Leak Detector	24
2-5	An Emergency Shutoff Valve	25
3-1	Dimensions for Underground Tank Installations	30
3-2	Size of Pea Gravel and Crushed Stone Recommended for Bedding and Backfill Material	32
3-3	Wet Hole Tank Installation	34
3-4	Tank Piping Details - Suction System	36
3-5	Tnak Piping Details - Submerged System	36
3-6	Minimum Dimensions for Piping Installations	38
4-1	Diagram of a Secondary Containment Vault	43
4-2	A Cutoff Barrier Used for Secondary Containment in an Area of High Groundwater	44
4-3	An Excavation Liner Used for Secondary Containment in an Area of Low Groundwater	46
4-4	A Trough Liner System in an Area of Low Groundwater	47
4-4A	Containment Liner Drain	48
4-5	Containment in Native Impermeable Soils	49
5-1	Types of Tank Ventilation Equipment	53
5-2	Installation of a Tank Cover Plate	56
7-1	A Typical In-Tank Testing System	66
7-2	Example of a U-Tube Installation	69
7-3	Examples of Observation Wells	70
7-4	Example of a Vapor Well	71
9-1	Float Vent Valves	82
9-2	Types of Couplings	84
9-3	Spill Catchment Basin	85

LIST OF TABLES

Table		Page
1-1	Organizations Providing Specifications and Other Information	2
1-1	Thickness of Steel Tanks	7
1-2	Sacrificial Anode Requirements	8
2-1	Considerations in Piping System Design	17
3-1	Planning and Design Considerations for Installing Underground Storage Facilities	28
3-2	Classes of Soil Corrosivity	29
3-3	Recommended Dimensions for Underground Tank Installations	30
5-1	Sources of Information on Safe Tank Rehabilitation Procedures	52
6-1	Important Considerations in Storage Tank Closure	59
6-2	References for Tank Cleaning Operations	63
8-1	Apparent Loss of Product Volume Due to Force on Tank Ends - In Gallons	77
8-2	Tank Testing Schedule	78
9-1	Level Detection Devices for Underground Storage Tanks	81

INTRODUCTION

A. THE RELATIONSHIP BETWEEN THE BULK STORAGE CODE, MANUFACTURER RECOMMENDATIONS, AND THIS RECOMMENDED PRACTICES MANUAL

The adequacy of the initial design and installation of underground storage systems for petroleum and derivative liquids is perhaps the most important factor in minimizing potential environmental hazards due to spills or leaks of these liquids. This applies not only to storage tanks, but to the tank appurtenances, other storage system components, and storage system maintenance practices.

1. The Bulk Storage Code

To ensure the proper design, installation, operation, and maintenance of these underground storage systems, the New York State Department of Environmental Conservation (hereafter referred to as the Department or DEC) will promulgate a Bulk Storage Code. This Code will be recorded in the New York State Rules and Regulations (6 NYCRR 612 and 613), and must be followed for all underground petroleum and petroleum derivative storage installations.

2. This Recommeded Practices Manual

The purpose of this report is to present Department recommendations and guidelines for systems that pose the least hazard to the environment. The items covered include the following:

- Underground storage tanks and piping systems.
- Installation practices.
- Containment and recovery systems.
- Storage system rehabilitation.
- Storage system closure and abandonment.
- Overfill prevention.
- Transfer spill prevention.
- Leak detection and tightness testing.

The recommendations which follow should guide all underground storage installations. They are consistent with generally accepted practices, and the recommendations of tank manufacturers. If these recommended practices are implemented, they will greatly reduce the likelihood of a major spill or leak incident. However, this guidance should be considered subordinate to the Bulk Storage Code, and to site-specific engineering practices which may be required for an individual facility.

3. Manufacturers' Recommended Practices

Proper installation is so crucial to the leak-free operation of a storage facility that major tank manufacturers warrant their tanks against failure only if they are installed and used in accordance with manufacturer instructions. For this reason, tanks should be installed in strict accord with manufacturers' recommendations.

B. THE APPROACH OF THIS MANUAL

This manual is intended for the use of owners of petroleum storage facilities, and others in government and the private sector who are concerned with minimizing the risks of leaks and spills to the environment. It is written for the layman as well as the engineer so that they may jointly consider and select appropriate bulk storage and handling practices for leak and spill prevention.

> The practices and guidelines recommended in this manual pertain to the storage of petroleum and derivative liquids, but many of the principles, performance criteria and recommended practices presented apply to the storage of other hazardous liquids as well.

The recommendations and guidelines presented focus on the level of performance necessary to prevent leaks and spills and protect the environment. Where appropriate, the standards and recommendations of organizations such as Underwriters' Laboratories (UL), the National Fire Protection Association (NFPA), the American National Standards Institute (ANSI), the American Society of Testing and Materials (ASTM), the American Society of Mechanical Engineers (ASME), and the American Petroleum Institute (API) have been referenced. Reference is also made throughout the report to the Technology Assessment Manual which was prepared as part of the New York State Bulk Storage Program. The reader may wish to refer to the specific documents highlighted throughout this report for more detailed information. Table I-1 provides a list of organizations whose specifications and/or reports may be of interest.

TABLE I-1

Organizations Providing Specifications and Other Information

ANSI	American National Standards Institute, Inc. 1430 Broadway, New York, New York 10018 (212) 354-3473
API	American Petroleum Institute 2101 L Street N.W., Washington, D.C. 20037 (202) 457-7000
ASME	The American Society of Mechanical Engineers 345 East 47th Street, New York, New York 10017 (212) 705-7703
ASNT	American Society for Nondestructive Testing 3200 Riverside Drive, Columbus, Ohio 43221 (614) 488-7921
ASTM	American Society for Testing and Materials 1916 Race Street, Philadelphia, Pennsylvania 19103 (215) 299-5400
AWWA	American Water Works Association 6666 W. Quincy Avenue, Denver, Colorado 80235 (303) 794-7711
AWS	American Welding Society 2501 N.W. 7th Street, Miami, Florida 33125 (305) 642-7090
CDA	Copper Development Association 405 Lexington Avenue, New York, New York 10017 (212) 953-7300
MSS	Manufacturers Standardization Society of the Valve and Fittings Industry 5203 Leesburg Pike, Falls Church, Virginia 22041 (703) 998-7996
NBS	Federal Specification: Superintendent of Documents United States Government Printing Office, Washington, D.C. 20402 (202) 541-3000
NACE	National Association of Corrosion Engineers P.O. Box 986, Katy, Texas 77450 (713) 492-0535
NFPA	National Fire Protection Association Batterymarch Park, Quincy, Massachusetts 02269 (617) 328-9290
PFI	Pipe Fabrication Institute 1326 Freeport Road, Pittsburgh, Pennsylvania 15238 (412) 782-1624
PPI	Plastics Pipe Institute 250 Park Avenue, New York, New York 10017 (212) 687-2675
SAE	Society of Automotive Engineers 400 Commonwealth Drive, Warrendale, Pennsylvania 15096 (412) 776-4841
UL	Underwriters Laboratories 333 Pfingsten Road, Northbrook, Illinois 60062 (312) 272-8800
STI	Steel Tank Institute 666 Dundee Road, Suite 705, Northbrook, Illinois 60062 (312) 498-1980

CHAPTER 1: UNDERGROUND TANKS

A. INTRODUCTION

The importance of selecting the proper material for underground storage tanks cannot be overemphasized. Factors which must be taken into account include the following:

- Corrosion resistance.
- Chemical compatibility with the stored product.
- Structural strength.
- Foundation (support requirements).
- Soil Aggressiveness.

In the past, bare steel (or carbon steel) tanks have been widely used for underground storage of gasoline and other petroleum products. These steel tanks are structurally strong, require relatively little in the way of foundation support other than uniform backfill, and are compatible with a wide range of liquids. However, carbon steel tanks are particularly susceptible to corrosion, especially when installed in highly corrosive soils or in groundwater. Approximately 50% of the bare steel tanks installed are leaking by the time they are 15 years old. For this reason, unprotected (bare) steel tanks should not be used for underground storage.

The types of tanks which are suitable for underground petroleum storage include the following:

- Cathodically protected steel tanks.
- Fiberglass-reinforced plastic tanks.
- Steel tanks which are clad with fiberglass-reinforced plastic.
- Double-walled steel or fiberglass-reinforced plastic tanks.

Recommended practices for the design and construction of these types of tanks listed above are given in the remainder of this chapter.

> All new underground storage tanks should be made of fiberglass-reinforced plastic, steel clad with fiberglass-reinforced plastic, or coated steel which is cathodically protected. These types of tanks, together with double-walled vessels, are the only types of tanks which should be used for underground petroleum storage in New York. Bare steel tanks are unsuitable for use as underground storage vessels.

B. GENERAL REQUIREMENTS FOR ALL TANKS

This report specifically addresses concerns associated with **atmospheric-type vented** underground storage tanks. These tanks constitute the vast majority of petroleum storage facilities. However, most of the recommendations found here also apply to pressure-rated tanks.

All storage tanks installed underground in New York State should include the following features:

- Proper labeling.
- Wear (striker) plates beneath fill openings.
- Factory pressure tests for tightness.
- Manholes. (Tanks over 64" in diameter)

The following discussion addresses each of those features in more detail.

1. Tank Labeling

In New York, each tank should have a label of permanent construction located at the pump access point which contains information on the manufacturer, tank capacity, date of manufacture, and standards of construction. This information is useful if a tank warrantee claim becomes necessary, when property or management changes, or in the investigation of tanks for leakage. Where possible, the label should be readable after the tank is in service.

In addition, it is desirable that each tank be marked in a prominent place (e.g., on the tank head or end) with important handling, safety, manufacturing, and installation instructions. This marking should also be of a permanent nature.

2. Wear Plates

All tanks should have a 1/4 inch steel wear plate (striker plate) centered under each opening. This plate should be rolled to the contours of the tank if it is of fiberglass construction. Steel tanks should have **flat** wear plates. A rolled wear plate could provide an opportunity for crevice corrosion between the plate and the tank bottom. Wear plates for steel tanks should be sandblasted to make sure they are anodic to the tank shell. Normal size for wear plates should be 12 inches square. These wear plates provide valuable protection against punctures from dip sticks and "blast erosion" which occurs under the fill tube.

3. Factory Pressure Tests

To assure tightness of all welds, seams, and fittings, tanks should be factory tested at 5 psig*, in accordance with UL standards and procedures, and guaranteed by the manufacturer to be tight. If the tank is compartmentalized, each section of the tank should be separately tested for leakage and repaired if necessary.

* FRP tanks with diameters above 10 ft. should be pressurized to 3 psig for tightness tests.

4. Manholes

Although it is possible to retrofit a tank with manholes, it is best to use a tank which has a factory-installed manhole. It is usually impractical to install a manhole on tanks less than 64 inches in diamater. This allows the owner to inspect the tank for soundness after installation or to enter the tank later to clean sludge from the bottom, internally inspect the tank for soundness, and make necessary repairs. Manholes also allow the manufacturer of steel tanks to enter the tank during fabrication to join seams with double welded butt joints. These joints are stronger than lap welds, and less susceptible to corrosion.

Manholes should be located above the highest normal liquid level of the tank, and should be of the bolted cover type. Manhole cover joints should be sealed with a gasket material which is compatible with the tank contents. The gasket should not be less than 1/8 inch thick.

Manholes may pose management problems for the owner. Manhole gaskets may lose their seal and leak, or air pockets may form in the manhole chamber. Either situation will present a problem when a tank is tested for a leak. Whenever manholes are opened, a new gasket is required for assuring that the cover will reseat itself when retightened. Cover bolt tightening sequences should be rigidly followed to ensure a positive seal. For tank testing purposes, there should be an air bleeder valve installed in the manhole cover.

C. DESIGN RECOMMENDATIONS - CATHODICALLY PROTECTED STEEL TANKS

A suitable cathodically protected steel tank, regardless of size, should be designed in accordance with Underwriter Laboratory Standard 58 [1], or the American Society of Mechanical Engineers (ASME) Code for pressure vessels [2]. A corrosion protection system should include these four measures of control:

- Cathodic protection via sacrificial galvanic anodes or anodes energized by impressed current.
- Monitoring to track the effectiveness of the cathodic protection system.
- A tough, factory-applied exterior coating which measures at least 10-15 mils in thickness. The two common coatings are epoxy-based or urethane-based.
- Electrical isolation of the tank from the piping system and other underground metallic structures.

To assure complete protection, it is essential that all of the above features are present. Figure 1-1 illustrates these tank construction features.

1. Steel Tank Design

The fabrication and design requirements of Underwriters' Laboratory are specified in UL 58, entitled **Standards for Steel Underground Tanks for Flammable and Combustible Liquids** [1]. The requirements of ASME are delineated in the **ASME Pressure Vessel Code, Section VIII, Division 1, Boiler and Pressure Vessel Code** [2].

UL Standard 58 requires that the length of the tank not be greater than six times the diameter. Table 1-1 shows the minimum thickness required by Underwriters' Laboratory for tanks up to 50,000 gallons in capacity. Note that for small tanks (below 1,100 gallons in capacity). UL allows the use of galvanized steel for cathodic protection. UL indicates that such tanks may have a shell thickness as thin as 0.07-0.14 inch. Although these tanks are structurally satisfactory and acceptable for aboveground use, the Department recommends that small tanks of these designs not be used underground. The zinc coating of galvanized steel and the light weight steel shell do not provide the long-term protection and corrosion allowances that are necessary for unmonitored small underground tanks. The Department recommends that the shell of any underground steel tank have a minimum thickness of at least 7 gauge (0.18 inch), with a 1/4 inch tank shell (if available) being preferable. The extra shell thickness provides the corrosion allowances and longer life expectancies which are comparable to those of a larger tank.

The joints of the tank may be butt welded or lap welded, according to UL or ASME standards, although double welded butt joints, as discussed earlier, are less susceptible to corrosion and stronger than lap joints.

2. Cathodic Protection

Cathodic protection is used to minimize corrosion of the tank which is exposed to corrosive conditions. This protection is achieved by applying an electric current to the structure which is greater in strength and opposite in direction to the flow of current which causes corrosion. For example, if steel is exposed to corrosive soil, it would normally emit a current and corrode over time. When a sacrificial anode is connected to the tank electrically (via wires), the anode produces a stronger current that flows to the tank and the anode, not the tank, corrodes.

Corrosion protection should be provided by using either an impressed current system which incorporates DC current and an energized anode to deliver current to the tank, or a galvanic anode which relies on the electromotive difference between a sacrificial metal and the tank to provide a protective flow of current to the tank. Regardless of which method is used, a negative voltage of at least -.85 volts, as measured by a copper-copper sulfate reference half cell, is usually sufficient to provide corrosion protection.

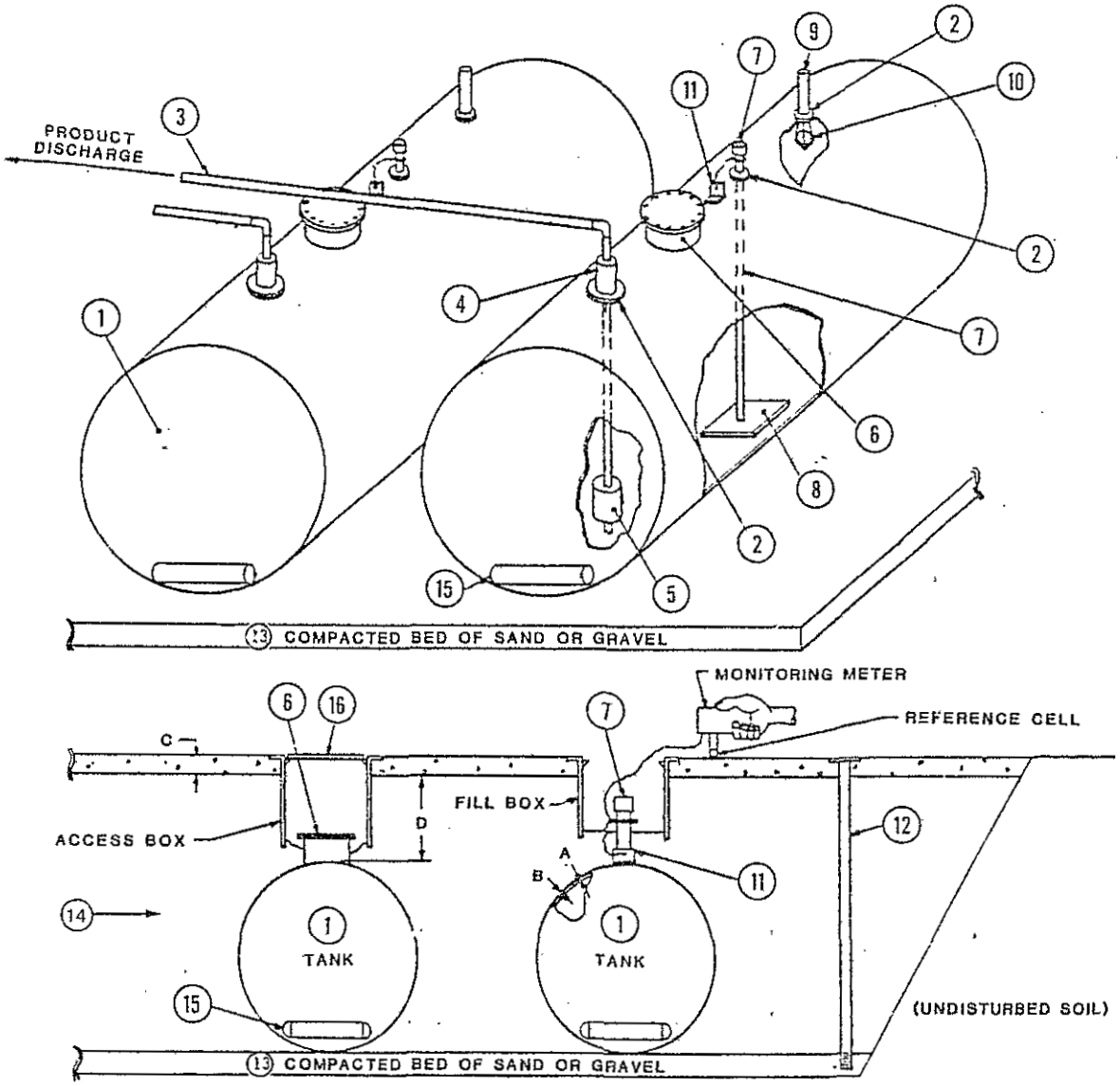
Impressed Current Systems. Impressed current cathodic protection systems require the use of a rectifier, which converts AC current to DC current, and a high silicon cast iron sacrificial anode (or graphite anode, if the soil environment is saline). Although the impressed current system is effective in almost any corrosive environment.

FIGURE 1-1

PRE-ENGINEERED UNDERGROUND STORAGE TANK

This figure show the components typically found in a pre-engineered (sacrificial anode cathodic protection) underground storage tank installation. These components include the following:

1 cathodically-protected, epoxy coated steel tank; 2 dielectric bushings providing electrical insulation between tank and all connecting lines; 3 product delivery line; 4 leak detector on product delivery line; 5 submerged product delivery pump; 6 access manway; 7 fill pipe; 8 striker plate below fill pipe; 9 vent line; 10 float vent valve in vent line for over-fill protection; 11 Cathodic Monitoring System; 12 leak observation well, inside the excavation; 13 compacted bed of sand or gravel (same material as backfill); 14 sand or gravel backfill; 15 sacrificial anodes; 16 waterproof, tamper-proof lids on fill lines and manways.



Notes:

A. Inner wall ¼" steel
B. Coal-tar epoxy set to rigid manufacturers specifications
C. 8" minimum thickness
D. 24" minimum distance

SOURCE: Highland Tank Mfg. Co., member Steel Tank Institute.

such systems are expensive and have been known to disrupt nearby communication circuits. Because of their complexity, they should only be installed by a qualified corrosion engineer.

Galvanic Systems. Pre-engineered galvanic cathodic protection systems provide an economical and effective means of corrosion protection. The best of these systems use high potential magnesium anodes or high purity zinc anodes which provide a strong natural flow of protective current to the tank. Table 1-2 shows the weight and number of magnesium anodes to be used for various size tanks. These anodes should be carefully installed on the outside of the tank and electrically connected with a lead wire to the tank, as shown in Figures 1-2 and 1-3.

"Pre-engineered" tank systems are those that are specifically designed to meet vigorous standards specified by industrial groups such as the Steel Tank Institute or individual companies such as Buffalo Tank Corporation.

If a tank which relies on galvanic protection is used, the flow of electrical current from the anode to the tank should be monitored at least semi-annually. Systems for continuous or intermittent monitoring are available commercially. A good idea is to test for galvanic protection when "meter proving" (i.e., calibrating the dispenser for accuracy) is done.

Galvanic protection for internal surfaces of the tank may be provided by installing zinc strips which act as sacrificial anodes in a manner similar to the exterior magnesium anodes. The Department recommends internal cathodic protection.

As with impressed current systems, a galvanic system should only be designed by a qualified corrosion engineer.

3. Coating

Active cathodic protection as discussed above should be supplemented by the passive protection of a tough factory-applied coating.

The coating should be factory applied to the entire exterior surface of the tank after anode holders and all bushings and plugs have been installed, immediately after sandblasting. Sandblasting should be completed in accordance with the Steel Structure Painting Council Specification No. 6, Commerical Blast Cleaning. A stronger, more intimate tank-coating bond can be achieved by a White Metal Blast Cleaning, SSPC-SP5. The coating material should be equal to one of the following:

- Tarset Standard No. 7001, produced by Porter Coatings, Division of Porter Paint Company
- Plas-Chem Chem-Mastic 2203, produced by Plas-Chem Coatings, Eagle Picher Industries, Inc.
- Koppers 300M, producted by Koppers, Inc.
- Corrocote II (Instant Setting) by Madison Chemical Industries, Inc.

The thickness of the coating on the tank shell should be 13 mils wet (10 mils minimum when dry); the thickness of the coating on the tank head and within 48 inches of shell-mounted anodes should be 22 mils wet (15 mils minimum when dry). **Note:** The Corrocote product does not change thickness as it dries; the wet thickness is the same as dry thickness. For proper curing, the coating must be applied at temperatures higher than 50F. Heat may be introduced into the tank to ensure proper coating at low ambient temperatures. Moisture must not touch the tank exterior or coating until the coating is thoroughly cured.

The finished coating should be inspected by the fabricator using non-destructive magnetic film gauge tester. However, it is recommended that a wet film thickness gauge be used frequently while applying the coating to ensure proper application thickness. Coverage of the anode holders and other tank appurtenances should be carefully checked to ensure that the coating has the proper film thickness on all surfaces and edges.

When the coating has dried, it should be tested electrically for holidays, bubbles and other coating defects. These defects should be promptly recoated.

The coated tank should be handled with care to minimize damage to the coating during loading, unloading, or installation activities. Padding between trucks and tanks, and on chains or wire rope, is recommended. The repair of any coating surface which is damaged by mishandling should be in strict accord with manufacturers' recommendations and should conform to the above specifications for minimum thickness.

Internal corrosion can be mitigated by using a coating on the inside of the tank in lieu of the sacrificial zinc anodes which were recommended above. This provides an extra measure of protection which is recommended by the Department. Internal coatings must be chemically compatible with product blends and additives, in order to be effective.

4. Electrical Isolation

All cathodically protected tanks should be equipped with fittings for electrically insulating the tank from piping. These fittings may be nylon bushings, bolted flanges with companion nylon flanges, commercially available flange insulation kits, or an equivalent system.

If nylon bushings are used, they should be properly tightened by the manufacturer so that they will not have to be removed or further tightened in the field. The nylon material must be able to withstand exposure to the material to be stored without swelling and/or degradation. If there is any question as to the compatibility of the nylon bushings with the stored material, bushings made of a compatible material or flanged openings with chemically compatible gaskets should be used. An alternate method of electrically insulating the tank using bolted flanges and nylon companion flanges is shown in Figure 1-4.

Another method of electrically isolating openings is to use commercially available flange insulation kits. As shown

TABLE 1-1

THICKNESS OF STEEL TANKS
RECOMMENDED BY UNDERWRITERS LABORATORY

Capacity		Maximum* Diameter		Manufacturers Standard or Galvanized Sheet	Nominal Thickness			
					Uncoated		Galvanized**	
U.S. Gallons	dm3	Inches	m	Gauge No.	Inches	mm	Inches	mm
Up to 285	Up to 1078	42	1.07	14 **	0.075	1.91	0.079	2.01
286 to 560	1082 to 2120	48	1.22	12 **	0.105	2.67	0.108	2.74
561 to 1100	2124 to 4164	64	1.63	10 **	0.135	3.43	0.138	3.51
1101 to 4000	4168 to 15142	84	2.13	7	0.179	4.55		
4001 to 12,000	15145 to 45425	126	3.20	1/4 inch	0.250	6.35		
12,001 to 20,000	45429 to 75708	144	3.66	5/16 inch	0.312	7.92		
20,001 to 50,000	75712 to 189270	144	3.66	3/8 inch	0.375	9.53		

Source:

This material is based on and taken, with permission, from Underwriters Laboratories Inc. **Standard for Safety for Steel Underground Tanks for *Flammable and Combustible Liquids*,** UL 58, Copyright 1976 (by Underwriters Laboratories Inc.), copies of which may be purchased from Underwriters Laboratories, Inc., Publication Stock, 333 Pfingsten Road, Northbrook, Illinois 60062.

Note:

UL shall not be responsible to anyone for the use of or reliance upon a UL Standard by anyone. UL shall not incur any obligation or liability for damages, including consequential damages, arising out of or in connection with the use, interpretation of, or reliance upon a UL Standard.

* Length of tank shall be not greater than six times the diameter.

** The use of galvanized steel and shell thicknesses less than 7 gauge are not recommended by the Department of Environmental Conservation.

TABLE 1-2

MAGNESIUM ANODE REQUIREMENTS

Surface Tank Area Sq. Ft.	Number of Anodes Required			Anode Weight, pounds		
	Each Head	Shell Anodes	Total Tank	Each Anode	Total Per Tank	Dow Galvomag Anode Type (1)
50-175	1		2	9	18	9D3
175-350	1		2	17	34	17D3
350-515	1		2	24	48	24D4
515-780	1		2	32	64	32D5
780-1000	1		2	48	96	48D5
1000-1280	2		4	32	128	32D5
1280-1600(2)	1		2	32	64	32D5
		1	2	48	96	48D5
1600-1900(2)	2		4	48	192	48D5
1900-2200(2)	1	2	4	32	128	32D5
	1		2	48	96	48D5
2200-2500(2)	1		2	32	64	32D5
	1	2	4	48	192	48D5
2500-2875(2)	2	2	6	48	288	48D5

Notes

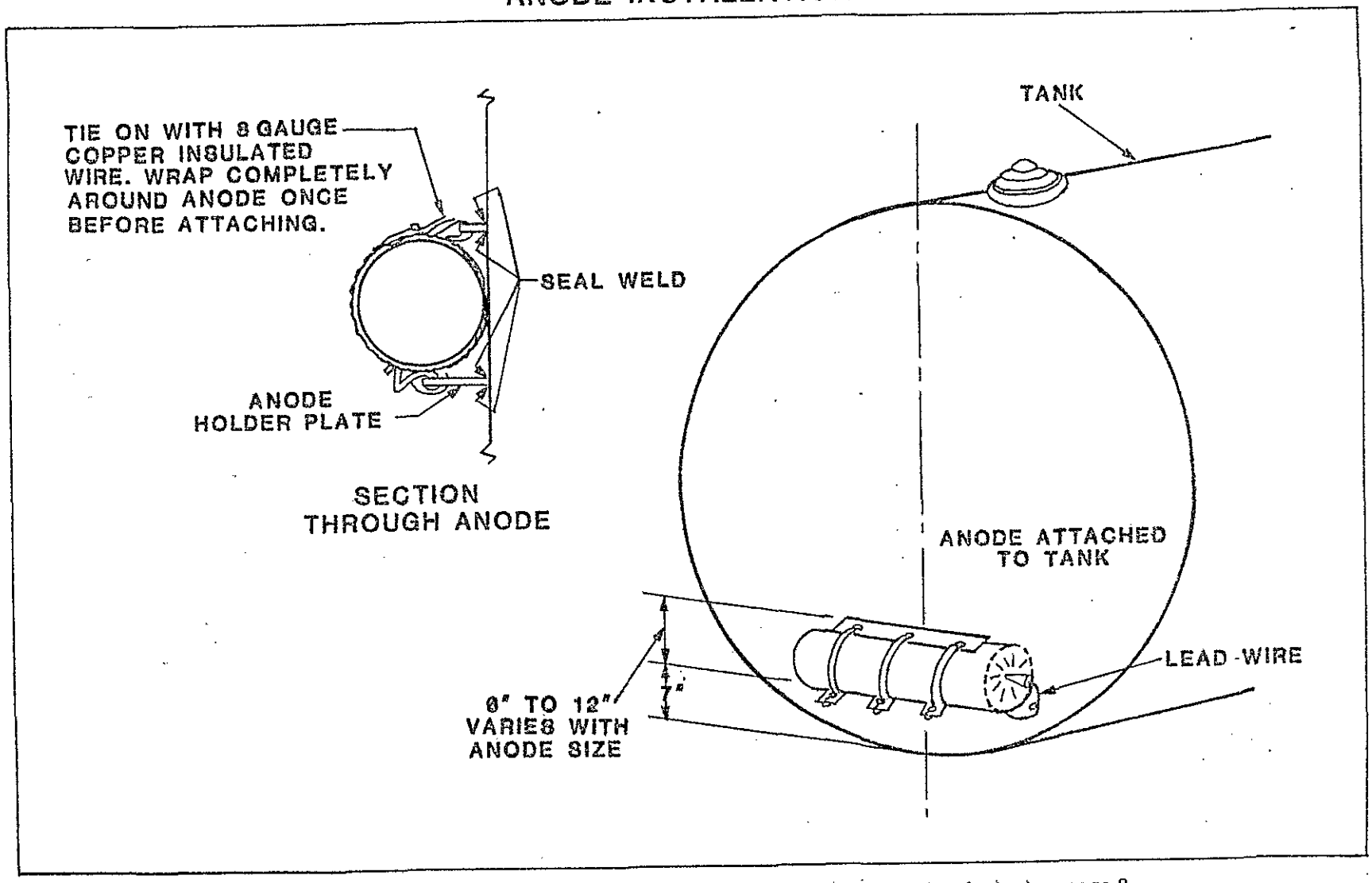
1. If size recommended is not available, use next larger size.
2. If tank length is over 35 feet, place anodes on heads and shell. Design assumes that tank of this size will have to be loaded, unloaded, and otherwise handled with a crane so that no rolling of tank will be necessary.

Adopted from sti-P_3® System specifications, copyright 1983, permission of the Steel Tank Institute.

Steel Tank Institute will not be responsibile to anyone for the use of or the reliance upon STI Standard by anyone. UL will not incur any obligation or liability for damages, including consequential damages arising out of or in connection with the use, interpretation of, or reliance on an STI Standard.

FIGURE 1-2

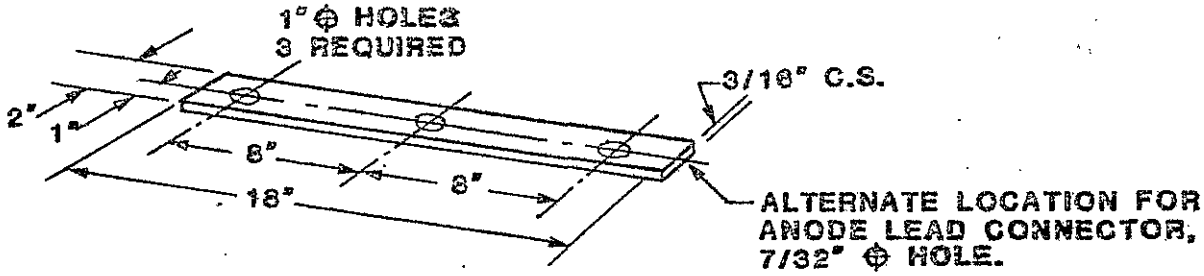
ANODE INSTALLATION



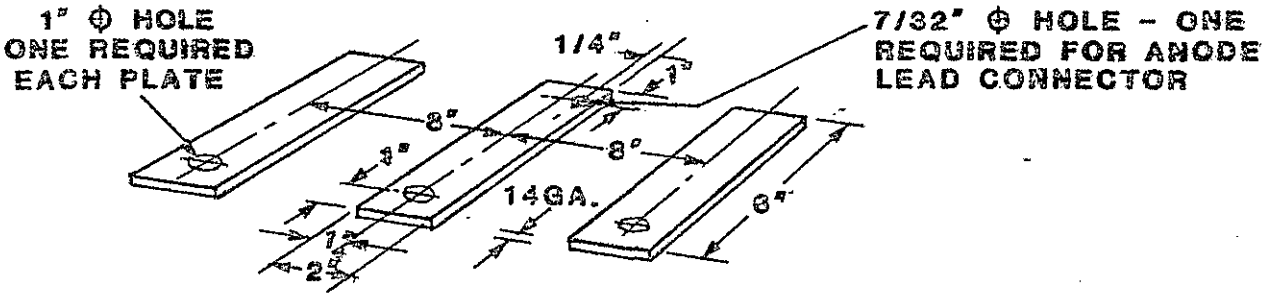
SOURCE: sti-P$_3$® System specifications, copyright 1983, permission of the Steel Tank Institute. See footnotes, page 8.

FIGURE 1-3

ANODE HOLDER DETAILS AND INSTALLATION



TOP ANODE HOLDER PLATE
ONE REQUIRED ON EACH END



BOTTOM ANODE HOLDER PLATES
REQUIRED ON EACH END

Notes:

(1) The hole locations and size of top anode holder plates and the number of bottom anode holder plates may be changed (but not the basic design or attachement) to use 2 bottom plates for 9lb., 3 for 17, 24 and 32 lb. and 4 for 48 lb anodes.

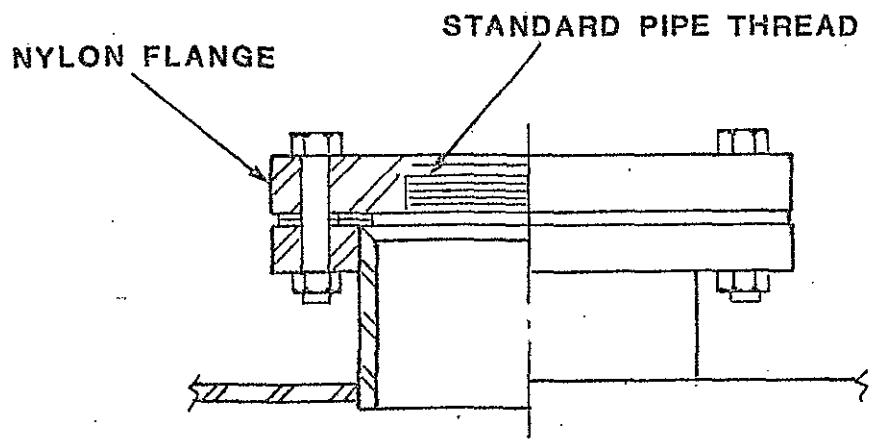
(2) For shell mounted anodes use two top anode holder plates and no bottom anode holder plates.

(3) Where two anodes are required for each head, two top anode holder plates are to be spaced above one set of bottom anode holder plates. Bottom anode shall be installed in the usual manner; top anode shall be installed in a manner similar to shell anodes.

SOURCE: sti-P_3® System specifications, copyright 1983, permission of the Steel Tank Institute. See footnotes, page 8.

FIGURE 1-4

ELECTRICAL ISOLATION USING A NYLON COMPANION FLANGE (WITH NYLON OF THE SAME SPECIFICATION AS THE BUSHING).



SOURCE: sti-P_3® System specifications, copyright 1983, permission of the Steel Tank Institute. See footnotes, page 8.

in Figure 1-5, these kits consist of a gasket, sleeves for bolts, and washers; all of these are composed of dielectric material. Flange insulation must be shipped installed in the tank with suitable threaded companion flanges so the flange isolation will not be disturbed in the field. It is recommended that the installation of flange insulation kits be such that the bolts will be grounded to the tank and, therefore, cathodically protected, but isolated from the companion flange.

D. DESIGN RECOMMENDATIONS - FIBERGLASS-REINFORCED PLASTIC TANKS

Fiberglass-reinforced plastic (FRP) tanks are manufactured by a highly specialized industry. These tanks must be designed and fabricated by engineers with expertise in the strength of fiberglass materials, material compatibility, and underground tank installation. For this reason, only FRP tanks constructed by a reputable manufacturer should be used.

The following recommendations cover spherical or horizontal cylindrical atmospheric-type tanks of fiberglass-reinforced plastic construction which are intended for underground storage of petroleum.

1. FRP Tank Design

FRP tanks should be UL listed and designed in accordance with Underwriters' Laboratory Standard 1316, **Standard for Glass-Fiber-Reinforced Plastic Underground Storage Tanks for Petroleum Products** (3), or Underwriters' Laboratory of Canada, Standard ULC-S615-1977, **Standard for Reinforced Plastic Underground Tanks for Petroleum Products** (4). These standards set forth requirements for structural strength, criteria for chemical compatibility of tank material with product stored, and surrounding soil, and test methods for quality control. Usually the wall thickness of an underground FRP tank is 0.22 inches, although a thicker wall may be necessary for large tanks or tanks storing products with a specific gravity greater than 1.5.

FRP tanks normally incorporate reinforcing ribs in their design. These ribs provide the additional structural strength that is necessary for tank integrity. Ribs are designed to withstand both the internal stresses from the stored product, and the external backfill, hydrostatic and buoyancy forces. The ribs are also designed to accept the hold down straps used to ballast the tank.

An FRP tank should be equipped with lifting lugs that are attached to the tank or can be attached to a fitting on the tank. Tanks with a capacity of 1,000 gallons or less may be equipped with only one lifting lug. The precise method of handling and lifting the tank should be prescribed by the manufacturer and these instructions should be carefully adhered to by the installer.

2. Compatibility of Materials

Many resins are available for use in FRP tanks, and each has its own characteristics of performance. Some resins dissolve, soften, or become brittle in acidic or saline soil environments. Others will lose structural strength when exposed to certain chemicals. Gasahol (a gasoline-ethanol blend) has been known to cause FRP tank failure particularly at mixtures of 15 to 20% ethanol. Methanol and other gasoline additives are known to be incompatible with certain resins. Manufacturers of tanks carrying a UL label are required to perform immersion tests to prove material durability and chemical compatibility. Underwriters' Laboratories in turn certifies only that the tank is compatible with certain chemicals.

In selecting an FRP tank, it is therefore of utmost importance that the tank manufacturer be notified of the exact chemical composition of the product to be stored. The manufacturer should then bear the responsibility for selecting the proper tank and providing the owner with a written assurance of chemical compatibility. Under no circumstances should products be switched from tank to tank unless the manufacturer provides assurances that the new product is compatible with the tank.

Because the resins used for FRP construction have changed over time, it is imprudent to reuse a FRP tank of unknown origin and age unless the prior use of the tank is known and the tank manufacturer is consulted on the compatibility of the tank resin with the new product to be stored.

3. Installation of FRP Tanks

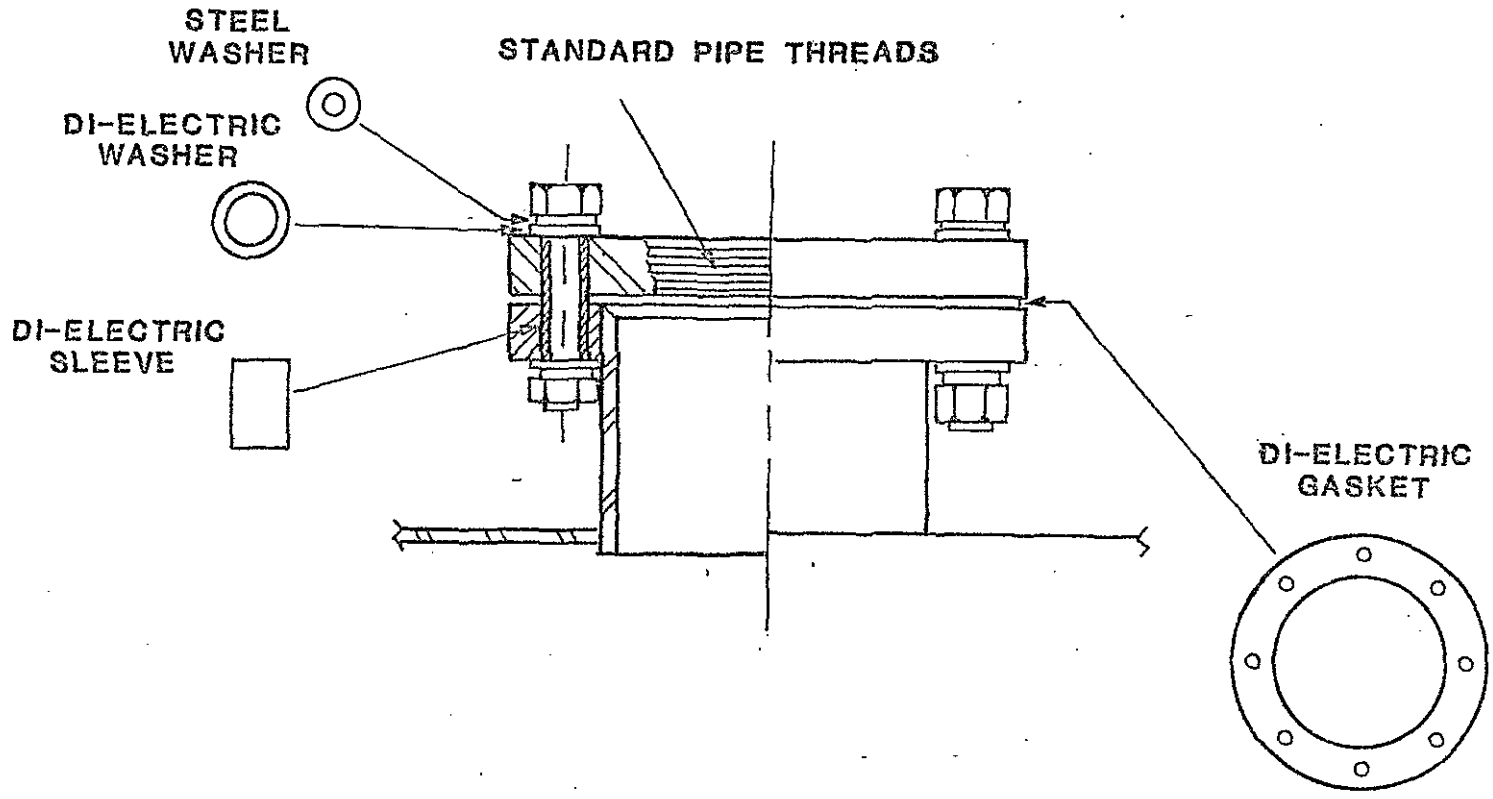
Fiberglass tanks have more exacting handling requirements than do steel tanks and they acquire most of their support strength from the backfill. For this reason, following the manufacturer's installation instructions and inspection of the installation is of critical importance. Chapter 3 discusses in detail the recommended practices for installing FRP tanks.

E. STEEL TANKS WHICH ARE CLAD WITH FIBERGLASS-REINFORCED PLASTIC

Steel tanks which are clad with fiberglass (often referred to as composite tanks) consist of a basic steel tank as prescribed under Section C of this Chapter, which has an outer layer of fiberglass resin reinforcement with a thickness of 100 mils bonded to the steel shell. Underwriters' Laboratories has a specific listing for composite tanks, but no official standard has been promulgated. Specific designs are considered on a case- by-case basis. These tanks, when fabricated by a reputable manufacturer, provide a storage vessel which is both strong and resistant to external

FIGURE 1-5

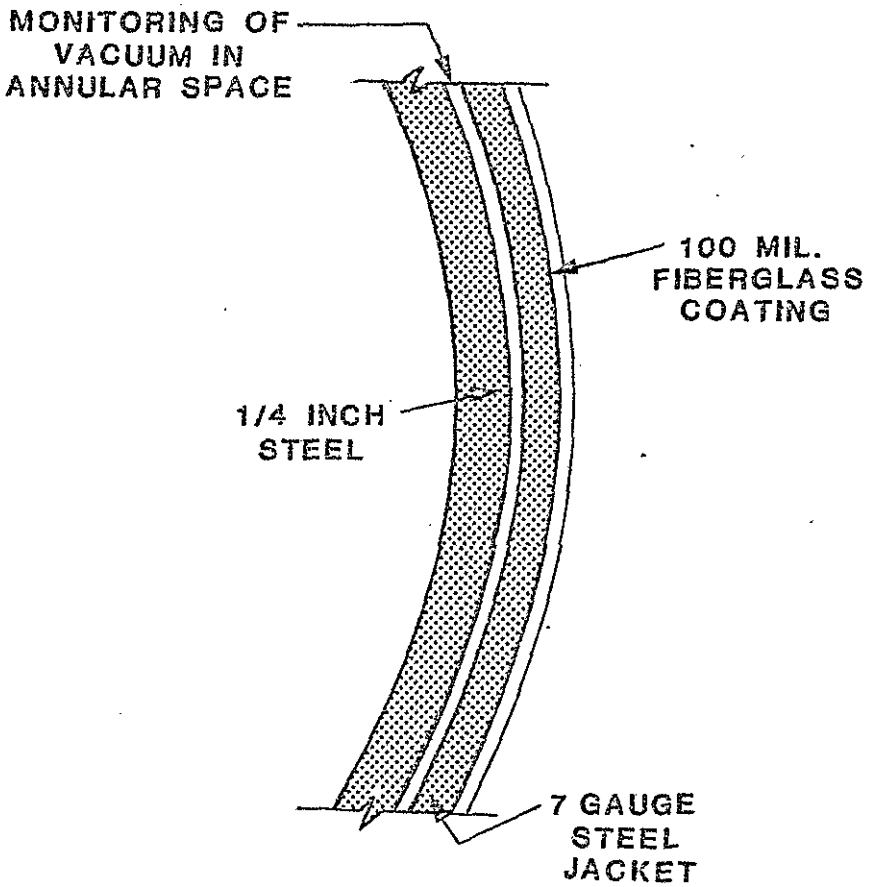
ELECTRICAL ISOLATION USING A FLANGE INSULATION KIT



SOURCE: sti-P_3® System specifications, copyright 1983, permission of the Steel Tank Institute. See footnotes, page 8.

FIGURE 1-8

DOUBLE-WALLED STEEL TANK WITH BONDED FIBERGLASS COATING



CROSS SECTIONAL VIEW
(DRAWN TO APPROXIMATE SCALE)

corrosion. They may also be custom manufactured with an internal fiberglass layer to provide protection from internal corrosion, or constructed in a two wall design.

1. Electrical Insulation

As with any steel tank, the composite tank should have nonconductive bushings or flanges at all piping connections to assure that the tank is electrically insulated from the piping system.

2. Coating

The fiberglass coating must be applied under strict quality control. The tank must be sandblasted free of rust and scale using the Steel Structures Painting Council specifications for commercial blast cleaning, SSPC- SP-6. Following sandblasting and vacuuming, the coating should be immediately applied to the surface under moisture-free conditions.

After curing, the coating should be inspected for air pockets, blisters, pinholes and electrostatically tested with 10,000 volts for coating short circuits (also known as spark testing).

The coating must have bonding quality and a coefficient of thermal expansion which is compatible with steel so that stress due to temperature changes will not be detrimental to the soundness of the coating and the permanent bond between the coating and the steel. The coating must be of sufficient density and strength to form a hard impermeable shell which will not crack, wick, wear, soften or separate. It must also be capable of containing the product under normal service conditions in the event that the steel wall should leak.

As with FRP tank designs, the resins used in the coating of a composite tank should be noncorrosive in underground soil environments and compatible with petroleum, petroleum additives, and petroleum derivative liquids.

F. DOUBLE-WALLED TANKS

Tanks of double-walled design with continuous monitoring of the annular (interstitial) space provide the best overall protection against leakage. Because monitoring of tank integrity and secondary containment are inherent and integral features of their design, double-walled tanks may be more economical than single-walled tanks with a monitoring well and containment liner installed separately in the excavation.

> Double-walled tanks provide the best protection against leaks. The Department recommends that these types of tanks be used on all environmentally critical installations.

Double-walled tanks should have an outer jacket which covers at least the bottom two-thirds (2/3) of the tank. The jacket should cover all straight and girth seams of the inner wall. There should be no penetrations of any kind through the jacket to the tank except the top entry fittings required for monitoring the interstitial space. Figure 1-6 details the construction of a double-walled tank.

The double-walled tank is most effectively monitored by applying a vacuum to the interstitial space and checking for vacuum loss.

A double-walled tank should incorporate all of the recommended practices for single walled tanks identified in Sections B through F of this chapter. If a double-walled cathodically protected tank is used, it should consist of a standard tank with an outer (second) wall made of steel with a minimum thickness of 10 gauge (0.135 inch). This outer wall should be covered by an epoxy coating or equivalent as discussed in Section C. If a double-walled fiberglass tank is used, all requirements for structural strength discussed in Section D should be addressed.

A double-walled steel/fiberglass composite tank should consist of a standard tank with a 10 gauge outer jacket covered by the fiberglass coating discussed in Section E.

All double-walled tanks of steel construction should include provisions to eliminate potentially corrosive water vapor from the annular (interstitial) space of the tank.

Double-walled tanks provide the following advantages:

- The highest level of containment technology.
- Product monitoring of the interstitial space to detect leaks.
- Secondary containment of the stored product, and prevention of its release into the environment.
- Tightness testing is usually not necessary in the event that groundwater contamination from an unknown source is discovered.
- They can be used in environmentally sensitive areas.
- They lead to lower environmental risks and inherently lower insurance costs.

References

1. Underwriters Laboratories, Inc., *Steel Underground Tanks for Flammable and Combustible Liquids,* UL 58, Underwriters' Laborartories, Inc., 333 Pfingsten Road, Northbrook, Illinois, October, 1976.

2. American Society of Mechanical Engineers, *ASME Pressure Vessel Code, Section VIII, Division 1, Boiler and Pressure Vessel Code,* American Society of Mechanical Engineers, 345 East 47th Street, New York, NY 10017.

3. Underwriters' Laboratories, Inc., *Standard for Glass-Fiber-Reinforced Plastic Underground Storage Tanks,* UL 1316, Underwriters' Laboratories, Inc., 333 Pfingsten Road, Northbrook, Illinois 60062, July 1983.

4. Underwriters' Laboratories of Canada, Inc., *Standard for Reinforced Plastic Underground Tanks for Petroleum Storage, ULC-S615-1977, Underwriters' Laboratories of Canada, Inc., 7 Crouse Road, Scarborough, Ontario, March, 1977.*

5. *New York State Department of Environmental Conservation, Technology for the Storage of Hazardous Liquids, A State-of-the-Art Review,* New York State Department of Environmental Conservation, 50 Wolf Road, Albany, NY 12233, January, 1983.

6. Steel Tank Institute, *sti-P_3® Specifications,* Steel Tank Institute, 666 Dundee Rd., Suite 705, Northbrook, Illinois 60062.

CHAPTER 2:
PIPE, FITTINGS, AND PUMPING SYSTEMS

A. INTRODUCTION

Piping and pumping systems perform the function of delivering stored product from underground storage tanks to aboveground dispensers without leakage. Figure 2-1 illustrates piping and pumping systems which are typical of a service station. This chapter will briefly discuss the elements of piping and pumping systems and recommend specific components.

B. PIPE MATERIALS

New underground pipes at a storage facility should always be protected against corrosion. The two most common materials that meet this criteria are fiberglass-reinforced plastic and cathodically-protected galvanized steel pipe.

Piping failure is a significant cause of underground leakage. According to a leak survey conducted by the American Petroleum Institute, piping failure accounted for fully 1/3 of all reported leaks at underground storage facilities [1]. The principle causes of piping failures are as follows:

- Corrosion.
- Settlement of backfill.
- Frost heave.
- Traffic loadings on poorly protected piping.
- Stresses resulting from changes in temperature.

Some of the general considerations associated with the design of piping systems are highlighted in Table 2-1. The principle remedies for these problems are corrosion protection, proper design by professional engineers, and installation by experienced and qualified installers.

There are several types of piping materials available which will provide protection against leakage. The materials recommended for use by the Department include cathodically protected steel, fiberglass-reinforced plastic (FRP), and stainless steel. Double-walled pipe is also recognized by the Department as a reliable means of conveying liquids.

TABLE 2-1

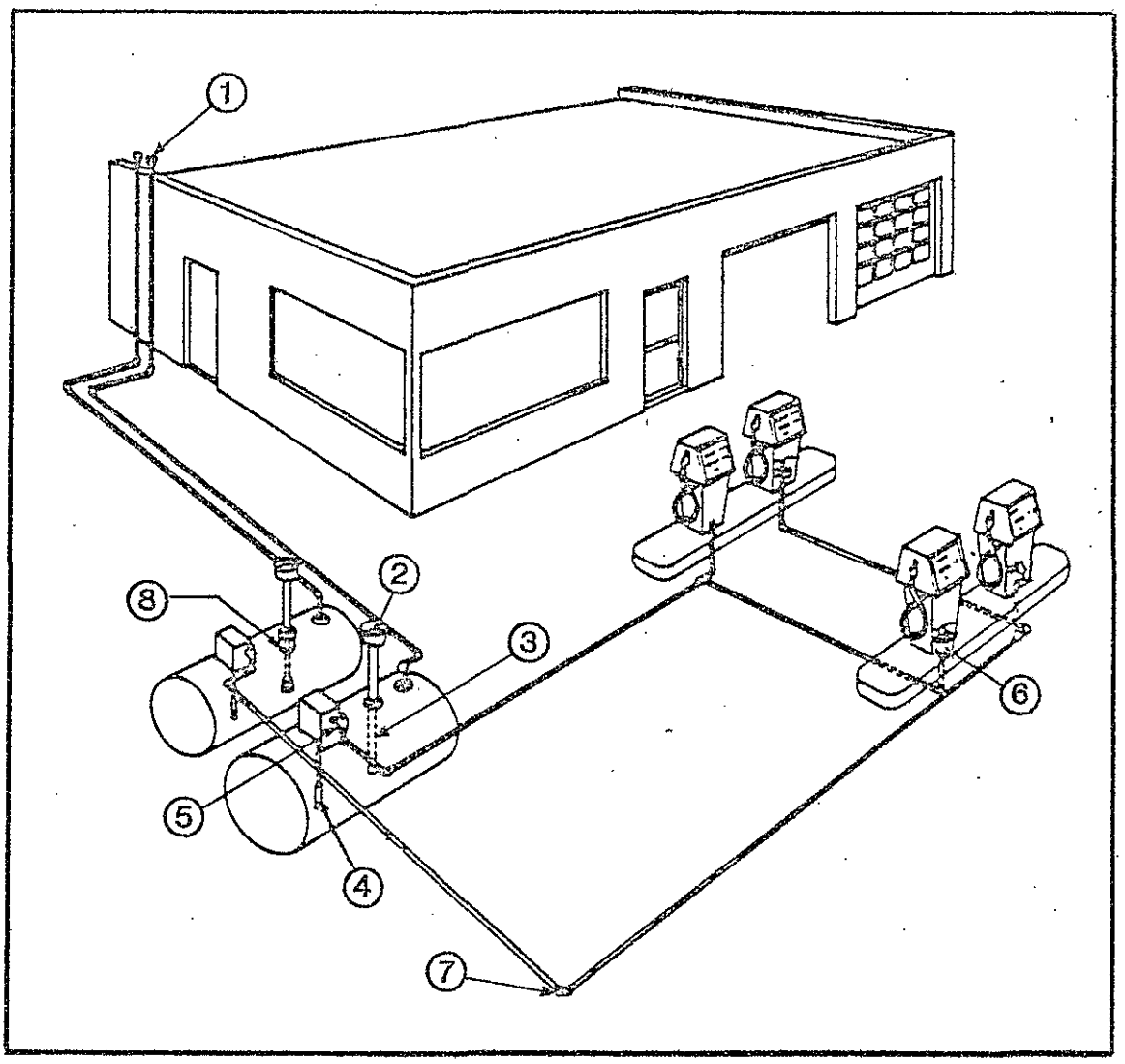
CONSIDERATIONS IN PIPING SYSTEM DESIGN

The following are some general considerations to be evaluated when selecting and applying materials in piping:

- The corrosive characteristics of the material to be transported, and the ability of the piping system components to withstand that corrosion.
- The characteristics of the external atmosphere (soil, water, etc.) to which the piping system components are exposed.
- Force loadings due to dynamic effects (fluid flow) and weight considerations.
- The susceptibility of the piping material to crevice corrosion in threaded joints, in socket welded joints, and in other stagnant, confined areas.
- The possibility of adverse electrolytic effects if the metal is subject to contact with a dissimilar metal, including older metals of the same type.
- The compatibility of lubricants or sealants used on threads, with the fluid handled.
- The suitability of packing, seals, and O-rings for the fluid service, including possible effects of or on the fluid handled.
- The compatibility of materials such as cements, solvents, solders, and brazing with the fluid being transported.

FIGURE 2-1

ELEMENTS OF AN UNDERGROUND PIPING SYSTEM



A TYPICAL PIPING SYSTEM AT AN UNDERGROUND STORAGE FACILITY, SHOWING THE FOLLOWING ITEMS:

1. STORAGE TANK VENT
2. TANK FILL CAP AND DROP TUBE ADAPTER
3. TANK DROP TUBE
4. SUBMERGED TRANSFER PUMP
5. PIPELINE LEAK DETECTOR
6. EMERGENCY SHUTOFF VALVE
7. SWING JOINT AT A CHANGE OF DIRECTION
8. EXTRACTOR ASSEMBLY (FOOT VALVE)

SOURCE: Service Station Products, courtesy of Emco Wheaton, Inc. (4)

1. Cathodically Protected Steel Pipe

In instances where steel is the preferred piping material, the Department recommends the use of cathodically protected, galvanized steel pipe. Steel pipe alone has excellent strength, but is susceptible to corrosion. Zinc galvanizing gives some corrosion protection to the pipe, but this protective coating is often scraped off or scratched during handling, pipefitting, and installation operations. Therefore, galvanizing alone does not provide adequate corrosion protection.

To provide adequate protection from corrosive elements, either galvanic or impressed current cathodic protection should be used. The galvanic cathodic protection method employs sacrificial anodes made of magnesium or zinc. These anodes are installed in electrical contact with the piping via bonding wires. The corrosion of these anodes creates electrolytic cells, generating a weak electric current that protects the pipe from corrosion.

The impressed current cathodic protection method employs D.C. current provided from an external source. This current is passed through the system by the use of non-sacrificial anodes composed of materials such as carbon, non-corrodible alloys, or platinum. These anodes are buried in the ground (to protect underground piping), or otherwise suspended in the electrolyte, and electrically connected to the positive terminal of the external power supply. The piping is then connected to the negative side of that power supply. The resulting flow of current prevents corrosion of the pipe. The layout of a typical impressed current cathodic protection system is shown in Figure 2-2.

Impressed current systems require special attention to ensure electrical continuity throughout the system. Monthly checks are not considered excessive.

In either type of cathodic protection system, the determination of the appropriate size, location, and spacing of the anodes requires engineering expertise; such expertise and guidance is available from organizations such as the National Association of Corrosion Engineers.

Alternatively, piping can be coated or wrapped. Pipe coating materials can be painted, brushed or sprayed on. The best method is to coat the piping after pipefitting operations are complete. Care must be taken to be certain of complete coverage, particularly on temporary support points, joints and the underside of the pipe, which is hidden from view. Coatings are especially formulated for hardness, durability and adhesion. They should not be confused with products such as red lead paint and bituminous coatings, which are worthless.

Pipe wrapping techniques involve priming the pipe with solvent based primer. This provides a surface which is tailored for bonding with a vinyl coated, mastic backed wrapping tape. This wrapping is most efficiently applied in the shop. There, lengths of pipe can be quickly and accurately wrapped. Joints must, of course, be wrapped in the field.

> In underground installations, it is important to remember that new steel is anodic to old steel. That is, if new steel pipe is connected to old steel pipe or near old steel structures, the new steel will corrode much more quickly than expected.

2. Fiberglass-Reinforced Plastic Pipe

FRP pipe has a distinct advantage over steel pipe in that it is inherently corrosion resistant, and thus provides excellent protection against leaks when installed correctly. It is also flexible enough to account for minor misalignment and earth movement. No swing joints are required except for very short pipe runs, or sharp turns. As a result, this material has found increasing acceptance for bulk storage applications in recent years.

However, FRP pipe has lower structural strength than steel pipe. It therefore requires fully-compacted bedding and extra caution in handling and installation. The recommended installation practices for this material are addressed in Chapter 3, Section F of this report.

FRP pipe and steel pipe are now considered to have the same installed cost. The cost of the fiberglass material is much higher than the cost of steel, but this is counterbalanced by lower handling and pipefitting costs.

Underwriters Laboratories has a listing of FRP pipe which is approved for **underground** petroleum products service. This listing is particularly appropriate for service station applications, and should be consulted if the use of this piping material is considered.

3. Stainless Steel Pipe

Stainless steel pipe is also suitable for underground use. It is well known for its corrosion resistance, and its industrial use is growing. The main drawback of stainless steel is cost. Its installed cost is approximately three times that of galvanized steel or FRP pipe. However, the added expense may be warranted where highly hazardous liquids are stored, or in environmentally sensitive areas.

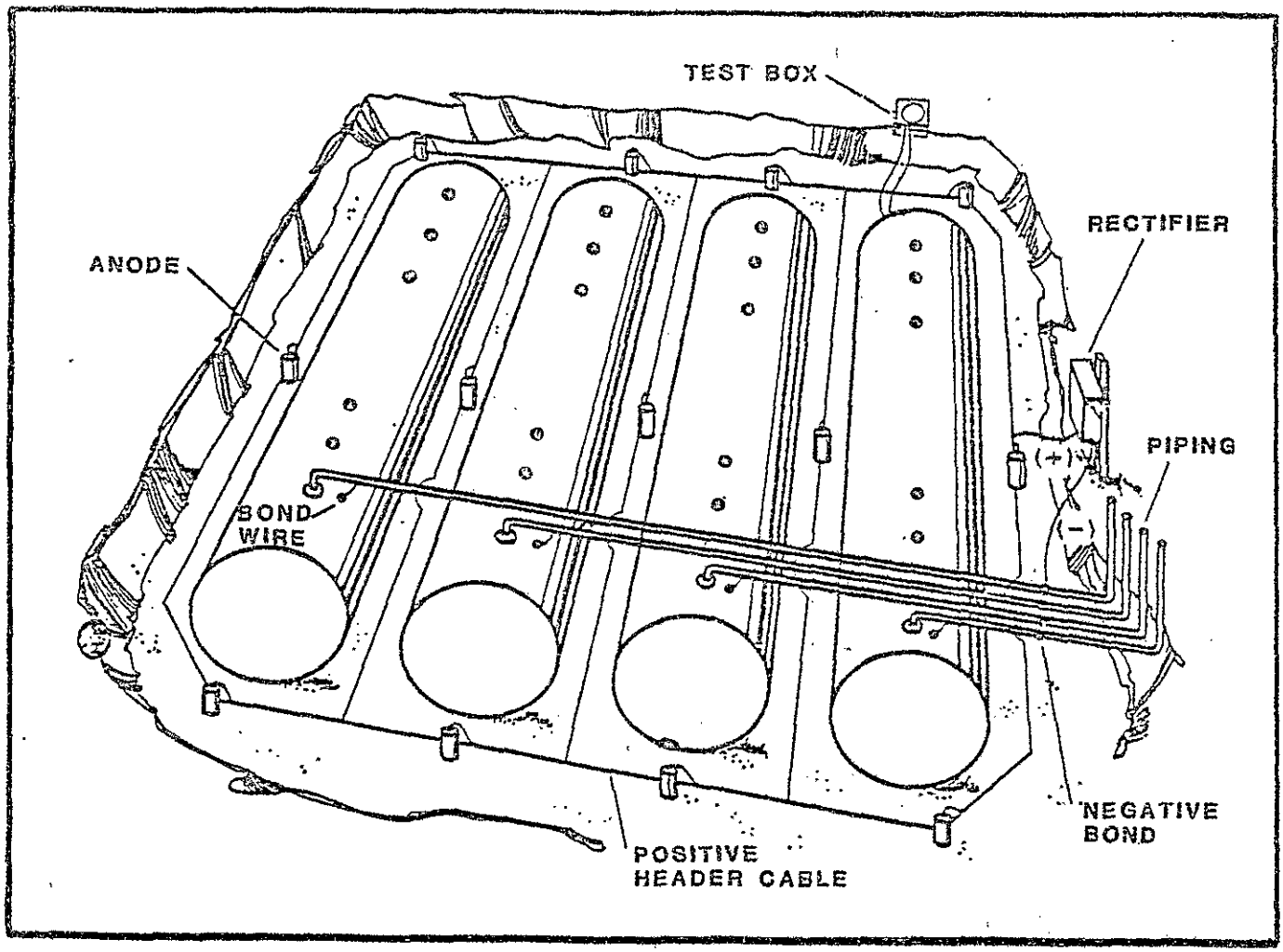
Schedule 10, Type 304 stainless steel is satisfactory in highly corrosive soil environments and is the most common kind of stainless steel pipe for service station-type, low pressure (20-40 psi) applications. Schedule 10 pipe has a thinner wall thickness than Schedule 40, but is of sufficient thickness for welded joints. Where screwed fittings must be used, a transition to Schedule 40 stainless pipe must be made.

Stainless steel pipe has the important advantages of being able to be installed without coatings or cathodic protection. However, it does require the same high quality bedding that the other materials require.

Even though stainless steel has a deserved reputation for corrosion resistance, the presence of some chemicals in the soil particularly sulfides, can result in corrosion. Therefore a corrsion specialist should be the one who makes a selection of the particular formulation of stainless to be used based on the chemical makeup of the native soils.

FIGURE 2—2

AN IMPRESSED CURRENT CATHODIC PROTECTION SYSTEM CONFIGURATION



SOURCE:

Suggested Ways to Meet Corrosion Protection Codes for Underground Tanks and Piping; The Hinchman Company, Detroit, MI.

4. Double-Walled Pipe

For situations involving the piping of very hazardous or toxic liquids, or in instances where the environment would be severly impacted by leakage, double-walled piping is endorsed as an acceptable choice.

Figure 2-3 illustrates one type of double-walled pipe. The outer wall encloses the inner pipe, which is supported at regular intervals. This ensemble is contained by a bulkhead at the end of each segment. The interstitial space between the inner and outer walls is slightly pressurized with nitrogen. This pressure is monitored. A **drop** in pressure indicates leakage in the outer wall, while a **rise** in pressure indicates that there is leakage from the inner pipe. This manufacturer coats its products with coal tar epoxy or FRP in a manner similar to that described for tank coatings in Chapter 1.

At this time, the use of double-walled pipes for underground petroleum products piping is something of a rarity in New York. The Department makes no specific recommendations as to material selections or wall thicknesses. However, corrosion protection is still of paramount concern, and the manufacturer's recommendations on this subject should be closely followed.

C. FITTINGS

Connections between pipe lengths and at the tank are a frequent source of leaks. This section will describe fittings by material type since there are few fitting elements common to all types of pipe materials.

When pipe is screwed together, thread lubricant (pipe dope) is necessary to ensure that the pipe and fitting are mated to the proper depth, to ensure that a tight seal has been made, and to provide some degree of protection against the crevice corrosion that can occur at joints. Where threads are joined, the union of two metals with just slightly different properties results in a galvanic cell which will corrode if not protected. Thread lubricant gives limited protection to joints. The practice of welding galvanized pipe fittings is uncommon and is an unsuitable practice for underground piping systems.

In addition to the usual elbows and couplings, **swing** joints should be used at all changes in direction. This is necessary to relieve stress on the pipe from such causes as frost action, temperature changes, and traffic loadings. **Expansion joints** (e.g., Dresser Couplings or Victaulics) have been used in the past for this purpose, but age and repeated flexing will eventually cause them to fail. Expansion joints should only be used aboveground.

Expansion loops are used to account for thermal expansion on long straight runs of pipe. Their use is endorsed for both above and underground applications.

Where metallic piping is attached to metallic storage tanks, **dielectric bushings** are highly recommended, except with impressed current systems. This practice prevents any stray electrical currents picked up by the pipe from being conducted to the tanks. These bushings are normally made from either nylon or teflon.

FRP joints are glued, except where transitions to pumps and emergency shutoff valves are made. Chapter 3 of this report details the concerns of fiberglass joint make-up.

Relatively thin-walled (Schedule 10) stainless steel pipe may be used for low pressure piping. The joints for this Schedule 10 piping are welded. Welding stainless steel is an operation requiring considerable skill and attention to detail. Where screwed connections are required, such as for the pump connection, a transition to Schedule 40 pipe must be made. The Schedule 40 pipe has sufficient thickness to allow for pipe threads to be cut.

The joining methods for **double-walled** pipe include flanges, welding, and resin-glueing. The exact method depends on the specific type of pipe chosen. Manufacturers' specifications should be consulted for more detailed information.

D. PUMPS

Under normal operation, pumps are not a major source of leakage. In fact, in some instances the pumping system of a bulk storage facility can be used to monitor the piping system for leaking. The following discussion will address the basic principles of the common types of pumping systems, and describe their utility as leak detection devices.

> The two most common types of pumping systems, remote pumping systems and suction pumping systems, are both acceptable for service at bulk storage facilities.

1. Remote Pumping Systems

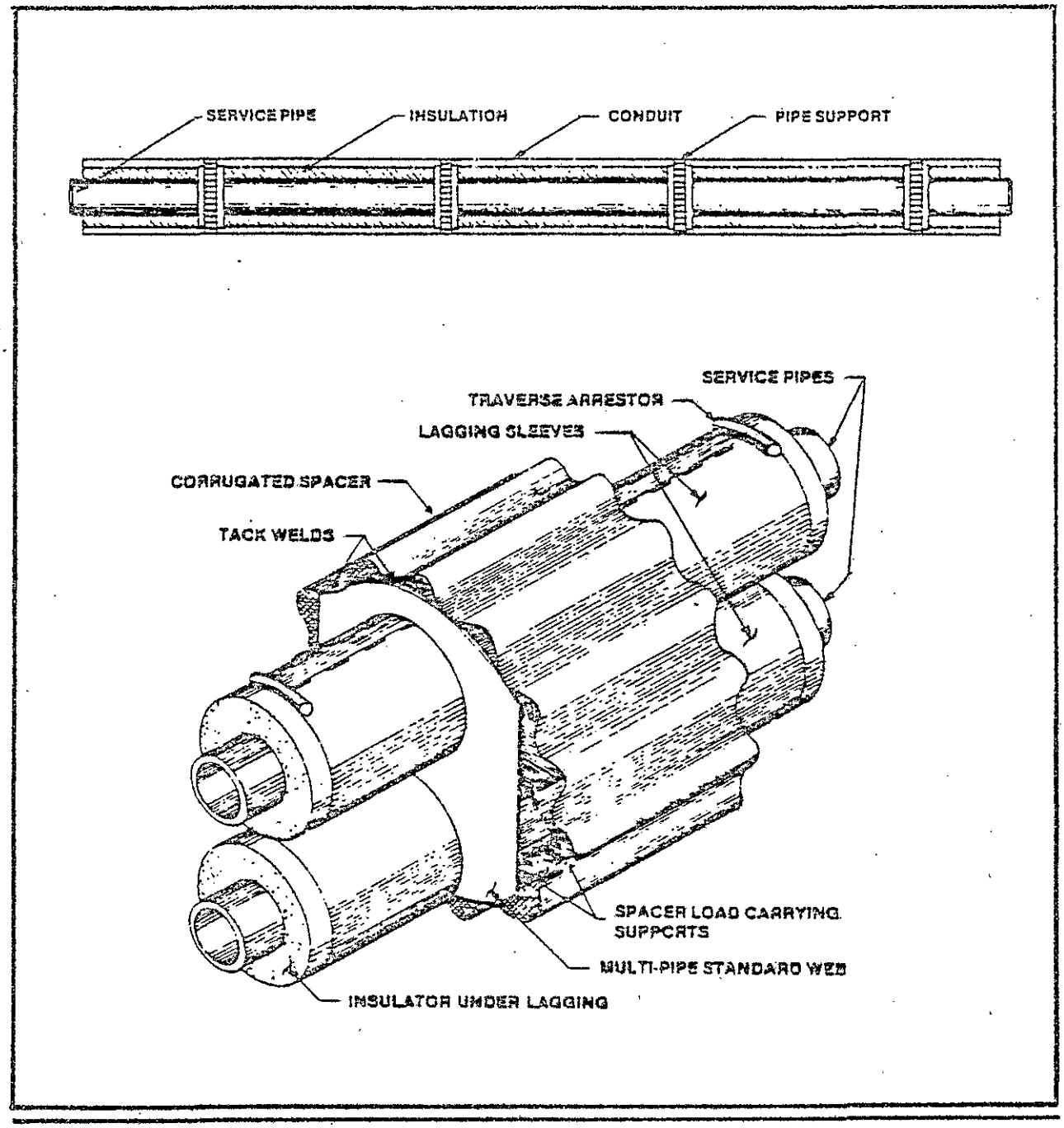
Remote pumping systems employ submerged transfer pump (STPs) to transport the stored liquid from the tank to product dispensers. These pumps are typically centrifugal pumps which are rated explosion-proof and immersed in the product storage tank. They pressurize the product delivery line, imparting a "positive head", or positive pressure, to the product to deliver it to aboveground and often remote dispensers.

Remote pumping systems are generally more energy-efficient than suction pumping systems. They also have an advantage in that one pump can service several dispensers, whereas suction pumps can only serve one dispenser per pump.

The drawback to this type of system is that a submerged transfer pump cannot differentiate between product dispensing and leakage in the delivery line. A leak or crack in a pipe may go undetected for some time because, unlike suction pumping systems, there is no interference with product flow. In addition, since the pipeline is operating

FIGURE 2—3

DOUBLE WALLED PIPE



SOURCE: PERMA-PIPE, Division of MIDWESCO, Inc.

under a positive head, losses tend to be rapid. For this reason, new facilities employing a remote pumping system should be equipped with a pipeline leak detector on the discharge side of the pump. These leak detectors should be capable of interrupting product flow if there is a drop in pressure in the delivery line. Figure 2-4 describes the operation of a leak detector of this type.

One recurring problem with remote pumps is failure of the O-ring seals. These seals should be periodically checked for signs of failure.

> The Department recommends that all remote pumping systems in use be retrofitted with a pipeline leak detector to avoid large scale leaks. These detectors are inexpensive and, in most cases, easily installed.

2. Suction Pumping Systems

Suction pumping systems employ pumps located at the dispenser units to "suck" liquid out of the storage tanks. This type of pumping system has decreased in popularity in recent years as STPs have become more sophisticated.

From an environmental standpoint, suction pumps have a built-in safety check. If there is a break in the line and product leaks out, the pump will experience a loss of prime and will sputter and hesitate or not work at all. However, to be effective as a leak detection method, there should be only one check valve in any suction line.

3. Emergency Shutoff Valves

The terminus of a remote pumping system should be an emergency shutoff valve such as the type shown in Figure 2-5. These valves, also referred to as impact valves, are mandated by Chapter 7 of NFPA 30, **The Flammable and Combustible Liquids Code** [3]. They are typically located at the base of the dispensing unit as shown in Figure 2-1, and shut off product flow in the event that the dispensing pedestal is knocked over or exposed to fire.

Monthly checks will make sure that the spring mechanism remains in good mechanical order.

4. Leaks from Pumping Systems

Although pumps do not represent a major source of spills or leaks, incidents resulting from leaking pump seals, pump casing failures, and losses of lubricating oil have been known to occur, particularly in the case of suction pumps or remote pumps which are mounted above (as opposed to in) the storage tanks. As a result, periodic inspections of pumps are necessary in a bulk storage facility; the Department recommends that such inspections be conducted at least on a monthly basis.

E. HOSES

Hoses are generally used at bulk storage facilities to transfer liquid during loading and unloading operations. There are a wide variety of materials currently used in the construction of hoses. As a general rule, the Department recommends that any hose used for liquid transfer at bulk storage facilities be UL listed for the intended service.

The major causes of leaks and spills associated with hoses include improper connection and handling of hoses during liquid transfer operations, leaks at joints or fittings, rupture of the hose due to internal pressure, and abrasive wear of hoses.

To prevent leaks and spills from these causes, the following practices are recommended:

- A trained operator should be present and alert during all bulk liquid transfer operations.
- It should be confirmed that the hose pressure specification is adequate for the intended service.
- Hose guards should be provided for areas of high abrasion.
- The hose should be inspected periodically for evidence of abrasion, cracks, or other signs of wear.
- All hoses failing physical exams should be replaced as soon as possible.

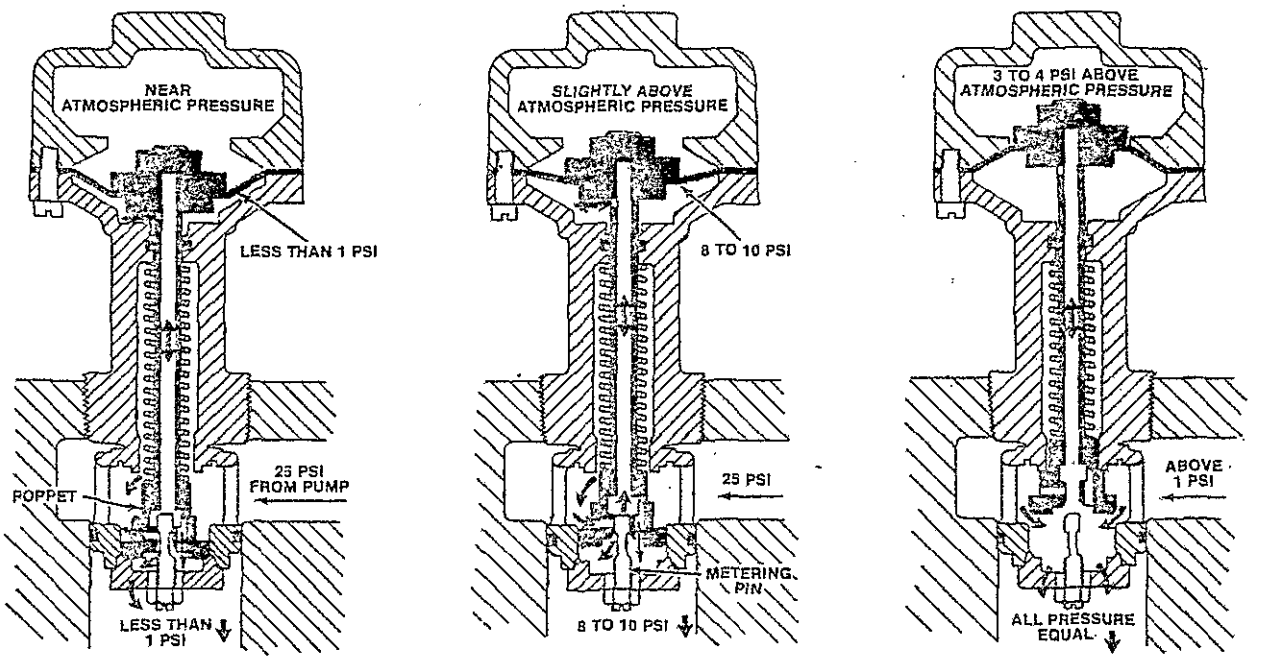
FIGURE 2—4

PIPELINE LEAK DETECTOR

The Red Jacket leak detector is a pressure sensing, diaphragm operated valve designed to indicate a leak in the piping between the leak detector and dispenser.

When the submerged pump is turned on, a controlled amount of product (three gallons per hour) is metered through the leak detector into the piping system. If a leak is present which equals or exceeds this amount, as much product escapes from the system as is metered in through the leak detector. Under this condition pressure cannot build up in the piping system. When a nozzle is opened a poppet in the leak detector moves to a position which restricts the flow to approximately 3 GPM. This is the indication to the operator that a leak is present.

If there are no leaks, pressure rapidly builds in the system forcing the leak detector to open to the full-flow position. In a system with no leaks it takes only two seconds for a complete test. No further line testing takes place until the line pressure drops below 1 PSI.

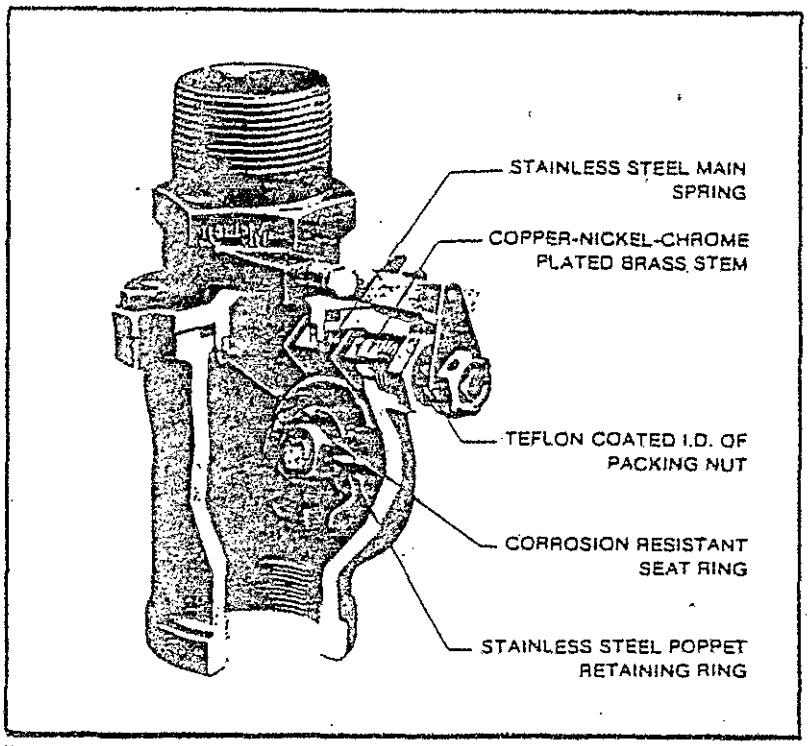


1. **THE "TRIP" OR RELAXED POSITION.** Under normal operating conditions, it is assumed that the lines are filled with gasoline which is essentially non-compressible. When the system pressure is less than 1 PSI, the diaphragm and poppet are in their "down" or "tripped" position. The position of the valve "poppet" is such as to allow approximately 3 GPM flow into the delivery line, through a bypass opening in the leak detector valve poppet, when the submersible pump starts. Since the system is full, pressure builds instantly and the poppet moves to the leak sensing position, assuming there is no leak present.
2. **LEAK SENSING POSITION.** As the pressure builds to approximately 8 to 10 PSI (instantly), the diaphragm has moved the "poppet" to such a position as to almost stop the flow into the piping through the leak detector valve poppet. In this position, all the flow must then travel around the metering pin which limits it to approximately 3 GPH rate. If a simultaneous loss from the system equals or exceeds this amount, the line pressure will not build beyond this point and the valve will remain in the leak sensing position with the main flow blocked. If there is an attempt to dispense while the valve is in this position, the line pressure will drop, the diaphragm will respond, and the poppet will return to position 1 where approximately 3 GPM will flow to the dispensers. Leaks smaller than 3 GPH will be indicated by the Leak Detector taking longer than two seconds to open completely. If there is no leakage in the system, the small flow around the metering pin increases the line pressure to 10 PSI in approximately two seconds at which point the diaphragm will snap the poppet to position 3. This all takes place in less time than it takes the dealer to reset the dispenser, walk to the car, remove the gas tank cap, insert and open the nozzle.
3. **NON-LEAK POSITION.** This position allows full flow. The poppet will remain in this position as long as the system pressure remains above 1 PSI. At less than 1 PSI the "poppet" will return to position 1.

SOURCE: Red Jacket Pumps [6].

FIGURE 2—5

A REMOTE PUMP EMERGENCY SHUTOFF VALVE



SOURCE: OPW DIVISION/DOVER CORP.

References

1. American Petroleum Institute, Underground Leak Survey Results as reported by F.B. Killmar to API Underground Leak Task Force, American Petroleum Institute, 2101 L Street, N.W. Washington, D.C. 20037, February, 1981.

2. New York State Department of Environmental Conservation, *Technology for the Storage of Hazardous Liquids, A State-of-the-Art Review,* New York State Department of Environmental Conservation, 50 Wolf road, Albany, N.Y. 12233, February, 1983.

3. National Fire Protection Association, *Flammable and Combustible Liquids Code,* NFPA 30, National Fire Protection Association, Batterymarch Park, Quincy, MA 02269, 1981.

4. Emco Wheaton Inc., *Service Station Products,* Catalog A - 12/72, Emco Wheaton, Inc., Chamberlain Blvd., Conneaut, Ohio 44030, December, 1982.

5. Perma-Pipe, div. of Midwesco, Inc. 7720 Lehigh Road, Nile, IL 60648.

6. Red Jacket Pumps, A Marley Pump Company, PO Box 3888, Davenport, Iowa 52808.

7. The Hinchman Company, *Suggested Ways to Meet Corrosion Protection Codes For Underground Tanks and Piping,* Job Number 1079-4542, The Hinchman Company, Corrosion Engineers, 1605 Mutual Building, Detroit Michigan 48226, April 8, 1981.

CHAPTER 3:

RECOMMENDED INSTALLATION PRACTICES UNDERGROUND STORAGE FACILITIES

Proper installation is an important factor in preventing leaks from underground bulk storage facilities.

A. INTRODUCTION

Many leaks are traced to mishandling of storage tanks and equipment prior to installation or to poor installation practices. The most common installation mistakes include the following:

- Damage to the protective coatings of steel tanks.
- Structural damage to tank materials during transportation and installation.
- The use of corrosive backfill materials.
- Poor foundations, the lack of bedding, or improper compaction of backfill.
- Poor anchoring of tanks in high groundwater areas.

Poor installation of tanks can lead to tank settling, tank floatation, or deflection of the tank walls; any of these can result in damage to the tank or piping. Failure to properly level a tank during installation can lead to the creation of air pockets in the tank during its use, preventing accurate measurement of inventory losses and tank leaks. Damage to coatings, or the use of poor or improper backfill material, can lead to accelerated corrosion of underground steel tanks.

Proper installation is so crucial that major tank manufacturers warrant their tanks against failure only if they are installed and used in accordance with manufacturer's instructions. For this reason, tanks should be installed in strict accord with manufacturer's recommendations.

The DEC recommendations which follow should guide all tank installations. They are consistent with generally accepted practices and the recommendations of tank manufacturers. If this guidance is followed, installation related tank and piping failures should not occur. This guidance should be considered subordinate to site-specific engineering practices which may be required for an individual facility.

Other Installation Information

Owens Corning Fiberglass Corporation has prepared a tank installation techniques manual which discusses solutions to some of the more common problems a contractor, inspector or engineer might face during installation of underground vessels [4]. Although its primary focus is on fiberglass tanks, the principles and guidelines are applicable to steel tanks as well.

B. PLANNING AND DESIGNING THE FACILITY

Many storage problems are due to poor site conditions, or improper layout and design. These topics are covered in the American Petroleum Institute (API) Publication 1615, Installation of Underground Petroleum Storage Systems [2] which is an excellent guide for engineers, marketers and contractors in the design of underground gasoline service station systems. Table 3-1 summarizes the major planning and design concerns presented in API Publication 1615. Copies of this document are available from API at the address given in the introduction of this manual.

The actual location and orientation of all tanks and piping system components should be noted on as-built drawings, especially if there is a change from original drawings. Photographs are also desirable to convey a physical idea of the location of underground equipment. Copies of all drawings, photographs, and plans should be maintained at the site for the life of the facility.

TABLE 3-1

PLANNING AND DESIGN CONSIDERATIONS FOR INSTALLING UNDERGROUND STORAGE FACILITIES

Site Conditions

Soil Characteristics - Clays, wet soils, cinders and acid soils are highly corrosive and can significantly affect the rate of corrosion of metal tanks and piping. See Table 3-2 for classes of soil corrosivity.

Depth to Groundwater - Tanks installed in areas of high groundwater or in floodways must be properly anchored. Tanks placed in water-filled excavations require ballasting and special installation.

Land Use at the Site - Sites which contain abandoned pipes and tanks, agricultural drainage tiles, or landfill materials pose special installation problems. New metal parts may become anodic to old tanks and pipes. Fill may be highly corrosive. Agricultural drainage tiles or old storm drains may breach secondary containment barriers. Old buried tanks which were not properly filled when they were abandoned may collapse and cause foundation problems for newly installed tanks and pipes. In addition, stray electric currents from nearby underground power lines or from improperly constructed electric systems, such as D.C. welders, may cause problems of accelerated corrosion. D.C. current is the normal cause of stray current corrosion.

Layout

Tank Fill Openings - Tank fill openings should be located to minimize manuvering during truck deliveries and so that delivery trucks are not blocking driveways or located on public right-of-ways.

Maps of Facilities - As-built drawings should be prepared so that underground electrical circuits, pipes and tanks can be readily located.

Design Considerations

Bimetallic and Galvanic Cells - Dissimilar metals in proximity to each other can cause prblems with corrosion. A bronze check valve joined to a steel pipe, a copper water line crossing the property, an electric service grounded to water service, or weld metal which is different from the parent metal are all potential causes of corrosion. For similar reasons, new steel tanks should not be installed next to old steel tanks.

Selection of Materials/Equipment - The choice of tank, whether steel or fiberglass, the dimensions of the tank, and the type of pump system may be determined by such factors as rock conditions, pumping lift requirements, or other site conditions described above.

Traffic - The type and amount of traffic above tanks and pipe galleries affect the physical loads on underground facilities and therefore must be considered in the design.

Venting - Each tank should be vented to prevent the buildup of excessive pressure or the blowback of vapor or liquid at the fill opening when the tank is being filled. **NOTE:** Vapor recovery systems are required by 6 NYCRR 630 on new tanks with a capacity of 250 gallons or more located at facilities in Nassau, Suffolk, Rockland, and Westchester Counties, and New York City.

TABLE 3-2

CLASSES OF SOIL CORROSIVITY

Soil *Corrosivity*	Soil *Characteristics*	Resistivity *(Ohm-centimeters)*
Very low	Well Drained Gravel	10,000 & higher
Low	Well Drained Sand & Gravel	5,000-10,000
Medium	Poorly Drained Sand & Gravel	2,000-5,000
High	Poorly Drained Fine Sand and Silt	1,000-2,000
Very High	Poorly Drained Clay	Less than 1,000

C. SITE PREPARATION

1. *Location of the Excavation*

Underground tanks must be located outside the prism of bearing pressure of structural footings so as not to receive foundation loads. To avoid footing pressures, undermining the foundations of existing structures, and other construction problems, tanks should, wherever possible, be located no closer than 10 feet to a building.

2. Excavation Size

In stable soils where shoring is not required to maintain a vertical wall from top to bottom, the excavation should be large enough for the tank plus a minimum clearance of 24 inches between adjacent tanks and between the tank sides and ends and the banks of the hole. This is large enough to allow tamping of backfill and to properly cushion the tank.

In unstable soils such as muck, peat or dry sand, a hole equal to 1 1/2 the diameter of tank being installed is usually necessary. Unstable soils are defined as those soils which have either less than 750 lbs/sq.ft. cohesion as calculated from an unconfined compression test, or an ultimate bearing capacity of less than 3,500 lbs/sq.ft.

If the excavation is oversized it should be backfilled with materials specified in Section F of this chapter, Bedding and Backfill.

3. Excavation Depth

Figure 3-1 and Table 3.3 show the minimum depth of cover and thickness of bedding required for underground tanks. The excavation depth is normally equal to these minimum depths plus 1 tank diameter. For atmospheric tanks of steel construction, tanks may be buried deeper but in no case should the burial depth be such that the static head imposed on the bottom of the tank exceeds 10 psig with the fill pipe or vent pipes filled with liquid, unless this tank is designed for higher pressure service. Also, if the depth of cover is greater than the tank diameter, the tank manufacturer should be consulted to determine if reinforcement is required.

Atmospheric tanks of fiberglass reinforced plastic construction may also be buried deeper but the depth of cover must not exceed 84 inches (7 feet) over the top of the tank.

4. Dewatering the Excavation

In areas of high groundwater or where surface runoff leads to accumulations of water in the excavation during installation, site dewatering may be necessary.

There are three methods for dealing with water accumulation in an excavation: (1) water can be allowed to flow into an excavation and pumped out from sumps or ditches; (2) the water table can be lowered prior to excavating, using either wells, wellpoints or ejectors; or (3) cutoff walls of slurry or grout can be installed. Any one or a combination of these three methods can be used to effectively dewater a site.

There are a number of factors which influence the choice of a dewatering procedure. Aside from the cost, these factors include the following:

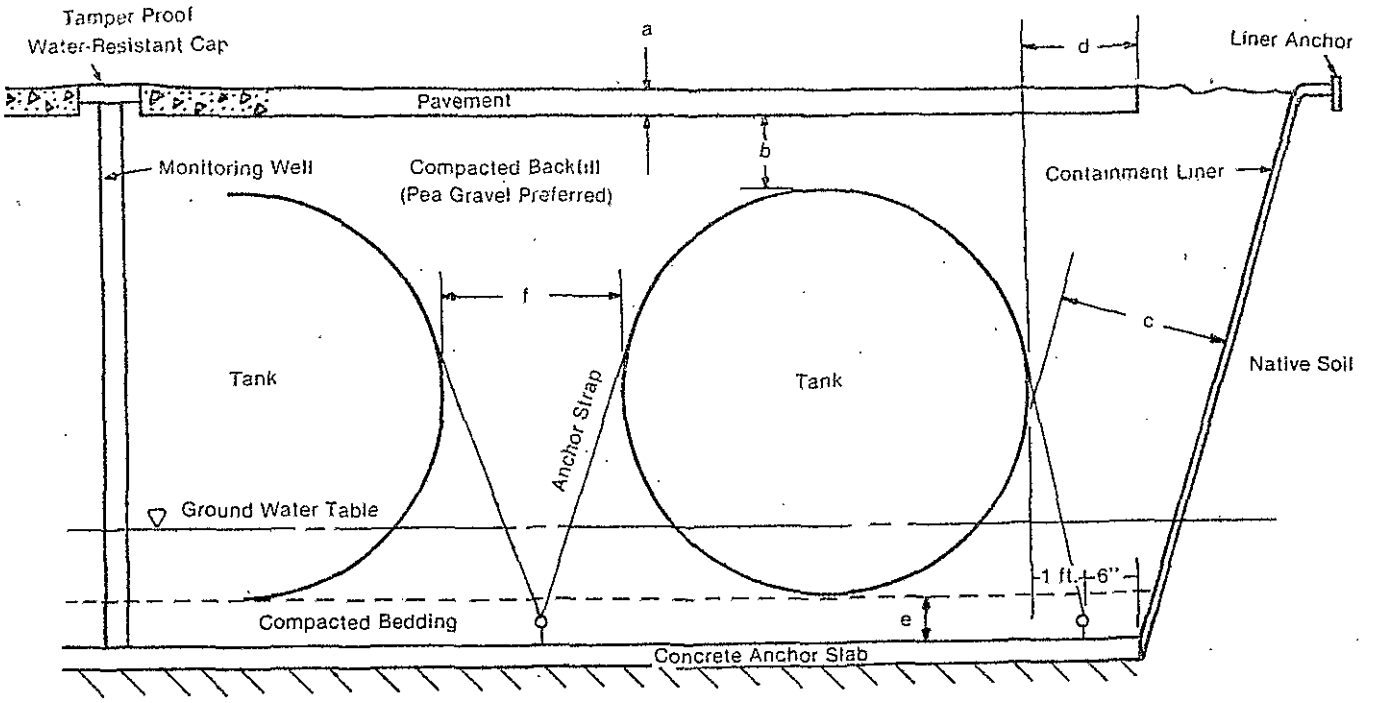
- The nature of the soil.
- The areal groundwater hydrology.
- The size and depth of the excavation.
- The proposed method of excavation and, if necessary, wall support.
- The proximity of existing structures.
- The construction schedule or required duration of dewatering operations.

The bulk of this information can be obtained through test borings, and analyses of the hydrogeology of the area.

Construction Dewatering, A Guide to Theory and Practice, by J.P. Powers [1] is a good source of background information on site dewatering. In practice, if dewatering is required, an experienced professional engineer, geologist, or hydrogeologist should be consulted.

FIGURE 3—1

DIMENSIONS FOR UNDERGROUND TANK INSTALLATION



Key
a-pavement thickness
b-depth of compacted backfill cover
c-distance between tank and excavation wall
d-pavement extension
e-depth of bedding
f-distance between adjacent tanks

TABLE 3-3

RECOMMENDED DIMENSIONS FOR UNDERGROUND TANK INSTALLATIONS

TYPE OF TANK	MINIMUM REQUIREMENT*
All Tanks	
Pavement Extensions(d)	12 inches
Distance Between Adjacent Tanks(f)	24 inches
Distance Between Tank and Bank of Excavation(c)	24 inches
Thickness of Compacted Bedding(e)	12 inches
Steel Tanks	
With Traffic Loads	
Reinforced Concrete Pavement(a)	6 inches
Plus Compacted Backfill Cover(b)	18 inches
or	
Asphaltic Concrete Pavement(a)	8 inches
Plus Compacted Backfill Cover(b)	18 inches
Without Traffic Loads	
Reinforced Concrete Pavement(a)	4 inches
Plus Compacted Backfill Cover(b)	12 inches

TYPE OF TANK	MINIMUM REQUIREMENT*
Fiberglass Reinforced Plastic Tanks (20,000 Gallons and Under)	
Maximum Burial Depth(b)	84 inches
With Traffic Load	
Reinforced Concrete Pavement(a)	6 inches
Plus Compacted Backfill Cover(b)	18 inches**
or	
Asphaltic Concrete Pavement(a)	6 inches
Plus Compacted Backfill Cover(b)	30 inches**
Without Traffic Loads	
Reinforced Concrete Pavement(a)	4 inches
Plus Compacted Backfill Cover(b)	12 inches**
Fiberglass Reinforced Plastic Tanks (Over 20,000 gallons)	
Maximum Burial Depth(b)	84 inches
With Traffic Loads	
Reinforced Concrete Pavement(a)	6 inches
Plus Compacted Backfill Cover (b)	36 inches
or	
Asphaltic Concrete Pavement(a)	6 inches
Plus Compacted Backfill Cover(b)	42 inches
Without Traffic Loads	
Reinforced Concrete Pavement(a)	6 inches
Plus Compacted Backfill Cover(b)	24 inches

*Unless Otherwise Noted
**In Wet Hole Installations, the Minimum Depth of Compacted Cover Is 36 Inches

D. PREINSTALLATION TESTING AND INSPECTION

The Department recommends that all tanks be tested prior to shipment. Once the tank has been delivered to the site, it is recommended that the tank be cleaned free of dirt clods, visually inspected, and pressure tested aboveground at the site prior to installation. The test usually consists of pressurizing the tank to 5 psi, soaping all joints, seams and fittings, and monitoring for pressure drop and bubbles. Soaping the whole tank is essentially cost free and may uncover a problem.

E. CARE IN HANDLING

Although tanks are designed to withstand normal handling and to provide secure storage of its product, they must not be dropped, handled with sharp objects, dragged or rolled. The protective coatings of steel tanks or the shells of fiberglass tanks can be damaged with mishandling. If the tank coating or shell is damaged, it must be repaired in accordance with manufacturer instructions.

The proper way of moving a tank is by lifting it, using lifting lugs installed by the manufacturer. Slings, cables or chains should never be used around the tank.

F. BEDDING AND BACKFILLING

1. Secondary Containment and Recovery System

The Department recommends that all new underground installations include a secondary containment system, a monitoring well and a well for recovering lost product. The design and installation of these systems are discussed in Chapter 4 (Secondary Containment) and Chapter 7 (Leak Detection).

2. Bedding and Backfill Materials

Fiberglass Tanks. Fiberglass reinforced plastic (FRP) underground tanks receive as much as 90% of their structural support from the backfill and bedding used. The selection of backfill material is therefore an important aspect of the installation.

FRP tanks should be installed using bedding and backfill of either pea gravel or stone/gravel crushings. If pea gravel is used it must be a clean naturally rounded aggregate with a mix of particle sizes with diameters not less than 1/8 of an inch or more than 3/4 of an inch. If stone/gravel crushings are used, they should be washed and free flowing, with angular particle sizes not less than 1/8 of an inch nor more than 1/2 of an inch. Figure 3-2 shows the size of pea gravel and crushed stone recommended for bedding and backfilling underground tanks and pipes. Pea gravel and crushed stone compact readily when placed in the excavation: this property makes them highly desirable as foundation materials.

All backfill material must meet the requirements of ASTM-33, Paragraph 9.1 for quality and soundness. No materials should have particles passing a #8 sieve. In freezing conditions, the materials must be dry and free of ice and snow. Under no circumstances will backfill with frozen lumps be acceptable. When they melt, these lumps can create voids in the backfill.

The supplier should be required to certify that the backfill and bedding material meets these specifications. If acceptable material is not available, the tank manufacturer or a professional engineer should be contacted for information on the use of light weight aggregate cement slurry or other alternative materials and the proper installation procedures for each.

Steel Tanks. Although steel tanks are less dependent on backfill material for structural support than FRP tanks, the use of quality materials and adherence to sound engineering practices are essential for proper steel tank installation. Pea gravel or crushed stone/gravel as specified for fiberglass tanks is preferred but a uniform clean sand or self-compacting gravel which is free of rocks, clay, loam, or cinders is acceptable.

3. Dry Hole Installation

Once the secondary containment barrier and a 12 inch (minimum) compacted bedding is installed, the tank should be carefully placed on the bed and checked again to ensure that it is free of dirt clods.

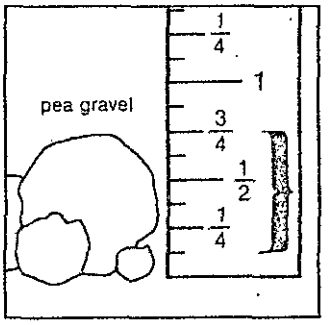
> An underground tank should never be placed directly on a concrete slab, timbers, beams or cradles.

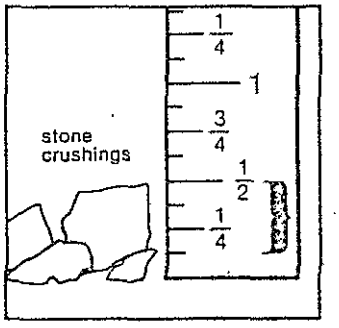
The tank should then be leveled and 12 inches of backfill placed along the bottom of the tank by hand shoveling and tamping to ensure that the tank is fully and evenly supported. A board and long handled probe can be used to penetrate backfill and move it to fill any voids. It is particularly important to work voids free at the ribs and caps of fiberglass tanks. One way of checking to see if voids have been removed is to enter the tank through the manway and to lightly tap the shell wall with a wooden screwdriver handle from side to side in the backfill area. Voids can be found by a distinct hollow sound.

If the tank is a cathodically protected steel tank, the anode lead-wire attachment to the tank should be checked at this point to assure that this connection has not been damaged. Where damaged, the connection must be repaired in strict accordance with manufacturer's specifications.

FIGURE 3—2

SIZE OF PEA GRAVEL AND CRUSHED STONE RECOMMENDED FOR BEDDING AND BACKFILL MATERIAL





Gravel

A clean naturally rounded aggregate with a mix of particle sizes not less than 1/8" or more than 3/4" is required. This material is commonly called pea gravel.

Stone or Gravel Crushings

Washed stone or gravel crushings with angular particle size not less than 1/8" or more than 1/2" are required.

Note: All backfill materials must meet ASTM C-33 paragraph 9.1 for quality and soundness. No backfill should have particles passing a #8 sieve.

In freezing conditions backfill must be dry and free of ice.

Note: You should require your backfill supplier to certify that the backfill meets this specification.

If your backfill does not meet the above requirements alternate materials may be used under the following conditions.

1. Only on 4' through 10' diameter tanks.
2. Particle size shall be a mix and can not exceed 1/2" with no particles passing a #200 sieve. The material must be free of organic materials, silt, dirt, or clay. The material must also meet the ASTM specification for hardness referenced above.
3. The material must be mechanically compacted in 12" lifts to achieve a 90% relative density to support the tank.
4. Verification of the 90% relative density must be furnished to the owner in writing.

SOURCE: Owens-Corning Fiberglas [4]

Leveling the tank, and hand placement and compaction of fill along the bottom edges of the tank are important steps for proper installation.

If the tank is a large (diameter 12 feet or larger) FRP tank, anchoring in strict accord with manufacturer's requirements is necessary.

Once the first backfill lift has been properly placed, successive 12-inch lifts can be similarly installed up to the sub-grade level for the slab. Placement and tamping of the soil in lifts will prevent flattening of the bottom of the tank and allows the tank to hold the cylindrical or spherical shape necessary for maximum strength.

Hand placement and compaction to 95% Standard Procter is especially important for the bed, the first two lifts, and the last two lifts between the top of the tank and cover slab.

If the backfill is brought to the top of the tank, but further backfilling of the excavation is delayed, it may be necessary to add water to the tank as ballast. This will prevent flotation should the site become flooded before the final cap is installed. Do not ballast the tank with water until the backfill is even with the top of the tank.

4. Wet Hole Installation

Tank installations in high groundwater areas, or where the hole may fill with water, are much more complex than dry hole installations. Although the requirements for bedding, leveling and compaction of backfill are the same as for dry hole situations, the tank must usually be ballasted with water during installation and anchored to prevent flotation. Many tanks and connecting pipes have been placed into service only to be later damaged by high groundwater levels. Although fiberglass tanks are particularly susceptible to flotation damage, even steel tanks can be damaged.

First of all, the water level in the excavation should be maintained at the lowest practical level. The dewatering methods discussed in Section C of this chapter are usually successful.

If the water level in the excavation cannot be lowered, ballast must be added to the tanks. This is accomplished by partially filling the tank with water until it settles gently on the prepared bed. The ballast level must never exceed the water level in the hole. Ballasting with petroleum or product is dangerous and not recommended. Figure 3-3 shows the concerns associated with a wet hole installation.

5. Weighting and Anchoring

Anchoring or weighting of a tank is usually necessary to protect against flotation in high groundwater areas.

Weighting or anchoring the tank is required under any circumstances where the ground may become saturated with water, such as in flood plains, groundwater aquifers, wetlands or in tight soils where rainfall and runoff cannot be successfully diverted from the site. Because of their additional weight, steel tanks are less susceptible to flotation than fiberglass tanks and smaller tanks are less buoyant than larger tanks. If there is any question on whether or not weighting or anchoring is necessary, estimates of expected groundwater levels and calculations of bouyant forces should be made by a professional engineer. Buoyancy tables for fiberglass tanks are available in the Owens-Corning Fiberglas Underground Tank Installation Techniques Manual. Tank manufacturers should be consulted for buoyancy information on steel tanks.

All FRP tanks over 12 feet in diameter must be anchored, whether installed in a wet site or not.

Weighting the Tank. Weighting the tank is accomplished by burying the tank deeper and/or by adding a thicker surface (cover) slab. The weight of the overburden holds the tank down. Sometimes buoyancy is counteracted by a concrete weight collar installed at the upper 1/3 level of the tank. This is called mid-anchoring and requires special installation procedures which should be conducted under the supervision of the tank manufacturer or field engineer.

Anchoring the Tank. Anchoring involves strapping the tank to a reinforced concrete anchor pad buried underneath 12 inches or more of bedding, or strapping it to reinforced concrete deadmen layed along each side and parallel to the tank. The weight of the concrete and the overburden on top of the slab or deadmen provides the necessary hold-down force. The size of the concrete reinforcement bars, the size of the slab or deadmen, positioning, and strapping requirements depend on the size of the installation and the soil conditions. They must be designed in accordance with accepted engineering practices and installed in accordance with manufacturer's recommendations. At a minimum, anchor slabs should be 8 inches thick and extend 18 inches beyond the ends of the tank and the vertical tangent line of the tank. Deadmen should be a minimum of 12 inches beyond the vertical tangent line of the tank. Deadmen should be a minimum of 12 inches by 12 inches and extend 12 inches beyond the ends and vertical tangent line of the tank.

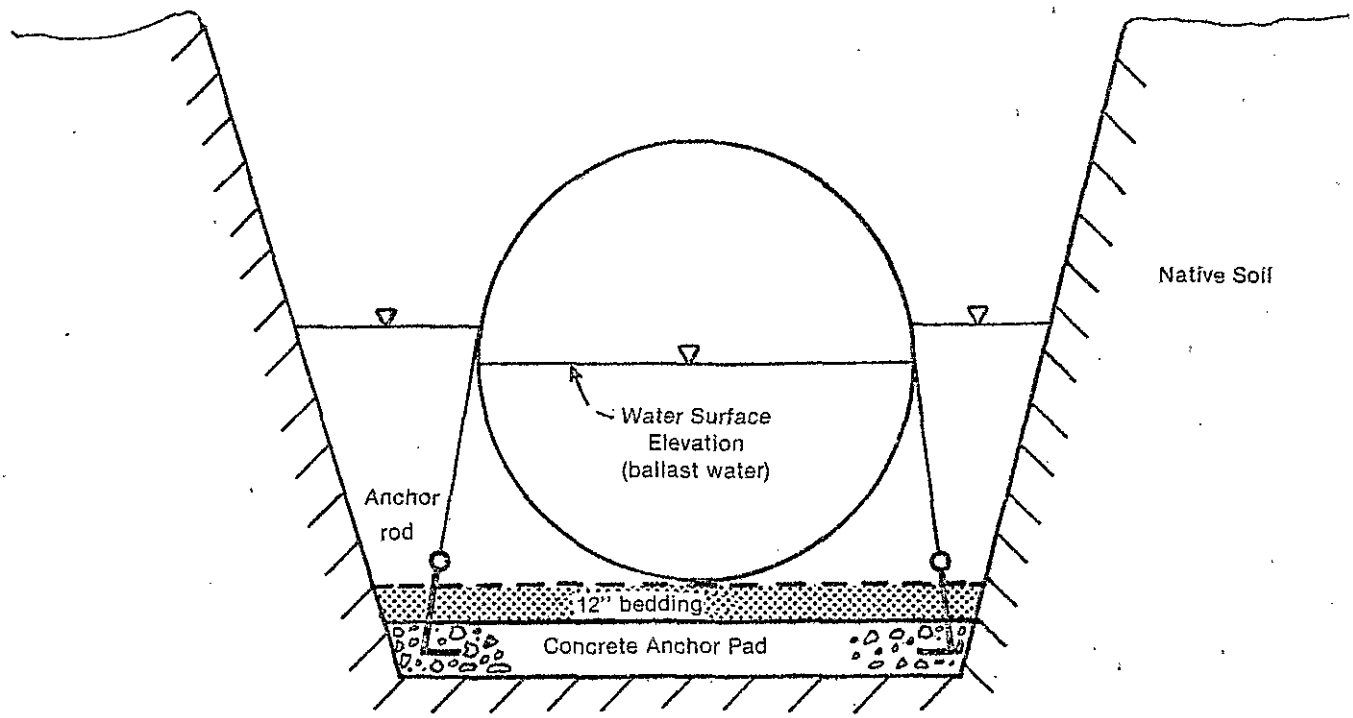
Anchor bolts should be imbedded in the slab and coated with epoxy to prevent corrosion.

Anchor Straps. The positioning of anchor straps is one of the most important steps in anchoring a tank. The straps must be uniformly tight and spaced so that the load will be evenly distributed. On fiberglass tanks all anchor points in the bottom of the tank excavation should be spaced a distance equal to the tank diameter plus 1 foot from the point in the bedding directly under the center line of the tank. Straps must be aligned on the ribs designated by the manufacturer, not between them.

On steel tanks, straps must be separated from the tank by a pad made of inert material. The pad should be at least

FIGURE 3—3

TANK BALLASTING



If the water level in the hole cannot be lowered, tanks will need ballasting. Ballast water in tanks must never exceed water levels in the hole during installation.

2 inches wider than the hold down straps. It prevents scratches in the coating and electrically isolates the tank from the straps and anchor. Neoprene or asphalt-impregnated expansion joint material is commonly used.

G. PAVEMENT OPENINGS

Any part of the excavation which has an opening or fitting that is connected to the tank must be protected from traffic and the infiltration or collection of water from precipitation. This protection must extend the full thickness of the pavement.

All fittings or accessways which extend through pavement openings must be raised at least one (1) inch above grade (the pavement surface), and the pavement must slope upward to the edge of this opening, as shown in Figures 3-4 and 3-5. This prevents the drainage of precipitation into the tank or tank excavation.

In many instances, there are cavities under pavement openings for functions such as pump access or imbiber bead pockets. The walls of these cavities are typically composed of materials such as square metal framing, clay tiles, or a section of culvert pipe. In any such situation, the cavity wall must never touch the underground storage tank. A minimum gap of three (3) inches must be maintained between the tank and the bottom of the cavity wall to prevent abrasion of the tank or coatings. (See Figures 3-4 and 3-5 for illustrations.)

H. COVER AND PAVEMENT

The final step of construction is to place a compacted backfill cover, a 10 mil (minimum thickness) polyethylene water barrier, and a concrete or asphalt slab over the tank. The cover material should be the same material as that used for backfilling and must be placed at a depth as prescribed in Table 3-3.

The concrete or asphalt slab thickness is also specified in Table 3-3. The slab and polyethylene underlayment are recommended even if traffic loads are not anticipated. They provide a factor of safety against tank flotation, prevent water from entering the excavation, and safeguard against vehicle and equipment traffic which may accidentally pass over the installation. (It is anticipated that some time in the 25 year lifetime of a storage facility, traffic will pass over the installation.)

I. TESTING AND INSPECTION

Since damage can occur at any stage of construction, it is desirable to make an inspection and perform a tightness test if the tank is dropped or accidentally damaged. This way the damage can be repaired before expensive additional work is completed. As a minimum, a tightness test and inspection should be performed before installation as discussed earlier, and again either after installation but prior to backfilling, or at the conclusion of construction (after paving and all pipes and pumps have been installed).

1. Tightness Tests

If the test is conducted prior to backfilling, the usual method is to soap the tank, all fittings, seams and dents and inspect for bubbling when the tank is pressurized to 5 psi. Large fiberglass tanks (over 25,000 gallons capacity) should be pressured to 3 psi. Air gauges should be monitored for one hour to observe pressure losses. Tank manways and the end caps of fiberglass tanks should not be approached while under pressure.

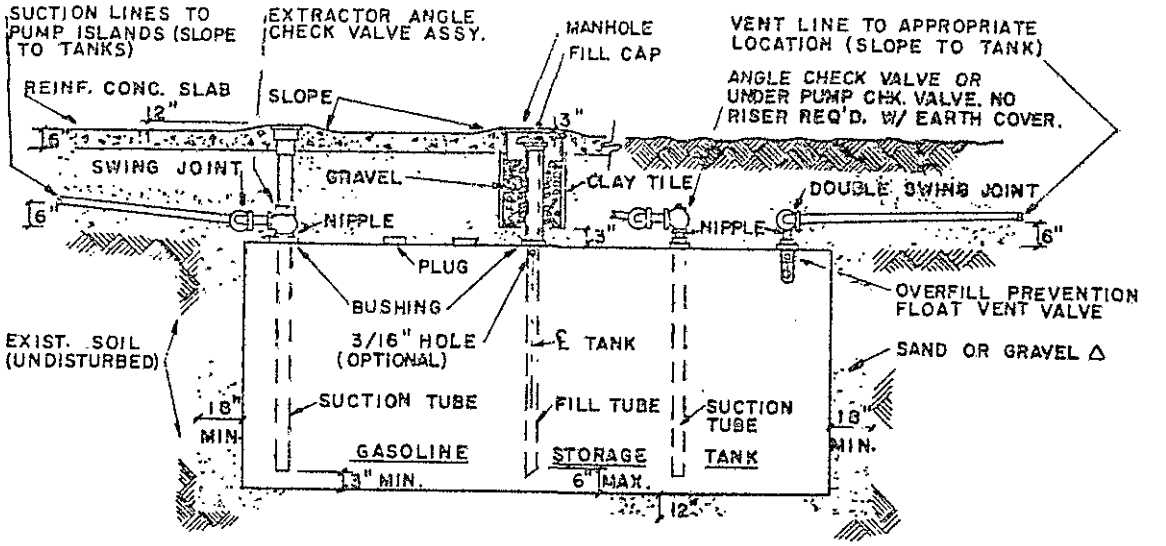
If the test is conducted after installation and product has not been put in the tank, the tank may be pressurized with air as above and monitored for pressure loss. This is the only time that the tank may be safely air pressure tested. Air pressure testing is intrinsically inaccurate. It is only good for discovering gross leakage.

Double-walled tanks can be readily checked for tightness by monitoring the annular space between the inner and outer wall by vacuum or pressure.

Precision testing is recommended before a tank is placed in service. This helps protect both the tank buyer and the installer.

FIGURE 3-4

TANK PIPING DETAILS - SUCTION SYSTEM



PIPING DETAILS FOR TANKS — UNDER CONCRETE

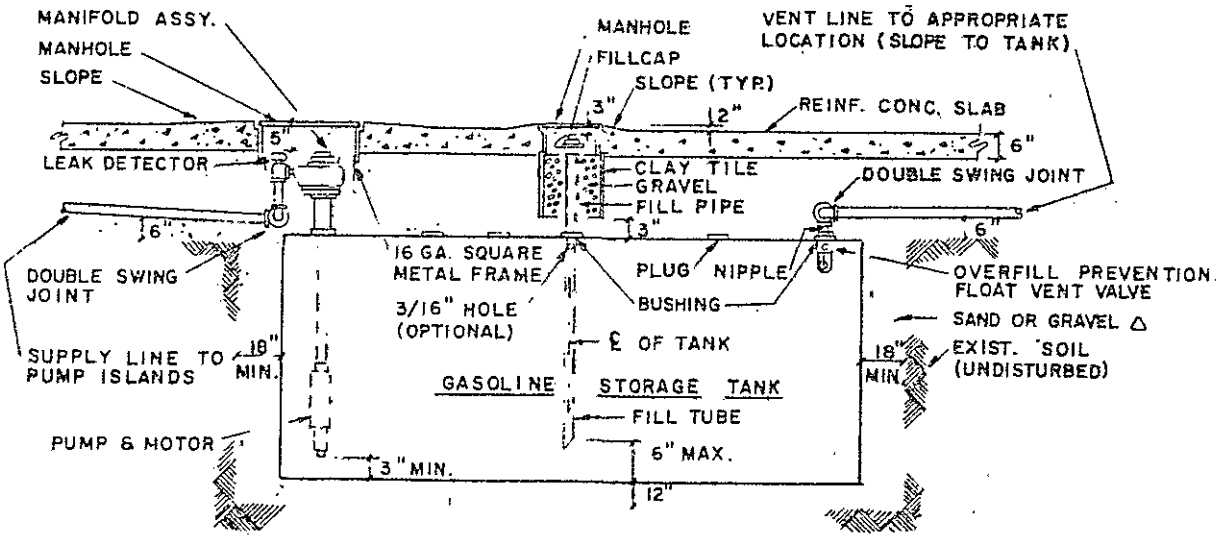
△ PEA GRAVEL FOR NON-METALLIC TANKS (OR MFR. APPROVED ALTERNATE)

NO SCALE

NOTE: ELIMINATE CONC. SLAB IN NON-TRAFFIC AREAS & CONSTRUCT CONC. PADS (ONLY) AROUND MANHOLES. THE EXTR. ANGLE CHECK RISER IS NOT REQ'D. W/ EARTH COVER.

FIGURE 3—5

TANK PIPING DETAILS - SUBMERGED SYSTEM



PIPING DETAILS FOR TANKS — UNDER CONCRETE

△ PEA GRAVEL FOR NON-METALLIC TANKS (OR MFR. APPROVED ALTERNATE)

NO SCALE

NOTE: ELIMINATE CONC. SLAB IN NON-TRAFFIC AREAS & CONSTRUCT CONC PADS (ONLY) AROUND M.H.'S.

SOURCE: API Publication 1615 [2].

2. Inspection

Measuring the inside dimensions of the tank for roundness is recommended for checking on the quality of the installation. Measurements can be done by entering the tank if a manhole exists or by measuring tank diameter at the fill tube prior to and after backfilling. If the tank is entered, Federal OSHA safety codes should be strictly followed.

If a manhole does not exist in the tank, the diameter can be checked at the fill tube riser. Making a tank diameter measurement at the riser is not a problem as long as the drop tube is not in place. All that is necessary to measure the distance from the tank bottom to top of riser with a dipstick and then measure the distance from top of tank to top of riser by driving a nail in the dipstick, catching the nail underneath the lip of the riser fitting and reading the measurement difference on the dipstick.

Measurements of tank roundness are particularly important on fiberglass tanks, which depend on the surrounding soil for structural support. Excessive deflection indicates residual stress on the tank which may cause cracking or may cause the suction line to penetrate the bottom of the tank. If deflections exceed the values shown in the following chart the tank manufacturer should be contacted before proceeding further with the installation.

Tank Diameter	Maximum Deflection
6′	5/8″
8′	1¼″
10′	1½″
12′	1½″

Fiberglass tank manufacturers will not warrant a tank against failure unless these criteria and other manufacturer's installation requirements are followed.

J. INSTALLATION OF PIPING SYSTEMS

Proper installation of piping system components is as important as proper installation of the storage tank. For example, in the API Leak Survey [7], fully 1/3 of all leaks detected from underground storage facilities were in the piping systems. Adherence to proper material selection and installation procedures could have prevented most of those leaks.

1. General Considerations

Regardless of the type of pipe selected for a particular application, there are a large number of considerations which are common to any piping system installation. These include the design criteria presented in Section B and Table 3-1 of this chapter. Other considerations which apply specifically to piping include the following:

- Piping should be located in a single trench. This will facilitate access to the pipe in case of a problem, and concentrate the piping so that future excavation at the site can be done safely.
- Piping should be sloped a minimum of 1/8 inch per foot toward the tank so that lines can be drained, and so there is no accumulation and blockage of product vent lines.
- Vent piping should extend at least 12 feet vertically aboveground and be a minimum of 2 feet higher than adjacent buildings. The use of rain caps is endorsed.

Figure 3-6 presents recommended minimum clearance dimensions for backfilled piping trenches.

2. Galvanized Steel Pipe Installation

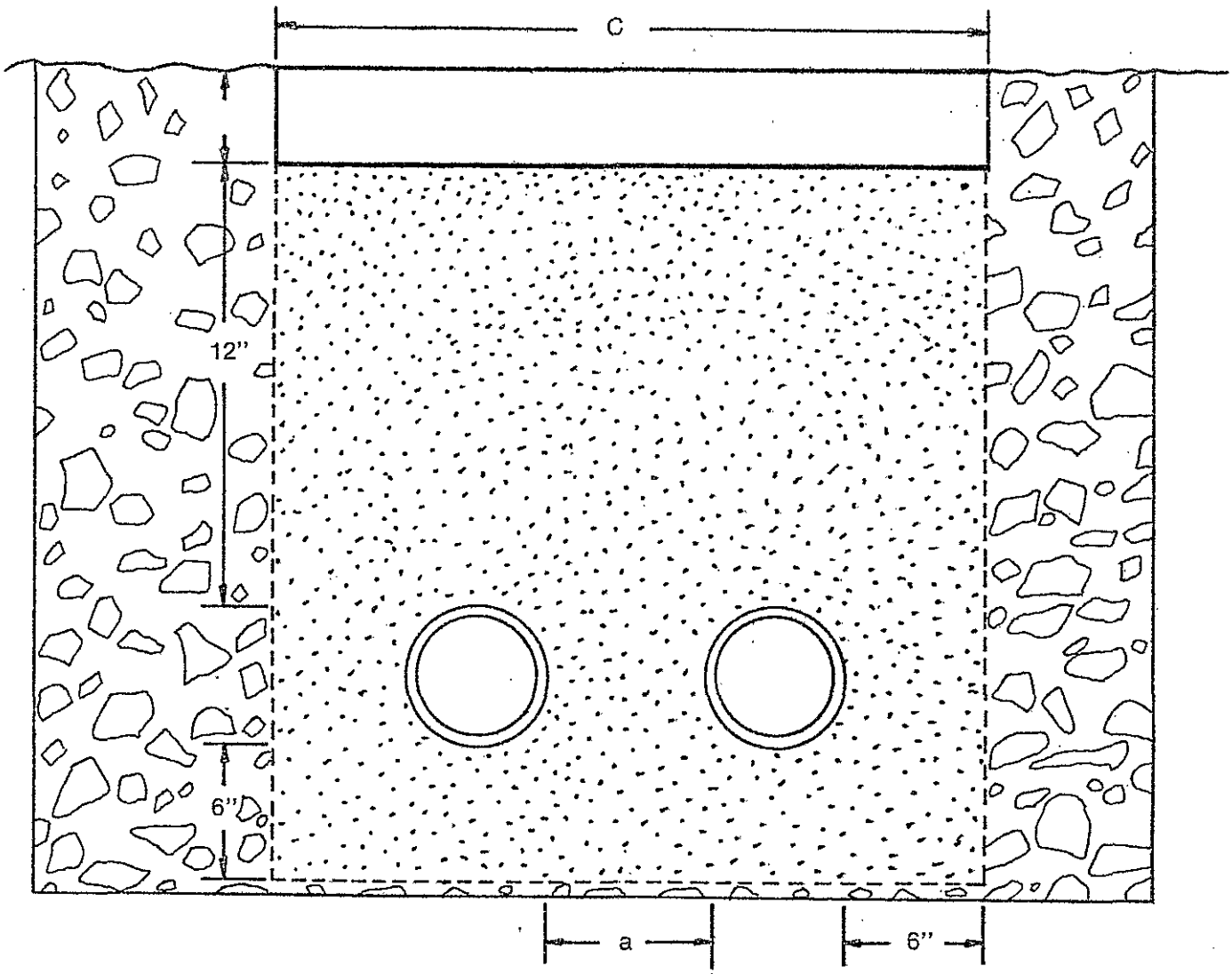
Galvanized steel pipe has become an industry standard because of its low cost. Installers are intimately familiar with installation techniques and generally are quite proficient. The Department recommends that good piping installation practices, such as those found in API Bulletin 1615 [2], be followed. Such recommended procedures include the following:

- **Piping Location.** Piping should be located so that it does not cross over underground tanks. Further, installed pipes should not pass close to water lines. This practice will reduce the possibility of conducting stray electrical currents to the tank.
- **The Use of Swing Joints.** Double swing joints should be used at all changes of direction, and at the end of each line. These joints help reduce stresses that can loosen or crack pipes. Stresses can arise from settlement, temperature change, and misalignment.
- **Pipe Fittings.** Pipes should be joined using standard 150 lb. malleable iron fittings. Care should be taken to protect threads from damage and dirt. Thread lubricant (pipe dope) which is compatible with the product to be stored should be used.
- **Corrosion Protection.** Cathodic protection is usually achieved through the use of either:
  a) a sacrificial anode system which creates a galvanic cell conducting a protective electrical current towards the piping; or
  b) an impressed current system which sends a current supplied by the electrical utilities through a non-sacrificial anode to the tank.

Further information on cathodic protection can be found in the DEC document entitled, **Technology for the Storage of Hazardous Liquids, A State-of-the-Art Review** (6). Both types of systems should be professionally designed, but in either case, the pipes should be coated against corrosion in addition to being galvanized. When the piping has been leak tested and proven tight, all joints must be coated and wrapped.

FIGURE 3—6

MINIMUM DIMENSIONS FOR PIPING INSTALLATION



NOTE:
Dimension a. twice the diameter of the pipe, but at least 4 inches.

b. pavement thickness, 4" of reinforced concrete or 6 inches of asphaltic concrete.

c. pavement width is at least equal to excavation width.

3. Fiberglass-Reinforced Plastic (FRP) Pipe Installation

The corrosion resistant properties of FRP pipe are similar to those of FRP tanks. However, there are some important points to be made regarding installation.

Pipefitting. FRP pipe is normally joined with adhesive, but other methods are available, including threaded adhesive and mechanical joints. The manufacturers' installation manuals provide the most detailed advice on joining methods. Important points to be remembered include the following:

- Both the pipe itself and particularly the ends must be protected from dirt and damage until joint makeup.
- All joint surfaces must be meticulously cleaned.

> Joint curing temperatures are critical. A temperature of at least 60° F must be maintained for the full cure time. If there is any likelihood that this temperature will not be maintained, auxiliary heat should be used.

Thermal Expansion. FRP pipe is inherently flexible and does not require swing joints if at least 4 feet of straight run is provided between directional changes. Otherwise, swing joints must be used. Where long straight runs encounter fixed end constraints, expansion loops may be used. The size of the expansion loop is a function of the length of the run.

Inspection. It is recommended that one person be responsible for piping inspection. Evidence of damage includes localized color differences called "star crazes". Potential joint failures can be identified by the following:

- **Joint Back-out.** During assembly of a bell and spigot joint, a bead of adhesive is normally found at the edge of the bell. If the joint backs out before the adhesive is set up, the bead will no longer be next to the bell.
- **Cocked Joint.** If a joint is misaligned, or "cocked", there will usually be a gap between the bell and spigot on one side. The opposite side will typically have no gap.
- **Improperly Cured Joint.** If the adhesive bead is soft and flexible when checked with a knife after the cure cycle, the adhesive is faulty.

4. Stainless Steel Pipe

The common perception of stainless steel pipe is that it is astronomically expensive. In fact, the installed cost is approximately triple that of ordinary galvanized steel. The Department feels that this cost can be justified in light of the increased corrosion resistance and longer lifespan, particularly in sensitive environmental areas.

Stainless pipe has the important advantage of being able to be installed without wrapping, coating, or anodes.

The Department recommends the use of Schedule 10, Type 304 stainless steel where joints are to be welded, and Schedule 40, Type 304 stainless steel where joints are to be screwed. The backfill and general requirements are the same as for other pipe materials.

5. Testing

Air pressure testing of piping is recommended only for low pressure service, such as filling stations. The recommended procedure is as follows:

- Isolate the piping system at both ends.
- Soap all joints.
- Gradually pressurize to 150% of working pressure or at least 50 psi. The gauge used should have a full scale reading of no more than twice the test pressure (e.g., if the test pressure is 50 psi, the gauge should be no more than 100 psi full scale).
- Inspect for bubble formation; monitor for pressure drop for an hour.
- No tightening or repairs should be attempted while the system is pressurized.
- Wrap or coat joints in preparation for backfilling operations.

References

1. Powers, J.P., "Construction Dewatering, A Guide to Theory and Practice" Wiley-Interscience Division, John Wiley and Sons, Inc., 605 Third Avenue, New York, NY, Copyright (c) 1981.

2. American Petroleum Institute, *Installation of Underground Petroleum Storage Systems*, API Publication 1615, American Petroleum Institute 2101 L Street, N.W. Washington, DC 20037, November, 1979.

3. Steel Tank Institute, *Specification for sti-p3* System of Corrosion Protection of Underground Steel Storage Tanks, Steel Tank Institute, 666 Dundee Road, Suite 705, Northbrook, Illinois 60062, May 15, 1980.

4. Owens-Corning Fiberglas, *Owens-Corning Fiberglas Underground Tank Installation Techniques Manual*, Publication No. 3-PE-9632, Owens-Corning Fiberglas Corporation, Non-Corrosive Products Division, Fiberglas Tower, Toledo, Ohio 43659; May, 1981.

5. Xerxes Fiberglass, Inc., *Century Fiberglass Tanks Installation Instructions, Publication No. CT 4-80-01, Xerxes Fiberglass, Inc., 34250 Mills Road, Avon, Ohio 44011.*

6. *New York State Department of Environmental Conservation, Technology for the Storage of Hazardous Liquids, A State-of-the-Art-Review*, Bureau of Water Resources, Division of Water, New York State Department of Environmental Conservation, 50 Wolf Road, Albany, New York 12233, January 1983.

7. American Petroleum Institute, "Underground Leak Survey results as reported by F.B. Killmar to API Underground Leak Task Force," American Petroleum Institute, 2101 L Street, Northwest, Washington, D.C. 20037, February 5, 1981.

8. Ciba-Geigy Pipe Systems, Inc., *Piping Specifications and Installation Practices*, Ciba-Geigy, Inc., 11999 Katy Freeway, Houston, TX 77079.

9. A.O. Smith-Inland, Inc., *General Installation Instructions*, Manual No. 9474, A.O. Smith-Inland, Inc., Reinforced Plastics Div., 825 Lehigh Avenue, P.O. Box 193, Union, NJ 07083.

CHAPTER 4:
SECONDARY CONTAINMENT SYSTEMS

> All new underground storage systems should include a secondary containment structure which collects and contains a spill or leak, and should include provisions for removing spilled or leaked material from the excavation.

A. INTRODUCTION

Underground spill or leak containment systems represent an important line of defense for protecting groundwater quality. They can also act to enhance the effectiveness of leak detection systems in tank excavations by concentrating the contaminant and channeling it to a monitoring sensor, and by confining a leak or spill until removal of the liquid is possible.

Containment systems work by establishing a barrier around the storage tank(s) so that leaked liquid does not have a free path to escape from the storage excavation. The Department recommends that this be accomplished through the use of one of the following: (1) double-walled tanks; (2) tank vaults; (3) cutoff barriers or containment liners; or (4) sites with highly impervious soils.

A secondary containment system would be inadequate without provisions for monitoring the containment area and removing leaked or spilled product. Recommended practices for monitoring and removal are addressed in Chapter 7 of this manual.

The selection of the best containment system for a particular storage application is dependent upon several factors, including the following:

- The type and quantity of material stored.
- The level of environmental protection needed.
- Groundwater levels.
- Soil conditions, especially soil permeability.

For more information on secondary containment options, refer to the Department manual entitled **Technology for the Storage of Hazardous Liquids, A State-of-the-Art Review** (*1*).

The remainder of this chapter presents Department recommendations for the design and installation of secondary containment systems. Double- walled tanks, vaults, cutoff barriers, containment liners, and areas with naturally-occurring impervious soils will be discussed.

B. DOUBLE-WALLED TANKS

Double-walled tanks incorporate all of the fundamental requirements for leak prevention, including a secure storage vessel, secondary containment via the outer wall, and monitoring of the interstitial space to check on the integrity of both the inner and outer walls. Such tanks, when built in accordance with the recommended practices for double-walled tank construc tion discussed in Chapter 1, provide not only an efficient means of achieving secondary containment, but also a high degree of overall environmental protection.

C. VAULTS

A vault is a secondary enclosure which houses the storage tank, contains any leaks from the tank, and provides protection from corrosive soils. They may contain one, or more than a dozen storage tanks. Some vaults have an open interior so that tanks can be entered through a manhole and physically inspected and repaired. Other vaults are filled with a bedding of sand or other acceptable backfill material which provides structural support for the tank; a typical situation would be the storage of very hazardous liquids where management decides that no contact with the liquid is the safest course.

In the case of open vaults, at least 24 inches of clearance should be left between the tanks and the vault walls to permit access for inspection. Tanks should be supported on cradles and properly anchored, with padding between the cradle and the tank. The cradling must be consistent with acceptable engineering practices.

If the storage tank is bedded in fill material, the bedding must consist of at least 12 inches of compacted backfill, and there must be at least 24 inches of clearance between the tank and the vault sidewalls to allow for proper compaction of the backfill material.

Reinforced concrete is the most common construction material used for vaults. If concrete is used, the reinforcing bars (rebars) should be epoxy coated to resist corrosion.

Concrete vaults should be continuous structures which are impervious to water and the stored product. The best construction method is to pour the walls and floor continuously. The vault cover can be added afterwards. The floor of the vault should be constructed with a slope (typically greater than or equal to 1/8 inch per foot) which channels any leaked or spilled product to collection trenches and a sump.

Provision should be made for removing sumpage from the vault. This can be done by a permanently installed pump in the vault or by a tube permanently installed in the vault to enable sumpage to be pumped from the surface. The collection sump is an excellent place for a leak/product sensing device to monitor the tanks (see Chapter 7).

Concrete used alone does not provide an effective liquid barrier; leaks through concrete can occur in the vapor phase after even limited exposure times. Therefore, it is important to have a continuous structure with chemical-resistant water stops where joints are necessary. In addition, the walls of the concrete vault must be covered with an

internal chemical-resistant coating to prevent liquids and vapors from entering or leaving the vault.

Vaults should contain no drain connections or other entries except top entry manholes and other top openings for filling and emptying the storage tank, monitoring or inspecting the vault interior, and recovering any leaked or spilled product which has collected in the vault. These openings all require waterproof seals.

Structurally, a vault should be designed just as carefully as other important projects. Most of the structural problems that have been experienced in vaults can be traced to the original design and construction. Vaults can be designed to withstand hydrogeology, earth movements and overhead traffic.

Figure 4-1 shows a diagram of a typical secondary containment vault. Such vaults are occasionally used for petroleum storage but more commonly used in extremely sensitive environmental areas where toxic materials are being stored.

Vaults are generally unsuitable in areas of high groundwater. If a vault is installed in such an area, there is a strong likelihood that long-term deterioration or chemical decay of the vault materials will lead to the eventual flooding of the inner chamber, resulting in the additional expense of continuous dewatering of the vault.

In New York City, where much of the City's complex infrastructure is underground, the standard method of secondary containment is encasement. Underground tanks are embedded in concrete that is at least 12 inches thick all the way around the tank. This protects the tank both physically, and chemically by providing an alkaline environment which is benign with steel.

D. CUTOFF BARRIERS AND CONTAINMENT LINERS

Cutoff barriers and containment liners (which include excavation liners, trough liners and containment bags) function by providing relatively impermeable surfaces which prevent the flow of leaked or spilled product away from the excavation. These types of systems are typically installed in or around the tank excavation prior to tank installation and backfilling. The choice of a containment scenario depends upon whether the storage installation is in an area of high or low groundwater. The selection of a containment material is dependent upon several factors which are discussed in detail later in this section.

1. Cutoff Barriers

If the known low level of the groundwater table is above the bottom of the storage excavation, cutoff barriers may be used for secondary containment. In this type of system, the groundwater actually acts as the bottom of the containment. The cutoff barrier prevents lateral movement of the product out of the containment area. This concentrates the spill or leak and greatly enhances detectability. The cutoff barrier should encompass the entire perimeter (side walls) of the excavation, and should extend five feet above the high groundwater level (preferably to the top of the excavation) and five feet below the low groundwater level or to the slab or excavation bottom, whichever is lower. This cutoff barrier must be impervious to and chemically compatible with (i.e., resistant to) the stored product, and be free of any holes, cracks, tears, punctures, or other means by which leaked product could escape from the site. Figure 4-2 shows a diagram of a cutoff barrier used in a high groundwater area.

Cutoff barriers are typically constructed of soil cement, bentonite, or a soil/bentonite slurry. However, it is possible to construct barriers of synthetic membranes or clays. These materials are discussed in Section F of this chapter.

2. Excavation Liners

Continuous containment liners, or excavation liners, are suitable for secondary containment in areas of low groundwater. This type of liner is installed along the perimeter (sidewalls) and bottom of the excavation before the tank foundation and tank are installed and backfilling is initiated; the intention of the liner is to catch and permit recovery of any product which is spilled or leaked at the site. The liner must be impervious to and chemically compatible with both water and the stored product, and it must be free of any holes, cracks, tears, punctures, or other means by which leaked product could escape from the site. The bottom of the excavation should be sloped with a minimum slope of 1/4 inch per linear foot to a dry well or collection sump where any water or leaked product will drain to facilitate detection and allow for periodic removal.

In addition, the excavation must have a watertight cover which extends at least one (1) foot beyond each side and end of the excavation. This cover can be constructed of asphalt, reinforced concrete, or a similar material which provides the required protection from traffic, and should be sloped to drainways leading away from the storage excavation. The only openings in this cover should be those openings required for access to the tanks and any leak detection equipment, and these openings should be provided with watertight caps.

If an excavation liner is to be installed in an area of high groundwater, that area must be dewatered until the liner, the storage tank and piping, and the backfill have been installed. In such an installation, the excavation backfill will apply pressure from its weight which will more than offset the pressure or buoyant force exerted by groundwater once dewatering has been terminated. In short, the weight of the backfill helps maintain the integrity of the excavation liner.

A properly designed and installed excavation liner should enable the operator to monitor the entire tank battery from one monitoring well. The drawback of this system is that it sacrifices the ability to distinguish exactly

FIGURE 4—1

SECONDARY CONTAINMENT, VAULT SYSTEM

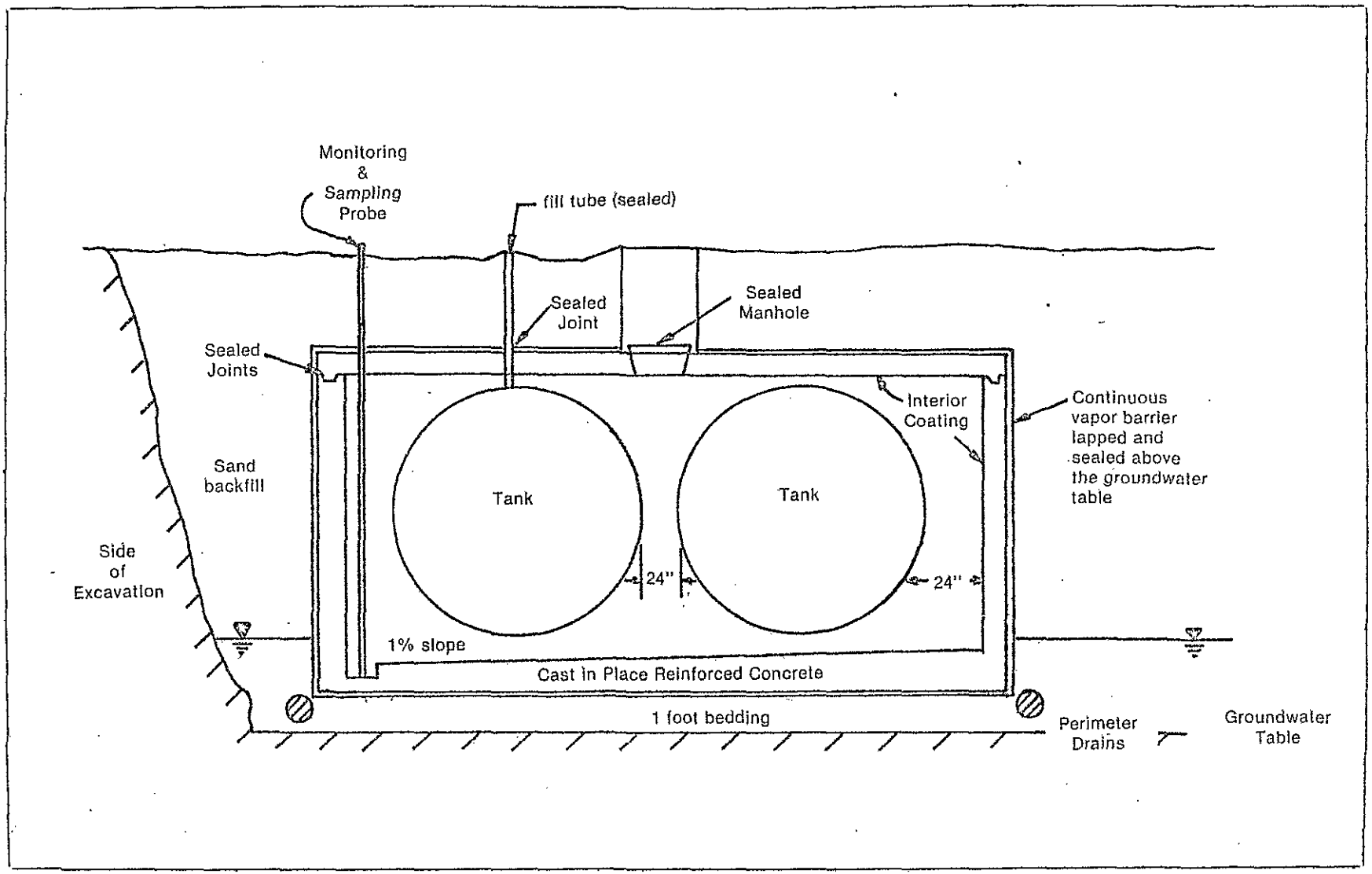
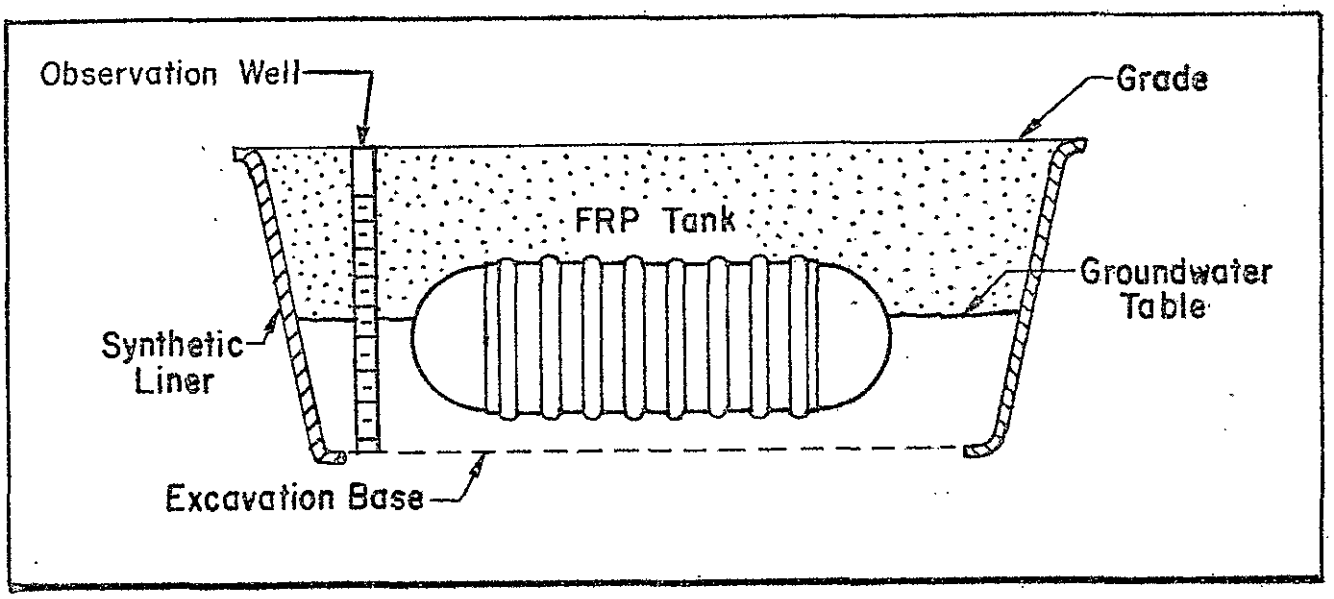


FIGURE 4—2

SCHEMATIC OF A CUTOFF BARRIER USED FOR SECONDARY CONTAINMENT IN AN AREA OF HIGH GROUNDWATER



which tank is leaking in a multi-tank storage facility because the entire excavation drains to a common sump.

Excavation liners can be constructed of synthetic membranes, bentonite, clay, or soil cement. The selection of the appropriate material depends upon the chemical characteristics of the stored product and the site-specific economics of these various materials. The characteristics of these liner materials are described in Section F of this chapter.

Figure 4-3 shows a diagram of secondary containment using an excavation liner in an area of low groundwater.

3. Trough Liners

In areas where the high groundwater level is below the bottom of the tank, a sloped, trough shaped liner can be installed under each tank as shown in Figure 4- 4. The trough liner may be used with a single monitoring and recovery well at the sump hole of each trough, or with a U-tube leak detection system in each trough.

The design and installation criteria for a trough liner (e.g., the slope of the liner, requirements for watertight covers over openings in the storage area, the need for periodic removal of sumpage, etc.) are the same as those presented above for excavation liners. This type of containment system is similar to the excavation liner system with the exception that each tank has its own trough and monitoring well. In such an arrangement, the source of a leak in a multi-tank storage facility can be more readily identified.

E. SITES WITH IMPERVIOUS SOILS

If the native soils of a particular site have very low permeability, they can form a natural barrier to the migration of leaked petroleum products, and be used as a containment material. Therefore, if in-site field permeability tests and other geological investigations show that soils are impermeable and areawide in extent, and there are no outcroppings of bedrock or other conduits for the escape of leaked product, no additional containment lining is required. Possible exceptions to this include the storage of highly toxic material and/or storage in environmentally sensitive areas.

Permeability Guidelines

- 0.035 inch/day (1×10^{-6} cm/sec) for facilities located within recharge areas for primary groundwater aquifers.
- 0.35 inch/day (1×10^{-5} cm/sec) for facilities located elsewhere in the State.

Because any excavation will tend to fill with water during wet periods, construction steps are necessary in a storage facility in soils of this type. These include: (1) the installation of a watertight cover over the tanks for draining surface water away from the excavation; and (2) the installation of a well which will serve for both monitoring and recovery. Figure 4-5 shows the construction details for a typical installation in impermeable soils.

F. LINER MATERIAL AND INSTALLATION PRACTICES

The materials which are satisfactory for the construction of cutoff barriers or containment liners include the following:

- Clay.
- Synthetic membrane liners.
- Concrete.
- Soil sealants, such as soil cement or bentonites.

The properties and installation requirements of these materials are discussed briefly below. More information on these materials is available in the Department manual entitled **Technology for the Storage of Hazardous Liquids, A State-of-the-Art Review** [1].

1. Clay Liners

Due to its general availability in many areas and relatively low cost, clay is often considered the first choice for a secondary containment liner. If the clay has a permeability rate of 1×10^{-6}cm/sec or lower and is installed properly, a clay liner will provide a suitable barrier against migration of a groundwater contaminant. The factors which influence the performance of clay liners include the following:

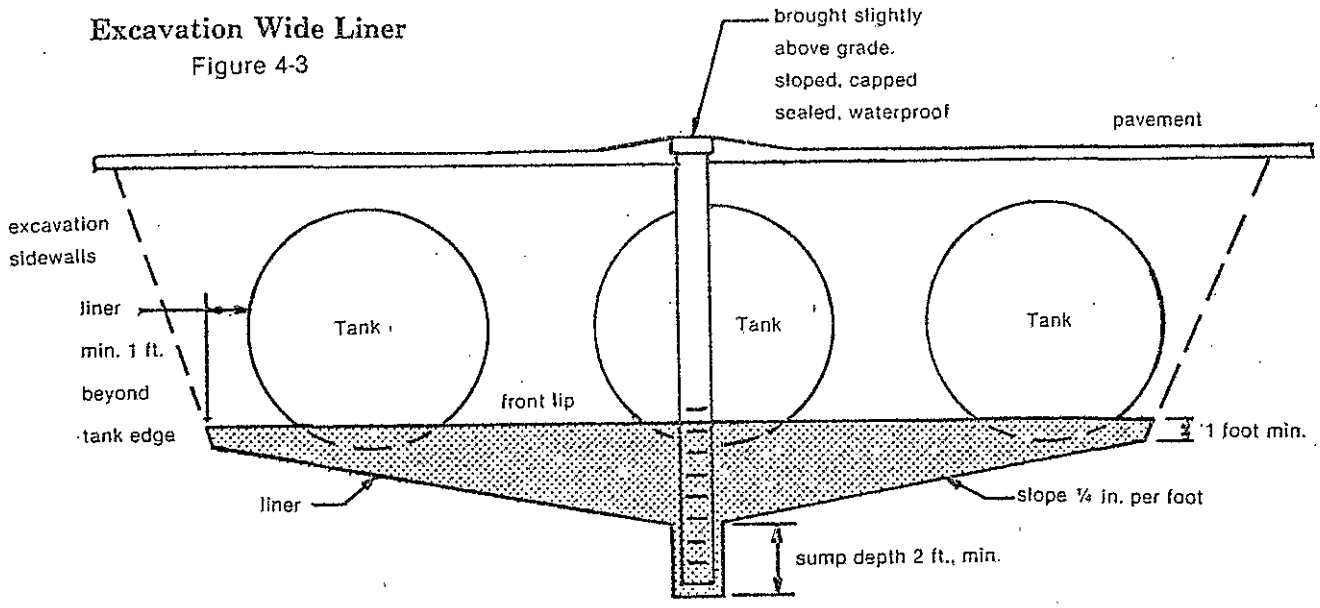
- Compatability with the stored product, particularly in the case of certain organic liquids
- Thickness of the clay.
- The shrink-swell potential of the clay.
- The plasticity of the clay.
- The moisture content, density, and degree of compaction of the clay.
- The angle of the excavation sidewalls.

It should be noted that some organic liquids degrade the mineral structure of clays and thus act to increase their permeability. This may be true of some petroleum products. It is therefore important that the selection of a clay material for a particular application be based upon tests and investigations by an experienced soils chemist or soils engineer.

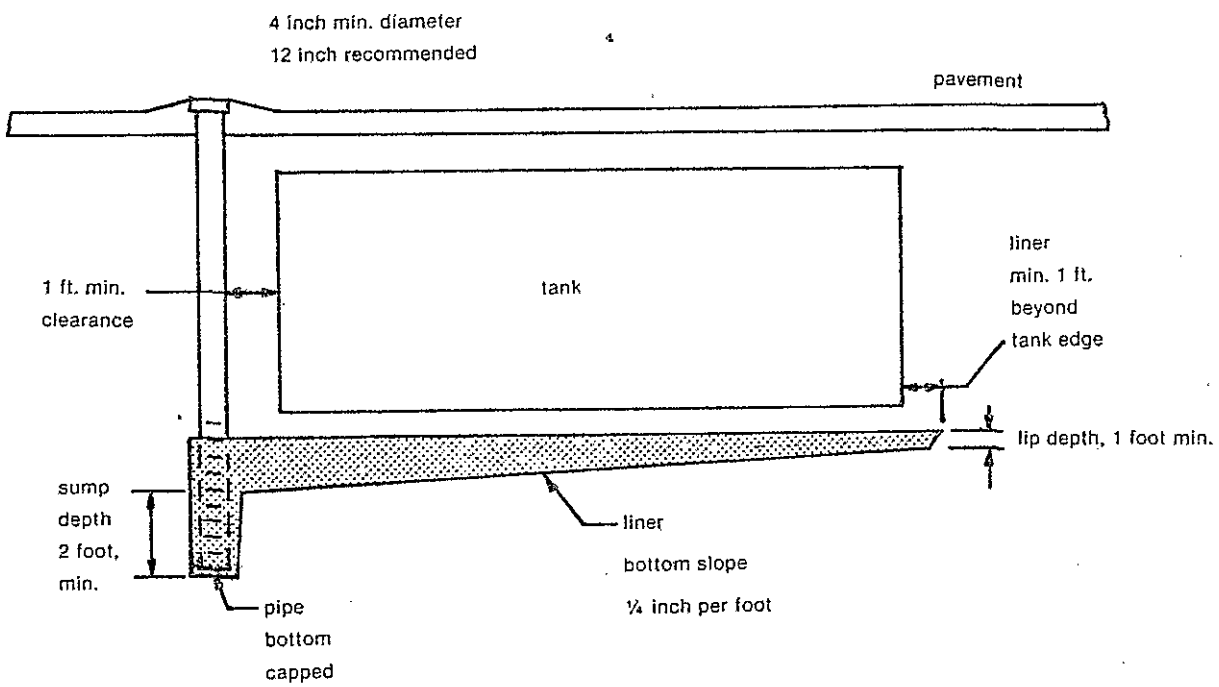
Before installing a clay liner, it is necessary to first drain and stabilize the excavation. After drainage, the liner is then laid in place and properly compacted at optimum moisture level. The layer of clay should be at least 6 inches deep and compacted to 95% of Standard Proctor. If the soils engineer recommends a clay liner that is more than 6 inches thick, it should be applied in layers no greater than 6 inches to assure proper compaction. The installation of clay liners is a complex operation and requires the supervision of a field engineer and a trained contractor to ensure high levels of quality control.

FIGURE 4—3

EXCAVATION WIDE LINER



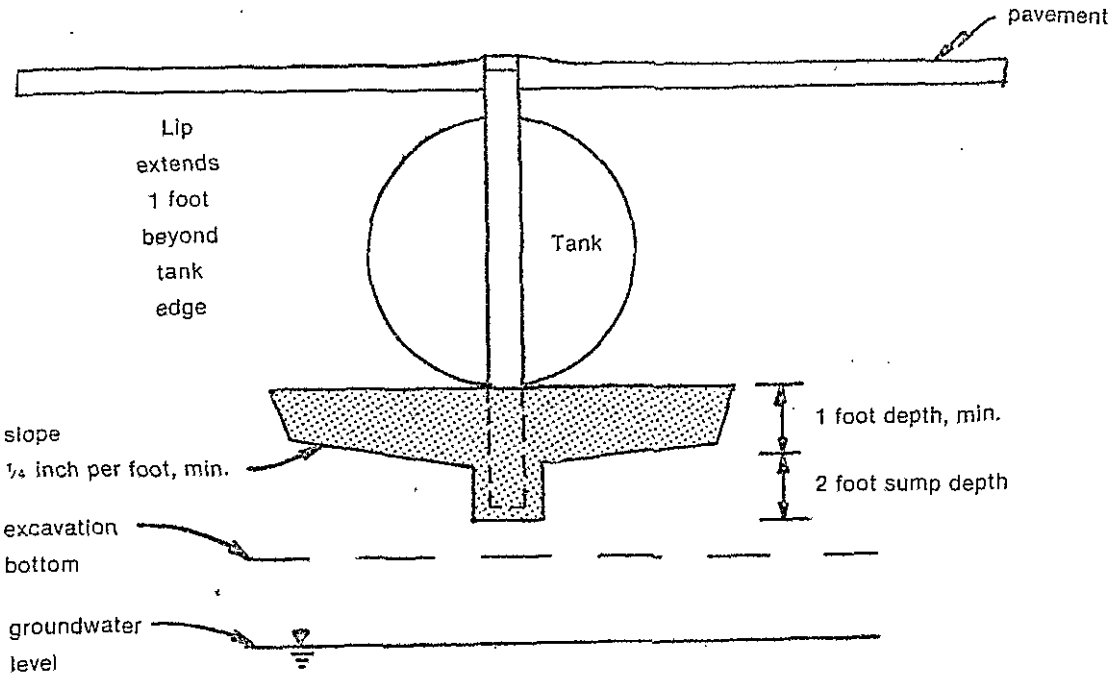
End View



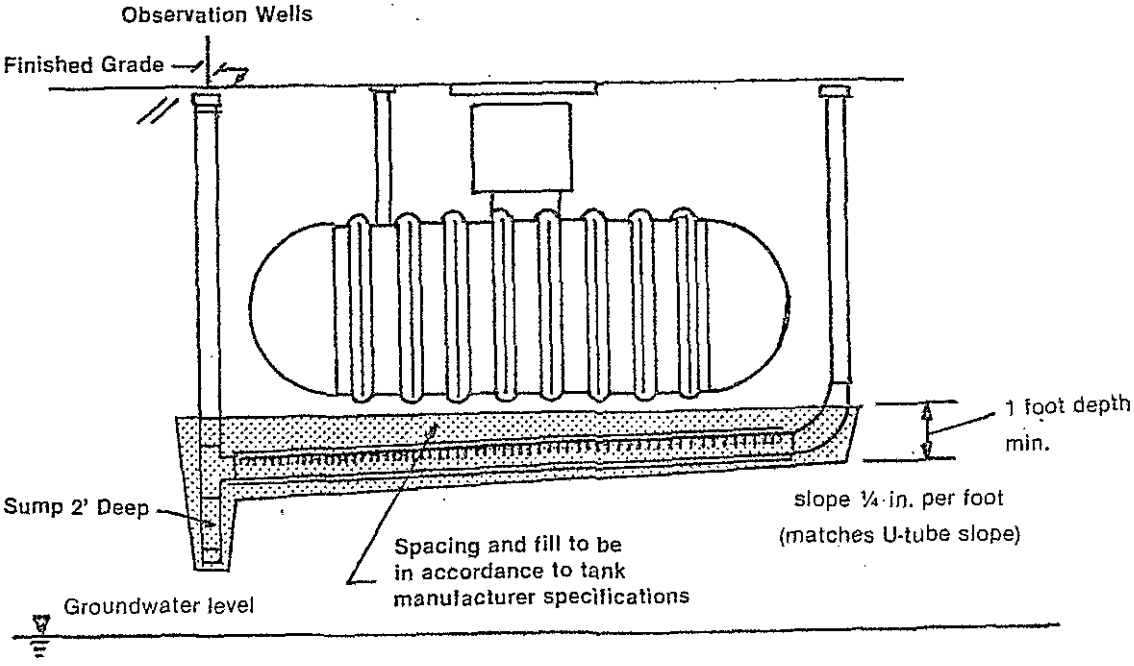
Side View

FIGURE 4—4

TROUGH LINER



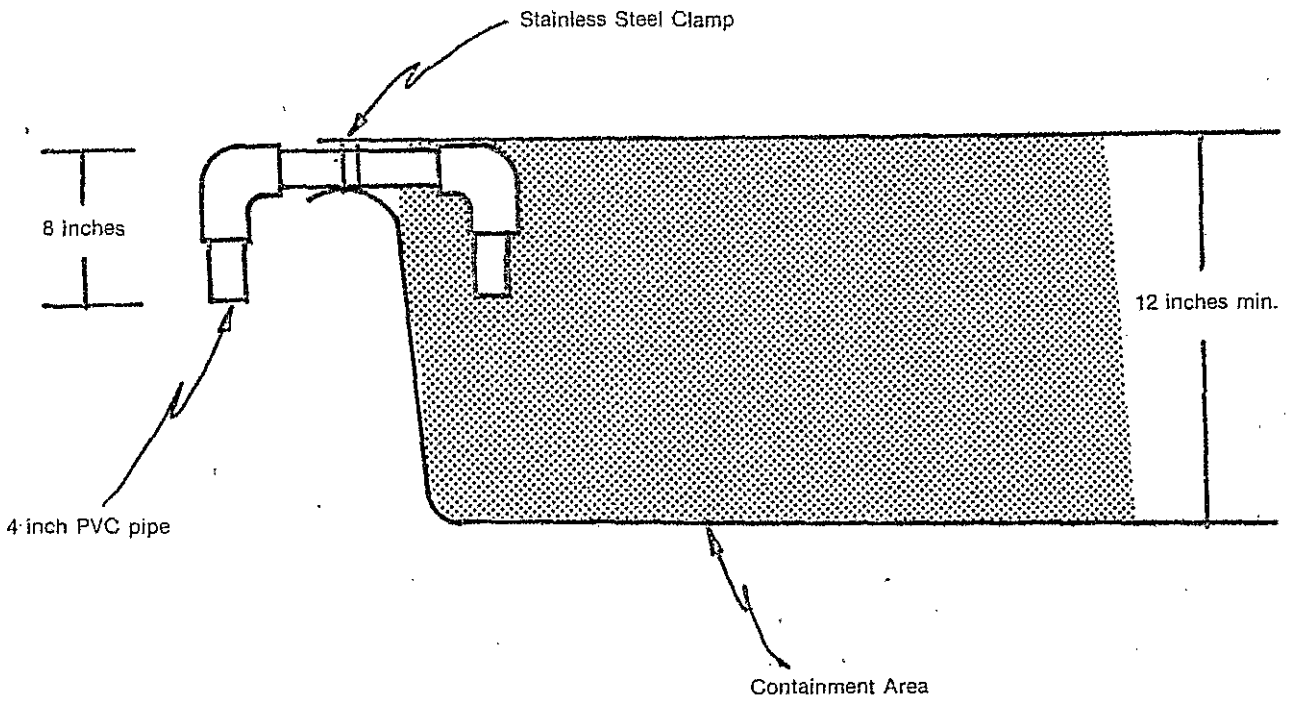
End View



Side View

FIGURE 4—4a

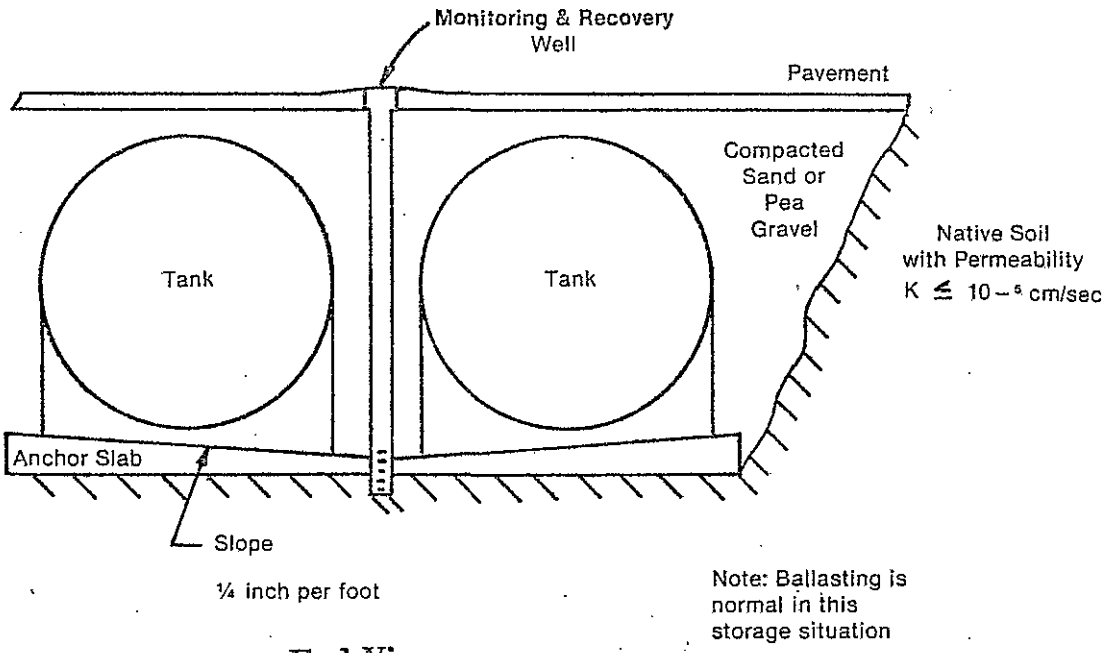
CONTAINMENT LINER DRAIN



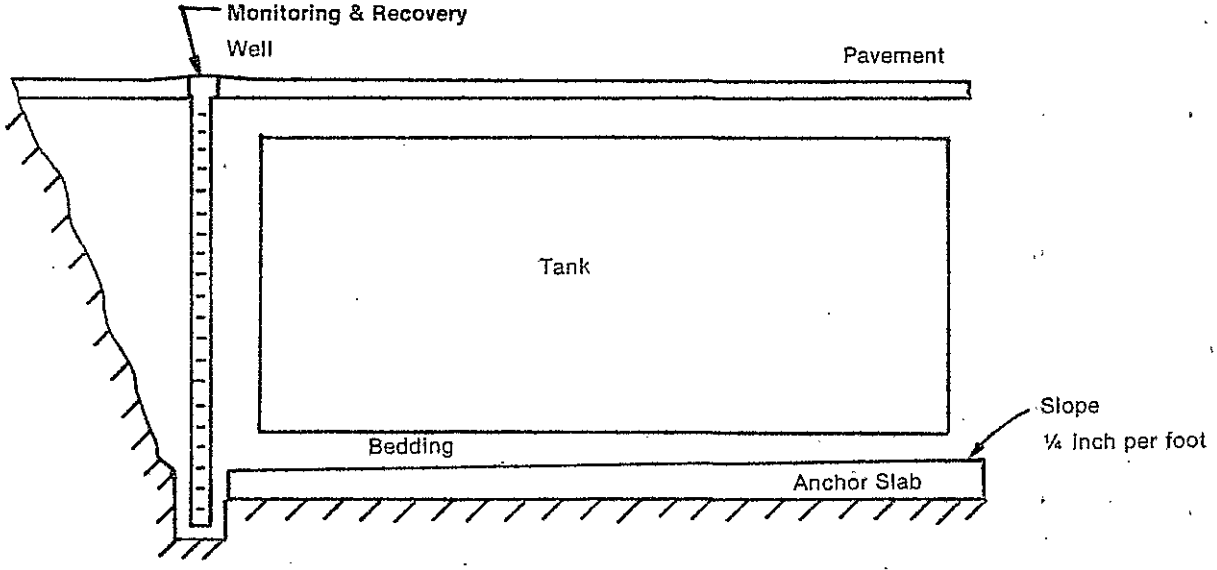
The pupose of this experimental liner drain is to allow water to flow out of the liner but retaining leaked product inside the liner. An API separator works in the same way. Petroleum floats on the water surface; as the water level rises to the top of the liner it also floats up through the pipe. Since the inlet of the pipe is a bit lower than the edge of the liner, water will flow out of the containment throught the pipe, rather than over the lip of the liner. The floating product stays on the surface for detection. The **key to installation** is keeping the horizontal part of the pipe lower than any other part of the liner, to make sure any flow out is through the pipe.

FIGURE 4—5

NATIVE SOILS WITH LOW PERMEABILITY



End View



Side View

2. Synthetic Membranes

Synthetic membrane liners are polymeric materials which are manufactured in sheet form. Two criteria are critical for successful liner applications. The first of these is chemical compatibility. The choice of liner materials which can successfully withstand long-term exposure to petroleum and petroleum derivatives is limited. The second important criteria is proper installation. Liners must be installed so there are no pressure points where the liner can tear or be punctured.

As a class, synthetic membrane liners have several advantages and disadvantages. Their advantages include the following:

- There are a wide variety of liner materials, each with individual qualities for specific applications.
- They have a good resistance to bacterial deterioration.
- They are relatively economical to install.
- They can be used in many containment designs.

In general, the disadvantages of synthetic membrane liners include the following:

- They may be vulnerable to attack from some chemicals, including ozone when compared to other lining materials.
- They have a limited ability to withstand heavy loads.
- They are difficult to properly install and are susceptible to laceration, abrasion, and puncture.
- They are prone to cracking at low temperatures, and stretching and distortion at very high temperatures.

Currently, there is research being done on developing better lining materials which are more resistent to gasoline degradation. The main problem is long-term exposure to the active solvent fractions of gasoline, mainly benzene. There are two liners coming to market which promise long-term resistence to hydrocarbons. They are: (1) Herclor - an epichlorohydrin rubber compound manufactured by Carlisle Corp. (5), and (2) a urethane coated fabric manufactured by Seaman Corp. (6). More generic liners which have less chemical resistence are high density polyethylene, oil resistent polyvinyl chloride, and neoprene.

The crux of the liner problem is that when a first-class tank is installed, leakage won't occur for many years. *Therefore, when the liner is exposed to petroleum products,* it will already be several years old. During this time, there may be residual product in the soil from an earlier spill event.

The manufacturers of the synthetic liners should be consulted on material selection. Long-term exposure to hydrocarbons should be the primary consideration in liner selection.

The proper installation of a membrane liner is as important to the overall success of the application as material selection. Liner installation is a relatively complicated task that should be performed by a qualified contractor, with attention given to important details such as the following:

- The base of the excavation should be compacted to prevent settling *under the liner and tank after they* are in use.
- The slopes of the excavation walls and floor should *be stable to avoid collapse after the liner has been* installed.
- The base and sidewall areas that will contact the membrane should be finely finished. All rocks, rubble and debris which could puncture the lining should be removed. Sand layers should be placed above and below the membrane to further prevent punctures and to facilitate underdrainage.
- The liner should be carefully placed and seamed (bonded) in accordance with manufacturers' specifications.

Considerations During Synthetic Liner Placement

Use a qualified installation contractor who has experience with membrane liner installation, preferably the generic type of liner being installed.

Plan and implement a quality control program which will help ensure that the liner meets specifications. Inspections should be documented for review and recordkeeping.

Installation should be done during dry, moderately warm weather if possible.

The excavation base and wall should be firm, smooth, and free of sharp rocks or debris.

3. Concrete

Concrete, if sprayed with a chemically resistant coating, is sufficiently impermeable to be used as a leak or spill containment material. A 6 inch slab constructed with an inexpensive 2500 psi concrete mix is adequate for this purpose.

A concrete pad properly sloped to collect a leak or spill can serve not only as a containment structure but also as foundation and anchor for the tank.

4. Soil Sealants

Bentonites are excellent soil sealants when properly designed and when installed under the supervision of an experienced engineer.

Bentonites are naturally occurring inorganic swelling clays which are usually chemical treated. They are marketed under various trade names. Mixtures of soil and chemically treated bentonites may be used to line excavations for underground tanks and contain spills. When the bentonite is mixed with a sandy soil and saturated with water, the granular bentonite particles in the soil swell to fill the voids, forming an impermeable barrier.

Before installing a bentonite liner, it is necessary to first drain and stabilize the excavation. The mixture of soil and bentonite is then used to line the walls and bottom of the excavation. The mixture is typically wetted to saturation, *and compacted using a wobble wheel or steel wheel roller.*

When preparing the bentonite mixture, the manufacturer's recommendations should be followed as to the percent of the clay and soil, the amount and quality of water used for wetting, and the degree of compaction required.

Recent research has shown that the impervious qualities of bentonites may degrade upon exposure to certain organic solvents. Therefore it is imperative that an experienced soils chemist or soils engineer be involved during the liner material selection process to ensure that product containment will be sufficient.

5. Soil Cement

Soil cement is a compacted mixture of Portland cement, water and selected in-place soils. The result is a low strength concrete with greater stability than natural soils. The permeability of this mixture varies with the type of soil used – a more granular soil produces a more permeable soil cement.

Soil cement is a suitable lining material for underground liners in some instances. However, caution should be used under the following conditions:

- Highly organic soil retards cement hydration because of absorption of calcium ions.
- Clean, well-graded gravels and crushed rock are sometimes unsuitable because of shrinking problems
- Clays are unsuitable because of the difficulty of mixing a fine cement powder into a wet, cohesive clay, and because the clay's properties are not significantly changed.
- Saline soil require a much larger cement content.

In general, soil cements are more permeable, but less expensive, than bentonites, clays or synthetic membranes.

Highlights of Soil Cement Design and Installtion

- Preparation of the base walls is extremely important. The base wall should be properly finished, and well moistened before placing the concrete to prevent the liner from drying too quickly.
- Soil cement mixtures must be stiff enough to avoid slippage when applied on side slopes, but plastic enough to consolidate well.
- Proper curing of the liner is important.

References

1. New York State Department of Environmental Conservation, *Technology for the Storage of Hazardous Liquids, A State-of-the-Art Review*, New York State Department of Environmental Conservation, Division of Water, Bureau of Water Resources, 50 Wolf Road, Albany, New York 12233, January 1983.

2. Petroleum Association for Conservation of the Canadian Environmental (PACE) Report No. 79-2 *State of the Art Review: Petroleum Product Containment Diking*, PACE, Suite 400, 130 Albert Street, Ottawa, Ontario K1P5G4.

3. U.S. Environmental Protection Agency, *Lining of Waste Impoundment and Disposal Facilities*, SW870, USEPA Municipal Environmental Research Laboratory, Cincinnati, Ohio 45268, September, 1980.

4. Jewett, M.A., Buyce, M.R., **A Review of Methods for Determining the Permeability Characteristics of Colorado Soils Exposed to Hazardous Waste**, prepared by Fred C. Hart Associates, Inc., prepared for U.S. Environmental Protection Agency, Region VIII, 1860 Lincoln Street, Denver, Colorado 80295, June, 1981

5. Carslile Corp., *Carslile SynTec Systems*, Carlisle Corp., P.O. Box 7000, Carslile, Pa. 17013.

6. Seaman Corp., 102 N. Washington St., Millersburg, Ohio 44654.

CHAPTER 5:
STORAGE TANK REHABILITATION

Under certain specific conditions, an underground tank may be rehabilitated by installing an interior lining. This can extend a tank's life for up to ten years. **NOTE:** Some localities prohibit tank relining, so local authority must be consulted before beginning relining operations.

This chapter presents recommended practices and guidelines for the interior lining, or rehabilitation, of steel and fiberglass-reinforced plastic (FRP) underground storage tanks. The interior lining of tanks can be an effective means of tank repair which can extend the usable life of a tank.

The activities associated with the rehabilitation of underground storage tanks include: (1) freeing the tank of all petroleum, sludge and vapors; (2) cleaning the interior surface of the tank and preparing it for coating; (3) plugging or patching holes in the tank; (4) relining the tank interior; and (5) closing and sealing the tank. These activities are discussed below, with guidelines and recommendations given for repairing steel and FRP storage tanks. Table 5-1 lists sources of technical assistance for safely carrying out these activities. In addition, the American Petroleum Institute has recently published recommended practices for tank relining [7].

A. GENERAL SAFETY PRECAUTIONS

Personnel and general public safety are critical considerations during any procedures that involve opening and entering a tank that contained petroleum. The following subsections descibe safety precautions which the Department recognizes as prudent and necessary for the rehabilitation of underground storage tanks.

TABLE 5-1
SOURCES OF INFORMATION ON SAFE TANK REHABILITATION PROCEDURES

- API Publication 2015, Cleaning Petroleum Storage Tanks, Second E., 1976.
- API Publication 2015A, Guide for Controlling the Lead Hazard Associated With Tank Entry and Cleaning, 1975.
- API R.P. 2003, Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents, Third Ed., 1974.
- API Publication 1631, Recommended Practices for the Interior Lining of Existing Steel Underground Storage Tanks, 1983.
- NFPA 327, Cleaning Small Tanks and Containers.
- NIOSH, Criteria for a Recommended Standard, Working in Confined Spaces. Dept. of Health, Education and Welfare. DHEW 80-106.

1. Preparations for Opening the Tank

Proper procedures for preparing the tank for opening and entry are essential to ensure the safety of all persons involved in the tank rehabilitation process. As such, the following are important:

- Controlling Sources of Ignition: All sources of ignition must be removed from the area surrounding the tank and vapor vents. All open flames and spark-producing equipment within the vapor exposure area must be shut down, and all electrical equipment used in the area must be explosion proof.
- Removal of Liquid Product: As much product and sediment or sludge as possible must be removed from the tank. Hand pumps should be used to remove residual product which is below the level of the product pump.
- Removal of Flammable Vapors: The tank must be thoroughly purged of flammable vapors. Figure 5-1 shows several common types of tank ventilation configurations.
- Testing Vapor Concentrations: After the tank has been vapor-freed, the flammability of the vapor remaining in the tank should be tested. Tank opening and entry operations should occur only after the vapor concentration is below 20% of the lower explosive limit (LEL).

Guidelines for these activities can be found in API Publication 2015, **Cleaning Petroleum Storage Tanks** [1].

FIGURE 5—1

TYPES OF TANK VENTILATION AIR MOVERS

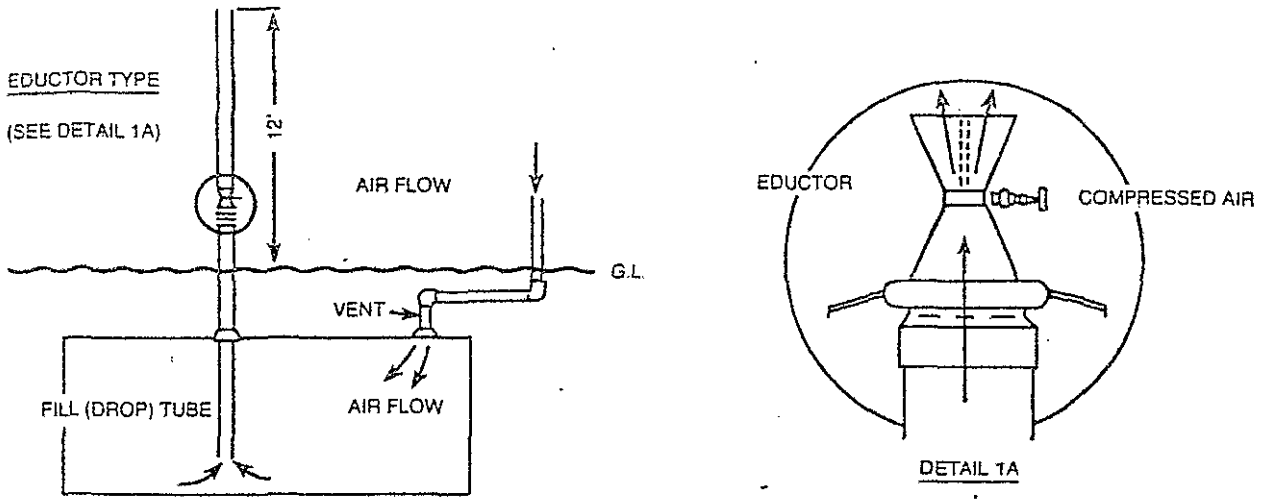
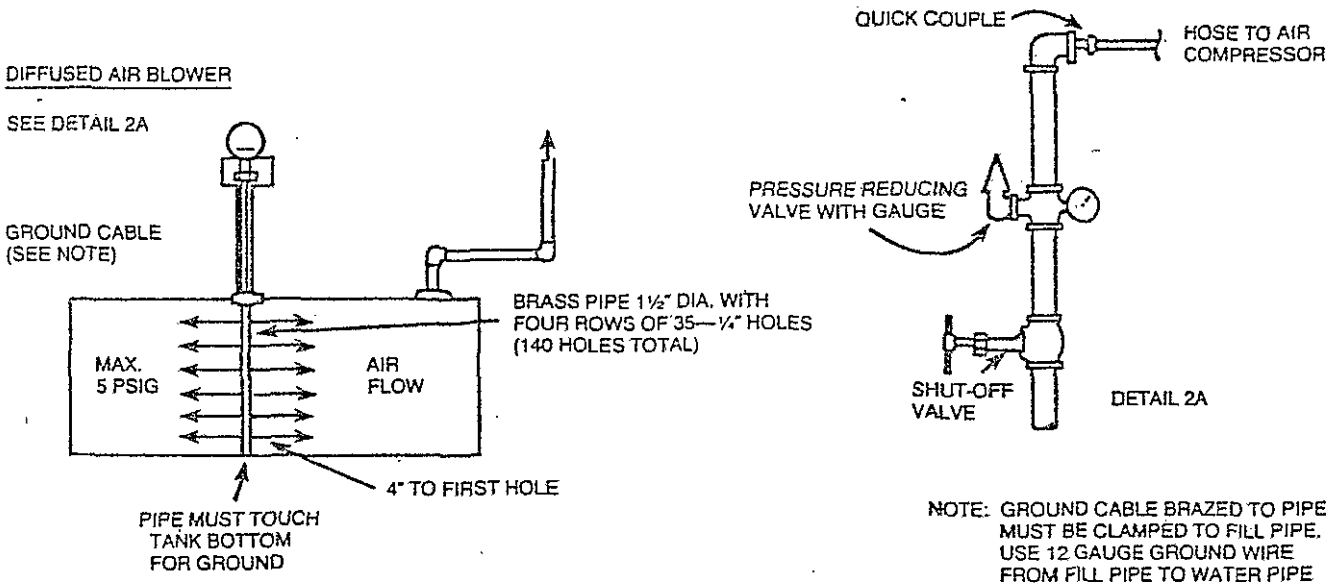


FIGURE 1



NOTE: GROUND CABLE BRAZED TO PIPE MUST BE CLAMPED TO FILL PIPE. USE 12 GAUGE GROUND WIRE FROM FILL PIPE TO WATER PIPE OR GROUND ROD.

SOURCE: API
Publication 1631

2. Opening the Tank

If no manway or hatch exists, a hole with the minimum dimensions of 18" x 18" (22" x 22" maximum) can be cut in the tank top (steel) or tank end cap (FRP). The tank must be cut using an explosion-proof (such as air driven) saber saw or snipper using lubricating oil to reduce friction, heat and possible sparks. Prior to the final cut, the section must be supported to prevent its falling into the tank.

After the hole is cut, the tank vapors must again be tested to verify that the tank is still safe. The readings should be lower than 20% LEL.

3. Tank Entry

Persons entering an underground tank for rehabilitation activities should be equipped with positive air displacement equipment with full face- mask at all times. Such persons should also wear a safety harness which is connected to a safety line held by an attendant outside the tank. The clothing worn by any personnel entering a tank should consist of the following:

- Cotton or other non-static producing fabric that covers the arms, legs, torso, and head.
- Oil, water and chemical resistent boots.
- Oil, water and chemical resistant gloves.

It is important that vapor freeing and tank ventilation operations continue while personnel are inthe tank. If the tank is perforated, product or fumes that have leaked out may re-enter the tank through the perforations.

B. REHABILITATION OF STEEL TANKS

1. Conditions for Rehabilitation

A steel tank may be relined, or rehabilitated, only if it meets the conditions given in the box below. If the tank does not meet these structural requirements, it is unlikely that rehabilitation operations will be successful. If these structural requirements cannot be met, the tank's service life is over. It cannot be relined or reused.

A steel tank may be relined or rehabilitated only if it meets the following structural conditions:

- It has a minimum design shell thickness of 0.18 inch(7 gauge).
- It has no open seam or split.
- It has less than ten (10) holes with none larger than one-half inch in diameter and no more than 2 within a 1-foot radius.
- It meets all the standards of the lining manufacturer for structural soundness.

A tank which fails to meet these requirements must be removed or abandoned.

To determine adherence to these requirements, the interior surface of the tank must be tapped by a ballpeen hammer to investigate for soundness. Weak areas, holes, and seams must be ballpeen hammered to obtain structurally sound edges. Holes must be reamed until the steel edge around the opening is a minimum of one-eighth (1/8) inch thick.

2. Preparation of the Tank Interior

Preparation of the tank interior includes procedures for sludge removal, if necessary, inspection of the tank surface, sandblasting of the tank surface, plugging of any perforations, and installation of striker plates.

Sludge Removal. Sludge which has accumulated in the tank constitutes a hazardous waste. It must be collected, placed in a tightly sealed container, and disposed of in accordance with Part 360 of the New York State Code of Regulations. Care should be taken during sludge removal operations to avoid causes of sparks or sources of ignitions.

Surface Inspections. *After any sludge has been removed,* the tank interior surface should be carefully reinspected to ensure that the tank meets the structural requirements for rehabilitation given above.

Sandblasting. The entire internal surface of the tank *must be sandblasted completely free of rust, scale, and* other foreign matter in accordance with the Steel Structures Painting Council Specification SPCC-SP 5-63 (S.S.S.a3) (White Metal Blast Cleaning). A White Metal Finish is defined as a surface with a gray-white uniform metallic color, slightly roughened to form a suitable surface for coatings. Following sandblasting, the entire surface must be brushed and vacuumed such that the surface is free of all moisture, oil, grease, dirt, visible mill scale, rust, corrosion products, oxides, paint, or other foreign matter.

Temporary plugging of all holes in the tank may be necessary prior to sandblasting to preclude re-entry of product liquids or vapors during the sandblasting operations. Temporary repairs can be made with non-corrosive plugs made of teflon or nylon.

Permanent Plugging. After sandblasting, all perforations should be permanently repaired as follows:

- All perforations should be reamed circular and be plugged with boiler plugs made of non-corrosive plastic. These boiler plugs should be covered with a laminate of resin and fiberglass cloth at least 6 inches by 6 inches.

Installation of Striker Plates. Prior to the application of an interior coating, striker plates, if not present and in satisfactory condition, should be installed under all tank access openings, such as the fill and gauging tubes. These striker plates are necessary to prevent or limit future damage to the tank, such as that which could be caused by dipsticking.

Each striker plate should be a one-quarter (1/4) inch steel plate with minimum dimensions of twelve (12) inches by twelve (12) inches. This plate size will help reduce both dipstick damage and blast erosion from product delivery. Each plate must be bonded to the tank and must be covered with a laminate of resin and fiberglass cloth.

3. The Interior Tank Lining

> The coating which is used to line the interior of the tank must maintain a permanent bond to the tank, and must form a hard impermeable shell which will not crack, wear, soften, or separate from the tank surface for a period of at least ten (10) years.

The material which is used to coat the interior surface of the tank must be guaranteed to last for a minimum of ten (10) years. This material must maintain a permanent bond with the steel surface of the tank, and it must be of sufficient thickness, density, and strength to form a hard, impermeable surface which will not crack, wear, or soften.

The Department does not specify minimum thicknesses in this manual because the minimum thickness requirements will vary with the coating material chosen. However, the coating material must be chemically compatible with the stored product. It must also have a coefficient of thermal expansion which is compatible with steel so that stress due to temperature changes will not be destructive to the coating or the coating-to-steel bond.

The coating material must be applied in strict accordance with manufacturer's specifications. Coating must be allowed to fully cure before product is put into the tank.

The coating material must also be applied as soon as possible after the tank surface has been cleaned and sandblasted, so as to avoid accumulations of dirt, grit, rust, or moisture. The Department recommends that not more than eight (8) hours elapse between surface preparation and application of the coating.

After application, the new lining must be tested for the presence of air pockets and pinholes. The Department recommends that an Elcometer Thickness Gauge or equivalent be used to check the coating thickness, and a Barcol Hardness Tester or equivalent be used to assure compliance with manufacturer's specifications for hardness. An electronic spark tester or equally effective device should be used to detect the presence of any holidays (holes or other defects) in the coating.

4. Closing the Tank

After the interior of the tank has been coated, all manways or access ways which have been used to enter the tank must be closed and sealed properly to prevent future losses of product or product vapors. To accomplish this, the Department recommends the procedures described in the following paragraphs, and illustrated in Figure 5-2.

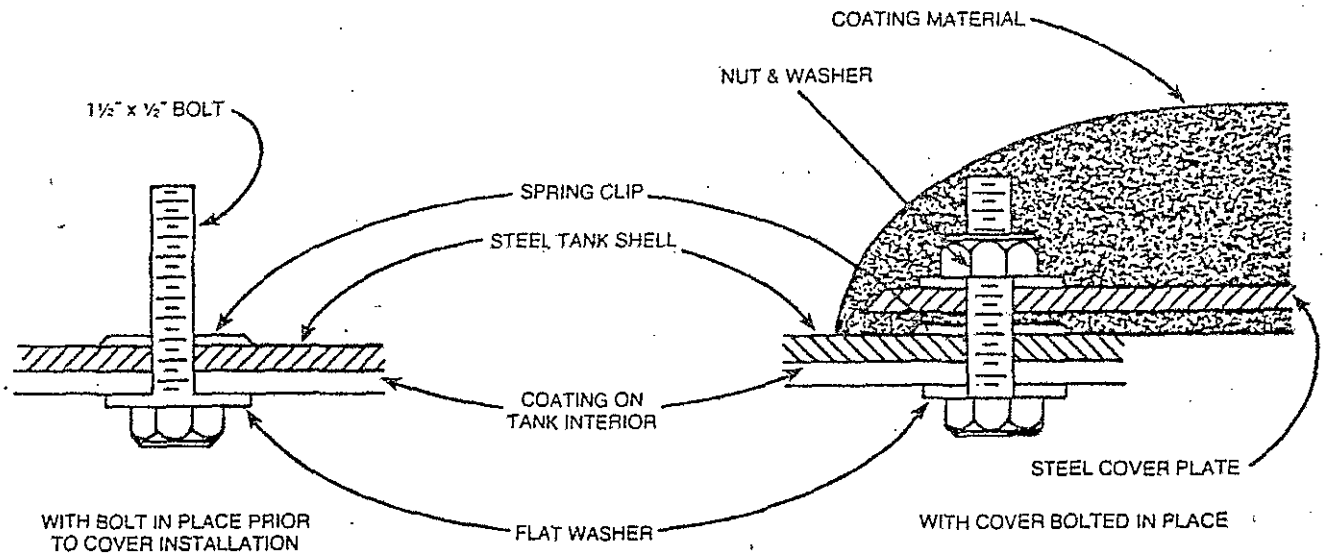
If the tank had a manhole, the manhole cover gasket must be replaced with a new one before resealing.

If an opening had to be cut to enter the tank, this opening should be sealed using these procedures:

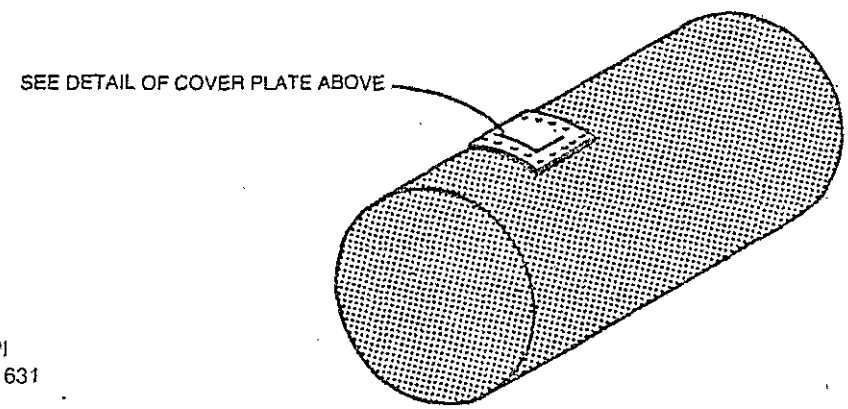
- A 1/4 inch thick steel cover plate, rolled to the contour of the tank, must be made to overlap the hole at least two inches on each side.
- The cover should be used as a template to locate 3/4 inch diameter holes on five inch centers, one inch from the edge of the cover.
- The cover plate should be sandblasted to the standard set forth above. Both sides and the entire inside surface must be coated with coating material to act as a gasket.
- Before the coating on the cover cures, the cover must be fastened to the tank using 1/2 inch (minimum) diameter bolts. The bolt shafts are to be placed through the holes from the inside of the tank and held in place by spring clips, then fastened with lock washers and nuts which have been dipped in a seam sealer.
- After being bolted to the tank, the cover plate and surrounding tank surface must be properly sandblasted, coated with coating material, and allowed to cure before backfilling the tank excavation.

FIGURE 5—2

INSTALLATION OF TANK COVER PLATE



CROSS SECTION



SOURCE: API
Publication 1631

5. Tightness Testing

Once the tank has been coated and closed, and before backfilling has occurred, the tank should be pressure tested to ensure that all plugging, patching, coating, and sealing procedures have been effective. A Precision Test is the best method to certify to the tank owner that the storage tank is liquid tight when it is placed back in service (see Chapter 8).

C. REHABILITATION OF FRP TANKS

The repair of FRP tanks must be conducted by experienced field personnel in strict accordance with manufacturers' specifications and guidelines.

1. Conditions for Rehabilitation

The primary criteria typically used to determine whether an FRP tank should be repaired or replaced is economics. The cost of a replacement tank is compared to the repair costs, depending on type and extent of damage. In some cases, the cost of repair is greater than the cost of replacement. Particular attention should be given to the cause of the damage. If the cause cannot be eliminated, such as an improper installation, repair will not correct the problem.

There may also be some instances in which the structural damage to a tank is so great that repair is not feasible or practical (as well as prohibitively expensive). In such instances, replacement of the tank is the only path to continued operation. Before rehabilitation of an FRP tank is attempted, the tank manufacturer should be consulted to determine if repair operations will result in a tank that continues to meet Department standards.

2. Repair Procedures

The repair or rehabilitation of fiberglass-reinforced plastic tanks typically involves patching holes or cracks in the tank shell or end caps, or repairing or replacing crushed or cracked ribs. In any activity of this type, close adherence to manufacturer's specifications is a necessity. The Owens-Corning Fiberglas Corp. Field Service Manual [6] is an excellent reference on this subject.

The repair of cracks or holes in the shell or end cap of a FRP tank involves the following steps:

1. **Surface Preparation.** The surface which is to be repaired must be cleaned and roughened so that bonding with new resin material will be facilitated. Typically, the damaged surface is ground or sanded to give it a rough surface, and then solvent cleaned to remove all dust and other foreign matter.
2. **Patching the Damage.** The crack or hole must be covered, patched, or bridged with an approved material, such as a resin-impregnated fiberglass mat. *The objective is to cover the damaged area effectively* with a material that can be adequately bonded to the tank.
3. **Curing the Patch.** The patch or mat used to cover the damaged area is allowed to cure to bond itself to the tank. After this step, the repair is basically complete.

In preparing the surface and patching the damaged area, it is typical to extend the area of repair beyond the area of damage. For example, in repairing small (less than 4 inches in diameter) holes in FRP tanks, Owens- Corning Fiberglas Corporation directs their repair teams to grind (roughen) the surface at least 6 inches beyond the damaged area in all directions, and to ensure that the patch that is used extends 4 inches beyond all sides of the damage [6].

The repair of damaged ribs requires similar steps, with the exception that the patch or replacement piece used must be in the original shape of the rib. This ensures that the repaired rib will supply proper structural support for the tank when it is under operational loads.

3. Testing

As with the steel tanks, a precision test after repairs are complete is the only way to be certain that the repair was successful. A testing program more frequent than the schedule in Ch. 8 would be appropriate, to assure that the repaired tank is leak free.

References

1. American Petroleum Institute, *Cleaning Petroleum Storage Tanks,* API Publication 2015, American Petroleum Institute, 2101 L Street, N.W., Washington, D.C. 20037, November 1976.

2. American Petroleum Institute, *A Guide for Controlling the Lead Hazard Associated with Tank Cleaning and Entry,* API Publication 2015A, First Ed., American Petroleum Institute, 2101 L Street, N.W., Washington, D.C. 20037, May 1975.

3. National Fire Protection Asociation, *Cleaning Small Tanks and Containers,* NFPA No. 327, National Fire Protection Association, Batterymarch Park, Quincy, MA 02269, 1975.

4. American Petroleum Institute, *Cleaning Mobile Tanks in Flammable or Combustible Liquid Service,* API Publication 2013, Fifth Edition, American Petroleum Institute, 2101 L Street, N.W., Washington, D.C. 20037, October 1975.

5. New York State Department of Environmental Conservation, *Technology for Storage of Hazardous Liquids, A State-of-the-Art Review,* New York State Department of Environmental Conservation, 50 Wolf Road, Albany, New York 12233.

6. Owens-Corning Fiberglas Corp., **Field Service Manual,** Bulletin 1, Owens-Corning Fiberglas Corp., Non-Corrosive Products Division, Fiberglas Tower, Toledo, Ohio 43659, October 1975.

7. American Petroleum Institute, *Recommended Practice for the Interior Lining of Existing Steel Underground Storage Tanks,* API Publication 1631, American Petroleum Institute, 2101 L Street, N.W., Washington, D.C. 20037, 1983.

CHAPTER 6:
RECOMMENDED PRACTICES FOR TANK CLOSURE AND ABANDONMENT

The use of proper procedures for the temporary or permanent closure of underground storage tanks is important to prevent environmental contamination and to ensure the future safety of the site.[1]

A. INTRODUCTION

Table 6-1 lists some of the environmental and safety concerns that are associated with the proper closure of underground storage facilities. The options available for temporary or permanent closure of such storage systems are as follows:

- Temporary closure: the tank and piping system are emptied and sealed to be "temporarily out of service."
- Abandonment in place: the tank and piping system are emptied and sealed, and the tank is filled with an inert material.
- Removal for reuse or disposal: the tank and piping systems are removed from the ground after being emptied.

The remainder of this chapter further describes these alternatives and presents recommended practices for each.

TABLE 6-1

IMPORTANT CONSIDERATIONS IN STORAGE TANK CLOSURE

- Product that is left in the bottom of the tank (e.g., below the withdrawal line) will eventually leak out, leading to potential environmental contamination and health hazard problems.
- Empty tanks left in place underground may be used for illegal storage or disposal of hazardous wastes.
- Improperly closed tanks may be accidently filled with a material that is incompatible with the previously stored material.
- Accidental intrusion into the abandoned tank site may occur. A classic example of this is children playing near an abandoned gasoline storage tank, where a casually discarded lit cigarette or match can lead to catastrophe.
- A tank may be accidentally reused in a sensitive application, such as for food product storage, without being properly cleaned and decontaminated.
- Tanks left empty in the ground may eventually collapse, causing ground subsidence.
- An empty, forgotten tank could pose a long-term threat, such as a threat of explosion, if the site is excavated.

B. TEMPORARY CLOSURE

1. General Description

Underground storage tanks which are out of service for 30 days should be temporarily closed by:

1. Removing all product down to the lowest drawoff point. Waste and sludge must be disposed of properly following the hazardous waste regulations.
2. Securing the tank by cutting off power to the pump and capping all openings to preclude unauthorized use.

2. Recommended Practices

Leaking tanks are not candidates for temporary closing. They must be abandoned, repaired or replaced.

The Department recommends that any temporary closure of an underground storage system include the following steps:

1. Remove all product from the tank and piping system, leaving sufficient quantity in the tank (a minimum of 4 inches, a maximum of 6 inches) to assure a rich, non-explosive vapor mixture.

2. Use concrete cast in place to cap all fill and draw-off lines.
3. Leave the vent lines open.
4. Cut off the power to all tank pumps and dispensers.
5. Secure the storage area against tampering. Isolation of the storage area through the use of a locked fence is recommended where practical.

In lieu of leaving standing product in the tank to ensure a non-explosive vapor atmosphere, the tank may be filled completely with a water solution containing a rust and corrosion inhibitor (to prevent rusting or corrosion of steel tanks). This practice would serve the same purpose of removing all fire and explosion hazards while preventing corrosion of steel tanks during temporary closure.

Considerations when water-filling a tank:

1. A tank that is leaking should be removed or replaced, not filled with water.
2. Any water put into the tank will be contaminated by stored product residue.
3. Proper disposal of the water must be planned beforehand. It should not be pumped out onto the ground.

Tanks that have been out of service should be precision tested before being put back on line. This is particularly apropos if ownership or control of the tanks changes hands.

C. PERMANENT CLOSURE

1. General Discussion

The determination of whether to abandon a tank in place or remove it for reuse or disposal is dependent upon several factors, such as the age and condition of the tank, its salvage value, and its potential for reuse. Governmental regulations may require tank removal. Other factors that are important include the following:

- Tank Location. The depth that the tank is buried and the type of soil in which it is buried will affect the ease, and hence, the cost, of tank removal. The potential for damage to concrete or asphalt traffic surfaces or nearby utilities should also be considered.
- Projected Use of the Site After Closure. If site plans call for development that involves excavation or regrading to the level of the tank, it is very likely that the tank will have to be removed.
- The Cost and Availability of Labor and Equipment. Tank removal will require the use of heavy equipment and experienced labor. If the cost of this labor and equipment is prohibitive, abandonment in place may be the preferred option.
- The Proximity of the Disposal Site. The proximity of the disposal site can also greatly affect the cost of tank removal. Tank transportation costs could be prohibitive, making abandonment in place the preferred option.
- Regulatory Requirements. Local laws or ordinances may require removal of the tank as part of any permanent closure procedures.
- The Presence of Other Tanks. The presence of other tanks still in use in the same excavation could affect the decision. If, for example, the tank which is to be closed is adjacent to an FRP tank, it should be abandoned in place to prevent structural damage to the remaining FRP tank. See Section 7 below for more information.

The Department requires that any new steel tank installation include cathodic protection and an exterior corrosion- resistant coating. Therefore, unprotected (bare) steel tanks cannot be salvaged and reused in underground applications.

2. Abandonment in Place

Tank removal is always the first choice. However, situations may arise where abandonment in-place is a proper alternative. Examples are where removing one tank may disrupt or undermine other tanks in an installation; another is a tank which has been installed near a foundation; and its removal might cause undue settlement.

Underground storage tanks may be effectively and safely abandoned in place through the following sequence of procedures:

1. Remove all liquid which can be pumped out of the tank and piping system. A hand pump or suction pump will be required to remove the bottom four inches of liquid from the tank.
2. Any remaining product can be removed by floating it with a small amount of water. Note that this contaminated water-product mix constitutes a hazardous waste that must be disposed of according to applicable NYS regulations.

   Flammable vapors will be expelled through the tank vent and remaining fill openings during the water filling operation. Purged product may also flow out of the tank openings if the tank is overfilled. Therefore, the entire operation should be considered hazardous, and precautions should be taken to prevent vapor ignition.

3. Dig down to the tank top at all fill and gauge openings and at connected lines.
4. Remove, or disconnect and plug all but one of the tank's fill, gauge, and product delivery lines. The remaining accessway will be used to pump grout into the tank.
5. Disconnect, empty, and cap all piping. Care must be taken to avoid spilling product from the piping into the excavation.
6. Fill the tank with a solid, inert material such as sand, a combination of sand and earth, a concrete slurry, or grout. This fill material can be introducted into the tank through the manway (if one exists), the opening that was used to add and remove water (if large enough), or a hole punched in the tank top using a backhoe or other equipment. **This operation should be considered hazardous, and precautions should be taken to prevent vapor ignition.**
7. Disconnect and cap all vent lines.
8. Cover the tank with backfill material and grade.

Underground tanks being abandoned in place must be filled to prevent the subsidence that would accompany tank collapse. Sand is an ideal fill material because it will readily flow into the tank and it is generally available. Any type of sand is suitable as long as it is free of rocks which might prevent leveling out in the tank. The sand may be introduced into the tank in dry form as long as it flows in freely and, when the cone nears the top of the tank, can be washed into the tank with a nominal amount of water and puddled to cause it to flow to the ends of the tank. The use of extensive amounts of water should be avoided in this instance as the tank might be filled with water before it is filled with sand.

A combination of sand and earth can also be used to fill the tank as follows: (a) fill the tank with sand to approximately 80 percent of capacity; and (b) pour a free-flowing mud consisting of soil and water into the tank opening and puddle until the tank is full.

Concrete or grout slurries can also be used to fill tanks which are being abandoned in place. Depending upon site economics, such as the availability and proximity of materials and labor requirements, these options may be somewhat more expensive than using sand or earth fill. However, they will eliminate the need for puddling to ensure that the tank is completely full, and as such may be attractive alternatives in some instances. If one of these options is used, the tank drop tube must be removed before the tank can be pumped full of the slurry.

Detailed records should be maintained during all storage facility closure procedures. These records should include, at a minimum, the following information:

- The date of the closure operation.
- The as-abandoned location of the tank and piping which remain in the ground.
- The amount of product removed and the method of disposal (or use) of that product.
- The amount of water used (for product removal) and the method of (treatment and) disposal of that water.
- The location of tanks abandoned in place should also be noted on the property deed.

3. Removal of Underground Tanks

The safe removal of underground tanks from storage facilities can be accomplished through the following procedural steps:

1. Remove all liquid from the tank. It will be necessary to use a suction pump or hand pump to remove the bottom few inches of product. All liquids including water must be disposed of properly and not just spilled on the ground.
2. Remove the fill tube from the tank if one is present.
3. Disconnect the fill, gauge, vent and product delivery lines from the tank. Cap or plug the open ends of all lines. Remove all liquid from the delivery lines, using care not to spill any liquid into the excavation.
4. Remove all flammable or otherwise hazardous vapors from the tank using one of the following methods. Note that the use of any of these methods will result in the release of vapors to the surrounding environment. Hence safety precautions with regard to the handling of hazardous (especially flammable or explosive) vapors should be observed.
   (a) If the stored product will float on water, if water is available, and if there is a suitable means for disposing of wastewater, the tank may be overflowed with water to expel any remaining product and vapors. Any remaining product should be pumped out as the tank fills. Care should be taken to avoid spillage of product and exposure to product vapors if a flammability or toxicity hazard exists. Once all product and vapor have been removed from the tank, the contaminated water should be removed and disposed of in accordance with applicable state and local regulations. All tank openings should then be capped or plugged.
   (b) An alternate method would be to ventilate the tank with air, using a small gas exhauster (eductor) operated with compressed air (as from a portable compressor or other suitable means). The flow of air through an opening near one end of the tank and the discharge of the vapor-air mixture out an opening near the opposite end of the tank will remove any vapor present. The vapor concentration in the tank can be checked with a gas concentration indicator during the operation. When the tank is gas-free, cap or plug all tank openings. Note that any air hoses used during this procedure must be grounded to prevent static discharges.

(c) Another method involves the use of solid carbon dioxide (dry ice) to purge flammable vapors and render the remaining tank gases inert. Dry ice should be introduced into the tank in the amount of 1.5 pounds per 100 gallons of tank capacity; the dry ice should be crushed and distributed evenly over the tank area to assure rapid sublimation. After all the dry ice has vaporized, all tank openings should be capped or plugged.

5. Remove excavation backfill to uncover the tops of the tank and any product lines.
6. The tank may now be uncovered and removed from the excavation.

Before the tank is moved from the site, be certain that all holes are plugged or capped. Use screwed (boiler) plugs to plug any corrosion leak holes. One plug should have a 1/8 in. vent hole to prevent the tank from being subjected to an excessive pressure differential caused by temperature changes.

Tanks should be removed from the premises as promptly as possible after these procedures have been completed, for the atmosphere in the tank will not remain gas-free indefinitely. If a tank remains at the site overnight, or longer, additional vapor may be released from liquid held in the scale or sediment in the tank. The vapor space should again be tested and the ventilation process repeated if necessary.

Extreme care must be taken in the offsite transportation of tanks which contained flammable vapors. All holes in the tank must be plugged and the tank positioned on the truck so that the plug having a 1/8" vent hole is located at the uppermost portion of the tank. All transportation regulations concerning hazardous materials must be followed.

Detailed records should be maintained during these operations. These records should include, at a minimum, the date of the operation, the methods of product and vapor purging, and the amounts of product removed and the method of disposal of any waste liquids.

4. Junking of Tanks

When tanks are no longer fit for the storage of flammable liquids or are considered junk, they should be disposed of. Whether sold to a junk or scrap dealer or discarded at an acceptable facility, sufficient holes should be made in tanks to render them unfit for further use.

When a tank is gas-freed it should be punctured with a pickax, chisel, or other heavy, sharp object; or many large holes may be drilled into it. When a tank is not gas-free it should be filled with water until overflowing and punctured, as above, while full of water. (**NOTE:** As previously stated, this large volume of water may become difficult to dispose of since it is contaminated.) Junked tanks should not be cut up with a torch because of the possibility of an explosion.

As an added precaution, regardless of condition, the tank should be labeled in legible letters with the following information:

"Tank Has Contained Flammable Liquids

Not Gas-Free

Not Suitable for Food or Drinking Water"

Prior to the junking of tanks, the latest applicable waste disposal regulations should be checked to determine if special attention or preparation is required.

5. Reuse of Storage Tanks

Used state-of-the-art tanks (constructed of fiberglass or coated steel) may have structural or coating damage. They should be thoroughly inspected and tested before being reused underground. Unprotected steel tanks should never be reused for below ground storage.

Any state-of-the-art storage tank that is reused for underground storage should include secondary containment, leak monitoring and overfill prevention.

At a minimum, any tank which is to be reused must undergo a thorough internal cleaning and careful inspection of both the interior and exterior surfaces. Tank cleaning procedures will include water-filling of the tank to remove all residual liquid, and manual removal of any product sludge, rust, and scale that remains after the water and product have been pumped out.

In any tank cleaning operation, concern must focus on worker safety. Without proper safeguards and procedures, injury or property damage may result from one or more of the following:

- Explosion or fire.
- Oxygen deficiency.
- The presence of toxic liquids, vapors or dusts that are dangerous to breathe.
- Physical hazards such as slipping, tripping or falling objects.

For more information on the procedures involved in tank cleaning, the degree of hazard associated with these operations, and the precuationary steps that should be taken, please refer to the sources listed in Table 6-2.

The goal of any tank inspection is to determine if the tank has sufficient integrity to be put back into service. The internal and external surfaces must be thoroughly inspected to determine if any pinholes or evidence of structural damage are present. All seams should be carefully inspected for cracks or other signs of wear or decay. The thickness of the tank wall should also be checked to ensure that it meets or exceeds the requirements of the Bulk Storage Code.

TABLE 6-2

REFERENCES FOR TANK CLEANING OPERATIONS

API-2015
Cleaning Petroleum Storage Tanks

API-2015A
A Guide for Controlling the Lead Hazard Associated with Tank Entry and Cleaning.

ANSI-Z28.2
Standard Practice for Respiratory Protection.

API Pub. 2013
Clean Mobile Tanks in Flammable or Combustible Liquid Service.

NFPA 327
Cleaning Small Tanks and Containers.

NIOSH, criteria for a recommended standard, Working in Confined Space.
DHEW 80-106.

These publications may be obtained from the following organizations:

API Publications:	American Petroleum Institute 2101 L Street, N.W. Washington, DC 20037 (202) 457-7173
ANSI Publications:	American National Standards Institute, Inc. 1430 Broadway New York, N.Y. 10018 (212) 868-1220
NFPA Publications:	National Fire Protection Association Batterymarch Park Quincy, MA. 02269 (617) 328-9230
NIOSH Publications:	National Institute for Occupational Safety and Health Public Health Service Center for Disease Control National Institute for Occupational Safety and Health

The Department recommends that acoustical or ultrasonic testing equipment be used to inspect storage tanks for structural flaws. Spark testing equipment should also be used on coatings to detect pinholes or holidays in the coatings. More information on this type of equipment is available in the Department publication **Technology for the Storage of Hazardous Liquids, A State-of-the-Art Review (4).**

In some situations, relining may be required to bring the tank in compliance with Department standards for reuse. Chapter 5 addresses tank rehabilitation in detail.

6. Storing Tanks for Reuse or Disposal

Used tanks that have been gas-freed cannot be guaranteed to remain gas-free because of the potential for the retention of liquid product (which may eventually vaporize) in crevices and under scale. It is therefore important that tanks stored for reuse or disposal be handled with caution. The recommended procedures for storing used tanks are listed below.

Tanks should be stored and secured where they can be safeguarded, usually on the locked premises of a tank user familiar with the hazards, or at another location where the general public will not have access. An open, fenced yard area, apart from other facilities, is desirable.

Before storing tanks, it is desirable to have them gas-freed via steaming or mechanical ventilation. If such facilities for gas-freeing are unavailable, tanks may be overflowed with water to expel vapors, and then drained.

Tanks will also become gas-free by natural ventilation if stored off the ground with all openings down and open for a protracted period. During this period of natural breathing caused by temperature change, the vapors may be within their flammable limits. To assure safe operations, the condition of the tanks should be indicated by a label or sign and they should be protected from unauthorized personnel during this period.

Any gas-freeing operations may release scale or sludge containing hazardous materials. Such scale or sludge must be carefully handled, and must be disposed of in accordance with applicable federal, state and local requirements.

Gas-free tanks may be safely stored with unplugged openings, but plugging of all openings is recommended to keep tank interiors clean.

In any of the foregoing cases where all tank openings are to be tightly plugged, screwed plugs should be used, and one plug should have a 1/8 in. vent hole to prevent the tank from being subjected to an excessive pressure differential caused by temperature changes.

The former contents and present vapor state of each tank, if known, or the gas-freeing treatment and date should be indicated by an appropriate label on the tank.

7. Abandoning Steel Tanks Adjacent to FRP Tanks

If the permanent closure of a steel tank which is adjacent to an FRP tank is necessary, this steel tank should be abandoned in place. This is necessary to prevent structural damage to the fiberglass-reinforced plastic tank due to the loss of lateral support. Improper abandonment or removal of the steel tank in this instance could lead to settlement, which would probably cause a failure in the FRP tank.

References

1. American Petroleum Institute, *Recommended Practice for Abandonement or Removal of Used Underground Service Tanks,* API Publication 1604, American Petroleum Institute, 2101 L Street, N.W., Washington, D.C. 20037, March, 1981.

2. American Petroleum Institute, *Cleaning Petroleum Storage Tanks,* API Publication 2015, American Petroleum Institute, 2101 L Street, N.W., Washington, D.C. 20037, November, 1976.

3. National Fire Protection Association, *Cleaning Small Tanks and Containers,* NFPA No. 327, National Fire Protection Association, Batterymarch Park, Quincy, MA 02269, 1975.

4. New York State Department of Environmental Conservation, *Technology for Storage of Hazardous Liquids, A State-of-the-Art Review,* New York State Department of Environmental Conservation, 50 Wolf Road, Albany, New York 12233.

5. American Petroleum Institute, *Cleaning Mobile Tanks in Flammable or Combustible Liquid Service,* API Publication 2013, Fifth Edition, 2101 L Street, N.W., Washington, DC 20037, October, 1975.

6. American Petroleum Institute, *A Guide for Controlling the Lead Hazard Associated with Tank Cleaning and Entry,* API Publication 2015A, First Ed., 2101 L Street, N.W., Washington, DC 20037, May, 1975.

7. American National Standards Institute, *Standard Practice for Respiratory Protection,* ANSI Publication Z28.2, 1430 Broadway, New York, N.Y. 10018.

CHAPTER 7:
LEAK DETECTION SYSTEMS

Leak detection systems and inventory monitoring practices that provide continuous surveillance for leaks and spills are an important requirement in underground bulk storage installations.

A. INTRODUCTION

Surveillance for a leak or spill from an underground storage tank is an extremely important function of any bulk storage installation. This is best accomplished with a leak detection system. The purpose of the detection system is to inform the operator that a leak has occurred before the leak can become a significant environmental health or safety problem.

The recommendations which follow focus on the types and operation of leak detection equipment, and represent minimum objectives for owners and operators of bulk storage facilities.

The types of leak detection systems which may be employed include the following:

- Interstitial monitors of double-walled tanks.
- In-tank testing equipment.
- Systems which monitor the excavation, such as U-tubes, vapor wells, observation or liquid sensing wells, and collection sumps equipped with sensors.

Leak detection is important at all underground storage facilities. Even a small pinhole leak, if undetected over a long period, can cause serious environmental contamination. A leak as small as 0.2 gallons per hour will result in a discharge of 1,750 gallons per year.

In addition to the use of leak detection systems, tank operators should monitor their storage inventories daily and maintain detailed inventory records.

B. INVENTORY MONITORING

Detection of leaks is facilitated by proper product accounting (recordkeeping), regular inspections of the visible parts of the product handling system, and prompt recognition of the conditions that indicate leaks in underground tanks and piping. Inventory monitoring is a technique that is widely applicable to any stored or transported product.

Evidence of leakage from buried tanks and pipelines can be gathered from inventory control records and from abnormal operation of pumping equipment. The following are some of the the more obvious symptoms of such leaks:

- Loss of product in a tank during periods when product is not dispensed usually indicates a leaking tank, but might also indicate faulty accounting or metering of the product, theft, or extreme temperature change.
- An unaccountable increase in water in an underground tank may be caused by a leak in the tank if the ground surrounding it is saturated. Under such circumstances, water may leak into the tank instead of product leaking out. The increase in water may also be caused by a leaking gauge or fill cap, and these should be examined and made watertight, if necessary, before concluding that the tank is at fault.
- Increasing differences between the amount of product received and dispensed may indicate a meter calibration problem, theft, or a leak in tanks or piping.
- Where fill boxes are located remotely from the tanks, differences appearing consistently between the amounts invoiced and the tank gauges after deliveries may indicate a leak in the remote fill line. In such event, the line should be tested.
- A hesitation in the delivery from a suction pump may indicate a leak in the suction piping, although such hesitation may also be caused by a leaking foot valve or, in warm weather, by vaporlock: Should this occur, the inventory control records may indicate whether the cause is mechanical or whether product is actually being lost.
- In a remote pumping system, pump operation without product delivery may indicate a leaking pipe.
- Another simple check is to record product depth with the gauge stick at the station's close of business and again at start of day. The longer this period, such as weekends or pump repair/servicing, the more accurate the test.

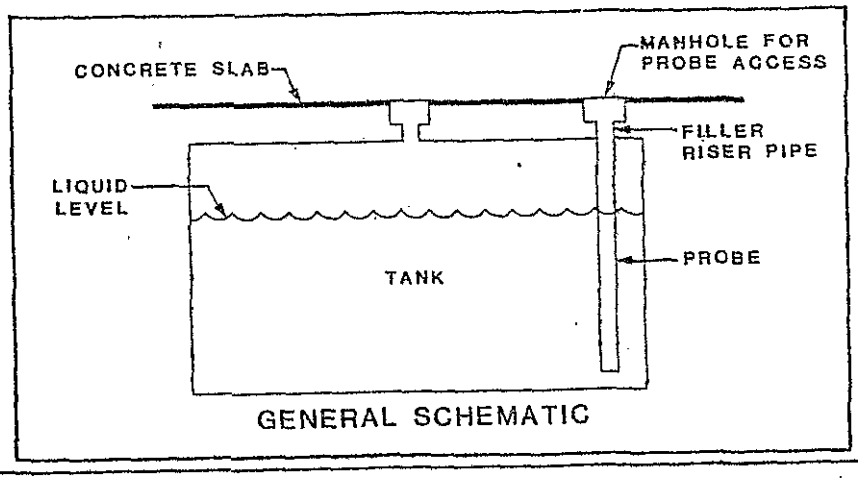
The Department recommends that any bulk storage inventory monitoring program include measurements of the following items:

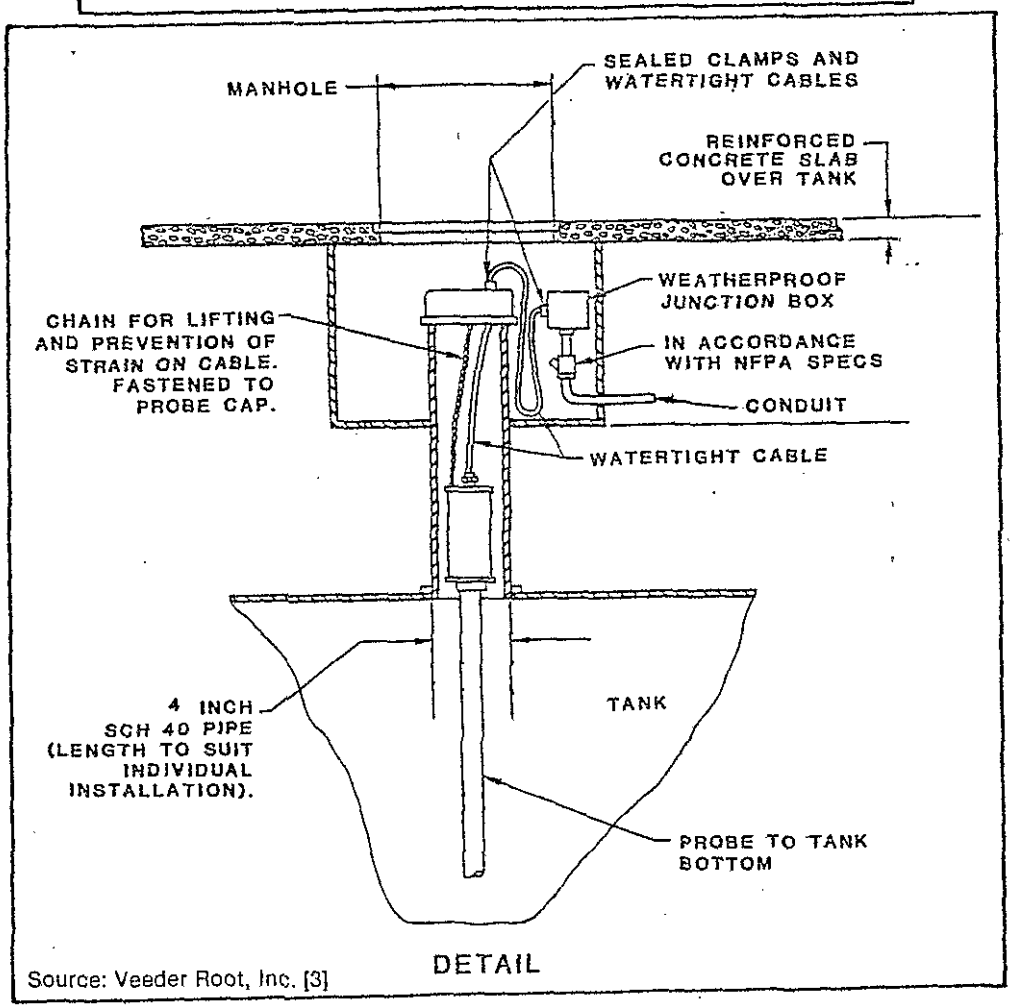
- The level of product in each tank.
- The level of water in each tank.
- Product sales.
- Deliveries to and draw-off from each tank.

These items should be measured and recorded at least once per day, and daily records should be maintained of gains or losses based upon these measurements These records should be maintained and kept on the premises for at least 3 years.

FIGURE 7-1

A TYPICAL IN-TANK TESTING SYSTEM





Source: Veeder Root, Inc. [3]

Inventory control measurements may be made by gauge, gauge stick, or by readout from an automatic gauging system such as the Veeder Root system described in Section D. Guidance on tank gauging is available in API Publication 1621, **Recommended Practice for Bulk Liquid Stock Control at Retail Outlets** [1], and from the New York State Association of Service Stations [2].

Whatever inventory monitoring system is used, that system should be capable of detecting a change (usually an increase) in the tank water level exceeding 1 inch on a day with no delivery, or apparent product losses exceeding one of the following:

- 0.75% of product stored.
- 7.5 gallons per 1000 gallons delivered.

Inventory control optimally can detect a loss of 0.50% of product stored. Generally, 1/2 of 1 percent loss indicates that there is likely to be a problem, but 0.75% loss makes this a certainty.

C. INTERSTITIAL MONITORING IN DOUBLE-WALLED TANKS

Systems which monitor the interstitial space between the walls of double-walled tanks using either vacuum sensors or fluid sensors represent the best mode of continuous leak surveillance available. In such systems, a leak can be detected due to failure of only one of the two walls of the tank. Thus, the operator can be made aware of the leak before stored product has left the tank and entered the environment.

In interstitial leak monitoring systems, sensors would be used to monitor tanks that have a vacuum drawn in the space between the tank walls. Failure of either the inner or outer wall is detected by loss of vacuum. Such systems are applicable in either wet or dry hole installations.

Fluid sensors, on the other hand, would be located between the tank walls to detect the presence of liquid due to failure of the inner wall (detecting an outflow of product) or the outer wall (detecting an inflow of water). Such systems are more applicable in wet hole installations where failure of the outer wall will result in the presence of a fluid in the interstitial space. Because failure of the outer wall can go undetected if fluid sensors are used in dry hole installations, such an application is not recommended if pressure sensors can be used instead.

In the case of either type of interstitial monitoring system, it is important that the tank be constructed to allow for free movement of fluids or gases in the space between the tank walls so that a leak anywhere in the tank can activate strategically located sensors.

D. IN-TANK TESTING EQUIPMENT

In-tank testing equipment, as shown in Figure 7-1, can be an effective method of leak detection. Such a system usually consists of a probe permanently mounted inside the tank which continuously monitors the levels of product and water in the tank. To assure that a small continuous leak does not go undetected, such a system should be capable of detecting any leak greater than two-tenths (0.2) gallons per hour, or roughly five (5) gallons per day, of water flow into the tank or product flow out of the tank. An example of such a system is highlighted in the box insert below.

In-Tank Sensing Equipment

The TLS-150 gasoline tank level sensing system by Veeder-Root can identify inventory losses and accurately track fuel dispensing and deliveries [2]. When in its inventory monitoring mode, this system continuously monitors the tank and provides an hourly printout of inventory changes. In addition, this leak detection system can provide an instantaneous tank inventory report which includes the following: (1) date and time; (2) level of product; (3) volume of product; (4) temperature of the product; and (5) the height of the water level in the tank.

Courtesy: Veeder-Root, Petroleum Products Div. (3)

E. EXCAVATION MONITORING SYSTEMS

Surveillance systems which monitor for product which has leaked into the excavation can be effective under many circumstances. These include U-tubes, vapor wells, observation or liquid sensing wells, and collection sumps equipped with leak sensors. The leak detector chosen for a particular storage system depends upon the nature of the product and the hydrogeologic conditions of the excavation site.

1. U-tubes

A U-tube consists of a 4 inch diameter (Schedule 40) PVC pipe installed as shown in Figure 7-2. The horizontal segment of the pipe is half-slotted (typical slot size - 0.06 inches), wrapped with a mesh cloth to prevent backfill infiltration, and sloped (pitched) toward the sump with a slope on the order of 1/4 inch per foot. At the higher end of the pipe there is a 90 degree sweep to a vertical pipe that is extended to grade. At the lower end of the horizontal pipe there is a tee connection with a vertical pipe; this vertical section is extended to grade, and extended 2 feet below the tee to act as a collection sump. All vertical pipe sections are unperforated, and the bottom of the sump is sealed to be

leak proof. All openings to grade are provided with watertight caps capable of being sealed. **It is imperative that these tubes be secured against products accidentally being delivered into them.**

These tubes may be installed under each tank in an excavation, or centrally located in the excavation. In either case, the excavation bottom must be sloped slightly (a minimum of 1/4 inch per foot) toward the U-tube to permit collection of any leaked material.

The collection sump of the U-tube should be equipped with a removable sensing device which is capable of detecting 1/8-inch of standing product or a 1/8 inch layer of product on water. This sensing device is installed so as to activate an alarm which is strategically located aboveground. Leak sensing devices are discussed further in Section 5 of this Chapter.

If the vertical section of the U-tube is designed as described above and shown in Figure 7-2, leaked or spilled product can be readily recovered from the collection sump using standard equipment such as a 3 3/8-inch submersible pump. Construction of the vertical section in this manner also permits easy sampling of leaked material to pinpoint the source of a leak. This may be necessary in situations where two or more similar products are stored, such as in an excavation housing both leaded and unleaded gasoline.

U-tubes can be used only in situations where the excavation is above the high level mark of the groundwater table (dry hole installations), the excavation has been provided with an impervious secondary containment layer on its floor, and the installation is covered with a waterproof cap. In such cases, any leaked material will eventually find its way to the U-tube's collection sump, where it can be detected without water interference.

2. Observation Wells

Observation wells are used to monitor for leaks from underground tank installations in areas of high groundwater. Here, groundwater will be present in the excavation for most or all of the year. A diagram of an observation well installation is shown in Figure 7-3.

An observation well, or liquid product sensing well, consists of, at a minimum, a 4 inch diameter (Schedule 40) PVC pipe placed in the tank excavation. The wells are constructed with a well screen long enough to provide a length of 5 feet or more above the water table, or to the well cap, and extending a minimum of 5 feet into the groundwater or 2 feet below the tank bottom, whichever is greater. Well screens typically have a slot size of 0.02 inches, and are extended to grade and covered with a water proof cap which is capable of being sealed.

As is true of the vertical section of the U-tube, if observation wells are constructed as described above and shown in Figure 7-3, they can be used for leak sensing, direct sampling, and product (and contaminated groundwater) recovery. When leak sensors are used, they must be capable of detecting a 1/8-inch layer of the stored product on the groundwater surface, and they must activate a strategically located aboveground alarm when that product is detected.

The selection of the number and location of observation wells in a particular storage system is dependent upon the local hydrogeology, including parameters such as the groundwater flow direction. The Department recommends that any installation using observation wells employ at least two (2) wells in each excavation.

Existing sites may have observation wells drilled to groundwater, providing the location and orientation of the tanks and piping is known.

3. Vapor Wells

A vapor well is similar to an observation well with the exception that it is intended for the monitoring of vapors or odors from underground storage systems. Such a well consists of a 4 inch diameter (Schedule 40) PVC pipe installed in the excavation within 5 feet of the tank. In dry installations, these wells extend to the containment liner on the floor of the excavation. In wet installations they extend into the groundwater.

The well screens in vapor wells should have a slot size of 0.02 inches. In dry hole installations, the screened opening should extend from the containment volume floor to a height of at least 5 feet. In wet hole installations, the well screen must be long enough to provide a length of 5 feet or more above the water table and should extend a minimum of 5 feet into the water table or 2 feet below the tank bottom, whichever is greater.

Vapor wells can be used only at uncontaminated sites. Once product vapors have entered the well, they will remain there until their source has been removed (the leak has been pinpointed and repaired) and the well has been purged free of residual vapors. If the well cannot be purged, the vapor well must be either retrofitted with an alternate means of sensing leaked product, or abandoned. A diagram of a typical vapor well is given in Figure 7- 4.

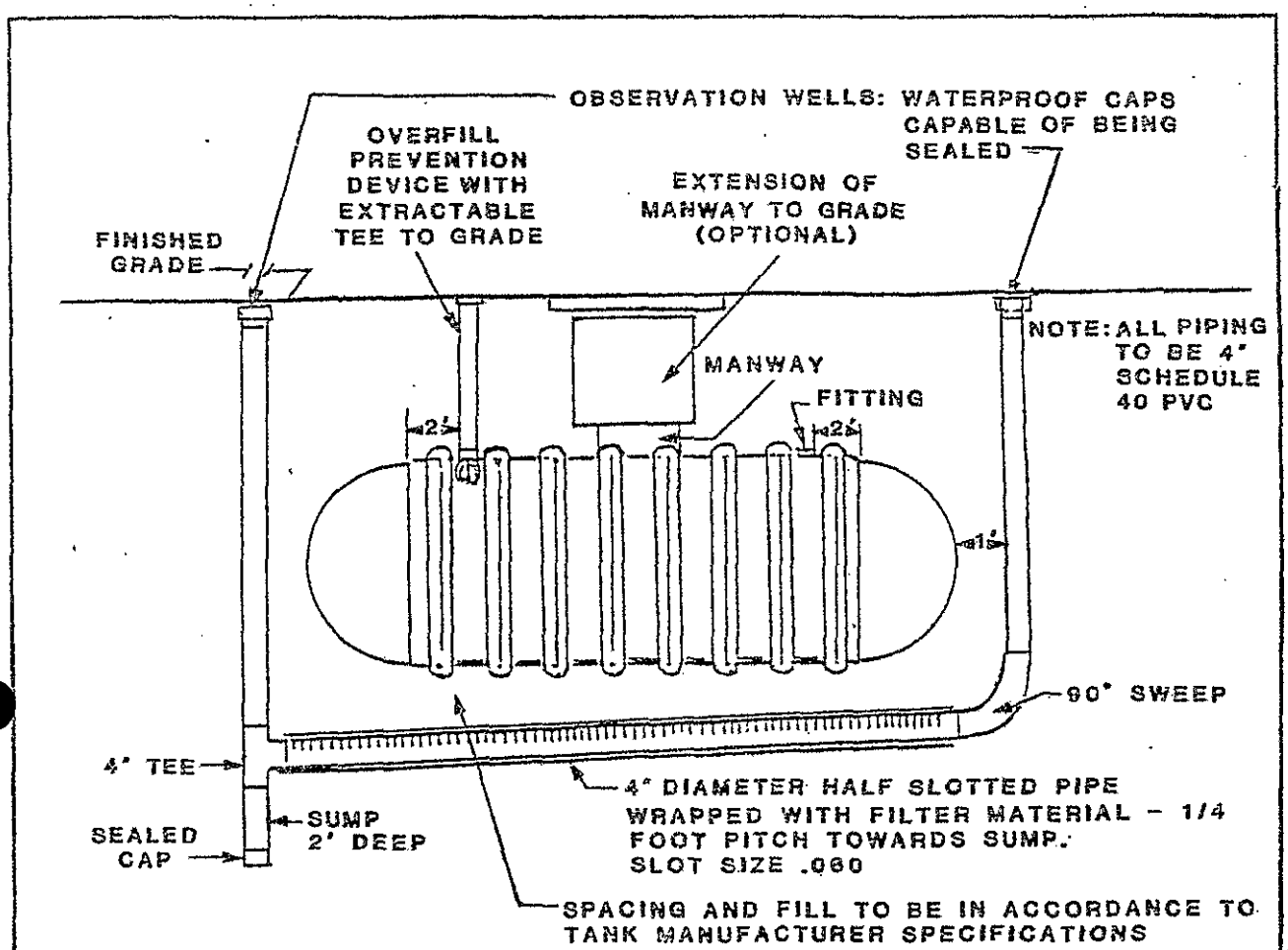
4. Collection Sumps

Collection sumps can be used in dry hole installations as a collection mechanism which aids in leak detection.

In this type of system, the floor of the storage excavation (or secondary containment liner) is sloped at a rate greater than or equal to 1/8 inch per foot to a collection sump. The sump should be at least 2 feet deep and be extended to grade via, at a minimum, a 4 inch diameter (Schedule 40) PVC pipe, and covered with a waterproof cap. This extension is essentially an observation well screened in the region of the sump. The sump should be equipped with a removable leak detection sensor capable of detecting 1/8 inches of standing product, which activates a strategically

FIGURE 7-2

EXAMPLE OF A U-TUBE INSTALLATION

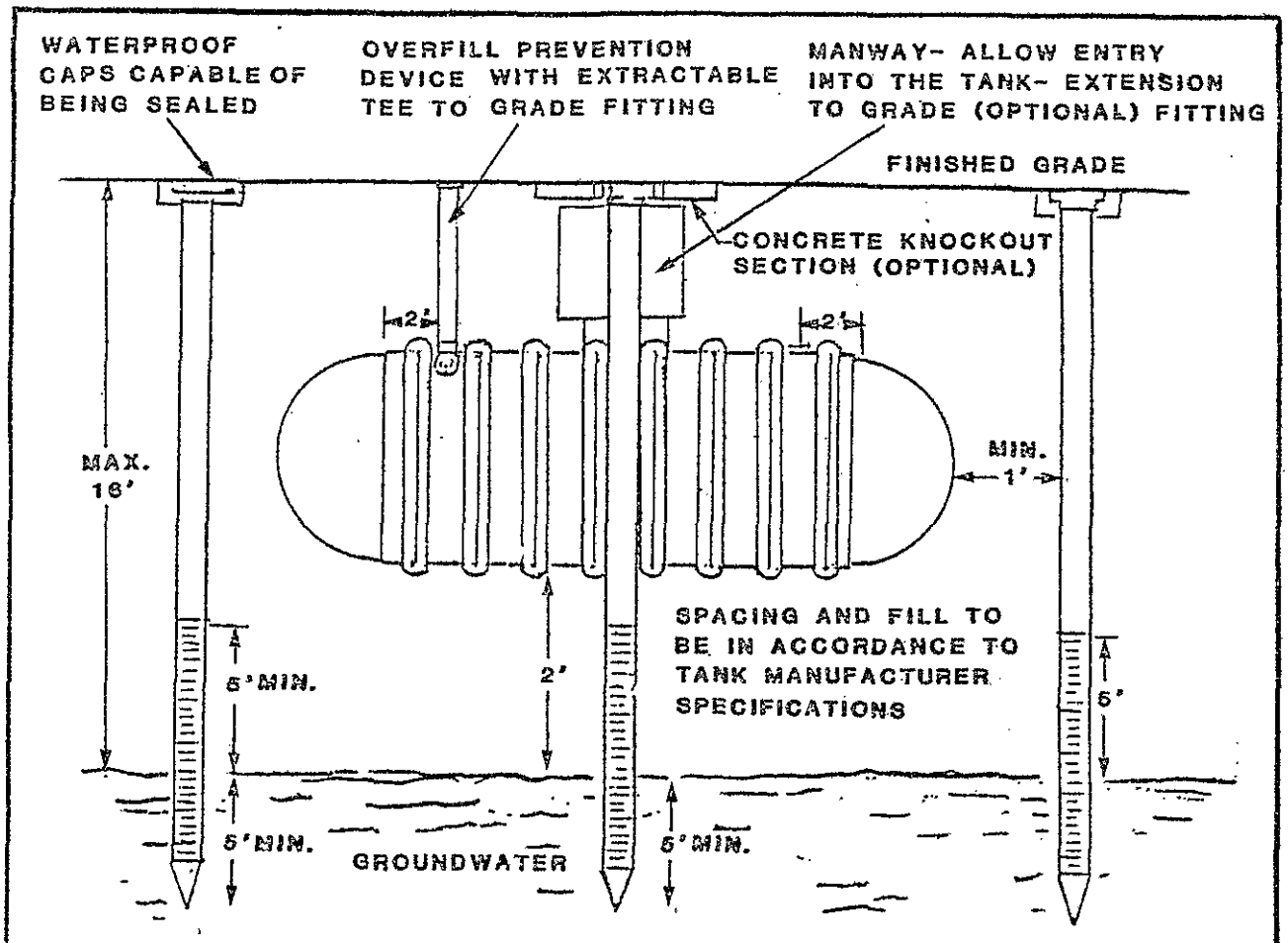


Source: James Pim, Suffolk County Dept. of Health Services

FIGURE 7-3

EXAMPLES OF OBSERVATION WELLS

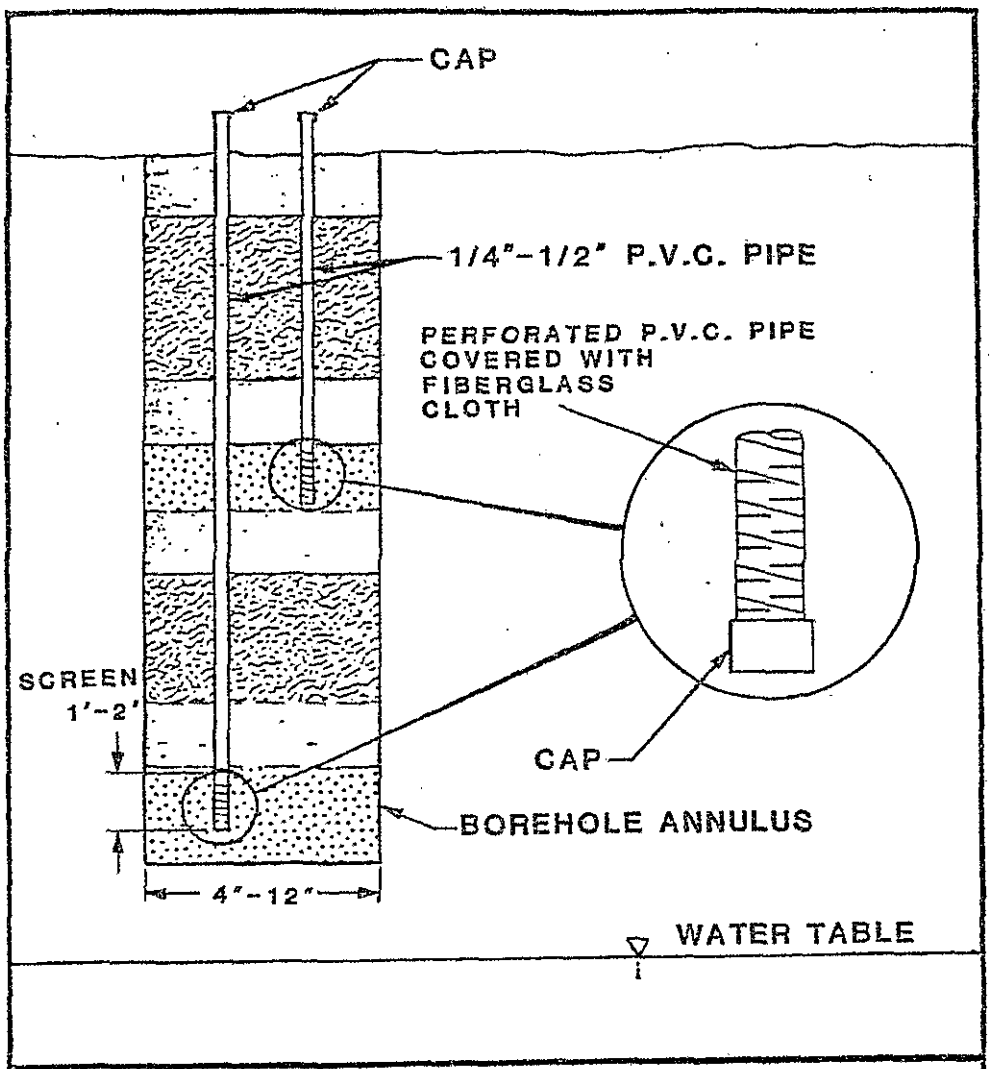
EACH WELL CONSISTS OF 4" PERFORATED PVC PIPE, DRIVEN AT LEAST 2 FEET BELOW THE BOTTOM OF THE TANK AND AT LEAST 5 FEET INTO THE GROUNDWATER



Source: James Pim, Suffolk County Dept. of Health Services

FIGURE 7-4

TYPICAL WELLS FOR CONTINUOUS GAS OR VAPOR MONITORING



LEGEND

- IMPERMEABLE PLUGS
- PEA GRAVEL
- BOREHOLE CUTTINGS

Source: Leak-X Corp., 560 Sylvan Ave., Englewood Cliffs, N.Y.

[illegible] so that product is present. If [illegible] and shown in Figure 7-5, [illegible] be used for leak sampling and [illegible] or spilled product.

[illegible]

[illegible] of sensors suitable for monitoring leaks from [illegible] petroleum storage facilities include the [illegible]

- Thermal Conductivity Sensors: This type of sensor detect changes in the thermal conductivity of its environment to determine if product is present. They may be used in either wet or dry installations, and are particularly applicable for the detection of hydrocarbons.
- Electrical Resistivity Sensors: These sensors rely on changes in the resistance of a wire due to exposure to the stored product. They are applicable for either wet or dry installations. Petroleum products degrade the rubber coating around the wire, creating a short circuit.
- Gas Detectors: This type of sensor is generally applicable in areas of permeable soil or backfill, and is particularly applicable in instances where the stored product is highly volatile and the excavation is dry (free of groundwater).

Another option in the case of U-tubes, observation wells, and collection sumps is direct sampling. While more accurate, this option is more expensive than the use of sensors, and as such is only employed in instances where it is necessary to pinpoint the source of a leak (e.g., in an instance where tanks containing similar but different products, such as leaded and unleaded gasolines, are located in the same excavation).

When thermal conductivity and electrical resistivity sensors are used, the level of accuracy is important. Such sensors must be able to detect 1/8-inches of standing product, or a 1/8 inch layer of product on the ground water surface.

More information on the advantages and drawbacks of the various types of sensors described above is available in the Department manual **Technology for the Storage of Hazardous Liquids, A State-of-the-Art Review** (4).

References

1. American Petroleum Institute, *Recommended Practice for Bulk Liquid Stock Control at Retail Outlets,* API Publication 1621, American Petroleum Institute, 2101 L Street, N.W., Washington, D.C. 20037, 1977.

2. New York State Association of Service Stations, 8 Elk Street, Albany, NY 12210.

3. Veeder Root, **TLS-150 Tank Level Sensor System,** Brochure No. 14-150, Veeder Root, Petroleum Products Division, 70 Sargeant Street, Hartford, Ct. 06102, 1983.

4. New York State Department of Environmental Conservation, **Technology for the Storage of Hazardous Liquids, A State-of-the-Art Review,** New York State Department of Environmental Conservation, Division of Water, Bureau of Water Resources, 50 wolf Road, Albany, New York 12233, January, 1983.

CHAPTER 8:

TIGHTNESS TESTING FOR STORAGE SYSTEMS

> Storage system tightness tests must be performed on a regular basis, and must incorporate equipment and procedures which have been approved by the Department.

A. INTRODUCTION

In many instances, the contamination caused by leaking underground storage tanks or piping has gone undetected for months or even years. At this point it is widespread, and very difficult and expensive to correct. Such situations should obviously be avoided. Regular testing and inspection of underground tanks and piping provide for early detection should such leaks occur. This chapter presents recommended practices and guidelines for inspection, for preliminary testing and final testing of underground storage systems.

B. INSPECTIONS OF UNDERGROUND TANKS

The inspection techniques which are recommended and described in this section are essentially screening techniques (often called preliminary tests) which can be used to develop a gross determination of the tightness and integrity of underground storage system components. The purpose of these techniques or tests is two-fold: (1) to detect existing leaks in the tank or its associated piping; and (2) to avoid sudden failure of the tank while in service by performing tests to determine tightness and integrity. These inspection techniques include the following:

- Inspections during tank installation.
- Checking tank bottoms.
- Checking for water in tanks.
- Monitoring of cathodic protection systems.

1. Inspections Prior to Backfilling

The inspection of a storage tank system prior to backfilling is an essential component of a comprehensive storage system installation procedure. The inspection of an FRP tank installation should include, at a minimum, soap tests of tanks in place prior to backfilling. Soap tests involve applying a soap solution to the external surface of the tank, pressurizing it to 3 or 5 psig. and inspecting the tank closely for bubbles which would indicate air leaks. The choice of the test pressure level is dependent upon the size of the tank as outlined in Chapter 1. The test pressure should be monitored for at least one hour.

The inspection of a steel underground tank prior to backfilling should include, at a minimum, soap tests of the tank in place, spark tests or holiday tests of the exposed external coating, and inspections of the cathodic protection system to ensure proper connection (wiring) and operation. The type of test most appropriate depends upon the coating type.

2. Checking Tank Bottoms

Experience has shown that many steel tanks develop leaks in a narrow band along the bottom. This often occurs because small amounts of water condense out of the stored liquid and settle at the bottom of the tank. This phenomenon can result in internal corrosion of the tank.

This internal corrosion will often be aggravated under the tank's fill tube or gauge hole as protective rust is removed by liquid flow against the tank bottom or the impact and movement of the gauge stick, either of which could lead to localized corrosion. Liquid flow through fill tubes and the action of gauge sticks can also lead to localized wear in fiberglass- reinforced plastic tanks, ultimately resulting in leaks.

The Department recommends that preliminary tests or inspections be conducted at least twice per year using the techniques outlined below to test for the presence of large leaks in the bottoms of underground storage tanks. Due to other variables which are discussed later, these preliminary tests are only useful in detecting the presence of large leaks. The failure to find a leak using these techniques does not indicate that a tank is completely leak-free, but if they do reveal a leak, a more conclusive (and more expensive) test becomes unnecessary.

Checking Under Tank Openings. The Department recommends that tank owners and operators inspect the areas under the openings of their underground tanks, such as the areas under the fill and gauge openings. A relatively simple method of testing for large holes in steel tanks is to construct a probe by driving an aluminum or brass nail (soft metals will prevent sparking in an empty tank) into the end of a gauge stick, leaving about 3/4 inch protruding. This gauge stick can then be used to check for a failure in the tank bottom under the fill and gauge tubes by probing or "feeling" the tank bottom with the nail head. This test requires a technique that is quickly learned, and it can be successful in identifying large leaks. This test is unsuitable for FRP tanks, or interior lined tanks.

Checking the Remainder of the Tank Bottoms. The bottom of the full length of the storage tank can be checked for large leaks by adding water and measuring for a decrease in water level over time. This technique is described in detail in the National Fire Protection Association's Standard NFPA 329, **Underground Leakage of Flammable and Combustible Liquids** [1]. This inspection technique will work only if it is practical for the stored liquid to come in contact with water, and if the liquid level in the tank is sufficiently higher than the groundwater table to overcome the hydrostatic pressure of the groundwater. This test is most effectively employed when a tank can sit without product being added or withdrawn for at least 48 hours, preferably longer.

3. Checking for Water in Tanks

If continuous monitoring of the water level in the tank of a given storage system is not used, then the tank should be *checked regularly for the presence of water and the level of* that water. For example, the water content of the tank can be determined when gauging the tank, both during deliveries and inventory checks, by using a water-finder paste smeared on the bottom portion of the gauge stick. An unaccountable increase in the water level may indicate a tank leak, especially if the increase occurs after a heavy rain. However, before concluding that the presence of water is due to a faulty tank, the fill cap, its seal, and other connections should be checked to ensure that they are performing properly.

If a test of this type or a continuous water monitor indicates that a significant amount of water is present (e.g., above the pump or pump suction pipe), the tank should be tested for leaks using a more definitive (final) test.

4. Inspection of Cathodic Protection Systems

When a steel tank and/or associated piping is equipped with cathodic protection, inspection and maintenance of the cathodic protection system is essential to ensure long-term effectiveness. In the case of an impressed current system, the flow of current may fail because of anode deterioration, broken lead wires, rectifier malfunction or interruption of power. Impressed current rectifiers should be checked monthly and adjusted as needed [4]. The output *of rectifiers should be monitored with a voltage or current* indicator. At least once a year, tank-to-soil potential measurements must be taken to check the adequacy of protection and determine if any rectifier adjustments are needed [4].

The cathodic protection system should produce a structure-to-soil voltage of at least -0.85 volts as measured on the tank at the most distant point from the anode by a copper-copper sulfate reference half-cell (or equivalent half-cell reference). The -0.85 voltage should be monitored annually and mantained for the life of the tank. If the structure-to-soil potential is less negative than -0.85 volts, the cathodic protection must be restored to that level, or the tank should be tested for tightness annually.

Soil conditions can sometimes result in a reading which doesn't fall in the normal -0.85 to -1.50 volt range. This situation can be recognized when the facility is put in service. The structure is still cathodically protected if the anodes raise the structure-to-soil potential at lease 300 millivolts.

*Galvanic cathodic protection systems are also suscep*tible to system failure, due to such phenomena as the loss of tank or pipe coatings, broken wires, and short-circuited electric insulators. In these types of cathodic protection systems, measurements of tank-to-soil potential and anode output should be made annually.

C. FINAL OR PRECISION TESTS

The Department approves only tightness tests which are a "precision test" or "final test", as defined by the National Fire Protection Association in NFPA 329, **Underground Leakage of Flammable and Combustible Liquids** (1).

Any final test technique which is used to determine the tightness of an underground storage system must first be approved by the Department. The test must be able to determine conclusively whether or not an underground storage tank is leaking. This means that the test must be capable of accurately detecting a tank or piping leak as small as 0.05 gallons per hour (gph), adjusted for all variables, such as the following:

- The presence of vapor pockets.
- *Thermal expansion or contraction of the product.*
- Temperature stratification in the tank.
- Evaporation.
- Pressure variations in the tank.
- The deflection of tank ends.

All of these variables can affect the volume of liquid in the tank, and can therefore act to distort leak measurements as discussed below.

1. *The Effect of Temperature*

Liquids expand with an increase in temperature and contract with a decrease in temperature. For example, a temperature increase of only 0.02F in one hour in a 6000 gallon tank would cause a volumetric change of 0.072 gallons, which exceeds the 0.05 gph leak rate that indicates a leak. If such a temperature change was not accounted for during a tightness test, a leak could be masked by thermal expansion, or thermal contraction could lead to a leak indication where no leak exists.

Another temperature effect that must be recognized and accounted for is temperature stratification or layering. Temperature varies with depth in an underground tank, particularly in a case where cool product has been added to warm product that is already in the tank.

2. The Effect of Pressure

With most final or precision tightness tests, measuring very small volumetric changes in a storage tank requires the filling of that tank to a point above grade where volumetric measuring equipment can be used. This increase in height of liquid increases the pressure inside the tank over the normal operating pressure.

For example, in a 6 ft. diameter tank, the average pressure on the end or "head" of a tank full of typical gasoline is .98 pounds per square inch. If the tank is buried 3 ft. below grade (as is typical for most gasoline tanks), the average pressure on the head will increase to approximately 2.95 pounds per square inch (psi) when the fill pipe and standpipe are filled to 3 ft. above grade for a tightness test. The increase of approximately 1.95 psi in pressure exerts an additional force on the ends or "heads" of the tank of about 8,000 pounds.

This increase in pressure can result in deflection of the heads or ends of the tanks. Under normal, unrestrained conditions, such as might occur if the tank were aboveground and its ends were not supported, it is possible to calculate the exact increase in volume associated with a given pressure. However, when tanks are located underground, they are subject to variations in support from the surrounding soil, and it is not possible to predict how much movement will take place. Very solid soil may provide close to full support, but normally soils will consolidate to some degree, particularly if they are wet, thereby allowing tank expansion and end deflection.

Extensive tests have shown that significant volumetric increases will occur when increases in pressure of this type take place during a tightness test. Table 8-1 shows the apparent loss of product due to varying degrees of tank end deflection. It is important that any final or precision test that is used take this phenomena into account to avoid erroneous results.

3. Final Test Frequency and Recordkeeping

A "precision" or "final" test should be conducted according to the schedule presented in Table 8-2. The tank owner/operator should keep test results on the premises permanently, but records should be kept for at least three years.

A good business practice is precision testing tanks if ownership or control changes hands.

4. Types of Final Tests

There are several types of tank testing procedures currently in use that meet the Department's criteria for a final or precision test. Some of these techniques also apply to detecting leaks in pipelines. For more information, please refer to the Department document **Technology for the Storage of Hazardous Liquids, A State-of-the-Art Review** (2).

D. PIPELINE TESTS

Recommendations for pipeline testing before the pipline has been placed in service are given in Chapter 3 of this manual.

Pipelines should be tested whenever precision testing is done on tanks, since the equipment will already be on hand.

Leaks in pressure piping can largely be eliminated by the use of pipeline leak detectors, as long as they are operating property. These detectors should be tested for proper operation at least semi-annually.

Pipeline leak detectors have an internal hydraulic circuit which tests the delivery line for a drop in pressure each time the dispenser is used. If the line pressure has dropped, the detector will shut off product flow. This detector action is automatic and requires no decision on the part of the dispenser user. Pipeline leak detectors are discussed in greater detail in Chapter 2 of this manual.

Leaks in suction systems become evident in the course of normal operations. It needs emphasis that a facility employing a suction pumping system must not be equipped with more than one check valve in the system. Additional check valves can mask the loss of prime experienced when a suction line develops a leak.

TABLE 8-1 APPARENT LOSS OF PRODUCT VOLUME DUE TO FORCE ON TANK ENDS - IN GALLONS

Tank Diameter	Outward Deflection at Center of Head in Inches											
(inches)	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	5/8	3/4	7/8	1
48	.49	.98	1.47	1.95	2.44	2.93	.42					
64	.87	1.74	2.61	3.48	4.35	5.22	6.10	6.97				
72	1.10	2.20	3.31	4.41	5.51	6.62	7.72	8.82	11.0			
84	1.50	3.00	4.50	6.00	7.50	9.00	10.50	12.00	15.0	18.0	21.0	
96	1.96	3.91	5.87	7.82	9.77	11.75	13.70	15.65	19.6	23.5	27.4	31.3
102	2.21	4.42	6.65	8.25	11.06	13.30	15.50	17.70	22.6	26.6	31.0	35.4
120	3.06	6.12	9.18	12.25	15.30	18.40	21.40	24.50	30.6	36.7	42.8	49.0

Source: NFPA 329,
Underground Leakage of Flammable and Combustible Liquids, [1].

TABLE 8-2

TANK TESTING SCHEDULE

Category A:	Unprotected steel tanks — test 10 years after installation, and every five years thereafter.
Category B:	Corrosion resistant tanks installed prior to the enactment of the Bulk Storage Code — test 15 years after installation and every five thereafter, unless the system has a leak monitoring system installed. Leak testing can be waived for systems with monitoring.
Category C:	Tanks installed according to the Bulk Storage Code with one of the monitoring systems described in Chapter 7 of this manual — no testing is required.

Common Corrosion Resistant Tanks

- FRP tanks
- Cathodically protected steel tanks
- FRP-clad steel tanks
- Double-walled tanks

Common Monitoring Systems

- Monitoring Well, preferably one with product sensor — suitable for retrofit
- Double-walled tank system
- Monitoring of secondary containment using one of the following types of containment:
  — A vault.
  — An excavation liner.
  — A trough liner.
  — A U-tube system.

References

1. National Fire Protection Association, *Underground Leakage of Flammable and Combustible Liquids,* NFPA 329, National Fire Protection Association, Batterymarch Park, Quincy, MA 02269, 1977.

2. New York State Department of Environmental Conservation, *Technology for the Storage of Hazardous Liquids, A State-of-the-Art Review,* New York State Department of Environmental Conservation, 50 Wolf Road, Albany, NY 12233, 1983.

3. Fitzgerald, J.H., "Corrosion Control for Buried Service Station Tanks," Paper No. 52, The International Corrosion Forum Devoted Exclusively to the Protection and Performance of Materials, April 14-18, 1975, Toronto, Canada, National Association of Corrosion Engineers, Publications Department, 1440 South Creek, Houston, TX 77084.

4. National Fire Protection Association, *Flammable and Combustible Liquids Code,* NFPA 30, National Fire Protection Association, Batterymarch Park, Quincy, MA 02269, 1980.

CHAPTER 9:

OVERFILL PROTECTION AND TRANSFER SPILL PREVENTION

The recommended practice for prevention of overfilling and transfer spills is the use of automatic systems which shut off the delivery of product when there is an impending over fill, and the use of dry-disconnect couplings to prevent transfer spills.

A. OVERFILL PREVENTION SYSTEMS

Overfilling and product transfer spills are the most common sources of spillage in underground bulk storage facilities. It is common practice to fill storage tanks without an automatic means to prevent overfilling. Without such protection, it is just a matter of time before an overfill incident or product spill occurs. To avoid these types of accidents, it is necessary that tank owners install and use overfill prevention systems.

The best overfill prevention systems contain the following elements:

- A high level alarm, which warns the operator of an impending overfill condition
- An automatic shutoff device which prevents overfilling by shutting off delivery pump or valve
- Interlocking of the unloading process and the overfill prevention system so that tank loading cannot take place if the overfill system is inoperative
- Bypass prevention so that the overfill prevention system cannot be overridden.

The level gauge should be accurate to within one-half (±1/2) inch, and should be easily visible to the operator in the control room. Audible alarms or individual visual alarms such as indicator lights are also needed to pinpoint the impending overfill situation. These alarms should be mounted so that they can easily be heard and/or seen by the control operator during filling operations. Table 9-1 lists various types of control gauges.

The concept of having separate and distinct levels of indication, alarm, and shutoff provides a versatile system of response to the overfill threat. Although it might seem that such a sophisticated system is prohibitively expensive, it is certainly warranted in most situations.

Recognizing that the best overfill prevention system may be prohibitively expensive for many underground storage facilities, the following are the minimally recommendable systems for overfill prevention at underground storage tanks.

Minimal Requirements for Overfill Prevention Systems

On tanks which are filled by gravity flow from the product delivery vehicle, the vent line must be equipped with a float vent valve or similar device.

On tanks which receive product under pressure from the product delivery vehicle, the tank must be equipped with a combined audible/visual high level alarm mounted in a location that is both visible and audible to the delivery vehicle operator.

Float vent valves are simple devices, as shown in Figure 9-1. When installed properly (in the tank vent line), the float will block the vent line when a high liquid level is attained, thereby preventing the escape of air from the tank. This action causes the pressure inside the storage tank to equalize with the discharge head in the delivery vehicle, thereby interrupting the flow of liquid. The valves are generally unsuitable for viscous products such as #4 or #6 fuel oils.

This device also includes a pressure relief bleed hole. Once the overflow condition is recognized, the delivery truck fill valve is shut. Then, as vapor escapes through the float vent valve bleed hole, the liquid remaining in the fill line can drain into the storage tank. The fill hose is then disconnected with no loss of product.

Float vent valves must be installed in an extractable tee connection which is extended to grade. This permits easy removal of the float vent valve when the tank is to be tested for leaks. These valves are normally installed in conjunction with vapor recovery equipment. Retrofitting is rarely a problem.

Float vent valves are never suitable for tanks which receive product under pressure. If the valves were to close, the tank would be overpressurized and rupture would be likely.

B. TRANSFER SPILL PREVENTION SYSTEMS

All liquid transfer equipment (hoses, piping) should contain valves which close automatically and provide a dry disconnection when transfer hoses or pipes are disconnected. Such valves should be located on both the discharge and receiving ends of the transfer coupling.

TABLE 9-1

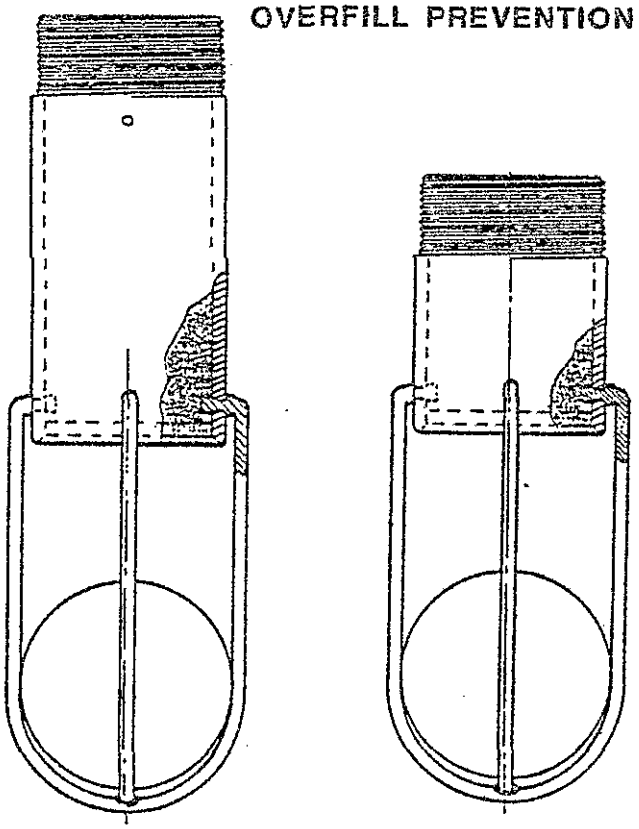
LEVEL DETECTION DEVICES FOR UNDERGROUND STORAGE TANKS

Type	Monitors Liquid Level	Type of Level Indication	Alarm and Shutoff Respose
Float Actuated Devices Tape float gauges	Yes	Gauge	Interfaces with electronic or pneumatic controls.
Float vent valves	No	None	Automatic Shut-off
Capacitance devices	Yes	Gauge	Audible alarm and automatic shut-off electronic controls.
Thermal conductivity devices	Yes	Gauge	Audible alarm andautomatic shutoff electronic controls.
Ultrasonic devices	Yes	Gauge	Audible alarm and automatic shutoff electronic controls.
Optical devices	Yes	Gauge	Audible alarm and automatic shutoff electronic controls.

FIGURE 9-1

FLOAT VENT VALVES

FLOAT VENT VALVES USED FOR OVERFILL PREVENTION



OPW 53-VSS OPW 53-FC

SOURCE: OPW DIVISION/DOVER CORP.

The use of tight couplings is essential to prevent spills when transferring hazardous liquids. Although many other types of couplings are available, the Department recognizes that dry-disconnect couplings are the best type of coupling available in terms of product spill control, and recommends them for use in all product transfer operations. Dry-disconnect couplings are equipped with a spring loaded valve which is normally closed until the coupling is attached and the valve is manually opened with a lever. The difference between the performance of dry-disconnect couplings and that of other types of quick-disconnect couplings is discussed in further detail in the Department manual entitled **Technology for the Storage of Hazardous Liquids, A State-of-the Art Review** [1]. Figure 9-2 shows this difference pictorially.

In the New York City Metropolitan Area (including Nassau, Suffolk, Rockland and Westchester Counties), vapor recovery systems have been mandated by 6 NYCRR 230 and are being installed. There are three types of systems in use, and two of the three are compatible with the use of dry- disconnect couplings. The **coaxial** vapor recovery system combines the product delivery return lines into one coupling. Dry-disconnect couplings are not available for this system at the present time. The other two systems use separate fill and vapor return lines which would not preclude the installation of dry-disconnect couplings.

A method of catching transfer spillage is illustrated in Figure 9-3, by Vestal-Helix Corp.(5) It has two components: one is an inexpensive plastic basin which fits snugly in the fill opening. At the bottom of this basin is an opening with a cartridge full of imbiber beads. Any water in the basin will drain through this cartridge. When product is spilled, it is absorbed by the imbiber beads and the cartridge swells shut, trapping the spill in the basin for removal. The cartridge is then removed and replaced for only a few dollars. This can prevent eventual contamination of vapor wells by long-term spillage of very small amounts of product.

Imbiber beads are a special type of sorbent material. They are small plastic spheres that will absorb ("imbibe") a wide range of organic liquids; in the process, they swell up to 27 times their own volume. The beads will not absorb water. Therefore, water may pass through a layer of these beads, but when a hydrocarbon causes them to swell, flow ceases.

To prevent product mixing, color coding of product types is recommended. Also, the use of different couplings for different product types can prevent product mixing. A system can be devised whereby a product delivery hose simply cannot be connected to the wrong tank.

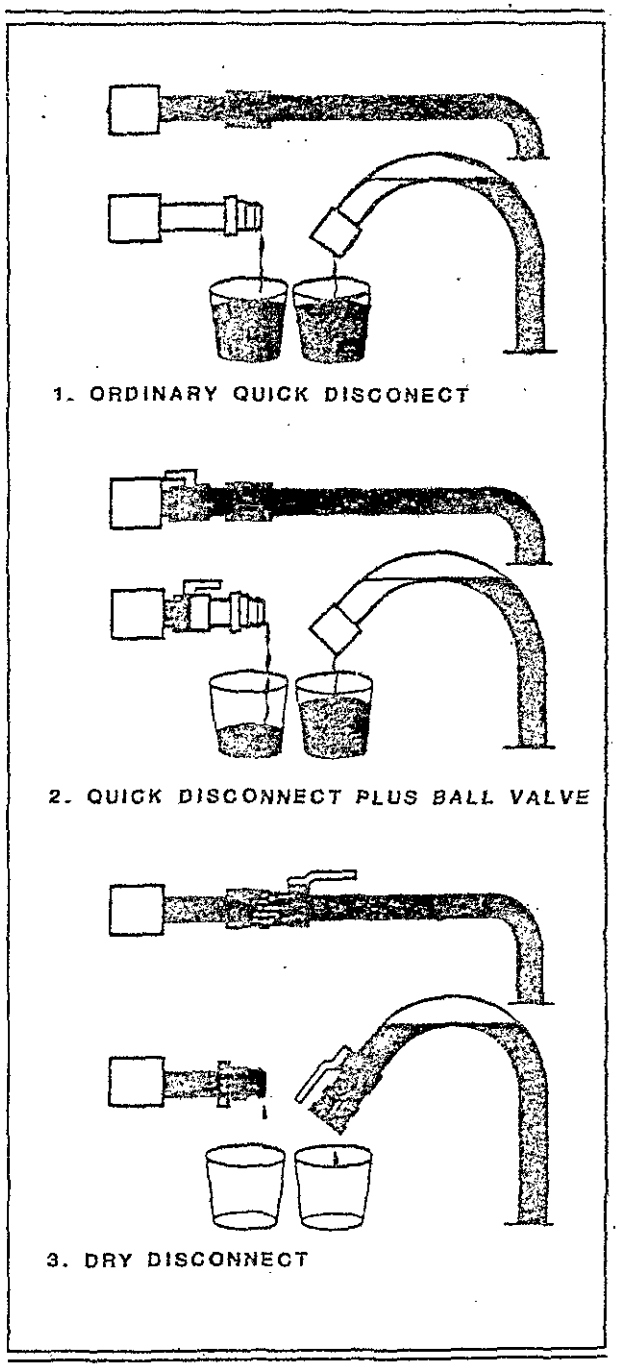
C. OPERATING PRACTICES

Certain operating practices are recommended to prevent overfilling of tanks and to limit the likelihood of transfer spills. These include the following:

- Loading and unloading of vehicles should be done only in approved locations.
- The driver, operator, or attendant of any delivery vehicle should not leave the vehicle unattended during the loading or unloading process. The delivery hose, when attached to the vehicle, should be considered to be a part of that vehicle.
- When transferring flammable liquids, motors of delivery vehicles and motors of auxiliary or portable pumps should be shut off during the making or breaking of hose connections. If loading or unloading does not require the use of the delivery vehicle's motor, the motor should be shut off throughout the liquid transfer operation.
- Labels, markings, or color codes should be used on all couplings and hoses to prevent accidental mixing of incompatible liquids.
- All transfer hoses should be inspected periodically for leaks.
- Any operator of a loading or unloading operation should be properly trained and should be aware of of all potential problems.
- All tanks should be gauged before product delivery to assure sufficient capacity.
- USDOT regulations governing transfer and unloading of hazardous materials are an excellent guide to safe operating practices.

FIGURE 9-2

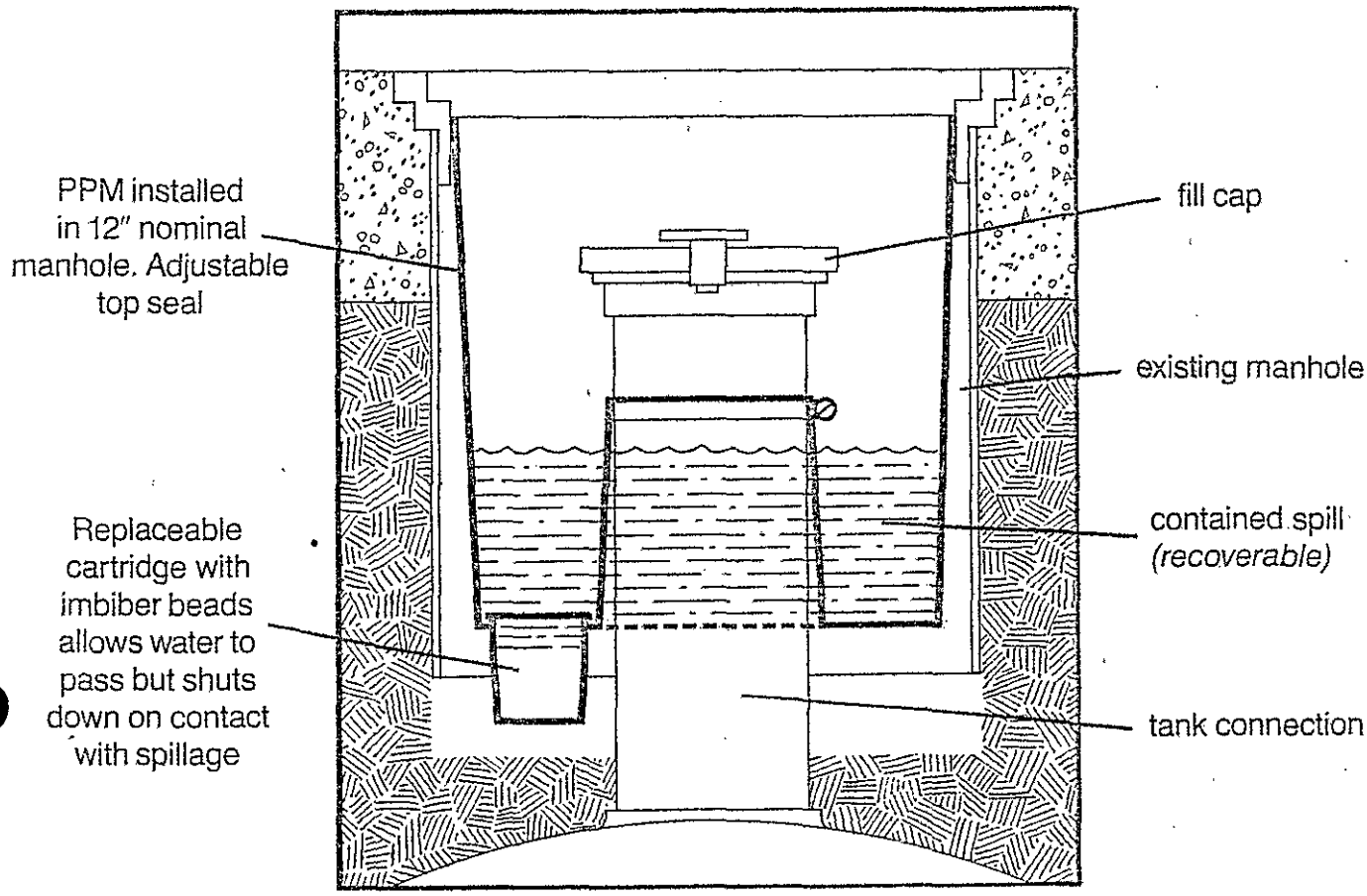
TYPES OF COUPLINGS



SOURCE: OPW DIVISION/DOVER CORP.

FIGURE 9—3

SPILL CATCHMENT BASIN



SOURCE: Vestal-Helix Corp [5]

References

1. New York State Department of Environmental Conservation, *Technology for the Storage of Hazardous Liquids,* A State-Of-The-Art Review, New York State Department of Environmental Conservation, 50 Wolf Road, Albany, New York, 12233, January, 1983.

2. National Fire Protection Association, *Tank Vehicles for Flammable and Combustible Liquids,* NFPA 385, National Fire Protection Association, Batterymarch Park, Quercy, MA 02269, 1979.

3. Dover Corp., **OPW Engineered Service Station Products,** Dover Corporation/OPW Division, 9393 Princeton-Glendale Road, P.O. Box 40240, Cincinnati, OH 45240.

4. Dover Corp., **OPW Kamvalok Dry-Disconnect Couplings,** Dover Corporation/OPW Division, 9393 Princeton-Glendale Road, P.O. Box 40240, Cincinnati, OH 45240.

5. Vestal Helix Co., 18 Blooms Corners Rd., Warwick, NY 10990.

67. Petroleum Association for Conservation of the Canadian Environment. Underground Tank Systems; Review of State of the Art and Guidelines, PACE Report No. 82-3, Ottawa, Ontario, Canada, February 1983

Underground Tank Systems

Review of State of the Art and Guidelines

PACE REPORT NO. 82-3

PACE
APCE

PETROLEUM ASSOCIATION FOR CONSERVATION OF THE CANADIAN ENVIRONMENT
ASSOCIATION PÉTROLIÈRE POUR LA CONSERVATION DE L'ENVIRONNEMENT CANADIEN

APR 14 1984
DIVISION OF
TECHNICAL SERVICES

Prepared by the

PRODUCTS STORAGE AND HANDLING COMMITTEE
OF
PETROLEUM ASSOCIATION
FOR
CONSERVATION OF THE CANADIAN ENVIRONMENT

1202-275 Slater Street,
Ottawa, Ontario
K1P 5H9

February 1983

No responsibility is accepted by PACE or any of its members concerned with the preparation, production or publication of this report for any statement therein or omission therefrom resulting in any loss, damage, or injury whatsoever to any person using the report.

PREFACE

These guidelines were prepared by a task force of the Products Storage and Handling Committee.

Members comprising the task force were:

J.R. Clendening (Chairman), Esso Petroleum Canada
D.M. Frost, BP Canada Inc.
J.A. Janovjak, Shell Canada Limited
D.W. Joyce, Gulf Canada Products Company

ABSTRACT

The information contained in this review can be used by those involved in the installation, design, operation and testing of underground tank systems, and the detection of leaking systems.

The problems related to underground tank leaks continue to be identified among the most significant petroleum industry marketing environmental concerns in North America.

Proper use of the information contained in this report can assist in ensuring the tightness of underground tank systems.

TABLE OF CONTENTS

		PAGE
PREFACE		ii
ABSTRACT		iii
LIST OF ABBREVIATIONS USED		v
ORDER SOURCES FOR REFERENCE PUBLICATIONS		vi
SECTION 1.	INSTALLATION PROCEDURES — STEEL AND FIBERGLASS TANKS	1
SECTION 2.	UNDERGROUND PIPING SYSTEMS	9
SECTION 3.	INVENTORY CONTROL AS A MEANS OF IDENTIFYING TANK LEAKS	13
SECTION 4.	UNDERGROUND TANK TESTING TECHNOLOGY	21
SECTION 5.	EXTERNAL CORROSION — CAUSES AND CONTROL	31
SECTION 6.	INTERNAL CORROSION — CAUSES AND CONTROL	39
SECTION 7.	EVALUATION OF UNDERGROUND ENVIRONMENT	45
SECTION 8.	PREDICTABILITY ANALYSIS OF TANK CONDITION	57
SECTION 9.	REMOVAL, DISPOSAL AND ABANDONMENT OF USED TANKS	65

LIST OF ABBREVIATIONS USED

API	—	American Petroleum Institute
ASTM	—	American Society for Testing Materials
FRP	—	Fiberglass Reinforced Plastic
NFPA	—	National Fire Protection Association
PACE	—	Petroleum Association for Conservation of the Canadian Environment
RTD	—	Resistance Temperature Detector
SAV	—	Soil Aggressiveness Value
T/S INDEX	—	Product of Tank Age in Years x Soil Aggressiveness Value
U/G	—	Underground
ULC	—	Underwriters' Laboratories of Canada

ORDER SOURCES FOR REFERENCE PUBLICATIONS

N.F.P.A. PUBLICATIONS —

Underwriters' Laboratories of Canada
7 Crouse Road
Scarborough, Ontario
M1R 3A9

PACE PUBLICATIONS —

Petroleum Association for Conservation of the Canadian Environment
1202 - 275 Slater Street
Ottawa, Ontario
K1P 5H9

A.P.I. PUBLICATIONS —

American Petroleum Institute
Publications and Distribution Section
2101 L Street Northwest
Washington, D.C. 20037
U.S.A.

ENVIRONMENT CANADA —

Environmental Protection Service
Environment Canada
Ottawa, Ontario
K1A 1C8

THE HINCHMAN REPORT —

The Hinchman Company
Francis Palms Building
Detroit, Michigan 48201
U.S.A.

SECTION I

SECTION 1:
INSTALLATION PROCEDURES FOR STEEL AND FIBREGLASS TANKS

General

The flammable nature of petroleum products is one of the significant reasons for underground tank installation. Careful consideration must be given to all aspects of the installation. Low quality work may result in poor performance of the tanks, leakage of the product, environmental hazards, safety hazards and high maintenance costs. It is therefore essential that only competent contractors install underground tanks, and do so in accordance with manufacturer's specifications, owner's specifications, locally-enforced building codes, fire regulations, gasoline handling restrictions, and municipal by-laws.

Successful tank installation is also dependent on:

— soil investigation;

— proper selection of materials for the specified location;

— reference to manufacturer's specifications for detailed instructions, definitions and dimensions.

— capable and adequate supervision and inspection during installation;

— thorough testing at appropriate stages of progress.

Procedures

Excavate a large enough hole to allow minimum acceptable distances between each tank and minimum acceptable distances between the extremities of the tanks and the walls.

- Where excavation occurs in unstable soil or adverse ground water conditions, the size of the excavation may be expanded or, an approved filter fabric material which permits water passage but limits the passage of soil particles may be used.

- Maintain ground water at lowest practical level during installation if high water table exists.

- Excavation should be deep enough to provide for the required depth of bury (depth of backfill from the top of the tanks to the finish grade level) and also to provide for minimum backfill below the bottom of the tanks.

- When adding tanks to existing installations, it is preferred that the tanks be installed in separate excavations leaving the native soil between the new and existing excavations undisturbed. Alternately, tanks may be installed in the original excavation providing minimum acceptable distances between tanks are maintained.

Place tanks in the excavation on a bed of specified backfill material and ensure minimum clearances are met.

- Tanks should be carefully lowered and placed (not dropped) on the bedding using lifting lugs and spreader bar where recommended.

- Prior to lowering steel tanks, any damaged portion of the protective coating should be repaired.

- Bare steel tanks without protective coating should not be used for underground installation unless they are protected using a cathodic protection system.

Anchor the tank system, if overburden weighs less than the buoyancy of the empty tank in a wet excavation condition.

- Anchors should be imbedded in a concrete slab and anchor straps should be installed in a manner that they do not interfere with the protective coating or structural stability of the tanks.

- Ballast with product in wet excavation condition. Seal all tank openings except vent which should be extended to allow escape of vapours to the atmosphere. It is a safe practice that product level should never exceed level of backfill (particularly with fibreglass tanks.).

Inspect protective steel tank coating for damage, and repair if necessary.

Measure internal diameter of fibreglass tanks during and after installation to note possible deflections. Deflection limits of fibreglass tanks are available from the tank manufacturer.

Test all underground systems in accordance with provincial legislation.

Backfill to top of tanks with approved backfill material in small uniform layers.

BACKFILLING

Fibreglass Tanks

- All backfill material must meet A.S.T.M. C-33 standards for quality and soundness.

- Preferred material is clean, naturally rounded aggregate with mixed particle size between 1/8 in. (3.0 mm) and 3/4 in. (19.0 mm), commonly referred to as "pea gravel".

- Alternate material may be washed stone or gravel crushing with angular particle size between 1/8 in. (3.0 mm) and 1/2 in. (13.0 mm).

- Backfill must be placed completely beneath tank bottom, between ribs and under endcaps. Proper backfilling must be followed to ensure necessary tank support.

Steel Tanks

- Backfill material below the tanks should be clean, non-corrosive sand, free of cinders and stones.
- Backfill material around the sides and top of the tank may be clean sand, fine gravel or pea gravel.
- Backfill material must be rodded into place under low radius of the tank and compacted by hand.

Connect and test piping and continue backfilling until ground level is reached.

Fill with product as soon as possible after backfilling.

- Maintain all safety procedures related to the handling of petroleum products.

Cover excavation as per ground cover specifications.

- Depth of bed and cover is dependent on ground water conditions, ground cover and traffic loads above the tanks.
- When concrete or asphalt pads are positioned on top of the installation, they must extend beyond edges of the tanks.

See attached Fig. 2, 3 & 4 showing schematic details of tank and piping installation.

Deviations from standard installation procedures should be approved in writing from the manufacturer, local authorities and/or the owner's engineering group.

NOTE: Legislation or company policy may prohibit installation of unprotected steel tanks (without corrosion protection). In that case installation of corrosion protection system (e.g., cathodic protection) must be incorporated in the installation procedures for the underground steel tanks (not required with FRP tanks).

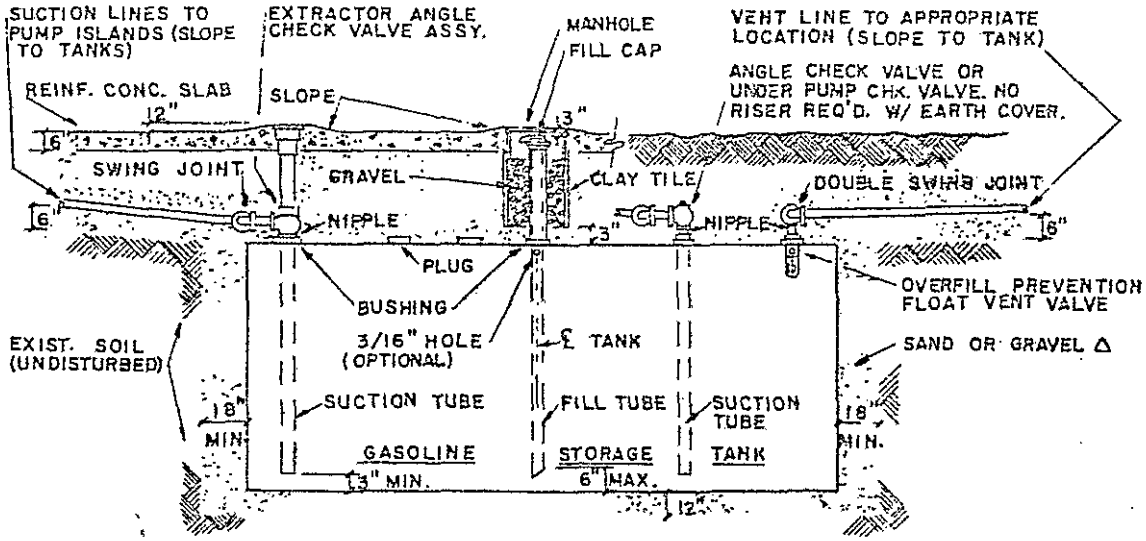
References: Installation of Underground Petroleum Storage Systems — "API Publication 1615" issued November 1979.

"A.S.T.M. C-33 Standard Specification for Concrete Aggregates".

Installation Recommendations by Tank Manufacturers.

FIGURE 2

TANK PIPING DETAILS - SUCTION SYSTEM



PIPING DETAILS FOR TANKS — UNDER CONCRETE

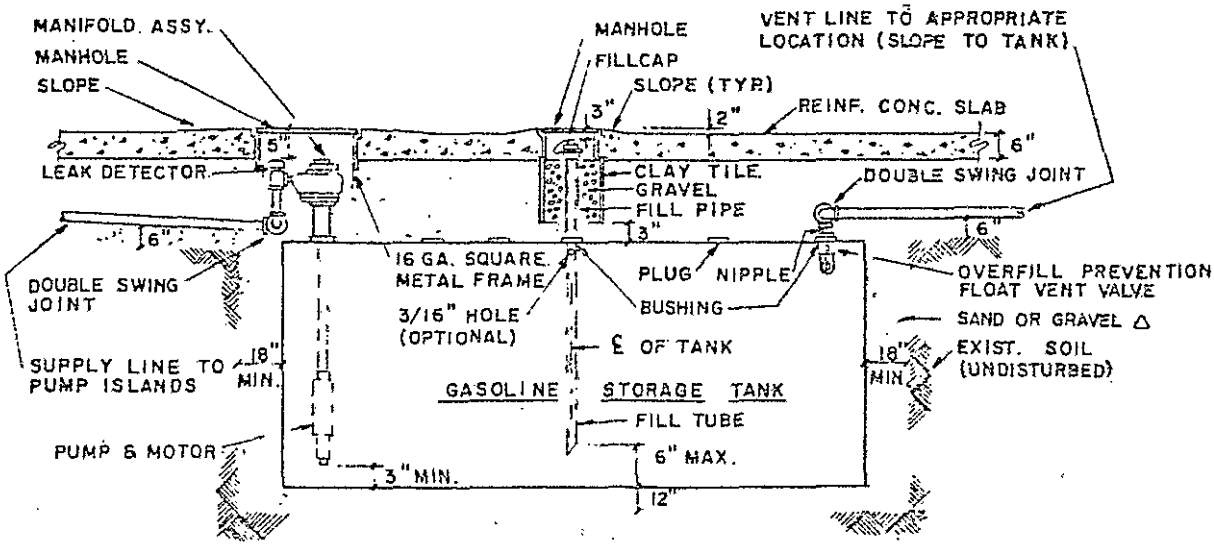
△ PEA GRAVEL FOR NON-METALLIC TANKS (OR MFR. APPROVED ALTERNATE)

NO SCALE.

NOTE: ELIMINATE CONC. SLAB IN NON-TRAFFIC AREAS & CONSTRUCT CONC. PADS (ONLY) AROUND MAN-HOLES. THE EXTR. ANGLE CHECK RISER IS NOT REQ'D. W/ EARTH COVER.

FIGURE 3

TANK PIPING DETAILS - SUBMERGED SYSTEM



PIPING DETAILS FOR TANKS — UNDER CONCRETE

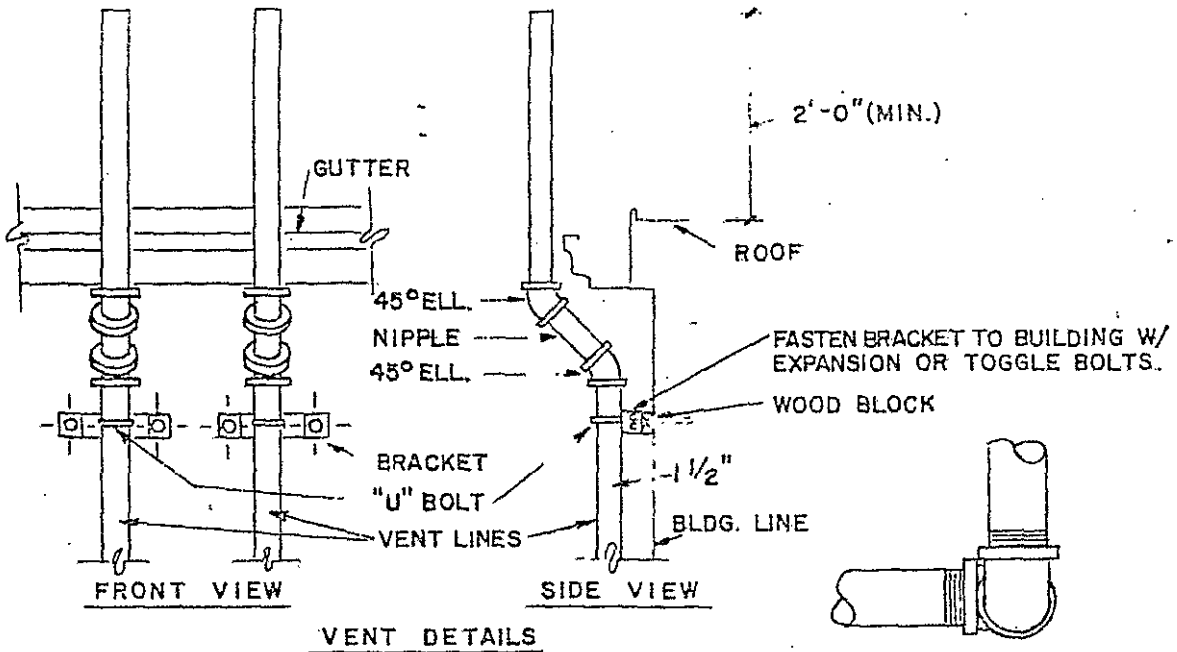
△ PEA GRAVEL FOR NON-METALLIC TANKS (OR MFR. APPROVED ALTERNATE)

NO SCALE

NOTE: ELIMINATE CONC. SLAB IN NON-TRAFFIC AREAS & CONSTRUCT CONC. PADS (ONLY) AROUND M.H.'S.

FIGURE 4

MISCELLANEOUS DETAILS



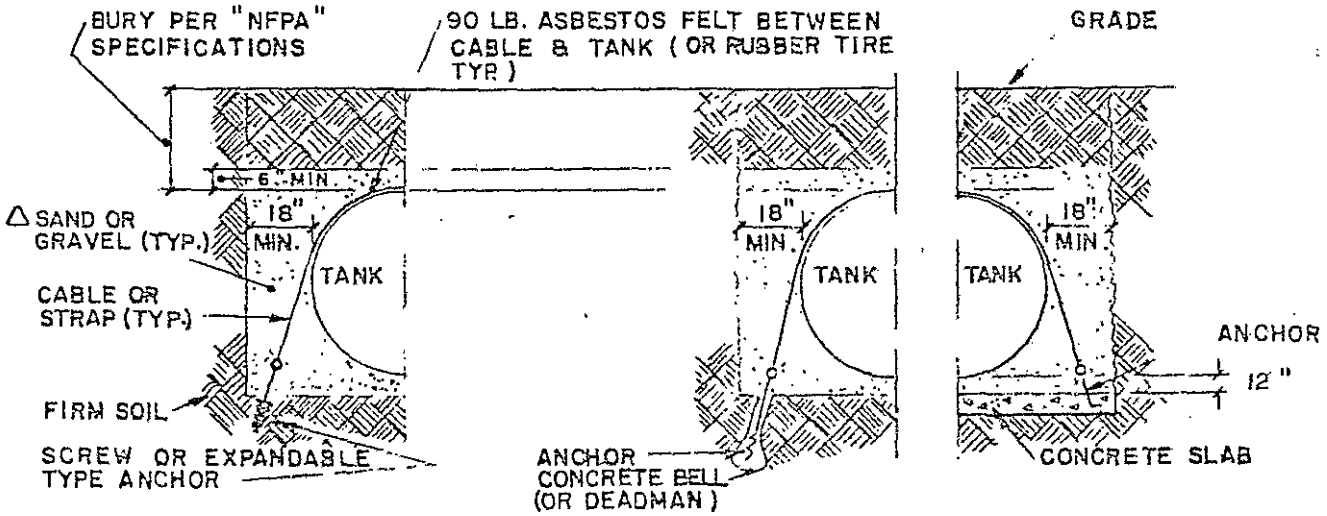
VENT DETAILS

NO SCALE

TYPICAL SWING JOINT

(ISLAND & VENT TERMINAL)

NO SCALE



NOTE: SEE MANUFACTURERS RECOMMENDATIONS FOR ANCHOR AND INSTALLATION INSTRUCTIONS.

TANK INSTALLATION

(WHERE SUB-SURFACE WATER CONDITIONS EXIST.)

NO SCALE

△ PEA GRAVEL FOR NON-METALLIC TANKS (OR MFR. APPROVED ALTERNATE)

SECTION 2

SECTION 2:
UNDERGROUND PIPING SYSTEMS

Piping systems are an essential part of the underground storage system for petroleum products and require installation and testing which meets specifications. For detailed recommendations on these systems, refer to API Publication 1615, "Installation of Underground Petroleum Storage Systems", November 1979.

The basic requirements for underground piping consist of:

- Schedule 40 steel pipe, either galvanized or wrapped black iron, cathodically protected or ULC approved non-metallic pipe, is recommended for all underground piping. Schedule 40 galvanized steel pipe is recommended for above-ground vent piping.

- Delivery piping from tanks to dispensers should be sized according to the recommendation of the pump manufacturer. In determining the piping size, consideration must be given to the length of runs, flow rates, and number of dispensers to be handled.

- Siphons may be used to equalize product levels in two or more tanks storing the same product. Material for siphons may be galvanized iron, wrapped black iron cathodically protected or nonmetallic. It is recommended that siphon piping be the same size as the suction and/or delivery lines to the dispensers.

- Each tank should be vented through adequately sized piping.

Some significant *installation* procedures:

- Product lines should be run in a single trench between the tank area and the pump island area. Similarly, vent lines, between the tank area and the building or other structure to which the above-ground vent lines are attached, should be placed in a single trench.

- Before any underground lines are laid, the trench or ditch for such piping should receive a minimum 6" (150 mm) deep bed of well-compacted noncorrosive material, such as clean, washed sand or gravel. All trenches should be wide enough to permit at least 6" (150 mm) of such protection around all underground lines. This applies to both metallic and nonmetallic underground piping. Bedding and the covering backfill should be of the same material. This will be helpful for grading the lines, and in providing corrosion protection for the steel pipe and for any adapter fittings used with non-metallic piping.

- Piping should be arranged so that lines do not cross over underground tanks.

- Underground product lines should have a uniform down slope of not less than 1/8" (1%) per foot toward the tank. Product lines should be at least 12" (300 mm) below the finished surface.

- Possible breakage of underground piping and vent lines, or the loosening of pipe fittings, which result in product leaks, will be minimized through the use of swing joints. (Some regulations require flexible connectors with fiberglass piping)

NOTE: When nonmetallic piping (that has been approved for underground use) is selected, it is extremely important that it be installed strictly in accordance with the manufacturer's specifications.

After the installation has been completed it must be tested either by an air test or a hydraulic test to at least 1 1/2 times its working pressure but not less than 50 psi (356 KPA) (or more than 100 psi (712 KPA) with an air test). With air testing it is necessary to soap all joints to find leaks and with either system the test must hold for usually one to two hours depending upon local regulations. For this test, the piping must be positively isolated from the tank.

Reference: API Publication 1615 "Installation of Underground Petroleum Systems."

SECTION 3

SECTION 3:
INVENTORY CONTROL AS A MEANS OF IDENTIFYING TANK LEAKS

Proper inventory controls, accurately maintained, form a first line of defence in the early detection of product leakage in underground tanks.

The operator and the owner of the underground tank system may be subject to financial penalties imposed by governmental agencies if product leakage causes contamination. They may also be liable for personal injuries and property damage caused by product leakage.

The use of these recommended procedures can assist in the reduction of bulk stock losses and result in a higher level of safety and pollution control while maximizing profits.

The use of these procedures can:

1. Reduce environmental contamination from leaking underground tanks and piping.
2. Reduce the safety hazards of gasoline vapours originating from leaking underground tanks and piping.
3. Reduce product loss.

Personnel involved with the handling of bulk petroleum products in underground tank systems should be familiar with inventory and stock control and follow these recommended procedures.

Inventory is defined as the volume of petroleum product in the underground tanks at any selected time.

Stock Control is defined as the method for accounting for change in the inventory, whether the change is caused by sale, loss or receipt of product.

Stock Control, based on the maintenance of accurate records, can be an effective tool in limiting product losses.

STOCK LOSSES

Detection of Stock Losses

Product losses can occur in several ways, e.g. leaking tanks and lines, spills, meter error or theft. These losses may be detected by:

1. Following the recommended procedures for daily product measurement and reconciliation.
2. Regular inspection of fill pipe area to detect evidence of spills.
3. Inspection of land around the property to detect evidence of gasoline surfacing from a leaking facility.

4. Detection of vapours in the vicinity of the facility.

5. Loss of pump suction or indication of air passing through the pump. These can result from a leaking line or defective foot valve.

6. Activation of "leak detectors" on remote pumping installations.

7. Accumulation of water in the tanks.

The owner of an underground tank system should take the necessary steps for corrective action when there are indications of product losses related to a leaking underground tank system.

Indicated Losses Resulting from Errors in Product Level, Measurement or Record Keeping (No Actual Loss of Product)

These types of "apparent" losses, while not causing environmental or safety problems, can result in losses of revenue.

These "apparent" losses can be caused by:

1. *Faulty meter calibration:* If the dispenser meter is not properly calibrated, the actual volume dispensed will not correspond to the meter reading. Reconciliation of meter readings and tank dips would not be possible. Good records may assist in identifying this problem.

2. *Product used from the underground tank when meters are calibrated:* Any product removed from the tank system should be accounted for in the resetting of the meters.

3. *Error in measurement of volume of product in tank:* Tank dips of underground tanks must be made properly and the product level read accurately. Care and accuracy is required when using the tank chart to convert the dip stick reading to a volume measurement and when recording meter readings.

4. *Errors in arithmetic:* Care must be taken when reconciling tank dips with meter losses to ensure that losses are not produced by errors in arithmetic.

Stock variations, which deviate from normal allowances, may be detected by effective stock control. This can avoid "run outs" and identify underground tank leaks. The effective use of accurate records and good operating procedures can minimize losses.

NOTE: Daily product reconciliations can fluctuate and indicate shortages and/or overages due to inaccuracies in tank sizes, tank slopes, dip readings, errors, etc. Periodic reconciliations over a longer period such as a month and selected when the opening inventory and the closing inventory are at approximately the same level in the tanks, will result in a more reliable reconciliation.

STOCK MEASUREMENT

Receipt for Product Delivered by Tank Truck

The attendant should ensure that the product delivery form has been completed properly. Verify that the quantity of product delivered, together with the opening and closing dips are recorded on the delivery form by the driver. Maintain the delivery form on file for future auditing requirements. The amount of product delivered must be taken into account when comparing the tank dip measurement with the volume recorded on the delivery form.

Measurement of Product in Underground Tanks

(a) *Use of gauge (dip) sticks to measure the volume of product in the tank:*

1. Coat the bottom, 3 inches (8 cm) of the dip stick with a light, even film of water detection paste. The coating should be on the side of the dip stick opposite to the depth markings. (The paste is unaffected by gasoline but changes colour when in contact with water.)

2. Remove the underground tank fill cap and insert the dip stick through the fill pipe of the tank until the tip of the stick touches the tank bottom.

   For each successive tank gauging, the dip stick must be held in a vertical position at the same point of the down pipe.

3. Keep the dip stick inside the tank for the time period specified for use of water detection paste.

4. Withdraw the dip stick and read the product and water "cuts" to the nearest 1/4" (0.5 cm).

5. Use a cloth to wipe off the petroleum product and detection paste and repeat the procedure to ensure accurate measurement.

6. Replace the tank fill cap and secure.

(b) *Use of tank charts:* Tank charts are supplied by the tank manufacturer and provide a listing of gallons (litres) beside the equivalent inches (centimetres) of measurement as registered on the gauge (dip) stick.

After using the dip stick to determine the depth of liquid in the tank, select the proper column on the tank chart and proceed as follows:

1. For dip stick measurements which are to the exact inch or centimetre, record the product volume from the chart.

2. For dip stick measurements which are 1/2" or 1.25 cm over or under the exact inch or centimetre, proceed as follows:

   (i) Note the two measurements on the chart for the exact inch (cm) readings which are above and below the actual reading on the dip stick.

e.g. If the dip stick reading for liquid in a 5000 gal. tank (22730 litres) is 48.5 inches (121.25 cm), note the chart volume at 49 inches (122.5 cm) and 48 inches (120 cm).

(ii) Subtract the volume shown on the scale for these two readings:-

Chart reading at 49 inches (122.5 cm) = 3039 gal. (13816 litres)
Chart reading at 48 inches (120 cm) = 2963 gal. (13470 litres)
Difference = 76 gal. (346 litres)

(iii) Multiply this volume by .5 (1/2 inch or 1.25 cm)

76 gal. (346 litres) × .5 = 38 gal. (173 litres)

(iv) Add the volume shown on the chart opposite the exact inch (cm) measurement to the 1/2 inch (1.25 cm) volume calculated in (iii):-

Volume at 48 inches (120 cm) = 2963 gal. (13470 litres)
Volume at 1/2 inch (1.25 cm) = 38 gal. (173 litres)
Total = 3001 gal. (13643 litres)

In this example, the liquid volume measurement for the dip stick measurement at 48.5 inches (121.25 cm) indicates 3001 gal. (13643 litres) of liquid in the tank.

3. If the above volume includes some water (as identified by the water detection paste), the actual volume of petroleum product is determined by subtracting the indicated amount of water from the total volume of liquid.

Reference the above measurements of 3001 gals. (13643 litres) of liquid in the tank, if the indicated water gallons are 50 gal. (227 litres), the actual volume of petroleum product is:

3001 gal. (13643 litres)
less 50 gal. (227 litres)
Total = 2951 gal. (13416 litres)

Note: It is important not to subtract the water dip from the total dip until the volumes are determined from the tank chart.

(c) Use of Automated Tank Gauging Systems:

A number of microprocessor based systems designed to improve inventory management are available on the market. These tank level sensing systems are designed to continuously monitor inventory levels and track fuel dispensing and deliveries.

These systems will monitor fuel levels in underground tanks continuously and will:

1. Automatically verify fuel deliveries with printouts of volume and temperature.
2. Measure and display height of fuel and water.
3. Calculate volumes and temperature compensated volumes.

Refer to local gasoline handling codes for the acceptability of this type of inventory monitoring in lieu of a manual dip requirement.

RECONCILIATION OF TANK MEASUREMENTS AND BOOK INVENTORY

The purpose of this reconciliation procedure is to verify the pump meter readings and/or to identify unaccounted for differences between the volume of liquid in the tank measurement and meter readings.

The reconciliation procedure includes reporting on the following readings:

1. Previous meter readings
2. Present meter readings
3. Product receipts
4. Previous tank measurements
5. Present tank measurements
6. Water content
7. Reference to the last pump meter verification

The Stock Control Record form (copy attached) provides a means to:

—establish a consistent format for completing the reconciliation procedure.

—maintain a daily record (ledger) of the meter readings, tank dips, and cumulative overages and shortages.

To assist in identifying leaking tanks, most provincial government regulations require completion and retention of these reconciliation records. The usual retention period is two years.

Recommendation

The owner and/or operator of an underground tank system should take the necessary steps for corrective actions when there are indications of a leak in his underground tank system. These are defined in NFPA 329 with particular references to Chapters 3 and 4.

Reference: PACE — Inventory Control as a Means of Identification of Underground Tank leaks

DAILY STOCK CONTROL RECORD

LOCATION _____ DATE _____

PUMPS			SUPER UNLEADED			REGULAR UNLEADED			REGULAR LEADED			DIESEL		
1		METER READINGS: PUMP NO. 1												
2		PUMP NO. 2												
3		PUMP NO. 3												
4		PUMP NO. 4												
5	1+2+3+4	TOTAL CLOSING METER RDGS.												
6	PREV. 5	TOTAL OPENING METERS												
7	5 less 6	METER SALES (Gals.)/(Litres)												
BOOK INVENTORY														
8	PREV. 17	OPENING INVENTORY												
9		DELIVERIES TODAY												
10	8+9	TOTAL INVENTORY												
11	7	LESS METER SALES												
12	10 less 11	INVENTORY SHOULD BE												
DIP INVENTORY			Inch cm	Water	Gals./Litres	Inch cm	Water	Gals./Litres	Inch cm	Water	Gals./Litres	Inch cm	Water	Gals./Litres
13		DIP READINGS: TANK NO. 1												
14		TANK NO. 2												
15		TANK NO. 3												
16		TANK NO. 4												
17	13+14+15+16	ACTUAL INVENTORY												
OVERAGE/SHORTAGE			Short		Over	Short		Over	Short		Over	Short		Over
18	12 less 17	DIFFERENCE—TODAY												
19	PREV. 20	DIFFERENCE—BROUGHT FORWARD												
20	18+19	DIFFERENCE—MONTH TO DATE												

NOTE: Water level should never exceed 1".
Unusual Daily shortages must be investigated (re-check dips and calculations).
Cumulative losses or gains for any product in excess of 200 gallons or 1000 litres should be investigated.
Regulations require that daily inventory records be maintained.

SECTION 4

SECTION 4:
UNDERGROUND TANK TESTING TECHNOLOGY

General

Because the oil industry stores most of its flammable and combustible material in underground storage tanks at the final sale point, the need to detect any leakage from those tank systems is a vital part of their operation. Leaks can cause safety hazards if the leaked fuel enters basements, sewers, utility conduits or other below ground facilities and can also cause much environmental damage to aquifers and potable water supplies. There is also the economic incentive to retain all product as the cost of it increases.

Before initiating any expensive tank or line testing at a site, all other possible causes of the loss should be investigated. Possible loss causes include: lack of accuracy in the inventory control system, product temperature variations, spills, inaccurate meters on pumps/dispensers and possible theft of product. Tank and line testing should not be carried out until all of these potential sources of loss are investigated and eliminated as the problem source. An excellent information reference for investigating underground tank leaks is NFPA publication 329 titled "Underground Leakage of Flammable and Combustible Liquids" and Chapter IV is of particular interest to those involved in underground tank testing.

The objective of underground tank testing systems is to be able to detect leaks in or out of storage as small as 0.05 U.S. gallons per hour. Leak detection to this level is difficult to accomplish because of the many variables including product temperature changes and consequent product expansion or shrinkage, trapped air pockets, and measurement system errors. The difficulty of identifying tank leaks to a level of .05 gals/hour was confirmed by speakers at the PACE Underground Tank Testing Symposium held in May 82, especially for short term tests. Longer term tests with accurate instrumentation tend to overcome some of the above variables and may achieve the 0.05 gal/hr. accuracy.

Before listing the current state of tank testing technology it should be noted that testing tanks by air pressure should *not* be carried out except for new, empty tanks that are exposed and can have all joints soaped for positive detection. Existing underground tanks should *never* be tested with air pressure. An excerpt from NFPA 329 states "*Pressure tests with air may be used to test pipe but shall not be used on tanks containing flammable or combustible liquids. With air testing there is severe danger of causing a tank rupture, or expulsion of contained liquid through normal openings; and, because of the volumes of air involved, results are very inconclusive.*

Air tests of tanks containing flammable and combustible liquids should not be required by regulations or ordinances and should be discouraged in practice".

Leak testing systems commercially available and in use at present are:

- Petro-Tite Tank Tester (Formerly Kent-Moore)
- * Sun Leak Lokator
- Ethyl Tank Sentry
- * Athabasca Research System (Tanknology)

- Smith & Denison System
- Hydrostatic System

* Indicates system available only as a contract package at this time

Leak testing systems under various stages of development include:

- Shell Canada System
- Underground Tank Leak Detector (PACE)
- Laser Beam Leak Detector (A.P.I.)
- Mooney Tank Leak Detector

This review will not attempt to quantify the advantages or disadvantages of any individual system. The main criteria will be listed by which any system should be judged since they are all attempting to arrive at an answer to the question, "is the system leaking". With these criteria, any system can be examined to determine if it meets the particular needs or operation.

Some of the criteria or questions to consider are as follows:

- How complicated is the test procedure? Does it require specially trained people? Are training programs available?
- Is the test set up complicated or simple? Does it require extensive preparation by different groups before the test can start?
- How long will the test require to verify the leak? Must the entire station be closed down during the test?
- What kind of accuracy can you expect from a particular tester device? Does the tester representative have available historical records or test data from other companies? Secure references and discuss with other users.
- Do extreme winter temperatures have any adverse affect on the testing system?
- Can the system compensate for external water table pressure?
- Are replacement parts or materials used in the test system readily available from suppliers with replacement equipment available in central locations?
- Are there any size limitations to the tank to be tested? (i.e. it may be difficult to stabilize the temperature in some very large underground tanks)
- Is the test equipment rugged and suitable for transport to sites around the country.
- If a contract service only is available the average response time, time to test, report, and leak reporting records and procedures should be determined.

- Cost of the system and its operation or cost of the contract work should be high on the priority list in considering the merits of each system. However, this should be related to the potential cost of a system which leaks in a critical area.

COMMERCIALLY AVAILABLE UNDERGROUND TANK TESTING SYSTEMS

Petro-Tite Tank Tester (Kent-Moore System): This system works on the principle of applying a hydraulic pressure head to the tank by means of an externally connected standpipe. Product is continually circulated to mix the tank contents and stabilize the temperature while very precise temperature measurements are taken with a thermistor probe in the tank. The height of the standpipe can be increased to compensate for any external pressure due to a water table. Product level in the standpipe is continually monitored for rise or fall and measured amounts of product are added or removed. During the test period precise calculations are made to relate product volume change versus temperature to detect leakage.

This system has been a recognized standard for accurate tank testing within the industry for many years. However, it requires trained people who are very precise in all phases of the test. This same operator accuacy requirement applies to all leak detection systems since we are attempting to detect extremely small changes in product volume.

Sun Leak Lokator LD 2000: This system, developed by the Sun Oil Company, works on the Archimedes principle of buoyancy. It measures tank leakage by sensing weight changes in a sensor which is suspended in the liquid of the tank. (The sensor is usually a closed bottom tube that is filled with liquid to a few inches higher than the liquid in the tank and its' top is open to atmosphere and the whole is suspended from an extremely sensitive scale). Any minute changes in weight are transmitted to a recorder that registers these changes as leaks in or out depending upon line direction on the recorder. Calibration is usually checked by adding a known small amount of product at the start of the test and observing the change on the recorder.

The tank must be isolated for a few hours before the test to allow normal temperature layering to occur, then a sensitive RTD is placed at the tank mid point. The probe's output is monitored by a strip chart recorder and a digital meter to the nearest 0.001°F.

This Sunmark Industries equipment is not for sale but the equipment, with Sun trained operators is offered as a contract service, with equipment mounted in vans. At the present time it is available only in some sections of U.S. It is expected that it will be licensed to Canadian contractors.

Ethyl Tank Sentry: The system was developed by Texaco (U.S.A.) and is marketed by the Ethyl Corporation. It is probably the simplest system available and for that reason it may be most practical for some users. However, it should be judged on the basis of how well it meets the needs when considered against suggested criteria. Also since the system uses an indicator fluid specifically suitable for gasoline, the system should not be used for tests on tanks containing distillate product such as diesel oil.

The Ethyl Tank Sentry System works on the manometer principle with a reservoir on one leg of the manometer. The system utilizes a light gravity indicator fluid, in the manometer, that is not miscible with gasoline. The equipment is valved so that the reservoir can be allowed to fill to the product level, then a control valve can be closed to isolate the tester from the tank except through the manometer. Any drop in tank level is sensed through the open leg of the manometer and this balanced against the pressure head of the trapped reservoir side which

measures the loss or gain by moving the indicator fluid. An increase in the level of the open side indicates a "leak out" while a rise in indicator fluid in the reservoir leg indicates a "leak into" the tank. The drop or increase in tank level can be determined by measuring the level difference in the indicator fluid in the manometer legs. Because of differences in specific gravity of the gasoline and the indicator fluid, there is a magnification of about 5 times in the manometer which helps detect very small surface level changes.

Temperature is measured by a sensitive RTD resting on the tank bottom at the start of the test and must be stable within $\pm 0.2°F$ for two consecutive readings at 1 minute intervals. A second set of readings are taken at the conclusion of the test and must not vary more than 1°F from the start temperature reading for the test to be valid.

Athabasca Research System (Tanknology)

A hydrophone (microphone adapted for liquid immersion) is suspended within the tank and connected to a microprocessor. The internal pressure of the tank is then incrementally reduced. If there is a leak in the tank, the reduced internal pressure will cause the ingress of air and the formation of bubbles. The bubble sounds are detected by the hydrophone, and have characteristics which permit the identification of the size of the leak and its approximate position in the tank. Anomalous situations, such as ingress of water because of high water tables, are identified by auxilliary sensors which detect and measure the ingress of water.

The testing equipment is not for sale and the testing service is provided on a contract basis through a number of vehicles equipped and manned by Tanknology Canada, Edmonton, Alberta.

Smith & Denison System

This system works on the principle of sealing all tankage openings, then pressurizing the empty tank and piping to a maximum of 0.5 psi using helium gas. The test team then searches for helium above the tank and piping using a detector connected to a mass spectrometer. After a grid of small holes on four foot centers is bored in the concrete above the tank and along piping, air samples are taken from the holes using a probe connected to the leak detector by a flexible tube. Thus, the point of highest helium concentration pinpoints the area where excavation should be carried out.

Piping tests should be made first. To do this, helium is injected into the partially filled tanks and the search for escaping helium is started. This test is usually completed in less than four hours. The points of maximum helium concentration are indicated on the paved surface with chalk or spray paint to show where excavation is recommended.

After piping leaks have been repaired the tank is pumped dry and again pressured with helium. Indication of tank leaks will be evident in a short time in porous soil, however, in wet clay backfill it may take several hours to find emerging helium. An overnight test is recommended when the tank is a suspected leaker and helium is not detected during the first day.

Hydrostatic Test

There are numerous versions of this test used by various companies but they all basically consist of filling the tank with product and applying hydrostatic pressure to the tank with a

hand pump or standpipe. Any liquid leak causes a quick drop in pressure and measured additional product is added to repressure the structure. This is related to some type of temperature measurement to determine whether there is actual leakage or whether it is merely product shrinkage as the temperature drops.

This test has the capability of detecting relatively large leaks but is normally not precise enough to detect the small leak rate specified by NFPA 329. (.05 U.S. gals/hour)

LEAK TESTING SYSTEMS UNDER VARIOUS STAGES OF DEVELOPMENT

These systems are either under development, or the particular methodology has been investigated and the principle of the system is described.

Shell Canada System

This is a new concept that has been devised by Shell Canada personnel and is currently under field evaluation. The system may be the simplest and most economical yet devised if it proves to have the accuracy requirements.

Magnification of a liquid level change due to product leaking from an underground tank is achieved by isolating the tank from atmosphere except for a 1 inch pipe that is inserted into the tank's fill pipe. This pipe extends from above the top of the fill to a point approximately 6 inches off the bottom of the tank. The tank has been previously filled so that the void in the tank is as small as possible.

The pressure in the void at the start of the test is equal to atmospheric pressure. However, since the void is now isolated from atmosphere, and should the size of the void increase due to a loss of product from the tank due to a leak, the pressure in the void will be reduced in accordance with the standard pressure, volume, temperature relationship.

The smaller the original void the greater impact the leak has on the internal pressure in the void. The difference between atmospheric pressure and the final pressure in the void displays itself in a difference in liquid level in the pipe inserted into the fill which is open to atmosphere and the liquid level in the tank. This liquid change in the insert has a magnification many times that of a drop in product level in the tank due to the liquid lost through a leak. The amount of magnification is a function of the size of the void and the rate of the leak.

The feasibility and possible commercial use of this system is being studied by a special PACE Task Force.

Underground Tank Leak Detector (System investigated by B.C. Research, Vancouver, for PACE)

This is a sophisticated system of sensors and microprocessor readouts. A detailed description of the system is reported on in PACE Report 81-3 "Report on Investigations and Research to Develop a Service Station Underground Tank Leak Detector".

The principle of operation requires the tank to be completely filled and a tube of known cross-section be mounted on the tank filling pipe. The tube which is interrogated by several sensors, is connected through a pressure reducing valve to a pressurized nitrogen gas line and the level change in the column observed at a minimum of three different pressures.

The basic measuring concept assumes that the relation between the system changes, per unit of time, at different pressures, depends entirely upon the size of the leak, provided the time test is kept short (few minutes).

Further development of this system has been terminated because of problems identified in PACE Report No. 81-3. This report indicates that in using this volume change measurement system it is not always possible to rapidly identify (30 minutes time duration) small tank leaks (.05 gals/hour). Differences in tank end deflection, differences in soil compaction at tank ends and traffic vibrations contribute to the inability to detect leaks with this system.

Laser Beam Leak Detector — SRI International investigation for API

The major components of this system for measuring product surface level, consist of the laser measurement system, two 10-foot long brass tubes, an aluminum float with an internal cube-corner reflector, a temperature measurement system, and a data acquisition microprocessor system.

The laser measurement system consists of a laser head and display, a beam splitter, and two interferometers. The laser head generates a beam that passes into the beam splitter and is divided into two beams. One of the beams passes directly through one of the interferometers. The second beam passes into the second interferometer where it is turned 90°. The beams are then directed down into the tubes, reflected off the cube-corner reflectors located in the floats, and are directed back through the interferometers.

The laser output of the surface-level measurement from each interferometer is shown on two numeric displays. This particular laser measuring device does not measure the absolute distance from the interferometer to the cube-corner reflector but measures the change over time of the corner-cube reflector from its initial position to its position at any later time.

A data acquisition microprocessor takes the measurement data, performes a data analysis reduction, and prints an output of test time, product level changes and air and gasoline temperature.

The lab and field work has indicated the desired system accuracy can be obtained. Commercial development of this system presently is not being pursued.

Mooney Tank Leak Detector

This system works on the principle that a buoyant member floating on the product will experience a change in elevation as product level changes in the tank and this change is measured by an indicator connected to the buoyant member. Precise temperature measurements are taken during the test at several levels within the tank to be sure that the change is caused by non-tight tankage rather than temperature shrinkage.

The underground tank is filled with gasoline until the level of the fuel rises into the tank fill line. A buoyant member is then floated on the surface of the liquid in the fill pipe and a measured amount of liquid is added and the elevation change is noted. This product addition and removal is done several times to calibrate the system and give meaning to readings during the test period.

The levels and temperatures are then measured over the test period and the temperature levels averaged to calculate the product level change due to this change. If the two do not agree, the system would claim that the tank was leaking.

References:

- NFPA 329
  Underground Leakage of Flammable and Combustible Liquids — 1977

- PACE
  Proceedings of Underground Tank Testing Symposium, May 1982 — Toronto

SECTION 5

SECTION 5:
EXTERNAL CORROSION — CAUSES AND CONTROLS

CAUSES

General

It is a well-known fact that steel will corrode in an adverse environment and that iron will try to revert to its more stable condition of iron oxides. All metals share this inherent tendency to revert to their more stable compounds, or to corrode, some having a greater tendency and others less than that of iron. Very simply, corrosion is the result of the deterioration of a material through electro-chemical reaction between the material and its environment. For such reaction to occur, there must exist areas of different potential which are electrically connected and in contact with an electrolyte. When these conditions are met, corrosion occurs through the loss of metal ions at the anodic area.

There are four basic elements necessary to the corrosion process. There must be an anode, a cathode, an electrolyte, and an electrical connection to complete the circuit. Sometimes it is difficult to identify all of these elements but, if corrosion is taking place, all of these elements must be present.

The principal types of electrolytic cells which are responsible for underground corrosion are as follows:

— **Bi-metallic Cell**
Such cells may form as a result of dissimilar metal couples, varying segregation of different phases in the same alloy, or differences in the condition of the metal surface.

— **Electrolytic Cells**
Dissimilar environments alone will often provide sufficient voltage to incite corrosion. Significant factors which affect the environment include variations in oxygen concentration, variations in the pH of the electrolyte, differential electrolyte concentrations, and temperature differences of the electrolyte.

— **Stray Currents**
Stray currents present in the ground from direct current operations, such as subways or railroads, may cause accelerated corrosion of adjacent metal structures.

In accordance with the electrochemical theory of corrosion, the rate of corrosion is a function of the magnitude of the current. The magnitude of this current flow in the cell determines the rate of corrosion at the anode.

There are a number of factors which influence the corrosion rate which is responsible for removing metal from the surface. *Such factors can either work collectively or in* isolation. They are as follows: soil resistivity; type and concentration of salts present in the soil; presence of certain types of bacteria; extent of polarization of the anode and cathode; size of anode and cathode surfaces; distance separating anode and cathode. Soil resistivity is probably the most important factor and is a function of moisture content, concentration of ionized salts present in the soil, and temperature.

CONTROLS

Coatings

The quality of a coating applied to an underground steel structure is very important even though the structure is to be cathodically protected. The effect of any deficiency or lack of quality will be to shorten the effective life of the anodes in a sacrificial system, or to increase the current requirements in an impressed current system. Poor quality coatings may result from any of the following:

— Poor quality coating materials;

— Inadequate surface preparation;

— Improper application;

— Too little coating or too few coats;

— Excessive damage during shipment or installation

It must be remembered that underground coatings are inaccessible for maintenance during the entire life of the structure, and such coatings must withstand high potentials and currents when contrasted to aboveground structures.

A premium type of coating widely used today by the oil industry is coal-tar epoxy which cures by the chemical action of a resin and a catalyst. The advantages of this type of coating are that they may be applied cold by spray or brush; they have excellent adhesion; they provide excellent resistance to gouging and scratching; they have good durability and are resistant to gasoline; and no special primer is required. Their disadvantages are that they are costly; require immediate application after mixing; and require excellent surface preparation.

Care must be employed in the handling and shipment of coated tanks to avoid damage to the coating. Padding must be used between chains and tanks. Tanks should be handled by cranes. The coating should be carefully inspected before and after the tank is positioned in the hole, and any damaged areas should be patched at the site using the same type of coating material.

No coating can be considered one hundred percent perfect, and pin-holes in the coating become major points of intensive corrosion action. It is for this reason that a sacrificial anode system or an impressed current system is installed.

Cathodic Protection — Sacrificial Anode System

One of the most important approaches to corrosion control is cathodic protection. This method depends upon the supply of an external current to polarize the cathodes of localized cells to the open circuit potential of the anodes. In other words, a positive current is applied to the local anodes so that there will be no tendency for metal ions to enter the soil.

With the sacrificial anode method of cathodic protection, the structure and the sacrificial anode (magnesium and zinc having the widest accepted use) operate as a bi-metallic cell in which the anode is expendable and is consumed or "sacrificed" to the structure, which now becomes the cathode. For a given current output, an anode will have a definite period of useful life.

Installation of sacrificial anode systems must be done with great care, especially backfilling operations to avoid breaking cables and connections. The location of anodes and ancillary cables should be accurately portrayed on a site plan so that future maintenance work will not result in damage. The placement of anodes in an installation and, in particular, their distance from the structure, is critical to avoid shielding problems. Electrical connections must be permanently made using thermite welding techniques and they should be taped to insulate them from the electrolyte. Test cables must be installed and brought to surface boxes for monitoring purposes.

Much of the problem regarding connection of anodes has been successfully solved by Underwriters laboratory of Canada in their ULC S603.1M Standards. Here the anodes are attached to the tank at the shop of the tank manufacturer, and the entire unit consisting of tank and anodes is installed in a single operation.

Unless the steel piping in an installation is electrically isolated from the tank, the sacrificial anodes will endeavour to protect the piping and underground water mains in the immediate vicinity. This is usually overcome by the use of an insulating tank bushing installed in all pipe openings of the tank.

Cathodic Protection — Impressed Current System

As stated previously, cathodic protection requires a source of direct current. Such a supply can be provided by conventional generating equipment, such as a rectifier connected to an AC power supply. A step-down transformer is also required to reduce the driving voltage. The current is caused to flow through the soil to the structure to be protected through an auxiliary anode. In this case, there is no need for the anode to corrode, so that "permanent" types of anodes, such as graphite or high-silicon iron are preferred. While they are called permanent, they have a definite life depending upon current output.

Impressed current systems may offer several advantages over sacrificial anode systems. Sacrificial anodes are limited by their inherent driving voltage, whereas impressed current systems are free of this restriction.

This is particularly important in the protection of existing uncoated tanks, where current requirements can be quite high. A further advantage of this type of system is that it may be used to protect all underground structures at the site including piping and hoist cylinders.

The impressed current cathodic protection system design commissioned and available through PACE and prepared by Corrosion Service Company Limited of Toronto represents a cost effective combination of components.

This guideline standard covers the cathodic protection of U/G steel tanks by means of an external current from a power system that is rectified to direct current and injected into the ground through electrodes (anodes) buried near the tank. By this method, a corrosion cell is created making the tank the cathode (current receiver and therefore non-corroding) and replace the corrosion energy with external current and the buried electrodes.

The system specified in the section can be used with almost all buried tankage. However, when the current requirements exceed 12 amps or there is a severe stray current corrosion problem at a site, then a corrosion specialist should be consulted to modify this design. It can be used equally with existing or new underground steel tank systems and is almost always used with uncoated tanks of the ULC — S603M1981 Design. However, for new tank installations most companies prefer to use either FRP tanks or the sacrificial anode type system to eliminate or reduce continuing monitoring and maintenance costs.

Comparison Summary of Systems

— *Sacrificial Anode System*
1. No external power supply is necessary
2. Maintenance and installation costs are minimized
3. Cathodic interference on neighbouring structures is not a problem providing effective isolation of the system is maintained.
4. Low potential provides self-regulation against over-protection
5. Potentials are low and relatively fixed
6. Current outputs are low and relatively fixed

— *Impressed Current Systems*
1. Larger driving voltages and higher current outputs are available
2. Can be used in environments of most resistivities
3. Voltage may be adjusted to regulate current output
4. Bare or poorly coated structures may be protected
5. Continuing power costs will be incurred
6. Installation and maintenance costs are higher
7. Cathodic interference can be a problem
8. Possible to switch off current making for no protection

Cathodic Protection — Monitoring of Systems

The varying nature of the underground environment defies precise evaluation and the conditions are subject to considerable variation throughout the life of the structure.

Despite the difficulties, cathodic protection is accepted as a sound basis for corrosion prevention. The criterion is that galvanic action on a structure has been halted when all points on its surface have been polarized to a potential which is equal to, or more anodic than, the open-circuit potential on the most anodic point of the structure.

The structure potential is measured relative to a copper-copper sulphate reference half-cell, which is used to contact the electrolyte. The half-cell is inserted into the ground sufficiently deep to contact moist earth. The volt meter is connected through its negative terminal to the structure and the reference electrode to the positive terminal, since a steel structure situated in earth will usually be anodic to the copper-copper sulphate test electrode.

The criteria used to determine the level of protection achieved are as follows:

1. A structure-to-electrolyte potential of 850 millivolts negative to a copper-copper sulphate electrode.

2. With bare structures, a change of the structure-to-electrolyte potential of 250 to 300 millivolts in the negative direction from the structure's unprotected potential.

The use of a copper-copper sulphate half-cell requires considerable experience on the part of the operator, particularly regarding the location where it is inserted into the ground. For this reason, it is not uncommon to install a permanent reference electrode, usually zinc.

Frequency of monitoring is important in all cathodic protection systems. In the case of an impressed current system, the procedure is considerably simplified, as instrumentation is usually built into the circuit. In the case of sacrificial anode systems, this involves field operations. It is recommended that, after the tanks are backfilled at the time of installation, a

reading should be taken of the potential between each tank lead in turn and the station ground. Connection to the latter may be made to the body of any electrical fitting. In each case, this reading should indicate 30 millivolts or more to prove electrical isolation. If no appreciable potential exists, the system is shorted and the short should be located before completing the installation.

Between one and six weeks after completion of the installation, the potential of each protected tank should be measured and recorded. This same test should be again conducted after the first year of operation and every two years thereafter. It is strongly recommended that the test also be conducted immediately after any excavation of the yard and around the tanks and between the tanks and the pump islands. If the volt meter is found to fluctuate widely, as would be caused by stray ground currents, or if the readings otherwise indicate that the tank is unprotected, then a corrosion engineer should be consulted.

References: Environment Canada Publication #EE14 "Evaluation and Prevention of Corrosion Leaks on Buried Storage Tanks"

Petroleum Equipment Institute Series of Papers on Corrosion by B. Hardcastle, BP Canada published in Tulsa Letter

PACE report on Impressed Current Cathodic Protection prepared by Corrosion Service Co. Ltd., Toronto

SECTION 6

SECTION 6:
INTERNAL CORROSION
CAUSES & CONTROL / INTERNAL LINING

Causes & Control

Internal corrosion of underground steel storage tanks can and will occur whenever conditions produce an electro-chemical cell as with external corrosion.

While much work has been done to assess the external environment for the tank, little has been done on the internal environment. However, it is just as important based on industry experience that a significant number of tank failures are due to internal corrosion.

The corrosivity of the internal environment is influenced by the following:

(i) water accumulation from the product or condensation

(ii) the amount of oxygen present

(iii) the formation and deposition of sludge

(iv) presence of bacteria

(v) accumulation of dirt and scale

Further, mechanical factors can affect the rate of corrosion of tank interiors

(vi) slope of the tank bottom

(vii) dents and irregularities caused by installation

(viii) impingement on the tank bottom by the dip stick

(ix) frequency of filling and emptying

(x) length of drop tube fill connection

From these conditions, severe internal corrosion will be expected to occur at weld joints of lap, butt and offset design where dissimilar metals will be in contact and immediately below any submerged drop tube and/or dipping point. In a report to the U.L.C. Underground Tank Committee, Thorco Tank Lining Seal Company found in a survey of 124 tanks in the prairie provinces, 30% exhibited internal crevice corrosion mostly at lap and offset welds. Corrosion below the fill-pipe occurred in 10% of the tanks surveyed. In unpublished findings by BP Canada, they report that of 372 tanks tested for corrosion below the fill-pipe in 1981, 12-13% showed moderate corrosion, and up to a further 5% showed severe (pitting of 4/32" or greater) corrosion. Although a high proportion of these tanks were 17-20 years old, a significant number were of a much younger age, and from this sample no correlation was found between age and incidence or severity of internal corrosion. A survey carried out from 1977-1980 by API found that approximately 30% of leaks in steel tanks with submerged fill-pipes occurred directly below the fill-pipe (internal and external corrosion). The same study

also states that of all tank failures from corrosion in the sample (678) 9.0% were due to internal corrosion.

Complete control of the above factors contributing to internal corrosion is impossible or impractical. Water and oxygen levels generally cannot be controlled at service stations. As gasoline is a hygroscopic product, a small amount of water is usually introduced with it and gas blanketing and breathing systems that operate on a positive pressure are probably impractical. Bacteria can be controlled by chemical bactericides, but considerable caution is required in selection as most are corrosive agents themselves. Avoiding couples of dissimilar metals leading to galvanic corrosion can really only be controlled by the manufacturer of the tank, unless the dissimilar metal is introduced during installation or accidentally later when in service. Butt welds are least susceptable to crevice corrosion, presumably because water is not usually trapped at such a weld.

The revised U.L.C. 603.M1981 standard for steel storage tanks specifies full penetration butt welds or partial seal welded lap and joggle welds to prevent crevice corrosion. Also PACE recommends a protective coating on the interior tank area immediately below the fill-pipe. These revisions have been incorporated into a revised U.L.C. 603.1M 1982. Careful tank installation is important to avoid dents or any pocket where water will accumulate and create a corrosion cell. For FRP tanks most manufacturers install a metal plate below all fittings.

Beyond these points, good housekeeping at the service station site, avoiding introduction of road salt and dipping with a plastic tipped stick will contribute to reduced rates of corrosion and fewer tank failures.

Methods of detecting internal corrosion 'in service' are limited generally to inspection below the fill-pipe, whereas welds can only be visually inspected by entry through a man-hole after emptying and gas freeing the tank. For determining corrosion below the fill-pipe, principles that can be applied are taking an impression with a mould, ultrasonic scanning and visual inspection using a fibre-optic probe. However, very little suitable test equipment is commercially available.

Internal Lining

Internal lining of steel tanks with an epoxy resin or the so called glass armour coating is extensively used in the USA and to a lesser extent in Canada. It involves isolating the tank, gas freeing, entering and sandblasting to clean the internal surface, spraying the resin to about 125-150 mils thickness and then resealing the tank. Generally, applicators work to their own specifications, as there is no industry accepted standard or one required by U.L.C.

However, recently API has established a task force which has drafted a Recommended Practice for Interior Lining of Steel Underground Storage Tanks setting *minimum* standards.

In particular, the draft states that internal lining can only be used to repair certain corroded tanks and protect from internal corrosion. The lining does not provide or replace any structural strength. Tanks that are split or have a significant perforation must be removed and not lined for further service. Some Provincial authorities prohibit lining any tank that contains one or more perforations.

References:

1. Report No. 7 — Investigation of Internal Corrosion of Steel Fuel Storage Tanks, The Hinchman Company 1970

2. *Report to Special Task Force of the U.L.C. Underground Tank Committee, Thorco Tank Lining Seal* Company 1980

3. Unpublished Findings of BP Canada on Internal Corrosion 1981

4. Tank and Piping Leak Survey — Results Published by Operations & Engineering Committee and Underground Leakage Task Force, API — February 1981

5. Draft "Recommended Practice for Interior Lining of Steel Underground Storage Tanks", API Task Force 1981

6. Technical Information Bulletin — Specifications — Glass Armor Repair of Gasoline Storage Tanks: Thorco Tank Lining Seal Company 1981

INTERNAL CORROSION (BELOW FILL-PIPE)

	ONTARIO	QUEBEC	TOTAL
NO. OF SITES TESTED	53	70	123
NO. OF TANKS TESTED	175	197	372
NO. OF TANKS WITH INTERNAL CORROSION	29	32	61

UNPUBLISHED 1981 DATA OF BP CANADA

SEVERITY OF CORROSION (INTERNAL)

DEPTH OF PITTING BELOW FILL-PIPE

INCHES	1/32	2/32	3/32	4/32	5/32	6/32	TOTAL	TANKS TESTED TOTAL
ONTARIO INCIDENCE	7	8	7	5	1	1	29	175
% INCIDENCE OF TOTAL TESTED	4	4.6	4	2.9	.6	.6	16.6	
QUEBEC INCIDENCE	5	13	6	6	2	0	32	197
% INCIDENCE OF TOTAL TESTED	2.5	6.6	3.0	3.1	1.0	0	16.2	
TOTAL INCIDENCE	12	21	13	11	3	1	61	372
% INCIDENCE OF TOTAL TESTED	3.2	5.7	3.5	3.0	.8	.2	16.4	

UNPUBLISHED 1981 DATA OF BP CANADA

SECTION 7

SECTION 7:
EVALUATION OF UNDERGROUND ENVIRONMENT

General

There are many items that affect the rate of external corrosion of underground steel tanks such as type of construction, nature of the underground environment and age of tankage. For new tanks we can take steps to construct tanks with fewer lap joints and of compatible plate, welding rod and attachments and can install protected tanks. However, for existing tankage upgrading to reduce underground leaks while still getting the best dollar value of installed tankage, a combination of soil evaluation and age becomes an essential tool to enable us to manage our systems.

Age of tanks is sometimes a difficult item to obtain but can usually be obtained with some searching through fixed records. The evaluation of the underground environment is probably the most vital part of any underground tank upgrading program and an individual study must be carried out at each site to be meaningful.

Procedure

Because of the variation in soil properties, even on one site, it is considered advisable to take soil samples from three separate locations on site, preferably separated by about 100 ft., (30 m) then analyze each sample separately and average the result. Samples should be taken in the natural soil of the area, if possible, since over time any backfill around the tank will tend to take on the properties of the surrounding soil due to infiltration and ground moisture movement. Holes should be drilled and samples obtained preferably at the level of the lower part of the underground tanks but in no case less than 3 ft. (1 m) deep to be below the topsoil and to be relatively representative of the soil around the tank.

Once the sample is obtained, it should be either evaluated on site immediately before it dries out or should be tightly sealed in a plastic bag for evaluation as soon as convenient. Properties of the soil that can affect the rate of corrosion and require tests are as follows:

- Resistivity — The lower this value is, the greater corrosion current can flow if a cell is present.
- pH (acidity) test — The more acid the soil, the more hydrogen ions are present which promotes greater corrosion damage.
- Moisture — This property tends to lower resistance to current flow and also improves corrosive conditions
- Sulfides — If any sulfides are present it indicates decaying vegetation, garbage or other such conditions that promote bacterial growth and stimulate corrosion.

An excellent source of rating these characteristics is contained in the Manuscript Series of documents issued by Environment Canada. Appendix A of their publication EE-14 "Evaluation and Prevention of Corrosion Leaks on Buried Storage Tanks" covers a Soil Sampling Program that is currently in use by at least one major oil company in Canada and is attached (Appendix A). This covers sampling procedures, equipment, a table for scoring the various soil properties, a facility Corrosion Survey and an evaluation graph that recommends upgrading action based on a combination of soil aggressiveness score and tank age.

Individual points are assigned to each of the characteristics of resistivity, acidity, moisture, sulfides and differential values of them (refer Table A1). These values are inserted in the chart on Table A3 and when summed up give a total to indicate the soil aggressiveness value. (SAV). The site score or index is obtained by multiplying this SAV value by the tank age in years.

These two values are plotted on the matrix shown as Figure A-1 (see page 61) and this chart then indicates the action required by the combination of the soil chemistry and the tank age.

The derivation of the chart figure A1 is based on factual data of leaking tanks obtained by a PACE Task Force in 1977. A 6 month detailed study of all tank leaks from all Canadian petroleum companies combining age and soil evaluation was the basis of the chart. The lower curve SAV × AGE = 69 represents a 95% probability that no leaks will have occurred and is based upon a regression analysis of the test data with a correlation coefficient of 0.72. The upper curve SAV × AGE equal to 180 represents a point where 40% of the detected leaks had occurred and is an arbitrary limit that could be higher or lower based on individual judgement. However, the lower 69 curve is a factual line based on hard data that cannot be raised to a larger value.

APPENDIX A

APPENDIX A:
SOIL SAMPLING PROGRAM

A.1.0 SAMPLE SELECTION

There are two separate cases to consider and these are either a general survey where no tank excavation is being done and the other is where tanks are being removed.

A.1.1

Sampling where no tank excavation is underway requires a power auger to drill sample holes. There should be 3 separate holes drilled for each site and if possible they should be separated by about 100 ft. (30 m) and be representative of the native soil in which the tank is buried (not the backfill around the tank). Holes should be at least 3 ft. (1 m) deep before the sample is removed and the sample, approximately 2 cup size, should be identified, placed in a plastic bag, and be tied to retain its natural moisture content until analyzed.

A.1.2

Where tanks are being excavated, three samples should be taken from the excavation at a level at or near the bottom of the tank. The samples should be obtained one from each end of the tank and one near the midpoint, should be fresh samples (dig into bank 2 or 3" (50 to 75 mm) before sampling), should be natural soil not backfill and must not be contaminated with petroleum products. Bag samples in plastic bags and identify. If possible, all samples should be analyzed on site or at least as soon as practicable after collection.

A.1.3 Test Sequence

a. Resistivity determination

b. pH test

c. Moisture evaluation

d. Sulfide test

e. Differential characteristics — i) resistivity ii) acidity

A.2.0 TEST & EVALUATION PROCEDURES

A.2.1 Resistivity

Equipment required. Agra Mk. 2 soil box and multimeter.

Procedure:

Remove sample from plastic bag with putty knife and place in soil box (do not touch it). Add some moisture or distilled water, if sample has dried out.

Press sample into soil box compacting it firmly so that no corner voids exist. Tamp sample with handle of putty knife to compress soil as near as possible to natural condition. Cut off soil flush with the top of the soil box with a putty knife.

Connect the red lead of the multimeter to one terminal and the black lead to the other terminal of the soil box with the meter set to measure ohms × 1000. If meter does not read mid-scale, turn resistance scale switch to read about centre scale. Take resistance reading above and multiply by 10 to obtain soil resistivity. Enter readings in appropriate block of Table A-3.

A.2.2 pH (Acidity) Test

Equipment required. Beckman 'pHistol' meter and buffer solutions.

Procedure:

With putty knife place a sample of soil in vial supplied with kit. Add distilled water and shake to prepare a slurry. Submerge probe in slurry and read meter. Enter pH reading in appropriate block of Table A-3. Follow instructions supplied with meter and calibrate daily with buffer solutions.

A.2.3 Moisture Evaluation

Equipment required. None.

Procedure:

Roll sample in hand.

Free moisture present	— saturated
Remains rolled — no free moisture	— wet
Remains partly rolled	— damp
Will not roll	— dry

A.2.4 Sulfide Test

Equipment required. Test tubes and rack, 15% Hydrochloric acid, tube of lead acetate strips.

Procedure:

With putty knife, lift a small sample of soil (about 1/8 teaspoon) and place in test tube. Add 15% hydrochloric acid to half fill test tube. Wait 30 seconds to 1 minute and insert a lead acetate test strip in vapour space above acid. Hold strip free of side of tube and above liquid.

If test strip does not change colour, there are no sulfides present. If test strip turns beige, brown or black, sulfides are present. Use this as a go/no go type of test and score 4 if any sulfides present or 0 for none. Do not interpret an average of 2 for trace. (Applicable to S.A.V. System)

A.2.5 Differential Characteristics

This is scoring based upon the maximum variations found in A.2.1 and A.2.2.

References:

- Environment Canada Publication EE-14 "Evaluation and Prevention of Corrosion Leaks on Buried *Storage Tanks*"

TABLE A-1
BASIS FOR THE EVALUATION OF UNDERGROUND ENVIRONMENTS (S.A.V. Systems)

		POINTS
I BASIC CHARACTERISTICS		
• Soil Resistivity	< 300	12
	300 - 1,000	10
	1,000 - 2,000	8
	2,000 - 5,000	6
	5,000 - 10,000	3
	10,000 - 25,000	1
	> 25,000	0
• Soil pH	< 3	8
	3 - 5	6
	5 - 6.5	4
	6.5 - 7.5	2
	7.5 - 9	1
	> 9	0
• Soil Moisture	Saturated	3
	Damp	2
	Dry	0
II DIFFERENTIAL CHARACTERISTICS		
• Resistivity (ratio of extremes)	> 1:10	3
	> 1: 5	2
	> 1: 3	1
	< 1: 3	0
Soil pH (Difference in pH Value)	3	2
	1.5 - 3	1
	0 - 1.5	0
III SULFIDES		
	Positive	4
	Negative	0

TABLE A-2
ENVIRONMENTAL RISK EVALUATION

CLASSIFICATION	ENVIRONMENTAL RISK
A	High risk — Facilities at which tank leaks could cause the greatest hazard to life or to the environment. Locations in the vicinity of basements, subways or tunnels or those adjacent to navigable waterways or streams are examples.
B	Moderate — These are sites where any tank leaks would present a moderate potential of hazard to human life and property and no damage to the environment.
C	Low — These will generally be remote facilities where a tank leak would cause no particular hazard to life, property, or no damage to the environment.

TABLE A-2
ENVIRONMENTAL RISK EVALUATION

CLASSIFICATION	ENVIRONMENTAL RISK
A	High risk — Facilities at which tank leaks could cause the greatest hazard to life or to the environment. Locations in the vicinity of basements, subways or tunnels or those adjacent to navigable waterways or streams are examples.
B	Moderate — These are sites where any tank leaks would present a moderate potential of hazard to human life and property and no damage to the environment.
C	Low — These will generally be remote facilities where a tank leak would cause no particular hazard to life, property, or no damage to the environment.

TABLE A-3
UNDERGROUND PREVENTIVE MAINTENANCE PROGRAM

— FACILITY CORROSION SURVEY —

RISK GROUP CLASSIFICATION: ..... FACILITY NUMBER: .....

SURVEY DATE: ..... LOCATION: .....

PREPARED BY: ....

II.(A) — SOIL AGRESSIVENESS EVALUATION:

MULTIMETER FUNCTION/RANGE	TEST		SAMPLE 1	SAMPLE 2	SAMPLE 3	AVERAGE	POINTS
KΩ	RESISTIVITY	INSTRUMENT READING:	KΩ	KΩ	KΩ		
		READING × 1000 =	Ω	Ω	Ω		
		OHMS × 10 ≈	Ωcm	Ωcm	Ωcm	Ωcm	
	PH (14-0)	INSTRUMENT READING:					
		pH					
	MOISTURE (SATURATED/MOIST/DRY)						
	SULFIDE (YES/NO)						
	DIFFERENTIAL CHARACTERISTICS		RESISTIVITY RATIO (HIGH ÷ LOW)				
			PH DIFFERENCE (HIGH − LOW)				
	SOIL AGGRESSIVENESS VALUE (SAV)						

* AGRA MARK II SOIL BOX

GENERAL

- TANKAGE

SIZE NUMBER AGE

- ANY KNOWN LEAK HISTORY? ☐ YES ☐ NO
- ARE PRESENT STEEL TANKS PROTECTED BY A CATHODIC PROTECTION SYSTEM ☐ YES ☐ NO

SITE SCORE = [ ] × [ ] = [ ]

SAV AGE T/S INDEX

SECTION 8

SECTION 8:
PREDICTABILITY ANALYSIS OF TANK CONDITION

At this time there are essentially two methods of applying soil analysis data to assess the probability of tank leak. These are the compilation of the Soil Aggressiveness Value (SAV) and the estimation of tank life from the Rogers' Regression Equation.

Soil Aggressiveness Value (SAV)

Soil aggressiveness values are a basis for comparing soil environments. When data on actual leaking tanks is compared to a graph where SAV is plotted against tank age, different ranges of SAV and age can be established to indicate conditions of high versus low probability of a leak occurring. Three elements constitute the SAV numerical total. These are:

I) basic characteristics which include soil resistivity, soil pH and soil moisture

II) differential characteristics which are the ratio of extreme values obtained at any one site of resistivity and pH — and

III) sulphides, either present or not present (see ref. Environment Canada Report EE 14 A-1).

Points from a predetermined scale are applied to each factor which when added together gives the SAV. While the weighting points are not empirically derived, they are based on field experience of leaking tanks and expected tank life within the industry.

Multiplying the SAV score by the tank age gives the T/S index. At least one major integrated oil company in Canada has based it's tank upgrading programme on the following decision criteria using the T/S index. If the index is greater than 180, then underground storage tanks are recommended for replacement. For T/S values between 69 and 180, tanks are leak tested and either replaced or cathodically protected with an impressed current system. Below the 69 level, and below a SAV reading of 4, soil is considered 'benign' and tanks will not experience significant corrosion before reaching a T/S index of 69. Above an SAV of 4 and below a T/S index of 69, tanks should be cathodically protected with an impressed current system. This tank evaluation procedure is shown in the attached graph (Figure A-1).

While a close fit between a high versus a low probability of tank failure may be found using SAV scores for a large sample of sites, the T/S index does not give a complete correlation. Evaluation of the environmental risk (i.e. the possible consequential damage that could be caused by a leak) is recommended in all cases to supplement the decision making process. A simple subjective classification can be found in Environment Canada Report EE-14 (A-2), but this can become more sophisticated depending on the need.

Rogers' Regression Analysis

This statistical analysis undertaken by Warren Rogers for API, aims at establishing whether the ages at which tank leaks occur are related to measureable characteristics of the tank environment. Sample data obtained from industry from which the formula was developed indicated leaks at tank ages from a low of 5 years to a high of 45. The analysis using soil data of resistivity, moisture, pH and sulphides, together with tank size, has resulted in a mathematical formula which explains approximately 75% of the variability in the actual tank life experienced from the industry data.

In addition, it is claimed that the statistical properties of the remaining 25% unexplained variability are such that reliable estimates of the probability of leak at any given time can now be made.

The equation can be stated as:

$$\text{Mean Age to Leak} = 5.75 \times R^{.05} \times S^{-.017} \times \exp\left(.12ph - .42M - .26\,Su\right)$$

where R = resistivity (ohm-cm.) pH = acidity/alkalinity Su = sulphides
S = tank size (Imperial Gallons) M = moisture

This means that within a standard deviation range of ± 2.5 years of the 'mean' tank life, the probability of a tank leak is 68%. The probability of a leak at any given time is the actual age minus the mean age to leak divided by 2.5 with the resulting ratio used with a standard normal distribution table of probabilities.

The equation is most sensitive to changes in moisture, followed by sulphides, pH and resistivity, as shown in the attached chart. Originally, values recommended in the Rogers' report were for moisture: either 1 if saturated, or 0; and for sulphides either 1 if present or 0. However, in recent (November 1981) unpublished work completed by BP Canada, a three point rating system was used. The rating system for moisture was saturated 1, damp 0.5, dry 0 and for sulphides was strongly present 1, trace 0.5 and no presence 0. This helped reduce the generally low estimated tank life predictions previously obtained (usually maximum life of 12 years) and further separate different sites in terms of expected life and therefore risk of leak. A summary of the unpublished BP Canada findings (attached) shows that the average estimated life of underground tanks at 227 sites in Quebec and Ontario soil sampled in 1981 was 14.9 years, with a low of 9.4 and a high of 23.8 years. This compares with variously quoted industry averages of tank life of 17-19 years.

As the Rogers' equation is further used, its reliability is likely to be improved with quantification of variables and comparison with actual leaking tanks. Additional work is also being carried out by Rogers to develop a predictive model for internal corrosion and incorporate all data analysis into a decision tree model to optimize management decision making required for any comprehensive upgrading programme. This is expected to be particularly valuable in allocating capital totalling many millions of dollars over a likely time-span of up to ten years.

References:

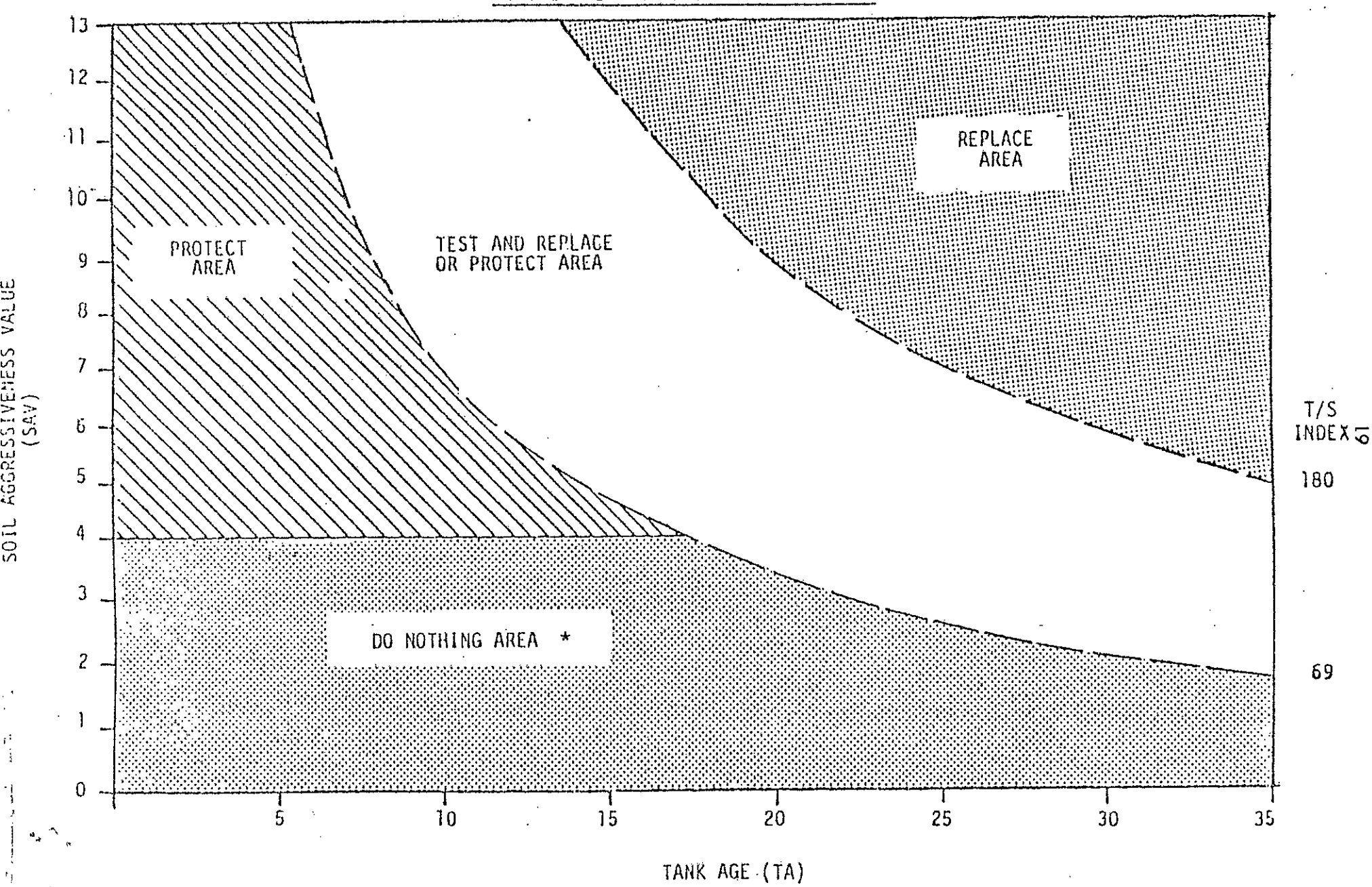
1. Environment Canada Report EE-14 'Evaluation & Prevention of Corrosion Leaks on Buried Storage Tanks'

2. 'Statistical Analysis of Time to Leak of Buried Gasoline Storage Tanks'

   prepared by Warren Rogers Associates Incorporated for the American Petroleum Institute

3. Unpublished 1981 data on use of Rogers' equation by BP Canada

FIGURE A-1 - TANK EVALUATION GRAPH



* environmental risk evaluation must be done.

SENSITIVITY OF ROGERS' EQUATION

$$\text{Mean Age to Leak} = 5.75 \times R^{.25} \times S^{-.017} \times EXP^{(.12PH - .42M - .26SU)}$$

DATA

RESISTIVITY (R)	10,000 OHM-CM	MOISTURE (M)	.5
TANK SIZE (S)	5000 IG	SULPHIDES (SU)	.5
PH	8		

MEAN AGE TO LEAK 14.66 YRS

IF	YEARS	CHANGE (Years)
PH 9	MEAN AGE TO LEAK 16.53	+ 1.87
PH 7	MEAN AGE TO LEAK 13.00	– 1.66
MOISTURE 0	MEAN AGE TO LEAK 18.08	+ 3.42
MOISTURE 1	MEAN AGE TO LEAK 11.88	– 2.78
SULPHIDE 0	MEAN AGE TO LEAK 16.69	+ 2.03
SULPHIDE 1	MEAN AGE TO LEAK 12.87	– 1.79
RESISTIVITY 60K OHM-CM	MEAN AGE TO LEAK 16.03	+ 1.37
RESISTIVITY 20K OHM-CM	MEAN AGE TO LEAK 15.17	+ .51
RESISTIVITY 5K OHM-CM	MEAN AGE TO LEAK 14.16	– .5

RESISTIVITY & PH MEASURED FINITELY

MOISTURE AND SULPHIDES PRESENCE DETECTED BUT NOT QUANTIFIED

OVERALL SOIL DATA & ROGERS' EST. TANK LIFE

RESISTIVITY OHM-CM	> 10,000	5,000-10,000	3,000-5,000	< 3,000	TOTAL
NO. OF SITES	98	49	51	29	227
PH (RANGE)	6.7-9.2	6.9-8.3	7.1-8.6	6.8-8.9	
MOISTURE (MOST COMMON)	.5 →				
SULPHIDES (MOST COMMON)	.5 →				
MEAN AGE TO LEAK ROGERS' ESTIMATED RANGE IN YEARS	10.9-23.8	11.7-17.1	10.5-17.5	9.4-17.3	
AVG. OF MEAN AGES	*16.0*	*14.7*	*13.6*	*13.5*	

AVERAGE OF ALL MEAN AGES 14.9 YEARS.

Unpublished 1981 data of BP Canada

SECTION C

SECTION 9:
REMOVAL, DISPOSAL & ABANDONMENT OF USED TANKS

Removal, disposal and abandonment of underground tanks, used for storage of flammable or combustible liquids, must be done with care. In order to prevent accidents, procedures outlined below should be followed.

I. REMOVAL

When an underground tank will not be used again, it must be removed from the ground:

- Remove all flammable or combustible liquids from the tank and connecting lines.
- Excavate down to the top of the tank, remove the fill tube and disconnect all lines.
- Plug all tank openings temporarily and complete the excavation.
- Remove the tank from ground and recover any product or sludge if spilled. Disposal of sludge would be required as per local regulations.
- Place tank in a secure position and block to prevent movement.
- Where the tank is not to be replaced, remove piping from the ground or purge the piping and permanently seal the ends.
- If the soil around and under the tank cavity is contaminated with product, remove such contaminated soil and product. For new tank installation replace excavated soil with clean, well compacted granular material.
- Where the tank is not to be replaced, fill the cavity with clean, permanent fill.

II. DISPOSAL

Underground tanks which have been removed from the ground can be disposed for reuse or scrap.

A. DISPOSAL FOR REUSE

Legislation generally prohibits reuse of existing tanks .

Where regulations permit reuse, the suggested procedure is:

- Clean removed tank
- Gas-free removed tank. Method of gas-freeing the tank shall be by adding dry ice (solid carbon dioxide) in the amount of 2 kg per 1000 L (2 lb. per 100 gal.) tank capacity. As the dry ice vapourizes, flammable vapours will flow out of the tank and may surround the area. Observe all normal safety precautions regarding flammable vapours.

Optional method of gas-freeing the tank is by using water providing there is suitable means for water disposal. Fill tank with water to force the vapours out of the tank. Remove product floating on the water as the level rises. Again observe safety precautions regarding flammable vapours which may surround the area. Dispose contaminated water in accordance with local regulations.

- Plug or cap all holes, provide about 3 mm (1/8 in.) hole in the plug to prevent build-up of pressure inside the tank.
- Inspect the tank for excessive denting, pitting or gouging which may prohibit reuse of the tank.
- Secure the tank on a truck and remove from the site to the new site or to storage (in a protected area)

B. DISPOSAL FOR SCRAP

Suggested steps when disposing for scrap are:

- Clean removed tank.
- Gas-free the tank (see gas-freeing procedure in Section A. Disposal for reuse)
- Puncture or cut the tank in several places to render it unfit for reuse.
- Apply stencil (or other) warning to the tank reading

Tank Has Contained Leaded Gasoline
(or Flammable Liquid)*
Not Gas-Free
Not Suitable for Food or Drinking Water

- Remove the tank to scrap.

*Use the applicable designation.

III. ABANDONMENT

Abandonment of a tank in place is not acceptable and regulations normally require removal.

If abandonment is approved by the regulatory authority for any reason, follow this procedure:

- Remove all flammable or combustible liquid from the tank
- Excavate down to the top of the tank and disconnect the suction, inlet, gage and vent lines and cap or plug their ends.

- Gas-free the tank. Fill the tank with water and remove the floating product as the water level rises. Flammable vapours will flow out of the tank and safety precautions must be observed. Gas-freeing by dry ice may be used as an alternative (see Sect. II. Disposal)

- After water has overflowed the tank, cut one or more large holes in the tank top (e.g. using back hoe), pump out the water and dispose of it as per local regulations.

- Fill the tank completely with an inert solid material (sand, granular material or combination of sand and earth fill). Use nominal amount of water to flow the material to the tank ends.

- Remove the piping or purge and permanently seal the ends.

- Restore site to the original state by using clean backfill material.

- Keep records of the tank location and date of abandonment.

References:

— Recommended Practice for Abandonment or Removal of Used Underground Service Station Tanks — API Bulletin 1604, March, 1981

— Federal, Provincial and local legislations and regulations.

68. Pfannkuel, Hans. "Problems of Monitoring Network Design to Detect Unanticipated Contamination," Ground Water Monitoring Review, Winter 1982, pp. 67-76

PROBLEMS OF MONITORING NETWORK DESIGN TO DETECT UNANTICIPATED CONTAMINATION

2645
2646
2647

Accidental spills along extended routes and unanticipated contamination from fixed locations offer special problems. A monitoring system designed within the context of a different set of objectives to resolve these problems is described.

by Hans-Olaf Pfannkuch
University of Minnesota

Special Problems of Unanticipated Contaminant Release

The unanticipated release and propagation of contaminants in the ground-water flow system is a special case of pollution. Strategies to handle such a contamination case are different from those employed in more current situations where the likelihood of pollution could be foreseen. This article deals with two problems of this kind.

The first problem is the accidental occurrence of spills at a point along an extended, linear route such as a pipeline break or a tank car accident. An unforeseeable element of chance or randomness is introduced because of the unknown location and time of the incident. The second problem involves leachate generation and propagation from unregulated or pre-regulation abandoned land disposal operations. The random element in this case is that, in general, the location, nature and strength of the source are unknown when the problem first surfaces. Both situations are characterized by the lack of general information about the hydrogeologic characteristics of the site and the dynamics of the ground-water flow system near the source. It is economically unfeasible to gather detailed information for every foot of transmission route before the actual occurrence of an accident, nor is it feasible to expend the efforts for studies on hundreds or thousands of suspected disposal sites before a problem is detected. This means that, in a situation in which a rapid response is necessary, the degree of preparedness is much lower than for those cases where potential contamination from a known source of fixed location has been planned for in the design.

The basic commonality in managing accidental spills along extended routes and contaminant detection from unknown sources is that rapid countermeasures have to be taken and that monitoring operations are tightly interwoven with the basic information gathering process, the development of the observation network and schedule, and the direction of the abatement and cleanup activities. Especially in the early stages of development, all of these operations occur simultaneously. This article discusses specific monitoring strategies to meet these special situations.

Monitoring in the General Pollution Control Context

In order to optimize the design and operation of monitoring systems it is appropriate to take a holistic view of monitoring as part of the information component in the overall management of pollution control operations (Pfannkuch, 1975). Controlling a spill or contamination case is a decision and management process with goals and objectives, economic and technological constraints and with optimization procedures and decisions about alternative courses of action. Management goals in response to a pollution incident may range from total removal of the pollutant and reconstitution of the environment to pre-pollution levels over abatement and mitigation to simply minimizing and containing the damage. Monitoring operations are a tool to assess the situation, to guide the action, and to evaluate its efficiency and compliance with set standards.

Figure 1 shows the relation of monitoring operations and monitoring systems design to the main management objectives, but also to the constraints imposed by the physical and technological realities, and by the socioeconomic environment (Pfannkuch and Labno, 1976). The economic optimization of the monitoring process is a resource allocation problem with the goal of developing the most cost-effective monitoring program in order to obtain the maximum protection of the ground-water resource from a technological point of view (Todd et al. 1976).

This article concentrates on the technological aspects of optimization, because before an economic decision can be reached a technological background has to be created on the basis of which different alternatives can be evaluated. The first important element in designing an efficient monitoring system is the proper understanding of the mechanics and dynamics of contaminant propagation, i.e., whether the contaminant moves as a soluble phase or by multiphase flow, whether the controlling mechanisms are described by vadose or saturated flow, piston displacement or diffusion-dispersion among other things. In addition, transport parameters of the flow system, such as permeability, porosity, capillarity and dispersivity of the material through which flow occurs must be evaluated. Along with the macroscopic or extensive parameters, such as the boundaries of the aquifer system and its hydrodynamic variables potential,

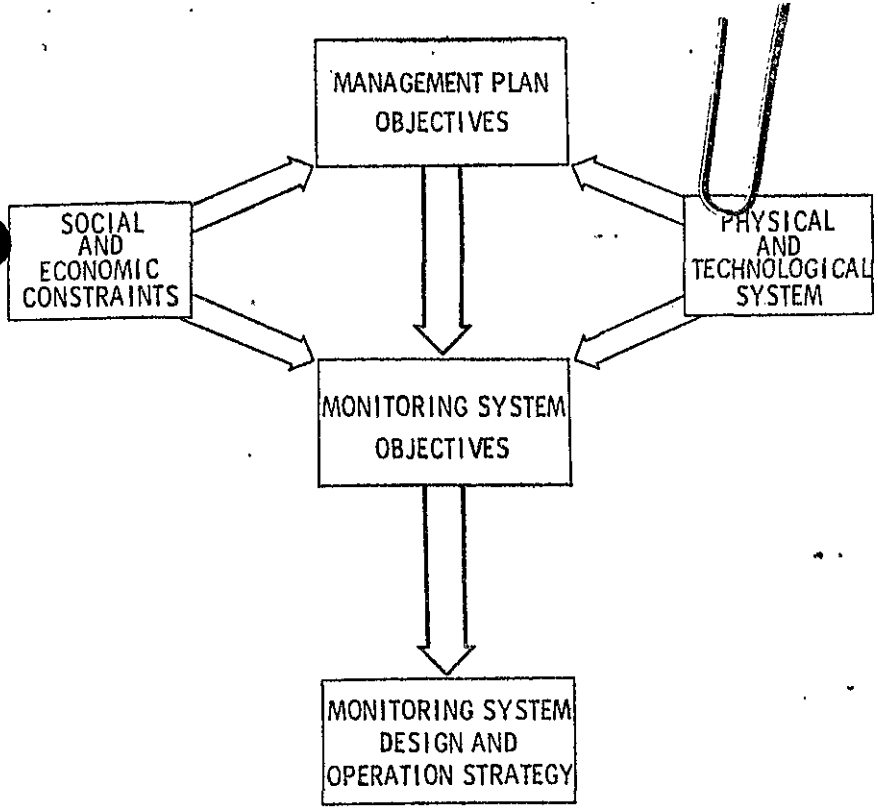


Figure 1. Monitoring system design and operation.

		RELATION TO ENVIRONMENT		
SOURCE	OPERATION	OPEN	RESTRICTED	ISOLATED
1° WASTE	DISPOSAL			
2° BY-PRODUCT	LAND-USE PROCESS			
3° PRODUCT	STORAGE TRANSPORT DISTRIBUTION			
ANTICIPATED RELEASE		ACCEPTED	CONTROLLED	ACCIDENTAL

Figure 2. General contaminant release matrix.

water table configuration and potential gradients, these factors determine the direction and velocity of movement and dispersion of the contaminant. Based on this information, the location and number of monitoring wells, and the frequency of sampling can be established. The reconnaissance and information-gathering operations in this first phase are not really monitoring operations per se, but in a compacted schedule of events a reconnaissance well may quite likely become a monitoring well later in the program. This phase should therefore be considered part of the monitoring effort.

The variables to be included in the monitoring program depend both on the propagation mechanism, the technological feasibility to sample and the objectives of the monitoring program. The different objectives in the case of an accidental spill or leachate propagation from an unknown source are:

- Determination of the extent, nature and degree of contamination (source monitoring).
- Determination of the propagation mechanism and hydrologic parameters to initiate appropriate response.
- Detection and warning of movement into critical areas.
- Assessment of effectiveness of immediate abatement and cleanup operations.
- Recording of long-term evaluation for ambient trend monitoring and compliance with standards.
- Initiation of research monitoring to validate and verify models and assumptions on which response action was based.
- Initiation of case preparation monitoring for litigation or other regulatory activities.

Other objectives may be determined and added as the local situation warrants.

Contaminant Release Into the Environment

Anticipated and unexpected contamination

The two examples discussed in this article represent two extreme positions of a whole range of possible interactions of potential contaminants with the environment. Figure 2 illustrates the situation by the cross-marked fields. The diagram shows three types of potential sources for contaminants, namely direct disposal of wastes, the release of byproducts of manufacturing processes or land use-related operations (road salting for instance), and release potential of products during storage, transport or distribution. The contact relationship to the environment in general or to groundwater flow systems in particular can be open, restricted or isolated. In the case of valuable raw materials (crude oils) or products, every incentive is given to limit wastage and spillage by isolation in pipelines or tanks. Release to the environment is only by accident.

The degree to which disposed wastes are isolated from the environment depends on their degree of hazard and magnitude of potential impact. Current municipal wastes are disposed in a relatively open environment. Certain types of industrial wastes are disposed into restricted environments such as subsurface injection sites. High-level radioactive wastes have to remain totally isolated from the hydrosphere and biosphere.

In planning, municipal waste disposal facility sites are selected on the basis of geologic and hydrologic studies. Monitoring systems are part of the planning and installation process. In case undesirable situations arise, early warning is given and countermeasures and contingency plans are readily activated. This of course is not the case in pre-regulation and illegal dumping sites and therefore special measures have to be taken. Basically these are quite similar to accidental spills along extended linear routes, where a high degree of detailed site planning and

installation of monitoring systems is economically impractical. By contrast, localized isolation and storage facilities go through the same or an even more restrictive environmental planning and monitoring design process than solid waste disposal sites anticipate and counteract accidental releases or spills.

Contaminant Propagation in Shallow Aquifer Systems

In line with the previous discussion about design and operation of a monitoring system, one must first determine the nature of the propagation mechanism and evaluate the physical properties of the release environment in order to plot the best strategy for field monitoring and related information-gathering processes.

Contaminant Propagation Mechanism

Two basic propagation mechanisms exist.

Water soluble contaminants: This is the case for all leachates generated from landfills which by definition are water soluble, although they may contain some oil and grease, stockpiles of soluble materials (road salts) or aqueous solutions (ammonia, liquid fertilizers, etc.).

A vertical cross section through contamination case is given in Figure 3. Four separate zones are distinguished.

Zone I determines the surface configuration of the spill or the leached body. Liquid spills are governed by the local topography and migrate toward depressions that allow accumulation of the spill material. For leaching solids, the engineering and layout of the site and its relation to the surface drainage will determine where infiltration will take place. The areal extent and shape of Zone I determines the surface from which infiltration will occur and how much the contaminant will be spread.

Zone II is the soil zone, which may or may not be fully developed. It presents certain characteristics such as high retention capacity for the aqueous solution, adsorption and exchange capacity for specific ions, and the possibility of biological activity as a potential mitigating process.

Zone III represents the vadose or unsaturated zone where the solution is retained by capillarity to field capacity and where some adsorption of contaminants to the solid surface occurs. Depth to the water table or thickness of the vadose zone, areal

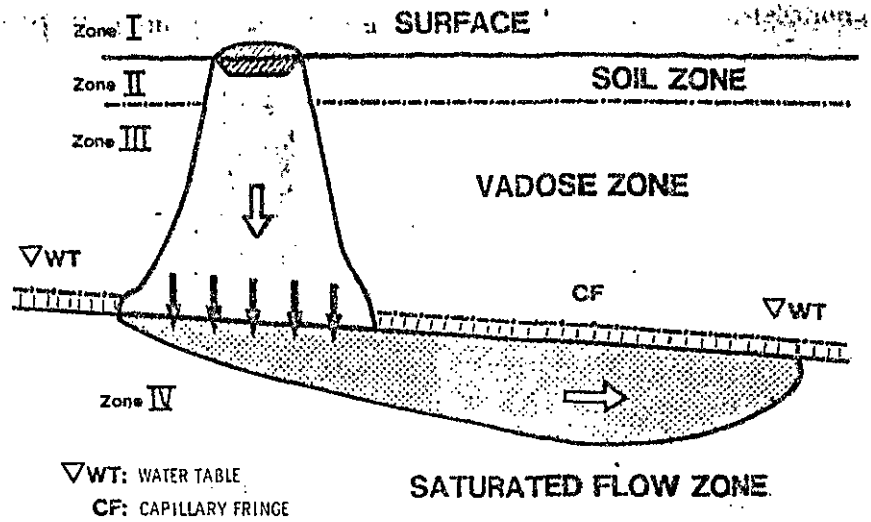


Figure 3. Subsurface propagation of a water-soluble contaminant.

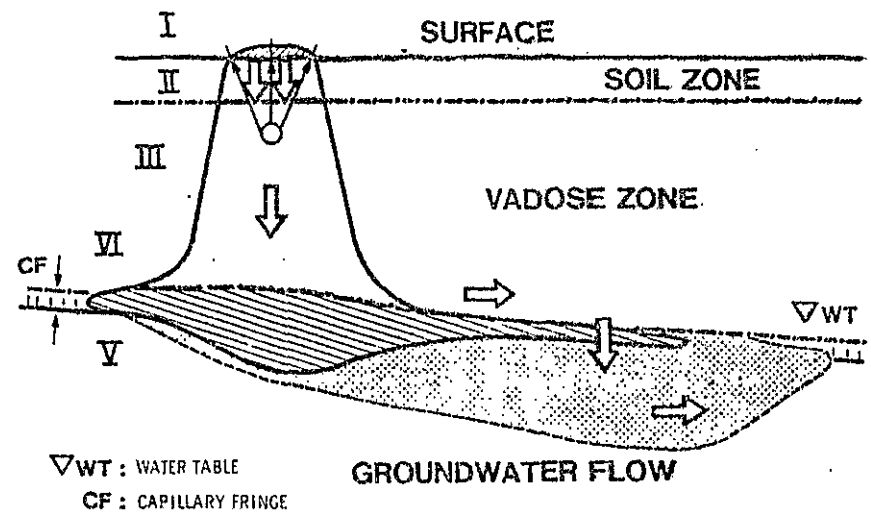


Figure 4. Subsurface propagation of a nonmiscible contaminant.

extent of the spill as defined in Zone I and antecedent soil moisture and specific retention determine the volume of contaminant solution that can be held temporarily. If the spill volume exceeds this amount, the excess volume will enter the saturated zone and the ground-water flow field. In the case of soluble materials, each subsequent precipitation and infiltration event will displace the dissolved contaminant retained by capillary movement downward. Changes in chemical environmental conditions such as pH or Eh may remobilize adsorbed contaminants. In a humid climate, all of the solute will eventually reach the ground-water body.

Zone IV is the ground-water flow field. As the dissolved contaminant leaves the vadose zone by downward vertical movement, it enters the capillary fringe and then the ground-water body. Under active flow it is transported laterally. The process at the interface between Zone III and IV is a simple entrainment of the constituents which, once having entered the ground-water flow system, are dispersed and diluted. A certain amount of adsorption on the grain surfaces can take place. This is the zone of the most active movement and potentially the one where the largest volume of ground water may be contaminated. It is therefore of utmost importance to determine ground-water flow directions and velocities and the dispersion characteristics of the aquifer materials.

Water insoluble or low solubility contaminants: Hydrocarbons and other organics belong in this category. These are the materials commonly released in pipeline breaks, tank car ruptures and reservoir tank corrosion. Although "oil and water do not mix," a small amount does dissolve into the water. In general, the amount dissolved is in direct proportion to the substance's volatility. Multiphase flow phenomena exist where immiscibility conditions prevail. Miscible or solution flow takes place where solubility condi-

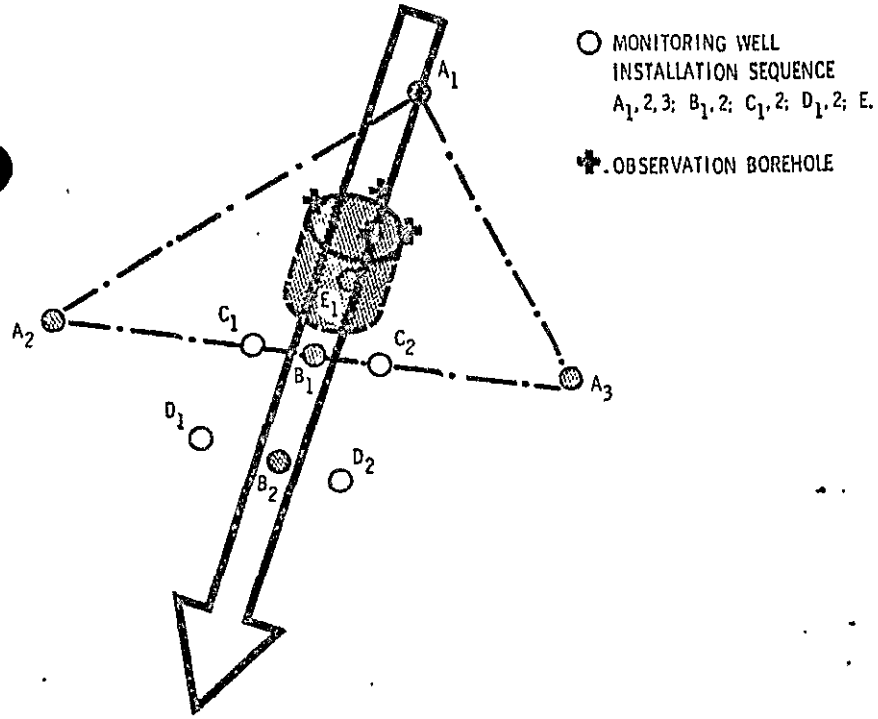


Figure 5. Drilling pattern around a spill site.

tions prevail and both can exist at the same time. The mechanism of spreading is shown in Figure 4 where five different zones are distinguished, some of them directly overlapping with the different zones of the soluble case in the previous figure.

Zone I is the above-ground and surface zone where leaked or projected oil runs off and collects in surface depressions, thus forming the area from which infiltration takes place. This area depends on the local topography, the amount spilled and the conditions of release or eruption.

Zone II is the soil profile. From Zone I the oil starts infiltrating into the subsurface via the organic soil layer, if such a layer is present. This zone is characterized by its high organic content and high moisture content due to soil structure. If the soil is oleophilic, it has a much higher oil retention capacity than the underlying nonorganic deposits.

Zone III is the vadose or unsaturated zone. This is the most important zone for oil retention. Water saturates the pore space only partially and ranges in value from zero to field capacity. Oil, as the nonwetting phase, moves downward under the forces of gravity. At first it moves as a more or less continuous phase or "oil body," displacing excess water from the larger pores. When all oil has infiltrated from the surface the "oil body" will move downward by translation, but small amounts of oil will be left behind the trailing end, trapped as insular disconnected droplets. The oil body continues to move in a disintegrated fashion until all of the oil is trapped in the pore spaces of the vadose zone, if its total retention capacity exceeds the infiltrated spill volume. Any oil in excess of this total retention capacity reaches the ground-water body and spreads on the water table through the capillary fringe.

Zone IV is the capillary fringe which is partially water-saturated, directly connected with the ground-water body vertically, but discontinuous laterally. When excess oil reaches this zone it will spread laterally under its own hydrostatic pressure and form a lens on the water table. The spreading will come to a halt when the hydrostatic forces in the oil phase are counter-balanced by the capillary forces at the outer edges of the spreading oil lens. This movement is governed by the phenomena of relative permeabilities and multi-phase flow in porous media.

If the porous medium is homogeneous and isotropic and the water table horizontal, then the oil lens would be perfectly circular around the center of infiltration. In most realistic cases the water table has a slope which gives rise to an elliptically elongated lens extending in the direction of flow. The shape of this lens depends on the water-table gradient, ground-water flow velocities, the capillary properties of the multi-phase flow system, and the shape and orientation of the original infiltration area.

Zone V is the ground-water body. Most hydrocarbon compounds in a spill are lighter than water and therefore tend to float on the water table. Under the hydrostatic head of the continuous oil column an actual depression and penetration of the ground-water body below the water table occurs. This inverted mound will dissipate as the overlying oil body spreads laterally. The penetration and subsequent retraction may result in leaving trapped insular oil behind in the ground-water body. The most important feature of Zone V in the emplacement stage is the formation of an interface between the bottom of the oil lens and the free flowing ground water. It is at this interface that small but significant amounts of hydrocarbon compounds go into solution with the water and are spread by convective and dispersive transport mechanisms.

The two zones of greatest importance in spill propagation are the retention zone in the vadose zone and the dispersion zone in the ground-water flow zone. The retention zone determines how much of the contaminant will reach the shallow ground-water body and how fast it will move, hence determining how much time is available for corrective action. The dispersion zone determines the largest area the contaminant plume will occupy, the direction and intensity of migration and the ultimate persistence of pollution.

Physical Properties of the Release Environment

The hydrologic parameters necessary to evaluate the subsurface spreading of the contaminant are retention capacity of the materials in the vadose zone, hydraulic conductivity and the dispersivity and adsorption capacity of the ground-water flow zone. In the present discussion and also for the examples cited below, it is assumed that the aquifer materials are unconsolidated and granular, such as glacial or alluvial deposits.

Indirect information about these parameters can most readily be extracted from analysis and interpretation of grain size distributions of the porous materials. A preliminary assessment should be carried out in the field—more precise relationships have to be established in the laboratory.

Field assessment: The two types of samples available are grab samples (from the surface or from trench-

ng operations) and borehole samples (when drilling is carried out). The grab samples will mainly give information as to infiltration capacity and characteristics of the vadose zone, whereas the borehole samples give information about the hydrologic characteristics at and near the water table and in the saturated zone. The lithology and representative (average) grain size, sorting and homogeneity of the near surface materials is found from these samples.

Further field inspection of the topographic surface, the presence of standing water, and the extent of wetlands or open water bodies allows first approximate statements about infiltration capacities and subsurface permeabilities. This type of information serves as the basis to guide a more intensive sampling program.

If the spill involves the hydrocarbon products, their presence can be detected either visually or by smell. A preliminary idea about the extent of the subsurface infiltration can be gained by a physical inspection of the area.

Laboratory measurements: Measurements of grain size and distribution allow a more precise, albeit indirect estimate, of the characteristics of the porous media. Grain size analyses can be carried out rapidly to estimate permeabilities and hydrologic conductivities via the Krumbein and Monk (1943) equation. They also can be used to estimate retention capacity. For oil retention into originally dry soils, Convery (1979) has established an empirical equation in close analogy to the Krumbein and Monk procedure:

$$PR = 6.33\,(MGmm)^{0.75}\,e^{0.813\sigma g}$$

where PR primary oil retention
MGmm mean grain size in mm
σg graphic standard deviation

This equation is valid for a range of mean grain sizes between 0.5 mm and 0.177 mm.

A more site-specific but tedious procedure for obtaining specific or primary retention of oil or water is through drainage experiments in columns packed with representative materials from the site or borehole samples. The disadvantage of this method is that it is very time consuming, especially for very fine grain sizes, to the point where it becomes inapplicable as an information base for rapid decisions. Furthermore, properly designed experiments often need much larger volumes of materials than exploration borings will yield. Centrifuge methods have been developed (Eames, 1981) that allow an order of magnitude estimate of retention under various conditions of initial saturation with a small sample and within only a day or so of lab work.

Dispersivity measurements on packed columns in the laboratory have relatively little information value since, in general, field coefficients of dispersivity are one or two orders of magnitude greater than laboratory coefficients. This is due to the preponderance of inhomogeneities and preferential flow paths in the field situation. Laboratory experiments are useful only when adsorption rates are to be determined because the contaminant sees the same surfaces in the lab and the field. Experiments are time consuming. Their value is to corroborate or explain transport phenomena in the later phases of spill propagation. It is more important to get field data by installing an appropriate network of monitoring wells. These are also necessary to determine direction and velocity of ground-water flow.

Strategy of Field Monitoring and Information Gathering Procedures

Operations dealing with field monitoring procedures merge and become inseparable from the information gathering phase for systems behavior. The strategy now is to maximize the information content for both. The objectives for the combined phase are to assess the physical situation and the dynamics of the system and to obtain this information with the least but still adequate number of observation points or wells, all of which potentially could serve as monitoring wells in the later, more single purpose monitoring phase.

Preliminary information base: The general steps are:

- *Rapid preliminary survey*—Its objectives are to obtain an overview of surface drainage and ground-water drainage conditions, and of the extent and shape of the surficial contaminant source and its relation to the drainage system. Information for this survey is most easily obtained from topographic maps. Ground-water drainage patterns can be estimated from the slope and position of the topographic surface. Estimates are based on the hypothesis that the water table is a subdued replica of the topographic surface and that the position and elevation of water courses or water bodies are ground-water outcrops. Water-level surveys of nearby wells may also give an initial idea of flow directions. Grab samples of soil materials can be taken to assess the infiltration characteristics.

At the same time, a number of uncontaminated surface-water samples and supply-well samples far enough away from the spill site should be taken and analyzed for the principal contaminant. This is to establish a base of neutral background data. This preliminary information serves to design the information/monitoring well network layout.

- Intermediate and permanent observation points: The drilling of observation boreholes has as its main objectives, first to obtain information through borehole sampling, and second to actually install monitoring wells.

In the first phase, three wells have to be drilled in a triangular pattern to determine ground-water flow direction and hydraulic gradients near the contaminant site by the well triangulation method. One of the wells should be located far enough upstream of the site to serve as an uncontaminated control point. The other two will be downstream as indicated on Figure 5. Since accurate levels have to be established and since at least one of the wells will remain a permanent control, normal screen and casing installations, including proper surface seals, are needed.

The next phase consists of locating wells directly downstream on the flow line passing underneath the site of heaviest surface contamination or where greatest infiltration is assumed. If there are several areas of concentration, more than one such flow line has to be designated. On each flow line at least two observation wells should be drilled, one as close as possible to the extending plume, the other one at some distance downstream in uncontaminated materials. Thus the actual flow velocity of the contaminant and its propagation in the field can be found by measuring travel times of contaminant between the two observation points. In addition at least two wells if not two sets of wells should be constructed at right angles to the center flowline. This is to obtain an idea about the lateral spreading of the contaminant in the ground-water flow field. These observation points must be located as close to the advancing plume as possible without being inside of it; otherwise, unambiguous travel times cannot be established.

The extent of direct subsurface contamination can be determined by a number of boreholes serving only as temporary observation points. They are especially useful when the contaminant is easily recognizable in the soil sample from the borehole (split spoon or bailed sample), as for example hydrocarbons and other pungent inorganics. If recognition on sight is not that simple, other rapid field methods to analyze for the contaminant or an associated tracer become necessary. Depending on their position in the flow field and with respect to the plume, a decision can be made whether to case the hole as a permanent observation well or not. At least one well should be located in the area of high concentration in the center of the plume near the infiltration site but only extend to the deepest position of the contaminant. Its objective is to monitor the evolution of contaminant concentration in the spill area with time.

The first-phase wells which were drilled outside the area of direct contamination give information about till or clay layers or other barriers in the vicinity of the spill. It is of utmost importance to avoid drilling through these seals in subsequent drilling phases so as not to provide easy pathways of cross communication for the contaminant to enter either deeper aquifers or portions of the same aquifer that were naturally isolated from the infiltration site.

The third phase of drilling deals with obtaining better resolution on the basis of information gathered in the first two phases and with locating monitoring wells in critical or vulnerable locations.

For the wells constructed in the second and third phases, the necessary information should be available to decide at what depth the intake should be or whether or not multilevel sampling would be desirable. This is of special interest if the contaminant solution is of higher density than the ground water.

Toward the end of the third phase, it may be necessary to install a number of warning wells upstream of critical areas such as domestic or municipal supply wells. Although these wells may not necessarily be in a location that would be of the highest monitoring efficiency for the overall system, they serve as additional safeguards.

The soil and aquifer materials that need to be studied for their hydrologic characteristics are borehole samples from the vadose zone near the site of infiltration and samples from the yet-uncontaminated areas. The first samples are used to determine retention characteristics on the basis of grain size analysis and centrifuge experiments. The second samples need only be taken in the saturated zone for porosity and permeability determinations by grain-size analysis or by permeameter experiment. Both measures are important to establish a material balance for a spill or infiltration condition. Furthermore, the permeability-porosity data can establish independent estimates of groundwater flow velocities.

The soil samples need to be analyzed for traces of the infiltration material in order to establish the volume of aquifer material contaminated. The dissolved-phase water samples have to be withdrawn from the wells. This, however, deals with establishing the extent of the impregnation body and the plume at the time of emplacement. These samples should be taken as soon as possible after the contamination incident has occurred.

• The true monitoring phase begins after the basic information about the case and the hydrogeologic parameters have been at least partially completed. Its objectives are to follow the evolution and fate of the contaminant in the ground-water body, to serve as an early warning system in case sensitive areas are approached by the plume, to assess the effectiveness of cleanup and abatement operations, and to determine the final or closeout phase, after which no further adverse effects are expected from the incident and monitoring operations can be terminated. For certain hazardous and toxic waste sites, monitoring operations will have to continue indefinitely and no termination phase would be contemplated in that case.

Monitoring phase: The principal monitoring operation is subdivided into three phases.

1. The first phase is concurrent with the general information gathering process and is characterized by high-density and high-frequency sampling. All possible wells are used for sampling, all pertinent parameters will be measured and samples will be analyzed for a large number of constituents. Many environmental parameters such as hydrometeorologic and climatologic data will be gathered. The main objective is to rapidly recognize trends and general directions in order to more effectively design the next and more significant phase.

2. The second phase is the principal phase, specifically covering all of the objectives defined for the monitoring process. At this level, the results of the primary phase are evaluated, and a model concept of the system dynamics is formulated. A combination of the theoretical concepts and empirical data permits an assessment of the network layout and operational procedures. Application of statistics permits the establishment of confidence limits, minimum number of observation points in the system and number of samples to be taken.

The spatial level of resolution or number of monitoring wells depends on the preponderant mechanism of contaminant propagation. From a protection point of view, it also depends on the magnitude of the expected impact and the likelihood of its occurrence.

The first level of observation and analysis simply follows the evolution of the spreading pollution plume. This serves to verify whether the system actually behaves the way it has been assumed. In a more formalized and analytical context, results from this monitoring phase can be used to validate, verify and calibrate formal computer simulation models of contaminant transport and to adjust these models to the real conditions by curve-matching procedures.

Based on this information, abatement and cleanup procedures can be chosen among different alternatives. The monitoring process serves to indicate whether the remedial actions are in the right direction, how effective they are, and how close the system performance comes to meeting predetermined or statutory standards.

3. Long-term and final monitoring phase. With respect to time horizons, the monitoring system operator may be interested in daily, weekly or monthly averages, or he may follow events on a seasonal basis or on an event-by-event basis. The latter deals with total reactance of the system to a precipitation and infiltration event which manifests itself in water-level fluctuations in the well hydrograph and in concentration fluctuation due to dilution, displacement or remobilization of retained or adsorbed phase contaminants.

At this point, decisions are made regarding which monitoring wells should operate in the long-term or final phase of monitoring and at what levels the entire monitoring and surveillance operations can be

terminated. It is conceivable that this process may be staggered over a relatively long period of time with some key wells operating on a quarterly or semi-annual basis and finally only one or two wells being checked at a yearly or longer interval. This phase should also look into the last leg of the rehabilitation and restoration phase, namely the removal from service of the monitoring network when its purpose has been served.

Materials and procedures: In all three of these phases, proper attention to selection of materials, installation and operation of the monitoring network has to be given.

The materials such as well casings, screens, valves, conduits, etc. have to be compatible with the nature of the contaminant. They should not adsorb to or react with the surfaces they encounter, nor should the surfaces release compounds that would interfere with the analysis or directly change the concentrations measured.

The sampling method also should take into account the nature of the contaminant and the conditions at the sampling point. Vacuum methods and contact with the free atmosphere should be avoided when the material is highly volatile. Gas lift pumps should operate with inert gases if any reaction with the contaminant or with the solute is expected. Environmental conditions representative of the sampling point environment should be maintained to give the same solubility conditions lest precipitation, concentration or evaporation occur. In the case of two-phase conditions such as a floating layer of hydrocarbons on the water surface in a well, care has to be taken to either measure it separately or to obtain an undisturbed sample using a bottom sampling device. Simple pumping in this case only draws in supernatant oil from around the well and the sample may over-represent the actual free oil phase and the dissolved phase which may have been increased by turbulent mixing in the well bore.

All materials, instruments and sampling procedures should be geared to analytical methods used for the final analysis and the special volume, handling and transportation conditions that guarantee the greatest efficiency.

Field Examples and Applications

To amplify the hitherto more general discussion, two practical cases are presented. The first deals with a pipeline spill and falls into the category of an accidental release of a product from an isolated environment (see Figure 2). It basically has the same random characteristics as accidents from ruptured railroad tank cars or tank trucks. The difference is that in batch transportation, spilled volumes are much smaller than those from a pipeline break. On the other hand, overland pipelines never carry highly toxic or extremely hazardous materials, as often is the case with tank trucks.

The second case deals with contamination from stationary sources where ignorance about existing conditions at the time of contaminant detection introduce an element of chance, to treat them as quasi-accidents.

Monitoring a Pipeline Spill

The following describes the monitoring and information gathering processes after a pipeline spill in north-central Minnesota. About 10,000 bbl of crude oil had been released by flow, eruption and spray into the environment. The site is typical for the glaciated terrain of central Minnesota. Specifically, the spill is located near the margin of a small outwash plain with moraine deposits.

Immediate response and site inventory: The first steps in managing the spill were to eliminate any hazardous conditions, stop the flow and contain the spill. Thereafter a detailed small-scale topographic map of the area was established by professional surveyors. On this map, the areal extent of heavy oil concentration that had accumulated in depressions, intermediate concentrations along flow paths, and light concentration in the sprayed or dusted portions was indicated. The map served further to exactly locate future boring and well positions with respect to the pipeline and established benchmarks.

Immediately, eight observation borings were drilled to outline the areas of heaviest oil infiltration. Within these, shallow collection trenches were dug and the inseeping crude was recovered by pumping.

The general position of the site with respect to lakes, ponds and surface drainage courses as well as the slope of the land surface gave preliminary indications about expected ground-water flow directions. At first, two observation well triangles were installed around the two most contaminated sites, one right at the rupture, the other near a depression into which a large amount of oil had drained and collected.

Water samples were taken immediately after installation for analysis, water levels were measured, and the altitudes of the top of the well casings were surveyed. On the basis of this information, tentative flow directions could be established. It was decided to fill in the network with more wells in order to draw equipotential lines of water-table elevation and to construct a flow net for the spill area. This was done because of the large extent of the affected area.

Also, in the very beginning, 35 samples of surface water were taken around the area but sufficiently far away so that no contamination by spray from the spill could be assumed. This was done to obtain a suite of background water quality samples. The area has peat bogs and other possible sources of organic materials that might give high readings of organics. Of the 35 samples taken, each showed that those organics of concern were below detection limits.

Twenty-six boreholes were drilled, and 15 were installed as monitoring wells. Drill-site location and the decision to use the boreholes as monitoring wells were made in incremental steps, based on the finding of the previous two or three borings.

During the design phase for well installation, recovery by pumping proceeded and about 6,500 bbls of oil were ultimately recovered. Visual inspection of the collection trenches seemed to indicate that the oil seepage was mostly controlled by inhomogeneities of the soil materials, which offered preferred and restricted paths of migration, and also provided the opportunity for some lateral movements in the vadose zone.

Boring samples ranged from totally oil-saturated to only a few percent saturation. In many cases, a low concentration layer might be located between an upper and lower highly saturated layer, confirming the role of heterogeneities in oil migration. Grain size analysis by sieving showed the generally sandy materials to range between medium-coarse to fine sands with hydraulic conductivities ranging from $K = 10^{-4}$ to $K \quad 10^{-2}$ m/sec.

Hydraulic gradients were established from the flow net. Gradients were typical for this type of terrain, about 17 ft. per mile or 3.33×10^{-3}. Darcy fluxes of q between 3.3×10^{-7} and 3.3×10^{-5} m/sec, and actual velocities assuming a porosity of about 0.3 of $v \quad 1.1 \times 10^{-7}$ to 1.1×10^{-5} m/sec were calculated.

These figures are of importance in determining spreading and dispersion since the degree of mixing depends on the actual flow velocity in the pores.

As plastic-based pipe and casing materials may interact with and/or adsorb organic contaminants, only steel pipe was used for well casing. Some hydrocarbons from the coating on the steel casing must have bled into the well water and contaminated early samples, even though they were well cleaned. Subsequently, only galvanized pipe was used, and all of the existing wells were steam-cleaned in the field.

Sampling and monitoring phase: In most wells, the water table was below the vacuum-lift range. No sophisticated sampling devices for small-diameter wells were on the market at the time, so a somewhat simplistic bailing method was used. If a floating layer or sheen of free-oil phase exists on the water surface in the well, repeated dipping of the bailer leads one to overestimate the amount of free oil in the well. Also, by mechanically mixing this surface layer into the bulk of the sample, higher dissolved oil concentrations than are actually present in the undisturbed aquifer may appear. Concentrations are reported as measured, but because of the above-mentioned situation, they may be higher than actual concentrations.

The State Pollution Control Agency required gravimetric determination of freon-soluble oil and grease by separatory funnel extraction (Storet No. 00556). The wells were sampled frequently in the beginning and with longer intervals subsequently. Most of the samples showed values around the lower end of the detection range of this method, approximately 5 mg/l. The precision of the method is also lowest here. Plus or minus 1 mg/l in this range represents a relative error of about 20 percent. Through statistical analysis and manipulation, the information content of the results was improved. The results of the statistical evaluation were used to identify wells with problem concentrations, to separate the dynamic effects from random effects, and to select the most critical wells for the extended monitoring phase. The first criterion for selection is the average concentration for all samples in a given well. Any values of 5 to 6 ppm or below were considered noncritical. Values between 6 and 10 ppm indicate an intermediate concentration determined with low but adequate precision, values of 20 ppm and above clearly indicate contamination. In order to rank the wells in a semi-quantitative way, a "problem index" (Ip) was developed. It consists of the product of the mean, the variability, and the maximum ratio. The latter is the highest value in a series divided by the mean to normalize it. Values clustered around indices of 1-2 and up to 10 (control), around 10 to 15 (borderline), and above 50 (critical). This became the base of selecting the ultimate sampling network of control, borderline and critical wells. In some cases, Wilcoxon W-statistics (a ranking procedure) were used to clarify borderline cases using control-well data and data from suspected contaminated wells.

Oil retention studies of the average soil material from the site were concurrently carried out to calculate the total retention capacity of the vadose zone beneath the site. For the final analysis, centrifuge data of specific oil retention were used for balance calculations. Penetration of free oil phase to the water table was possible only through preferred channels or under extremely heavy surface concentrations which meant that only a minimal amount of crude could have reached the ground-water system. No free oil on the water table was detected in observation wells except directly beneath the most concentrated spill sites.

Abatement procedures parallel the monitoring phase. Free oil spray was burnt off the vegetative surface; 10 percent to 20 percent of the oil had evaporated and about 10,000 cubic yards of oil-contaminated soil were excavated from the sites that monitoring operations had indicated were especially critical. The excavated material was spread over 15 acres, fertilized and cultivated to permit rapid bacterial decomposition.

Oil and grease readings have been declining steadily. The number of wells monitored has been reduced to half, and frequencies now are at a quarterly interval and should soon be terminated.

Pre-regulation Land Disposal Sites

Site inventories: The state of Minnesota, especially the St. Paul-Minneapolis metropolitan area, may have potential problems with contaminant release from pre-regulation or unregulated (illegal) waste disposal sites. The problem becomes especially obvious when urban development reaches into areas with unanticipated problems.

Sites giving rise to problems range from those whose location and contained material are known, but for which no specific hydrologic data exists to clandestine or illegal disposal operations of actually hazardous wastes. In between lie a whole range of other combinations of known locations but unknown materials, unknown or forgotten sites, approximate locations with some vague ideas about the input, etc. Many fill operations have also operated as burning dumps so that the character of the input has drastically changed.

Common to all of these situations is the lack of information about their hydrogeologic and environmental impact. When a problem surfaces, usually by contamination of a drinking water supply, then all of the same methodology used in accidental spill monitoring has to be deployed. This has the disadvantage that little time is available for planning and making rational decisions. The main objectives are to protect the water supply, to identify the source and type of contaminant, and then to plan development of alternative supply sources or the abatement and removal of the contamination source. Operations are usually costly, can often not be assessed to the responsible party, and stir public opinion.

In order to address the problem, the Minnesota Pollution Control Agency (MPCA) has instigated an open dump site inventory in compliance with section 4005(b) of the Resource Conservation and Recovery Act. It identified about 1,400 sites outside and 120 in the metropolitan area. In addition, the MPCA has established a task force that reacts immediately to reporting of contaminants and also acts on statewide information about past or present improper disposal practices. The objective of this inventory is to direct information gathering operations at the critical sites so that problems may be anticipated. The most important problem at this point is to rank the known sites and to identify those that need immediate attention. Thus, resources and effort for hydrologic investigations and monitoring installations would go to

those sites that most probably have or will develop critical pollution problems.

Development of ranking systems: The hydrogeology group the University of Minnesota was involved in establishing such criteria for metropolitan sites.

The MPCA has a ranking system based on federal guidelines from top to low priority including those that are in compliance with statutes and that probably will not emit contamination. The technical ranking is according to degree of pollution potential. The system is not explicit enough from a technical point of view to avoid ambiguities and subjectiveness of surveyors.

The more extensive theoretical criteria that were evolved deal with:

1. Infiltration and dispersion characteristics of the hydrogeologic environment.
   - Surface drainage pattern around site.
   - Infiltration characteristics of soil.
   - Retention capacity of unsaturated zone.
   - Depth to water table.
   - Ground-water flow pattern and activity, including the existence of preferred flow patterns such as in fractured or cavernous rocks.
   - Interaction pattern of surface water bodies and ground water.
2. Impact characteristics.
   - Waste characteristics
     - Nature of wastes (toxic, hazardous, inert)
     - Volume and area covered
     - Solubility characteristics
     - Residence time since emplacement
   - Human geography characteristics.
     - Degree and nature of development (density, i.e., urbanized residential, industrial, farm, etc.).
     - Land ownership as a measure of ease to initiate response activities (public, state, municipal, private, etc.)
     - Relation of flow path to ground water use (intensity of withdrawal and customers served).
     - Relation of flow path to environmentally sensitive areas.

In all of these criteria, it is easy to qualitatively indicate relative severities: the deeper to the water table the better, the higher the retention capacity the better, the lower the toxicity and the lower the density of affected users the better, and so on. However, it is very difficult to assign uniformly applicable numerical values to these situations. Even before it reaches this point, other difficulties due to insufficient information show up.

The first step in assessing pollution potential is to obtain information about the hydrogeology of the site. Search of files, existing well logs, and records in city and county engineers' offices are necessary to get some background information. Site inspection and reference to topographic maps offer some clues about potential infiltration, ground-water flow directions, and the relation of the site to surface drainage systems. This is about as far as a preliminary survey can go. At most, three categories can be established:

- Visual evidence of pollution by leachate.
- Site within or very near the saturated zone.
- Site normally above water table.

Actual field work is needed for more detail especially since situation one, the intuitively more offensive one, might have less impact than an undetected severe condition under situation three.

Determining anything about waste volumes and their degree of toxicity or hazard is almost impossible for pre-regulation landfills, where no logs were required. Some information can be obtained by interviews of residents or former operators about possible sources for the wastes and about the management practices during active operations.

Another approach is to reconstruct the industrial or commercial waste-generating potential within the area served while the facility was operating. The assumption is that if no hazardous wastes were generated in the area it is unlikely that any large amounts are to be found in the dump site. Information about past industrial activities can be obtained through chambers of commerce and state agencies dealing with economic development and activities.

Human geography data are the easiest to come by. Information such as location of high density residential areas, municipal ground-water withdrawal sites and volumes, types of land use and degree of development is relatively easy to obtain. Much information can be gathered at the municipal or county level and, in areas with effective regional government such as the Twin Cities Metropolitan Council, much of this information may already have been collated and put into directly usable form.

Sample assessments of 25 sites in the metropolitan area resulted in a simplified and reduced list of workable ranking criteria. The first group deals with the actual knowledge of suspicion of hazardous wastes in the site. This is amplified if management control and general maintenance have been lax. The next two groups are almost equal in importance for ranking, but they are weighted according to the amount of information available for each and its reliability. The two groups are: a) the hydrologic conditions as measured by the three categories: position near water table-above water table indicated above, and b) the bulk of the demographic and user information that constitutes the severity of any potential impact from unexpected contaminant releases. It is on the basis of this information that resources for more detailed study, field investigation and the development of monitoring networks around abandoned waste disposal sites should be allocated. Once the site is studied in depth, some of the critical aspects may shift and, for example, it might be shown that the hydrogeologic situation creates a serious problem although the original input into the site was less hazardous than in other comparable sites.

Summary

Accidental releases and unexpected detection of contaminants requires an immediate response to mitigate and eliminate the resulting pollution. Management decisions and subsequent responses have to be carried out rapidly. The information phase to study and present alternatives for decision-making and for the monitoring process run concurrently rather than sequentially as in planned and controlled containment and management schemes. Therefore, it is necessary to obtain information rapidly and to maximize its efficiency by conjunctive use between the different sectors of the management/decision process. For the monitoring phase, this is done by incremental collection of information, immediate evaluation and dynamic incorporation in the network design process.

Acknowledgement

This study was partially supported by the Department of Interior, under project A-041 through the Water Resources Research Center, University of Minnesota, as authorized by the Water Resources Act of 1964, public law 88-379.

References

Convery, M.P. 1979. The behavior and movement of petroleum products in unconsolidated surficial deposits. M.S. Thesis, University of Minnesota, Minneapolis.

Eames, V.A. 1981. Study of oil retention under field and laboratory conditions. M.S. Thesis, University of Minnesota, Minneapolis.

Krumbein, W.C. and C.D. Monk. 1943. Permeability as a function of the size parameters of unconsolidated sand. AIME Trans., v. 151, pp. 153-163.

Pfannkuch, H.O. 1975. Study of criteria and models establishing optimum level of hydrogeologic information for ground-water basin management. Bulletin 81, Water Resources Research Center, University of Minnesota, Minneapolis.

Pfannkuch, H.O. and B.A. Labno. 1976. Design and optimization of ground-water monitoring networks for pollution studies. Ground Water, v. 14, no. 6.

Todd, D.K., R.M. Tinlin, K.D. Schmidt and L.G. Everett. 1976. Monitoring ground-water quality-monitoring methodology. Report EPA-600/4-76-026, Las Vegas.

Biographical Sketch

Hans-Olaf Pfannkuch attended the University of West Virginia School of Mines from 1952-53, received his Diplom-Ingenieur in Mining from Rheinisch-Westfalische Technische (Germany) in 1957, and his Ingenieur-Docteur from the Universite de Paris in 1962. Since that time, he has served as research engineer at the Institut Francais du Petrole, as assistant professor at both the University of Illinois and Southern Illinois University, and as associate professor at the University of Minnesota, his current position. He has written several text books including Elsevier's Dictionary of Hydrogeology (1969), and journal articles on subjects ranging from petroleum well logging to design and optimization of ground-water monitoring networks. While at the University of Minnesota, he has been active in a wide variety of applied research projects dealing with ground water and surface water and with information requirements for managing and monitoring ground-water systems. As a consultant, he has been involved in field studies and network design problems of spills due to pipeline breaks in central and northern Minnesota.

Allan W. Shatto is the engineering team leader for Decontamination Technology and Data Management in the U.S. Army Toxic and Hazardous Materials Agency, Aberdeen Proving Ground, Maryland. He has designed and implemented the Army's automatic data collection system for installation restoration environmental surveys. Currently, data is being collected from 15 installations with 12 additional sites scheduled this year. Shatto has a BS degree in chemical engineering from Lehigh University and a MS degree in administration of research and development from George Washington University.

☐ **Yes, I'd like to order _____ copies of "Introduction to Ground Water Hydrology." (Copies are $20 each, $18 each for orders of 10 copies or more.) I have enclosed my check for _____ made out to Water Well Journal Publishing Co.**

☐ **Please send me one sample copy for consideration as a text in a scheduled hydrology class. I have enclosed $5 to cover costs.**

Name of class _____

When scheduled to begin _____

University or College _____

Name _____

Title _____

Company Name _____

Address _____

City _____ **State** _____ **Zip** _____

69. Popkin, Barney. "Guidelines for Ground-Water Quality Assessments for Hazardous Waste Facilities," Ground Water Monitor Review, Spring 1983, pp. 65-70

2645
2647

GUIDELINES FOR GROUND-WATER QUALITY ASSESSMENTS FOR HAZARDOUS WASTE FACILITIES

Reviews the sequence, purposes, highlights and pitfalls of making ground-water quality assessments.

by Barney P. Popkin

Introduction

Ground-water quality assessments for hazardous waste facilities (impoundments, landfarms, landfills) are prudent and logically mandated extensions of ground-water monitoring practices. The basics of such assessments have been promulgated by the U.S. Environmental Protection Agency (U.S. EPA) in response to the Resource Conservation and Recovery Act (RCRA). However, many industrial clients are interested in more complete assessments because of potential environmental risks under criminal and civil liability and business-continuance practices.

The long-term values of periodic assessments include: developing a ground-water quality data base; tracking changes in ground-water quality over time; providing the basis for modifying monitoring networks; setting limits on potential liabilities; identifying a contaminant plume; suggesting remedial measures; and complying with regulations. Preliminary assessments, completed after the initial water-quality sampling and testing events, may lead to refining monitoring programs. Annual assessments may lead to reducing or increasing industrial and public concerns or initiating remedial or cleanup activities, as they may affirm benign or imminent conditions.

This article presents guidelines for ground-water quality assessments. It includes discussion of program planning, literature review, field investigation, office analysis, report preparation and client presentation. It is based on ground-water monitoring and quality-assessment projects completed by the author for industrial clients in the Gulf of Mexico coastal plain over the past three years. This article does not review the design or installation of monitoring wells or execution of sampling and analysis plans as previously published issues of GWMR discuss these issues. A recent presentation by Popkin and James (1982) provides details of anomaly and statistical analyses as applied to ground-water quality assessments.

Table 1 presents highlights of selected ground-water quality assessments recently completed in the Gulf coastal plain. The details and client names are not given to preserve confidentiality. The fifth example is a summary of 10 assessments which notes a conflict between current regulations and monitoring practices. The examples illustrate the application of various assessment techniques discussed herein.

Program Planning

Successful ground-water quality assessments, completed on schedule, within budget and with high-quality results, require careful planning and experienced execution. The scoping and schedule and cost estimating in the proposal stage may determine if the project will be approved, funded and initiated.

The schedule and cost of a ground-water quality assessment will largely depend on site access and hydrogeologic conditions. In the Gulf Coast, the shallowest aquifer lies within a few meters of the ground surface in soils or unconsolidated sediments. Typically, ground-water monitoring and quality-assessment projects in the Gulf Coast require two to three months to complete. They currently cost between $35,000 to $55,000, including field, laboratory, office activities, report preparation and client consultation.

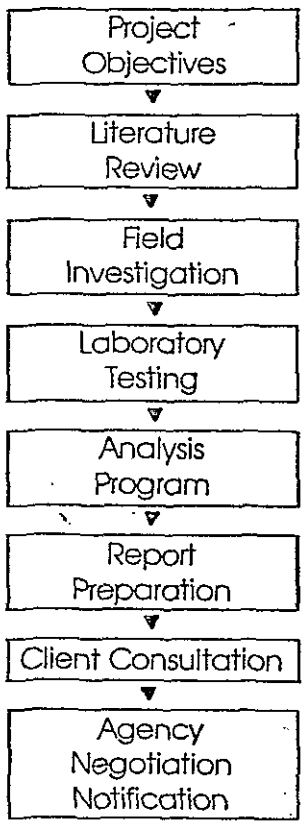
Figure 1 shows the key sequential elements of the ground-water quality planning process. In some cases, such as where significant ground-water contamination is assessed or where public or agency concerns require, agency negotiation or notification may be appropriate after client consultation.

The planning process should include an early overview of all planning elements to ensure adequate scope development, cost and schedule estimates, health and safety for field and laboratory activities, contingency and liability con-

siderations and quality and tracking controls. Project objectives should be clearly and narrowly defined, along with an appropriate scope, and ultimately, cost, schedule and personnel requirements. The planning document should be reviewed by the consultant's project manager and senior hydrogeologist, with consultation of principal investigators and other key personnel.

Insights developed during the planning process will pay off at all later stages of the project. Critical decisions, such as selection of drilling, soil-testing and water-quality analytical services, will benefit from careful planning. This is also the time to decide whether to conduct the project in phases or in total.

Figure 1. The planning process for ground-water quality assessments



Literature Review

Reviewing the published literature and client data is nearly always required in successful project execution. It is usually the least costly element of the project. This review may put limits on the extent, depth and location of required borings and monitoring wells, define the type and number of soil and water-quality analyses and identify potential hydrogeologic complexities and contingencies. The latter may include the presence of faults, multiple and pre-existing land uses, potential for reversing ground-water gradients, likelihood of variable background water quality and uncertain stratigraphy.

The literature review also includes a review of the client's files, permits, as-built drawings and other data which describe the site history, and land uses, processes and activities and hazardous waste facilities. Activities at the site prior to the present facility should also be noted because they may have affected ground-water quality.

In general, contact with representatives of the U.S. Army Corps of Engineers, the USGS, the Soil Conservation Service and appropriate state agencies, can produce updated information on flooding; land use; geology; ground-water use, quality and gradient; soils and related information. The Corps of Engineers, for example, has completed extensive borings for locks and dams and other structures; the Geological Survey monitors regional ground-water levels and quality; the Soil Conservation Service conducts county-wide and specialty soil surveys; state agencies often compile historical land use, geologic and

Table 1. Highlights of Selected Ground-Water Quality Assessements

1. A very large hazardous waste storage impoundment was found to be the source of high levels of heavy metals and organic chemicals detected in shallow ground water in southeastern, coastal Louisiana. Ground Water was found to be contaminated in all directions from the impoundment as a result of leachate mixing with nearby tidal and canal waters. Tidal variations and intermittent canal flows periodically reversed gradients. The site is an ore processing works.
2. An abandoned solid waste landfill was found not to be the source of high salinity, sulfate and chloride levels detected in shallow ground water in east Texas. Ground water was found to be contaminated from oilfield drilling and operational activities, independent of the landfill. Hydraulic analysis and time-of-arrival studies were used to eliminate superfluous monitoring wells. Frequency analysis was used to identify four on-site ground-water-quality classes. The site is a forested chemical dump.
3. Two solid waste treatment ponds were found to be the source of high salinity, sulfate and organic halogens levels detected in shallow ground water downgradient of the ponds in coastal Texas. A nearby downgradient bayou, which was connected to a saline estuary, was found to be the source of salt contamination of adjacent ground water. Anomaly analysis suggested four on-site ground-water-quality classes. The site is a refinery.
4. Two hazardous waste impoundments and a landfarm were found not to be the source of refined petroleum products detected in shallow ground water in the Houston Ship Channel in coastal Texas. Ground water was found to be contaminated from leaking pipeline valves, continued surface spills and unchecked practices which included dumping of product wastes into observation wells. The imminent public hazard was reduced by a shallow recovery system. The site is a refinery and tank farm.
5. Time-of-arrival analyses were performed after ground-water monitoring networks were installed at hazardous waste facilities in 10 coastal sites. The analyses used hydrogeologic and hydraulic data collected during the installation activities. The analyses indicated that only three of the networks could be expected to detect hypothetical contamination originating from the monitored facilities within 20 years. All of the networks, however, were found to be in compliance with current state and federal regulations under RCRA when installaed. The sites included refineries, petrochemical and chemical plants, iron and metal works, chemical dumps and paper mills.

water use information for planning studies. Some of the readily available results of this work are unpublished, and are accessible by a telephone call and a few well-directed questions.

Field Investigation

Conducting the field investigation is the most critical and costly element of the project. It is with this element that the consultant may have time delays and cost overruns from poor planning and coordination, miscommunication and uncooperative weather. There is much to do in the field: siting the borings; coordinating with the driller; developing the wells; collecting soil and water samples; coordinating with the surveyor; conducting in-place permeability tests; keeping timely, accurate and complete notes on subcontractor services and field data; making unanticipated decisions; communicating with numerous personnel of various responsibilities.

The field effort for monitoring and assessment projects is similar to geotechnical foundation projects which require subsurface borings. In addition, the former has these special requirements:

- Location and development of an appropriate number of monitoring wells, upgradient and downgradient of the hazardous waste facility. Large or multiple waste facilities may require more than the minimal one-upgradient and three-downgradient wells completed in the shallowest water-bearing material. It is crucial to locate the downgradient wells close enough to the waste facility so as to intercept the travel of likely facility contaminants during the period of sampling.
- Special care should be taken during the logging of borings to describe not only the location of soil types, but the observable conditions of soils which may affect water movement. These conditions include the presence of fissures, dessication cracks, calcareous nodules, woody material and slickensides. Zones of lost water circulation or high water pressure should be noted.
- Measurement of the depth to ground water and to the water level in the completed well (which may represent the water table or piezometric water surface). It is critical to distinguish between the depth to water encountered in the boring as opposed to the depth to water in the developed well. This may require dry auger drilling until ground water is encountered.
- Collection of undisturbed soil samples for laboratory tests of vertical permeability above the encountered water.
- In-place permeability tests for measuring horizontal permeability in the shallowest water-bearing materials.
- So that the direction and magnitude of the shallowest ground-water gradient may be calculated, the following should be determined accurately: depth to water levels in wells, elevations of water-level measuring points and location of wells on a suitable-scale map.
- Field testing of ground-water quality samples for specific conductance, pH and temperature should be made. Nearby canals, reservoirs, runoff storage areas, bayous, creeks, rivers and bays should also be sampled and tested.
- Careful well development, well evacuation and appropriate water-quality sampling and laboratory analytical procedures, including sample preparation, chain-of-custody and timely analysis. Split samples for water-quality analysis are an important quality-control measure.

Laboratory Testing

Laboratory tests are performed on soil and water samples for assessments. Soil samples are tested for classification, texture, permeability, porosity and to establish stratigraphic relationships. Water samples are tested for priority pollutants, interim drinking water parameters and miscellaneous, site- or process-specific indicators. In complicated hydrogeochemical situations, it may be necessary to analyze for major anions and cations and other elements to help classify water quality and identify migration. Testing procedures are generally standardized.

Care should be taken to fully saturate soil samples for laboratory permeability tests, and to apply appropriate in-place consolidation pressure related to sample depth.

It is also important to collect adequate sample volumes, and make correct sample preparation. The laboratory should report its actual results to detectable analytical limits, not just to "less than" a specific drinking water standard.

Office Analysis

The office analysis is generally performed by a project or senior hydrogeologist in coordination with key staff engineers. It consists of conducting the mathematical and heuristic analyses of data provided from the literature review, field investigation and laboratory testing. In smaller projects, the office analysis is performed when preparing the report. In larger projects, an office analysis may be performed and documented at the end of key literature, field and testing results.

Products of the office analysis include numerical restatement of historic and regional water levels, gradients, stratigraphy, aquifer properties, ground-water conditions, water and land use. Quantification of flooding, tidal phenomenon, river history, faulting and land subsidence may be important.

In a preliminary assessment, specific order-of-magnitude hydraulic analyses should be made. More detailed assessments will generally require computer modeling and more complex analyses not discussed in this paper.

Site-specific hydraulic calculations are made to define the direction and magnitude of the ground-water gradient. A hydraulic time-of-travel analysis of a hypothetical, conservative (nonreactive) contaminant is performed as this contaminant seeps vertically from the waste facility into the shallowest ground water, then horizontally within the water-bearing materials (Table 2). This hydraulic analysis utilizes Darcy's Law, with the effective porosity term (Freeze and Cherry 1979, U.S. EPA 1982). Fried (1975) and Freeze and Cherry (1979) present analytical methods which account for dispersion and attenuation.

Site-specific ground-water quality data are analyzed to classify water types, identify anomalies and perform statistical tests of significance. Water classifications are generally based on major anions and cations. Anomaly analyses are performed by planar mapping and mechanical contouring of isochem values (Bishop 1960). Statistical tests include the mandated Student's t-test, and, if at least 10 data points are available, frequency analysis. Note that if laboratory reports data as "< X," where X is a data value, use X/2 for < X when calculating the mean value of the data set (Texas Department of Water Resources 1982).

Student's t-test analysis is discussed in general statistical texts (Benjamin and Cornell 1970, Dixon and Massey 1957) and applied to ground-water assessments (Rovers and McBean 1981, Zar 1982).

Popkin and James (1982) recently presented a review of the method. Because the method is well known, it is not discussed further here.

Though frequency analysis is not specified by the U.S. EPA (1982), it is applicable to ground-water quality assessments for data reduction, water-class (type) definition, anomaly analysis and contaminant-source identification (Popkin and James 1982). Table 1 provides some relevant examples of its application.

Frequency analysis is a powerful analytical tool, familiar to all engineers who have calculated recurrence intervals for storms, floods and other hydrologic phenomena (Walton 1970). Frequency of occurrence (F, percent) is calculated from m (magnitude of occurrence, where m is unity for the largest data value, and ranges consecutively as integers from unity to n) and n (number of data values) by the equation $F = (m \times 100)/(n+1)$.

The parameter F is a good estimate of data frequency distribution when the sample size (n) is large. A minimum value of n is 10 for the distribution to be meaningful. In making the calculations, consider that equal data values will have different consecutive values of m and F, and the value of n is constant for a given frequency analysis problem. Values of F versus data values are plotted on logarithmic normal-probability paper, where F is the frequency-scale abscissa, and the data value is the logarithmic scale ordinate. A best-fitting straight line is drawn on the plot of F versus data values. Points which fall on or near the straight line comprise a normal distribution, and represent a similar system or class. Points which fall far from the straight line comprise a dissimilar population, or are deviant from the normally distributed data.

If the fitted line accounts for most of the plotted points, a good estimate of the population frequency of data occurrence is found directly from the fitted line: the 50.0-percent frequency estimates the average population value, and the 15.9-percent and 84.1-percent frequencies estimate a standard deviation above and below the average (Dixon and Massey 1957, Benjamin and Cornell 1970).

Report Preparation

The report is the final product of the ground-water quality assessment, and should be clear and comprehensive. It should provide the client with definitive and useful information, draw conclusions which can be substantiated and make reasonable recommendations. The report should include supportive evidence and summarize, if not detail, all data collected during the assessment (Wilson 1952).

Table 2. Time-of-Travel Equations for a Conservative Ground-Water Contaminant

$$q = (K \times I)/p^*$$
$$T = d/q$$

where

q = average linear velocity, m/s
K = hydraulic conductivity, m/s
I = hydraulic gradient, dimensionless
p = effective porosity, dimensionless

and

t = arrival time, s
d = linear travel distance, m

Note that all variables are with respect to the same direction, and the equations are for water-soluble conservative contaminants in nondispersive and nonattenuative porous media flow. A guide for K and p values is shown below (Davis 1969). Freeze and Cherry (1979) note that anisotropy in unconsolidated deposits is primarily caused by the orientation of clay minerals. They state that the ratio of horizontal to vertical hydraulic conductivity of core samples of clays is usually less than 3:1, and rarely greater than 10:1. The ratio for gravels and sands is usually less than 2:1.

Unconsolidated Deposits	Hydraulic Conductivity m/s, K	Hydraulic Conductivity ft/day	Porosity, p
Gravel	10^{-3} to 1	10^{2} to 10^{5}	0.25 to 0.40
Clean sand	10^{-6} to 10^{-2}	10^{-1} to 10^{3}	0.25 to 0.50
Silty sand	10^{-7} to 10^{-3}	10^{-2} to 10^{2}	0.30 to 0.50
Silt, loess	10^{-9} to 10^{-4}	10^{-4} to 10	0.35 to 0.50
Clay	10^{-13} to 10^{-9}	10^{-8} to 10^{-4}	0.40 to 0.70

*Freeze and Cherry 1979, p. 71.

Table 3. Outline of Ground-Water Quality Assessment

- Introduction
- Setting
- Facility Description
- Regional Hydrogeology and Ground-Water Quality
- Site Hydrogeology and Ground-Water Quality
- Assessment and Recommendations
- Figures
  - Site Location Map or Vicinity Map
  - Ground-Water Monitoring Wells on Site Plan
  - Subsurface Profiles
  - Geohydrologic Column
- References
- Appendices
  - Field Exploration and Soil Laboratory Tests
  - Ground-Water Monitoring Program
  - Analyses of Ground-Water Samples

Table 3 is an outline for a ground-water quality assessment report. The items include the body and appendices of a typical assessment. Care should be taken in consistent terminology, units, abbreviations, balance and emphasis in writing reports. The draft and final reports should be read thoroughly at least once by the project manager and senior hydrogeologist.

"Introduction" should include the background, contract and proposal citation, and objectives of the assessment. Abbreviations for the client and facility to be used throughout the report should be included in this section.

"Setting" should include regional and local description of geographic matters, such as climate, rainfall, flooding, runoff and drainage, attitude, land use and agricultural soils, surface geology, topography and other factors.

"Facility Description" should locate the site on a regional map (first figure), describe the site features, land use, chemical processes and waste storage, treatment and disposal activities. This section should include information on land surface elevations, local drainage and slopes. It is important to describe the geometry of the waste facilities, including the as-built elevation of the base of the facilities, description of any liners and operating procedures.

"Regional Hydrogeology and Ground-Water Quality" should include a discussion of the major aquifers, their usage, stratigraphy, ground-water conditions—gradient directions and magnitudes, elevation of the ground-water surface. An indication of regional ground-water quality and related issues, such as seawater intrusion and oilfield brine disposal practices should be made.

"Site Hydrogeology and Ground-Water Quality" should provide locations of borings and piezometers (second figure), and include discussions of the site stratigraphy, subsurface profiles (additional figures) and shallowest water-bearing soils. Shallow ground-water conditions—gradient directions and magnitude elevation of water table or piezometric surface should be covered in detail. This section should also include a description of local ground-water quality, with significant anomalies and frequencies, and seasonal fluctuations noted.

"Assessment" should combine the hydraulic analysis of the site hydrogeology, and the anomaly analysis of hypothetical leachate. A reasonable picture of the potential for contaminant migration from the waste facility from seepage and horizontal movement through and off the site should be produced. Imminent and potential ground-water quality risks to the public must be identified.

"Recommendations" should refine the quality of the hydraulic and water-quality analysis and evaluate the synthesis of hydrogeologic and anomaly analysis, and work towards statistical significance if needed. Recommendations should suggest remedial action and closure if appropriate. Recommendations should be presented in a natural and supportive way, so that the client is logically drawn toward them.

"Figures" should include a vicinity map, a site plan with boring and monitoring well locations, one or two subsurface profiles, and a local geohydrologic column at a minimum. The site plan should show the location of the subsurface profiles, and the direction and magnitude of the gradient. If ground-water anomalies are clearly present, additional figures may highlight this through anomaly maps which overextend the size of anomalies because of sparse and distant control points.

"References" should include all cited literature, the consultant's and client's files, conversations with agency personnel and client reports. Confidential reports completed for other clients with nearby facilities should not be explicitly cited.

"Appendices" should include field exploration and soil laboratory testing, ground-water monitoring network, ground-water sampling and analysis plans and analyses of ground-water samples. Specific tables, such as logs of borings, summary of ground-water-level measurements, well completion data, soil laboratory tests, field water-quality analyses, laboratory water-quality analyses and chain of custody records are appropriate. Personnel involved and procedures utilized in the various phases of the project should be identified. Examples include notations such as "water levels were measured with a steel tape by . . ."; "elevations were determined with a topographic survey by . . ."; "field measurements were made with a conductivity meter, pH meter and thermometer by . . ." etc. Data should be reported to significant figures. Basic data collected during the investigation must be provided so that the client can perform an independent assessment.

The draft and final reports should be thoroughly reviewed for technical acccuracy and editorial consistency. Reports should be checked for numerical, citation and typographical errors, as well as tone, consistency, emphasis and logic. A poorly written report will erode credibility, diminish future opportunities and cause later expense and embarrassment.

Client Presentation

The client should generally be given a draft final report to review. The client may correct any facility related or procedural errors that the consultant may make, though the consultant must make this draft as clear and accurate as possible.

It is generally more vivid and consequently more effective for the consultant to review the report in the physical presence of the client. This presents an opportunity to educate and learn, to profitably exchange viewpoints and to develop new work. It is also an opportunity to appear disorganized, inarticulate and to incorrectly interpret sparse data. The consultant should be fully prepared to make the presentation, and should make practice presentations to a critical staff who have not worked on the project.

The consultant should be prepared to make specific recommendations for modifying, expanding or continuing ground-water monitoring programs. Peripheral consulting services, such as data-base management, quarterly report preparation and agency negotiations should be offered if appropriate. The consultant should anticipate questions that the client might ask.

Special care must be taken in agency negotiation and notification. The consultant has a professional responsibility to inform the client if client practices violate public policy, but the client's information is confidential. In notifying agencies, only the required data should be supplied. In negotiating with agencies on behalf of clients, the consultant must be forthright and yet represent the interests of the client. Notification and negotiation are special skills which all consultants must cultivate. The consultant must learn to judge what is too much and what is too little in these matters.

Acknowledgment

I would like to thank Law Engineering Testing Co. in supporting

my efforts in the preparation of this article.

Carl L. Brassow, chief engineer, and Phillip L. Fitzwater, project hydrogeologist, of Law Engineering/Houston branch contributed useful review comments.

References

Benjamin, J.R. and C.A. Cornell. 1970. Probability, statistics and decision for civil engineers. McGraw-Hill Book Co. Inc. New York, 684 pp.

Bishop, M.S. 1960. Subsurface mapping. Wiley, New York, 198 pp.

Davis, S.N. 1969. Porosity and permeability of natural materials. In R.J.M. DeWiest, editor. Flow through porous media. Academic Press, New York, pp. 54-81.

Dixon, W.J. and F.J. Massey Jr. 1957. Introduction to statistical analysis. McGraw-Hill Book Co. Inc. New York, 488 pp.

Freeze, R.A. and J.A. Cherry. 1979. Ground water. Prentice-Hall Inc. Englewood Cliffs, New Jersey, 604 pp.

Fried, J.J. 1975. Ground-water pollution. Elsevier, New York, 330 pp.

Popkin, B.P. and W.R. James. December 3, 1982. Use of monitoring wells to assess ground-water quality near hazardous waste facilities. Paper presented to "Ground Water—Prospects and Problems." Symposium sponsored by the Texas Section, American Water Resources Association. Austin, 33 pp.

Rovers, F.A. and E.A. McBean. 1981. Significant testing for impact evaluation. Ground Water Monitoring Review, v. 1, no. 2, pp. 39-43.

Texas Department of Water Resources. July 26-27, 1982. Workshop for Industrial Waste Generators. Houston.

U.S. EPA. July 26, 1982. Federal Register, v. 47, no. 143.

Walton, W.C. 1970. Ground-water resource evaluation. McGraw-Hill Book Co. Inc. New York, 664 pp.

Wilson, E.B. Jr. 1952. An introduction to scientific research. McGraw-Hill Book Co. Inc. New York, 373 pp.

Zar, J.H. 1982. Power and statistical significance in impact evaluation. Ground Water Monitoring Review, v. 2, no. 3, pp. 33-35.

Biographical Sketch

Barney P. Popkin is a senior hydrologist and project manager with Law Engineering Testing Co. of Houston, Texas. He has more than 18 years of experience in ground-water development and waste management, and has presented more than 50 technical papers in hydrology and water resources. Popkin was educated at New York University, New Mexico Tech and the University at Arizona. He is a professional geologist (Georgia) and a certified professional soil scientist (ARCPACS), and is active in the American Institute of Chemical Engineers, American Society of Civil Engineers, American Water Resources Association, National Water Well Association and the Texas Roundtable on Hazardous Wastes.

70. Reed v. Angelo Scandinavian Corp., 298F. Supp. 310 (1969)

such person shall be imprisoned, unless the sentence be sooner terminated by commutation or pardon by the Governor of the State." * * *

Section 2940 of the California Penal Code provides as follows:

"Where the Adult Authority is authorized to *fix and refix* the term of imprisonment of a prisoner, such prisoner shall be discharged from custody upon the completion of said term *so fixed or refixed* * * *." (Emphasis added)

Since Cal. Penal Code § 2940 recognizes that sentences may be "fixed and refixed" it is clear that a sentence, once fixed, could be refixed and the term of imprisonment lengthened for any amount of time up to the maximum prescribed by law.

[2, 3] The basic premise of petitioner's argument—that his sentences for the robbery and kidnapping convictions *were permanently determined* at eight years—is incorrect. As Sturm v. California Adult Authority, 395 F.2d 446, 448 (9th Cir. 1967) teaches,

"* * * all indeterminate sentences are for the maximum, and any determination by the Adult Authority is only tentative."

When the Adult Authority reduces a maximum sentence, its action is only tentative and may be changed whenever good cause is shown. Petitioner has no vested right to have the term of imprisonment which he is serving fixed or remain fixed at less than the maximum term prescribed by law. In Re Smith, 33 Cal.2d 797, 804, 205 P.2d 662 (1949).

Petitioner cites In Re Beasley, 256 Cal.App.2d 721, 64 Cal.Rptr. 540 (1967) to support his contention, but that case is clearly distinguishable from the case at bar since in *Beasley* the originally set term had already expired when the Adult Authority reset the sentence. The principle of the *Beasley* case is stated as follows:

"Section 2940 of the Penal Code requires that a prisoner be discharged on completion of his term as *fixed or* refixed. The Adult Authority has power to redetermine sentences. (Pen.Code, § 3020.) But this must be within the sentence as fixed or refixed. Revival of a completed term by later action of the Adult Authority is impossible." In Re Beasley, supra, 256 Cal.App.2d at 723, 64 Cal.Rptr. 541.

In the instant case, the redetermination of petitioner's sentence was well within the originally set term, which would have lasted until 1966. The parole was revoked, and the sentence was reset on December 18, 1963. Thus it is clear that neither the *Beasley* rationale nor the statutory language compel us to cause the issuance of a writ of habeas corpus.

For the foregoing reasons, and it clearly appearing that an evidentiary hearing is not required, this Court finds that petitioner is not entitled to any relief.

Therefore, it is hereby ordered that the Petition for Writ of Habeas Corpus be, and the same is, denied.

V. J. REED as Trustee in Bankruptcy for Dorothy Penny Hansen, dba Porter's Apparel and Ski Shop, Plaintiff,

v.

ANGLO SCANDINAVIAN CORPORATION, Defendants.

Civ. S-781.

United States District Court
E. D. California.
March 12, 1969.

Action under Bankruptcy Act by trustee to avoid bankrupt's prior transfer of property. On plaintiff's motion for summary judgment, the District Court, MacBride, J., held that sale in vicinity of 5 per cent of total inventory

was a transfer of "a substantial part of the inventory" and was subject to California bulk transfer provisions, and since there was no statutory notice given creditors, the transfer was void under California law and voidable by trustee in bankruptcy.

Motion granted.

2. Fraudulent Conveyances ⟹47

Major purpose of bulk transfer statutes is to afford merchant's creditors an opportunity to satisfy their claims before merchant can transfer his assets to a bona fide purchaser and vanish with proceeds of the sale. West's Ann.Cal. Com. Code, §§ 6105, 6107.

3. Bankruptcy ⟹175
Fraudulent Conveyances ⟹47

Sale in vicinity of 5 per cent of total inventory was a transfer of "a substantial part of the inventory" and was subject to California bulk transfer provisions, and since there was no statutory notice given to creditors, the transfer was void under California law and voidable by trustee in bankruptcy. Bankr. Act § 70, sub. e(1), 11 U.S.C.A. § 110 e(1); West's Ann.Cal.Com.Code, §§ 6102(1, 3), 6105.

See publication Words and Phrases for other judicial constructions and definitions.

Thomas McCampbell, Chico, Cal., Milton Maxwell Newmark, Lafayette, Cal., for plaintiff.

Evans, Jackson & Kennedy, Sacramento, Cal., for defendant.

AMENDED MEMORANDUM AND ORDER

MacBRIDE, Chief Judge.

This is an action under section 70e of the Bankruptcy Act by the trustee to avoid the bankrupt's prior transfer of property.

On May 7, 1967, Dorothy Penny Hanson (hereinafter the debtor), proprietor of Porter's Apparel and Ski Shop, sold an assortment of skis and ski boots to the defendant, Anglo Scandinavian Corporation. In the Fall of 1967 the debtor was adjudged bankrupt. The trustee now moves for summary judgment. The defendant opposes this on the ground that there are still issues of fact to be determined.

Section 70e(1) of the Bankruptcy Act provides:

> A transfer made or suffered or obligation incurred by a debtor adjudged a bankrupt under this Act which, under any Federal or State law applicable thereto, is fraudulent as against or voidable for any other reason by any creditor of the debtor, having a claim provable under this Act, shall be null and void as against the trustee of such debtor.

Plaintiff trustee here alleges that the sale of merchandise to defendant is void under the provisions of the California Commercial Code annulling certain bulk transfers. If the trustee can prove that this was a "bulk transfer," void under California law, he will prevail in this action.

California Commercial Code § 6105 provides that a "bulk transfer" is fraudulent and void against any creditor of the transferor unless the transferee gives the required statutory notice to creditors. A "bulk transfer" is "any transfer in bulk and not in the ordinary course of the transferor's business of a *substantial part of the* materials, supplies, merchandise, or other *inventory* * * * of an enterprise subject to this division." [emphasis added] Cal.Com. Code § 6102(1) (West 1964). Being a retail merchant, the debtor in this case was subject to the law. Cal.Com.Code § 6102(3) (West 1964).

A perusal of the memoranda and affidavits of the parties discloses that there is no genuine disagreement as to any fact necessary for plaintiff's recovery except what proportion of the total inventory was transferred.[1] Plaintiff

[1] Defendant incorrectly insists that there are other issues of fact to be determined:

1.) Insolvency of the debtor at the time of transfer. (While pleaded in the com-

sets the percentage at "approximately 7.5 per cent." Defendant offers to prove that the transfer was of "less than 5 per cent" of the total inventory. The parties also disagree about what constitutes "a substantial part of the inventory of an enterprise" under the bulk transfer law. Plaintiff argues that since, according to the debtor's testimony, the transfer was of about 50 per cent of the ski boot inventory, it was a transfer of "a substantial part of the inventory." Defendant rejoins that the proper measure is the percentage of the whole inventory of the enterprise not the percentage of the particular item transferred.

Surprisingly, there are few cases construing the words "substantial part of the inventory." It is indisputable, however, that to be "substantial" the proportion transferred need not be 50 per cent or even close to 50 per cent. The Uniform Commercial Code uses the words "major part." The California Commercial Code substituted the words "substantial part" to preserve prior California law.[2] In California as little as 6.3 per cent,[3] 15 per cent,[4] and 16 per cent[5] of the total inventory have been held to constitute a "substantial part" within the meaning of this section. The cases[6] also illustrate that the proper gross measure is the entire inventory and not as plaintiff suggests: the proportion of the specific item transferred.[7]

It is undisputed that the purchase price of the merchandise transferred to defendant was $5,489.64. I have concluded that plaintiff is entitled to summary judgment in this amount.

While it is true that the total value of the debtor's inventory at the time of transfer (and thus the exact percentage which was transferred) is still in dispute, that does not preclude summary judgment in this case. In the first place, it is likely that there will never be a more accurate determination of the inventory.[8] Secondly, I have concluded that even taking the defendant's estimate—less than

plaint, it is superfluous—section 70e transfers need not be made during insolvency to be voidable.) 2.) Whether the transfer was "in the ordinary course of business" since allegedly customary in the trade. (This contention was laid to rest by the 9th Circuit in Jubas v. Sampsell, 185 F.2d 333, 334 (9th Cir. 1950).)

2. Bohn and Williams, California Code Comment to Commercial Code § 6102 (West 1964).

3. Markwell & Co. v. Lynch, 114 F.2d 373 (9th Cir. 1940).

4. Jubas v. Sampsell, 185 F.2d 333 (9th Cir. 1950).

5. Schainman v. Dean, 24 F.2d 475 (9th Cir. 1928).

6. The three cases cited *supra*, notes 3–5, are the only ones I have found construing "substantial part of the inventory."

7. Common sense also indicates that plaintiff's suggestion cannot be right. According to his view if the debtor in this case had instead sold her entire supply of Chap Stick, worth say $20, that would be voidable as a bulk transfer even if the ski shop's total inventory was $100,000. The bulk transfer law clearly does not contemplate such a result.

8. The unaudited financial statements in the file indicate that as of December 31, 1966, the business's inventory was $137,000. For the ten-month period ending December 31, 1966, cost of goods sold averaged $10,700 per month. Projected purchases for the period April 1967 to September 1967 were $17,600. Inventory on hand on March 31, 1966, was $82,000. Although not necessary for this decision, a reasonable projection of inventory as of May 7, 1967, based on these figures, indicates that pegging the transfer at about 5 per cent of inventory is not unreasonable. In an affidavit Herbert Kahn, who sold the store to the debtor in March 1966 and bought it back at the trustee's sale in November 1967, estimates the inventory at the time of transfer to be $80,000. This led to plaintiff's estimate of 7.5 per cent. I do not know how defendant arrived at its figure, but I am convinced that a trial would not perceptibly narrow the range of possibilities.

per cent—the dollar amount of the transfer brings it within the meaning of the bulk transfer law.

[12] The major purpose of these bulk transfer statutes is to afford the merchant's creditors an opportunity to satisfy their claims before the merchant can transfer his assets to a bona fide purchaser and vanish with the proceeds of the sale.[9] In Markwell v. Lynch, supra, the court held that a transfer of as little as $600 or 6.3 per cent of the total inventory was a bulk transfer. Where the interests of creditors are involved, the dollar amount of the transfer is relevant in assessing the potential damage to creditors.[10] Thus, in this case where the amount of the transfer, $5,489.64, is sufficient to prejudice the interests of creditors to a substantial degree, I hold that a sale in the vicinity of 5 per cent of the total inventory is a transfer of "a substantial part of the inventory" and is subject to the bulk transfer provisions.[11] Since there was no statutory notice given to creditors, the transfer is void under California law[12] and voidable by the trustee in bankruptcy under section 70e of the Bankruptcy Act. There being no further genuine issue as to any material fact, the plaintiff trustee is entitled to a summary judgment. Fed.Rule of Civil Proc. 56(c).

It is therefore ordered that plaintiff's motion for summary judgment be granted and that judgment in this case be rendered for the plaintiff in the amount of five thousand four hundred eighty-nine dollars and sixty-four cents ($5,489.64).

9. Ring, Bulk Sales Problems in California, 42 California Law Review 579 (1954) (citing comment to the Uniform Commercial Code).

10. From an examination of the financial records in the file, it can be said that a bulk transfer of this size had a significant effect on the business's financial profile. So in that sense also it was a "substantial" transfer of assets.

11. Future business transactions will not be prejudiced by this holding if the transferor is on solid financial ground. The law does not prohibit any bulk transfers so long as the proper notice is given to creditors. Cal.Com.Code §§ 6105 & 6107 (West 1964 & Cumulative Supplement 1968). That is not an inordinate burden.

12. Cal.Com.Code § 6105 (West 1964).

The AMERICAN GREINER ELECTRONIC, INC.
v.
UNITED STATES.

R.D. 11658; Reappraisement R61/20888.

United States Customs Court.
April 8, 1969.

Reappraisement proceeding involving the proper dutiable value. The Customs Court, Ford, J., held that the importer of Swiss watch timers had successfully proved that difference between price at which manufacturer sold timers to importer as a selected purchaser and price which manufacturer sold timers to its Swiss wholesalers was accounted for by specific differences in costs incurred in such sales and successfully proves the nature and amount of costs in support of its claim of export value.

Judgment accordingly.

1. Customs Duties ⟹79

To prove market value of its merchandise as basis for further computations of export value, importer need only show by satisfactory evidence that certain price is price which its product is able to command in foreign market, and price need not be the same as that of other manufacturers of same or similar merchandise. Tariff Act of 1930, § 402 (b, d) as amended 19 U.S.C.A. § 1401a (b, d).

2. Customs Duties ⟹79

If government introduces evidence which tends to cast doubt on genuineness

71. Rinaldo-Lee, M.R. "Small vs. Large Diameter Monitoring Wells," Ground Water Monitoring Review, Winter 1983, pp. 72-75

2646

SMALL- VS. LARGE-DIAMETER MONITORING WELLS

Well diameter is one of the most important aspects of monitoring system design.

by Marjory B. Rinaldo-Lee

Designing an effective ground-water monitoring program and using proper monitoring well design is a matter of concern for both regulatory agencies and private industry. Although many factors must be considered when designing a ground-water monitoring program, such as location of monitoring points and the type of monitoring installation, well diameter is one of the important parts of the monitoring installation design.

In this article, small-diameter wells are considered 2-inch diameter or smaller. Two-inch diameter was chosen as the upper limit for small-diameter wells for several reasons. First, the drilling methods used to install 2-inch or smaller wells are often different from those used to install wells with a larger diameter. Second, until quite recently submersible pumps were only available for 3-inch or larger diameter wells.

The factors which influence choice of well diameter for a monitoring program fall into two groups: economic and technical. Although technical and economic factors will be discussed separately, they should be considered concurrently when designing a monitoring program. Technical factors can influence the cost of a program and conversely economic factors can influence the extent of the technical program.

Technical Factors

In designing any ground-water monitoring program, the first issue to be addressed is the purpose of the program. The designer must ascertain what questions are to be answered by the investigation. The three main purposes for ground-water monitoring are baseline data accumulation, ground-water resource evaluation and ground-water contamination studies. The approach used for each of these types of studies is quite different.

Baseline data studies are usually initiated to provide data on long-term trends or general hydrogeologic conditions in an area. For some baseline data investigations, long-term water-level fluctuations are of interest. If the monitoring points are at remote locations, or continuous water-level readings are needed, automatic recorders may be desired. Since large-diameter wells can more easily accommodate floats for automatic recorders they would be preferred for this type of investigation. However, if the goal of the study is to define hydrogeologic conditions over a broad area where many well points are needed, small-diameter wells may be preferred due to their comparative ease of installation and lower cost. Thus, depending on the specific needs of the investigation, either small- or large-diameter wells may be preferred for a baseline study.

A ground-water resource investigation is quite different from a baseline data study. These investigations are usually initiated in response to a demand for a source of water supply. A ground-water resource investigation could be initiated because water is needed for drinking water, industrial processes, agricultural activity or some other use. Alternatively, a resource investigation could also be initiated to determine how to dewater an area for some activity requiring a lowered water table, such as construction or mining. A pump test is often needed for determining both the amount of water available for use, or the amount of water which must be withdrawn. A large-diameter well may be needed to accommodate a submersible pump with a large enough capacity to allow a pump test to be conducted. However, small-diameter wells are adequate for observation wells to allow monitoring of drawdown and evaluation of pump tests. Thus, both large- and small-diameter wells are commonly used in ground-water resource investigations.

Monitoring requirements for ground-water contamination studies are quite different from those for the preceding studies. Often many wells are needed in various geologic formations to determine the extent of past contamination or the potential for contaminant migration from a proposed site. For ground-water contamination studies, small-diameter wells are often preferred because they are less expensive and more sampling points can be installed for a fixed amount of available funds. Another reason for the use of small-diameter wells in contamination studies is the comparative ease of sampling from such wells.

Wells are normally purged before sampling in contamination studies to remove stagnant water from the borehole and to ensure that the water sample is representative of formation water. The volume of water which must be removed from a small-diameter well is much less than that from a large-diameter well because the volume increases with the square of the well radius. As shown in Figure 1, there are 0.16 gallons/ft of water in a 2-inch diameter well and 1.47 gallons/ft of water in a 6-inch diameter well. Because purging a well requires removing

from three to 10 volumes of water from the well casing, considerably more water must be removed from a 6-inch diameter well than from a 2-inch diameter well. To purge 10 volumes of water from a well containing 10 feet of water in the casing, 16 gallons of water must be removed from a 2-inch diameter well, as opposed to 147 gallons of water from a 6-inch diameter well.

Another sampling consideration is obtaining a sufficient quantity of water from a well for analysis. Small-diameter wells have a much smaller volume of water per foot of length (Figure 1). However, for many sampling situations, one gallon of water is sufficient for a large number of analyses. Table 1 demonstrates that a 6.13-foot column of water in a 2-inch diameter well produces one gallon of sample, while a 0.68-foot column of water produces a gallon of sample in a 6-inch well.

A third factor which favors small-diameter wells for contaminant sampling is the time of recovery. Because the time of recovery is directly proportional to the well volume, the time for recovery also increases with the square of the well diameter. For a given hydraulic conductivity, it takes less time for a small-diameter well to recover when a slug of water is removed than for a large-diameter well. Figure 2 illustrates the time of recovery for various diameter wells assuming a given hydraulic conductivity, screen length and instantaneous lowering of the water surface in the well. Assuming a hydraulic conductivity of 0.028 ft/day (1×10^{-5} cm/sec), screen length of 10 feet and an instantaneous lowering of the water table by 6 feet, it would take 11-1/2 minutes for a 2-inch diameter well to recover 5 feet. Twenty-three and a half minutes would be required for the same recovery in a 3-inch diameter well and 42 minutes for the same recovery in a 4-inch diameter well. These recovery times are important in contaminant sampling because unlike ground-water resource investigations, the formation being investigated for a contamination study may be fairly impermeable. If a large-diameter well is purged before sampling in a fine-grained soil, it may take many hours to recover, while a small-diameter well will recover more quickly.

Hydrogeologic conditions also influence the choice of well diameter. Hydrogeologic conditions can generally be divided into two categories: aquifer characteristics and the ground-water regime. Aquifer characteristics include the formation parameters which influence ground-water movement, such as hydraulic conductivity. Factors included under ground-water regime include depth to the potentiometric surface, the nature of the aquifer (whether confined or unconfined) and the number of aquifers being investigated. All of these factors influence the choice of well diameter.

If the formation of interest has a low hydraulic conductivity, small-diameter wells are preferred for monitoring. Not only do small-diameter wells recover more quickly for water sampling, they stabilize more quickly after initial installation. In a clay formation with a low hydraulic conductivity (3×10^{-4}-3×10^{-5} ft/day), it could take months for a 4-inch diameter well to stabilize.

Depth to the water table from the ground surface was once a limiting factor in using small-diameter wells. Bailers were the only means for withdrawing water from wells where the potentiometric surface was below the suction limit (about 25 feet). However, with the advent of a variety of small-diameter submersible pumps which fit inside 2-inch diameter wells and various air-lift and positive displacement pumps for 2-inch diameter or 1-inch diameter wells, it is not necessary to use a

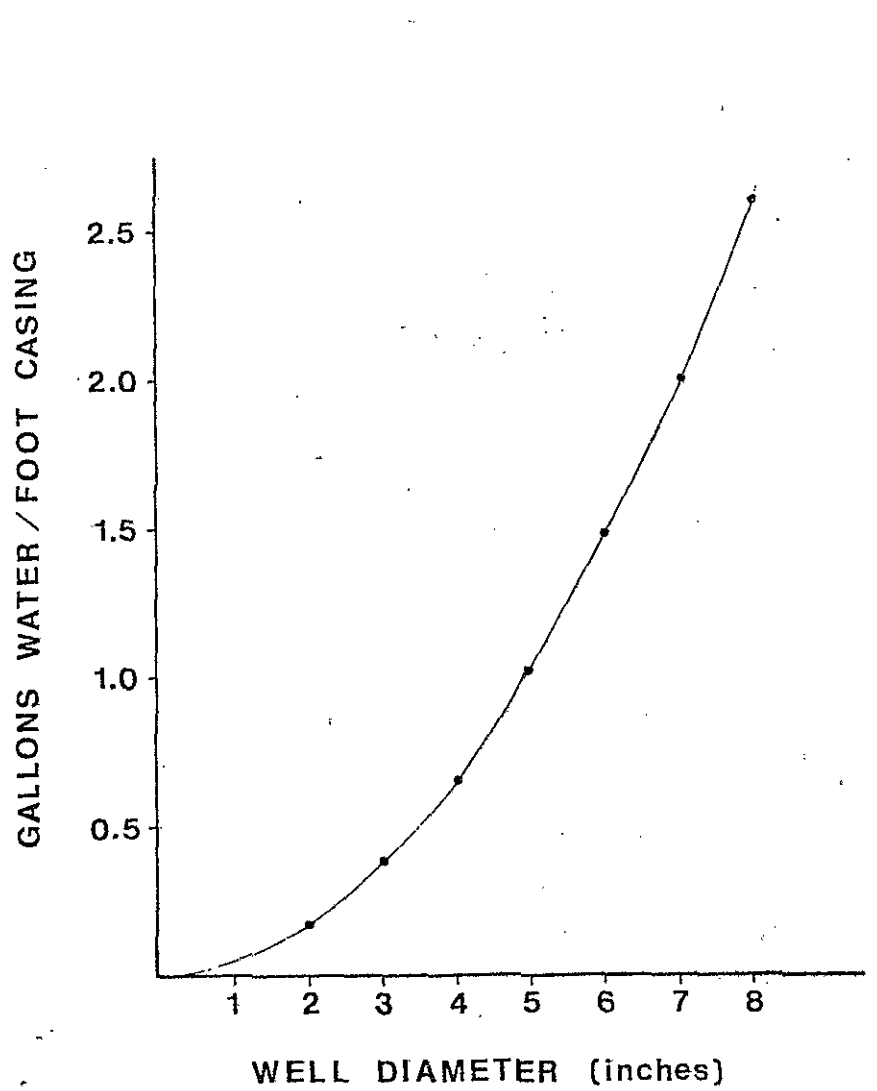


Figure 1. Volume of water in well casing

Table 1
Comparison of Length of Well Casing Containing One Gallon of Water with Well Diameter

Well Diameter (inches)	2	3	4	5	6
Length of well casing needed to obtain 1 gallon water (feet)	6.13	2.72	1.53	0.98	0.68

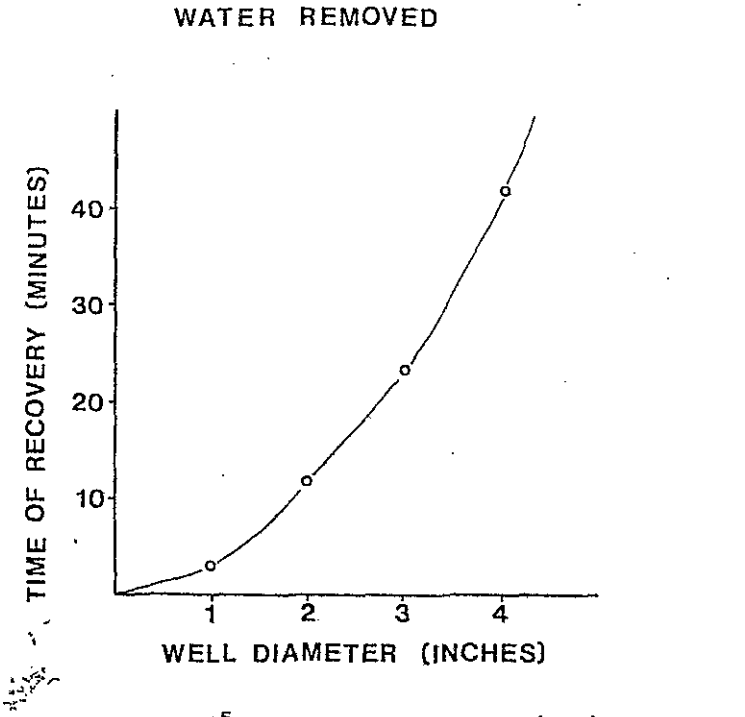


Figure 2. Time required for well recovery when slug of water removed

bailer to remove water from small-diameter wells.

Depth to the potentiometric surface may be a limiting factor in the use of small-diameter wells where the water-table surface is very deep (i.e. several hundred feet). In the western U.S., where aquifers may be hundreds or thousands of feet deep, a small-diameter well may not be desirable due to difficulties in well construction procedures and the increased probability of well casing failure at depth. Although sampling devices have been developed for very deep wells, it can still be difficult to sample deep small-diameter wells. Larger diameter wells may be preferred in this situation.

Another geologic consideration is the number of aquifers or levels within a single aquifer being investigated by the monitoring program. If multilevel sampling points are needed to monitor various aquifers, or various levels within one aquifer, small-diameter wells are generally preferred due to their low cost and ease of installation.

Economic Factors

Along with technical factors, economic factors have a significant influence on the choice of well diameter. Funds for a ground-water investigation are generally limited and it is always desirable to obtain the most information for the least cost. The economic factors which influence the cost of installing monitoring wells include drilling cost, materials cost and labor cost.

Drilling costs depend on the method of well installation and the drilling contractor. One of the methods often used to install monitoring wells in unconsolidated deposits is the hollow-stem auger. Hollow-stem augers are used because soil samples can be taken during drilling and the monitoring well can be installed inside the hollow stem without collapse of the borehole. However, a normal hollow-stem auger has an inside diameter of only 2-1/4 to 3-3/4 inches so it cannot be used effectively to install a well with a diameter of more than 2 inches. A larger hollow-stem auger with a 6-inch inside diameter can be used to install up to 4-inch diameter wells; but the cost of drilling using the larger hollow-stem augers is greater. The cost of drilling and obtaining soil samples is about $8/ft using a small-diameter hollow-stem auger compared to $17.50/ft for the large hollow-stem auger (Table 2). Generally, a water well contractor is more cost-effective to use for drilling a 4-inch or larger diameter well than a geotechnical-soil contractor. Since most water well contractors are not equipped for soil sampling, if soil sampling were required to define subsurface conditions, it might require hiring both types of contractors.

Drilling costs for a geotechnical-soils contractor to install wells in rock are generally higher than for drilling through unconsolidated deposits. The differential between drilling in rock and drilling in unconsolidated deposits is much greater if rock samples are required. Coring to obtain rock samples adds significantly to the cost of drilling. Rock coring by a geotechnical contractor is about $26/ft for a hole large enough for a 2-inch diameter well and $35/ft for a hole large enough for a 4-inch diameter well. Generally, a water well contractor is more cost-effective to use for installing large-diameter wells in rock formations. However, water well contractors are usually not equipped for rock coring. If this is deemed necessary to the investigation program, two contractors may be required to install monitoring wells in rock formations.

Labor and material costs are also factors affecting choice of well diameter. Well installation, well development and well purging are all labor costs associated with a monitoring program. Small-diameter wells are generally easier to install and therefore take less time. They also take less time to develop and purge since a smaller volume of water must be removed. Thus, labor costs are lower for small-diameter wells. Material costs are also lower for small-diameter wells (Table 2). The cost per foot of well casing and screen increases with well diameter for both PVC and stainless steel, the most common types of casing/screen used in monitoring wells.

When drilling costs, labor costs and material costs are all taken into consideration, the total cost to install the same type of well, using different diameter well casings, can be compared (Table 3). If a 50-foot PVC well is installed with a 10-foot PVC well screen, the total installation cost in unconsolidated materials, including conventional standard split spoon sampling at intervals of 5 feet, would be $1,200, or about $24/ft. The cost to install a comparable 4-inch diameter in the same unconsolidated material with standard sampling would be about $2,500 or about $50/ft, or more than twice the cost for the 2-inch well. The cost for installing a 2-inch diameter well after coring through rock would be about $2,600 or $52/ft. The increase

in cost of installing a well as the diameter of the well is increased will influence the design of the monitoring program.

Summary

Both technical and economic factors influence monitoring well design. Depending on the purpose of the monitoring program, the hydrogeologic conditions and the economic constraints, both small- and large-diameter wells have advantages (Table 4). The advantages of small-diameter wells are: 1) they stabilize quickly in low permeability formations; 2) they require removing only a small amount of water to purge them prior to sampling; 3) they develop more quickly; 4) they are generally more easily installed; and 5) the materials, labor and drilling costs are lower than for large-diameter wells.

There are certain monitoring situations which may require large-diameter wells. Pumping tests for ground-water resource evaluation may require large-diameter wells for the pumping well. Ground-water investigations in very deep aquifers may also require large-diameter wells. In addition, specialized monitoring needs such as automatic water-level recorders or evaluation of remedial measures for ground-water contamination studies may also necessitate the installation of large-diameter wells.

In conclusion, small-diameter monitoring wells are economically advantageous because they cost less to install and less to maintain for long-term sampling purposes. Moreover, they can be used in the majority of monitoring situations. However, large-diameter wells are still necessary for a pumping test and may also be needed in areas where the water table is very deep.

Biographical Sketch

Marjory Rinaldo-Lee received a B.A. in geology from Mount Holyoke college and an M.S. in geology and water resources management from the University of Wisconsin. She is currently a hydrogeologist with Empire Soils Investigations/Thomsen Associates in Groton, New York, where she is responsible for management of hydrogeologic projects ranging from ground-water resource development to site contamination investigations. Previously she worked as a hydrogeologist for Residuals Management Technology Inc. in Madison, Wisconsin, where she was involved with hydrogeologic investigations and feasibility studies for waste disposal sites.

Table 2
Comparison of Approximate Cost for Drilling and Materials for Monitoring Wells

Economic Factors		Well Diameter 2-Inch	3-Inch	4-Inch
Drilling Cost/Ft	Rock Coring	$26.00	$26.00	$35.00
	Hollow Stem Auger	$ 8.00	$17.50	$17.50
Materials Cost/Ft	Stainless Steel	$11.00	$14.50	$20.00
	PVC	$ 2.50	$ 5.50	$ 7.00

Table 3
Comparison of Cost to Install Monitoring Wells

Geologic Material	Type of Drilling	Diameter of PVC Pipe 2-Inch	3-Inch	4-Inch
Rock	Rock Coring	$2,600	$3,800	$4,300
	Rock Drilling	$1,300	$2,400	$2,600
Unconsolidated Deposits	Drilling & Sampling	$1,200	$2,200	$2,500
	Drilling	$1,050	$2,100	$2,300

Assumptions: Well depth = 50 ft., well screen = 10 ft.
Well casing and screen are PVC

Table 4
Comparison of Advantages of Small- and Large-Diameter Wells

Advantages of large-diameter wells	Advantages of small-diameter wells
• Accommodate large submersible pumps for pumping tests	• Stabilize more quickly in low permeability formations
• Accommodate automatic water level recorders easily	• Lower labor costs due to easier installation, quicker development and smaller volume of water removed during purging
• Accommodate specialized monitoring equipment easily for very deep wells or other specialized monitoring requirements	• Lower materials cost
	• Lower drilling costs

72. Santa Clara Valley Water District. Groundwater Monitoring Guidelines, December 1983

GROUNDWATER MONITORING GUIDELINES

December 1983

Santa Clara Valley Water District

SANTA CLARA VALLEY WATER DISTRICT

GROUNDWATER MONITORING GUIDELINES

DECEMBER 1983

DISTRICT BOARD OF DIRECTORS

Joe Pandit	District 1	James J. Lenihan	District 5
Patrick T. Ferraro	District 2	Sig Sanchez, Chairman	At Large
Robert W. Gross, Vice Chairman	District 3	Audrey H. Fisher	At Large
Joseph H. Donohue	District 4		

101-2836tp

TABLE OF CONTENTS

	Page
SUMMARY	1
Classification of Hazardous Materials Storage Facilities	1
Non-Motor Fuel Storage	1
Commercial Motor Fuel Storage	1
Individual Agricultural and Suburban Motor Fuel Storage	2
Monitoring Requirements	2
Non-Motor Fuel Hazardous Materials Storage Facilities	2
Shallow Groundwater Conditions	2
Deep Groundwater Conditions	4
Adequacy of Monitoring Coverage	7
Commercial Motor Fuel Storage Facilities	7
Individual Agricultural and Suburban Motor Fuel Storage Facilities	9
Monitoring Schedule	12
INTRODUCTION	13
Hazardous Materials Storage Permit Ordinance	13
Monitoring Program and Guidelines	13
Administration and Enforcement Agencies	13
CLASSIFICATION OF HAZARDOUS MATERIALS STORAGE FACILITIES	15
MONITORING PROGRAM	16
Purpose, Scope and Limitations	16
Responsibility of Performance	16
Compliance with Existing Statutes	17
Well Construction Permit	18
MONITORING REQUIREMENTS	19
WELL CONSTRUCTION GUIDELINES	20
Well Diameter	20
Borehole Diameter	20
Construction Materials	20
Casing, Screen and Perforations	20
Gravel Pack Envelope	21
Annular Seal	21
Construction Procedures and Requirements	21
Drilling Methods	21
Soil Sampling	22
Casing, Well Screen, Perforated Casing Installation	22
Bottom Plug	23
Gravel Pack Envelope Installation	23
Annular Seal Placement	23
Well Development	24
Surface Security and Identification	24

Page

VADOSE ZONE MONITORING 25

Required Vadose Monitoring 25
Vapor Monitoring 25
Suction Lysimeter 27
Interface Well 29
Installation and Materials 29
Surface Security and Identification 30

SAMPLING, MONITORING SCHEDULE AND REPORTING 31

Soils Testing 31
Non-Motor Fuel and Commercial Motor Fuel Storage Facilities 31
Individual Agricultural and Suburban Motor Fuel Storage Facilities 31
Monitoring Schedule 32
Non-Motor Fuel Storage Facilities 32
Commercial Motor Fuel Storage Facilities 32
Individual Agricultural and Suburban Motor Fuel Storage Facilities 32
Modification of Monitoring Schedule 32
Groundwater Sampling and Laboratory Testing 32
Non-Motor Fuel Storage Facilities 32
Commercial Motor Fuel Storage Facilities 33
Vapor Monitoring 33
Suction Lysimeter Monitoring 34
Interface Well Monitoring 34
Individual Agricultural and Suburban Motor Fuel Storage Facilities Monitoring 34
Reporting 34

GLOSSARY 35

APPENDICES

A Ordinance 75-6 38
B Standards for the Construction of Wells - Santa Clara County 40
C Standards for the Sealing of Abandoned Wells - Santa Clara County 48

FIGURES

1. Typical Monitoring Facility, Non-Motor Fuel Storage Facility, Shallow Groundwater 5
2. Typical Monitoring Facility, Non-Motor Fuel and Commercial Motor Fuel Storage Facility, Placed within Tank Backfill, Unsaturated Conditions 6

Page

3. Typical Monitoring Facility, Non-Motor Fuel and Commercial Motor Fuel Storage Facility, Placed Outside of Tank Backfill, Unsaturated Conditions 8
4. Typical Monitoring Facility, Commercial Motor Fuel Storage Facility, Shallow Groundwater 10
5. Typical Monitoring Facility, Individual Agricultural and Suburban Motor Fuel Storage Facility 11
6. Typical Vapor Monitoring Device Installation, Unsaturated Conditions 26
7. Typical Pressure/Vacuum Lysimeter and Its Installation, Unsaturated Conditions 28

SUMMARY

The purpose of the monitoring program is to detect as early as possible any leakage from an underground hazardous material storage facility should one occur. To accomplish this, site-specific monitoring facilities are to be constructed adjacent to the storage facility and are to monitor either the first aquifer zone or the immediate unsaturated zone beneath the storage facility, depending upon the depth of the water table beneath the facility.

This monitoring program as herein presented is one means to validate the storage facility performance and is to be used in conjunction with the Hazardous Materials Storage Permit Ordinances as adopted by the cities and the County of Santa Clara. It is the purpose and intent of the Permit Ordinance to protect groundwater supplies from contamination which might result from leakage of underground storage facilities.

These Guidelines will outline requirements, recommendations and suggested alternatives for the proper monitoring of existing underground storage facilities. These Guidelines also provide a monitoring schedule for the installation. Any unusual or unique installations will be handled on a case by case basis.

Classification of Hazardous Materials Storage Facilities

Non-Motor Fuel Storage

Non-motor fuel storage facilities include all commercial and non-commercial underground tanks for the storage of non-motor fuel hazardous materials as described in the Hazardous Materials Storage Permit Ordinances. Bulk storages of waste oil not located at retail outlets (service stations) are included in this classification as such storages could contain other than waste petroleum products.

Commercial Motor Fuel Storage

Commercial motor fuel storage facilities include all underground tanks for storage of motor fuels which are intended for commercial resale, including retail and wholesale

outlets and bulk storage facilities. Also included are bulk storages for transit stations and industrial and municipal facilities as well as individual agricultural and suburban storages greater than 1,000 gallons.

Individual Agricultural and Suburban Motor Fuel Storage

Individual agricultural and suburban motor fuel storage facilities include non-commercial underground tanks of less than 1,000 gallons for motor fuel storage on agricultural properties, on suburban homesites, and on business sites where fuel is stored solely for use by the owner/resident in the course of his business or for his vehicles and equipment. All motor fuel storages for commercial resale are excluded from this classification.

For motor fuel storage, whether it be commercial, agricultural or suburban, the Administering Agency of the Permit Ordinance may reclassify the storage facility on an individual basis. Such individual reclassification may be in accordance with an unusual condition of use or the size of the storage facility.

Monitoring Requirements

In order to provide adequate coverage, monitoring requirements may vary from one storage facility to another based upon the depth of groundwater beneath the facility, the size of the facility and upon the character and properties of the materials stored.

Non-Motor Fuel Hazardous Materials Storage Facilities

Shallow Groundwater Conditions - A groundwater monitoring well shall be constructed at a storage facility where groundwater occurs at a shallow depth, defined as within 45 feet of the surface. Oftentimes the precise depth to groundwater is not known at a storage facility site unless a specific monitoring well exists within 500 feet of the site. In cases where the precise depth to groundwater is not known, the procedure is to drill a hole within the tank backfill or within ten feet of the storage tank down to groundwater or to a maximum depth of 45 feet if groundwater is not encountered. The hole is to be placed on the estimated down groundwater gradient side of the storage

facility, as based upon professional judgement. The hole is to be carefully logged and soils samples obtained for laboratory tests in order to determine concurrent performance of the tank. Soils samples are to be obtained, starting at the bottom of the tank, every five feet to the water table. If water is encountered, a water sample shall be taken. Testing of soil and water samples shall be in accordance with the requirements of these Guidelines.

When the hole is terminated at a depth of 45 feet after failing to encounter groundwater, but in a case where the soils continue to be apparently contaminated based upon field observations, these conditions are to be reported to the enforcing agency. The data will be reviewed and a program for further investigation (which is beyond the scope of this monitoring program) will be initiated where appropriate. All laboratory test results are to be reported to the Administering Agency of the Permit Ordinance (the county or city of jurisdiction).

When groundwater is encountered or known to be within 45 feet of the surface, the drill hole will be extended through the depth of the aquifer to a competent clay layer or aquitard. A competent aquitard is greater than five feet thick. To test the competency of the aquitard or clay layer, the hole must be drilled five feet into it. Then the excess hole is to be backfilled with concrete and the monitoring well shall be completed in the aquifer above it, screening the full thickness of the aquifer. If the clay layer is found to be less than five feet thick, it may be assumed to represent a local lens. Should the first saturated aquifer be greater than 20 feet thick, the well will be completed at a depth of 20 feet below the top of the saturated aquifer.

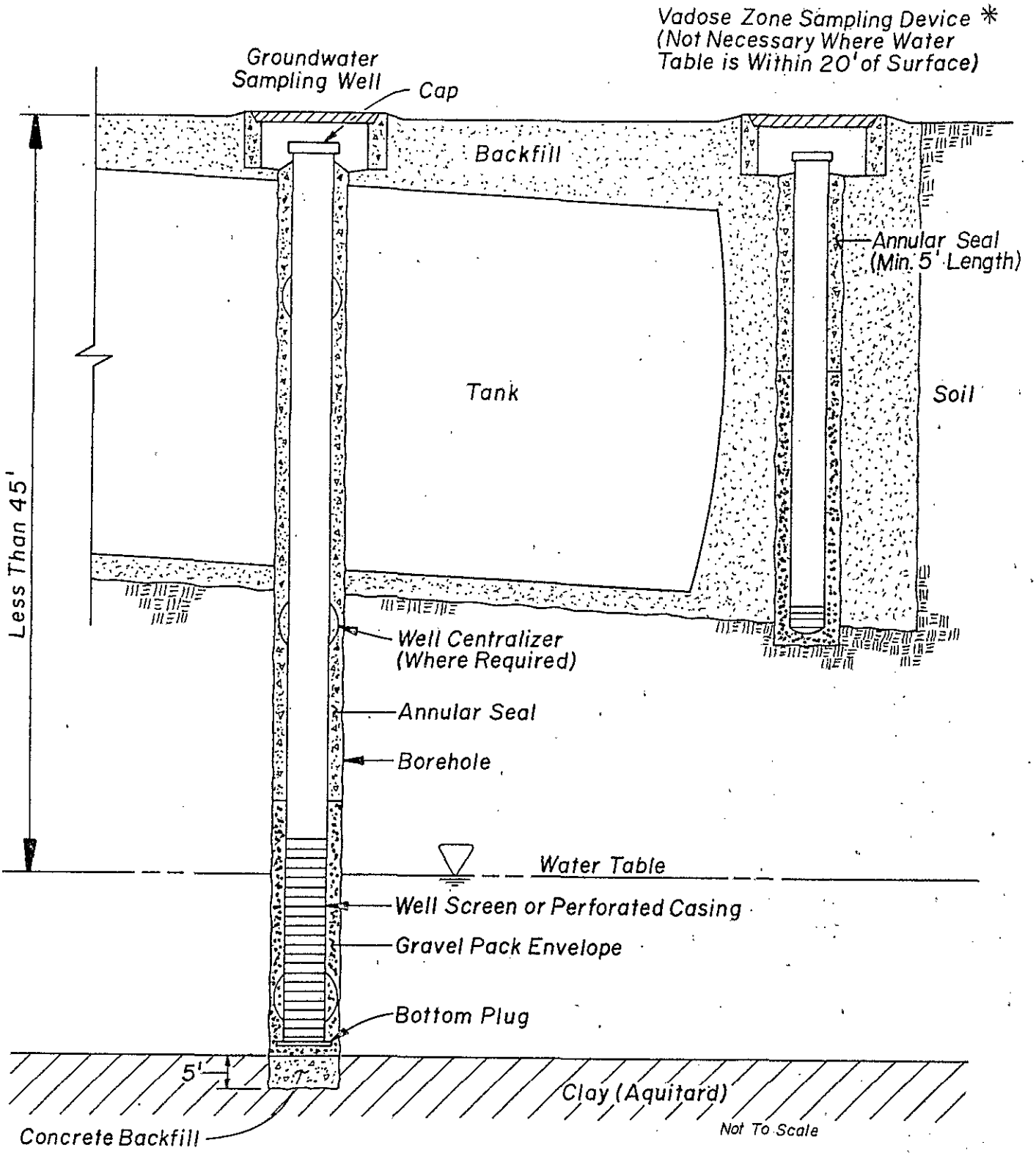
The screened or perforated interval is to be gravel packed to a minimum of two feet above the uppermost screen or perforated interval. An annular seal of neat Portland cement, cement mix or thick bentonite slurry shall be placed from the top of the gravel pack to the surface.

If groundwater is encountered at less than 45 feet but greater than 20 feet from the surface, a vadose (unsaturated zone) monitoring device shall be additionally required so that early detection may be possible by the combination monitoring installation. This vadose monitoring device is to be installed within the tank backfill at the location where the backfill is at the lowest level, if known. The sensing zone of the vadose monitoring device shall be placed at the bottom of the backfill. Required vadose monitoring shall include (1) a vapor monitoring well for volatiles or (2) either a suction lysimeter or an interface well for nonvolatiles. These alternative vadose monitoring devices which may be employed are discussed on Page 25 of the Guidelines. Refer to Figure 1 for a typical example of a monitoring facility herein described, where groundwater occurs at a shallow depth.

Soils sampling procedure, analytical laboratory soils and water testing methods and tests required of the vadose zone monitoring devices are outlined within the body of these Guidelines.

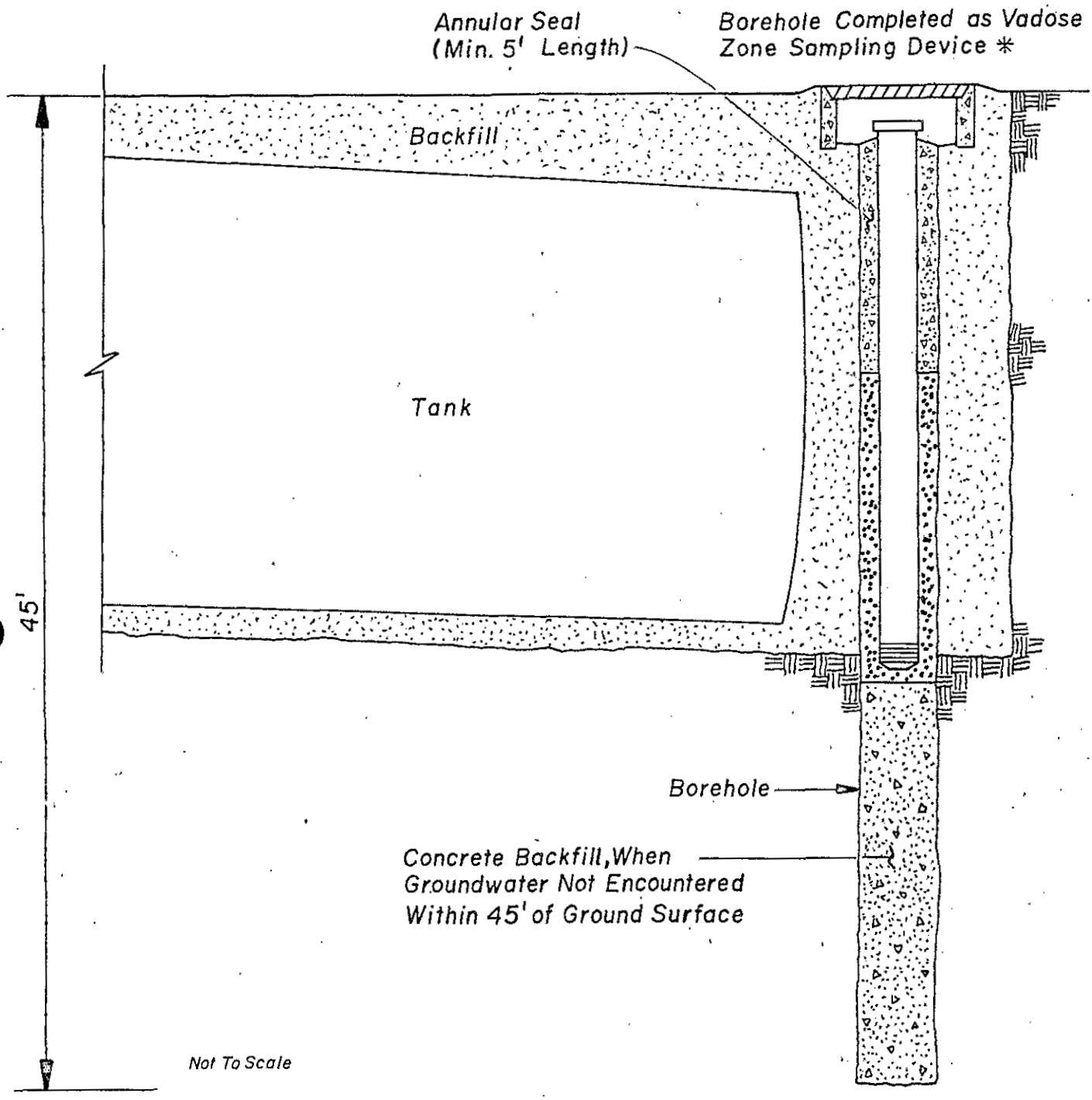
Deep Groundwater Conditions - If groundwater is not encountered within 45 feet of the surface in the drilled hole, the well is to be completed with a vadose monitoring device in the unsaturated zone beneath the tank. The excess hole, drilled to explore for the groundwater and to obtain soils samples, shall be backfilled with concrete and the monitoring device placed within the remaining hole. The concrete backfill is to prevent the hole from serving as a possible conduit for downward movement of any contaminant or drainage water.

If the hole is started within the tank backfill, the vadose monitoring device shall be completed at the bottom of the backfill. Upon this completion a minimum length of five feet of annular seal shall be placed above the sensing zone (gravel packed interval) to the surface to prevent drainage water from entering the borehole. Variance will be allowed for minimum length of annular seal should 5 feet prove to be impractical due to shallow depth of tank backfill for a small tank. Refer to Figure 2 for a typical monitoring installation herein described.



* Vapor Monitoring Well Where Volatile Compounds Are Stored and Either a Lysimeter Installation or an Interface Well Where Nonvolatiles Are Stored.

Figure I. Typical Monitoring Facility, Non-Motor Fuel Storage Facility, Shallow Groundwater



* Vapor Monitoring Well Where Volatile Compounds Are Stored and Either a Lysimeter Installation or an Interface Well Where Nonvolatiles Are Stored.

Figure 2. Typical Monitoring Facility, Non-Motor Fuel and Commercial Motor Fuel Storage Facility, Placed Within Tank Backfill, Unsaturated Conditions

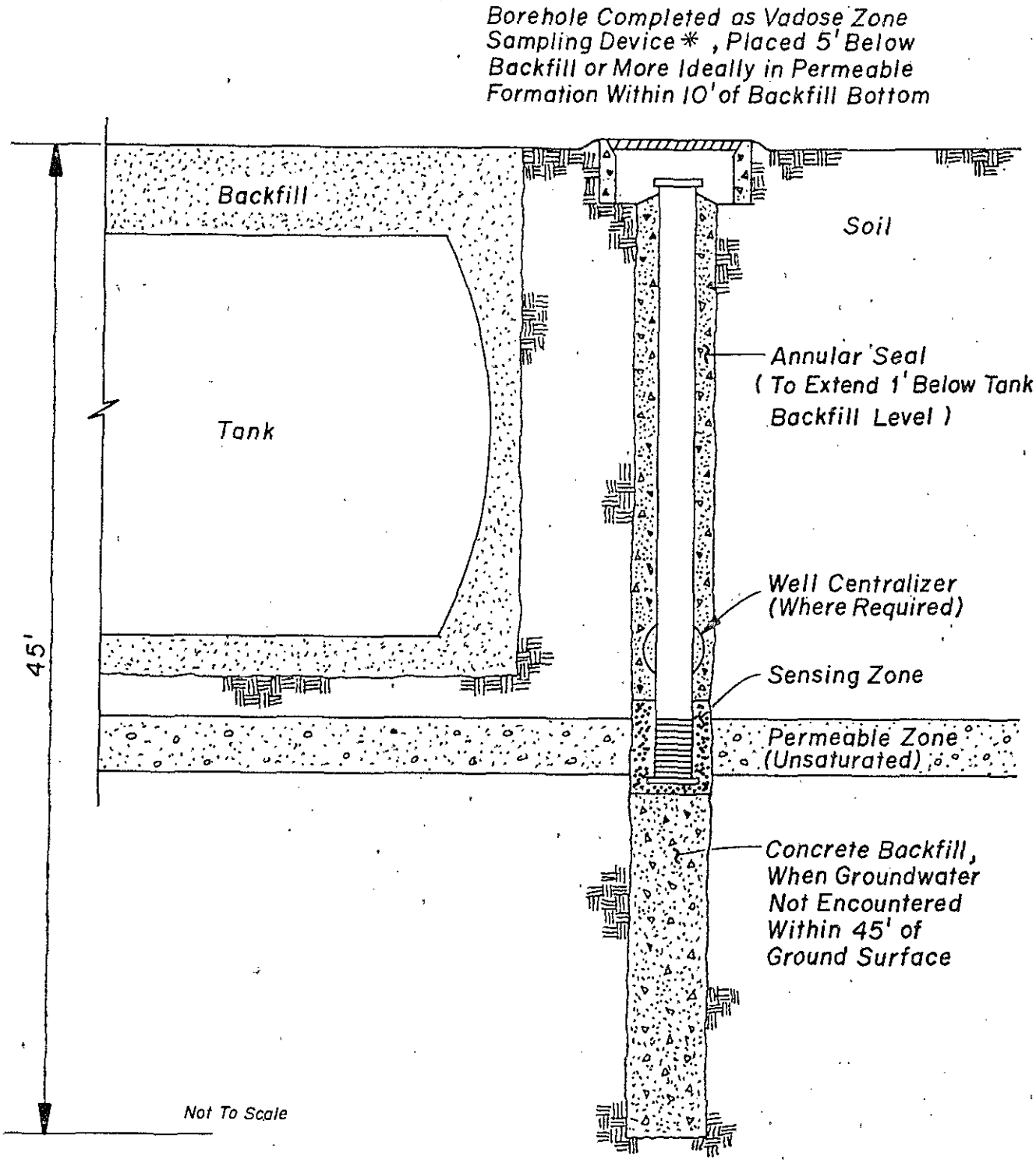
If the hole is started in natural formation outside of the tank backfill, the vadose monitoring device is to be completed at a level five feet beneath the tank backfill or, more ideally, in aquifer materials (herein unsaturated) within ten feet of the bottom of the tank backfill. The occurrence of such an ideal situation is determined from the log of the borehole when it was drilled. An annular seal shall be installed above the sensing zone of the monitoring device, which shall be from a level one foot below that of the tank backfill bottom, to the surface. Refer to Figure 3 for the typical monitoring installation herein described.

Adequacy of Monitoring Coverage - The number of monitoring wells, or combination of groundwater and vadose monitoring wells shall depend upon the size of the storage facility (individual tank or cluster of tanks). One well or combination shall be required for each dimensional length, or collective length when tanks are clustered, of 35 feet or less. Where more than one well or combination is required, they shall be appropriately distributed so as to accomplish optimal distributed coverage, taking into consideration the gradient of groundwater for groundwater monitoring wells and the lower levels of the tank backfill bottom for vadose monitoring wells.

Where groundwater occurs at a depth greater than 45 feet, only the first hole shall be required to make this determination. However, soils samples shall be obtained from the additional wells from levels beneath the tank and the hole shall be continued to a level where the soil becomes apparently free of contaminant as based upon field judgement (but to no greater depth than 45 feet).

Commercial Motor Fuel Storage Facilities

The monitoring well requirement for commercial motor fuel storage shall be essentially the same as for a non-motor fuel hazardous materials storage facility. The only difference in concept is in the extended upper length required in the screened or perforated casing interval of the groundwater monitoring well. As motor fuel products are essentially nonmiscible with water and are lighter than water, they will float on top



* Vapor Monitoring Well Where Volatile Compounds Are Stored and Either a Lysimeter Installation or an Interface Well Where Nonvolatiles Are Stored.

Figure 3. Typical Monitoring Facility, Non-Motor Fuel and Commercial Motor Fuel Storage Facility, Placed Outside of Tank Backfill, Unsaturated Conditions

of the water table. The important interval to monitor is at the motor fuel-water interface. Since groundwater levels fluctuate seasonally and on a long-term basis, the screened interval would have to be necessarily longer to accommodate these fluctuations. This consideration may also apply to certain non-motor fuel hazardous materials that exhibit such similar properties as motor fuels.

All other well requirements, including the possible need of a combination groundwater-vadose monitoring installation, are the same as for the monitoring of non-motor fuel storages. Refer to Figure 4 for monitoring installation herein described. Also refer to Figures 2 and 3 where they apply to cases where the groundwater is not encountered within a depth of 45 feet.

The required soils sampling and testing shall be the same as for non-motor fuel storage facilities. These procedures are outlined in the body of the Guidelines. Also water sampling procedure and field testing of water samples are outlined in the body of these Guidelines.

Individual Agricultural and Suburban Motor Fuel Storage Facilities

The monitoring requirement of individual agricultural and suburban motor fuel storage facilities shall be accomplished by the installation of one well to be placed within the tank backfill and shall be extended to the bottom of the backfill, regardless of the depth to groundwater. This well shall be placed at the lowest level of the backfill if known. The lower one-half of the total length of this well shall be screened or the casing shall be perforated and gravel packed. An annular seal of concrete, neat cement, cement grout or a thick slurry of bentonite shall be palced above the gravel pack extending to the surface to prevent surface drainage from entering the well. Such a well is referred as an "interface vadose monitoring well" when groundwater is not encountered as the sensing zone monitors the backfill-natural formation interface. Refer to Figure 5 for such a typical installation.

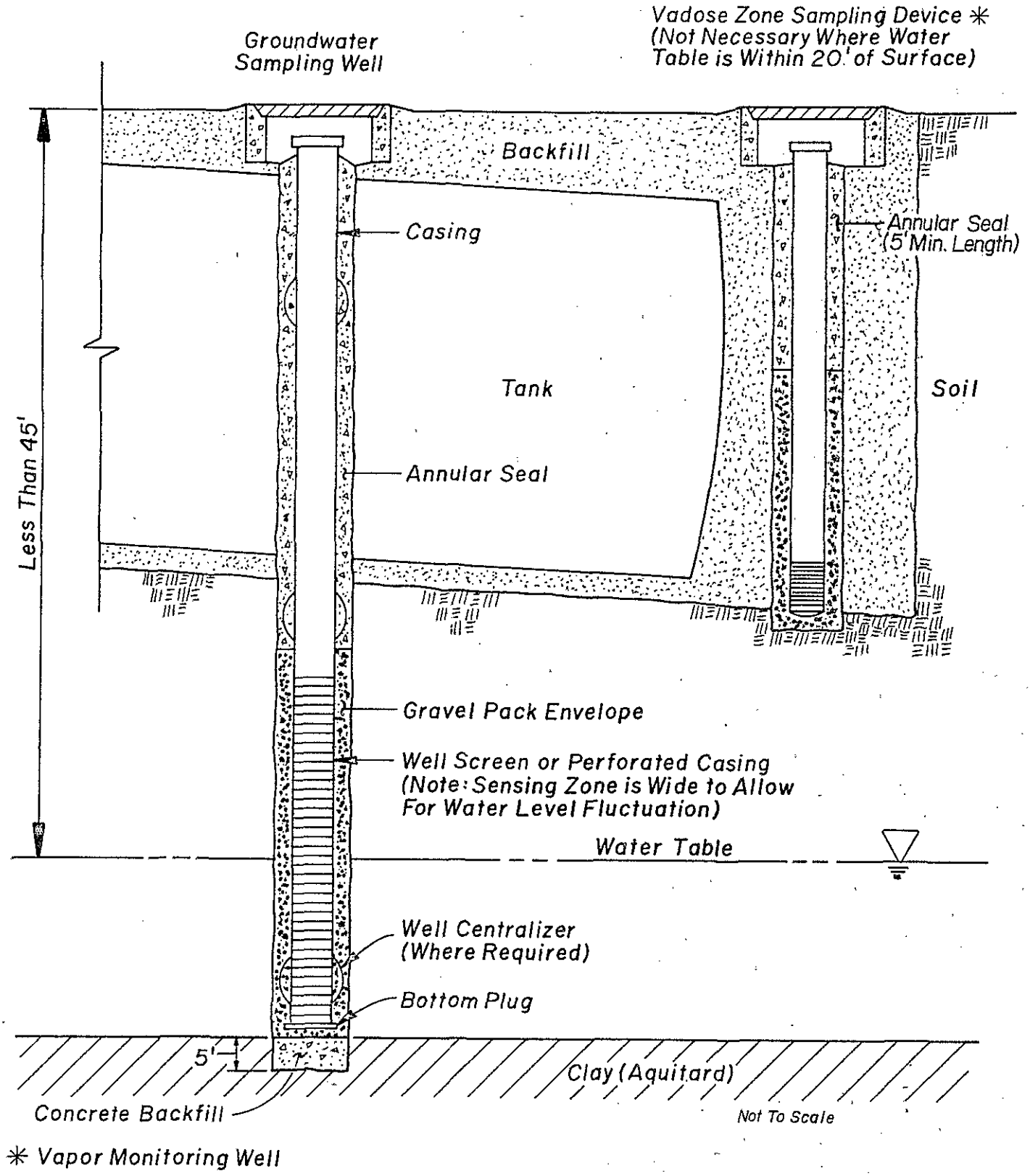


Figure 4. Typical Monitoring Facility, Commercial Motor Fuel Storage Facility, Shallow Groundwater

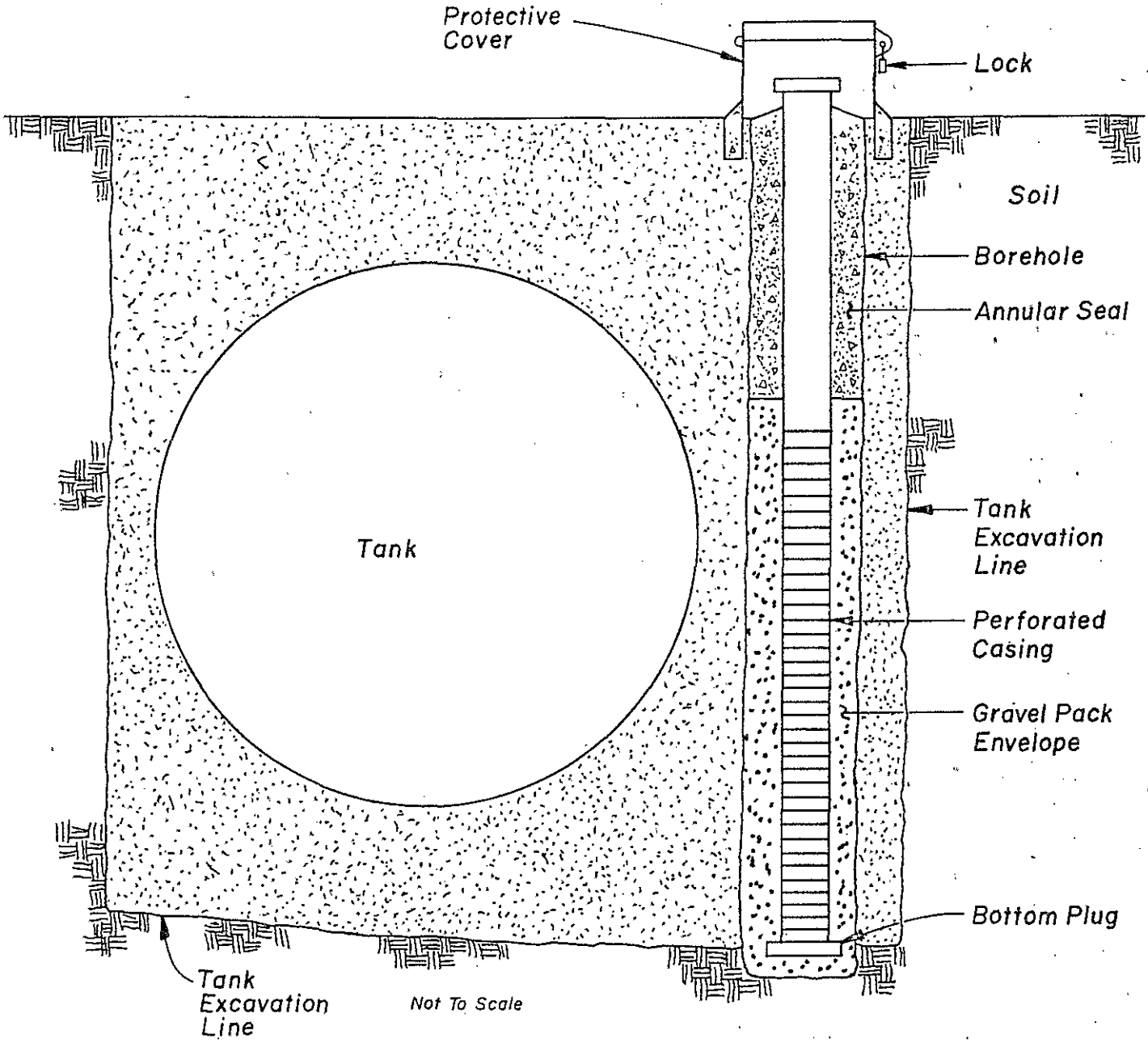


Figure 5. Typical Monitoring Facility, Individual Agricultural and Suburban Motor Fuel Storage Facility
(Serves as an Interface Well Under Unsaturated Conditions)

Monitoring is to be accomplished by determining the presence or absence of motor fuel product which might accummulate atop the groundwater or, in the absence of groundwater, upon the tank backfill-natural soil interface should a leak occur or surface drainage water leaches down. Such a determination is to be made by probing the well with a clear (transparent) plastic ball-valve bailer whereby visual determination is to be performed. The well can also serve as an indicator of the presence of motor fuel vapors.

The monitoring well can be installed by a power auger or a hand auger. A soils sample shall be obtained at the bottom of the bore hole for field inspection in order to determine the apparent presence or absence of motor fuel contamination. The results of the judgemental field inspection are to be reported to the Administering Agency of the Permit Ordinance.

Monitoring Schedule

The schedule for groundwater sampling and testing and for obtaining measurements of vadose monitoring devices is as follows:

A. Non-Motor Fuel Storage Facilities: Semiannually for groundwater sampling and laboratory testing and for vadose monitoring measurements.

B. Commercial Moter Fuel Storage Facilities: Monthly for groundwater sampling and field testing and quarterly for vadose monitoring measurements.

C. Individual Agricultural and Suburban Motor Fuel Storage Facilities: semiannually for inspections.

INTRODUCTION

Hazardous Materials Storage Permit Ordinance

It is the purpose and intent of the Hazardous Materials Storage Permit Ordinance to protect groundwater from contamination which might result from leakage of underground storage facilities. The protective means are to be approached from the standpoint of leakage prevention or of early detection through validation systems to determine storage facility performance.

Monitoring Program and Guidelines

The monitoring well program as herein presented is one of the means to validate storage facility performance and to determine, in a timely manner, any occurrence of leakage. These Guidelines will outline requirements, recommendations and suggested alternatives for a proper monitoring installation. They will also cover soils sampling procedures, means of obtaining samples or measurements, analytical testing methods, monitoring schedules and reporting procedures.

Administration and Enforcement Agencies

The administration and enforcement agencies of the Hazardous Materials Storage Permit Ordinance are Santa Clara County and the individual cities that have adopted a Permit Ordinance. All applications under the Permit Ordinance are to be initiated through the administering and enforcing agency having jurisdiction in the area.

The Santa Clara Valley Water District (SCVWD), a Countywide agency, through Ordinance 75-6, is the administering and enforcing agency for the construction of wells and the destruction of abandoned wells. All monitoring wells which are constructed in natural formation, and therein have the potential to compromise or violate the natural protective overlying formations, come under the provisions of SCVWD Ordinance 75-6. These Guidelines for monitoring well construction included herein were prepared by the SCVWD and serve as an extension of Ordinance 75-6 (See Appendix A). SCVWD will

serve as the administration and enforcement agency for the construction of monitoring wells in conformance with the requirements of the Hazardous Materials Storage Permit Ordinances. Where a monitoring well is required, the owner shall be responsible for obtaining a permit from the SCVWD for the monitoring well construction. See Standards for Well Construction in Appendix B.

When the monitoring well is no longer needed and is to be abandoned, it shall be properly destroyed in accordance to the provisions of Ordinance 75-6. The well owner is responsible for obtaining a well destruction permit from the SCVWD and properly destroying the well. See Standards for Well Destruction in Appendix C.

CLASSIFICATION OF HAZARDOUS MATERIALS STORAGE FACILITIES

See Summary on Page 1 of these Guidelines.

MONITORING PROGRAM

Purposes, Scope and Limitations

The purpose of a monitoring well under this program is to detect as early as possible any leakage from an underground hazardous material storage facility, should one occur. To accomplish this, a site-specific monitoring well is to be constructed adjacent to the storage facility (within ten feet of the tank). The well is to monitor either the first aquifer zone or the immediate unsaturated zone beneath the storage facility, depending upon the depth of the water table beneath the facility; in some cases both the groundwater and overlying unsaturated zones may require monitoring installations. Additionally, the monitoring well is to be constructed in a manner which will not allow the well to serve as an avenue for the transmission of contaminants, either from the surface to the first aquifer or from the first aquifer or unsaturated zone should a leak occur to any underlying aquifer or underlying unsaturated zone.

This monitoring program is limited solely to the detection of facility leakage and is not intended to have any other investigative purpose.

Responsibility of Performance

These Guidelines will suggest typical monitoring well construction, taking into account various hydrogeologic conditions and contaminant properties in meeting the objectives of the monitoring program. The examples presented are expected to be appropriate to suit most of the varying local conditions. However, it is recognized that the specified requirements may not be appropriate to all conditions and, hence, individual well designs are not limited to the examples presented. Nor do these Guidelines preclude the use of other methods or equipment. However, any alternatives or deviations from the suggested Guidelines must meet the objectives of the program and must provide equivalent or superior protection of the aquifers by their construction. When an alternative concept is considered by the enforcing agency, the SCVWD, shall review and approve or disapprove its use.

As provided in the Permit Ordinance, it is intended that the owner of any underground storage facility shall install and perform the monitoring program. As the installation and performance of the monitoring require professional judgments and important field decisions, the owner is responsible for the enlistment of a qualified professional (or consultant) to assume the technical responsibility for performance. For the purposes of these Guidelines, the overall technical responsibility is to be assumed by a State Certified Engineering Geologist or a State Registered Civil Engineer.

The only exception to the requirement of a State registered or certified professional is in the installation and monitoring program for individual agricultural and suburban motor fuel storage facilities

Compliance with Existing Statues

The implementation of the monitoring program must comply with existing federal, State and local ordinances. All monitoring wells, regardless of depth, which are drilled into the natural formation, are subject to SCVWD Ordinance 75-6. (See Appendix A) The Ordinance allows for variances for shallow wells. The following items discuss differences of these Guidelines to Ordinance 75-6; in these instances the proper course for these Guidelines are specified.

1. A monitoring well constructed wholly within the artificial backfill (as distinguished from the intact natural formation) around an underground storage facility does not have the potential to compromise the natural groundwater protection. It is excluded from the provisions of Ordinance 75-6 and does not require a well drilling permit from the SCVWD.

2. The construction of water wells is solely limited to a driller with a State water well contractor's (C-57) license but other qualified and licensed contractors may also be employed to construct monitoring wells (e.g., a contractor with a State C-61 license).

3. The submittal of a well completion report to the SCVWD shall be by the owner

or by his professional consultant, rather than by the driller. The final completion report shall be in the form of a standard State Water Well Driller's Report. This requirement does not relieve any well drilling contractor of the requirements that he file a report of all the wells and test holes in accordance with the State Water Code.

4. The use of bentonite for an annular seal is permitted in addition to Portland cement or cement mix as specified in Ordinance 75-6.

5. As indicated under item No. 1 above, the monitoring well required for individual agricultural suburban motor-fuel storage facilities is exempted from the provisions of Ordinance 75-6. However, its construction shall comply with the provisions set forth in these Guidelines. Such a monitoring well may be constructed by the owner or by a contractor.

Well Construction Permit

Under the provisions of SCVWD Ordinance 75-6, a well drilling permit must be obtained for each well installation prior to its construction, unless exempted. The owner, owner's agent, or consultant is to apply for such a permit from the SCVWD at the District Office, 5750 Almaden Expressway, San Jose, (408) 265-2600; at the Santa Clara County Central Permits Office located at 70 West Hedding Street, San Jose, (408) 299-2454, and at the South County Office located in the Gilroy City Hall (408) 847-6484.

MONITORING REQUIREMENTS

Monitoring requirements which discuss the appropriateness of the approach to monitoring for a particular classification of storage facility, varying hydrogeologic conditions, number and location of monitoring devices required, and requirement of soils sampling have already been covered in the Summary on Page 2 of these Guidelines.

WELL CONSTRUCTION GUIDELINES

These Well Construction Guidelines set forth recommended or required parameters with regard to the design, drilling and sampling, construction, development, and security of wells which are required for monitoring beneath subsurface hazardous material storage facilities. These Guidelines also set forth recommended or required procedures for boring and sampling where soil samples and/or identification of groundwater levels are required.

Well Diameter

The minimum well diameter shall be two inches but larger diameters can be considered and are acceptable.

Borehole Diameter

The diameter of the borehole shall be of sufficient size to encase the perforated casing or well screen in a gravel pack envelope of sufficient annular thickness. Such a width thickness is a minimum of two inches and a maximum of six inches (e.g., a three-inch O.D. casing would require a hole diameter of seven inches minimum and 15 inches maximum). These limits provide an adequate width space for the proper installation of the annular surface seal while not inhibiting well development.

Construction Materials

Casing, Screen and Perforations

Well casing, screen and perforated casing shall be constructed of materials that have the least potential for affecting the quality parameter of the sample, have sufficient strength and resist rapid deterioration from corrosion. Acceptable construction materials include polyvinyl chloride (PVC), stainless steel or low carbon steel. The most suitable material for a particular installation will depend upon the parameters to be monitored. Casing and screen joints may be connected by means of arc

welding of metals or they may be threaded and coupled. The use of organic bonding compounds is not permitted.

Gravel Pack Envelope

Gravel pack envelope materials, when employed in well construction, shall be durable, waterworn, and washed clean of silt, dirt, and foreign matter. They shall be well rounded (crushed material is unacceptable) and shall be graded to an appropriate size for retention of aquifer materials encountered in the borehole. When the gravel pack materials are of sand sizes, they shall be appropriately screened silica sand.

Annular Seal

Annular seal shall consist of neat cement, cement grout, concrete or thick bentonite slurry (or bentonite pellets). When cement is used it shall be Class A Portland cement.

In the sealing of PVC casing, the heat of hydration generated by cement would have to be considered. The heat of hydration could be moderated with the addition of bentonite or sand or by cooling the mix before installation.

Construction Procedures and Requirements

Drilling Methods

The following drilling methods are acceptable alternatives where the sole objective is the construction of a monitoring well in the borehole: solid and hollow stem auger, percussion (cable tool), direct circulation (mud) rotary, and air circulation direct and reverse rotary. For certain installations consideration shall be given to a method that minimizes the introduction of foreign materials or fluids.

All tools used in connection with the boring of the hole shall be cleaned before commencement of drilling.

If drilling mud is employed, drilling fluid additives shall be limited to inorganic and non-hazardous compounds.

As stated under "Monitoring Requirements", the drilling of a monitoring well in the tank backfill for individuals agricultural and suburban motor fuel storage facilities and for shallow vadose monitoring wells may also be accomplished by hand augering.

Soil Sampling

The requirements for obtaining soils samples are discussed in the Summary under Monitoring Requirements on Page 2 of these Guidelines.

Soil samples for laboratory analysis shall be collected by driving a thin-walled Shelby tube or a California type drive sampler. Upon collection, the sample tube is to be capped on both ends with a teflon cap. Alternatively, aluminum foil can be used to cover the ends of the sampling tube and then sealed with an air-tight cap on each end. These samples are to be immediately placed in a refrigerated ice chest for transport to a laboratory. Soils samples for testing by visual field inspection in the installation of a monitoring well for individual agricultural and suburban motor fuel storages could be obtained in the same manner or by obtaining disturbed samples with a power or hand auger.

Analytical testing methods for soils samples are presented under "Sampling, Monitoring Schedule and Reporting".

Casing, Well Screen, Perforated Casing Installation

Before installation, all casing, couplings, well centralizers, well screens or perforated casing and all other components are to be thoroughly cleaned. Cleaning can be accomplished with the use of detergent, clean water, trisodiumphosphate or other approved cleaning compound. Whenever possible the well column (casing, perforated casing or well screen) should be held in tension whereby the column is held above the bottom of the hole during the gravel pack and seal installation. Also, whenever possible or when required, well centralizers are to be attached to the well column so that the well screen, perforated casing and well casing can be properly centered in the gravel pack and annular seal envelope. Centralizers would not be required in hollow-stem auger hole-type construction as the well column is held in center when the well is constructed.

Bottom Plug

The bottom of the well shall be permanently plugged, either by a screw-on or friction cap and without the use of an organic bonding compound. The bottom plug is to keep the well from silting and to eliminate the possibility of a cavity from developing in the formation by pumping.

Gravel Pack Envelope Installation

Gravel pack envelopes shall be installed by a tremie pipe. When drilling mud is used, it must be thinned out. These measures are to avoid bridging and void creation. The gravel pack is to cover the full length of the perforated or screened interval in addition to rising a minimum of two feet above the uppermost perforation.

Annular Seal Placement

The annular seal is to be placed above the gravel pack and extended to the ground surface. A transition of finer sand, soil or bentonite pellets may be required to prevent sealing materials from entering the gravel pack material. Mixing of sealing materials in preparation for placement shall be with clean water and thoroughly mixed (no dry lumps). Annular sealing materials shall be placed in a manner that prevents bridging, dilution and segregation when placed under water. Slurried annular seal materials shall be emplaced by a tremie pipe down to the bottom of the interval to be sealed and then filled from the bottom upward, withdrawing the tremie pipe as the placement progresses but at all times keeping the end of the pipe submerged in the sealing material placed. If groundwater occurs in the annular space, the placement of the sealing material from the bottom to the surface shall displace the water out of the top of the hole. Bentonite pellets, however, can be placed by free fall under gravity as they can sink to the bottom underwater before fully expanding to form a tight seal.

When Portland cement is used, the placement of the seal is to be performed in one continuous lift for the interval to be sealed.

Well Development

All monitoring wells shall be developed to clean the well and to stabilize the sand, gravel, and aquifer materials around the screens or perforations. Well development may be accomplished by bailing, mechanical or air lift pumping, surging, or swabbing. Well development shall continue until the well is thoroughly developed and free of sand, silt, and turbidity.

In some cases where low permeability formations are involved or the drilling mud used fails to respond to cleanup, initial development pumping may immediately dewater the well casing and thereby inhibit development. When this occurs, clean, potable grade water can be introduced into the well, followed by surging of the waters introduced with a swabb or surge block. Care must be taken not to damage the well screen or casing while swabbing or surging. This is to be followed by pumping. The procedure could be repeated as required to establish full development.

Surface Security and Identification

The surface of each monitoring well is to be protected from fluid entry, accidental damage, unauthorized access and vandalism. Wellheads may be secured above or below the ground surface, depending on local conditions. In all cases, a watertight cap shall be installed on the wellhead. If not otherwise secured, the cap shall also be locked.

Wellheads secured below the ground surface should be completed in a concrete or other vault, with a locking cover. The vault shall be installed with provisions for drainage to prevent accumulation of rainfall or surface runoff. Venting of the well, if required, can be accomplished inside the vault, with suitable backflow prevention against inflow of rainfall or surface runoff.

Each well shall be obviously identified, including well owner, well number, type of installation or device installed and key construction data such as depth, hole and casing diameters, and location of screen or perforated intervals.

VADOSE ZONE MONITORING

The requirements for vadose (or unsaturated) zone monitoring are outlined in the Summary of these Guidelines. This section discusses the types of vadose monitoring required and the guidelines for their installation.

The available vadose monitoring devices can be broadly categorized into two groups: (1) active devices which are sampling devices, and (2) passive which are nonsampling devices. Active devices include vapor monitoring wells, suction lysimeters and interface wells. Passive devices include tensiometers, electrical resistance blocks and other devices to measure relative changes in soil moisture content, temperature and salinity. Minimum requirement as specified under these Guidelines considers only active type devices.

Required Vadose Monitoring

For the purposes of these Guidelines, where vadose monitoring is required, a vapor monitoring well shall be installed where volatile and semivolatile products are involved, and either a suction lysimeter or an interface well shall be installed where nonvolatile products are involved.

Vapor Monitoring

A vapor monitoring installation can be constructed in several ways. One way is to construct a conventional well to the desired depth, in these cases to the bottom of the tank bankfill or just below it as described in the Summary, and have the well screened or perforated at the bottom. Monitoring is to be performed by lowering a small tigon sampling tube to the bottom. An inflatable packer is set above the screened interval. Refer to Figure 6 for an example of a typical installation as described. Vapor testing is to be accomplished by pumping the vapors to the surface and then passing them through a portable measuring device and exhausted through an activated carbon filter or field samples can be collected by passing the vapor through an adsorption medium which is then sent to a laboratory for analysis.

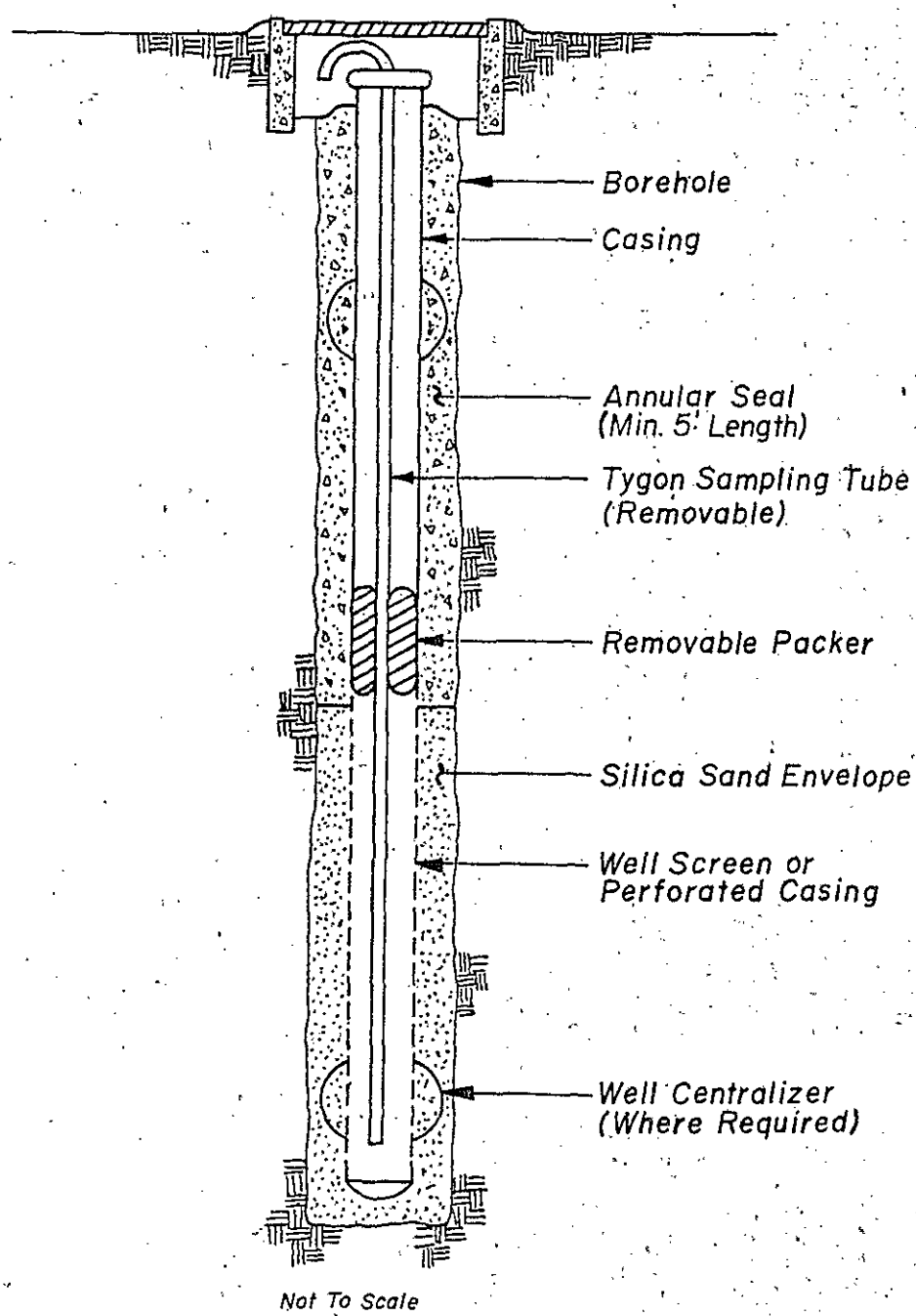


Figure 6. Typical Vapor Monitoring Device Installation, Unsaturated Conditions

This conventional type of vapor monitoring well is preferred over others as measurements for the presence of fluids, should a saturated condition occur, could also be taken and fluid samples be obtained. Testing of such fluids would serve as a better indication of the concurrent conditions than would vapor testing.

Another method of installation is to construct a permanent gas probe tip enclosed in a silica sand pack envelope with a sampling tube to the surface for vapor pumping. A nominal bentonite pellet seal shall be placed above the sand pack envelope and the rest of the hole shall be sealed to the surface with conventional sealing materials. A nominal length of casing shall be installed at the surface for protection of the sampling tube.

Driven steel well points can also be employed as vapor sampling tips. These can be installed through a hollow-stem auger or in a solid stem auger hole and driven to the depth desired. The small, permanently attached sampling tube is also of steel and is to be sealed to the surface.

Suction Lysimeter

Suction lysimeters are commonly used to extract small volumes of fluids from unsaturated, though quite moist, soil zones, usually at shallow depths. A typical example of a commercially available pressure/vacuum lysimeter is presented in Figure 7. Modified versions with check valves can be employed for deeper zone sensing. Fluids are drawn into the lysimeter by lowering the air pressure in the lysimeter by vacuum pumping and then in the second cycle the fluid is purged to the surface by pressure pumping. Vacuum and pressure pumping can be accomplished with a hand pump. The fluid samples are to be collected for laboratory analysis. The use of lysimeters is required for non-motor fuel storage and nonvolatile storage facilities when the depth to the saturated zone is greater than 20 feet from the surface.

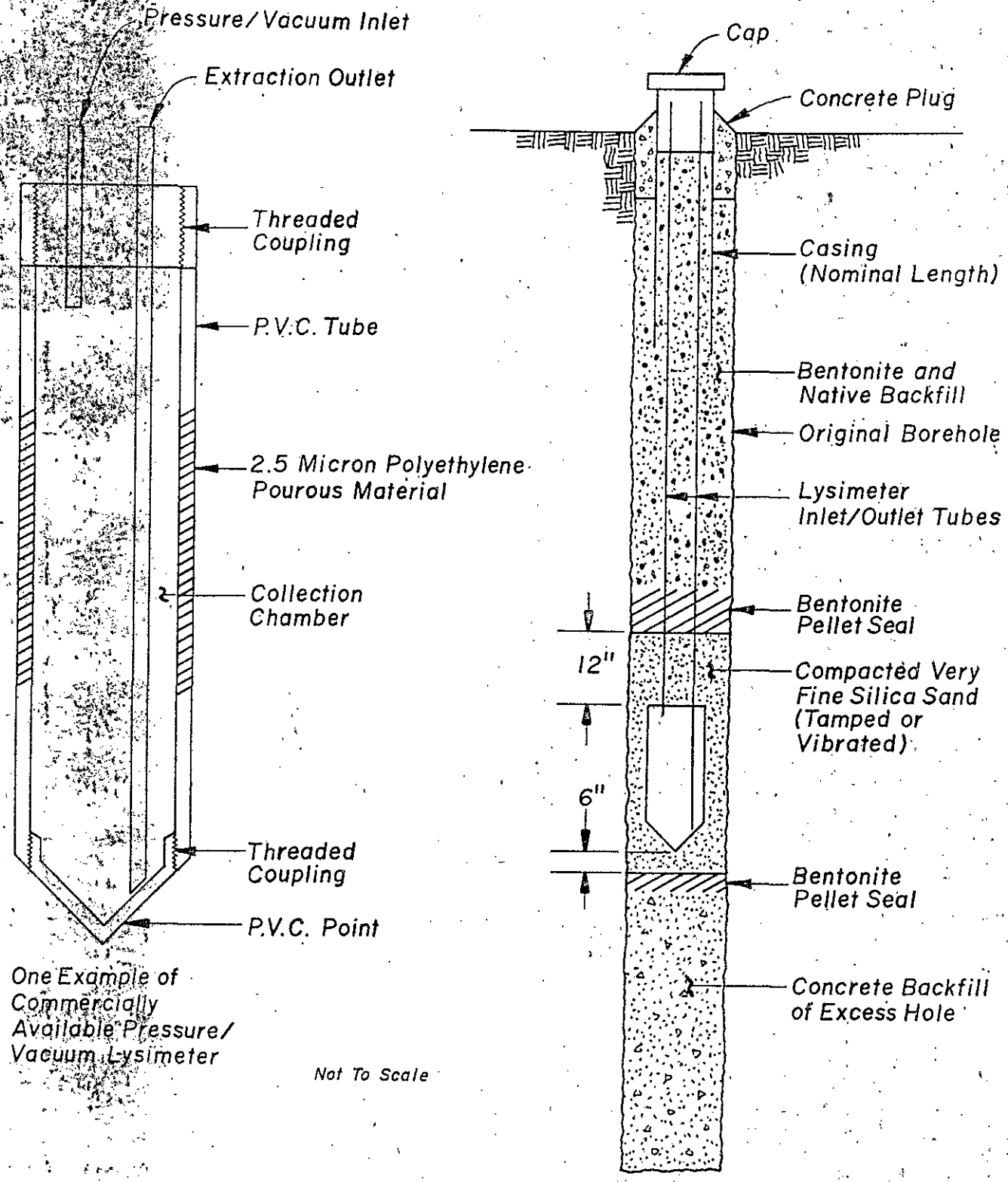


Figure 7. Typical Pressure/Vacuum Lysimeter and Its Installation, Unsaturated Conditions

The suction lysimeter shall be installed in the bottom of the borehole. The hole shall then be backfilled with a very fine pure silica tremiing sand (commercially available) as to encase the lysimeter. The very fine sand is to be installed by either tremiing a sand-water slurry into the hole or by hand pouring the sand into the hole and tamping continuously to ensure a good tightly compacted contact between the lysimeter and the materials to be monitored (soil formation or tank backfill). A nominal bentonite pellet seal is to be placed above the sand pack envelope followed by the placement of slurried bentonite mix sealing materials to the surface. A nominal length of casing shall be installed at the surface for protection. Other provisions for the installation of lysimeters shall follow instructions provided by the commercial supplier. Refer to Figure 7 for a typical suction lysimeter installation.

Interface Well

An interface well is a vadose monitoring well that is constructed in the same conventional manner as a groundwater monitoring well with a screen or perforated casing that is gravel packed to form the sensing zone. The sensing zone is placed at a formational interface in the unsaturated zone. The interface is usually a permeable material or formation overlying an impermeable or slightly permeable zone, e.g., sand backfill (of the bank tank excavation) or sand/gravel formation underlain by a clayey formation. Fluid sampling with a teflon or stainless steel bailer may be possible when a temporary condition of saturation develops at the interface as a result of tank leakage or leaching down of surface drainage waters. Examples of such installations are the vadose monitoring devices as shown on Figures 1, 2, 3 and 4.

Materials and installation procedures for construction of an interface well are as specified under "Well Construction Guidelines".

Installation and Materials

Vadose monitoring devices are to be installed in boreholes drilled by solid-stem or hollow-stem drilling. Where the level of installation is shallow, they may be installed in

a hand augered hole. Materials such as casing and well screen, depending upon the type of device installed, and the annular seal and sealing materials are as specified under "Well Construction Guidelines". Where applicable the minimum length of annular seal shall be 5 feet from the surface to prevent drainage water from entering the bore hole. A variance will be allowed for minimum length of annular seal should 5 feet prove to be impractical due to shallow depth of tank backfill for a small tank.

Surface Security and Identification

The surface of each installation is to be protected from fluid entry, accidental damage, unauthorized access and vandalism. The monitoring equipment may be secured above or below the ground surface, depending on local conditions. In all cases, a watertight closure is required for the instruments, and each installation shall be secured by a locking device.

Equipment secured below the ground surface should be completed in a concrete or other appropriate type vault having a locking cover. The vault shall be installed with provisions for drainage to prevent accumulation of rainfall or surface runoff.

Each well shall be obviously identified, including well owner, well number, type of monitoring device, and key construction data such as depth, diameter, casing size, and sensing zone depth.

Soils Testing

The requirements for soils sampling and the procedures for soil sampling are discussed in the Summary and Well Construction Guidelines, respectively.

Non-Motor Fuel and Commercial Motor Fuel Storage Facilities

Soils samples obtained from non-motor fuel and commercial motor fuel storage facilities shall be laboratory analyzed individually or they shall be composited in a manner as to composite two succeeding samples together starting with the top two, etc. The samples from the uppermost zone(s) shall be analyzed first and any or all succeeding samples may not have to be analyzed if the previous set of samples above it is determined to be "clean."

When the history of the storage facility is precisely known and documented to the satisfaction of the enforcing agency, laboratory analyses shall test for the materials and related materials that are and were stored in the facility. If the history is not precisely known, a complete gas chromatography/mass spectroscopy (GC/MS) scan of volatile organics (EPA Method 624) and/or acid/base/neutral extractables (EPA Method 625) shall be performed as appropriate for the types of materials which may have been stored. Testing of soils shall employ EPA Standards Procedures in all appropriate cases. Otherwise recognized standards are to be employed.

Individual Agricultural and Suburban Motor Fuel Storage Facilities

Soils samples obtained at individual agricultural and suburban motor fuel storage facilities can be field tested. Tests to be performed are (1) presence of motor-fuel odor, and (2) the observance of an oil sheen after which the soil sample is vigorously mixed with water in a clear (transparent) glass vessel.

Monitoring Schedule

For the purposes of these Guidelines the following schedule of groundwater sampling and other measurements shall be observed:

Non-Motor Fuel Storage Facilities

Groundwater sampling and vadose monitoring shall be performed on a semiannual basis, starting upon the completion of the installations. Water samples are to be laboratory tested.

Commercial Motor Fuel Storage Facilities

Groundwater sampling shall be performed on a monthly basis, starting upon the completion of the installation. Vadose monitoring shall be performed on a quarterly basis, starting upon the completion of the installation.

Individual Agricultural and Suburban Motor Fuel Storage Facilities

Probing for the detection of motor fuel product and water in the monitoring well shall be conducted on a semi-annual basis starting upon the completion of the well.

Modificaton of Monitoring Schedule

On an individual basis, the Administering Agency may alter any monitoring schedule or request special supplemental sampling and testing, based upon the results of previous tests. On the same basis, specific quality control measures may also be specified.

Groundwater Sampling and Laboratory Testing

Non-Motor Fuel Storage Facilities

The sampling of groundwater for laboratory analysis shall be accomplished in the following manner:

A. The well shall be bailed or pumped to remove four to ten well volumes prior to sampling. If the well is evacuated before four to ten well volumes are removed, the sample shall be taken when the water level in the well recovers to approximately 80% of its initial water level.

B. Following the required volume of evacuation from the well, the sample shall be obtained with a teflon or stainless steel bailer or a gas actuated positive displacement bladder pump (whereby gas is not in contact with the fluid being pumped). Air-lift form of sampling shall not be used.

C. Water samples shall be handled and preserved according to the latest EPA methods as described in the Federal Register (Volume 44, No. 233, Monday, December 3, 1979, Page 69544, Table II) for the type of analysis to be performed.

Detailed procedures or assistance can be obtained from a qualified commercial laboratory.

Constituents to be laboratory tested are to include materials or related materials that are being stored or had been stored in the storage facility. If this is not precisely known, a complete scan of all possible contaminants shall be performed. Laboratory testing of waters shall employ EPA Standard Procedures in all appropriate cases (as stated under "Soils Testing"). Otherwise recognized standards are to be employed.

Commercial Motor Fuel Storage Facilities

Water well sampling is to be accomplished by using a clear (transparent) plastic ball-valve bailer. Water samples are to be field inspected for the presence of odor and the observance of product or sheen on the water sample.

Vapor Monitoring

For commercial motor fuel storages, vapor samples are to be pumped from the vapor monitoring well and are to be passed through a portable field analyzer. For non-motor fuel storages, especially when a wide scan of constituents is necessary, vapor samples are to be pumped and passed through an adsorption medium for laboratory desorption and analytical testing.

Procedures and testing of vapors shall follow recognized standards. Assistance can be obtained from a qualified commercial laboratory.

Suction Lysimeter Monitoring

Water or fluids extracted from a suction lysimeter (from non-motor fuel storage) shall be handled, preserved and analyzed in the same manner as for groundwater samples for laboratory analysis.

Interface Well Monitoring

Fluid sampling, should a saturated condition develop upon the interface, for non-motor fuel storage, shall be accomplished with a teflon or stainless steel bailer. Fluids obtained are to be handled, perserved and laboratory tested in the same manner as described previously under "Groundwater Sampling and Laboratory Testing".

Individual Agricultural and Suburban Motor Fuel Storage Facilities Monitoring

Monitoring of individual agricultural and suburban motor fuel storage facilities is to be accomplished by the probing of the monitoring well for the detection of motor fuel product or any fluids in the well. This can be performed by lowering a clear plastic ball-valve bailer.

If fluids are present in the well, the clear plastic ball-valve bailer would secure a sample which can be tested for the presence of motor fuel by noting the presence of odor and the observance of product or sheen on the water sample.

Reporting

The results of all soils testings, water sample observations and analyses, and vadose monitorings are to be reported to the Administering Agency in a timely manner following obtaining the results.

GLOSSARY

Administrating Agency - that local city or county government that administers the Permit Ordinance.

Annular Seal - that impermeable material that fills the space between the borehole and the well casing

Annular Thickness - that distance between the borehole and the outside casing wall

Aquitard - a usually horizontal geologic formation with very low permeability that restricts fluid flow.

Borehole - the hole created by a drilling devise.

Bottom Plug - the plug placed at the bottom of well casing to preclude erosion of the backfill material.

Casing - the conduit placed in a borehole to extract fluids or vapors.

Drilling Mud - a heavy suspension fluid circulated as part of the operation of hydraulic rotary drilling, usually consisting of a mixture of water, mud, clay (bentonite) and chemical additives.

EPA - Enviornmental Protection Agency

Filter Pack - that select uniformly graded material used to backfill the annular space around a well screen or perforated casing.

Formations - those geologic strata that underlie the ground surface.

GC/MS - gas chromatography/mass spectroscopy; laboratory testing methods.

Gravel Pack Envelope - that properly graded material surrounding the annular space around a well screen or perforated casing.

Guidelines - Groundwater Monitoring Guidelines

Hazardous Materials - those materials discussed in Part II of the Hazardous Materials Storage Permit Ordinance

Hazardous Materials Storage Permit Ordinance - the Ordinance adopted by the administrating agencies to regulate the construction monitoring and reporting of underground hazardous materials storage facilities.

Hydrogeologic Conditions - those conditions dealing with the behavior of groundwater.

Interface Well - vadose or unsaturated zone monitoring well, conventionally constructed with the screened or perforated interval located at a formational interface, usually permeable materials overlying impermeable or slightly permeable materials. Fluid sampling is possible when a temporary condition of saturation develops at the interface.

Motor Fuels - those hazardous materials used primarily for the operation of internal combustion engines, including lubricating and cleaning fluids.

Natural Formation - An undisturbed material.

Non-Motor Fuels - all those hazardous materials not used primarily for the operation of internal combustion engines.

Ordinance 75-6 - an ordinance of the Santa Clara Valley Water District regulating the construction and destruction of wells. (Appendix A)

Perforated Casing - well casing with holes or slots permitting the passage of fluids or vapors.

Permit Ordinance - the Hazardous Materials Storage Permit Ordinance

Saturated Zone - those geologic strata containing extractable groundwater.

SCWVD - Santa Clara Valley Water District

Sensing Zone - the point or interval beneath the surface as controlled by the installation construction from which liquid or vapor samples may be obtained.

State Water Well Driller Report - a State of California form on which a well driller records pertinent information about a well. Water well drillers are required to submit such a report for each well drilled.

Suction Lysimeter - a devise for extracting liquid samples from the unsaturated zone.

Summary - the summary of the Guidelines.

Surface Seal - a shortened annular seal used to insure no contaminents will enter the annular space from the ground surface.

Tank Backfill - that select material used to backfill an underground storage facility.

Tremie Pipe - a conduit used during construction to place materials in a well from the bottom up.

Unsaturated Zone - those underlying strata that are above the water table.

Vadose Monitoring Devices - devices to be installed in the vadose (unsaturated) zone for the purpose of monitoring. They are classified as 1.) active devices which include vapor wells or suction lysimeters and 2.) passive devices such as tensiometers, electrical resistance blocks, etc.

Vadose Zone - the unsaturated zone.

Water Table - the depth below which the ground is saturated.

Well Centralizer - a device used to center well casing in a borehole.

Well Development - the procedure after well construction used to assure stabilization of the gravel pack envelope and adjacent formation and the production of water free of turbidity.

Well head - the surface portion of the well casing.

ORDINANCE NO. 75-6

AN ORDINANCE OF SANTA CLARA VALLEY WATER DISTRICT REGULATING THE CLASSIFICATION, CONSTRUCTION AND SEALING OF WELLS.

The Board of Directors of the Santa Clara Valley Water District ordains as follows:

SECTION 1: PURPOSE

1.1 It is the purpose of this ordinance to provide within the District, for the classification of existing wells, the construction of new wells, the deepening of existing wells and the sealing of wells which will never again be used, including cathodic protection wells, exploratory holes, and wells found to be a public nuisance, to the end that such wells will not cause pollution or contamination of groundwater or otherwise jeopardize the health, safety or welfare of the people of the District.

SECTION 2:
CLASSIFICATION OF WELLS

2.1 All wells within Santa Clara County will be placed into one of the following classifications.

2.2 Active Well – An active well is a well that has been utilized at least once in the preceding 12 months for the production of groundwater. Active wells within groundwater charge zones of the District are subject to the District's groundwater production requirements and require, pursuant to the District Act, the filing, semiannually, of groundwater production statements.

a. If the pump from an active well has been removed for repair or replacement, the well is still considered to be an active well. During the repair period, the well shall be adequately covered to prevent injury to people and to prevent the entrance of undesirable water or foreign matter.

2.3 Inactive Well – An inactive well means a well that has not been used for a period of one year or more for the production of groundwater but is maintained in such a condition that it could be so used.

a. The owner of an inactive well, if he desires to place or maintain a well in this classification, shall obtain from the District, at intervals set by the District, a permit verifying classification of the well as inactive.

2.4 As further evidence of the owner's intention for continued use and as conditions of the permit, he shall properly maintain the well in such a way that:

a. The well has no defects which will permit the impairment of quality of water in the well or in the water-bearing formations penetrated.

b. The well head is to be appropriately protected to prevent accidental entry and to prevent the entrance of undesirable water or foreign matter.

c. The well is marked so that it can be clearly seen.

d. The area surrounding the well is kept clear of brush or debris.

e. Wells used for observation of the groundwater are considered inactive wells so long as they are maintained for this purpose. However, such wells shall be in compliance with this ordinance and bear an appropriate cap, with the label, "Observation Well", and the name of the agency or organization using the well. It shall be securely locked when measurements are not being made.

f. Cathodic protection wells and cased or uncased test holes deep enough to promote interaquifer transfer of groundwater shall be considered inactive wells.

2.5 Permanently Abandoned Well – A permanently abandoned well is a well that will never be reactivated. Wells will not be considered permanently abandoned until they are properly sealed in accordance with this ordinance.

SECTION 3: DEFINITIONS

3.1 Definitions of terms shall be as set forth in 1) Chapter II and Appendix I of the Department of Water Resources Bulletin No. 74, "Water Well Standards: State of California", 2) "Standards for the Sealing of Abandoned Wells", by the Santa Clara Valley Water District and the Santa Clara County Health Department, referenced in Section 7 of this ordinance, and 3) as set forth below:

a. "Person", as used in this ordinance, shall mean any person, association, firm, corporation, municipality, the County of Santa Clara, special district or public agency.

b. "District" shall mean the Santa Clara Valley Water District.

c. "Board" shall mean the Board of Directors of the Santa Clara Valley Water District.

d. "Environmental Health Services" shall mean the Santa Clara County Environmental Health Services.

f. "Public Nuisance" shall mean any well or condition that impairs or threatens to impair the quality of groundwater or otherwise jeopardize the health or safety of the public.

g. "Abatement" means the reconstruction, repair or destruction of a well so as to eliminate a public nuisance.

h. "General Manager" shall mean the General Manager of the Santa Clara Valley Water District or his authorized designee.

i. "Inspecting Officer" shall mean a person designated by the General Manager and authorized to ensure that the provisions of this ordinance are enforced. Such person will be a member of the staff of the District or the Environmental Health Services.

SECTION 4: STATE REPORTING

4.1 Nothing contained in this ordinance shall be deemed to release any person from compliance with the provisions of Article 3, Chapter 10, Division 7 of the Water Code of the State of California or any amendment thereto.

SECTION 5: PROHIBITIONS

5.1 No person within the County of Santa Clara shall construct, or seal a well, unless a written permit has first been obtained from the Santa Clara Valley Water District.

SECTION 6:
PERMIT PROCEDURES

6.1 Application – Permits required by this ordinance shall be subject to conditions set forth in this ordinance or as required by law. The General Manager shall prescribe and provide a regular form of application for permits under the terms of this ordinance. Said application form shall contain space for the name and address of the applicant, together with such information as in the judgement of the General Manager is necessary to establish the location of the well, the purpose of the permit and the extent of any proposed work. Drawings and specifications for any proposed work shall accompany the application form and shall be detailed enough to demonstrate compliance to the standards.

6.2 Fees – Fees to cover District costs required for the review of applications, issuance of permits and inspection of work under this ordinance, and the method of payment of such fees may be as established and adopted by the Board from time to time by resolution.

6.3 Waiver or Payment of Fees and Costs, Hardship Claims – At the recommendation of the General Manager and

approval by the Board, all or any part of the fees and costs of compliance with this ordinance may be waived or paid by the District in accordance with guidelines and procedures as may be established by the Board.

6.4 Term of Permit and Completion of Work — Work authorized by a permit issued pursuant to this ordinance shall begin within ninety (90) days from the date of issuance of the permit unless officially extended. If the work is not so begun, or extension requested by permittee, the permit shall become void. The permittee shall notify Distract as specified on the permit before starting any work authorized by the permit.

6.5 Guarantee of Performance – Prior to the issuance of a permit, the applicant shall post with the General Manager a cash deposit or bond guaranteeing compliance with the terms of this ordinance, such bond to be in an amount determined by the General Manager as necessary to protect the District and the public against faulty or uncompleted work. The amount of said bond shall not exceed the total estimated cost of the work. Such deposit or bond may be waived by the General Manager if he determines other assurances of compliance are adequate.

6.6 Liability – Permittee shall assume all liability imposed by law for personal injury or property damage resulting from any work performed by permittee or his agent under the permit, or resulting from failure of permittee to perform his obligation under said permit. If any claim of such liability is made against the District, their officers, employees, or agents, permittee shall defend, indemnify and hold them and each of them, harmless from such claim.

6.7 Review and Appeal — Any person aggrieved by the refusal to issue a permit, the terms of a permit, or any decision made by the Inspecting Officer required by this ordinance may, upon written request, have the matter reviewed by the General Manager. Upon receipt of such a written request, the General Manager shall schedule the matter for review within two weeks and give applicant at least ten (10) days written notice of the time and place of said review unless applicant agrees to a lesser time. If the applicant is not satisfied with the results of the review by the General Manager, he may present his appeal to the Board. Such appeals must be in writing and must be submitted within two weeks after the General Manager's decision has been mailed to or served upon the applicant. The Board shall hold a hearing of said appeal within two weeks of receipt of such appeal and shall mail notice in writing of the date thereof to the applicant at least five (5) days before the hearing date. The decision of the Board shall be final and binding upon all parties.

SECTION 7: STANDARDS

7.1 Standards for the construction, or sealing (permanent abandonment) of wells will be in accordance with the latest revision of "Standards for the Construction of Wells, Santa Clara County" and "Standards for the Sealing of Abandoned Wells, Santa Clara County" prepared by the Santa Clara Valley Well Construction/Sealing Standards Review Committee in cooperation with the Santa Clara Valley Water District and the Environmental Health Services.

SECTION 8: ENFORCEMENT

8.1 Notice of Violation – In the event a well subject to this ordinance is found to be a public nuisance constructed or sealed contrary to the terms of this ordinance or the permit issued pursuant to this ordinance, the General Manager shall give written notice to the owner of the land as shown on the most recent equalized assessment roll, or to the permittee at his address listed on the permit if a permit has been issued; which notice shall state the nature of the violation, the corrective measures to be taken, and a reasonable time within which such corrections must be made. Said notice shall include a statement that if the landowner or permittee fails to make corrections within the period specified, the District may abate the condition at owner or permittee's expense.

8.2 Abatement by District – If the corrections listed in the notice given pursuant to 8.1 above are not made as required in said notice, the General Manager with the approval of the Board, and after a reasonable opportunity for the person notified to be heard by said Board, may abate the condition. The owner or permittee shall be liable for the cost thereof.

8.3 Emergency Abatement – If the General Manager finds that a well subject to this ordinance is, by reason of condition, operation or maintenance, causing significant irreparable damage to the groundwater or presents an immediate danger to health and safety, and that it is impracticable to notify the owner or permittee, the General Manager may perform emergency work necessary to abate the condition without giving notice as required in 8.1 above, and the owner of the land as shown on the last equalized assessment roll, shall be liable for the cost thereof.

SECTION 9

9.1 Conflicts – All ordinances of District in conflict with the terms conditions of this ordinance are hereb repealed to the extent of such conflict.

SECTION 10

10.1 Severability – If any section, subsection, paragraph, subparagraph, sentence, clause or phrase of this ordinance is for any reason held to be invalid or unconstitutional, such invalidity or unconstitutionality shall not affect the validity or constitutionality of the remaining portions of this ordinance; and the Board declares that this ordinance and each section, subsection, paragraph, subparagraph, sentence, clause and phrase thereof would have been adopted irrespective of the fact that one or more of such section, subsection, paragraph, subparagraph, sentence, clause or phrase is declared invalid or unconstitutional.

SECTION 11

11.1 This ordinance shall take effect and be in force in thirty (30) days from and after the date of its passage and before the expiration of fifteen (15) days after its passage it shall be published once with the names of the members voting for and against the same in the San Jose Mercury, a newspaper of general circulation published in the County of Santa Clara.

PASSED AND ADOPTED by the Board of Directors of Santa Clara Valley Water District on October 14, 1975, by the following vote:

AYES: Directors: J. Chiri, M. E Dullea, P. T. Ferraro, J. J. Lenihan, E. A Mirassou, C. Rush, R. T. Sapp.

NOES: Directors: None.

ABSENT: Directors: None.

SANTA CLARA VALLEY
WATER DISTRICT
By: ROBERT T. SAPP
Chairman of the
Board of Directors.

ATTEST:
VIOLET V. ENANDER
Clerk of said
Board of Directors

Amended July 27, 1976

STANDARDS FOR THE CONSTRUCTION OF WELLS SANTA CLARA COUNTY (Abridged)

PURPOSE

The purposes of standards for well construction are not only to provide adequate protection of water in wells but equally, if not more importantly, to protect and preserve the groundwater supply in aquifers for future uses. These purposes are to be accomplished by properly locating the well site, by requiring an annular seal in the upper portion of the well to prevent well contamination from surface sources, and by specifying construction requirements to prevent interaquifer transfer or mixing of degraded groundwaters with good quality waters through wells. Furthermore, wells properly constructed could be easily and adequately destroyed after their usefulness is over without having to resort to complicated and expensive procedures in order to protect the aquifers. The protection of groundwater supplies is a complex problem, and, although poor well construction may not be the principal cause of groundwater contamination, the problem of aquifer contamination must be attacked from all possible aspects.

WATER WELL LOCATION WITH RESPECT TO CONTAMINANTS AND POLLUTANTS

All water wells shall be located an adequate horizontal distance from potential sources of contamination and pollution. Most of the factors involved in determining safe distances are usually not known. The following distances, on the basis of past experience and general knowledge, are safe where dry upper unconsolidated formations, less permeable than sand, are encountered:

Sewer	50 feet
Subsurface sewage leaching field, septic tank, or pit privy	100 feet
Cesspool or seepage pit	150 feet

No water well shall be located closer than the above distances from the specified sources of contamination. Where, in the opinion of the enforcing agency, adverse conditions exist, the usual distances shall be increased or special means of protection shall be provided.

If possible, the well shall be up the groundwater gradient (upstream) from the specified source of contamination.

WATER QUALITY ZONES

Since subsurface conditions vary from place to place, the standards must be formulated so as to conform to the groundwater geohydrologic and water quality conditions of the specific areas within the ground water basins of Santa Clara County. For well construction and sealing purposes, the groundwater basins of Santa Clara County have been divided into three water quality zones. Zone 1, which is the largest portion of the basins, represents the areas where the quality of water at all pumping depth intervals is generally good. Zone 2, near San Francisco Bay, is a multi-aquifer area where the shallow zone (0 to 150 feet) may be contaminated or could become contaminated by sea water. In Zone 3, the Evergreen area, degraded quality water occurs below a depth of 300 feet with good quality water overlying this zone. These water quality zones are delineated on Figure 1.

The bedrock areas outside the groundwater basins have their individual potential problems and well construction requirements for these areas are also included in these standards.

WELL CONSTRUCTION REQUIREMENTS

All wells are to be constructed in such a way that they will not serve as a channel allowing surface waters to enter the groundwater body nor will they serve as a channel for interaquifer groundwater flow when such a flow may result in the deterioration of the quality in any or all water-bearing formations penetrated. The following paragraphs present examples of well construction standards that meet the protection objectives in the various water quality zones and in the bedrock areas. If the enforcing agency finds that compliance with any of the requirements prescribed herein is impractical for a particular location because of unusual conditions and would result in construction of an unsatisfactory well, the enforcing agency may prescribe alternative requirements which are equivalent to these standards in terms of protection obtained.

Zone 1

In Zone 1, where the quality of water within the groundwater basin is generally unimpaired, the objective of the construction standards is to prevent well and aquifer contamination from surface sources. Here, a "general construction standard" will apply which entails the requirement of an effective surface seal. This is to be accomplished by the placement of a neat cement, cement grout, or concrete seal in the annular space between the well and the wall of the drilled hole to a minimum depth of 50 feet below the surface. In stratified formations the seal should terminate in a clay or other impermeable material. Special sealing depth requirement on an individual basis will be set forth by the enforcing agency for application of wells to be constructed less than 50 feet in depth. The sealing material shall be applied from the bottom of the interval to be sealed to the top in a manner that will prevent bridging, dilution, or segregation of the sealing material (by employing either a tremie pipe or a pressure grouting method). The thickness of the seal shall be in accordance with the State of California Standards.

A concrete floor slab, or base, shall be constructed around the top of all pumping or injection wells. The top of the floor slab shall slope away from the casing and the outer edge of the slab shall be at least six inches above the ground surface.

For a pump above the surface, a concrete pedestal shall be constructed atop the floor slab on which the pump is to be placed.

Examples of acceptable sealing construction for Zone 1 for nongravel packed wells are shown on Figure 2 and for gravelpacked wells on Figure 3.

Zone 2

In Zone 2, adjacent to San Francisco Bay, degraded quality water occurs in the shallow zone to a depth of 150 feet with good quality water in the lower aquifers. The specific objectives of the well construction standards are to prevent interaquifer flows from the shallow aquifer into the lower aquifers through wells and, in addition, to meet the construction objective for Zone 1. In order to accomplish these, all provisions stated under "general construction standards" discussed under Zone 1 shall be employed plus the extension of the surface seal into a clay or other impermeable layer at a minimum depth of 150 feet. An example of acceptable well construction in Zone 2 is shown on Figure 4.

If a gravel packed well were to be constructed in Zone 2, the construction of an annular seal as shown on Figure 3 would have to be extended into a clay layer at a depth of around 150 feet.

Zone 3

In Zone 3, the portion of the Evergreen area where aquifers below a depth of 300 feet have yielded poor quality water, the specific objectives of the well construction standards are to prevent interchange of groundwater between the lower aquifers containing mineralized

connate water and the upper unimpaired water quality aquifers, and also to meet the objective for Zone 1. In order to accomplish these, all provisions stated under "general sealing standards" for *Zone 1 shall be employed* plus limiting the depth of wells to be constructed to a maximum of 300 feet. An exception in regards to the maximum depth can be made if the owner can prove to the *enforcing agency that waters at a greater* depth are of good quality. This has to be based on the results of laboratory testing of a sample obtained only from the lower zone. In order to obtain such a sample, the lower zone *shall be isolated from the* upper zones during sampling.

BEDROCK AREAS

Bedrock areas present special conditions for the safe construction of water wells in that waters in bedrock could be, in part, recharged and transmitted unfiltered through open fractures. This is in contrast to the filtering that occurs as water is recharged and transmitted *through unconsolidated granular materials* of the groundwater basins.

For wells constructed in bedrock, the objective is to prevent contamination from surface sources, just as for wells *constructed within* the groundwater basin. This is to be accomplished by selecting the well site in a manner to obtain maximum security from potential sources of contamination and requiring *the construction of an annular seal in the* upper portion of the well.

In the selection of a well site, the conditions listed earlier under the heading "Water Well Location with Respect to *Contaminants and Pollutants*" *shall* be observed. In places where adverse conditions exist, the minimum distances listed shall be increased or special means of protection shall be provided.

In order to construct the upper annular seal, an oversize hole must be constructed to the depth and diameter required for the seal and casing installed to retain the seal. All public water supply wells including individual domestic wells to be constructed in bedrock in subdivided lands under the jurisdiction of the County Land Development Regulations shall incorporate at least a 50-foot annular seal from the surface. Public water supply wells constructed in bedrock are also subject to Environmental Health Services approval before being placed into service. For individual domestic wells on lands not subject to Land Development Regulations shall also incorporate a 50-foot annular seal from the surface, unless these wells are less than 65 feet deep. For these wells, the annular space shall be sealed in the upper three-fourths of the depth of the well. All other requirements of the general well construction standards shall apply to wells in bedrock.

A typical example of an acceptable seal for well construction in bedrock is *shown in Figure 5.*

CATHODIC PROTECTION WELLS

Cathodic protection wells (or "deep anodes") also present hazards to groundwater quality just as a water well may in that both represent an opening from the *surface through various aquifers.* Just as for water wells, it is the objective of these standards to protect the quality of water in aquifers by requiring cathodic protection wells to be constructed in such a *manner that they will not serve as a* channel allowing surface waters to enter the groundwater body nor will they serve as a channel for interaquifer groundwater flow when such flow may result in the deterioration of *the quality in any or all* the aquifers penetrated. It is also the purpose of these standards to facilitate the effective sealing of these wells when their useful life has expired.

The sealing requirements for Zones 1 and 2 are similar to that of water wells constructed in these respective zones as illustrated in Figure 6, examples A and B, respectively (the latter, in Zone 2, if the well is deeper than 150 feet). In Zone 3, if the well is deeper than 300 feet, the annular seal would have to be extended to a depth of 300 feet as shown in Figure 6, example C, in order to protect the upper aquifers from rising waters from the degraded lower aquifers. If the cathodic *protection* well is to be less than 150 feet in depth in Zone 2 and less than 300 feet in Zone 3, general sealing requirements as for Zone 1 shall apply.

The top of the well shall be protected *against the entrance of surface water* draining from the surrounding land by installation of watertight caps, covers, plugs or similar devices. In drainage ways, exclusive of highways, streets, paved surfaces *(such as parking lots, equipment* yards, etc.), sidewalks, and the like, the top of the well shall terminate above, or otherwise be protected against, known conditions of flooding. When extended above ground *surface, the vent pipe shall* be terminated at the rectifier housing or other protective housing at an elevation which is above known conditions of flooding.

The diameter of the vent pipe is to be of sufficient size in order to be properly backfilled when the useful life of the anode has expired (sealing of an abandoned well).

DISINFECTION OF WELL

All public water supply, individual domestic, and industrial wells shall be disinfected following construction, repair or when work is done on the pump, before the well is placed into service.

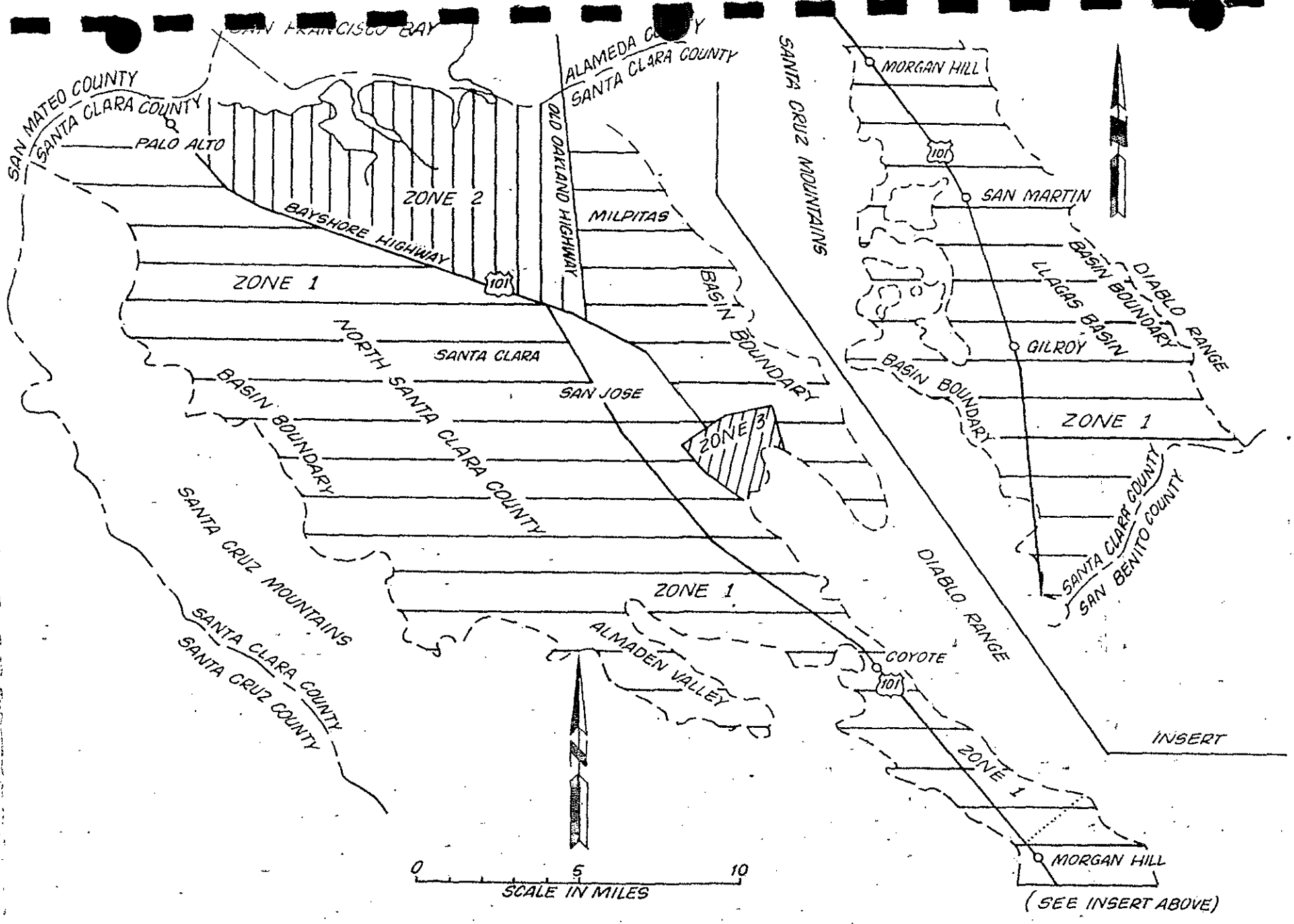
COMPLIANCE WITH STATE CODES

In complying with these standards the well driller must also comply to the provisions of the various State codes relating to water well drilling. These include provisions regarding Contractor's License Law and the filing of notice of intent and well completion reports under the provisions of the Water Code.

REFERENCE

Reference is made to the unabridged version of the Well Construction Standards for a more detailed account of the purposes, objectives, and well construction requirements in addition to the bibliography and other pertinent information. The Well Construction Standards is one of two documents pertaining to water well ordinance, the companion document being "Standards for the Sealing of Abandoned Wells, Santa Clara County", October, 1972. The "Sealing Standards" also contain as Appendix A "Geology", Appendix C – "Definition of Terms", and Appendix D "Water Quality Criteria" which will not be repeated in the Well Construction Standards Document.

The general requirements along with specifications on procedure, materials surface construction features, disin *fection, water quality sampling, and other* pertinent features conform to Chapter II of California Department of Water Resources Bulletin 74, "Water Well Standards State of California", February 1968, except where *exceptions are noted* in these Standards.



GROUNDWATER QUALITY ZONES
SANTA CLARA COUNTY

FIGURE 1

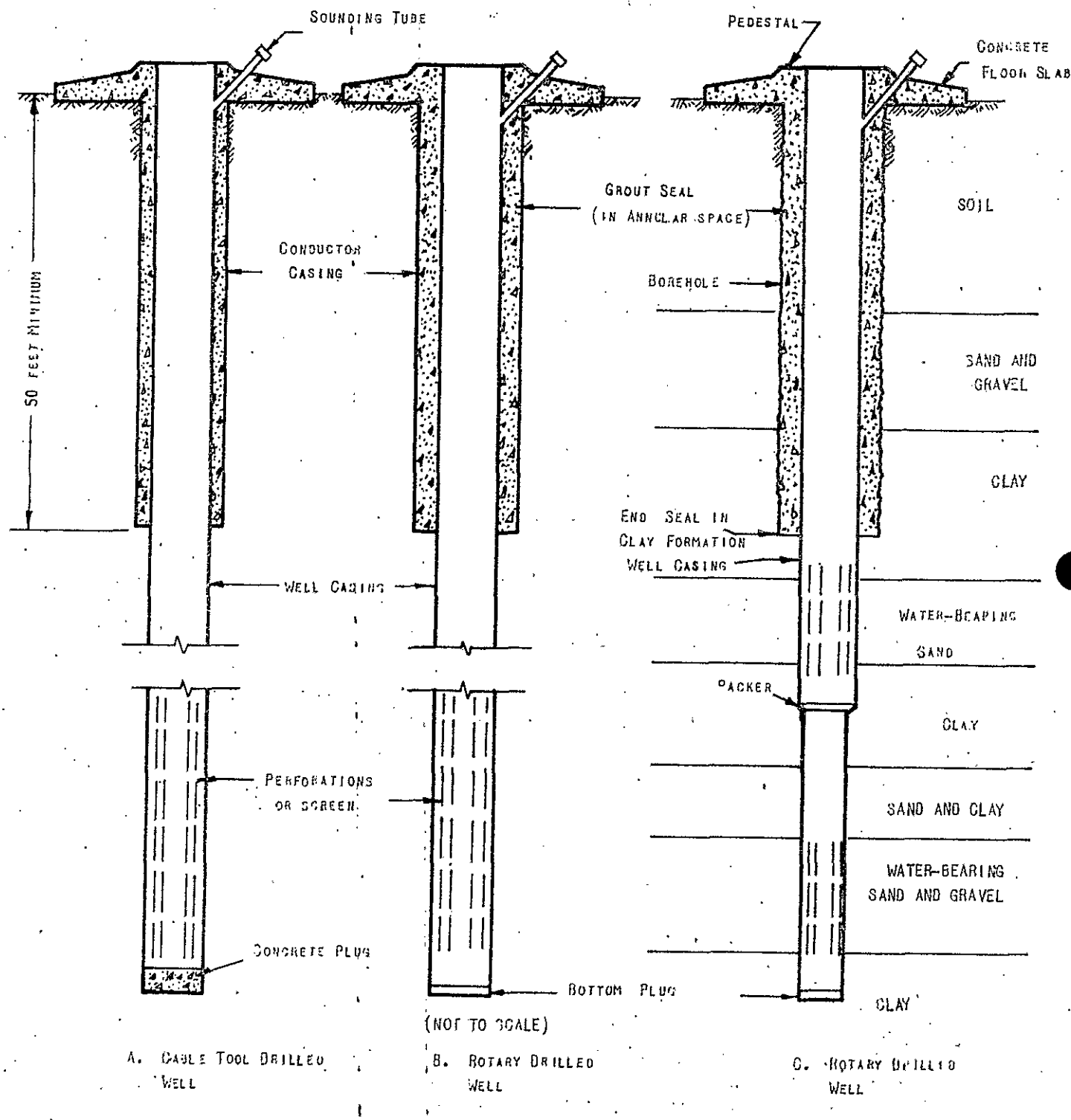


FIGURE 2. SEALING CONDITIONS FOR UPPER ANNULAR SPACE NONGRAVEL PACKED WELLS

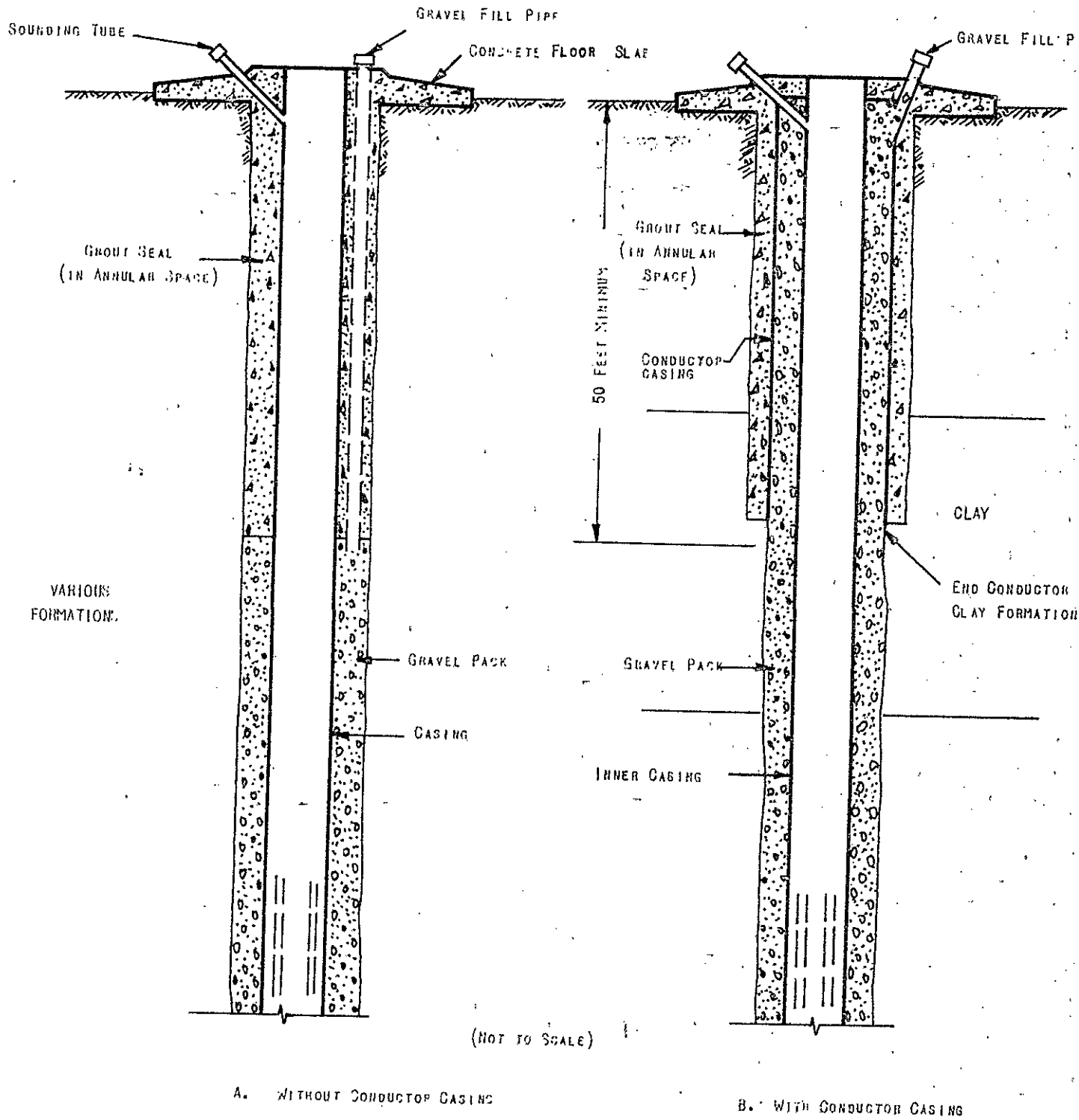


FIGURE 3. SEALING CONDITIONS FOR UPPER ANNULAR SPACE
GRAVEL PACKED WELLS

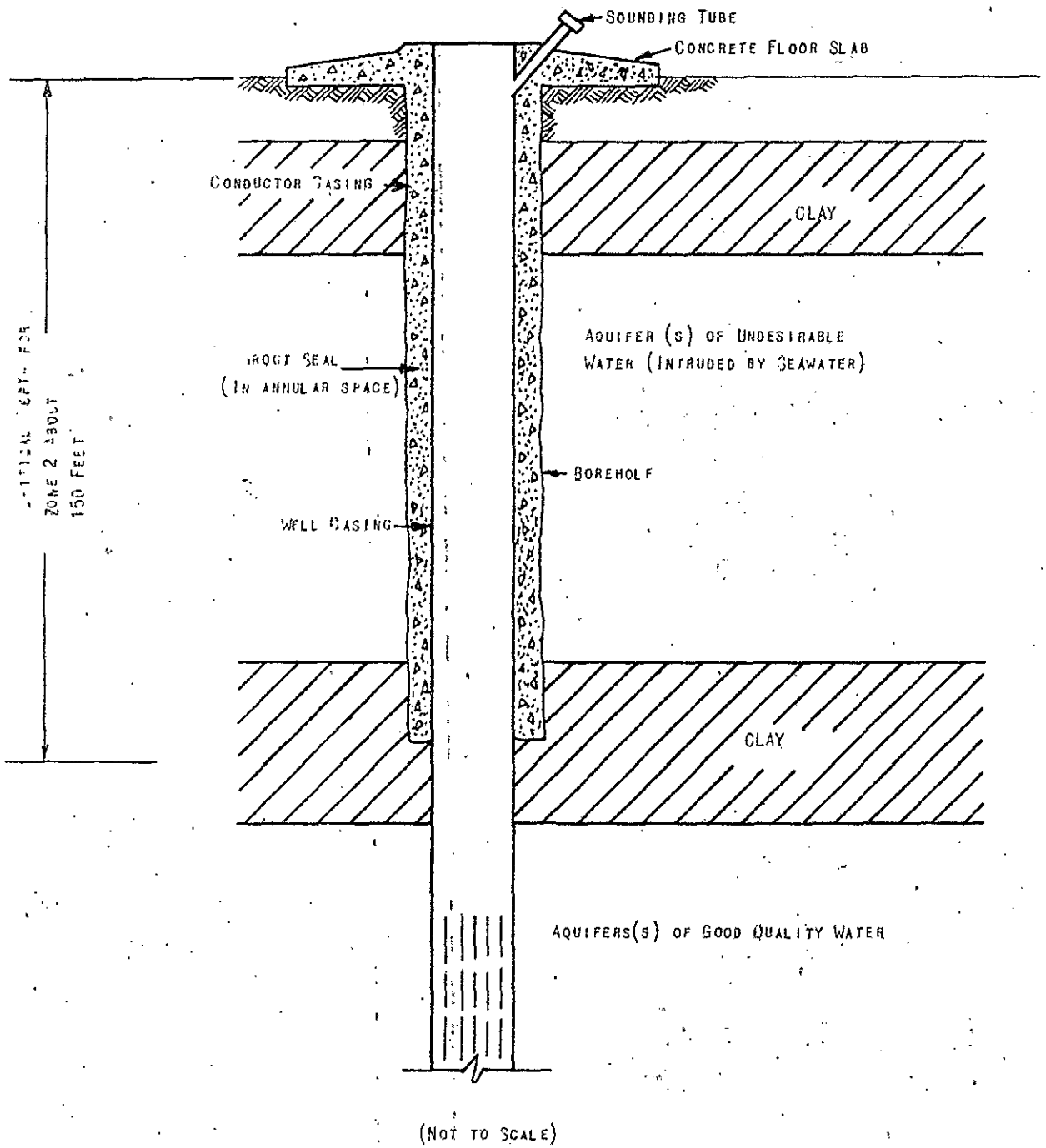


FIGURE 4. EXAMPLE OF SEALING UPPER AQUIFER ZONE WELL IN ZONE 2

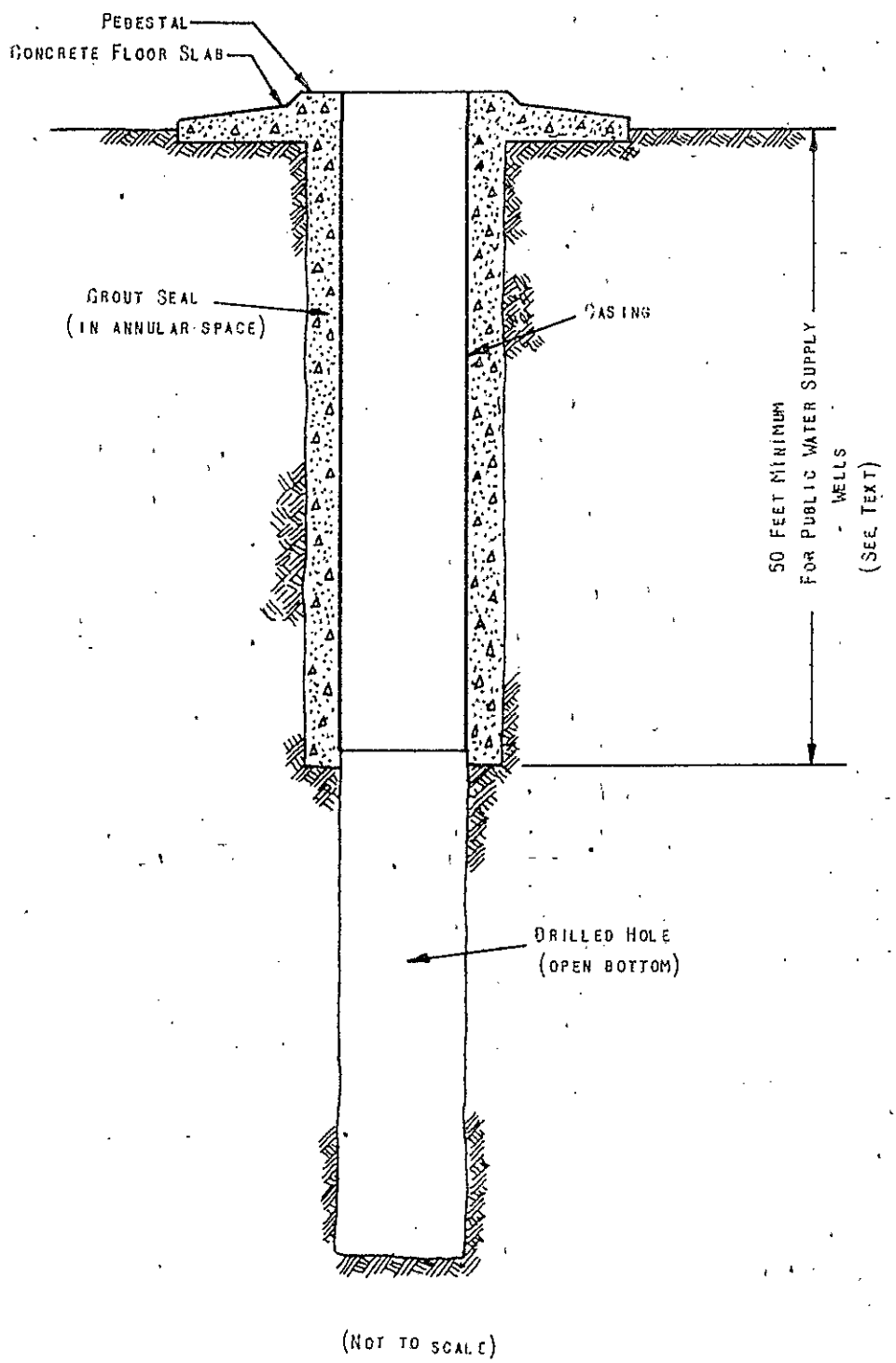
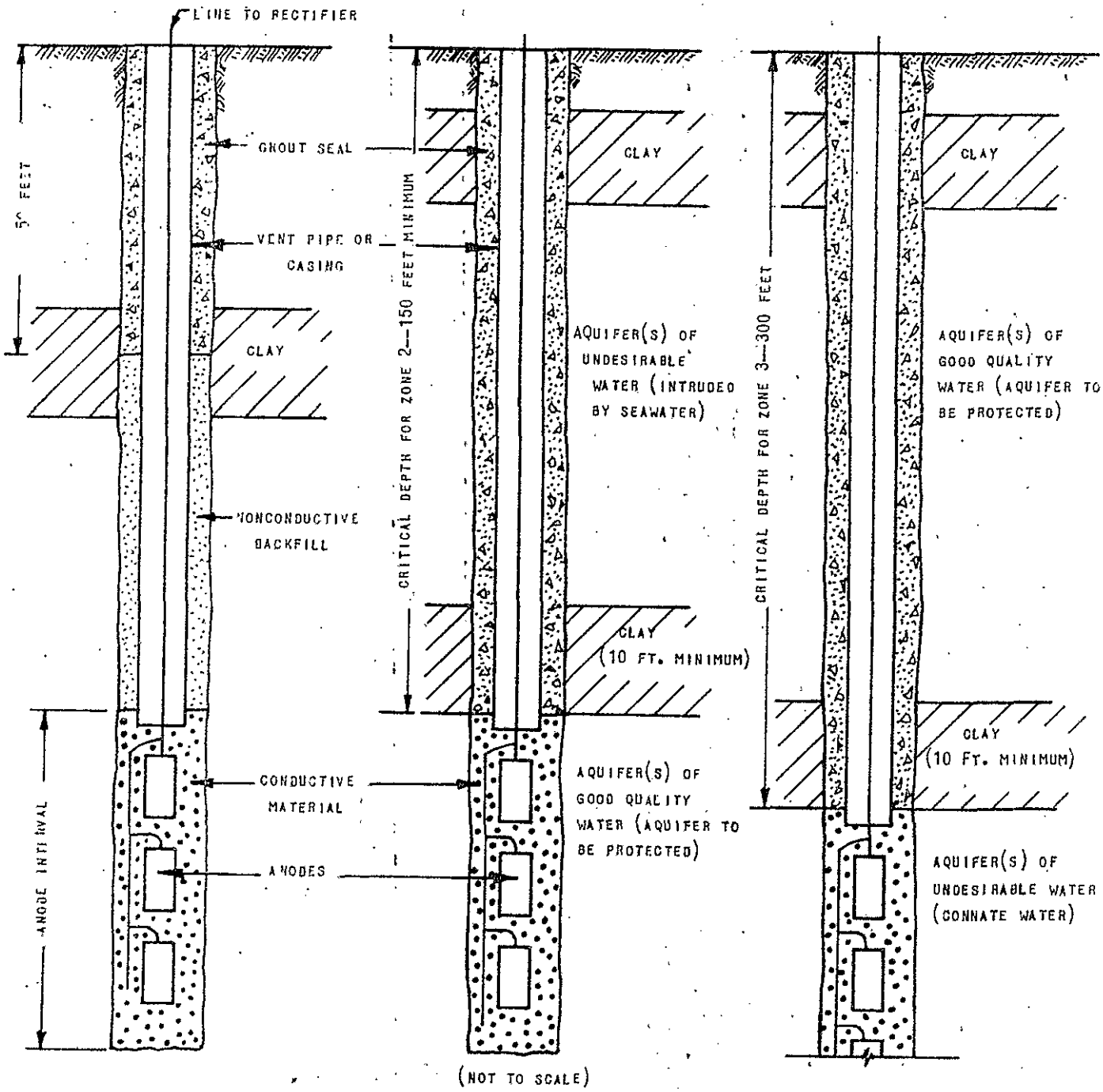


FIGURE 5. EXAMPLE OF SEALING UPPER ANNULAR SPACE
WELL IN BEDROCK FORMATION



A. General Requirement, Zone 1.

B. Sealing Requirement for Wells Deeper Than 150 Feet in Zone 2.

C. Sealing Requirement for Wells Deeper Than 300 Feet in Zone 3.

FIGURE 6. EXAMPLES OF SEALING CONDITIONS CATHODIC PROTECTION WELLS

APPENDIX C

STANDARDS FOR THE SEALING OF ABANDONED WELLS SANTA CLARA COUNTY (ABRIDGED)

PURPOSE

The purpose of standards for the sealing of abandoned wells is to protect and preserve the groundwater supplies for future uses and to eliminate the potential physical hazard that exists from wells that are not being used. This is to be accomplished by restoring, as nearly as possible, those subsurface conditions which existed before the well was constructed. Since subsurface conditions vary from place to place, such standards must be formulated so as to conform to the groundwater geohydrologic and water quality conditions of the specific areas within the groundwater basins of Santa Clara County.

WATER QUALITY ZONES

For well sealing purposes, the groundwater basins of Santa Clara County have been divided into three water quality zones, based on the different quality of waters present and on the local geologic conditions. Zone 1, which is the largest portion of the basin, represents the areas where the quality of water at all pumping depth intervals is generally good. Zone 2, near San Francisco Bay, is a multiaquifer area where the shallow zone (0 to 150 feet) may be contaminated or could become contaminated by seawater. In Zone 3, the Evergreen area, degraded quality water occurs below a depth of 300 feet with good quality water overlying this zone. These water quality zones are delineated on Figure 1.

WELL SEALING PROCEDURE

All "abandoned" wells shall be destroyed in such a way that they will not produce water or act as a channel for the interchange of water, when such interchange may result in deterioration of the quality of water in any or all water-bearing formations penetrated, or present a hazard to the safety and well-being of people and animals.

Zone 1

In Zone 1, where the quality of water is generally unimpaired, the objective of the sealing standard is to prevent contamination of the aquifer from surface sources. Here, a "general sealing standard" will apply which will entail the filling of the well with an impervious filler material (inorganic soils of low permeability, bentonite, concrete, or cement grout) from the bottom of the well to a depth of 50 feet. The upper 50 feet of the well shall be filled by the placement of cement grout, neat cement or concrete. Placement of the filler and sealing materials is to be performed in a manner that will prevent bridging, dilution or segregation of the sealing material (tremied into the well from the bottom). Placement of an annular grout seal in the upper 50 feet will be required if there is an annular opening or a gravel envelope around the well casing. Placement of the annular seal in the upper 50 feet, if necessary, shall be accomplished by either the removal of the upper casing or the perforation of the casing with the cement grout forced to pass into the annular opening or gravel pack. Typical general sealing features of a destroyed well are shown on Figure 2.

Zone 2

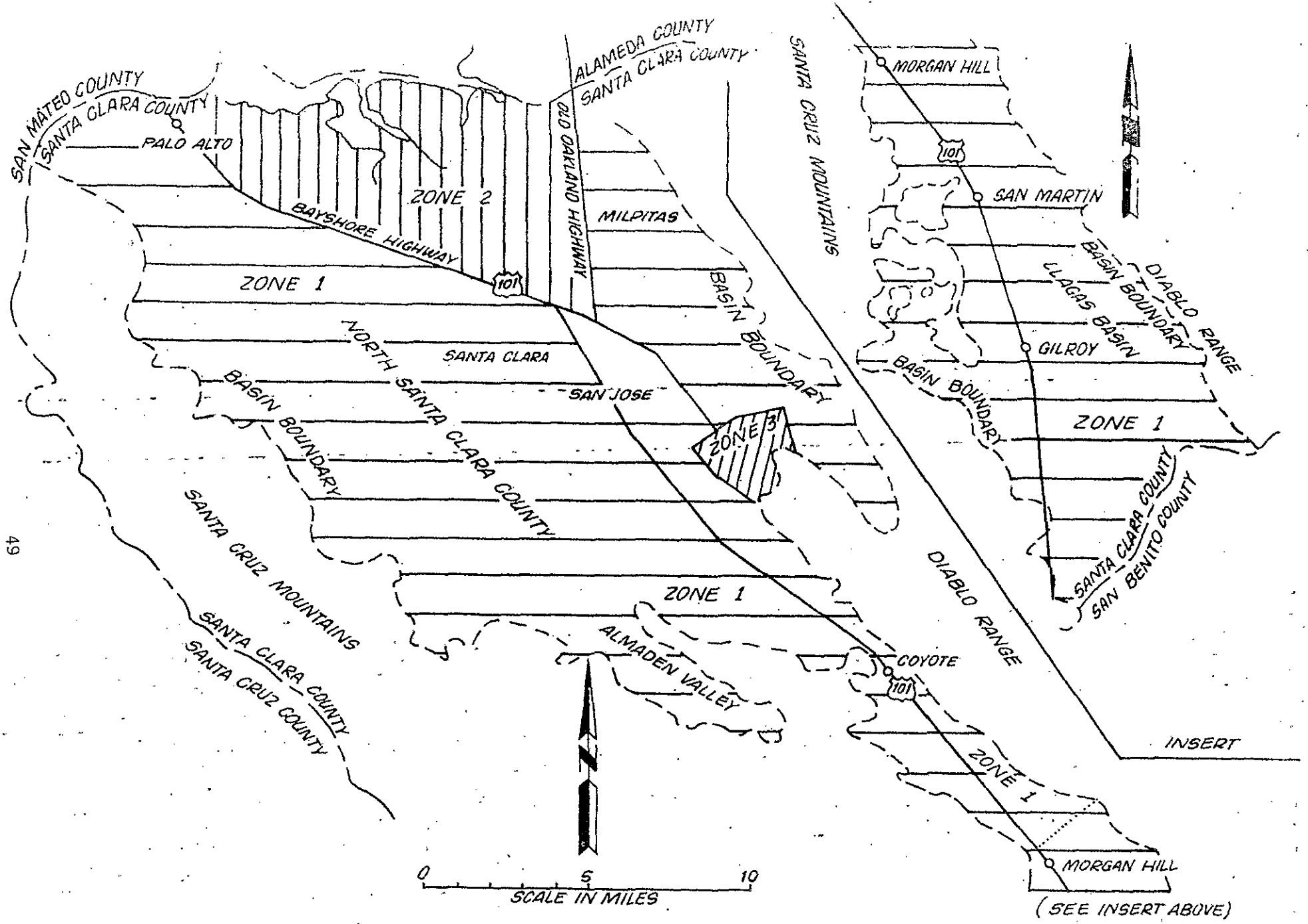
In Zone 2, adjacent to San Francisco Bay where degraded quality water occurs in the shallow zone to a depth of about 150 feet with good quality water in the lower aquifers, it is the objective of the well sealing standard to prevent interaquifer flows from the shallow aquifer into the lower aquifers through abandoned wells. In order to accomplish this, all the provisions stated under "general sealing standard" discussed under Zone 1 shall be employed plus the placement of an annular seal opposite a clay layer at a depth of about 150 feet. The annular seal is to be placed by perforating an interval not less than 10 feet at a depth of 150 feet, then filling the casing with cement grout and forcing the cement grout to flow into and seal the annular opening between the well casing and the clay formation or into and seal the gravel pack. Typical sealing features of a destroyed well for Zone 2 are presented on Figure 3.

Zone 3

In Zone 3, the portion of the Evergreen area where aquifers below a depth of 300 feet have yielded poor quality water, it is the objective of the well sealing standard to prevent interchange of water between the lower aquifers containing mineralized connate water and the upper unimpaired water quality aquifers. In order to accomplish this, all provisions stated under "general sealing standards" in Zone 1 shall be employed plus the placement of an annular seal opposite a clay layer at a depth of about 300 feet. The annular seal is to be placed in a similar manner as discussed under Zone 2 and the upper 300 feet of the well shall be sealed with concrete or cement grout. Typical sealing features of a destroyed well for Zone 3 are presented on Figure 4.

REFERENCE

Reference is made to the unabridged version of the Standards for a detailed account of the purposes, objectives, well sealing procedures, sealing materials, additional requirements in urban areas, definition of terms, bibliography, geology of the groundwater basin, water quality criteria, and other pertinent information. Said unabridged version is available for inspection in the District office.



GROUNDWATER QUALITY ZONES
SANTA CLARA COUNTY

FIGURE 1

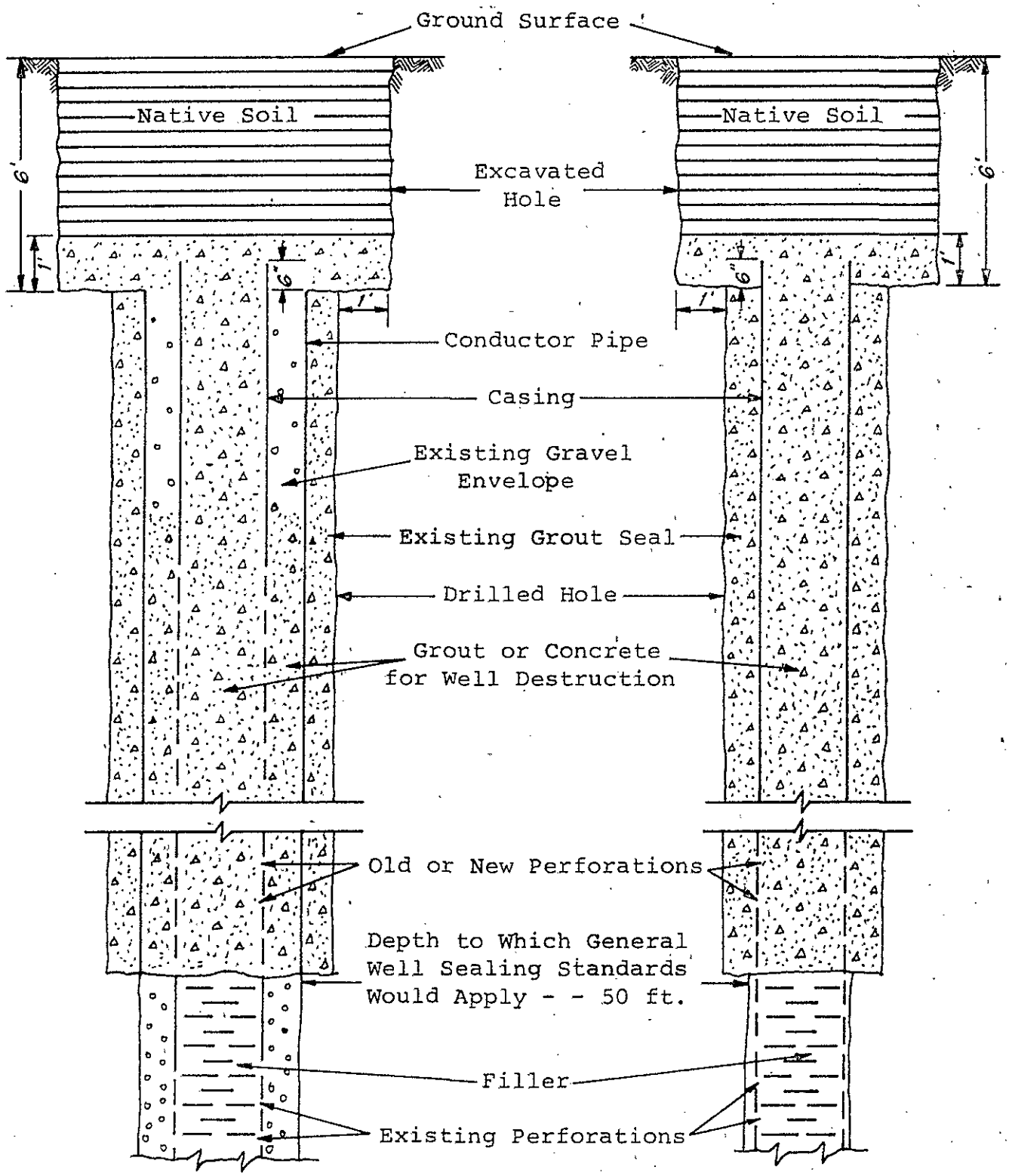


Figure 2(a) Well With Gravel Pack

Figure 2(b) Well Without Gravel Pack

NOT TO SCALE

FIGURE 2. TYPICAL SEALING FEATURES OF DESTROYED WELLS

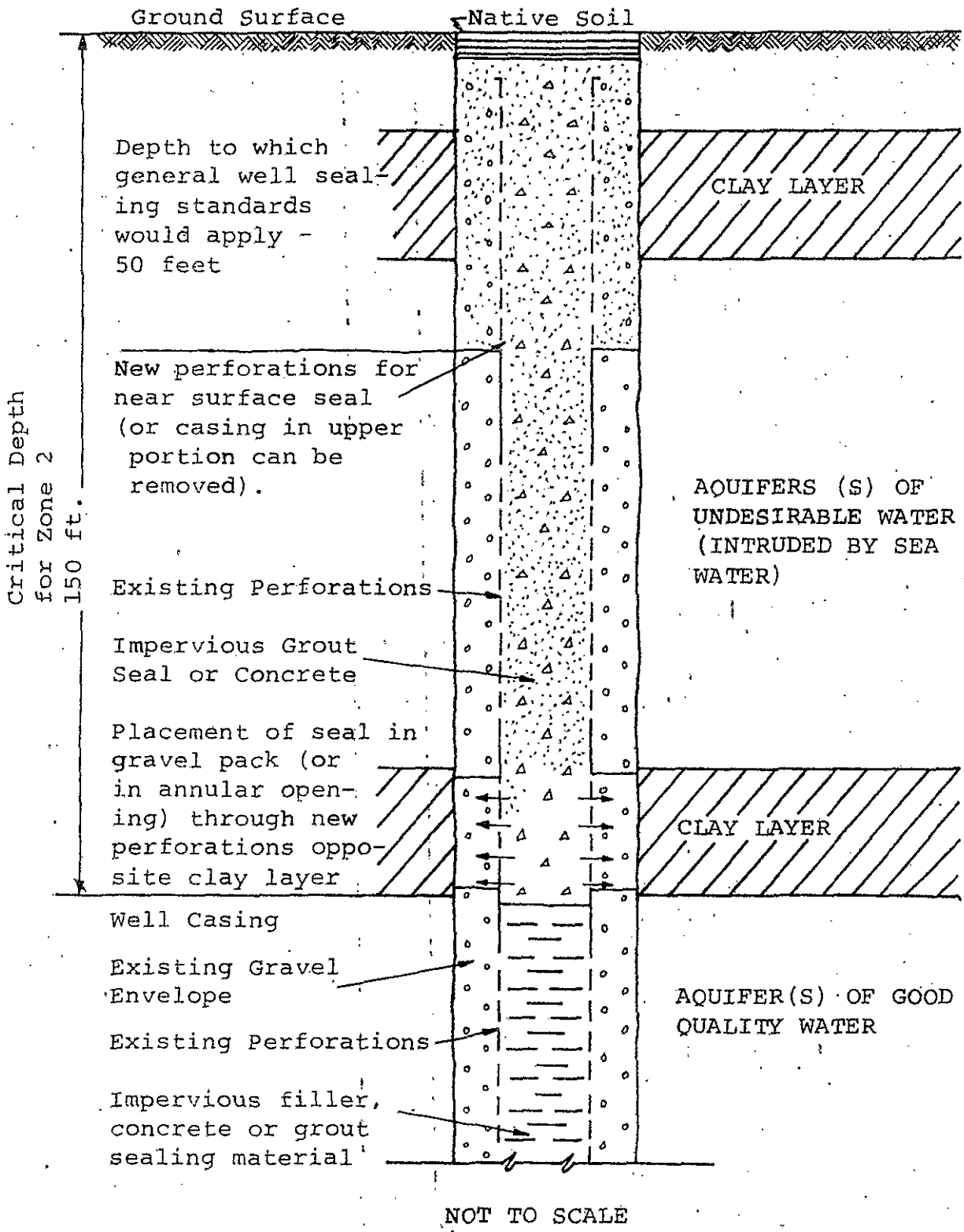


FIGURE 3. TYPICAL SEALING FEATURES OF DESTROYED WELLS FOR ZONE 2 (for gravel packed wells)

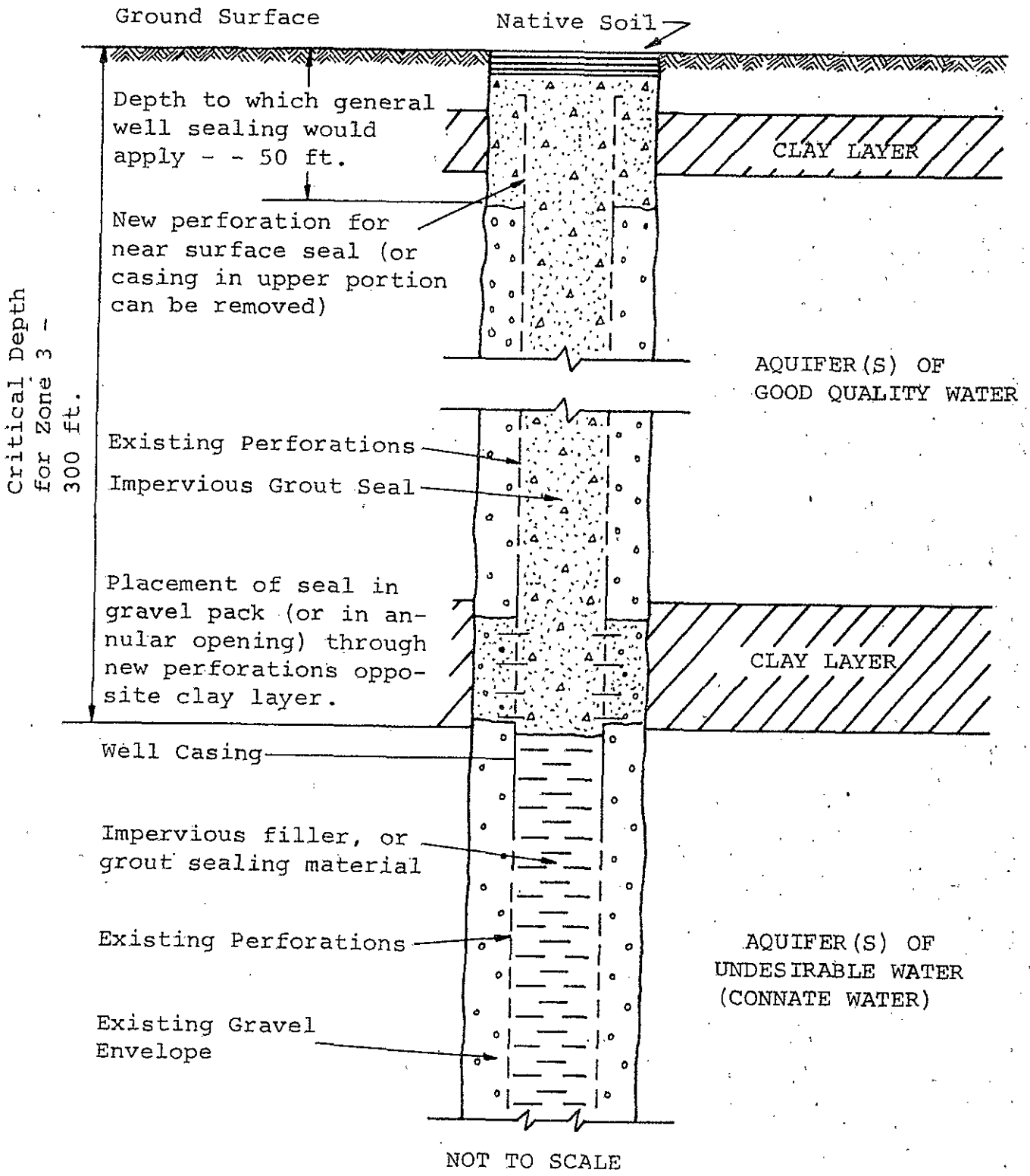


FIGURE 4. TYPICAL SEALING FEATURES OF DESTROYED WELLS FOR ZONE 3 (for gravel packed wells)

73. Schmidt, K.D. et al. "Brine Pollution at Fresno Twenty-Six Years Later," Reprinted from Ground Water, Vol. 19, No. 1, 1981, pp. 12-19

Brine Pollution at Fresno — Twenty-Six Years Later

2647

by K. D. Schmidt[a], J. A. Krancher[b], and G. Bisel, Jr.[b]

ABSTRACT

Chloride pollution of ground water was discovered in 1953 downgradient of seepage pits and wells used for disposal of waste waters. An ice plant and water softening plant at the Fresno railroad yard were the sources of pollution. A plume of polluted ground water was delineated, and the discharge from the major source (the water softening plant) was stopped in 1953. Sampling in the late 1970's indicated that high chloride contents were still present in ground water downgradient of the railroad yard. The plume expanded both vertically and horizontally in the aquifer, from a volume of about 1,500 acre-feet (1.85 million cubic meters) in 1953 to 15,000 acre-feet (18.5 million cubic meters) in 1979. Trilinear diagram plots of waste waters and ground water indicate that waste water from the ice plant continued to produce an impact into the 1970's. Recharge from canal seepage has created an important boundary, particularly on the west side of the plume. The rate of ground-water flow, calculated on the basis of the advance of the chloride front, was about 200 feet (61 meters) per year, in close agreement with estimates based on water-level slope and aquifer parameters.

INTRODUCTION

In the early 1950's, anomalously high chloride contents were found in ground water near the Southern Pacific Railroad yard, about two miles (3.3 km) northwest of downtown Fresno in the San Joaquin Valley, California. Some wells were sampled by the local health authority after complaints by several owners of wells located southwest of the yard. The complaints concerned the appearance of high salinity and hardness in water from wells that previously had produced water of excellent quality. Following the preliminary sampling, the Fresno County Health Department sampled water from numerous wells in the area in April 1953. A chloride content exceeding 1,000 mg/l was found in water from one well, whereas background contents were generally less than 20 mg/l in the Fresno area at that time. The California Division of Water Resources (1953) then commenced an investigation of waste disposal practices and ground-water quality near the yard. As a result, the major source of pollution was eliminated. The objective of the authors is to update information on this occurrence of high chloride ground water and to interpret changes in quality with time and causative factors. This information is of great interest because it largely reflects the effect of cessation of a waste discharge 26 years previously. Thus, it is a valuable case history in terms of implementation of control measures for sources of ground-water pollution.

WASTE DISCHARGES

The two most obvious sources of the high chloride contents in ground water near the railroad yard were an ice plant and water softening plant at the yard. The well supplying water for both plants was pumped continuously at about 750 gpm (47.3 lps) in 1953. A process was used at the ice plant whereby brine was cooled and then used to freeze water to make ice for refrigerator cars. A continuous flow of 80 gpm (5.1 lps) of ice melt and overflow from brine dipping tanks was discharged to a collection sump and thence to seepage pits. During the peak of operations, an additional flow of 200 gpm (12.6 lps) was discharged to two disposal wells. Pits and wells were considered necessary for disposal because of the presence of a nearly impermeable iron-silica hardpan near the land surface, which precluded use of percolation ponds. Shallow dry wells were originally used; however, their capacity was inadequate and thus they were deepened. One was deepened to 60 feet (18.3 meters), about 10 feet (3.1 meters) below the ground-water level in 1953, which was 50 feet (15.2 meters) below the land surface.

The water softening operation made use of the sodium zeolite process, whereby pumped ground water was softened and used for locomotive boiler feed water. The spent zeolite was regenerated by washing with a mixture of saturated sodium

[a]Ground-Water Quality Consultant, 1111 Fulton Mall, Suite 306, Fresno, California 93721.

[b]Sanitarians, Fresno County Health Department, Environmental Health Services, Fresno, California 93721.

Discussion open until July 1, 1981.

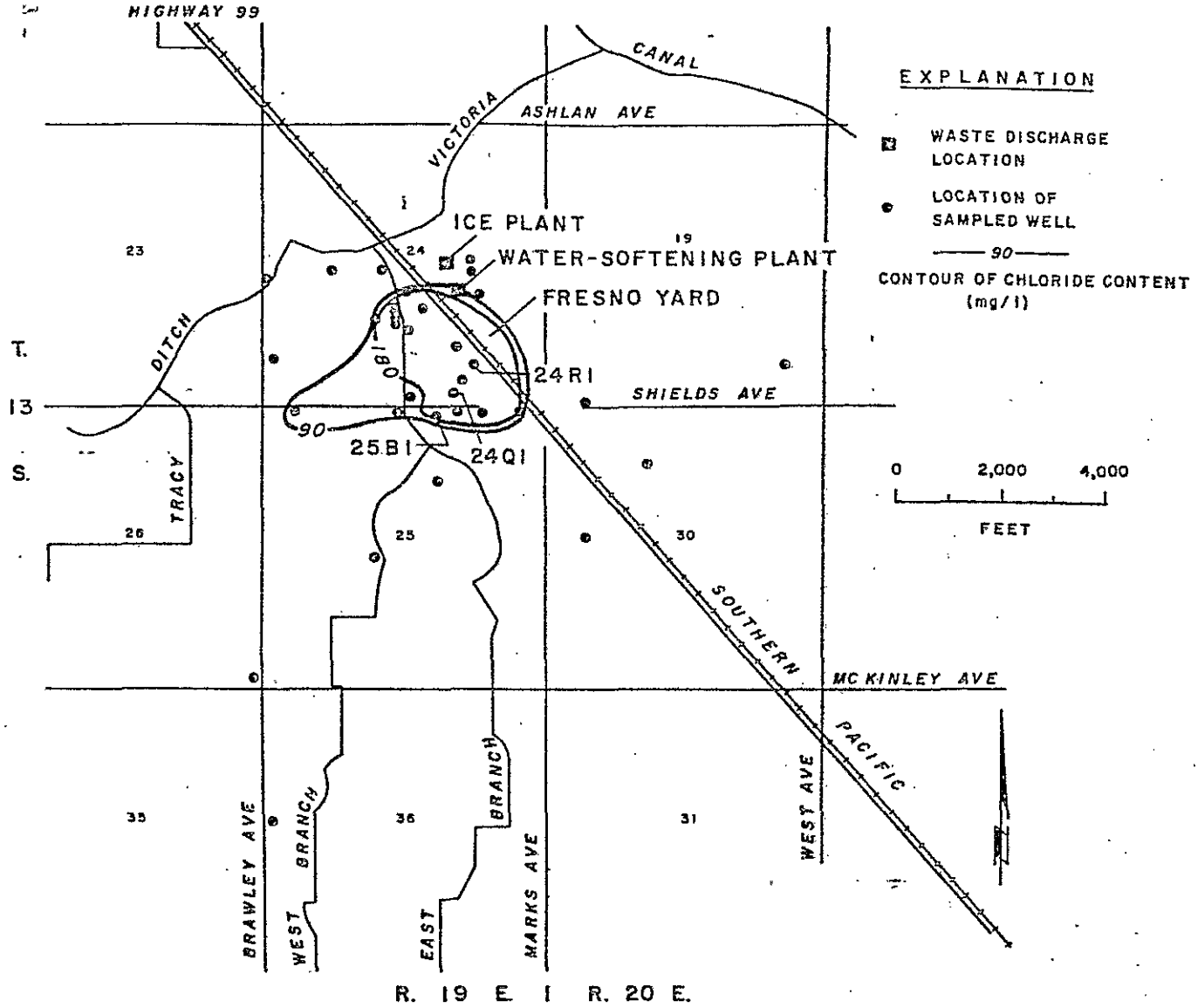


Fig. 1. Location of waste discharge sites and high-chloride ground water in 1953.

chloride solution and well water. The resulting calcium and magnesium chloride solution was discharged to a sump. The filter used in the process was backflushed with well water before and after regeneration. Waste water from backflushing and regeneration was discharged to a sump and thence to a seepage pit. A total of 15,000 gallons (57 kiloliters) of waste water was discharged during each regeneration cycle. This amount of waste water contained 250 pounds (114 kg) of salt. Regeneration cycles were generally conducted at 18-hour intervals. The exact depth of the pit used for disposal was unknown, but was reported to be greater than 30 feet (9.1 meters). Figure 1 shows the location of both waste discharge sites in 1953.

COMPOSITION OF WASTES

Water samples were collected from the sump and one disposal well at the ice plant in May 1953. Composite samples indicated that the chloride content was usually between 200 and 300 mg/l, and the electrical conductivity was usually between 900 and 1,000 micromhos per centimeter at 25°C. Water samples were also collected at the water softening plant in May 1953. Sodium contents of discharged waste water ranged from 400 to 3,400 mg/l and chloride contents ranged from 600 to 12,000 mg/l (California Division of Water Resources, 1953). Table 1 contains chemical analyses of wastes from the discharges at the railroad yard.

EXTENT OF CHLORIDE PLUME IN 1953

Ground water in the Fresno area is present in unconsolidated Quaternary alluvial deposits. Substantial ground-water production is possible from highly permeable sand, gravel, and cobble deposits. Specific capacities average about 70 gpm per foot (14.4 lps per meter) for wells about 200

to 300 feet (61 to 91 meters) deep. The direction of ground-water flow in June 1953 was determined from about 40 water-level measurements in wells near the yard. The direction of flow near the railroad yard was primarily westward. A water-level contour map prepared for those measurements indicated recharge due to seepage from several irrigation canals traversing the area.

Water samples were collected from about 40 wells in the vicinity in June and July 1953. At this time most wells in the area had been drilled by the cable-tool method and were open-bottomed (equipped with unperforated casing). Figure 1 shows the location of high chloride content in ground water near the yard in 1953. A plume was delineated, extending to the south and southwest of the railroad yard. The plume covered an area of about 200 acres (80 hectares) in 1953. The maximum chloride content in the ground water was 840 mg/l, found at a well about 2,000 feet (610 meters) south of the disposal site for the water softening plant. Except for this well, chloride contents in water from wells in the plume were less than 300 mg/l. The maximum longitudinal extent of the plume in 1953 was about 3,700 feet (1,130 meters). Because chloride is mobile in the soil-aquifer system at Fresno and contents are low in the native ground water, it can be used as a tracer. Waste water had been disposed at the yard for about 20 years by 1953; thus the rate of ground-water flow was about 190 feet (58 meters) per year. Only wells less than 100 feet deep showed the effects of waste disposal. The vertical extent of the plume was limited to the upper 50 to 80 feet (15 to 24 meters) of saturated alluvium. The volume of polluted ground water in 1953 is estimated to have been about 1,500 acre-feet (1.85 million cubic meters).

The water softening plant, which was considered to be the major source of pollution, was voluntarily closed down in July 1953, and there was reportedly no further discharge from this source. However, discharge from the ice plant continued, apparently into the 1970's. About one month after discharge ceased from the water softening plant, water samples were collected from the previously sampled wells. The California Division of Water Resources (1953) reported large decreases in chloride content in the water from two wells and slight decreases in water from some other wells in the plume. These changes were attributed to the cessation of discharge, and the problem was apparently considered to be solved by the health authorities. Later data presented by Schmidt (1977) and Nightingale and Bianchi (1980) indicated that these rather sudden decreases in chloride content were likely due to either seasonal or short-term variations in chemical quality due to pump operation and pumping patterns, as opposed to the cessation of discharge.

EXTENT OF CHLORIDE PLUME IN 1979

There was only occasional sampling in the vicinity of the plume between 1953 and 1978. This limited sampling indicated that high chloride contents continued to persist through the late

Table 1. Chemical Analyses of Waste Discharges at Southern Pacific Railroad Yard

	Ice Plant	*Water Softening Plant*		
Constituent (mg/l)		*No. 1*	*No. 2*	*No. 3*
Calcium	14	471	1,950	150
Magnesium	7	288	1,140	79
Sodium	181	63	3,360	1,860
Potassium	6	20	87	30
Carbonate	0	0	0	0
Bicarbonate	96	62	65	92
Sulfate	5	—	65	—
Chloride	260	1,710	12,000	3,350
Nitrate	8	—	—	—
Fluoride	0.2	—	—	—
Total Hardness ($CaCO_3$)	62	2,359	9,550	700
pH	7.2	7.0	7.4	7.0
Electrical Conductivity (micromhos/cm @ 25°C)	964	5,190	30,400	9,830
Total Dissolved Solids	593	—	18,700	—
Date	5/21/53	5/20/53	5/20/53	5/20/53

[Samples for the ice plant were taken from the waste-water sump. Samples for the water softening plant were taken from overflow weir box from backflow through filter. Data from California Division of Water Resources (1953).]

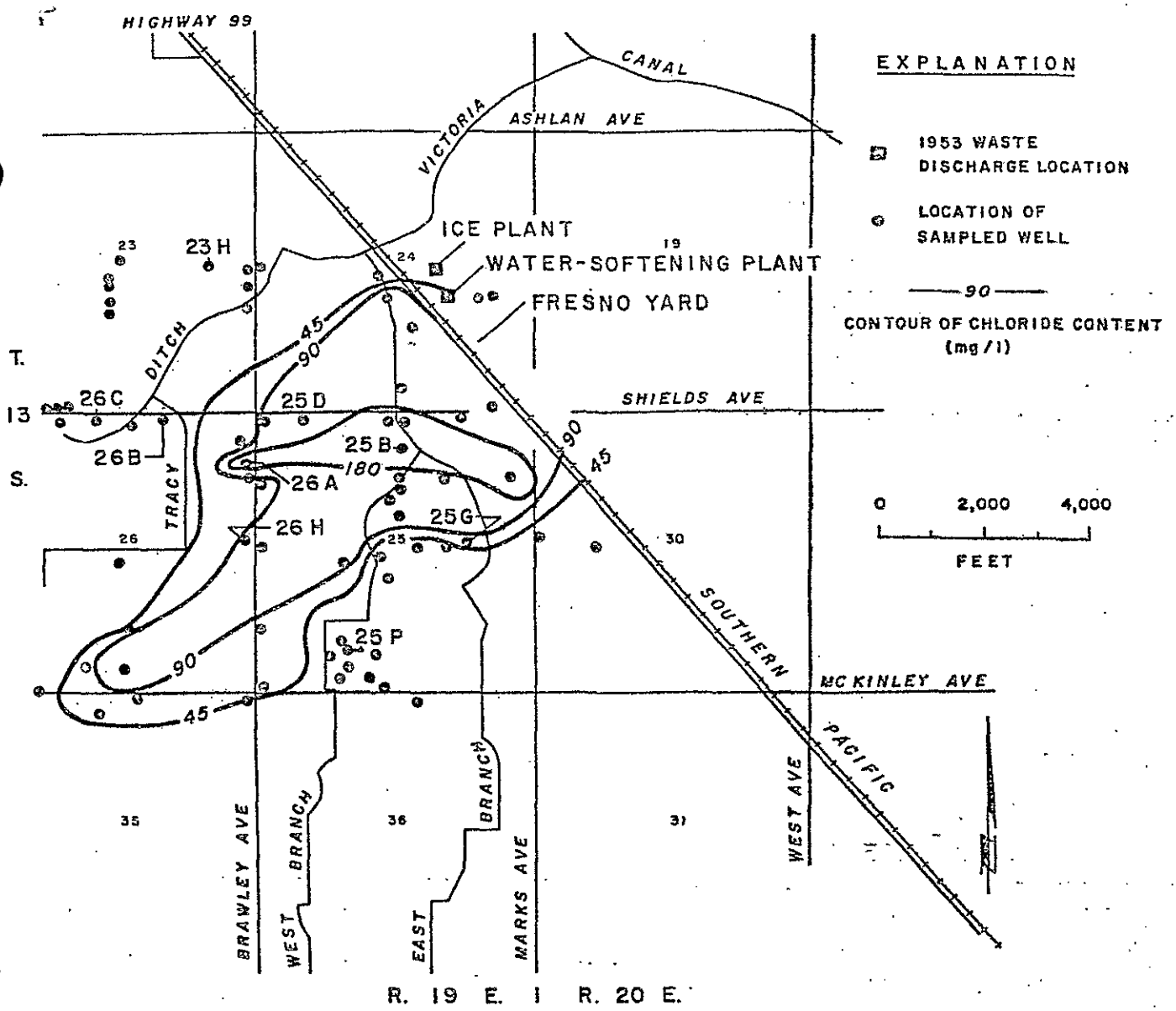


Fig. 2. Location of high-chloride ground water in 1979.

1970's. Interest by local residents lead to a detailed sampling program in the vicinity and downgradient of the plume in 1979. Approximately 80 domestic wells were sampled and analyzed by the Fresno County Health Department, Environmental Health Services. All samples were analyzed for electrical conductivity and chloride and selected samples were analyzed for the major inorganic chemical constituents.

Figure 2 shows the location of the chloride plume in 1979. The persistence of ground-water pollution, even in an area with substantial recharge, is illustrated. The major factors influencing the location of the plume include the rate of ground-water flow, the direction of ground-water flow, recharge from canals, and local pumping patterns. Due to overdraft in the Fresno urban area, the water level had fallen to a depth of 85 feet (26 meters) by 1979. The direction of ground-water flow was to the southwest in 1979.

By 1979, the downgradient edge of the plume extended about 9,800 feet (3,000 meters) longitudinally from the sites of waste discharge. The plume covered an area of about 800 acres (325 hectares) in 1979. The highest chloride content in ground water in the plume was 490 mg/l, for a well about 2,300 feet (700 meters) south-southwest of the former disposal pit for the water softening plant. Chloride contents in ground water in the plume were less than 180 mg/l, except for three wells. Based on the location of the downgradient edge of the plume in 1953 and 1979, the rate of ground-water flow was about 230 feet (70 meters) per year. This estimate and the one for the period prior to 1953 are in close agreement with that based on aquifer characteristics and water-level

slope. Using an average slope of seven feet per mile for recent decades, a transmissivity of 110,000 gpd per foot (1,370 square meters per day), and an estimated porosity of 0.40, the rate of ground-water flow is calculated to be 180 feet (55 meters) per year.

The vertical extent of the plume in 1979 has not been determined in detail, because of a lack of deep wells in the vicinity. However, several wells in the plume that were cased to about 180 feet (55 meters) in depth have been affected by the waste discharge. This indicates that pollution extended to a depth of at least 100 feet (30 meters) below the water table in 1979. In addition, a well (T13S/R19E-25C) was drilled by the cable-tool method within the highest chloride area to a depth of 222 feet (68 meters) in August 1979. Water samples were collected during drilling by bailing from nine different depths between 100 and 220 feet (30 and 68 meters). Results of analyses for sodium, chloride, and electrical conductivity (Table 2) indicate that the plume extended to at least 220 feet (68 meters), or about 135 feet (41 meters) below the water table. Thus the plume spread vertically, as well as horizontally, in the 26-year period. The driving force for the downward movement of waste water in the aquifer likely has been vertical head differences, but also could be due to the high density of the disposed brines. This would be similar to a phenomenon observed by Kimmel and Braids (1980) in a plume from landfill leachate in Long Island, New York. Interestingly enough, samples collected from above a depth of 130 feet (40 meters) indicate that the upper 45 feet (13.7 meters) of the plume have been diluted by local sources of recharge. The most likely source is seepage from the Victoria Canal, which is adjacent to the well. The lowest chloride content in well water in recent years in the area was 3 mg/l for well T13S/R19E-2Q, which is cased to 325 feet (99 meters) in depth. This well was near the downgradient edge of the plume, and the low chloride content indicates that the vertical extent of the plume had not reached a depth of 240 feet below the water table by 1979. The volume of polluted ground water is estimated to be more than 15,000 acre-feet (18.5 million cubic meters) in 1979

Table 2. Results of Depth Sampling for Well T13S/R19E-25C, August-September 1979

Depth (feet)	*Depth (meters)*	*Sodium (mg/l)*	*Chloride (mg/l)*	*Electrical Conductivity (micromhos/cm @ 25°C)*
100	30.5	110	178	1,100
124	37.8	88	169	820
132	40.3	162	275	1,225
140	42.8	160	320	—
147	44.8	166	327	1,275
154	47.0	163	335	1,275
173	52.7	137	275	1,350
200	61.0	150	330	1,375
222	67.7	163	338	—

(Analyses by County of Fresno, Department of Health, Division of Laboratories.)

CHEMICAL QUALITY CONSIDERATIONS

Table 3 contains the results of chemical analyses of native ground water near the plume in the late 1970's. The water was of the mixed cation bicarbonate type, with electrical conductivity averaging about 500 to 550 micromhos. Iron and manganese were present at moderate levels in water from some wells.

Table 4 contains the results of chemical analyses of water from wells within the plume in the late 1970's. Ground water in the plume had higher contents of sodium, potassium, and chloride and higher salinity than native ground water. Whereas chloride contents were usually less than 25 mg/l in the native ground water, they commonly exceed 45 mg/l within the plume. Sodium contents were also usually less than 25 mg/l in the native ground water, but commonly exceeded 50 mg/l within the plume. The electrical conductivity within the plume commonly exceeded 700 micromhos, whereas the average was about 500 micromhos in the native ground water. On the other hand, bicarbonate contents were lower in the plume than in the native ground water. Bicarbonate contents within the plume were commonly less than 200 mg/l, whereas they averaged about 280 mg/l in the native ground water.

Figure 3 is a trilinear diagram plot for native ground water, polluted ground water, and the waste waters formerly disposed at the railroad yard. The anion field of this diagram is the most meaningful, and indicates that water from wells within the plume represents a mixture of native ground water and recharged waste waters. In the field, water from wells within the plume falls into two categories. The first (wells 24R1, 25B1, and 25D) plots in an almost identical position to one of the samples of waste discharge from the water softening plant. Water from these wells contains a higher percentage of calcium and magnesium than water from wells in the second category. Since the wastes discharged at the ice plant were

Table 3. Chemical Analyses of Water from Wells Unaffected by Brine Disposal

Constituent (mg/l)	T13S/R19E 23H	25P	26B	26C
Calcium	29	20	27	31
Magnesium	26	25	22	28
Sodium	26	23	23	23
Potassium	8	8	5	6
Bicarbonate	274	286	280	307
Sulfate	31	15	17	15
Chloride	24	17	25	11
Nitrate	22	12	25	18
Fluoride	<0.10	0.06	0.10	0.10
Iron	<0.05	0.26	0.08	0.05
Manganese	<0.01	0.06	0.05	0.01
Total Hardness ($CaCO_3$)	233	244	198	251
pH	8.6	7.8	7.7	8.0
Electrical Conductivity (micromhos/cm @ 25°C)	510	500	480	580
Date	4/20/78	2/17/76	6/13/77	8/28/78
Perforated Interval (feet)	85-145	96 O.B.	160 O.B.	48-108
Perforated Interval (meters)	25.9-44.2	29.2 O.B.	48.8 O.B.	14.7-33.0

[Analyses by County of Fresno, Department of Health, Division of Laboratories. O.B. is open-bottomed well (unperforated casing).]

basically sodium chloride brines, the first category of wells appears to be influenced primarily by wastes from the water softening plant. Water from wells in the second category plots between native ground water and samples of waste discharge from both sources.

An inspection of chloride contents in water from specific wells in the late 1970's indicates that values from 150 to 175 mg/l were common immediately downgradient of the discharge site from the ice plant. These values are somewhat less than the chloride content in the ice plant discharge (estimated to average 250 mg/l). The influence of this source appeared to be limited to

Table 4. Chemical Analyses of Water from Wells Affected by Brine Disposal

Constituent (mg/l)	T13S/R19E 25B	25D	25G	26A	26H
Calcium	32	44	33	20	56
Magnesium	25	25	30	26	26
Sodium	144	59	25	138	55
Potassium	10	7	12	8	10
Bicarbonate	195	105	224	165	—
Sulfate	26	10	12	16	77
Chloride	240	165	85	270	125
Nitrate	13	10	18	18	9
Fluoride	0.06	0.09	0.10	<0.1	0.09
Iron	0.86	0.16	0.64	<0.05	0.04
Manganese	0.10	0.04	0.07	<0.01	—
Total Hardness ($CaCO_3$)	214	176	272	198	230
pH	8.4	7.6	8.1	8.3	—
Electrical Conductivity (micromhos/cm @ 25°C)	1200	720	660	770	770
Date	2/14/78	1/12/76	8/18/78	3/22/79	8/6/75
Perforated Interval (feet)	120-140	170 O.B.	170 O.B.	80-140	152 O.B.
Perforated Interval (meters)	36.6-42.7	51.8 O.B.	51.8 O.B.	24.4-42.7	46.3 O.B.

[Analyses by County of Fresno, Department of Health, Division of Laboratories. O.B. is open-bottomed well (unperforated casing).]

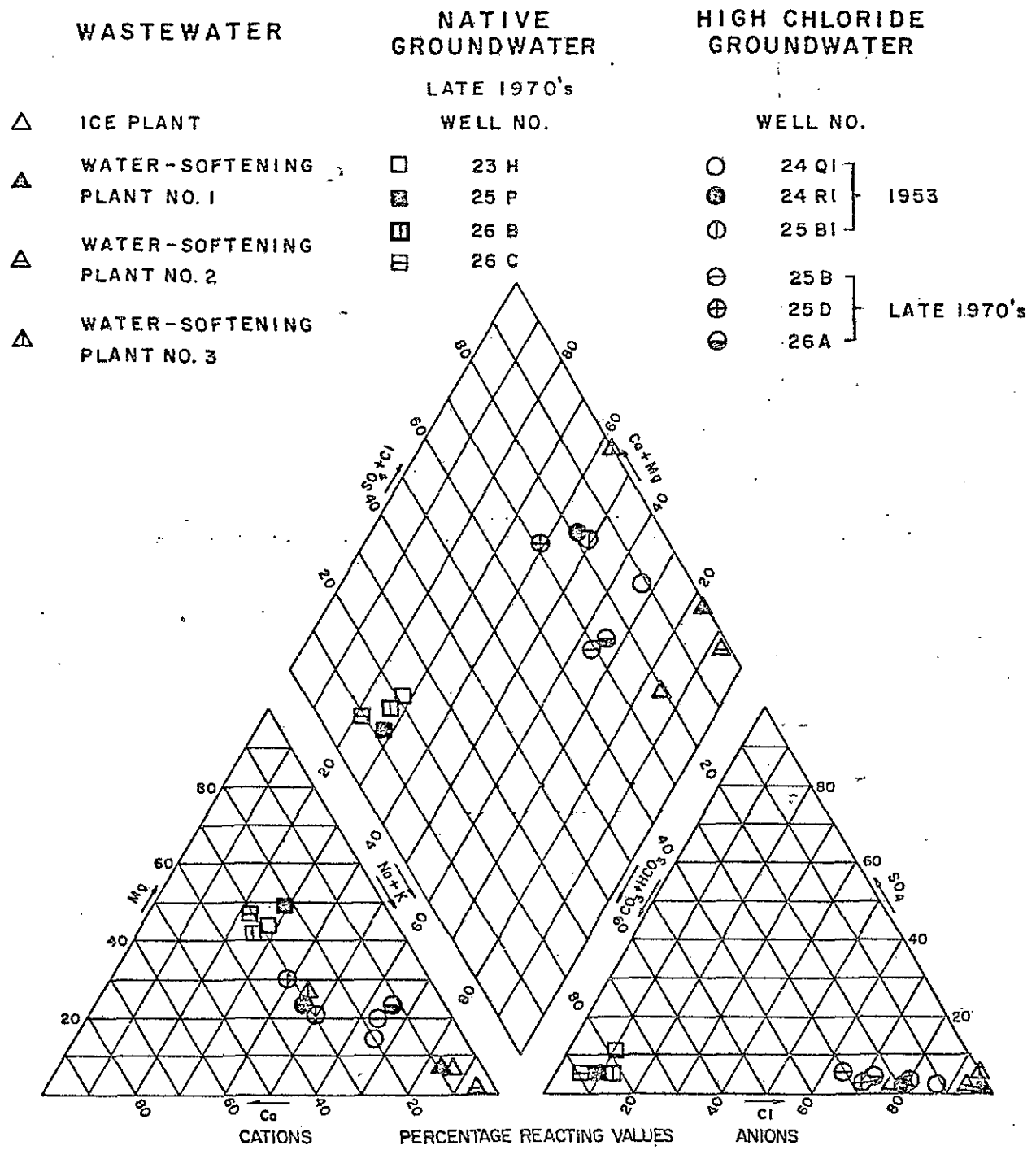


Fig. 3. Trilinear diagram for waste water and ground water near Southern Pacific Railroad Yard (T13S/R19E).

the northwestern edge of the plume in the late 1970's. The influence of the waste water from the ice plant appears to have extended only to near the intersection of Shields and Brawley Avenues, which is about 4,500 feet (1,380 meters) downgradient of the site of discharge. Based on chloride contents, wells producing water with values from 150 to 175 mg/l and downgradient of the ice plant discharge site were pumping a mixture of about 60 percent recharged waste water from the ice plant and 40 percent native ground water in the late 1970's.

One well producing water with a chloride content of 490 mg/l in the late 1970's was located about one-half mile downgradient of the former discharge site for the water softening plant. Several wells within the highest chloride part of the plume produced water averaging about 260 mg/l chloride content in the late 1970's. The well producing water with 840 mg/l chloride content in 1953 was obviously affected primarily by the water softening plant discharge. Assuming that this well produced water that was a mixture of native ground water and a sodium chloride brine, the

average concentration of chloride in the discharge from the water softening plant can be determined from the trilinear diagram. Calculations indicate that the chloride content in the waste discharge from the water softening plant averaged about 2,200 mg/l. The well producing water with a chloride content of 840 mg/l in 1953 thus pumped a mixture of about 60 percent native ground water and 40 percent recharged waste water from the water softening plant. Wells producing water with 260 mg/l chloride content in the late 1970's pumped a mixture of about 90 percent native ground water and 10 percent recharged waste water from the water softening plant. This is in agreement with the fact that discharge from this source ceased in 1953.

CONCLUSIONS

A plume of polluted ground water due to disposal of high salinity waste waters in pits and wells was identified in 1953. The two sources of pollution were an ice plant and water softening plant at the Fresno railroad yard. Although corrective measures were undertaken for the primary source of pollution (the water softening plant), the plume persisted through 1979, 26 years after it was first delineated. Although chloride contents decreased in most of the plume, the volume of polluted ground water increased tenfold during this period. The longitudinal extent of the plume indicates a rate of ground-water flow of about 200 feet (61 meters) per year, which is in agreement with a determination based on the water table slope and aquifer characteristics.

Water samples were collected from about 80 domestic wells in 1979. Chloride contents indicate that the downgradient edge of the plume had moved about 9,800 feet (3,000 meters) from the discharge sites by 1979, compared to 3,700 feet (1,130 meters) in 1953. The plume extended to a depth of at least 135 feet (41 meters) below the water table in 1979, compared to less than 80 feet (24 meters) in 1953. The vertical expansion of the plume is likely due to vertical head gradients and possibly to the greater density of the recharged waste waters compared to that of native ground water. Wells downgradient of the ice plant discharge site were pumping a mixture containing about 60 percent recharged waste water and 40 percent native ground water in the late 1970's. Many wells downgradient of the water softening plant discharge site pumped a mixture of about 10 percent recharged waste water and 90 percent native ground water in the late 1970's. These values are consistent with the fact that discharge from the water softening plant ceased in 1953; however, discharge from the ice plant continued into the 1970's.

REFERENCES

California Division of Water Resources. 1953. Effect of waste discharge from the Pacific Fruit Express ice plant and the Southern Pacific zeolite water softening plant, Fresno County. Water quality investigations. Report to Central Valley Regional Water Pollution Control Board. 26 pp.

County of Fresno. 1979. Interim best management plan for water quality, Fresno-Clovis Urban and Northeast Fresno County. v. II. Work task reports.

Kimmel, G. E. and O. C. Braids. 1980. Leachate plumes in ground water from Babylon and Islip landfills, Long Island, New York. U.S. Geological Survey Professional Paper 1085. 38 pp.

Nightingale, H. I. and W. C. Bianchi. 1980. Well-water quality changes correlated with pumping time and aquifer parameters — Fresno, California. Ground Water. v. 18, no. 3, pp. 274-280.

Piper, A. M. 1944. A graphic procedure in the geochemical interpretation of water analyses. Transactions, American Geophysical Union. pp. 914-923.

Schmidt, K. D. 1971. The distribution of nitrate in ground water in the Fresno-Clovis metropolitan area, San Joaquin Valley, California. Unpublished Ph.D. dissertation. University of Arizona. Committee on Hydrology and Water Resources. 301 pp.

Schmidt, K. D. 1977. Water quality variations for pumping wells. Ground Water. v. 15, no. 2, pp. 130-137.

* * * *

Kenneth D. Schmidt received a B.S. in Geology from Fresno State College and an M.S. and Ph.D. in Hydrology from the University of Arizona. His Ph.D. dissertation involved nitrate pollution in the Fresno urban area. Since 1972, he has been the principal of a firm headquartered in Fresno and specializing in ground-water quality investigations. In 1979, Schmidt completed a comprehensive study of nonpoint sources of ground-water pollution in the Fresno area as part of a 208 program. He lived for five years within one-quarter mile of the Southern Pacific Railroad Yard.

Jan A. Krancher received his undergraduate training at the State College of Tropical Agriculture, Deventer, the Netherlands. Later he attended the University of Hawaii in Honolulu where he earned a B.S. degree. He entered the health field and earned an M.S. in Health Science at California State University, Fresno. He is employed in the Fresno County Health Department, Environmental Health Services and is involved in special studies in the Water Surveillance Section.

Glenn Bisel, Jr. received his undergraduate training at Pacific Union College, Angwin, California and California State University, Fresno, respectively, and earned a B.A. degree in Natural Science at the latter. He has been employed by the Fresno County Health Department since 1953, and has participated in many ground-water studies during this period. Mr. Bisel participated in the original study at the Fresno railroad yard in 1953.

74. Schmidt, K.D. "The Case for Large-Diameter Monitoring Wells," Water Well Journal, December 1982, pp. 28-29

 Eagle

2648

The Case for Large-Diameter Monitor Wells

by K.D. Schmidt

Recently, I was contacted by a local driller who has decided to enter the monitor well drilling business. He asked me as a ground water hydrologist, "What do you want in a monitor well, particularly in terms of diameter?" This article is a long-winded answer to his question.

Most wells that are being drilled throughout the country for monitoring ground water quality are smaller than 4 inches in diameter. Many of these monitor wells are not constructed by water well drillers. Instead, soil boring rigs, augers and other equipment are often used to construct the "monitor wells" that commonly range from 2 to 3 inches in diameter. Some such wells are little more than holes in the ground with some pipe thrown in.

In my opinion, small-diameter monitor wells are one of the greatest obstacles to successful ground water quality monitoring. Such wells have many disadvantages. Many have inadequate gravel packs and annular seals. Such wells can only be sampled by a limited number of methods, and most of these permit the withdrawal of water from the well at only a small rate. In many situations where moderate or highly productive aquifers are present, it is desirable to pump monitor wells at rates ranging from 20 to 50 gpm for sampling. If possible, it is also desirable to pump several thousand gallons of water from the monitor well before a water sample is collected for analysis. The smaller the volume of water withdrawn from a monitor well prior to sampling, the less will be the volume of the aquifer represented by the sample. The chemical quality of ground water is often not uniform from place to place, particularly near sources of pollution. There can be dramatic differences in chemical quality at various depths at a particular location, as well as laterally, from well to well. Because of this variability, small water samples often only represent a localized zone near the well. In situations where this is the case, hundreds of thousands of small-diameter monitor wells might be required at a particular site to adequately characterize the chemical quality.

In California and Arizona, small-diameter wells are not commonly drilled by local water well drillers, which is another limitation. Previous reports on ground water quality monitoring programs throughout the country have indicated that many monitor wells are not properly developed. Too small a casing diameter can greatly limit the available development methods. In many small-diameter monitor wells, it is difficult or impossible to measure the water level while the sampling equipment is in the well.

Experience in the western U.S. during the past decade has shown the numerous advantages of using a 6-inch diameter casing for monitor wells. A proper casing, gravel pack and annular seal can be installed in such a well by an experienced water well driller and a submersible pump readily installed for sampling. Pumping is often the advisable way to obtain water from a monitor well, because the effects of using an actual domestic or public supply well are simulated and water-quality standards apply to pumped water. From 20 to 50 gpm can usually be pumped from such wells in most parts of the western U.S. A small-diameter access tube can also be installed along with the pump to allow water-level measurements by electric sounder. If it is desired to utilize other methods of obtaining the water sample, the large diameter provides maximum flexibility. If a permanent pump is not installed in such a monitor well, installation of a normal water-level recorder can be used for continuous measurements between sampling rounds. If necessary, large-diameter monitor wells can be used for other purposes. For example, one of the monitor wells that we have routinely sampled for several years in Phoenix, Arizona, is used to irrigate nearby landscaping. Such wells can also serve at a later time as extraction wells if polluted ground water is found and removal is desired. A 4-inch diameter casing can also be used for a monitor well, but I consider this a marginal diameter, with minimal flexibility, particularly if a permanent pump is not installed.

Frequently the costs of 2-inch and 6-inch diameter monitor wells are compared and it is concluded that the expense of the larger diameter wells is not warranted. Such a comparison is usually invalid, because the same information cannot be obtained from the

types of wells. Instead, one 6-inch diameter monitor well may provide the equivalent information of five or 10 small-diameter wells at a particular site. This is because the large-diameter well can be pumped at a higher rate and more water can be withdrawn from the well in a short period of time. A water sample collected from such a well may represent from five to 10 times as much ground water in the aquifer as a sample from a small-diameter monitor well.

Large-diameter monitor wells are also more suited for aquifer testing. Frequently, the rate of ground water flow at a waste disposal site is desired to be known. If a suitable water-level elevation contour map is available and the permeability can be determined from a pump test, then the ground water flow rate can be calculated. Results from pump tests on large-diameter wells are more meaningful in terms of pollutant travel than results from small-diameter wells, because larger parts of the aquifer are represented when a well is pumped at a greater rate.

An interesting observation can be made based on an examination of some of the numerous ground water quality monitoring programs in place throughout the country. My experience indicates that many investigators in the western U.S. have switched from small- to large-diameter monitor wells during monitoring programs conducted at a particular site. Sometimes years elapse before the change is made. On the other hand, I know of virtually no site where investigators have switched from large- to small-diameter monitor wells. I believe that this speaks for itself as to the advantages of large-diameter monitor wells.

In conclusion, my opinion is that only qualified water well drillers should install most monitor wells. In addition, such wells should normally be at least 6 inches in diameter for maximium flexibility in monitoring. Where possible, 20 to 50 gpm should be pumped from the monitor well prior to sampling, and in most cases about 30 to 90 minutes will be an adequate pumping time prior to water sample collection.

Kenneth D. Schmidt is a ground water quality consultant in Fresno, California.

75. Schmidt, K.D. "Monitoring Groundwater Pollution", Reprinted from IEEE International Conference on Environmental Sensing and Assessment, 1976

MONITORING GROUNDWATER POLLUTION

Kenneth D. Schmidt
Groundwater Quality Consultant
Fresno, California

2640
2641
2646
2647
2648

Monitoring groundwater pollution entails source monitoring, evaluation of infiltration potential, and monitoring in the topsoil, vadose zone, and aquifer. Soil, geologic materials, water, and solid and liquid wastes can be sampled. The emphasis of groundwater pollution monitoring is water in the aquifer, and the primary sampling tool is the pumped well. The usefulness of high-capacity wells pumped for long time periods has been demonstrated in the assessment of regional groundwater pollution.

Introduction

The monitoring of groundwater pollution encompasses a number of techniques, including the sampling of water wells. Since most sources of pollution originate at or near the land surface and most groundwater samples are taken from wells, the entire soil-groundwater system must be analyzed. Potential pollutants applied at the land surface in many cases must pass through topsoil and the vadose zone before reaching the water table. The recharged pollutants then ordinarily move through the aquifer a certain distance before they are sampled. Thus groundwater pollution monitoring depends heavily on a knowledge of soil and hydrogeologic factors that control pollutant movement. An understanding of the natural factors affecting groundwater quality is necessary in order for pollutant monitoring to be effective.

There are five basic parts of the system: 1) land surface, 2) topsoil, 3) vadose zone, 4) aquifer, and 5) well. Considerable confusion exists in some groundwater quality investigations due to a lack of understanding of the pertinent physical, chemical, biological, soil, and geologic factors. Sanitary engineers, surface water hydrologists, and regulatory agencies have often focused attention almost exclusively on the land surface. Soils scientists have usually evaluated the topsoil and secondarily the vadose zone. Groundwater hydrologists and geologists have usually analyzed the portion of the system below the water table. Water supply and regulatory agencies have focused on well sampling in areas where groundwater is an important source of supply. The entire sequence of events must often be interpreted in specific situations in order to successfully monitor groundwater pollution.

Groundwater pollution monitoring encompasses monitoring at the land surface (source monitoring), in the topsoil and vadose zone, and in the aquifer. A number of tools are available to monitor potential pollutants in each portion of the system. As the parts of the system are closely interrelated, the successful development of a monitoring program largely depends on selection of the appropriate mix of tools for the system. Land surface monitoring includes land use surveys, inventories of waste amounts, and sampling of liquids and solids. Significant storage capacity for potential pollutants may exist in the vadose zone, and some pollutants can be significantly attenuated in passage through the topsoil and vadose zone. In some cases, pollutants introduced at the land surface may travel through great thicknesses of geologic materials above the water table. Long travel times in the vadose zone, such as decades or centuries, may render aquifer monitoring ineffective.

The heart of groundwater pollution monitoring usually lies in the aquifer, as this is where water is ultimately pumped from wells for use at the land surface. Water sampling of wells is a key item, and along with source monitoring is the primary technique for monitoring groundwater pollution. Past groundwater pollution monitoring has demonstrated the effectiveness of well sampling; however, a considerable amount of experience and judgment is necessary in most cases.

Source Monitoring

Sources of groundwater pollution can be conveniently separated into 1) point, 2) line, and 3) diffuse. These subdivisions generally correspond to the sources of groundwater recharge. The impact of a specific waste discharge on groundwater quality depends on the areal extent and configuration of the discharge at the land surface. Thus, the type of applicable monitoring program differs considerably from a point source to a diffuse source. Common point sources are solid waste disposal sites, percolation ponds for liquid wastes, solid wastes in stockpiles, leaking tanks, and confined animal wastes. Line sources include polluted streamflow, wastes leaking from sewers and pipelines, liquid wastes disposed of to dry stream beds, and materials used for highway deicing. Diffuse sources include agricultural return flow, polluted precipitation, septic tanks, and lawn fertilizers.

Potential pollutants in each source can be characterized as: 1) physical, 2) inorganic chemical, 3) organic chemical, 4) bacteriological, or 5) radiological. Physical parameters of most importance are density and temperature. Inorganic chemical constituents include the major constituents commonly found in groundwater, other constituents, and trace elements. Organic chemicals include pesticides, hydrocarbons, detergents, and other organic compounds. Bacteriological constituents include bacteria, viruses, and pathogenic organisms.[1] Methods of analysis have been discussed in several comprehensive works.[1, 2, 3, 4]

Types of Waste Disposal

There are a variety of types of waste disposal which may affect groundwater. These include storage basins and other ponds containing liquids which may escape the land surface and percolate to the groundwater. The stockpiling of solid materials from which pollutants may be leached is another type. Irrigation and disposal to normally dry stream channels are widely used types of waste disposal in the western U. S. Seepage trenches, percolation pits, seepage pits, and wells are also used for waste disposal. The method of disposal determines if a portion of the soil-groundwater system is bypassed. For example, percolation pits and seepage pits may allow pollutants to bypass the topsoil and part of the vadose zone. Wells may permit pollutants to bypass the topsoil and vadose zone and directly enter the aquifer.

Monitoring Techniques

Non-sampling techniques, at the land surface include a wasteload inventory, pipeline and tank tests, testing of artificial liners, land use surveys, and aerial surveillance. An inventory of waste loads includes collection and tabulation of data on the volume of liquid wastes and weights of solid wastes and their compositions. Data on the physical, chemical, bacteriological, and radiological characteristics of the wastes should be collected. Field surveys, land use surveys, and aerial surveillance can be used to determine sources of pollution and methods of disposal. Testing for leakage is an important monitoring procedure, since many of the pollutants in tanks, pipelines, and lined ponds may present significant pollution potential.

Sampling of polluted surface water bodies, wastewater, and solid wastes is an integral part of a groundwater pollution monitoring program. Rivers, lakes, estuaries, and canals which are polluted and may recharge the groundwater should be sampled. Surface water sampling will be conducted through federally mandated monitoring programs.[5] Hem[6] and Brown, Skougstad, and Fishman[2] have also discussed

Copyright © 1976 by The Institute of Electrical and Electronics Engineers, Inc.
Reprinted from IEEE International Conference on Environmental Sensing and Assessment. Printed in U.S.A.

surface water sampling. The most important type of land surface monitoring will generally be wastewater sampling. The American Public Health Association[1], Wells[7], American Society for Testing Materials[3], and the U. S. Environmental Protection Agency[8] have discussed wastewater sampling. There are two basic categories of wastewater sampling in relation to groundwater pollution: 1) discharge stream, and 2) pond. The sampling of pond waters subject to percolation is the more direct approach, but is generally more difficult and time-consuming. Consideration should be given to groundwater recharge in selection of sampling sites. Sampling of pond water often involves either the construction of special walkways or the use of boats for sample retrieval. In some ponds where water is being recycled, collection devices allow for relatively easy sampling. Many solid wastes can be categorized as to chemical composition on the basis of past experience and references in the literature. Occasional sampling is necessary, for example, for trace element and radiological determinations on phosphate ore stockpiled for use in fertilizer manufacture.

Evaluation of Infiltration

One of the key parts of a groundwater pollution monitoring program is the determination of the amount of wastewater which can leave the land surface and potentially percolate to the water table. This amount is related to the method of waste disposal used. For some methods, such as wells and seepage pits, the topsoil and significant parts of the vadose zone are bypassed. In this situation, the volume of wastewater potentially reaching the water table is equivalent to the volume of waste discharge. Factors operative in the topsoil, such as evapotranspiration, must be considered for waste disposal in percolation ponds, dry stream channels, and many diffuse sources. The major methods of disposal discussed in the following sections are: 1) percolation ponds, 2) irrigation, 3) dry stream beds, and 4) seepage trenches.

Percolation Ponds

In this report, "percolation pond" is used to signify any pond which permits significant movement of pollutants into the underground. The water budget method can be used to calculate seepage from percolation ponds. Waste discharge and precipitation are summed as the input, and percolation calculated as the residual between input and evaporation. Storage changes in the pond must also be considered. Evaporation from free water surfaces can be determined from measurements for land pans or floating pans.[9, 10] Factors such as temperature and salinity affect both evaporation and percolation rates. Stable isotopes have great potential for application in the determination of pond evaporation.[11] Field measurements using lysimeters can be used to determine evaporation from soil surfaces.[12]

Irrigation

The water budget method is also used to evaluate return flow from applied irrigation water. Precipitation and applied water are summed as the input, and evapotranspiration calculated as part of the output. Return flow is then calculated as the residual between input and evapotranspiration. Evapotranspiration in irrigated areas can be determined by a number of methods.[13] These methods are generally based on several climatological parameters, and most have been developed for application in certain geographical areas. Applied water can be determined from records of surface water deliveries and groundwater pumpage. "Irrigation efficiency" is often defined as the evapotranspiration divided by the applied water. When wastes are being disposed of by irrigation, the waste discharge is added as part of the input; in some cases it may comprise all of the applied irrigation water.

Dry Stream Beds

In many parts of the southwest, significant volumes of wastes are disposed of into normally dry stream channels. The part of the water that does not evaporate or leave the area as runoff can infiltrate and eventually reach the groundwater. Mining wastes and sewage effluent in Arizona and oilfield wastes in California are commonly disposed of by this method. Streamflow records at different gaging stations, combined with records of precipitation, evaporation, and streamflow diversions, can be used to calculate percolation. In this case both evaporation from the free water surface and wetted channel must be considered.

Seepage Trenches

Effluent from septic tanks and other wastes is commonly disposed of in trenches several feet beneath the land surface. As such, these wastes are usually emplaced in the topsoil and are subject to evapotranspiration. Determination of evapotranspiration loss of effluent is often difficult in this case because of widely varying soils conditions, septic tank disposal practices, and other factors. Rooting depth of plants growing in the area is a key factor in plant uptake of effluent from trenches. Precipitation is combined with waste discharge as the input, evapotranspiration is part of the output, and percolation is calculated as the residual. In this case evapotranspiration is the sum of evaporation from bare soil surfaces and transpiration by crops, lawns, or trees growing in the disposal field area. If there is irrigation, this item must be added to the input.

Monitoring in the Topsoil and Vadose Zone

Monitoring the movement of pollutants in the topsoil requires consideration of 1) soil water, 2) soil physics, 3) soil chemistry, 4) microbiology, and 5) physical chemistry. Historically soil scientists were more concerned with the soil conditions affecting growing crops than with the quality of percolating waters. Today this situation is rapidly changing and many studies are being conducted concerning percolate quality. An extensive body of literature is available on water quality changes in the topsoil, particularly in journals such as Journal of Environmental Quality and Soil Science Society of America Proceedings. To date much of this information has not been used in groundwater quality studies.

The vadose zone has commonly been approached by the "black box" method, but recent years have shown significant advances in research, particularly by soils scientists. The vadose zone in many areas is not comprised of soil in the sense of the topsoil of agricultural workers. More often the materials comprising the vadose zone are geologic formations with little or no soil development. One of the major constraints in past groundwater pollution monitoring has been the difficulty in determination of travel times of water from the land surface to the water table. The approximate rate of travel in the vadose zone must be known in order to monitor groundwater pollution. If the travel time approaches decades or centuries, there is little use in detailed, frequent monitoring of aquifer water quality.

Travel Time

The travel time of recharged wastes through the vadose zone is intimately related to the storage capacity and moisture characteristics of the vadose zone. In parts of the southwest, where water tables may be greater than 500 feet in depth and the geologic materials are moisture deficient due to lack of recharge, considerable amounts of water may be added at the land surface before percolation to the water table occurs. The portion of the porosity known as specific retention must be satisfied before downward percolation can occur in the vadose zone. In other areas where precipitation or irrigation has supplied abundant recharge for decades or centuries, the specific retention is generally already satisfied. In the case of relatively shallow water levels, there

may be relatively rapid percolation through the vadose zone. In some cases, isotopes and other tracers may provide an indication of the rate of travel in the vadose zone.[11]

Attenuation Capacity

Attenuation capacity for pollutants introduced at the land surface is due to physical and other factors. Pollutant attenuation commonly occurs due to the following processes: dilution, filtration, sorption, buffering, precipitation, oxidation and reduction, volatilization, biological assimilation and degradation, and radioactive decay. Recharge from precipitation, streamflow, canals, and other sources can lead to dilution of polluted water in the vadose zone. The capacity for attenuation of many potential pollutants due to other processes is often limited by the nature of the geologic materials present. This is especially true for many organic chemicals, trace elements, and radionuclides. This limited capacity is in sharp contrast to the almost unlimited ability of many unconsolidated materials to remove bacteriological pollutants. In general the mobility of the various potential pollutants from the land surface to the water table is highly variable. The bacteriological constituents are least mobile and the major inorganic chemical constituents are the most mobile. Trace elements, organic chemicals, and radionuclides generally have an intermediate mobility.

Monitoring Techniques

A number of techniques have been developed for monitoring water movement and water quality in the topsoil.[14] Monitoring in the vadose zone will require extension of technology developed in the topsoil and in the aquifer. Generally, in a homogenous porous media, percolating water will pass vertically through the vadose zone. However, in a heterogenous, stratified material, such as most of the alluvial deposits of the southwest, percolating water may become perched above layers of low permeability. In this situation, lateral movement at substantial rates can occur above the water table.[15]

Monitoring in the topsoil and vadose zone generally requires retrieval of soil, geologic materials, and water. Ordinarily water in the vadose zone occurs in the unsaturated state, and pressure head is negative. Special sampling devices are necessary to retrieve water samples, as this water will not enter wells or holes open in the vadose zone. However, local saturated zones are present in the vadose zone as perched groundwater. Augers can be used for much of the sampling of soils and geologic materials, although standard water well drilling rigs may be necessary for deeper sampling. Water content can be determined from core samples or in-place by neutron logging.[16] Recently the technique has been used to monitor water storage in the vadose zone and to estimate flow rates.

Tensiometers are used to measure soil water pressures during unsaturated flow. A tensiometer consists of a porous ceramic cup cemented to a rigid plastic tube. Negative pressure is measured by means of a mercury manometer. When properly enplaced in the soil, the pores in the cup will form a continuum with the pores in the soil. Electrical resistance blocks are also used to measure negative pressures. The blocks consist of electrodes embedded in porous materials, such as fiberglass. The principle of operation of these blocks is that the negative pressure within the blocks responds to the suction of the soil with which the blocks are in intimate contact. The tensiometer is generally the most effective device for monitoring water flow to negative pressures of about -1 atmosphere. In characterizing water movement, a battery of tensiometers must be installed, with units terminating at successive depths in the vadose zone. It is necessary to install more than one battery to detect horizontal flow. To measure negative pressures below about -1 atmosphere, the thermocouple psychrometer has been developed.[17] In-place negative pressure measurements are possible with this tool down to -30 atmospheres. The basic principle involved is that a relation exists between negative pressure and relative humidity.

Monitoring in the topsoil and vadose zone includes sampling of soils and geologic materials. Important physical parameters include texture, bulk density, porosity, water content, and hydraulic conductivity. Development of a soil-water chemical characterization curve, relating water content and pressure, is helpful in evaluation of water movement. Analyses include soluble ions, cation exchange capacity, exchangeable ions, pH, electrical conductivity, and base saturation. Many constituents are often determined on the saturation extract, because this can be generally related to field moisture conditions. Chemical analysis of soil and geologic materials is extremely valuable where large amounts of potential pollutants are retained above the water table.[18]

Water samples may be obtained from unsaturated regions by the use of the tensiometer or suction cup. In this case a suction is applied to bring the water sample to the land surface. Suction cups are the best available tool for obtaining water samples in the unsaturated parts of the vadose zone. However, the cups are operative only at negative pressures greater than about -1.0 atmosphere. Because of the small openings in the ceramic cups, certain bacteriological and organic constituents may be filtered out. Hanson and Harris[19] discussed the limitations of this tool in monitoring in the vadose zone. Where water is perched in the vadose zone, samples may be collected as in the aquifer, for example, by bailing or pumping.

Recently salinity sensors have been developed for in-place measurement of soil salinity.[20] The principle of operation of these devices is the relation between electrical conductivity and total dissolved solids in the water. Electrodes embedded in a porous ceramic plate in hydraulic continuity with water in the vadose zone can be used to directly measure the electrical conductivity of the water. The temperature of the water must be measured carefully when using this tool, and the sensors cannot be used at negative pressures of less than -2 atmospheres.

Aquifer Monitoring

Monitoring groundwater quality below the water table requires a knowledge of 1) hydrogeology, 2) well hydraulics, 3) geochemistry and physical chemistry. Since most recharge passes through the topsoil and vadose zone, groundwater quality evaluations must include consideration of the full sequence of events above the water table. Of principal importance in understanding groundwater quality is the development of the hydrogeologic framework. The hydrogeologic framework is important from two standpoints: 1) control on groundwater and pollutant movement, and 2) geochemical considerations. Geochemical processes impart natural characteristics to groundwater quality. To date little of the knowledge from geochemistry or physical chemistry has been applied in groundwater pollution studies. An extensive body of literature is available on natural groundwater quality, especially with regard to carbonates and some silicates.[6] Well sampling for groundwater pollution monitoring has little value unless well hydraulics are thoroughly considered. A number of examples of aquifer pollution monitoring were presented at the first two National Ground Water Quality Symposiums and the 1974 National Water Well Association Technical Division Education Program, and subsequently published in Ground Water.

Attenuation Factors

Many of the processes which occur in the topsoil and vadose zone occur below the water table, but to a different degree. Oxygen poor waters are common in aquifers and the geologic materials comprising aquifers are often devoid of organic matter. Some geologic formations lack many of

the common substrates for sorption. Because of these factors, if the topsoil and vadose zone are bypassed during waste disposal, the pollution potential is greatly increased. However, once pollutants reach the water table, they are subject to a physical attenuation in most aquifer systems. This attenuation results in the commonly observed phenomena that point sources produce only local polluted zones in the groundwater. The attenuation in most cases is determined by the following factors:

1) The volume of wastewater reaching the water table per unit time
2) The concentration of pollutants reaching the water table
3) The waste loading, i.e. the volume or weight of pollutant reaching the water table per unit area of the water table
4) Areal hydraulic head distribution
5) Transmissivity of aquifer materials
6) Vertical head gradients and vertical permeabilities through confining beds, if present
7) Quality of native groundwater and recharge sources
8) Extent of recharge reaching the water table from other sources at the land surface
9) The pumping of wells and well construction

In some cases, certain factors do not attenuate pollutant concentrations, but act in an opposite fashion. An example is the presence of a large depression cone in an agricultural area due to irrigation well pumpage, whereby pollutants are drawn into the area from many directions, and are prohibited from leaving.

Non-sampling Techniques

There are several techniques for monitoring groundwater pollution in the aquifer which do not involve sampling. Water-level measurements and pump tests are usually necessary in specific areas to evaluate the hydraulic head distribution and aquifer parameters. Test drilling may be necessary to adequately define the subsurface geological conditions. Surface resistivity surveys can sometimes be effectively used to delineate the extent of a polluted zone in the aquifer.[21] However, in general the polluted water must be shallow, and the subsurface geology must be well defined. Borehole geophysics can be used to determine the electrical conductivity of water in the aquifer at specific depths below land surface.[22] If the chemical nature of water in an aquifer is known from chemical analysis, resistivity logs can be used to determine the approximate quantities of the ions present.

Sampling Techniques

Sampling in the aquifer includes geologic sampling and water sampling. Solid materials comprising the aquifer are ordinarily sampled only in cases where significant amounts of pollutants are retained in this zone. This generally occurs in cases of a thin vadose zone or where the topsoil and vadose zone are bypassed during well disposal. In unconsolidated deposits the finer-grained deposits are generally of most interest. The texture, type of clay, cation exchange capacity, and pH are important parameters. For some rock formations, information on mineral and trace element and radionuclide content may be required. Geologic sampling can generally be done only during well drilling. The method of drilling highly influences the usefulness of the sampling.

Water samples can be collected from aquifers in several ways. In cases of shallow water level, tile drains beneath agricultural areas may provide suitable sampling sites, however, often they tap only the upper portion of the aquifer. Springs represent groundwater discharge, and along with baseflow in streams can provide integrated samples of groundwater quality over large areas. For most common situations, however, wells are required for aquifer sampling. In cases where existing wells do not suffice, it may be necessary to construct special monitor wells.

Well Sampling

Water well sampling is somewhat of an art, and the usefulness of the sample often depends on the experience, perception and hydrogeologic judgment of the person taking the sample or supervising the program. The composition of a water sample from a well is influenced by well location and construction, pumping time, recharge sources, and the three-dimensional distribution of groundwater quality. Wells near point or line sources can also show a rapid response to waste disposal operations. Time trends in and the spatial distribution of groundwater quality must be considered in a monitoring program. There are a number of reasons for sampling water, and each may require a different approach. For example, the main concern may be the quality for subsequent use of the water. For drinking water, a sample might be taken from the household tap rather than from the well. For irrigation purposes, a sample could be taken of water in a ditch at the entrance to a field. For groundwater pollution monitoring, the water sample would ideally be taken directly from the aquifer. However, for practical purposes, a sample from the well discharge will be collected in most cases.

A number of techniques can be used to obtain water samples from open wells. Portable submersible pumps are useful for a number of monitor wells near a point source and when only periodic pumping is required. Water can be air-lifted from a well by forcing compressed air down a pipe lowered into the well. Water samples can also be taken by bailing. A weighted bottle or short section of pipe capped at the bottom may be lowered into small diameter wells in order to collect water samples. Thief samplers have been developed which can be closed at a specific depth inside the well, thus allowing water quality sampling at different depths. Mechanical or inflatable packers can also be installed which temporarily isolate selected water-bearing zones for pumping.

Well pumping is generally much more effective than sampling at individual points in the aquifer. With high-capacity wells and long pumping times, significant amounts of water can be withdrawn. In general, low-capacity wells with small pumps should be used to evaluate local conditions. For example, the effect of an individual septic tank in a rural area could be monitored by a nearby domestic well. However, to evaluate regional conditions, such as pollution due to diffuse sources, high-capacity wells with large pumps may be more effective. A high-capacity well pumped for several weeks or months can often provide an integrated sample that is impossible to duplicate by other methods. High-capacity wells can integrate vertical and areal variations in water quality. In some cases an integrated sample is the most important; in others an integrated sample is purposefully not desired.

Well sampling can also be used occasionally to monitor the vadose zone. For example, in wells with perforations above the water table, perched water may enter the well and "cascade" to the water level. In some agricultural areas where irrigation wells are inactive for several months of the year, cascading water accumulates near the well during this period. If a water sample is collected during the first few hours of pumping such a well at the beginning of the irrigation season, it may provide a valuable integrated sample of return flow. In any case, the importance of wells cannot be overstressed, as they act to supply source water for various uses.

Spatial Water Quality Patterns

Zones of polluted groundwater have a three-dimensional configuration. Large-capacity wells have been used to delineate the areal distribution of polluted zones. Nitrate patterns in groundwater near Tucson, Arizona determined from sampling of irrigation wells were directly related to land disposal of sewage effluent.[23] There is evidence that nearly every well must be sampled to clearly delineate some sources. For example, the quality of water pumped from

irrigation wells southwest of Fresno, California appears to reflect the influence of a leaking trunk sewer between the urban area and sewage treatment plant.[24] In this case chlorides are an excellent tracer due to low background contents. The extent of the polluted zones from recharge of sewage effluent at the Fresno Sewage Plant has also been delineated by sampling large-capacity irrigation wells during periods of maximum pumpage.[24] The background areal distribution of groundwater quality must be defined prior to monitoring pollution.

The vertical distribution of groundwater quality is often difficult to assess. Water samples obtained during the drilling of wells by the cable-tool method can provide valuable information on the vertical stratification of water quality in the aquifer. Open-bottomed wells, which have no perforations or openings other than at the bottom of the casing, can provide valuable data on water quality at specific depths in the aquifer. Such high-capacity municipal wells in unsewered parts of the Fresno area have provided sound data on groundwater pollution from septic tanks.[25] The open bottom type of well construction merits attention in the case of monitor wells. As well yield is not as important as in the case of water supply wells, there is less need for specialized well screens, gravel packs, and other features devoted to enhance production.

Time Trends

If a well penetrates an aquifer of rather uniform areal and vertical water quality, the composition of the water may not change much over long periods of time. However, in the case of vertical stratification of groundwater quality, which is common in areas of groundwater pollution, significant changes can occur in water quality with time. Just as water levels in a well change rapidly soon after the pump is turned on, so can the quality of pumped water. Rarely have water samples for chemical analyses been taken frequently enough to adequately describe these short-term changes. The result has often been widely varying analytical results from one sample to the next. Just as water levels are measured on a logarithmic frequency during aquifer tests, water samples can be collected simultaneously. That is, samples can be taken on a more frequent basis during the early part of the pumping period. Frequent nitrate analyses during pump tests on high-capacity wells in the Fresno urban area have illustrated exponential decreases in concentration with pumping time. If water samples are to be collected from high-capacity wells after only minutes or hours of pumping, short-term time trends must be considered. In the case of high-capacity wells which have been inactive for several weeks or months, several days or weeks of continuous pumping may be necessary to purge the well of atypical aquifer water. This water may have short-circuited down the side of the casing through perforations or the gravel pack.

Seasonal changes in water quality can also be significant for high-capacity wells near pollution sources. Such changes have been noted for nitrate and chloride contents during monthly sampling of irrigation wells at sewage effluent disposal sites near Tucson, Arizona.[23] Wells near sewage effluent percolation ponds near Fresno, California have shown significant seasonal variations in nitrate, ammonia, and pH.[25] High-capacity municipal wells in unsewered parts of the Fresno urban area have shown significant seasonal variations in nitrate and chloride. In all cases the seasonal changes are in some way related to waste disposal operations. Seasonal fluctuations must be established before effective monitoring programs can be implemented. In an analagous fashion, seasonal fluctuations in depth to water were commonly monitored in the early days of water-level measurement programs.

Once the short-term and seasonal time trends are established in an area for individual wells or groups of wells, long-term trends in groundwater quality can be established. In the case of diffuse sources, decades of such records will often be necessary to adequately monitor groundwater pollution. Long-term records in many areas have documented the development of groundwater pollution sources. These records can also be used to illustrate the ameliorating effects of groundwater pollution abatement activities.

Conclusions

Monitoring groundwater pollution entails source monitoring, evaluation of infiltration potential, monitoring in the topsoil and vadose zone, and aquifer monitoring. The heart of groundwater pollution monitoring lies in water well sampling. Source monitoring includes inventoring and sampling solid and liquid wastes which may eventually percolate to the water table. Waste disposal methods partly determine infiltration potential and whether or not portions of the soil-groundwater system are bypassed. Pollutants can be categorized into physical, inorganic chemical, organic chemical, bacteriological, and radiological. In general the major inorganic constituents are the most mobile in soils-groundwater systems, whereas the bacteriological constituents are the least mobile.

Monitoring in the vadose zone is especially important in areas where significant amounts of pollutants are retained in this zone. In arid areas with deep water tables and little recharge, a large storage capacity for pollutants may exist above the water table. In some cases recharged waters may take decades or centuries to reach the water table. However, in most humid areas and beneath lands irrigated for long periods of time, travel times are often in the order of weeks, months, or several years. However, significant retention of trace elements and other constituents may still occur. Water budgets and moisture characteristics in the vadose zone provide information on travel time above the water table. Both water and soil can be taken from the vadose zone and analyzed. Sampling in the vadose zone has been most widespread and effective beneath point sources of pollution. This is because relatively small amounts of materials are sampled compared to those in the entire system.

Monitoring in the aquifer can occasionally be done by surface geophysics, borehole geophysics and other methods. However, most cases require water well sampling. If existing wells are not sufficient, specially designed monitoring wells may have to be constructed. There are a number of ways to retrieve water samples from open wells, and geologic samples are usually taken during drilling. Pumped high-capacity wells can provide meaningful water samples for many sources of pollution. Pumped wells can also occasionally provide direct information on the quality of water in the vadose zone. Time trends and the three-dimensional distribution of groundwater quality must be evaluated to successfully monitor aquifer pollution. Careful hydrogeologic judgment must be used in the establishment of monitoring programs for groundwater pollution.

References

1. American Public Health Association, 1971, "Standard Methods for the Examination of Water and Wastewater", 13th Edition, 874 p.
2. Brown, E., Skougstad, M.W., and M.J. Fishman, 1970, "Methods for Collection and Analysis of Water Samples for Dissolved Minerals and Gases", Techniques of Water-Resources Investigations of the U. S. Geological Survey, Book 5, Laboratory Analysis, Chapter A1, 160 p.
3. American Society for Testing Materials, 1973, "ASTM Standards", Part 23, Water.
4. U. S. Environmental Protection Agency, 1974, "Methods for Chemical Analyses of Water and Wastes", National Environmental Research Center, Cincinnati, Ohio, 298 p.
5. U. S. Environmental Protection Agency, 1974, "Water Quality and Pollutant Source Monitoring, Proposed Rules", Federal Register, vol. 39, no. 168, pp. 31500-31505.
6. Hem, J.D., 1970, "Study and Interpretation of the

Chemical Characteristics of Natural Water", U. S. Geological Survey Water-Supply Paper 1473, Second Edition, 363 p.
7. Wells, D.B., 1975, "Monitoring Industrial Wastewater", Deeds & Data, Water Pollution Control Federation, June issue, 8 p.
8. U. S. Environmental Protection Agency, 1971, "Handbook for Monitoring Industrial Wastewater", Office of Technology Transfer.
9. Kohler, M.A., 1954, "Water-Loss Investigations: Lake Hefner Studies, Technical Report", U. S. Geological Survey Professional Paper 269.
10. Harbeck, G.E., Jr., Kohler, M.A., Koberg, G.E., and others, 1958, "Water-Loss Investigations: Lake Mead Studies", U. S. Geological Survey Professional Paper 298.
11. American Geophysical Union, 1967, "Isotope Techniques in the Hydrologic Cycle", Geophysical Monograph Series No. 11, edited by G.E. Stout, American Geophysical Union, Washington, D.C., 199 p.
12. Van Hylckama, T.E.A., 1968, "Water Level Fluctuations in Evapotranspirometers", Water Resources Research, vol. 4, no. 4, pp. 761-768.
13. Cruff, R.W., and T.H. Thompson, 1967, "A Comparison of Methods of Estimating Potential Evapotranspiration from Climatological Data in Arid and Subhumid Environments", U. S. Geological Survey Water-Supply Paper 1839-M, 28 p.
14. Black, C.A. and others, 1965, "Methods of Soil Analysis", Agronomy Monograph No. 9, American Society of Agronomy, Madison, Wisconsin.
15. Wilson, L.G., 1971, "Observations on Water Content Changes in Stratified Sediments During Pit Recharge", Ground Water, vol. 9, no. 3, pp. 29-40.
16. Van Bavel, C.H.M., Nixon, P.R., and V.L. Hauser, 1963, "Soil Moisture Measurement with the Neutron Method", U. S. Dept. of Agriculture, Agricultural Research Service Publ. 41-70, 39 p.
17. Watson, K.K., 1967, "A Recording Field Tensiometer with Rapid Response Characteristics", Journal of Hydrology, vol. 5, pp. 33-39.
18. Walker, W.H., 1974, "Monitoring Toxic Chemical Pollution from Land Disposal Sites in Humid Regions", Ground Water, vol. 12, no. 4, pp. 213-218.
19. Hanson, E.A., and A.R. Harris, 1975, "Validity of Soil-Water Samples Collected with Porous Ceramic Cups", Soil Science Society of America Proceedings, vol. 39, no. 3, pp. 525-536.
20. Richards, L.A., 1966, "A Soil Salinity Sensor of Improved Design", Soil Science Society of America Proceedings, vol. 30, pp. 333-337.
21. Zohdy, A.A., Eaton, G.P., and D.R. Mabey, 1974, "Application of Surface Geophysics to Ground-Water Investigations", Techniques of Water-Resources Investigations of the U. S. Geological Survey, Book 2, Chapter D1, Collection of Environmental Data, 116 p.
22. Brown, D.L., 1971, "Techniques for Quality of Water Interpretation from Calibrated Geophysical Logs, Atlantic Coastal Area", Ground Water, vol. 9, no. 4, pp. 25-38.
23. Schmidt, K.D., 1972, "Groundwater Contamination in the Cortaro Area, Pima County, Arizona", in Hydrology and Water Resources in Arizona and the Southwest, vol. 2, Arizona Section AWRA, pp. 95-111.
24. Schmidt, K.D., 1975, "Regional Sewering and Groundwater Quality in the Southern San Joaquin Valley", Water Resources Bulletin, vol. 11, no. 3, pp. 514-525.
25. Schmidt, K.D., 1972, "Nitrate in Groundwater of the Fresno-Clovis Metropolitan Area, California", Ground Water, vol. 10, no. 1, pp. 50-64.

76. Schmidt, K. D. "Monitoring Groundwater Quality at State Permitted Sites in California", Paper given at 13th Biennial Groundwater Conference, September 1981

Paper given at 13th Biennial Groundwater Conference September 1981

I want him to come back to the Board in plenary

MONITORING GROUNDWATER QUALITY AT STATE PERMITTED SITES IN CALIFORNIA

by Kenneth D. Schmidt

The objective of this paper is to discuss the problems with present groundwater quality monitoring approaches in California and to recommend solutions.

See page 7

National Perspective

The nationally known groundwater consulting firm of Geraghty and Miller, Inc. (1977) reported on groundwater quality monitoring at selected industrial waste-disposal sites throughout the U.S. This investigation was perhaps the first comprehensive, independent review of such monitoring networks. It has a profound significance, because these sites, due to the hazardous nature of the disposed wastes, should have been monitored better than most other types of waste disposal sites. Geraghty and Miller, Inc. (1977) stated (page 148):

2640
2646
2647
2648

> "Based on the results of this study,... it was found that monitoring wells are usually installed simply because existing regulations require them, with no specific objective in mind. This has led to poorly designed, installed and operated monitoring facilities. Most of the systems observed involved one or more of the following deficiencies:
>
> 1. the number and positioning of wells.
> 2. their design, installation, and development.
> 3. the method of sampling employed.
> 4. the chemical constituents analyzed.
> 5. the disposition of analytical results."

This report, interestingly enough, was met with disfavor by some state regulatory agencies responsible for over-seeing these monitoring networks.

The U.S. Environmental Protection Agency (1980) issued hazardous waste regulations which contained provisions for monitoring groundwater quality at such sites. Basically, the number of monitor wells was specified and a statistical technique established to allow evaluation of the results of chemical analyses. However, the procedure to be used for sampling wells and alternative methods of monitoring groundwater quality were not addressed. Schmidt (1976) discussed the framework for monitoring groundwater pollution, including the various components to be monitored. Omitted from the EPA regulations were items such as wastewater sampling, sampling of solid materials, vadose-zone monitoring and non-well techniques for saturated zone monitoring. There is, thus, an over-emphasis on the use of wells and statistics in groundwater quality monitoring to the exclusion of other important aspects.

California Experience

I have reviewed groundwater quality monitoring programs at dozens of waste-disposal sites in California during the past decade. These include sites for disposal of municipal solid wastes, sewage effluent, industrial wastes, urban storm runoff, hazardous wastes, oil and gas fields, and geothermal facilities. Most of these sites are permitted under the Porter-Cologne Act (California State Water Resources Control Board, 1973), and the discharge requirements usually indicate that "there shall be no pollution of the groundwater". My experience indicates that few of these sites are adequately monitored, although the situation is changing. The impact of a specific waste discharger on the underlying groundwater is often unknown. As the groundwater pollution at the

Occidental Chemical site near Lathrop and the Aerojet General site east of Sacramento have demonstrated, this is an untenable situation. These are two of the more serious groundwater pollution sites yet identified in the Western U.S., and both were state permitted sites while at least some of the pollution was occurring. Overall, groundwater quality monitoring networks near pollution sources in California are little different than those in most other states, despite the Porter-Cologne Act.

I believe that the following are the major reasons for the present situation in California:

1. Experienced groundwater hydrologists or geologists have rarely been involved with the monitoring.

2. The qualifications of individuals competent to undertake such monitoring and interpretation of the results have not been adequately specified, at either the state or federal level.

3. The staffs of local, state, and federal regulatory agencies have usually not had and do not have a sufficient understanding of groundwater hydrology or geology to make meaningful decisions.

4. There has been a lack of definition of the specific hydrogeologic conditions at waste disposal sites. Decisions have commonly been made based on generalities that are often erroneous.

5. There are no agreed-upon approaches for groundwater quality monitoring. Rather, trial and error methods have often been applied at a high economic cost.

Qualifications of Those Performing Monitoring

The topic of qualifications for those doing monitoring is controversial, partly because of the multi-disciplinary nature of the soil-aquifer system and the complexity of pollution mechanisms. For example, wastewater, solid wastes, soil, and water and geologic materials in the vadose zone and aquifer may be sampled.

Also, an adequate understanding of the hydraulic aspects of the soil-aquifer system is necessary. Highly complex chemical reactions may be involved, and a knowledge of water chemistry, soils chemistry, and geochemistry is advantageous in monitoring. Many studies now are focusing on trace organic chemical constituents, and some knowledge of organic chemistry is advisable. Few individuals or firms have attained such knowledge in the Western U.S., partly because of the lack of past groundwater pollution studies.

My opinion is that registration is needed in the specialty of hydrogeology or groundwater hydrology. In California, many people categorize this specialty under the discipline of engineering geology. This, in effect, does a disservice to the groundwater profession. Most engineering geologists practice groundwater hydrology only on a part-time basis, because they are involved in rock mechanics, slope stability, septic-tank disposal design, seismic studies, and other aspects. Much of the work involved in groundwater hydrology has no relation to engineering problems. Thus, there is no compelling reason to subjugate the groundwater hydrology profession beneath any other discipline. Registration in groundwater would require completion of an academic program in groundwater hydrology or the equivalent full-time work experience.

Although universities in Arizona, New Mexico, and Nevada have specific degree programs in groundwater hydrology, I know of no university program specifically in groundwater hydrology in California. To those of us who are natives of California and have completed such programs in other states, this is amazing! The usual situation in California is that one or several classes in groundwater are taught in engineering, geology, or soil science

departments. There is a need to train individuals in the field of groundwater hydrology utilizing the multi-disciplinary approach, which has proven to be paricularly effective at the University of Arizona. There is also a need to develop academic programs emphasizing groundwater quality, pollution, and monitoring approaches and methods. Such programs are virtually non-existant at present in the Western U.S. Programs focusing on arid lands would be of great value in the southwest. I foresee the day when registration in hydrogeology will be commonplace, with sub-categories in specific fields such as groundwater quality and pollution.

Monitoring Approaches

Basic guideines need to be developed for at least the following items relative to monitor wells:

1. Siting
2. Casing type and diameter
3. Well development
4. Annular seal and gravel pack
5. Methods of water sample collection
6. Frequency of sampling
7. Constituents to be analyzed

location! wells - without - never!

In addition, guidelines for sampling solid materials in the vadose zone and aquifer should be developed. Sampling of percolating water in the vadose zone should be given special attention. Guidelines for sampling wastewater and solid wastes should be described. Besides approaches for direct monitoring, procedures should be established for background hydrogeologic investigations, such as:

1. Preparation of subsurface geologic cross sections.
2. Water-level elevation contour maps and flownets.
3. Determination of direction and rate of groundwater flow.
4. Determination of pollution potential of various sources.
5. Definition of the character of the vadose zone.

These background investigations provide the framework upon which successful groundwater quality monitoring programs can be developed.

A groundwater quality monitoring methodology was developed in the mid-1970's for the U.S. Environmental Protection Agency (Todd, et al, 1976). A more specific and up-to-date methodology could be made for California. Monitoring approaches could be developed based on methods of disposal, such as:

1. Waste ponds or pits
2. Injection wells
3. Disposal to dry stream channels
4. Irrigation
5. Soil injection or incorporation.

An alternative would be to develop monitoring approaches based on the type of waste or source of wastes, such as:

1. Urban storm runoff
2. Landfills
3. Sewage effluent
4. Industrial wastes
5. Feedlots and dairies
6. Irrigation return flow
7. Hazardous wastes
8. Oil and gas activities
9. Mining
10. Geothermal activities

For California, monitoring approaches could be developed for at least the following different hydrogeologic situations:

1. unconsolidated rocks
2. consolidated sedimentary rocks
3. crystalline rocks

Monitoring groundwater quality in crystalline and consolidated rocks often presents substantial problems because of the irregularity of water-bearing fractures or other openings. Many techniques usable in alluvial groundwater basins cannot be applied to the other situations. It would seem feasible to develop such approaches in priority regions of the state.

Conclusions

Adequate groundwater quality monitoring networks are operative at only a small percentage of the state permitted waste disposal sites in California. One of the premier monitoring networks is at the Occidental Chemical site near Lathrop. However, this network was only installed after serious groundwater pollution had occurred and enforcement actions were initiated. Hopefully, a procedure can be developed whereby adequate groundwater quality monitoring programs can be inacted to prevent such occurrences. The main problems at present are the lack of qualified groundwater professionals in the regulatory agencies, the lack of involvement of such professionals in the monitoring at many sites, the lack of academic training programs focusing on groundwater quality, pollution, and monitoring, and the lack of a uniform procedure for groundwater quality monitoring at waste disposal sites. Solutions to these problems have been proposed, and they involve no new monies. Rather, they require a firm re-dedication to the goal of protecting groundwater quality in California.

REFERENCES

California State Water Resources Control Board, 1973, "The Porter-Cologne Water Quality Control Act, 68p.

Geraghty and Miller, Inc., 1977, "The Prevalence of Subsurface Migration of Hazardous Chemical Substances at Selected Industrial Waste Land Disposal Sites", U.S. Environmental Protection Agency Report EPA/530/SW-634, 166p.

Schmidt, K.D., 1976,"Monitoring Groundwater Pollution," Proceedings of the International Conference on Environmental Sensing and Assessment, Groundwater Section, sponsored by EPA, WHO, and University of Nevada, Las Vegas, Nevada, September 1975, The Institute of Electrical and Electronics Engineers, Inc., vol 1, session 9, no. 4, pp 1-6.

Todd, D.K., Tinlin, R.M., Schmidt, K.D., and L.G. Everett, 1976, "Monitoring Groundwater Quality: Monitoring Methodology", U.S. Environmental Protection Agency, Evnironmental Monitoring Series, Report EPA 600/4-76-026.

U.S. Environmental Protection Agency, 1980, "Hazardous Waste and Consolidated Permit Regulations", Federal Register, vol 45, no 98, part VII.

77. Schmidt, K.D. "Water Quality Variations for Pumping Wells," Reprinted from Ground Water, Vol. 15, No. 2, 1977

SECTION S-5
Bull. 130-75
SHELF v.2
ITEM .2

STATE OF CALIFORNIA
The Resources Agency
Department of Water Resources

BULLETIN No. 130-75

HYDROLOGIC DATA: 1975

Volume II: NORTHEASTERN CALIFORNIA

CALIFORNIA RESOURCES AGENCY LIBRARY
Resources Building, Room 117
1416 9th Street
Sacramento, California 95814

MAY 1977

CLAIRE T. DEDRICK
Secretary for Resources
The Resources Agency

EDMUND G. BROWN JR.
Governor
State of California

RONALD B. ROBIE
Director
Department of Water Resources

Water Quality Variations for Pumping Wells

2647

by Kenneth D. Schmidt[a]

ABSTRACT

Past ground-water quality monitoring programs have often involved sampling of low-capacity wells near point or line sources of recharge or pollution. However, large-capacity wells produce much of the ground water pumped for municipal, industrial, and agricultural uses. Short-term, seasonal, and long-term fluctuations in quality are common for water pumped from many large-capacity wells. In many cases, there is a considerable difference between in-situ "ground-water quality" and the quality of water sampled at the well discharge.

Short-term pump tests for several municipal wells in the San Joaquin Valley, California have indicated that nitrate concentrations decreased exponentially with pumping time. Variability in pump operation creates substantial short-term changes in well-water quality. Short-term changes are most evident for infrequently pumped, shallow wells near point or line sources of recharge or pollution. Seasonal changes in quality have been documented for water from wells in areas of diffuse sources of pollution, such as agricultural return flow and septic tanks. These changes are primarily due to significant changes in depth to water and vertical hydraulic head gradient. Once the short-term and seasonal trends are established, the optimal sampling approach can be determined in order to establish long-term trends.

INTRODUCTION

Monitoring programs for various parameters of environmental quality are growing at a rapid rate. Proposed monitoring programs for ground-water quality are no exception. Although sampling of springs, tile drains, and baseflow of streams may provide an indication of ground-water quality, most of the discussion in this paper concerns water sampling of pumping wells. This is not meant to minimize the value of land surface monitoring, sampling in the vadose zone, and sampling of non-pumping wells.

One item of concern in monitoring ground-water pollution is the location of the well with respect to the pollution source. Also, well construction and the hydrogeologic framework determine the depth interval from which ground water is produced by a pumped well. Thus, a second item is the vertical extent of the polluted zone and its relation to the producing zone of the well. Thirdly, the frequency of sample collection is of crucial importance to ground-water quality monitoring. Care should be taken to differentiate between "ground-water quality" and "well-water quality." It has frequently been stated that ground-water quality changes very slowly. Perhaps of more importance is the variability in quality of water discharged from pumping wells, a topic to be addressed in this paper.

In this paper, "short-term" trend in well-water quality refers to a sampling period over minutes or hours after the initiation of pumping. "Seasonal" trend in well-water quality refers to a sampling period sufficient to establish seasonal variations. "Long-term" trend in well-water quality refers to a sampling period of many years or decades. A "high-capacity" well is generally one which is pumped at rates exceeding several hundred gpm. A "low-capacity" well is generally one which is pumped at rates of less than 50 gpm. "Point," "line," and "diffuse" sources of recharge or pollution are used in the hydrologic context. A "point source" generally covers a small area, such as a landfill or percolation pond. A "line source" has the length dimension much greater than the width, such as a stream channel. A "diffuse source" covers a large area, such as return flow from crop irrigation.

REASONS FOR WATER QUALITY VARIATIONS FOR PUMPING WELLS

At first glance, it might seem that the quality of water pumped from a well should be rather constant with time. The situation is somewhat

[a]Ground-Water Quality Consultant, 1111 Fulton Mall, Fresno, California 93721.

Discussion open until August 1, 1977.

Reprinted from the March-April 1977, Volume 15, Number 2 issue of *Ground Water*

analagous to that during the early stages of aquifer analysis, when the simplest cases received first attention. In the early stages of aquifer analysis, hydraulic head declines during pumping were analyzed for the "ideal" aquifer. Later developments in aquifer analysis included derivations for other situations such as water-table aquifers, leaky artesian aquifers, partial penetration, and assessment of boundary conditions. It should be noted that factors altering the response in hydraulic head to pumping can also influence the quality of water pumped from the well.

In general, there may be a distinct water quality in each strata penetrated by a well. The variation in composition of aquifer materials with depth, along with possible differences in the source of recharge for some strata, may result in vertical stratification of ground-water quality. Secondly, the permeability of individual strata also varies. Thus, the water pumped from a well represents an integration of the quality of ground water in various producing zones. Thirdly, there is a radial variation in quality of water in the aquifer with distance from the pumped well. This is particularly so for wells near point or line sources of pollution. These factors combine to produce changes in well-water quality with time during pumping.

Flow net considerations for cross sections of aquifer systems clearly indicate differences in flow patterns for wells penetrating confined as opposed to unconfined aquifers. If a source of pollution is at or near the land surface and has affected the shallow ground water, the quality of water pumped by wells in these two basic aquifer types is clearly different. Continued pumping of a confined aquifer may produce inflow of water from nearby unconfined areas. Water in the unconfined aquifer may be of much different quality than that of water originally in the confined aquifer. Leakage from overlying or underlying aquifers during long-term pumpage may induce flow into the confined aquifer of water of a much different quality. Partial penetration is common in many aquifer systems. Hydraulic head patterns are affected near pumping wells and significant changes in the quality of pumped water may result. Subsidence due to hydraulic head declines results in water being expelled from finer-grained materials in aquifer systems. Such water comprised as much as 40% of the water withdrawn by wells in subsiding areas of the San Joaquin Valley. This water may be of different composition than ground water in the remainder of the system.

LITERATURE REVIEW

A review of a number of published accounts of ground-water quality monitoring indicates that water well sampling has been extensively utilized in certain situations. One situation is near point or line sources of recharge or pollution, where large volumes of water or wastewater are recharged per unit area of the land surface. Artificial recharge and liquid waste disposal by percolation ponds, pits, and injection wells, and solid waste disposal by landfills are in this category. A second common situation is the case of monitoring ground water affected by water of high salt or ion concentration. Examples are in areas of salt-water intrusion, oilfield brine disposal, road salt contamination, and industrial waste disposal. Some cases involve both of these situations simultaneously. Hydrographs illustrating the variation of water quality parameters with time have frequently been presented in case histories for these situations.

On the other hand, the effect of recharge or pollution from diffuse sources, excluding salt-water intrusion, has seldom been analyzed by means of hydrographs for well-water quality. Examples of these sources include irrigation return flow and septic tanks, which are certainly of major concern in many parts of the western U.S. Hem (1970) and Piskin (1973) analyzed water quality hydrographs for wells likely affected by agricultural practices. Schmidt (1972) and Quan *et al.* (1974) used this tool in evaluations of septic tank pollution. However, water quality fluctuations during pumping of large-capacity wells have received little attention. Such fluctuations are important, as a large proportion of ground water used for municipal, industrial, and agricultural use is withdrawn by such wells. These wells can be extremely useful for purposes of ground-water quality monitoring because of the large volume of water pumped compared to that normally obtained from small-diameter observation wells and other devices.

Past water well sampling near point or line sources of large recharge volume and/or high salt or ion content has amply demonstrated the need for frequent sampling. Significant changes in water quality have often been documented in such situations on a daily, weekly, or monthly basis. In many cases, this is due to the rapid recharge of large volumes of water and/or pollutants per unit area in the vicinity of wells. However, the sampling frequency required for water sample collection from wells, in order to evaluate the effects of diffuse sources of recharge or pollution on ground-

water quality, remains an unknown in many areas. In this case, a relative small volume of water or pollutant load per unit area is slowly recharged. Two difficulties are often faced. First, a number of sources of pollution and recharge are usually present. Secondly, travel times of water and pollutants from the land surface to the water table in this case are often unknown. Presented in the following paragraphs are examples of the use of water quality hydrographs for analysis of diffuse sources of recharge or pollution.

EAST YORKSHIRE, ENGLAND

Foster and Crease (1974) reported on nitrate pollution of ground water in the chalk aquifer of East Yorkshire, England. Travel times of water in the saturated zone have been well documented, and commonly are in the range of tens or hundreds of feet per day. Travel times in the vadose zone in this area are a topic of great controversy. Municipal supply wells were frequently sampled during the 1962 to 1972 period. Nitrate contents ranged from about 11 to 20 mg/l from 1960 to 1969 and were relatively constant in water pumped from each well. However, sharp increases in nitrate content occurred for many wells during 1970 to 1972, at which time the nitrate content of well water was commonly 35 to 50 mg/l. Seasonal variations in nitrate content of water pumped from some wells approached 10 mg/l during this latter period. Maximum nitrate contents occurred during the late spring and early summer whereas minimum nitrate contents occurred in the fall. Daily and weekly samples did not reveal any rapid fluctuations.

Land use above the unconfined aquifer is primarily agricultural and soils are light-textured and freely-drained. A marked increase in fertilizer application rates occurred in about 1959 (Foster and Crease, 1974). Water samples from shallow depths in the vadose zone beneath fertilized farmland frequently contained more than 65 mg/l of nitrate, whereas the nitrate contents in water samples below unfertilized grasslands were usually less than 2 mg/l. Other sources of nitrogen did not appear to be regionally significant over the study area. The increasing nitrate contents of well water about ten years later indicate that average travel times in the vadose zone may be about ten years. However, flow rates in the vadose zone are uncertain, due to the possibility of both intergranular and fissure flow. The authors illustrated the importance of frequent sampling of wells. Relevant factors at the land surface and in the vadose zone were assessed.

GROVER CITY, CALIFORNIA

The California Department of Water Resources (1962) and Stout *et al.* (1965) studied nitrates in ground water of the Grover City-Arroyo Grande area in San Luis Obispo County, California. Alluvial deposits several hundred feet thick comprise the aquifer. Rainfall averages 18 inches (46 centimeters) per year and wells provide the water supply for municipal and agricultural use. Many wells in the area had nitrate contents exceeding 100 mg/l in the early 1960's. Primary nitrogen sources were fertilizers, sewage effluent, and septic tank effluent. Sandy soils in many areas enhance percolation of nitrogen compounds from the land surface to the water table. The highest nitrate contents appeared in wells immediately downgradient of an unsewered part of Grover City, and secondarily, downgradient of the Arroyo Grande sewage treatment plant and nearby irrigated fields.

The California Department of Water Resources (1962) reported on semi-annual sampling of wells during 1958-60. Low nitrates in the spring and high nitrates in the fall were common for water from some wells, and some seasonal fluctuations exceeded 25 mg/l. Stout *et al.* (1965) subsequently showed that under crop irrigation, return flow from excess applied irrigation water could reach the water table in about two years. Sufficient analyses were not available to evaluate long-term trends.

Two heavily pumped municipal wells in Grover City were chosen for frequent sampling by Stout *et al.* (1965) in July 1964. Both wells were reported to be 180 feet (55 meters) deep, and the casing perforated from 36 to 180 feet (11 to 55 meters) below land surface. They were both drilled by the direct rotary method and gravel packed. One well was sampled during a 15-hour continuous pumping period and the second was sampled during continuous pumping for about six hours after a 48-hour shutdown. The nitrate contents for water sampled during both pump tests were essentially constant. These short-term tests illustrate the consistency in chemical quality of water pumped from some wells during heavy pumping periods.

DELANO, CALIFORNIA

The California Department of Water Resources (1968) reported on the Delano nitrate investigation. Delano is a small town in a predominantly agricultural area north of Bakersfield, California in the San Joaquin Valley. Alluvial deposits comprise the aquifer and sandy, permeable soils overlie much of

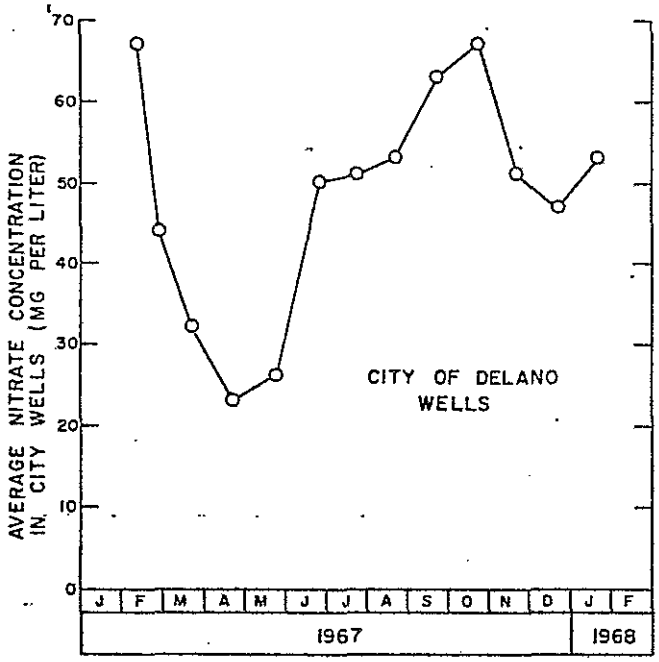


Fig. 1. Seasonal nitrate variations for municipal water-supply wells at Delano.

the area. The mean annual rainfall is about 10 inches (25 centimeters). Overdraft due to excessive ground-water pumpage had lowered the water level over 200 feet (61 meters) over a large area by 1950. However, imports of surface water in the Friant-Kern Canal began in 1951, and a subsequent recovery in water levels of up to 150 feet (46 meters) had occurred by 1968. The depth to water near Delano was in the range of 100 to 150 feet (30 to 46 meters) below land surface in 1967. The average nitrate content of water samples taken in March 1967 from 105 wells was over 50 mg/l.

Substantial increases in the nitrate content of ground water accompanied the water-level rises of the 1950's and 1960's. The likely source of high nitrate contents in ground water is nitrogen fertilizer. Nitrate contents in water pumped from large-capacity municipal wells in Delano showed a substantial seasonal variation (Figure 1). This variation was directly related to water-level fluctuations. Seasonal fluctuations in depth to water of 20 to 30 feet (6 to 9 meters) were common and in some cases exceeded 50 feet (15 meters). The California Department of Water Resources (1968) postulated that during periods of rising water levels, high nitrates in water formerly above the water table were intercepted by the ground water. Chemical analyses documented substantial seasonal and long-term changes in ground-water quality in a situation where water levels fluctuated in an extreme manner.

A two-hour pump test was conducted on a Delano municipal well in August 1967 during a period of heavy pumping. The well was 1,038 feet (316 meters) deep, had a 14-inch (36-centimeter) diameter casing installed to the bottom, was gravel packed, and perforated from 300 feet (91 meters) to the bottom. The static water level was about 200 feet (61 meters) deep, discharge was 1,380 gpm (87 lps), and the drawdown after two hours of pumping was about 30 feet (9 meters). Figure 2 is a semi-logarithmic graph of nitrate content with pumping time made by this author from the test results. The California Department of Water Resources (1968) ascribed the high nitrates of the first few minutes of the test to the removal of shallow water standing in the well. Calculations indicate that it would take less than one minute to remove a volume of water equivalent to that of the water in the well between the static water level and the top of the perforations. About five minutes would be required to remove a volume of water equivalent to that in the entire well prior to pumping.

Considerable stabilization of nitrate content occurred after about three minutes of pumping. A decrease in nitrate content with the logarithm of pumping time is apparent, which is analagous to a water-level decline during pumping. These results indicate the variability in well-water quality that may occur if an arbitrary time is selected for sampling after pumping has begun. A number of large-capacity wells in the San Joaquin Valley and elsewhere are commonly sampled after the pump has been turned on for only 5 or 10 minutes.

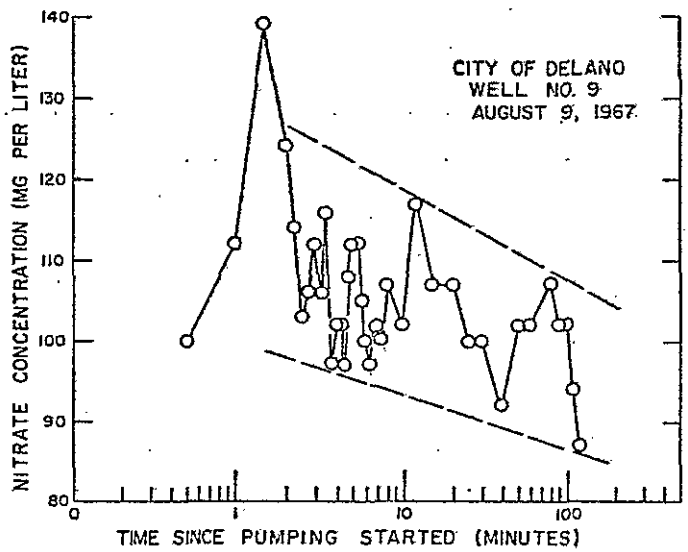


Fig. 2. Nitrate contents during short-term pump test at Delano.

FRESNO, CALIFORNIA

Schmidt (1972) previously described in detail the hydrogeologic framework, nitrogen sources, and distribution of nitrate in ground water of the Fresno urban area.

Long-Term Trends

One of the most difficult problems in assessing long-term trends in ground-water quality in many parts of the San Joaquin Valley is the lack of uniform sampling and analytical procedures over the period of record. It is not uncommon to have a half dozen or more different agencies or investigators involved during decades of sampling, each using different sampling approaches and analytical techniques. In the following example of long-term water quality trends, this problem is minimal.

Well T13S/R20E-21E1 is a municipal water-supply well in the northwestern part of the Fresno urban area. The alluvium is several thousand feet thick and the water table has been declining due to extensive pumpage in this area in recent decades. Septic tanks were used until about 1973, and because of the presence of a rather impermeable shallow hardpan, seepage pits were commonly used for disposal of the septic tank effluent. Nineteen nitrate analyses are available over the period 1955 to 1975, with most since 1966. The well is 185 feet (56 meters) deep and has an unperforated casing extending to 154 feet (47 meters) in depth. The well produces about 800 gpm (50.5 lps) at a drawdown of about 8.5 feet (2.6 meters). Static water levels have declined from less than 70 feet (21 meters) in 1958 to more than 100 feet (30 meters) below land surface by 1975.

The long-term trend from 1955 to 1975 indicates a constancy of nitrate (Figure 3), as values have fluctuated about an average of about 15 mg/l. The same trend is shown by water quality hydrographs in a number of the wells in this area. This is probably because of several factors. First, the area is underlain by extensive cobble, gravel, and sand layers which permit considerable recharge from areas upgradient of the septic tank area. Secondly, the well does not draw water from the shallowest part of the aquifer where the nitrate contents are the highest. Schmidt (1972) previously illustrated the vertical stratification of nitrate in ground water of this area. The layered nature of the alluvium hinders downward movement of nitrate into deeper parts of the aquifer.

Semi-annual sampling (May and November) was undertaken for several years. Seasonal trends

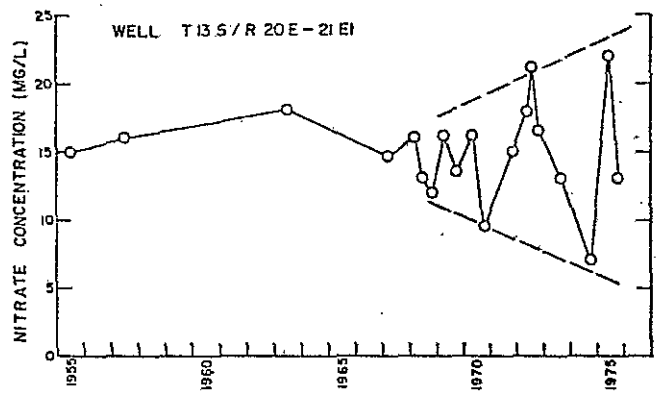


Fig. 3. Long-term nitrate trends in an unsewered part of Fresno.

were apparent (Figure 3), with generally higher nitrate contents occurring in May. Between 1970 and 1975, larger nitrate fluctuations occurred than previously. These fluctuations appear to be related to the water-level declines. As water levels decline, the well gradually draws water from shallower parts of the aquifer. The primary producing zone for this well in 1955 was about 90 to 110 feet (27 to 34 meters) below the water table. By 1975, this zone was only 50 to 70 feet (15 to 21 meters) below the water table. Fluctuations in nitrate content are greater in the shallow parts of the aquifer than in the deeper zones because recharge from septic tanks, canals, and other sources originates at or near the land surface. The areal distribution of water quality parameters in the shallow part of the aquifer is thus less uniform than that in deeper ground water.

Seasonal Trends

Monthly samples were taken in 1972-73 from several large-capacity, pumping municipal water-supply wells in the same area as the previous example.

Well T13S/R20E-17G1 is 180 feet (55 meters) deep with a 12-inch (30-centimeter) diameter unperforated casing installed to 150-feet (46-meters) depth. The depth to water was about 100 feet (30 meters) below land surface in 1972-73. The well pumped about 700 gpm (44 lps) with a drawdown of about seven feet (2.1 meters). Figure 4 illustrates nitrate and chloride hydrographs for the sampling period. Nitrate contents vary seasonally from as low as 12 mg/l in the winter to as high as 40 mg/l in the summer. This seasonal trend has also appeared during semi-annual sampling of many other wells in this area. Most of this seasonal variation is attributed to hydraulic head differences during pumping.

Water-level measurements for piezometers in comparable parts of the San Joaquin Valley have indicated the variation in hydraulic head with depth on a seasonal basis. Nitrate contents are highest in the shallower parts of the aquifer. During heavy pumping, downward movement of nitrate into the producing zone is induced by the lowered hydraulic head of the producing zone compared to that in shallower depth zones. This could also explain the seasonal nitrate fluctuations observed at Grover City and Delano. In this case, nitrate and chloride seasonal time-trends are similar for several reasons: (1) nitrate and chloride are both supplied largely by septic tank effluent, (2) nitrate and chloride are both mobile in the soil/ground-water system, and (3) physical factors, such as hydraulic head differences, largely control changes in the quality of water pumped from wells. This example illustrates the magnitude of seasonal variations in well-water quality under some

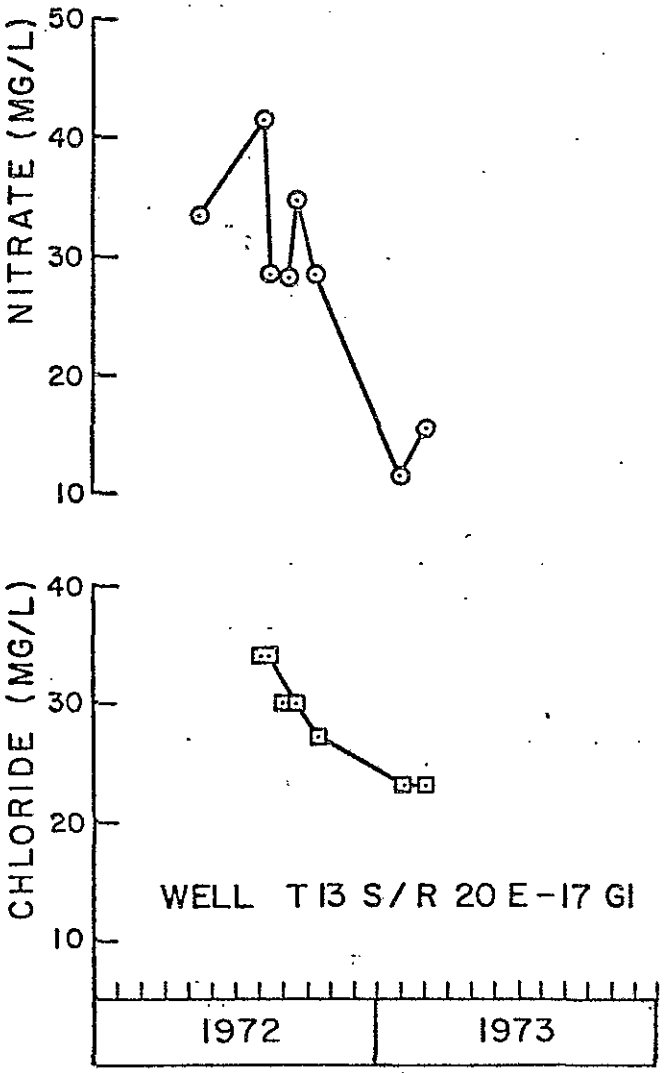


Fig. 4. Seasonal water quality variations in an unsewered part of Fresno.

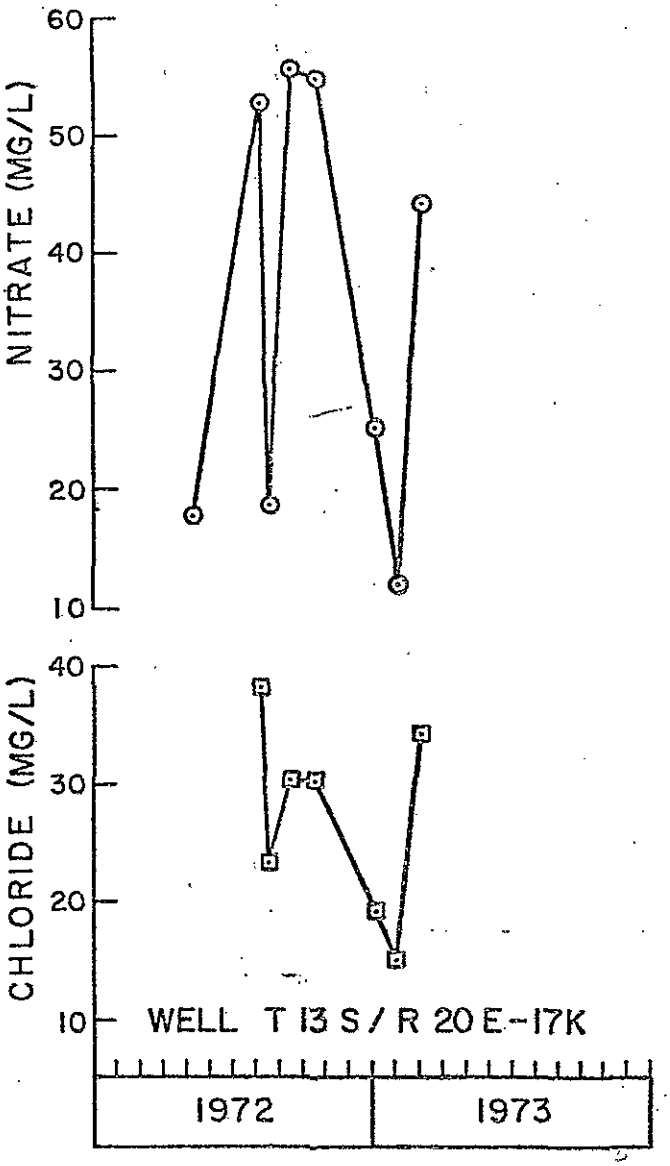


Fig. 5. Seasonal water quality variations in an unsewered part of Fresno.

circumstances. The importance of utilizing other quality parameters, such as chloride, is evident.

A second well (T13S/R20E-17K) in the same area showed large nitrate fluctuations during the sampling period (Figure 5). This well is 305 feet (93 meters) deep, has a 14-inch (36-centimeter) diameter casing perforated from 150 to 300 feet (46 to 91 meters), and is gravel packed. Nitrate content ranged from a low of about 10 to a high of 55 mg/l during 1972-73. Nitrate and chloride trends are again parallel. For the first few samples, it was unknown how long the well had been pumping when the water samples were collected. Subsequent sampling indicated that the nitrate content of pumped water actually varied from day to day, from less than 20 mg/l for some samples to more than 50 mg/l for others. Inspection of the pumping pattern indicated that

this well was being pumped in a very erratic manner. In some cases the pump was on for only several minutes at a time. High nitrate contents appeared in the well water during this situation. After several hours of continuous pumping, nitrate contents were much lower. This example indicates the importance of knowing the frequency of pump operation when sampling large-capacity wells. It also suggests that chemical analyses of well water during short-term pump tests would be valuable in some cases. Such tests duplicate actual pump operation and demonstrate water quality fluctuations of a very practical nature.

Short-Term Trends

The author collected frequent water samples during pumping of two large-capacity municipal wells in the Fresno urban area in June 1970. Well T14S/R21E-6Q is 520 feet (159 meters) deep, has a 20-inch (51-centimeter) diameter casing perforated from 140 to 420 feet (43 to 128 meters), and is gravel packed. The well had been idle for the 24 hours prior to the pump test, and depth to water was about 70 feet (21 meters). Figure 6 is a graph of nitrate contents with the logarithm of time. Nitrate contents decreased exponentially with pumping time. At about 35 minutes into the pump test, the well was surged due to excessive sand production. Pumping was stopped for about two minutes, then resumed. In this case the nitrate content almost doubled when pumping was resumed. The source of nitrate is probably from septic tanks in nearby unsewered areas upgradient of the well. The well was treated with sodium hypochlorite prior to the pump test which could affect bacteriological reactions and nitrate contents. Water samples taken annually in June in subsequent years have contained a nitrate content between 8 and 15 mg/l. Such values can be extrapolated from the first part of the 1970 pump test for a pumping time of about two hours. The high values are similar to those after only several minutes of pumping during the 1970 pump test. This example clearly documents rapid changes in well-water quality as related to pump operations. A suitable sampling schedule should thus take into consideration the length of pumping prior to sample collection.

Well T14S/R20E-9B, in the downtown Fresno area, was also tested in June 1970. This well was 177 feet (54 meters) deep and had 167 feet (51 meters) of unperforated 20-inch (51-centimeter) diameter casing. Depth to water was about 70 feet (21 meters). This well was normally not in use, as it was an older well and commonly produced high nitrates in the pumped water. Water samples could not be collected during the first ten minutes of pumping, but nine samples were taken later (Figure 7). There was a nitrate peak about 15 minutes after the initiation of pumping. Except for this peak, most of the values show a nearly linear decrease in nitrate with logarithm of time. Thus an exponential decrease in nitrate with pumping time was again evident. Chloride analyses indicate that the source of nitrate in this case is probably leaking sewers in the downtown area. This example illustrates the changes in well-water quality which can occur for wells which are infrequently pumped. This point deserves consideration in the sampling of monitor wells which may either be infrequently pumped or not pumped at all.

SUMMARY AND CONCLUSIONS

The validity of the commonly accepted adage that "ground-water quality changes slowly" may not apply to pumped large-capacity wells. The U.S. Environmental Protection Agency (1975) Interim

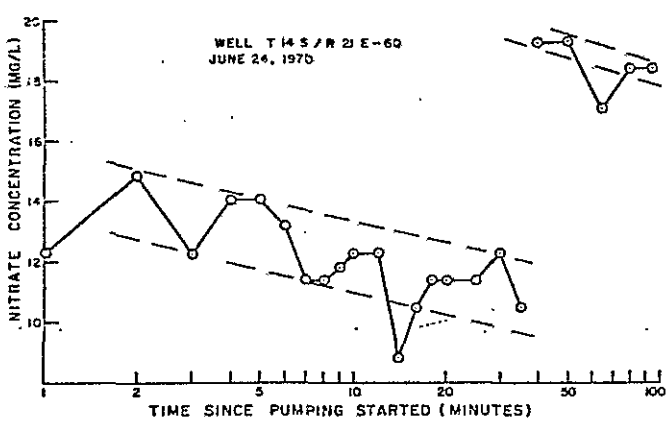


Fig. 6. Nitrate contents during a short-term pump test near an unsewered part of Fresno.

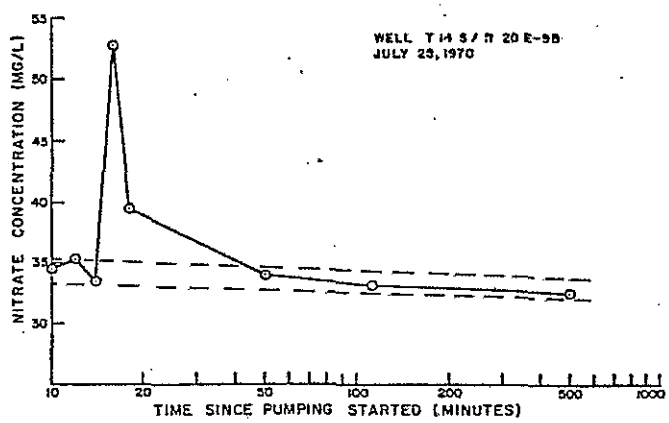


Fig. 7. Nitrate contents during a short-term pump test in downtown Fresno.

Primary Drinking Water Regulations establish a triennial sampling frequency for inorganic chemicals in community water systems utilizing only ground-water sources. Frequencies such as this are not advisable unless short-term and seasonal changes have first been evaluated. Annual sampling is generally not nearly of sufficient frequency in the case of wells near point or line sources of recharge or pollution.

Short-Term Trends

Changes in water quality after a few minutes or hours of pumping are often related to pump operation. Large fluctuations in water quality over short time periods can occur under the following circumstances:

1. After only a few minutes of pumping at any time.

2. After only a few hours or days of pumping if the well has been inactive for several weeks or months. This is particularly true where perforations extend above the water table.

3. When the well is periodically surged or infrequently pumped.

4. When wells are constructed so as to draw water directly from the strata nearest the water table in developed areas.

5. When wells are close to point or line sources of recharge or pollution, particularly in cases where large volumes of recharge or high pollutant loads are involved.

Seasonal Trends

Seasonal changes in well-water quality are related primarily to (1) pumping patterns, (2) variations in the magnitude and quality of recharge from point or line sources, and (3) amount and quality of water reaching the water table from the vadose zone. Obviously, heavy pumping may alter the hydraulic head distribution significantly. The horizontal and vertical components of ground-water movement may change significantly, both in magnitude and direction. There are almost always seasonal variations in the amount of recharge from precipitation, stream seepage, canal seepage, artificial recharge basins, and waste disposal ponds. The quality of the water recharged also usually varies seasonally.

Long-Term Trends

Long-term changes in ground-water quality can most effectively be demonstrated by utilizing optimum sampling frequencies. Analysis of short-term and seasonal changes must first be made. In some cases this will require frequent sampling during continuous pumping for several hours or days, followed by monthly sampling during the year for several years. Once the seasonal variability is established, annual or semi-annual sampling will probably suffice in most areas where diffuse sources of recharge or pollution are present. One of the most severe limitations of available analyses in most areas is the lack of uniformity of sampling and analytical methods over long time periods.

Long-term ground-water quality trends primarily reflect (1) long-term hydrologic phenomena that affect recharge, (2) variations in recharge rate and water quality of pollution sources, and (3) changes in water level and direction of ground-water movement. For successful monitoring of ground-water quality in areas of diffuse sources of recharge or pollution, water samples must be taken from large-capacity wells over long time periods, in the order of decades. To interpret the results of this monitoring, detailed knowledge of the soil-aquifer system is essential.

REFERENCES

California Department of Water Resources. 1962. Investigation of nitrates in ground water, Grover City, San Luis Obispo County. Report to Central Coastal Regional Water Pollution Control Board. 15 pp.

California Department of Water Resources. 1968. Delano nitrate investigation. Bulletin No. 143-6. 42 pp.

Foster, S. S., and R. I. Crease. 1974. Nitrate pollution of a chalk groundwater in east Yorkshire: a hydrogeological appraisal. Journal Inst. Water Engr. v. 28, pp. 178-194.

Hem, J. D. 1970. Study and interpretation of the chemical characteristics of natural water. U.S. Geological Survey Water-Supply Paper 1473, 2nd Edition. 363 pp.

Piskin, R. 1973. Evaluation of nitrate content of ground water in Hall County, Nebraska. Ground Water. v. 11, no. 6, pp. 4-13.

Quan, E. L., H. R. Sweet, and J. R. Illian. 1974. Subsurface sewage disposal and contamination of ground water in east Portland, Oregon. Ground Water. v. 12, no. 6, pp. 356-368.

Schmidt, K. D. 1972. Nitrate in ground water of the Fresno-Clovis metropolitan area, California. Ground Water. v. 10, no. 1, pp. 50-64.

Stout, P. R., R. G. Burau, and W. R. Allardice. 1965. A study of the vertical movement of nitrogenous matter from the ground surface to the water table in the vicinity of Grover City and Arroyo Grande, San Luis Obispo County. Report to Central Coastal Regional Water Pollution Control Board. 51 pp.

U.S. Environmental Protection Agency. 1975. National interim primary drinking water regulations. Federal Register. v. 40, no. 248, pp. 59566-59574.

78. State Department of Water Resources. Bulletin No. 130-75; Hydrologic Data: 1975 Volume I: North Coastal Area, December 1976

STATE OF CALIFORNIA
The Resources Agency

Department of Water Resources

BULLETIN No. 130-75

HYDROLOGIC DATA: 1975

Volume I: NORTH COASTAL AREA

DECEMBER 1976

CLAIRE T. DEDRICK
Secretary for Resources
The Resources Agency

EDMUND G. BROWN JR.
Governor
State of California

RONALD B. ROBIE
Director
Department of Water Resources

TABLE OF CONTENTS

	Page
AREAL COVERAGE OF VOLUMES	ii
FOREWORD	iii
METRIC CONVERSION TABLE	iv
ABSTRACT	vi
ACKNOWLEDGMENTS	vi
ORGANIZATION	vii
APPENDIXES	
APPENDIX A: CLIMATOLOGICAL DATA	1
Figure A-1 Climatological Observation Stations	viii
Table A-1 Precipitation in North Coastal Area During Water Year 1975	1
Table A-2 Storage Gage Precipitation Data	4
APPENDIX B: SURFACE WATER MEASUREMENTS	7
Figure B-1 Surface Water Measurement Stations	6
Table B-1 Annual Unimpaired Runoff	8
Table B-2 Monthly Unimpaired Runoff	11
Table B-3 Daily Mean Discharge	12
APPENDIX C: GROUND WATER MEASUREMENTS	17
Figure C-1 Ground Water Basins, Water Level Measurements	16
Table C-1 Average Change of Ground Water Levels and Summary of Well Measurements Reported	19
Table C-2 Ground Water Levels at Wells	20
APPENDIX D: SURFACE WATER QUALITY	23
Figure D-1 Surface Water Sampling Stations	22
Table D-1 Sampling Station Data and Index	25
Table D-2 Mineral Analyses of Surface Water	26
Table D-3 Minor Element Analysis of Surface Water	36
Table D-4 Nutrient Analysis of Surface Water	40
Table D-5 Pesticides in Surface Water	44
APPENDIX E: GROUND WATER QUALITY	47
Figure E-1 Ground Water Basins, Water Quality Samples	46
Table E-1 Mineral Analyses of Ground Water	48
Table E-2 Minor Element Analysis of Ground Water	54

APPENDIX F: WASTE WATER DATA, which appeared in certain volumes of the Bulletin No. 130 series, has been discontinued. For information regarding waste water, the reader is referred to the recently reactivated Bulletin No. 68 series: "Inventory of Waste Water Production and Waste Water Reclamation Practices in California".

ABSTRACT

The report contains tables showing data on precipitation, surface water flow, ground water levels, and surface and ground water quality in the north coastal area during the 1974-75 water year. Figures show the location of climatological stations, surface water measurement stations, surface water sampling stations, and ground water basins.

ACKNOWLEDGMENTS

Valuable assistance and contributions were received from several agencies and many private cooperators. The cooperation of the National Weather Service (formerly the U. S. Weather Bureau) and the U. S. Geological Survey was particularly helpful and is gratefully appreciated.

A special note of thanks is extended to the many loyal and dedicated weather observers whose unselfish efforts have contributed immeasurably to our knowledge of historical weather conditions in the north coastal area.

APPENDIX C

GROUND WATER MEASUREMENTS

This appendix contains ground water level measurements from 61 wells for the period October 1, 1974 through September 30, 1975. It also contains a table which summarizes the measurements. Wells in the network are continuously reviewed and, when conditions dictate, replacement wells are located and measured.

There are nine ground water basins in the North Coast Region for which data are reported.

Two numbering systems are used by the Department to facilitate the processing of water level measurement data. The two systems are the Region and Basin Designation and the State Well Numbering System as described below.

The regions are those of the California Regional Water Quality Control Boards whose geographic areas are defined in Section 13200 of the Water Code. That portion of Northern California covered by this report is included in the North Coast Region. A decimal system of the form 0-00.00 has been selected according to geographic regions, ground water basins, and subbasins or subareas as follows:

1 - 01 00

Region (North Coast Region) — 1
Ground Water Basin (Smith River Basin) — 01
Subbasin or Subarea (Subbasins or subareas have not been defined in the North Coast Region) — 00

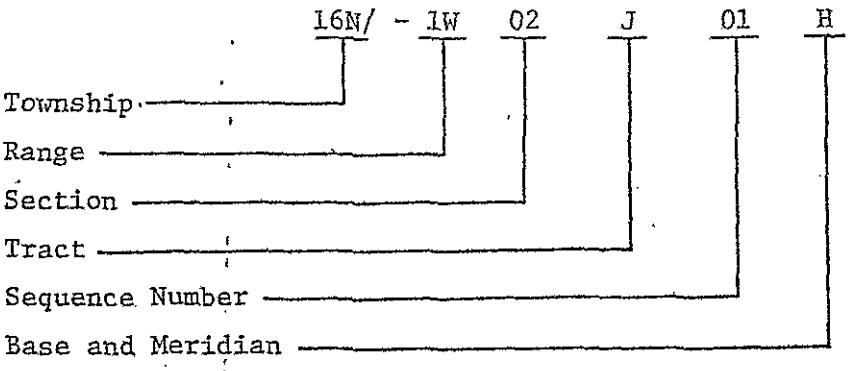
The State Well Numbering System is based on township, range, and section subdivisions of the Public Land Survey.

A section is divided into 40-acre tracts as follows:

D	C	B	A
E	F	G	H
M	L	K	J
N	P	Q	R

Sequence numbers in a tract are generally assigned in chronological order.

The number of a well, assigned in accordance with this system, is referred to as the State Well Number, as illustrated below:



This number identifies and locates the well. In the example, the well is in Township 16 North, Range 1 West, Tract J of Section 2, located in the Humboldt Base and Meridian.

TABLE C-1

AVERAGE CHANGE OF GROUND WATER LEVELS
AND SUMMARY OF WELL MEASUREMENTS REPORTED
NORTH COASTAL AREA

Ground Water Basin		Average Change Spring 1974 to Spring 1975 in feet	Measuring Agency	Number of Wells Reported	
Name	Number			Fall 1974	Spring 1975
NORTH COASTAL REGION					
Smith River Plain	1-01.00	-0.9	DWR	8	8
Butte Valley	1-03.00	+1.8	DWR	15	13
Shasta Valley	1-04.00	-0.2	DWR	9	8
Scott River Valley	1-05.00	-0.7	DWR	5	5
Mad River Valley	1-08.00	-0.9	DWR	2	3
Eel River Valley	1-10.00	-1.5	DWR	7	6
Round Valley	1-11.00	-0.9	DWR	4	7
Laytonville Valley	1-12.00	-0.4	DWR	3	4
Little Lake Valley	1-13.00	-1.4	DWR	5	5

DWR - Department of Water Resources

TABLE C-2

GROUND WATER LEVELS AT WELLS

An explanation of the column headings and the code symbols follows:

State Well Number - Refer to the explanation presented on page 17.

Ground Surface Elevation - The numbers in this column are the elevation in feet above mean sea level (USGS datum) of the ground surface at the well. Elevations are usually taken from topographic maps and the accuracy is controlled by topographic standards.

Date - The date shown in the column is the date when the depth measurement given in the next column was made.

Ground Surface to Water Surface - This is the measured depth in feet from the ground surface to the water surface in the well; some of the depth measurements in the column may be preceded by a number in parentheses to indicate a questionable measurement. The code applicable to these "questionable measurements" is as follows:

(1)	Pumping	(6)	Other
(2)	Nearby pump operating	(7)	Recharge operation at or near well
(3)	Casing leaking or wet	(8)	Oil in casing
(4)	Pumped recently	(9)	Caved or deepened
(5)	Air or pressure gage measurement		

When a measurement was attempted, but could not be obtained, then only a number in parentheses is shown in the column. The code applicable to these "no measurements" is as follows:

(1)	Pumping	(6)	Well has been destroyed
(2)	Pump house locked	(7)	Special
(3)	Tape hung up	(8)	Casing leaking or wet
(4)	Cannot get tape in casing	(9)	Temporarily inaccessible
(5)	Unable to locate well	(0)	Measurements discontinued

The words FLOW and DRY are shown in this column to indicate a flowing or dry well, respectively. A minus sign preceding the number in this column indicates that the static water level in the well is this distance in feet above the ground surface.

Water Surface Elevation - This is the elevation in feet above mean sea level (USGS datum) of the water surface in the well. It was derived by subtraction of the depth measurement from the ground surface elevation.

Agency Supplying Data - Each of these numbers is the code number for the agency supplying data for that measurement. The Department of Water Resources is the sole agency supplying ground water level measurement data for this report. It has been assigned an agency code number of 5050.

TABLE C-2

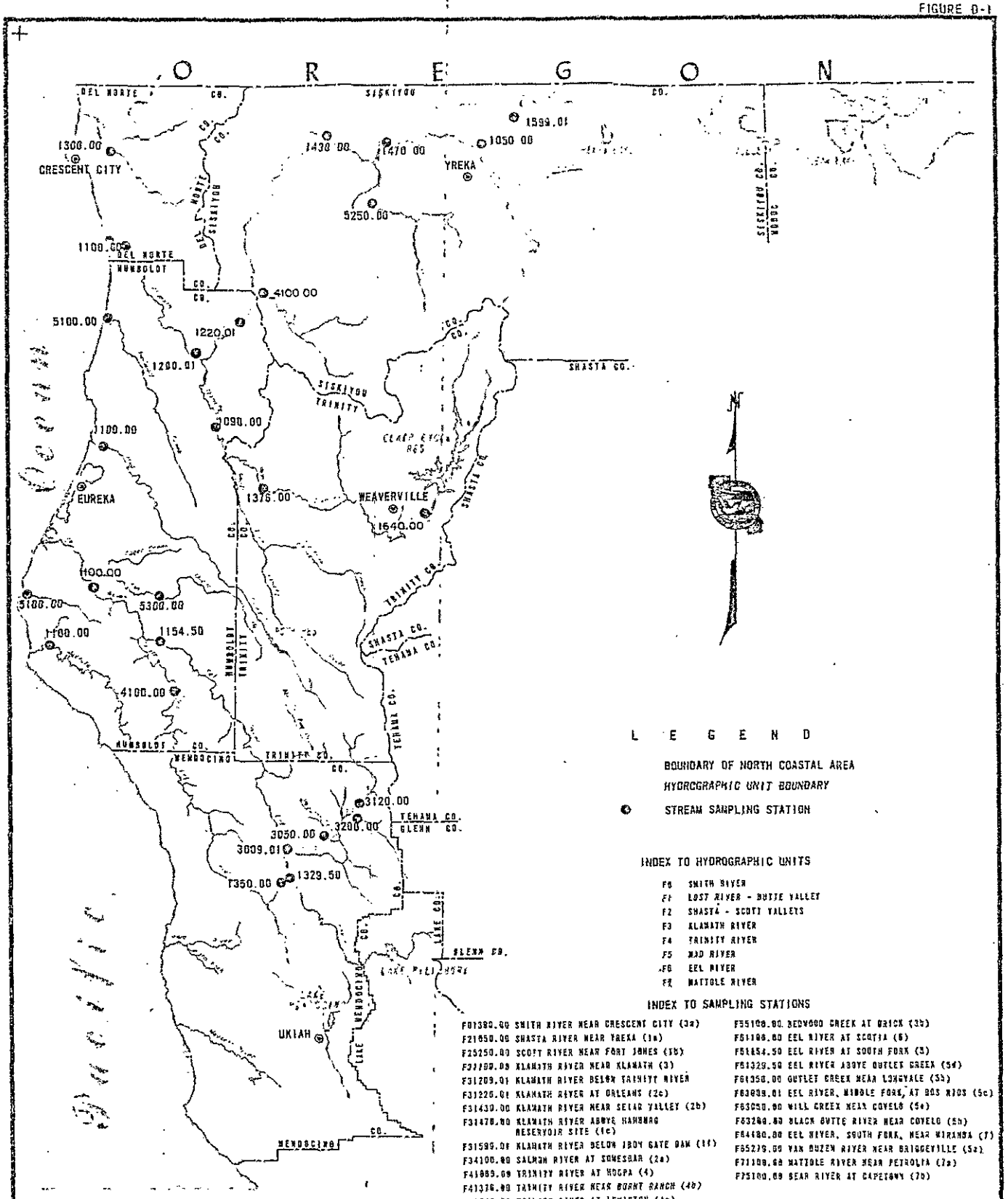
GROUND WATER LEVELS AT WELLS

NORTH COASTAL AREA

STATE WELL NUMBER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEVATION IN FEET	AGENCY SUPPLYING DATA
SMITH RIVER PLAIN 1-01.00					
16N/01W-02J01H	127.0	11-10-74	28.0	99.0	5050
		4-28-75	17.2	109.8	5050
16N/01W-17K01H	48.0	11-10-74	22.6	25.4	5050
		4-28-75	12.2	35.8	5050
17N/01W-02P01H	31.0	11-10-74	21.0	10.0	5050
		4-28-75	16.8	14.2	5050
17N/01W-03E01H	14.0	11-10-74	13.1	0.9	5050
		4-28-75	9.8	4.2	5050
17N/01W-15H02H	21.0	11-10-74	16.6	4.4	5050
		4-28-75	9.0	12.0	5050
17N/01W-20Q01H	15.0	11-10-74	6.0	9.0	5050
		4-28-75	1.9	13.1	5050
17N/01W-27Q05H	40.0	11-10-74	20.5	19.5	5050
		4-28-75	11.5	28.5	5050
18N/01W-27P03H	15.0	11-10-74	8.3	6.7	5050
		4-28-75	5.3	9.7	5050
BUTTE VALLEY 1-03.00					
45N/01E-01E01M	4388.0	11-06-74	161.7	4226.3	5050
		4-17-75	161.3	4226.7	5050
45N/01W-06A01M	4258.0	11-06-74	27.5	4230.5	5050
		4-17-75	24.8	4233.2	5050
45N/02W-11P01M	4275.0	11-06-74	40.0	4235.0	5050
		4-17-75	36.5	4238.5	5050
46N/01E-06N01M	4242.0	11-06-74	23.2	4218.8	5050
		4-17-75	17.5	4224.5	5050
46N/01W-17E01M	4246.0	11-06-74	38.6	4207.4	5050
		4-17-75	29.8	4216.2	5050
46N/01W-18Q01M	4247.0	11-06-74	23.2	4223.8	5050
		4-17-75	14.7	4232.3	5050
46N/02W-25R02M	4256.0	11-06-74	25.5	4230.5	5050
		4-17-75	23.0	4233.0	5050
46N/02W-26Q01M	4254.0	11-06-74	14.8	4239.2	5050
		4-17-75	11.2	4242.8	5050
47N/01E-06A02M	4244.5	11-06-74	32.3	4212.2	5050
		4-17-75	29.3	4215.2	5050
47N/01E-20D01M	4240.0	11-06-74	24.2	4215.8	5050
		4-17-75	21.8	4218.2	5050
47N/01W-04D01M	4241.5	11-06-74	6.8	4234.7	5050
		4-17-75	(9)		
47N/01W-04D02M	4241.5	11-06-74	7.3	4234.2	5050
		4-17-75	(9)		
47N/01W-19L01M	4238.0	11-06-74	4.7	4233.3	5050
		4-17-75	1.6	4236.4	5050
47N/01W-27B01M	4233.0	11-06-74	8.0	4225.0	5050
		4-17-75	4.8	4228.2	5050
47N/01W-34Q01M	4237.0	11-06-74	19.0	4218.0	5050
		4-17-75	15.8	4221.2	5050
SHASTA VALLEY 1-04.00					
42N/05W-20J01M	2882.0	10-15-74	6.6	2875.4	5050
			6.1	2875.9	5050
42N/05W-10I01M	2835.0	10-15-74	9.8	2825.2	5050
			3.0	2832.0	5050
43N/05W-11A01M	2740.0	11-07-74	126.0	2614.0	5050
			125.4	2614.6	5050
43N/06W-15F03M	2663.0	10-15-74	13.3	2649.7	5050
			6.7	2656.3	5050
43N/06W-22A01M	2665.0	11-07-74	17.0	2648.0	5050
			6.6	2658.4	5050
43N/06W-33C01M	2810.0	10-15-74	45.0	2765.0	5050
			42.8	2767.2	5050
44N/05W-34H01M	2637.0	10-15-74	26.5	2610.5	5050
			27.1	2609.9	5050
44N/06W-10F01M	2537.0	10-15-74	13.6	2523.4	5050
			26.8	2510.2	5050
44N/06W-19E01M	2538.0	10-15-74	21.5	2516.5	5050

STATE WELL NUMBER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEVATION IN FEET	AGENCY SUPPLYING DATA
SCOTT RIVER VALLEY 1-05.00					
42N/09W-02A02M	2746.0	10-15-74	10.4	2735.6	5050
		4-18-75	4.8	2741.2	5050
42N/09W-27H01M	2930.0	10-15-74	8.4	2921.6	5050
		4-18-75	2.9	2927.1	5050
43N/09W-23F01M	2728.0	10-15-74	5.8	2722.2	5050
		4-18-75	3.0	2725.0	5050
43N/09W-24F01M	2735.0	10-15-74	5.5	2729.5	5050
		4-18-75	3.5	2731.5	5050
44N/09W-28P01M	2711.0	10-15-74	14.6	2696.4	5050
		4-18-75	3.5	2707.5	5050
MAD RIVER VALLEY 1-08.00					
06N/01E-07M01M	11.0	11-11-74	9.5	1.5	5050
		4-29-75	3.4	7.6	5050
06N/01E-17D01M	23.0	11-11-74	13.8	9.2	5050
		4-29-75	6.7	16.3	5050
06N/01E-19Q01M	19.0	4-29-75	10.5	8.5	5050
06N/01E-29F01M	25.0	11-11-74	(0)		5050
EEL RIVER VALLEY 1-10.00					
02N/01W-08B01M	34.0	11-11-74	22.7	11.3	5050
		4-29-75	13.5	20.5	5050
03N/01W-18D01M	15.0	11-11-74	5.2	9.8	5050
		4-29-75	3.3	11.7	5050
03N/01W-30N01M	19.0	11-11-74	17.0	2.0	5050
		4-29-75	12.5	6.5	5050
03N/01W-34J01M	53.0	11-11-74	35.4	17.6	5050
		4-29-75	31.2	21.8	5050
03N/02W-13J01M	10.0	11-11-74	7.1	2.9	5050
		4-29-75	4.3	5.7	5050
03N/02W-26R01M	12.0	11-11-74	10.4	1.6	5050
		4-29-75	(0)		5050
03N/02W-35M02M	13.0	11-11-74	10.4	2.6	5050
		4-29-75	7.0	6.0	5050
ROUND VALLEY 1-11.00					
22N/12W-04B01M	1351.0	11-11-74	16.5	1334.5	5050
		4-25-75	6.6	1344.4	5050
22N/12W-06E02M	1395.0	4-24-75	2.9	1392.1	5050
22N/12W-06L03M	1370.0	11-11-74	4.5	1365.5	5050
		4-24-75	-10.0	1380.0	5050
22N/13W-01N01M	1420.0	4-24-75	5.0	1415.0	5050
22N/13W-12B01M	1400.0	11-11-74	30.1	1369.9	5050
		4-24-75	6.0	1394.0	5050
23N/12W-28N03M	1374.0	4-24-75	8.0	1366.0	5050
23N/13W-36C03M	1410.0	11-11-74	28.7	1381.3	5050
		4-24-75	8.9	1401.1	5050
LATTONVILLE VALLEY 1-12.00					
21N/14W-30M01M	1688.0	11-11-74	17.3	1670.7	5050
		4-24-75	4.9	1683.1	5050
21N/15W-01L02M	1682.0	11-11-74	(2)		5050
		4-24-75	6.8	1675.2	5050
21N/15W-12H02M	1630.0	11-11-74	17.5	1612.5	5050
		4-24-75	3.7	1626.3	5050
21N/15W-24A01M	1653.0	11-11-74	13.5	1639.5	5050
		4-24-75	0.0	1653.0	5050
LITTLE LAKE VALLEY 1-13.00					
18N/13W-08L01M	1340.0	11-11-74	9.2	1330.8	5050
		4-24-75	0.5	1339.5	5050
18N/13W-17J01M	1370.0	11-11-74	29.0	1341.0	5050
		4-24-75	14.7	1355.3	5050
18N/13W-18E01M	1365.0	11-11-74	20.4	1344.6	5050
		4-24-75	18.5	1346.5	5050
19N/13W-32F01M	1347.0	11-11-74	13.9	1333.1	5050
		4-24-75	6.4	1340.6	5050
19N/13W-32L02M	1350.0	11-11-74	12.5	1337.5	5050
		4-24-75	8.5	1341.5	5050

FIGURE D-1



SURFACE WATER SAMPLING STATIONS

79. State Department of Water Resources. Bulletin No. 130-75, Hydrologic Data: 1975 Volume II: Northeastern California, May 1977

STATE OF CALIFORNIA

The Resources Agency

Department of Water Resources

BULLETIN No. 130-75

HYDROLOGIC DATA: 1975

Volume II: NORTHEASTERN CALIFORNIA

Copies of this report at $5.00 may be ordered from:
State of California
DEPARTMENT OF WATER RESOURCES
P.O. Box 388
Sacramento, California 95802
Make checks payable to State of California.
California residents add sales tax.

MAY 1977

CLAIRE T. DEDRICK
Secretary for Resources
The Resources Agency

EDMUND G. BROWN JR.
Governor
State of California

RONALD B. ROBIE
Director
Department of Water Resources

BULLETIN No. 130

HYDROLOGIC DATA
AREAL COVERAGE OF VOLUMES

EACH VOLUME CONTAINS

Appendix A: Climatological Data
Appendix B: Surface Water Measurements
Appendix C: Ground Water Measurements
Appendix D: Surface Water Quality Data
Appendix E: Ground Water Quality Data

THIS VOLUME :

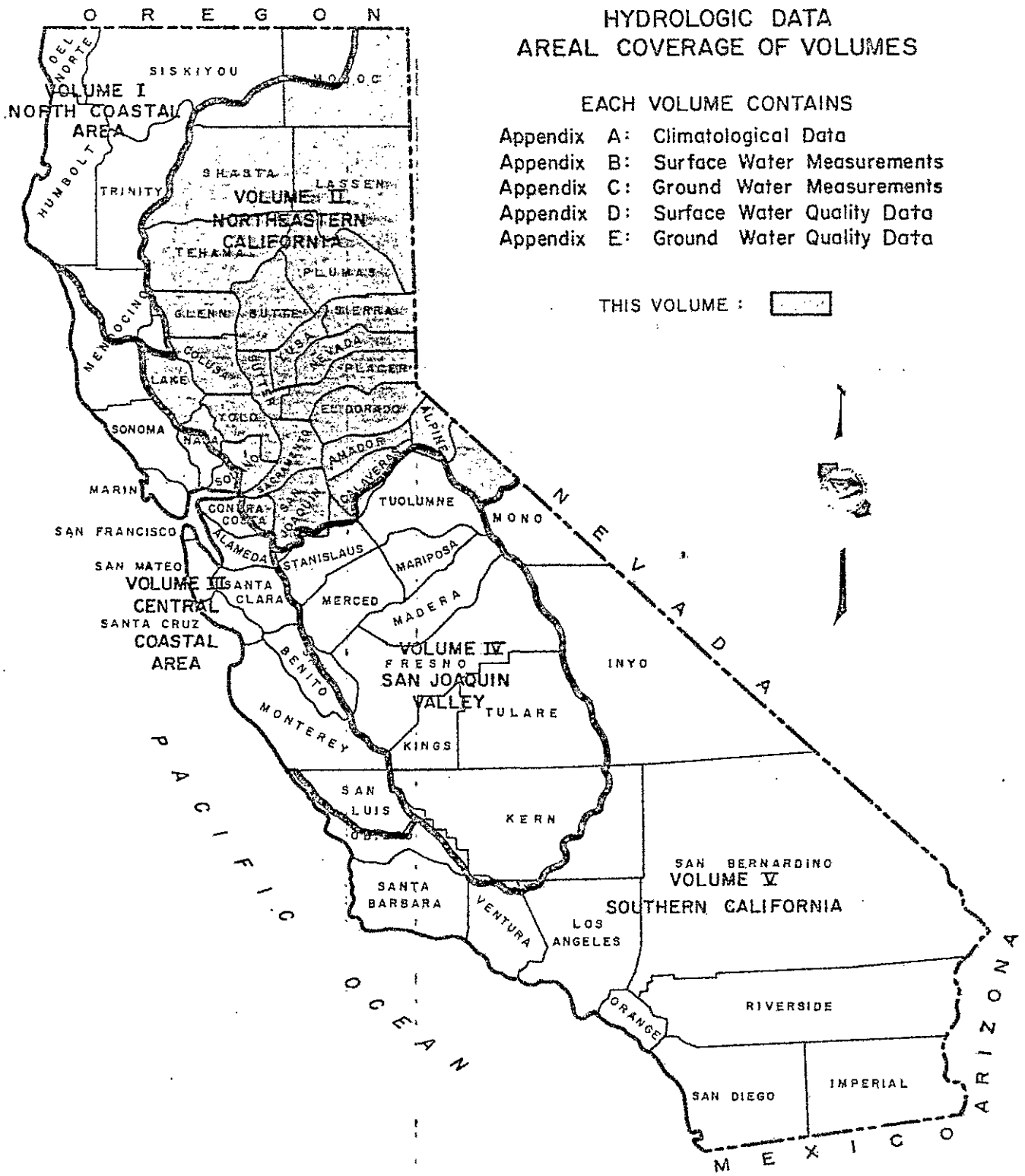


TABLE OF CONTENTS

	Page
AREAL COVERAGE OF VOLUMES	ii
FOREWORD	iii
CONVERSION FACTORS	iv
ORGANIZATION	vi
ACKNOWLEDGMENTS	vii
INTRODUCTION	1
APPENDIXES	
Appendix A: CLIMATOLOGICAL DATA	3
Figure Number	
A-1 Climatological Observation Stations	4
Table Number	
A-1 Precipitation in Northeastern California During Water Year 1975	11
A-2 Index of Storage Gage Precipitation Stations	16
A-3 Storage Gage Precipitation Data	18
APPENDIX B: SURFACE WATER MEASUREMENTS	19
Alphabetical Index to Tables	28
Alphabetical Index to Surface Water Measurement Stations	29
Hydrographic Area Code Number Index to Surface Water Measurement Stations	31
Figure Number	
B-1 Surface Water Measurement Stations	20
B-2 Surface Water Measurement Stations, Sacramento-San Joaquin Delta Area	26
Table Number	
B-1 Annual Unimpaired Runoff	35
B-2 Monthly Unimpaired Runoff	36
B-3 Summary of Monthly Water Supply and Utilization, Sacramento-San Joaquin Delta	37
B-4 Streamflow Measurements at Miscellaneous Sites	39
B-5 Daily Mean Discharge	41
B-6 Diversions	126
B-7 Deliveries from Folsom and Nimbus Reservoirs	134
B-8 Importations into Northeastern California	134
B-9 Exportations from Northeastern California	134
B-10 Maximum and Minimum Gage Heights	135
B-11 Daily Mean Gage Height	140
B-12 Daily Tides	161
B-13 Contents of Reservoirs	224
B-14 Daily Inflow	229
B-15 Gaging Station Additions and Discontinuations	233
B-16 Corrections and Revisions to Previously Published Reports of Surface Water Data	234
Appendix C: GROUND WATER MEASUREMENTS	239
Index to Ground Water Measurement Data	240
Figure Number	
C-1 Ground Water Basins in Northeastern California	241
C-2 Fluctuation of Average Ground Water Level in Selected Areas	244
C-3 Fluctuation of Water Level in Wells	247
Table Number	
C-1 Average Change of Ground Water Levels and Summary of Well Measurements Reported	242
APPENDIX D: SURFACE WATER QUALITY DATA	253
Figure Number	
D-1 Surface Water Quality Sampling Stations	254
D-2 Surface Water Quality Sampling Stations, Sacramento-San Joaquin Delta Area	264
Table Number	
D-1 Sampling Station Data and Index	261
D-2 Mineral Analyses of Surface Water	266
D-3 Minor Element Analysis of Surface Water	311
D-4 Miscellaneous Constituents in Surface Water	317
D-5 Nutrient Analysis of Surface Water	335
D-6 Pesticides in Surface Water and Sediment	359
D-7 Daily Maximum and Minimum and Monthly Average Water Temperature	363
D-8 Daily Maximum, Minimum, and Average Specific Conductance	368
D-9 Biological Analysis of Surface Water	378
Appendix E: GROUND WATER QUALITY DATA	381
Index to Ground Water Quality Data	382
Figure Number	
E-1 Ground Water Basins in Northeastern California	383
Table Number	
E-1 Mineral Analyses of Ground Water	384
E-2 Minor Element Analysis of Ground Water	414
E-3 Supplemental Minor Element Analysis of Ground Water	421
Appendix F: WASTE WATER DATA	427

STATE OF CALIFORNIA
Edmund G. Brown Jr., Governor

THE RESOURCES AGENCY
Claire T. Dedrick, Secretary for Resources

DEPARTMENT OF WATER RESOURCES
Ronald B. Robie, Director

Robin R. Reynolds
Deputy Director

Gerald H. Meral
Deputy Director

Robert W. James
Deputy Director

Charles R. Shoemaker
Assistant Director

This report was prepared in the

CENTRAL DISTRICT

Wayne MacRostie . . . . . District Chief
Lee W. Carter . . . . . Chief, Data and Operations Branch

by

Edward J. Labrie . . . . . Chief, Data Evaluation Section

assisted by

Grant C. Ardell . . . . . Water Resources Engineering Associate
Emil M. Padjen . . . . . Water Resources Engineering Associate

A portion of the data was furnished by the

NORTHERN DISTRICT

Albert J. Dolcini . . . . . District Chief
Wayne S. Gentry . . . . . Chief, Planning Branch

by

Robert F. Clawson . . . . . Chief, Water Quality and Biology Section
Thomas C. Mackey . . . Chief, Watermaster Service and Hydrology Section
Philip J. Lorens . . . . . Chief, Geology and Ground Water Section
Robert R. McGill . . . . . Chief, Land and Water Use Section

Reviewed and Coordinated by
Division of Planning
Environmental Quality Branch
Water Resources Evaluation Section

Appendix C

GROUND WATER MEASUREMENTS

This appendix contains summary and selected information concerning the level of ground water in wells within 32 ground water basins or areas in Northeastern California. Wells are selected to reflect the ground water conditions of the area. These wells are continuously reviewed and, when conditions dictate, replacement wells are located and measured.

Earlier editions of this report contained a tabulation of individual measurements of ground water levels at wells. This type of data collected by the Department will be available at the various district offices of the Department. Please see the introduction at the front of this volume for the addresses of these district offices.

Table C-1 shows the average change in ground water levels for the various basins in Northeastern California from spring 1974 to spring 1975 This table also shows the number of well measurements collected in the various areas. Figure C-2 contains graphical presentations of the average levels of ground water in the spring for the past several years. Figure C-3 is a graphical representation of the fluctuation of ground water level in certain selected wells for the past several years. An attempt has been made to select wells that represent conditions in the basin where the well is located. However, some caution in the use of these data is in order because ground water conditions can vary markedly with relatively small changes in horizontal location.

Two numbering systems are used by the Department to facilitate processing of water level measurement data. The two systems are the Region and Basin Designation and the State Well Numbering System. The regions used in Bulletin No. 130 are geographic areas defined in Section 13200 of the Water Code. This volume comprises the northern portions of Central Valley Region No. 5 and Lahontan Region No. 6. A decimal system of the form 0-00.00 has been selected according to geographic regions, ground water basins, and subbasins or subareas as follows:

5 - 21 - 05

Region (Central Valley) — 5
Ground Water Basin (Sacramento Valley) — 21
Subbasin or Subarea (Sutter County) — 05

The State Well Numbering System is based on township, range, and section subdivisions of the public land survey. The number of a well, assigned in accordance with this system, is referred to as the State Well Number, as illustrated below on the left.

39N / 13E - 08 J 04 M

Township — 39N
Range — 13E
Section — 08
Tract — J
Sequence Number — 04
Base and Meridian — M

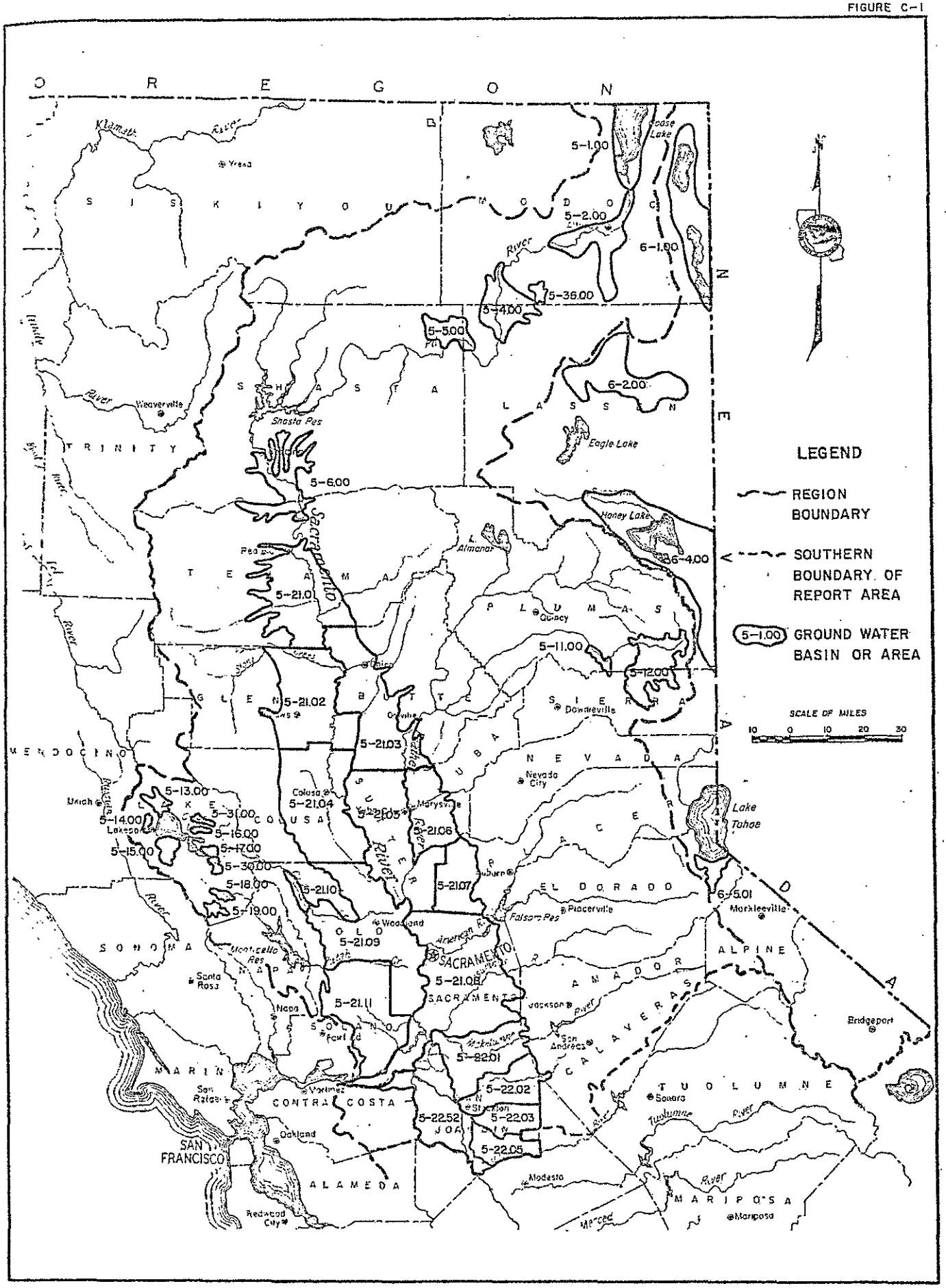
D	C	B	A
E	F	G	H
M	L	K	J
N	P	Q	R

This number identifies and locates the well. In the example, the well is in Township 39 North, Range 13 East, Tract J of Section 8, referenced to the Mount Diablo Base and Meridian. A section is divided into 40-acre tracts as shown above on the right. Sequence numbers in a tract are generally assigned in chronological order. The example designates the fourth well to be assigned a number in Tract J.

INDEX TO GROUND WATER MEASUREMENT DATA
IN NORTHEASTERN CALIFORNIA

Number		Page
	CENTRAL VALLEY REGION 5-00.00	
5-01.00	Goose Lake Valley	
5-02.00	Alturas Basin	242
5-04.00	Big Valley	242
5-36.00	Round Valley	
5-05.00	Fall River Valley	242
5-06.00	Redding Basin	242, 247
5-11.00	Mohawk Valley	242
5-12.00	Sierra Valley	242
5-13.00	Upper Lake Valley	242
5-14.00	Scotts Valley	242
5-15.00	Kelseyville Valley	242
5-31.00	Long Valley	
5-16.00	High Valley	242
5-17.00	Burns Valley	
5-30.00	Lower Lake Area	242
5-18.00	Coyote Valley	242
5-19.00	Collayomi Valley	242, 247
5-21.00	Sacramento Valley	244
5-21.01	Tehama County	242, 244, 247
5-21.02	Glenn County	242, 244, 247
5-21.03	Butte County	242, 244, 248
5-21.04	Colusa County	242, 244, 248
5-21.05	Sutter County	242, 244, 248
5-21.06	Yuba County	242, 245, 249
5-21.07	Placer County	242, 245, 249
5-21.08	Sacramento County	243, 245, 250
5-21.09	Yolo County	243, 245, 250
5-21.10	Capay Valley	243, 245
5-21.11	Solano County	243, 245, 250
5-22.00	San Joaquin Valley	
5-22.01	Mokelumne River Area	243, 246, 251
5-22.02	Calaveras River Area	243, 246, 251
5-22.03	Farmington-Collegeville Area	243, 246, 251
5-22.05	South San Joaquin Irrigation District	243, 246
5-22.52	Delta Area	243
	LAHONTAN REGION 6-00.00	
6-01.00	Surprise Valley	243
6-02.00	Madeline Plains	
6-04.00	Honey Lake Valley	243
6-05.00	Tahoe Valley	
6-05.01	South Tahoe Valley	243

FIGURE C-1



GROUND WATER BASINS IN NORTHEASTERN CALIFORNIA

TABLE C-1

AVERAGE CHANGE OF GROUND WATER LEVELS
AND SUMMARY OF WELL MEASUREMENTS REPORTED

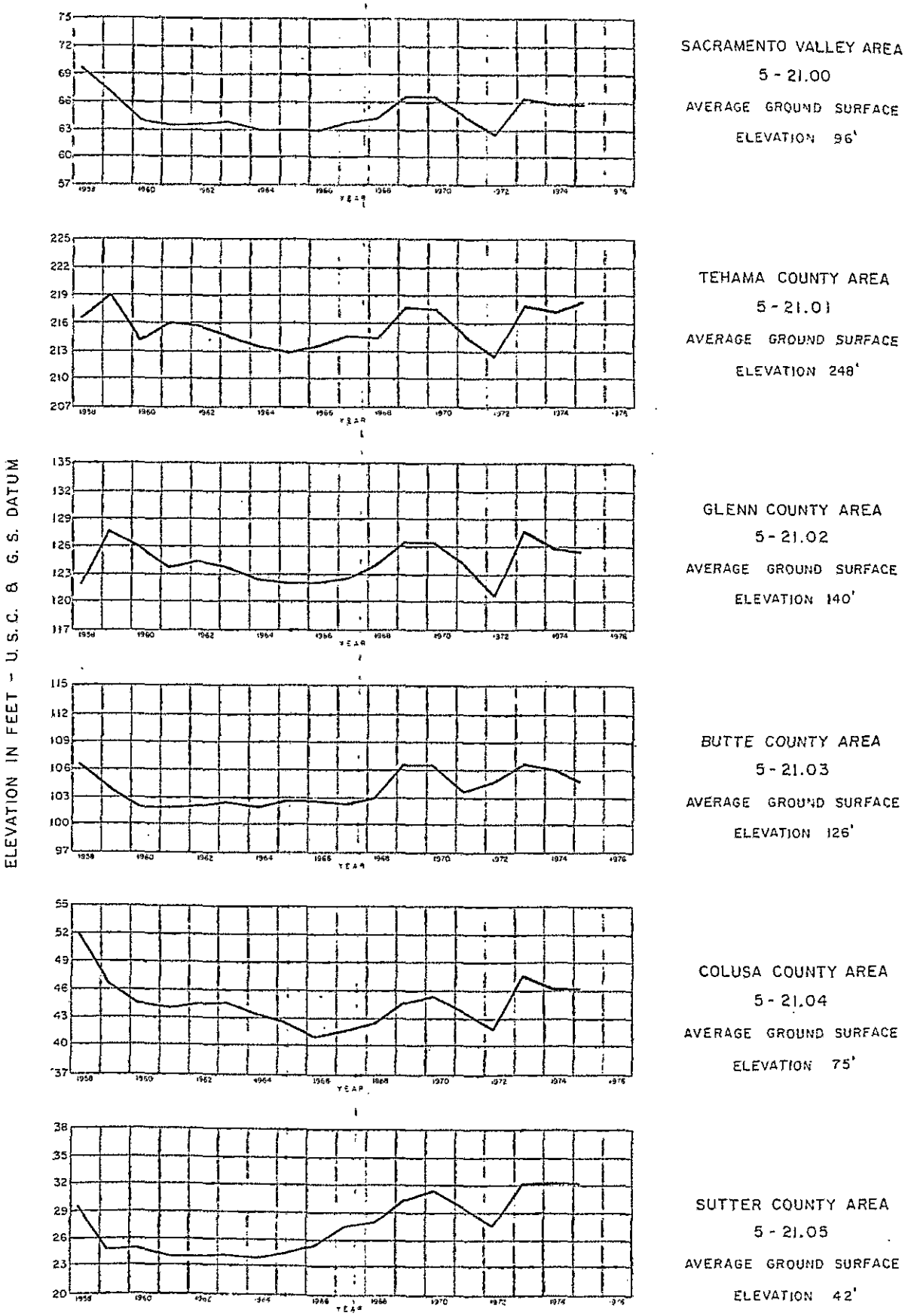
Ground Water Basin or Area		Average Change Spring 1974 to Spring 1975 in Feet	Measuring Agency	Number of Well Measurements Reported		
Name	Number			Monthly 1974-75	Fall 1974	Spring 1975
CENTRAL VALLEY REGION						
Goose Lake Valley	5-01.00					
Alturas Basin	5-02.00	-0.6	Department of Water Resources		9	9
Big Valley	5-04.00	-0.3	Department of Water Resources		4	4
Round Valley	5-36.00					
Fall River Valley	5-05.00	-0.6	Department of Water Resources		4	4
Redding Basin	5-06.00	+0.2	Department of Water Resources	1	9	9
Mohawk Valley	5-11.00	+1.5	Department of Water Resources		1	2
Sierra Valley	5-12.00	-0.3	Department of Water Resources		20	20
Upper Lake Valley	5-13.00	-0.3	Department of Water Resources		4	4
Scotts Valley	5-14.00	+3.2	Department of Water Resources		1	1
Kelseyville Valley	5-15.00	-0.1	Department of Water Resources		9	9
Long Valley	5-31.00					
High Valley	5-16.00	-6.2	Department of Water Resources		2	2
Burns Valley	5-17.00					
Lower Lake Area	5-30.00	+0.8	Department of Water Resources		1	1
Coyote Valley	5-18.00	+1.3	Department of Water Resources		1	1
Collayomi Valley	5-19.00	+1.3	Department of Water Resources		2	2
Sacramento Valley	5-21.00					
Tehama County	5-21.01	+1.0	Department of Water Resources	19	49	47
Glenn County	5-21.02	-0.3	Glenn County		77	70
			U. S. Bureau of Reclamation		11	11
			Department of Water Resources	14	1	1
Butte County	5-21.03	-1.1	Department of Water Resources	16	74	72
Colusa County	5-21.04	0.0	U. S. Bureau of Reclamation		13	13
			Department of Water Resources	8	44	46
Sutter County	5-21.05	0.0	South Sutter Water District		25	25
			Department of Water Resources		113	112
Yuba County	5-21.06	-0.2	Department of Water Resources	1	96	96
Placer County	5-21.07	+0.4	South Sutter Water District		2	2
			Department of Water Resources	7	80	80

TABLE C-1 (Continued)

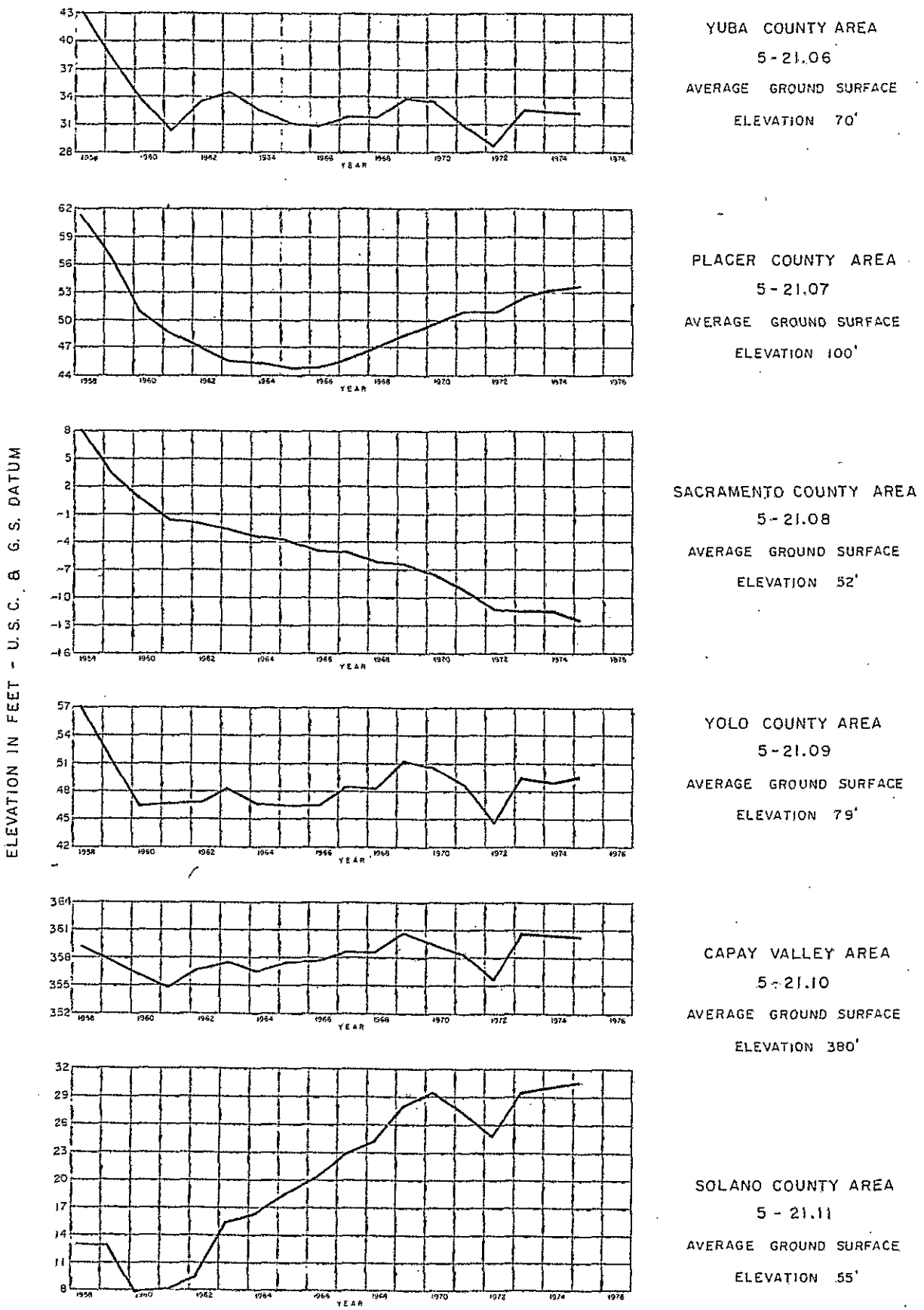
AVERAGE CHANGE OF GROUND WATER LEVELS
AND SUMMARY OF WELL MEASUREMENTS REPORTED

Ground Water Basin or Area		Average Change Spring 1974 to Spring 1975 in Feet	Measuring Agency	Number of Well Measurements Reported		
Name	Number			Monthly 1974-75	Fall 1974	Spring 1975
Sacramento Valley (Continued)						
Sacramento County	5-21.08	-1.0	Sacramento County		89	87
			Sacramento Muni. Utility Dist.		19	19
			Arcade Water District		26	38
			U. S. Bureau of Reclamation		82	81
			Department of Water Resources	17	70	69
Yolo County	5-21.09	+0.7	Yolo County		169	169
			U. S. Bureau of Reclamation	3	76	75
			Department of Water Resources	11	26	23
Capay Valley	5-21.10	-0.2	Yolo County		21	20
Solano County	5-21.11	+0.5	Solano County		22	21
			U. S. Bureau of Reclamation	3	96	90
			Department of Water Resources	13	22	22
San Joaquin Valley	5-22.00					
Mokelumne River Area	5-22.01	-1.7	San Joaquin County		97	97
			California Water Service Company		4	4
			East Bay Municipal Utility Dist.	99	217	212
			U. S. Bureau of Reclamation		2	2
			Department of Water Resources	1	46	46
Calaveras River Area	5-22.02	-1.0	San Joaquin County		88	88
			California Water Service Company		18	18
			East Bay Municipal Utility Dist.		6	6
			Stockton-East Water District		34	34
			Department of Water Resources	3	38	38
Farmington-Collegeville Area	5-22.03	-1.4	San Joaquin County		57	57
			Oakdale Irrigation District		2	2
			Stockton-East Water District		1	1
			Department of Water Resources	1	18	19
South San Joaquin Irrigation District	5-22.05	-1.3	San Joaquin County		8	9
			Oakdale Irrigation District		1	1
			Department of Water Resources		41	41
Delta Area	5-22.52	-0.6	San Joaquin County		9	8
			Department of Water Resources	1	18	18
LAHONTAN REGION						
Surprise Valley	6-01.00	-3.3	Department of Water Resources		12	12
Madeline Plains	6-02.00					
Honey Lake Valley	6-04.00	-0.1	Department of Water Resources		10	10
Tahoe Valley	6-05.00					
South Tahoe Valley	6-05.01	-0.7	Department of Water Resources		19	19
TOTAL				218	2,116	2,099

FIGURE C-2 SHEET 1 OF 3

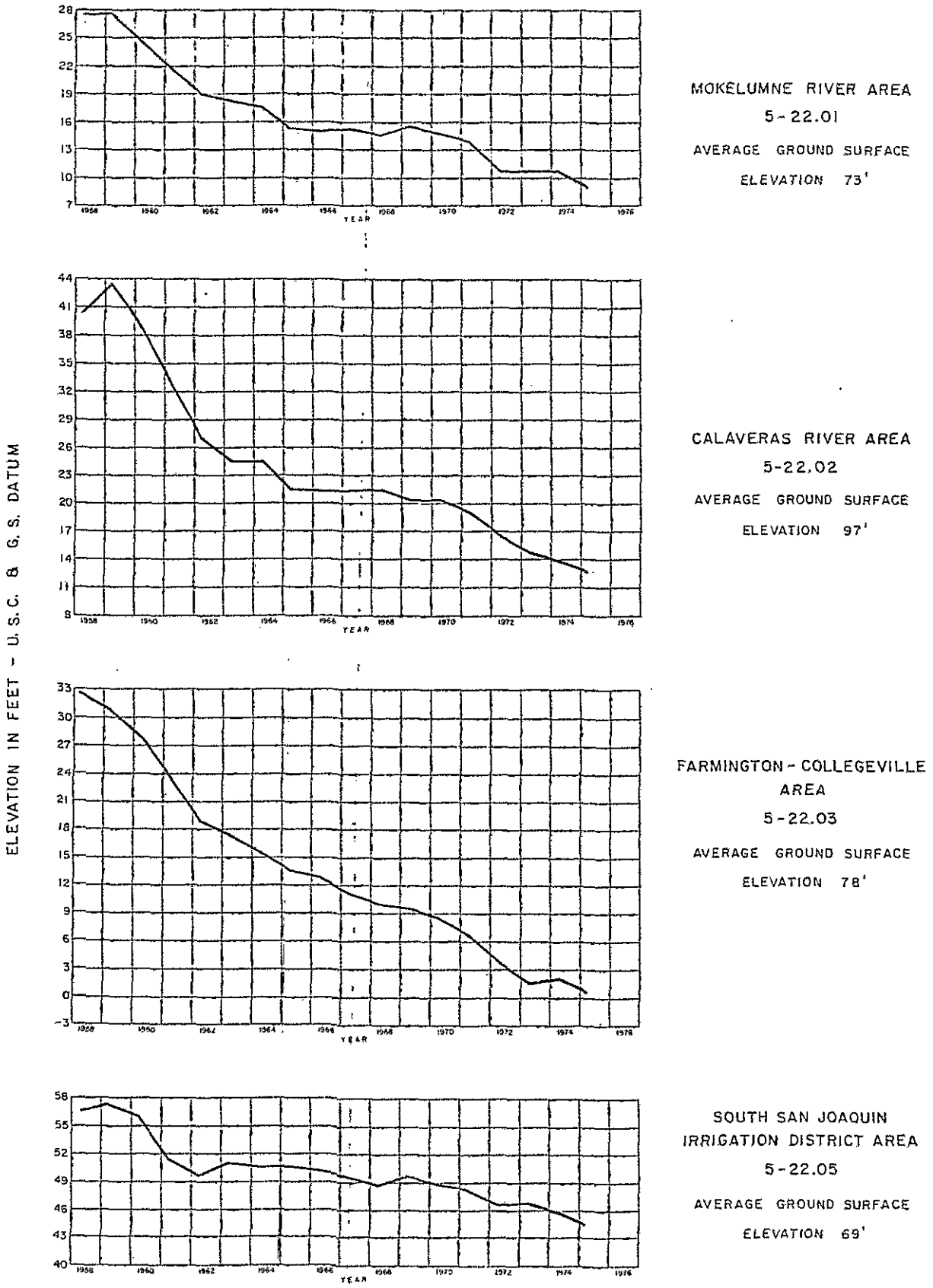


FLUCTUATION OF AVERAGE GROUND WATER LEVEL IN SELECTED AREAS

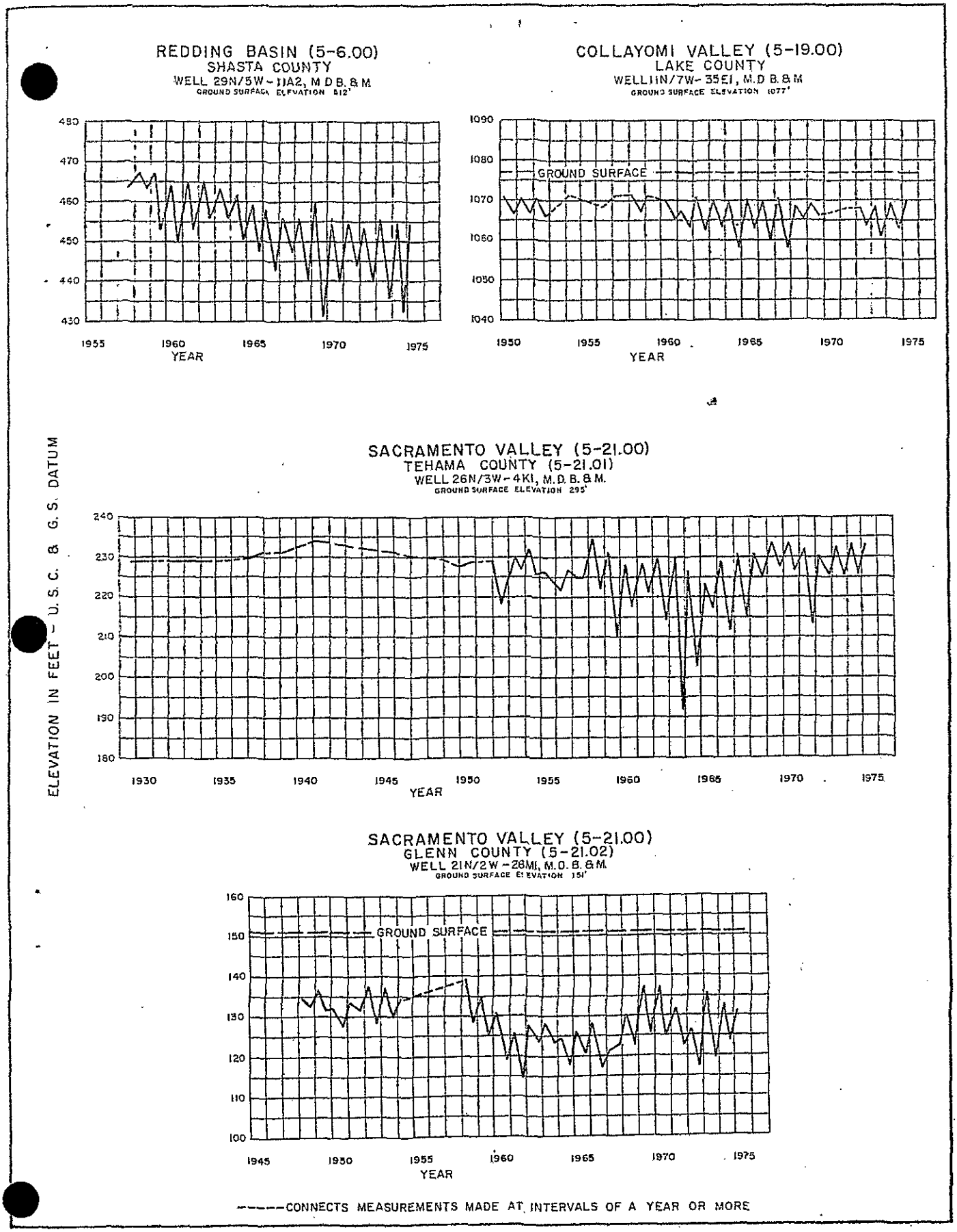


FLUCTUATION OF AVERAGE GROUND WATER LEVEL IN SELECTED AREAS

FIGURE C-2 SHEET 3 OF 3

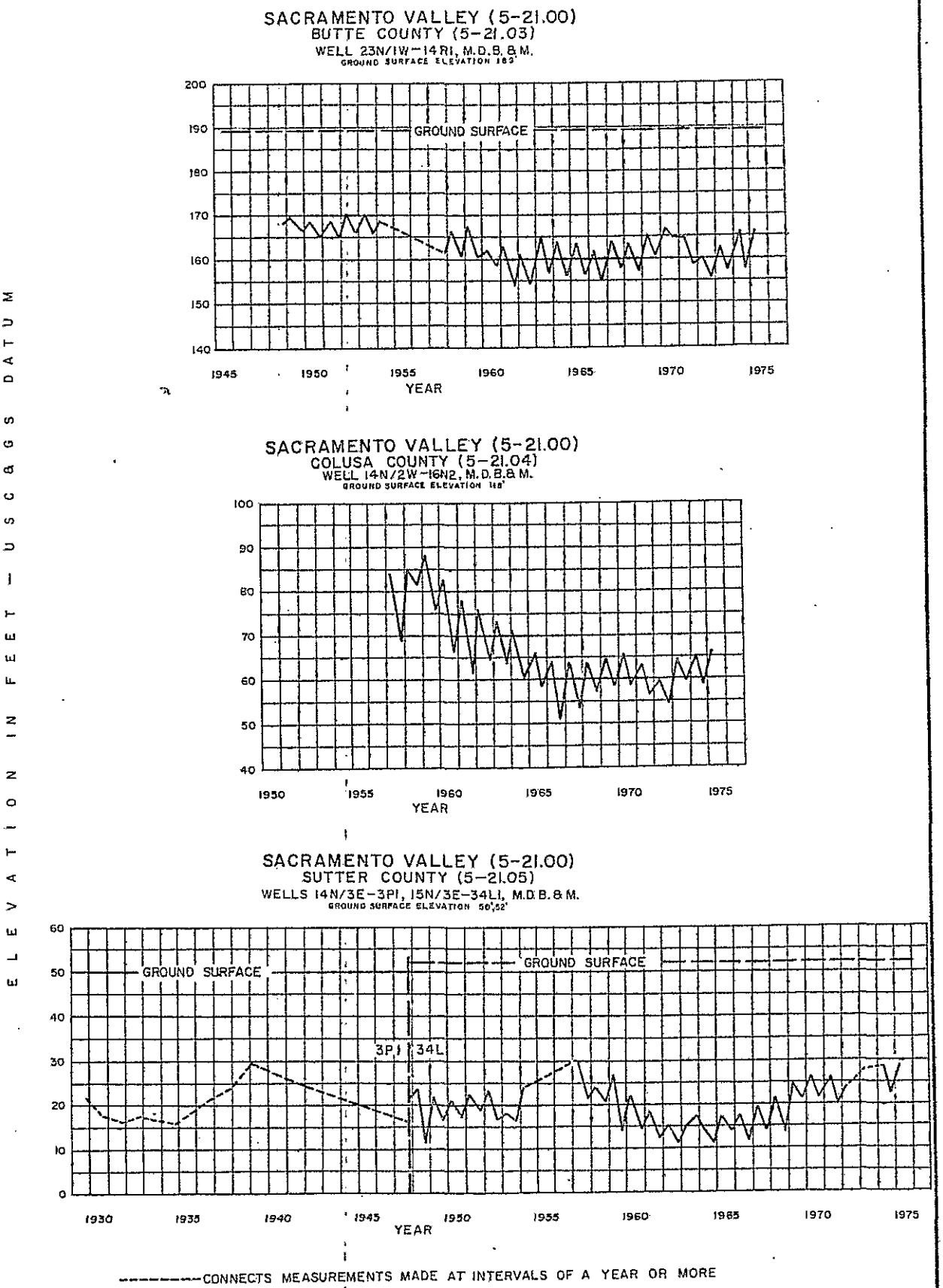


FLUCTUATION OF AVERAGE GROUND WATER LEVEL IN SELECTED AREAS

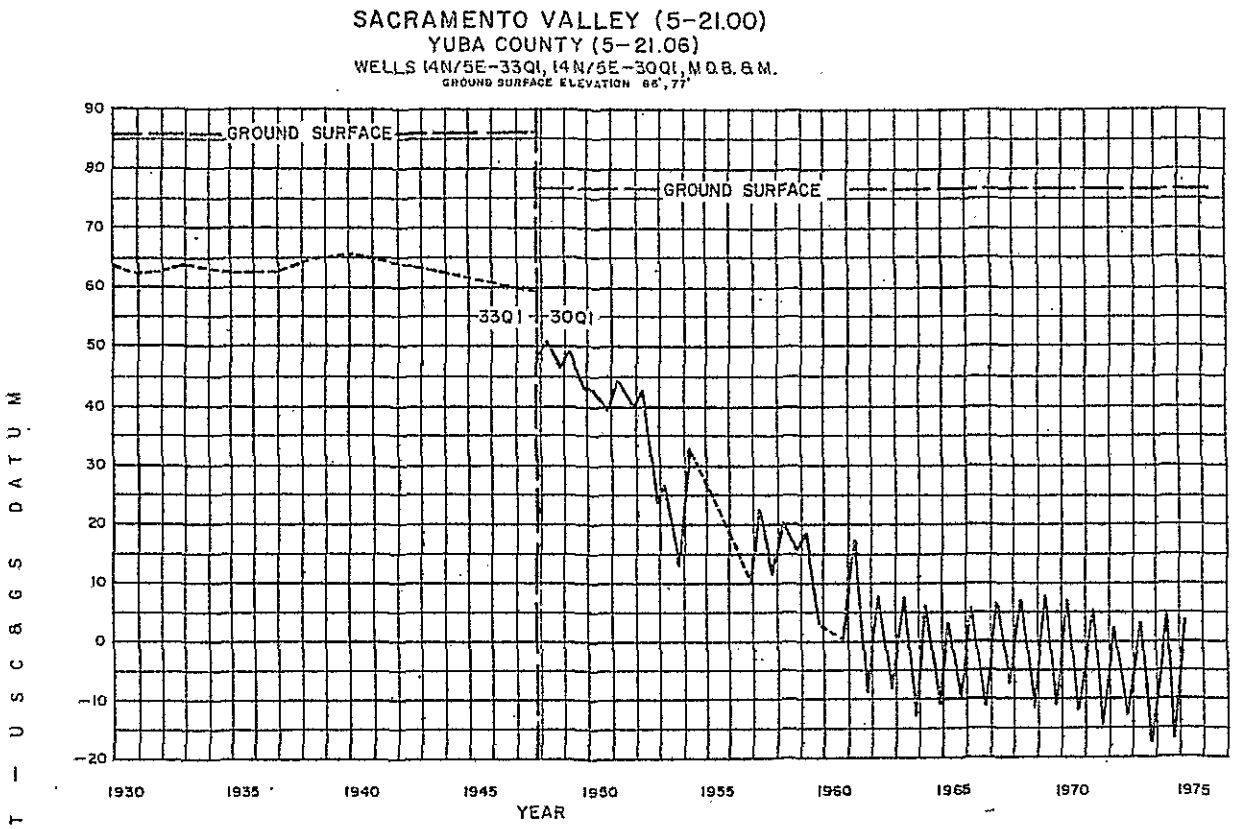


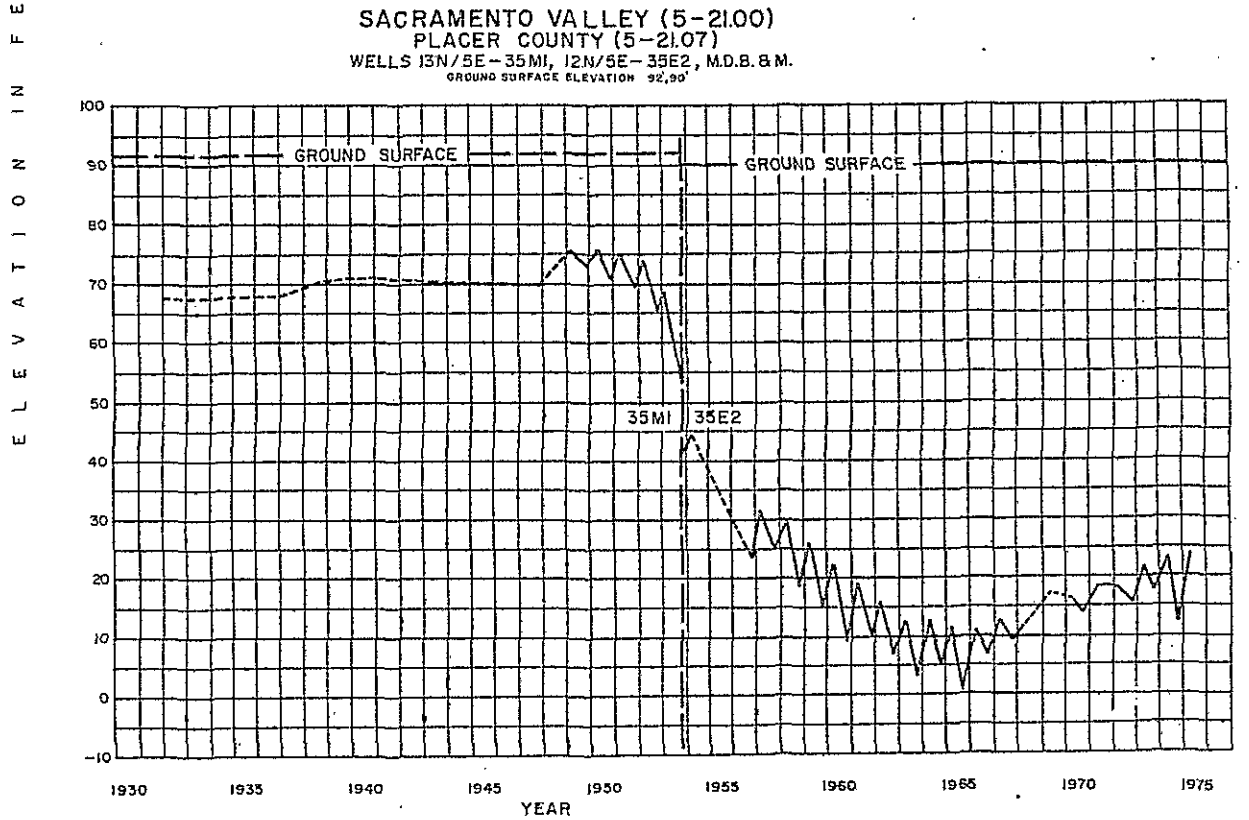
FLUCTUATION OF WATER LEVEL IN WELLS

Figure C-3 SHEET 2 OF 5



FLUCTUATION OF WATER LEVEL IN WELLS

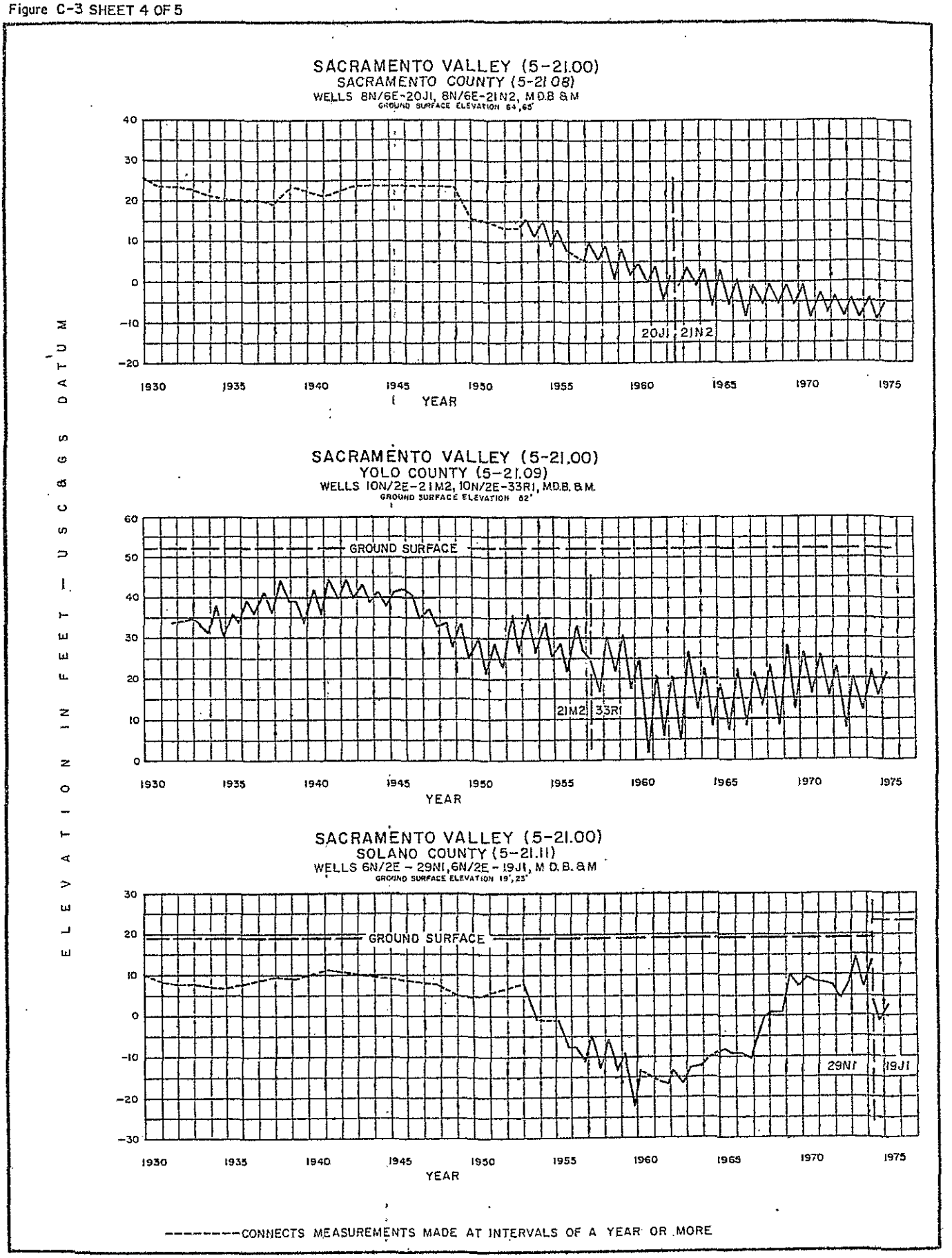




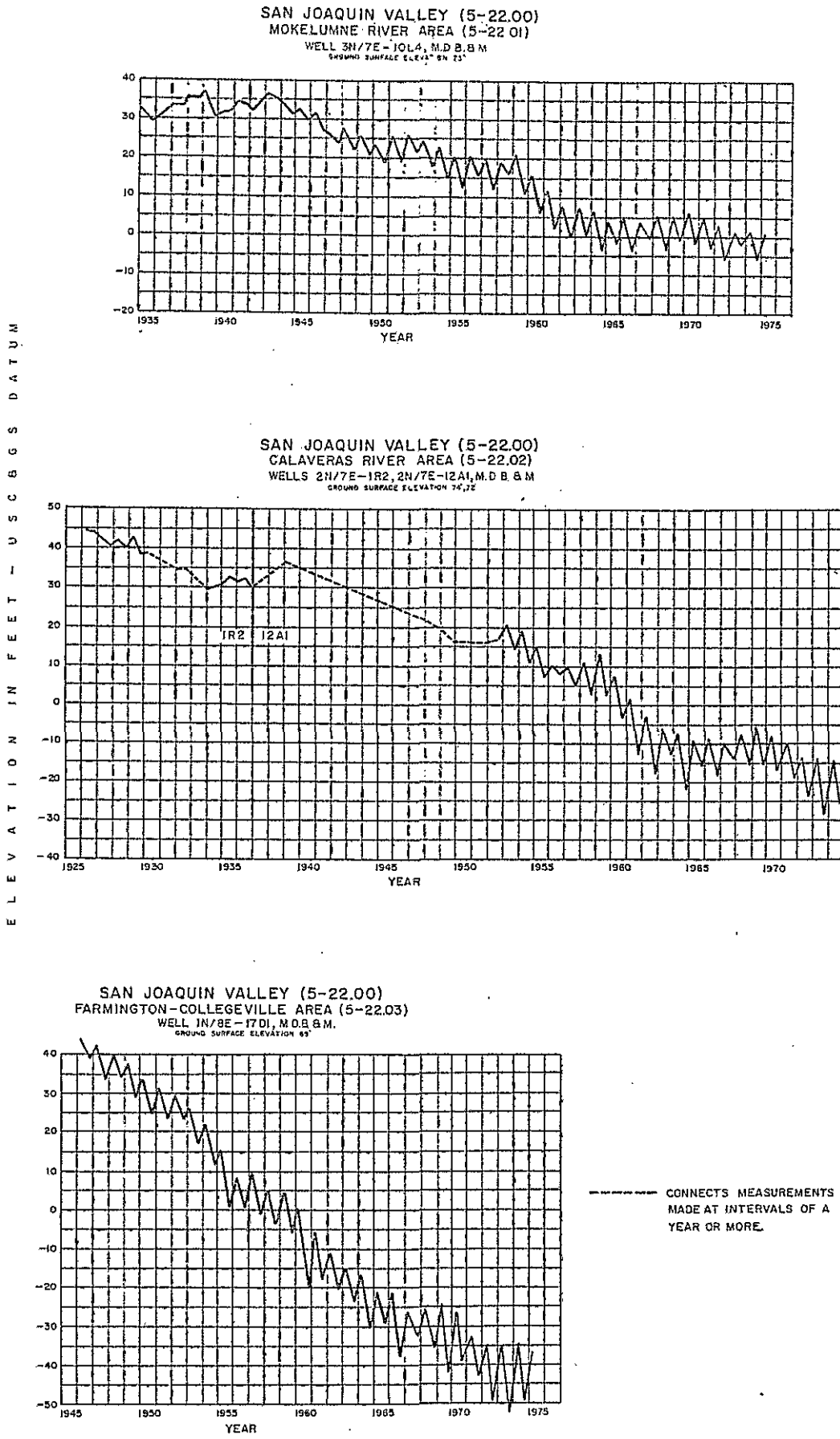
——— CONNECTS MEASUREMENTS MADE AT INTERVALS OF A YEAR OR MORE

FLUCTUATION OF WATER LEVEL IN WELLS

Figure C-3 SHEET 4 OF 5



FLUCTUATION OF WATER LEVEL IN WELLS



FLUCTUATION OF WATER LEVEL IN WELLS

80. State Department of Water Resources. Bulletin No. 130-75; Hydrologic Data: 1975 Volume III: Central Coastal Area, February, 1977

STATE OF CALIFORNIA
The Resources Agency
Department of Water Resources

BULLETIN No. 130-75

HYDROLOGIC DATA: 1975

Volume III: CENTRAL COASTAL AREA

FEBRUARY 1977

CLAIRE T. DEDRICK
Secretary for Resources
The Resources Agency

EDMUND G. BROWN JR.
Governor
State of California

RONALD B. ROBIE
Director
Department of Water Resources

STATE OF CALIFORNIA

The Resources Agency

Department of Water Resources

BULLETIN No. 130-75

HYDROLOGIC DATA: 1975

Volume III: CENTRAL COASTAL AREA

Copies of this bulletin at $3.00 each may be ordered from:
State of California
DEPARTMENT OF WATER RESOURCES
P.O. Box 388
Sacramento, California 95802

Make checks payable to STATE OF CALIFORNIA
California residents add sales tax

FEBRUARY 1977

CLAIRE T. DEDRICK
Secretary for Resources
The Resources Agency

EDMUND G. BROWN JR.
Governor
State of California

RONALD B. ROBIE
Director
Department of Water Resources

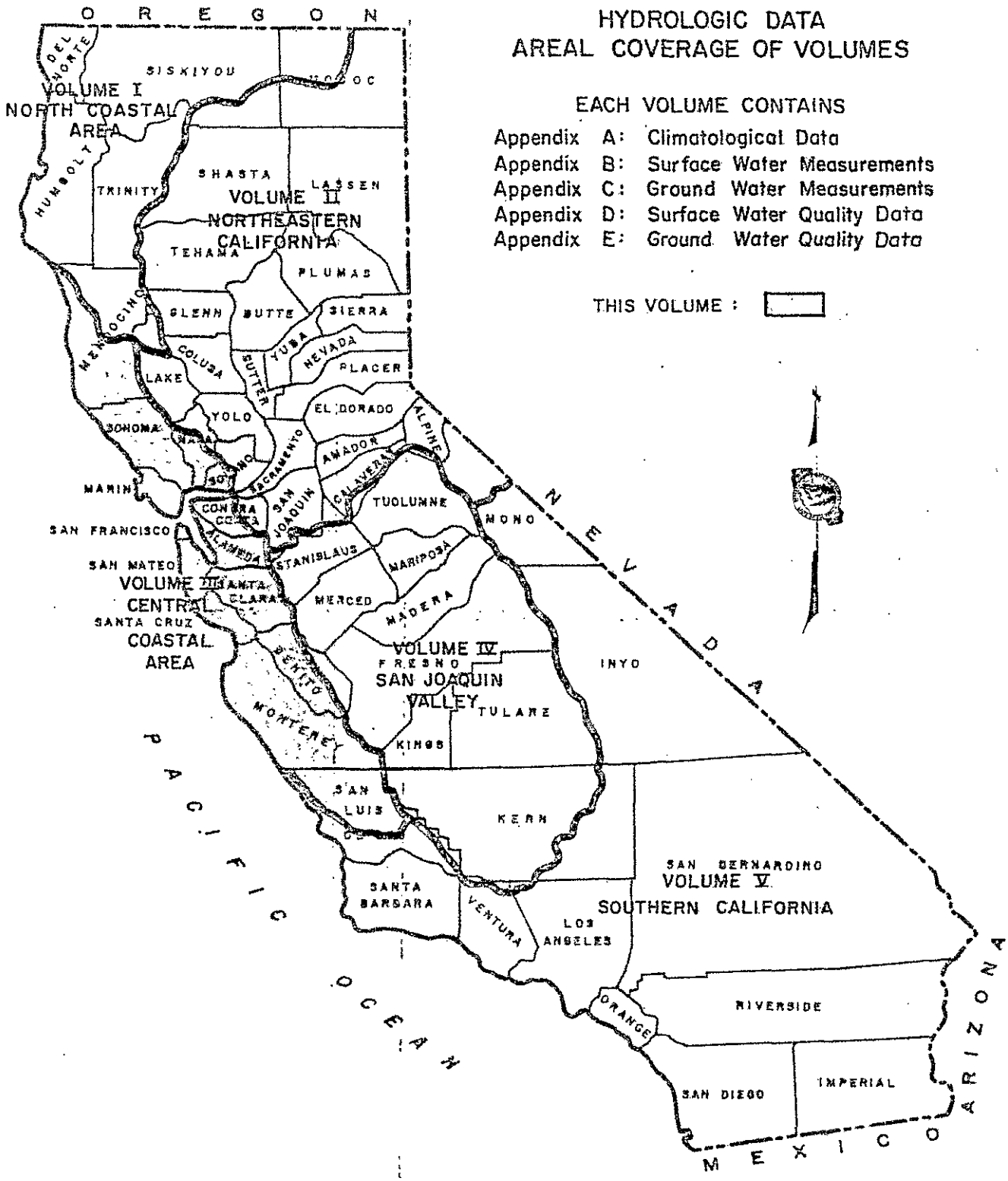
BULLETIN No. 130

HYDROLOGIC DATA
AREAL COVERAGE OF VOLUMES

EACH VOLUME CONTAINS

Appendix A: Climatological Data
Appendix B: Surface Water Measurements
Appendix C: Ground Water Measurements
Appendix D: Surface Water Quality Data
Appendix E: Ground Water Quality Data

THIS VOLUME :



FOREWORD

The data collection programs of the Department of Water Resources have been designed to supplement the activities of other agencies to satisfy specific needs of the State. Bulletin No. 130-75 presents useful, comprehensive, accurate, and timely hydrologic data which are prerequisites for monitoring environmental conditions as well as effective planning, design, construction, and operation of water facilities.

The Bulletin No. 130 series has been published annually in five volumes since 1963. Each volume presents hydrologic data for one of five reporting areas of the State. These areas are delineated on the map to the left.

This Bulletin No. 130-75 is the last of this series to be published. It is to be replaced with a statewide hydrologic data index, which will show what data are available and where they may be obtained.

Ronald B. Robie

Ronald B. Robie, Director
Department of Water Resources
The Resources Agency
State of California

CONVERSION FACTORS

English to Metric System of Measurement

Quantity	English unit	Multiply by	To get metric equivalent
Length	inches (in)	25.4	millimetres (mm)
		.0254	metres (m)
	feet (ft)	.3048	metres (m)
	miles (mi)	1.6093	*kilometres (km)*
Area	square inches (in^2)	6.4516×10^{-4}	square metres (m^2)
	square feet (ft^2)	.092903	square metres (m^2)
	acres	4046.9	square metres (m^2)
		.40469	hectares (ha)
		.40469	square hectometres (hm^2)
		.0040469	square kilometres (km^2)
	square miles (mi^2)	2.590	square kilometres (km^2)
Volume	gallons (gal)	3.7854	litres (l)
		.0037854	cubic metres (m^3)
	million gallons (10^6 gal)	3785.4	cubic metres (m^3)
	cubic feet (ft^3)	.028317	cubic metres (m^3)
	cubic yards (yd^3)	.76455	cubic metres (m^3)
	acre-feet (ac-ft)	1233.5	cubic metres (m^3)
		.0012335	cubic hectometres (hm^3)
		1.233×10^{-6}	cubic kilometres (km^3)
Volume/Time (Flow)	cubic feet per second (ft^3/s)	28.317	litres per second (l/s)
		.028317	cubic metres per second (m^3/s)
	gallons per minute (gal/min)	.06309	litres per second (l/s)
		6.309×10^{-5}	cubic metres per second (m^3/s)
	million gallons per day (mgd)	.043813	cubic metres per second (m^3/s)
Mass	pounds (lb)	.45359	kilograms (kg)
	tons (short, 2,000 lb)	.90718	tonne (t)
		907.18	kilograms (kg)
Power	horsepower (hp)	0.7460	kilowatts (kW)
Pressure	pounds per square inch (psi)	6894.8	pascal (Pa)
Temperature	Degrees Fahrenheit (°F)	$\frac{tF - 32}{1.8} = tC$	Degrees Celsius (°C)

TABLE OF CONTENTS

	Page
AREAL COVERAGE OF VOLUMES	ii
FOREWORD	iii
CONVERSION FACTORS	iv
ORGANIZATION	vi
ACKNOWLEDGMENTS	vii
INTRODUCTION	1
APPENDIXES	
Appendix A: CLIMATOLOGICAL DATA	3
Figure Number	
A-1 Climatological Observation Stations	4
Table Number	
A-1 Precipitation in Central Coastal Area During Water Year 1975	7
Appendix B: SURFACE WATER MEASUREMENTS	11
Table Number	
B-1 Surface Water Imports to the Central Coastal Area	12
B-2 Daily Gage Height, Rector Reservoir near Yountville	13
B-3 Daily Tides	14
B-4 Corrections and Revisions to Previously Published Reports of Surface Water Data	18
Appendix C: GROUND WATER MEASUREMENTS	19
Index to Ground Water Measurement Data	20
Figure Number	
C-1 Ground Water Basins in the Central Coastal Area	21
C-2 Fluctuation of Average Ground Water Level in Selected Areas	25
C-3 Fluctuation of Water Level in Wells	29
Table Number	
C-1 Average Change of Ground Water Levels and Summary of Well Measurements Reported	24
Appendix D: SURFACE WATER QUALITY DATA	35
Figure Number	
D-1 Surface Water Observation Stations	38
Table Number	
D-1 Sampling Station Data and Index	36
D-2 Mineral Analyses of Surface Water	41
D-3 Minor Element Analysis of Surface Water	81
D-4 Supplemental Minor Element Analysis of Surface Water	85
D-5 Miscellaneous Constituents in Surface Water	87
D-6 Nutrient Analysis of Surface Water	104
D-7 Pesticides in Surface Water	118
D-8 Daily Maximum, Minimum, and Average Specific Conductance	121
D-9 Phytoplankton Analysis of Surface Water	123
D-10 Biological Analysis of Surface Water	126
Appendix E: GROUND WATER QUALITY DATA	129
Index to Ground Water Quality Data	130
Table Number	
E-1 Mineral Analyses of Ground Water	131
E-2 Minor Element Analysis of Ground Water	162
E-3 Supplemental Minor Element Analysis of Ground Water	174
Appendix F: WASTE WATER DATA	183

STATE OF CALIFORNIA
Edmund G. Brown Jr., Governor

THE RESOURCES AGENCY
Claire T. Dedrick, Secretary for Resources

DEPARTMENT OF WATER RESOURCES
Ronald B. Robie, Director

Robin R. Reynolds
Deputy Director

Gerald H. Meral
Deputy Director

Robert W. James
Deputy Director

Charles R. Shoemaker
Assistant Director

This report was prepared in the

CENTRAL DISTRICT

Wayne MacRostie . . . . . District Chief
Lee W. Carter . . . . . Chief, Data and Operations Branch

by

Edward J. Labrie . . . . . Chief, Data Evaluation Section

assisted by

Grant C. Ardell . . . . . Water Resources Engineering Associate
Emil M. Padjen . . . . . Water Resources Engineering Associate

A portion of the data was furnished by the

SAN JOAQUIN DISTRICT

Carl L. Stetson . . . . . District Chief
Floyd I. Bluhm . . . . . Chief, Water Supply and Utilization Branch
Cledith L. Chastain . . . . . Chief, Water Supply Section

and by the

NORTHERN DISTRICT

Albert J. Dolcini . . . . . District Chief
Wayne S. Gentry . . . . . Chief, Planning Branch

Reviewed and Coordinated by
Division of Planning
Environmental Quality Branch
Water Resources Evaluation Section

Appendix C

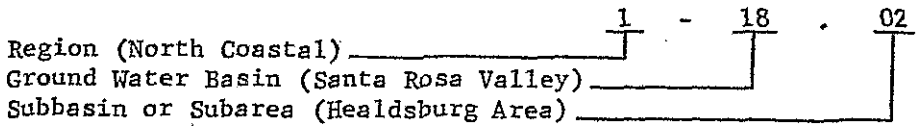
GROUND WATER MEASUREMENTS

This appendix contains summary and selected information concerning the level of ground water in wells within 36 ground water basins or areas in the Central Coastal Area. Wells are selected to reflect the ground water conditions of the area. These wells are continuously reviewed and, when conditions dictate, replacement wells are located and measured.

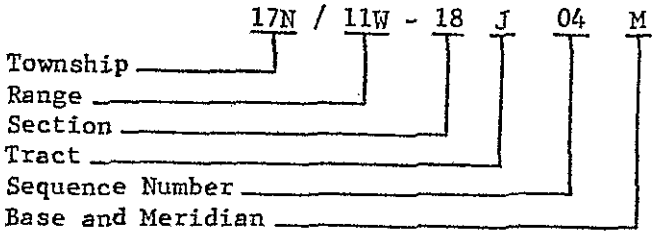
Earlier editions of this report contained a tabulation of individual measurements of ground water levels at wells. This type of data collected by the Department will be available at the various district offices of the Department. Please see the introduction at the front of this volume for the addresses of these district offices.

Table C-1 shows the average change in ground water levels for the various basins in the Central Coastal Area from spring 1974 to spring 1975. This table also shows the number of well measurements collected in the various areas. Figure C-2 contains graphical presentations of the average levels of ground water in the spring for the past several years. Figure C-3 is a graphical representation of the fluctuation of ground water level in certain selected wells for the past several years. An attempt has been made to select wells that represent conditions in the basin where the well is located. However, some caution in the use of these data is in order because ground water conditions can vary markedly with relatively small changes in horizontal location.

Two numbering systems are used by the Department to facilitate processing of water level measurement data. The two systems are the Region and Basin Designation and the State Well Numbering System. The regions used in Bulletin No. 130 are geographic areas defined in Section 13200 of the Water Code. This volume comprises the southern portion of North Coastal Region No. 1, the northern portion of Central Coastal Region No. 3, and all of San Francisco Bay Region No. 2. A decimal system of the form 0-00.00 has been selected according to geographic regions, ground water basins, and subbasins or subareas as follows:



The State Well Numbering System is based on township, range, and section subdivisions of the public land survey. The number of a well, assigned in accordance with this system, is referred to as the State Well Number, as illustrated below on the left.

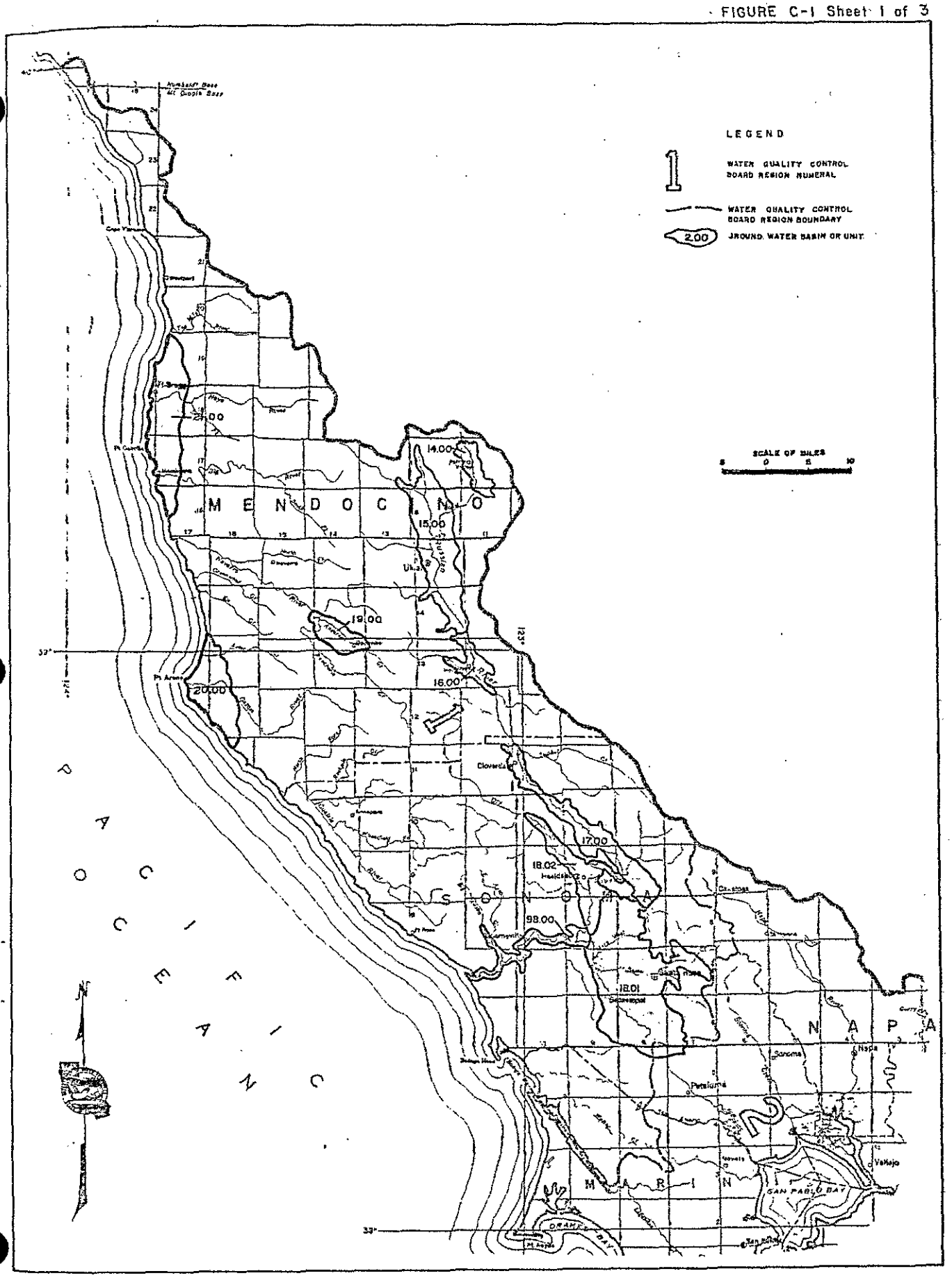


D	C	B	A
E	F	G	H
M	L	K	J
N	P	Q	R

This number identifies and locates the well. In the example, the well is in Township 17 North, Range 11 West, Tract J of Section 18, located in the Mount Diablo Base and Meridian. A section is divided into 40-acre tracts as shown above on the right. Sequence numbers in a tract are generally assigned in chronological order. The example designates the fourth well to be assigned a number in Tract J.

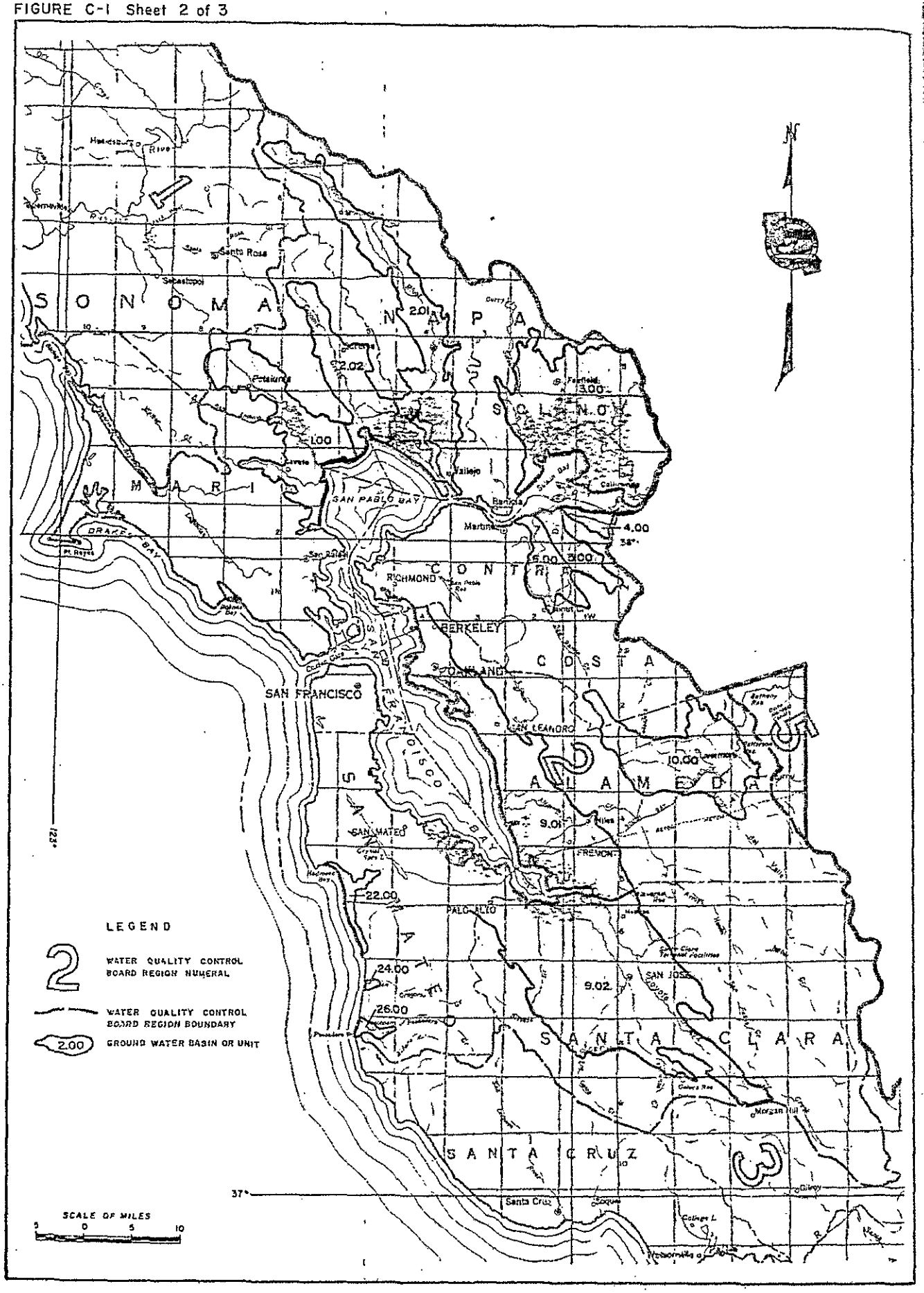
INDEX TO GROUND WATER MEASUREMENT DATA
IN THE CENTRAL COASTAL AREA

Number	Basin	Page
	NORTH COASTAL REGION 1-00.00 (Figure C-1, Sheet 1)	
1-14.00	Potter Valley	24, 25
1-15.00	Ukiah Valley	24, 25, 29
1-16.00	Sanel Valley	24, 25, 29
1-17.00	Alexander Valley	24, 25, 29
1-18.00	Santa Rosa Valley	
1-18.01	Santa Rosa Area	24, 25, 29
1-18.02	Healdsburg Area	24, 25, 29
1-19.00	Anderson Valley	
1-20.00	Point Arena	
1-21.00	Fort Bragg Terrace	
1-98.00	Lower Russian River Valley	24
	SAN FRANCISCO BAY REGION 2-00.00 (Figure C-1, Sheet 2)	
2-01.00	Petaluma Valley	24, 26, 30
2-02.00	Napa-Sonoma Valley	
2-02.01	Napa Valley	24, 26, 30
2-02.02	Sonoma Valley	24, 26, 30
2-03.00	Suisun-Fairfield Valley	24, 26, 30
2-04.00	Pittsburg Plain	24, 26
2-05.00	Clayton Valley	24
2-06.00	Ygnacio Valley	24, 27, 30
2-09.00	Santa Clara Valley	
2-09.01	East Bay Area	24, 27, 31
2-09.02	South Bay Area	24, 27, 31, 32
2-10.00	Livermore Valley	24, 27, 32
2-22.00	Half Moon Bay Terrace	24, 27, 32
2-24.00	San Gregorio Valley	24, 28, 33
2-26.00	Pescadero Valley	24, 28, 33
	CENTRAL COASTAL REGION 3-00.00 (Figure C-1, Sheet 3)	
3-01.00	Soquel Valley	24, 28, 33
3-02.00	Pajaro Valley	24
3-03.00	Gilroy-Hollister Valley	
3-03.01	South Santa Clara County	24, 28, 34
3-03.02	San Benito County	24, 28, 33
3-04.00	Salinas Valley	
3-04.01	Pressure Area	24, 34
3-04.02	East Side Area	24
3-04.03	Forebay Area	24
3-04.04	Arroyo Seco Cone	24
3-04.05	Upper Valley Area	24, 34
3-04.06	Paso Robles Basin	24
3-04.08	Seaside Area	24
3-04.09	Langley Area	24
3-04.10	Corral De Tierra Area	24
3-05.00	Cholame Valley	
3-07.00	Carmel Valley	24
3-26.00	West Santa Cruz Terrace	24
3-27.00	Scotts Valley	24

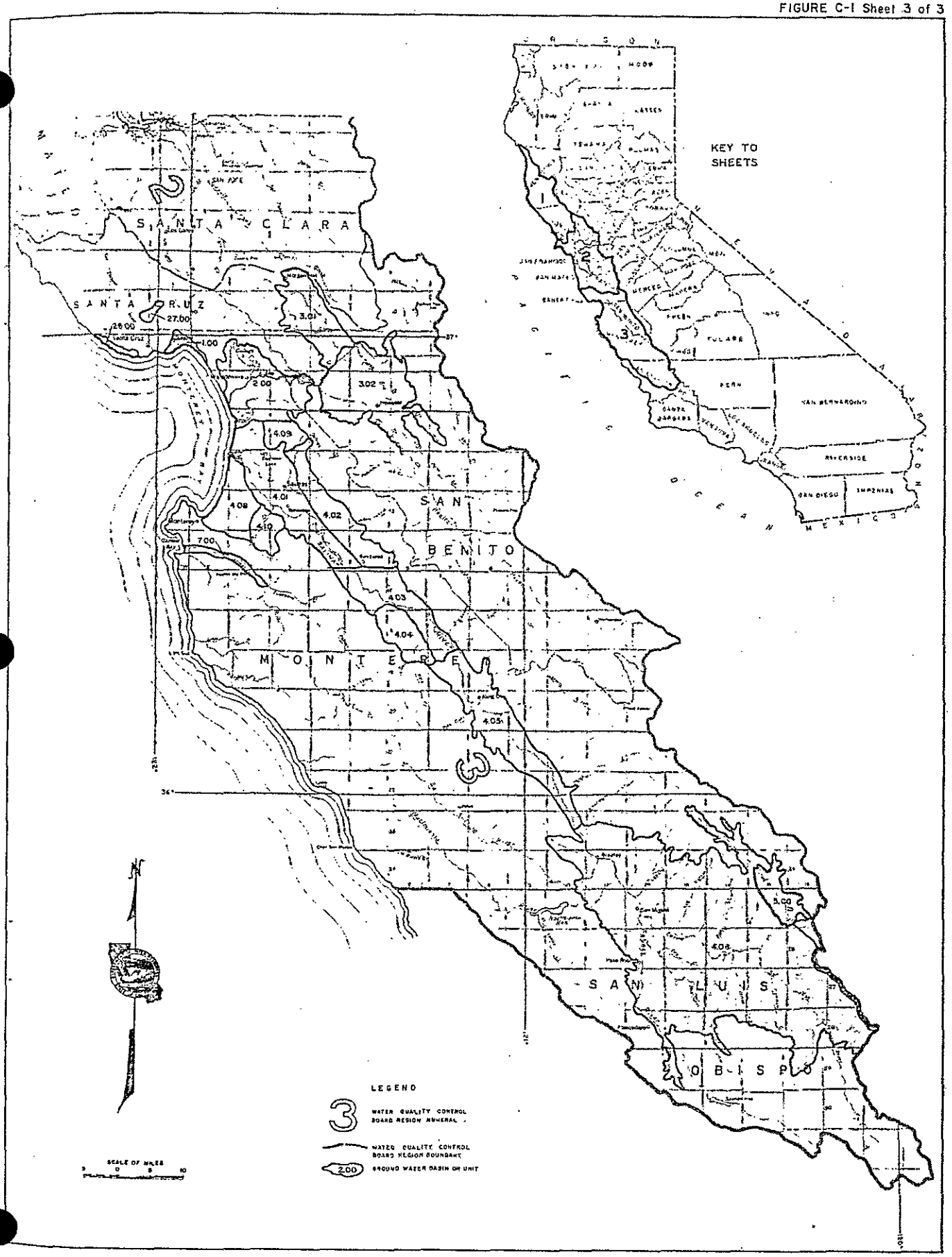


GROUND WATER BASINS IN THE CENTRAL COASTAL AREA

FIGURE C-1 Sheet 2 of 3



GROUND WATER BASINS IN THE CENTRAL COASTAL AREA



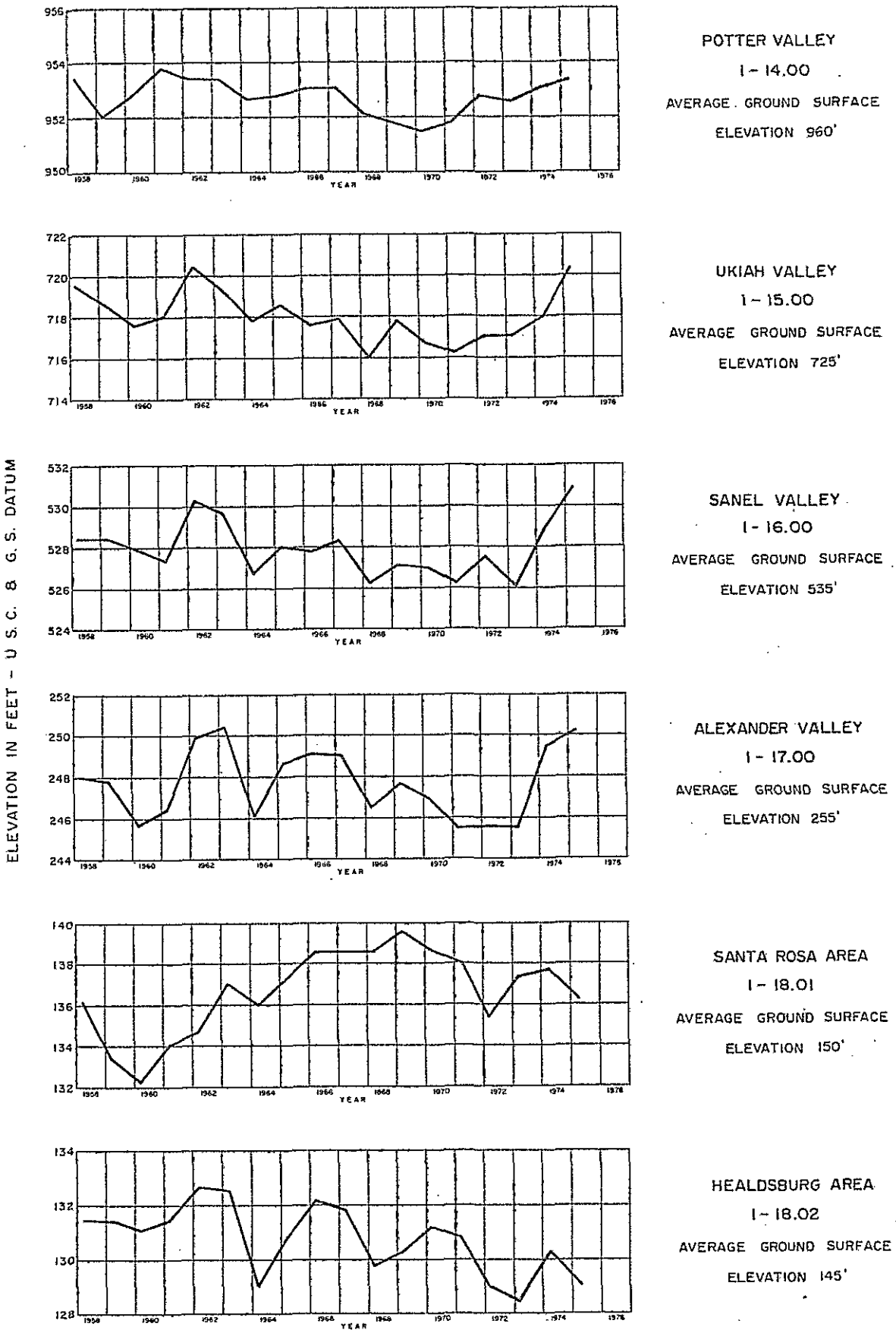
GROUND WATER BASINS IN THE CENTRAL COASTAL AREA

TABLE C-1

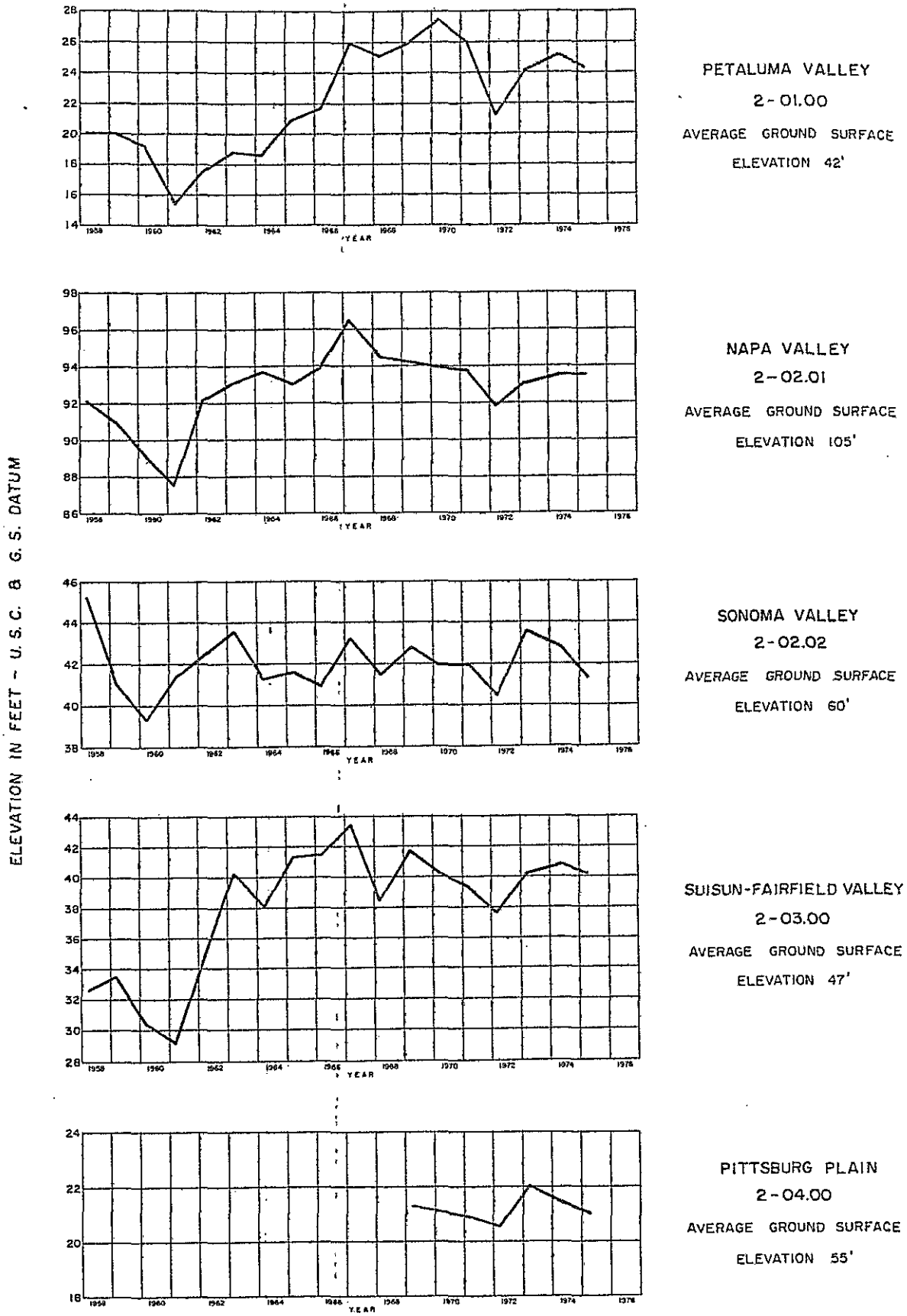
AVERAGE CHANGE OF GROUND WATER LEVELS
AND SUMMARY OF WELL MEASUREMENTS REPORTED

Ground Water Basin or Area		Average Change Spring 1974 to Spring 1975 in feet	Measuring Agency	Number of Wells Reported		
Name	Number			Monthly 1974-75	Fall 1974	Spring 1975
NORTH COASTAL REGION						
Potter Valley	1-14.00	+0.2	Department of Water Resources		2	2
Ukiah Valley	1-15.00	+2.3	Department of Water Resources		7	7
Sanel Valley	1-16.00	+2.0	Department of Water Resources		3	3
Alexander Valley	1-17.00	+0.7	Department of Water Resources		11	10
Santa Rosa Valley	1-18.00					
Santa Rosa Area	1-18.01	-1.4	Department of Water Resources		26	26
Healdsburg Area	1-18.02	-1.2	U. S. Geological Survey		9	9
Lower Russian River Valley	1-98.00	-1.6	Department of Water Resources		2	2
SAN FRANCISCO BAY REGION						
Petaluma Valley	2-01.00	-0.8	Department of Water Resources		12	12
Napa-Sonoma Valley	2-02.00					
Napa Valley	2-02.01	-0.1	Napa County		94	95
			Department of Water Resources		5	5
Sonoma Valley	2-02.02	-1.5	Department of Water Resources		12	12
Suisun-Fairfield Valley	2-03.00	-0.7	Solano County		13	13
			Department of Water Resources	11		
Pittsburg Plain	2-04.00	-0.4	Department of Water Resources		5	5
Clayton Valley	2-05.00	-1.9	Department of Water Resources		7	7
Ygnacio Valley	2-06.00	-2.3	Department of Water Resources		5	5
Santa Clara Valley	2-09.00					
East Bay Area	2-09.01	-1.4	Alameda County FC & WCD	3	42	44
			Alameda County Water District		378	370
South Bay Area	2-09.02	+10.7	Santa Clara Valley WD	477		
Livermore Valley	2-10.00	+1.0	Alameda County FC & WCD	12	139	137
Half Moon Bay Terrace	2-22.00	-3.2	Department of Water Resources		8	8
San Gregorio Valley	2-24.00	-2.2	Department of Water Resources		5	5
Pescadero Valley	2-26.00	-1.8	Department of Water Resources		6	6
CENTRAL COASTAL REGION						
Soquel Valley	3-01.00	-2.1	Department of Water Resources		5	5
Pajaro Valley	3-02.00	+2.4*	Monterey County FC & WCD		38	
			Department of Water Resources		5	
Gilroy-Hollister Valley	3-03.00	+0.1				
South Santa Clara County	3-03.01	-0.8	Santa Clara Valley WD			68
			Department of Water Resources			14
San Benito County	3-03.02	+0.7	San Benito County			83
			Department of Water Resources			8
Salinas Valley	3-04.00	+2.2				
Pressure Area	3-04.01	+2.4*	Monterey County FC & WCD		137	
East Side Area	3-04.02	+7.0*	Monterey County FC & WCD		89	
Forebay Area	3-04.03	+0.2*	Monterey County FC & WCD		50	
Arroyo Seco Cone	3-04.04	+0.7*	Monterey County FC & WCD		18	
Upper Valley Area	3-04.05	-0.3*	Monterey County FC & WCD		35	
Paso Robles Basin	3-04.06	-2.4	San Luis Obispo FC & WCD			35
Seaside Area	3-04.08	+1.2*	Monterey County FC & WCD		15	
Langley Area	3-04.09	+2.0*	Monterey County FC & WCD		15	
Corral de Tierra Area	3-04.10	-1.0*	Monterey County FC & WCD		29	
Carmel Valley	3-07.00	-0.6*	Monterey County FC & WCD		24	
West Santa Cruz Terrace	3-26.00	+0.2	Department of Water Resources		3	4
Scotts Valley	3-27.00	-0.1	Department of Water Resources		4	5
TOTAL				503	1258	997

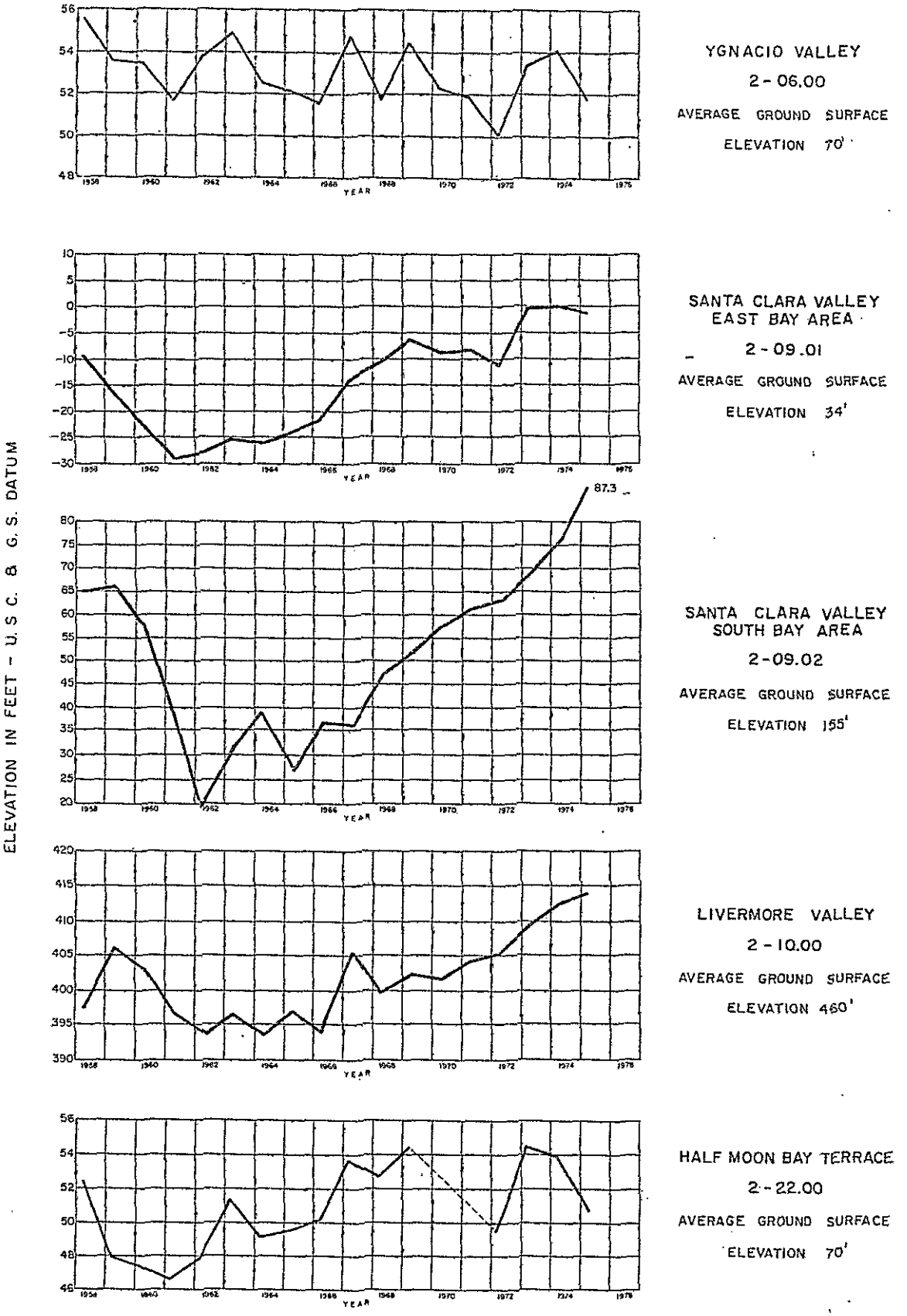
*Average change determined from water level measurements made during fall of 1973 and fall of 1974



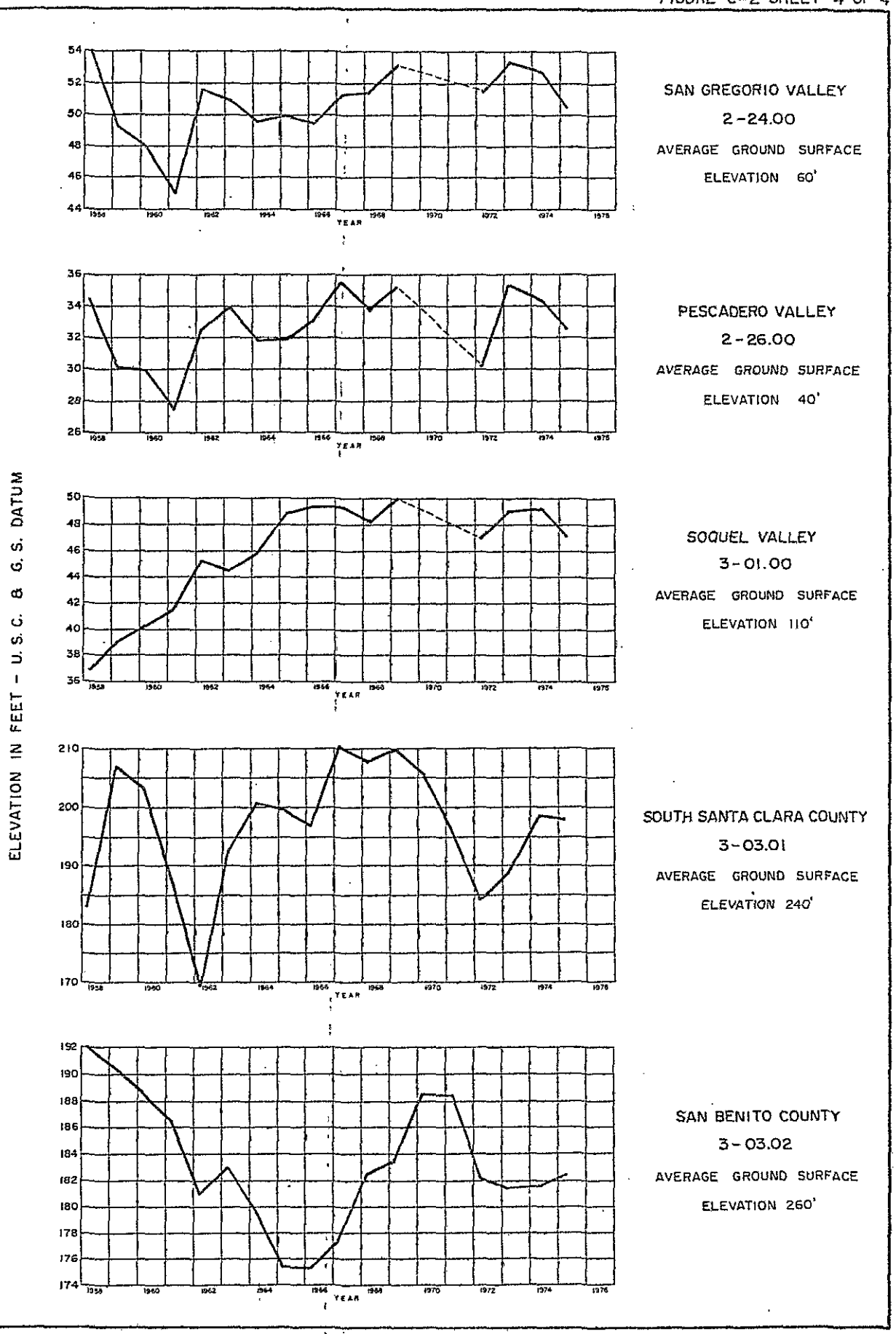
FLUCTUATION OF AVERAGE GROUND WATER LEVEL IN SELECTED AREAS



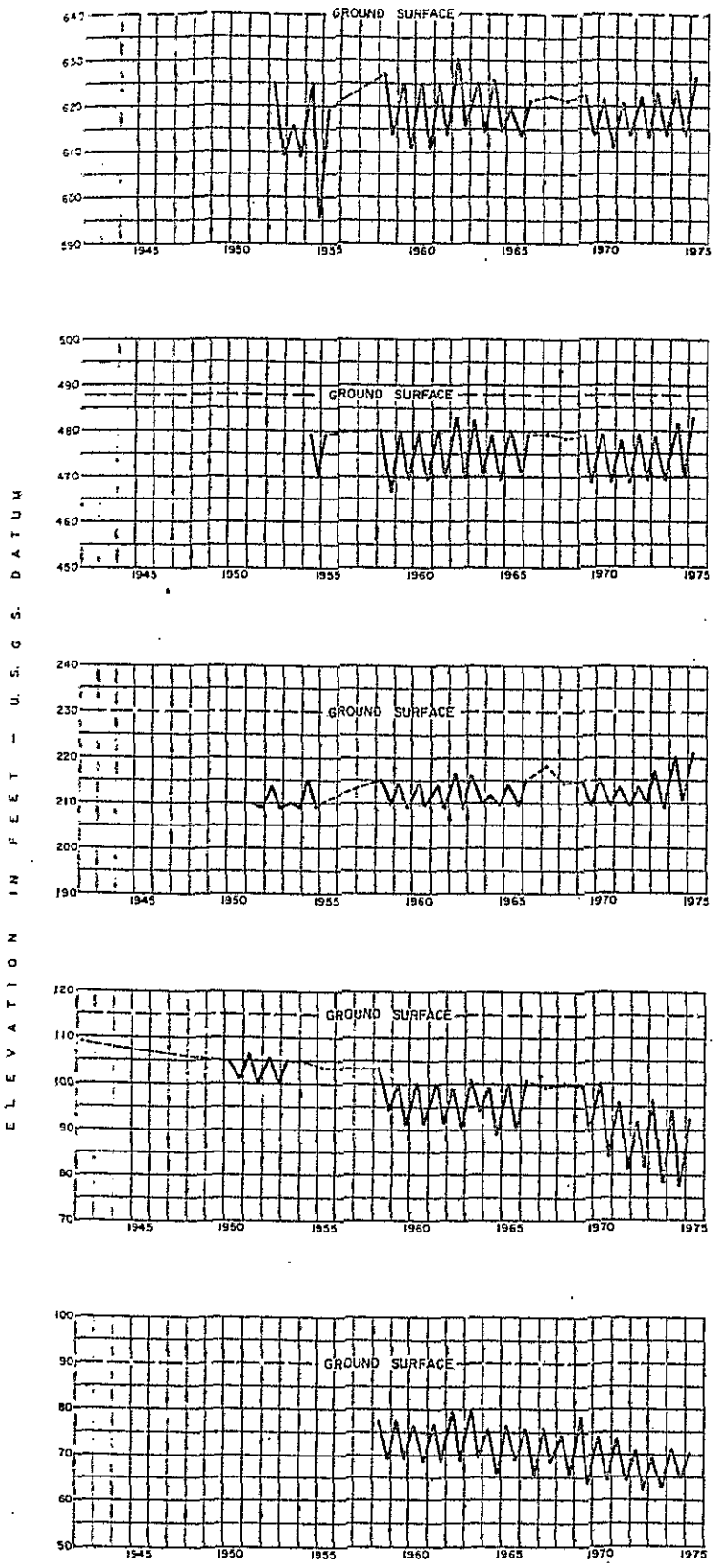
FLUCTUATION OF AVERAGE GROUND WATER LEVEL IN SELECTED AREAS



FLUCTUATION OF AVERAGE GROUND WATER LEVEL IN SELECTED AREAS



FLUCTUATION OF AVERAGE GROUND WATER LEVEL IN SELECTED AREAS



UKIAH VALLEY (1-15.00)
WELL NUMBER 15N/12W-8L1
GROUND SURFACE ELEVATION 640'

SANEL VALLEY (1-16.00)
WELL NUMBER 13N/11W-19P1
GROUND SURFACE ELEVATION 488'

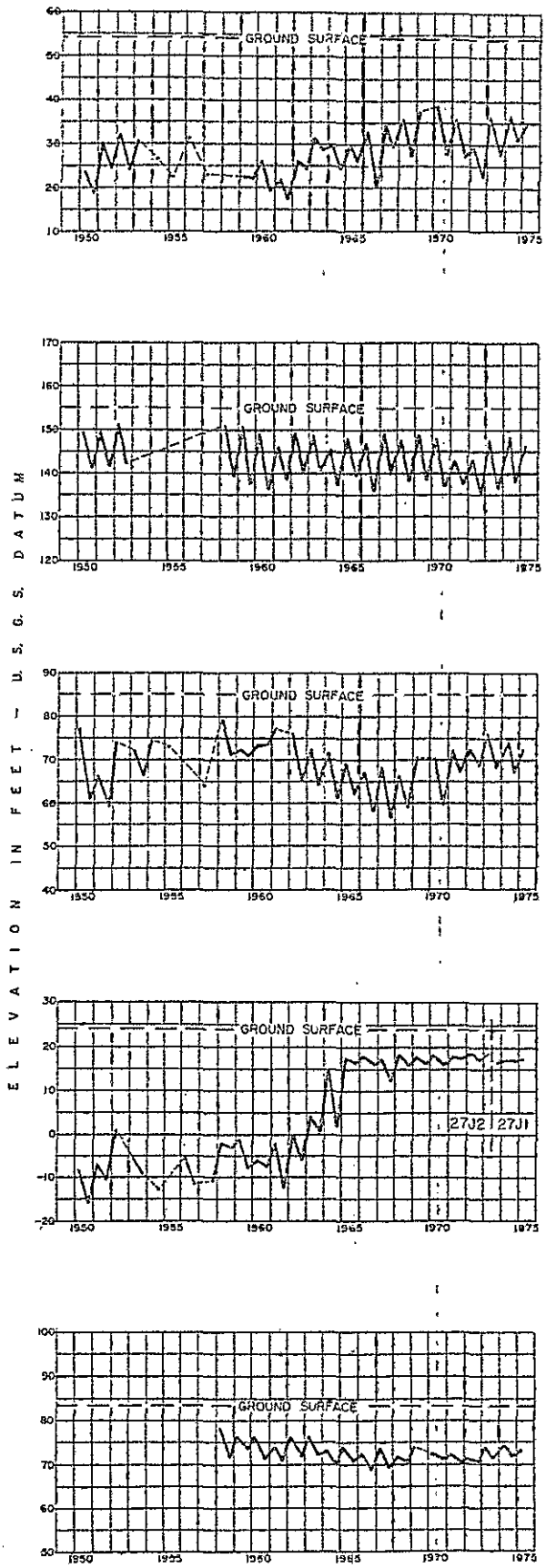
ALEXANDER VALLEY (1-17.00)
WELL NUMBER 10N/9W-18B1
GROUND SURFACE ELEVATION 230'

SANTA ROSA AREA (1-18.01)
WELL NUMBER 6N/8W-13R1
GROUND SURFACE ELEVATION 115'

HEALDSBURG AREA (1-18.02)
WELL NUMBER 9N/9W-28N1
GROUND SURFACE ELEVATION 90'

------- CONNECTS MEASUREMENTS MADE AT INTERVALS OF A YEAR OR MORE

FLUCTUATION OF WATER LEVEL IN WELLS



PETALUMA VALLEY (2-01.00)
WELL NUMBER 5N/7W-26R1
GROUND SURFACE ELEVATION 54'

NAPA VALLEY (2-02.01)
WELL NUMBER 7N/5W-9Q2
GROUND SURFACE ELEVATION 155'

SONOMA VALLEY (2-02.02)
WELL NUMBER 5N/5W-17C1
GROUND SURFACE ELEVATION 85'

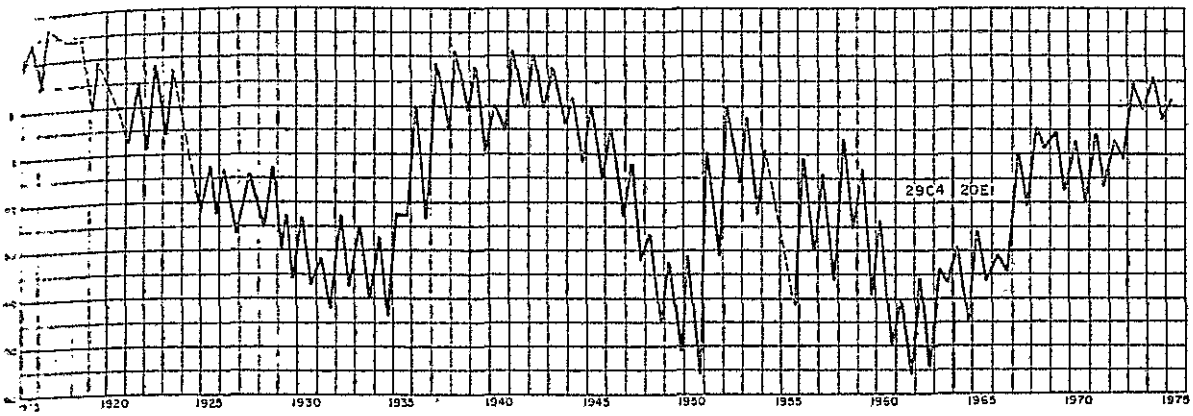
SUISUN-FAIRFIELD VALLEY (2-03.00)
WELL NUMBER 5N/2W-27J2,27J1
GROUND SURFACE ELEVATION 24'

YGNACIO VALLEY (2-06.00)
WELL NUMBER 1N/1W-7K1
GROUND SURFACE ELEVATION 83'

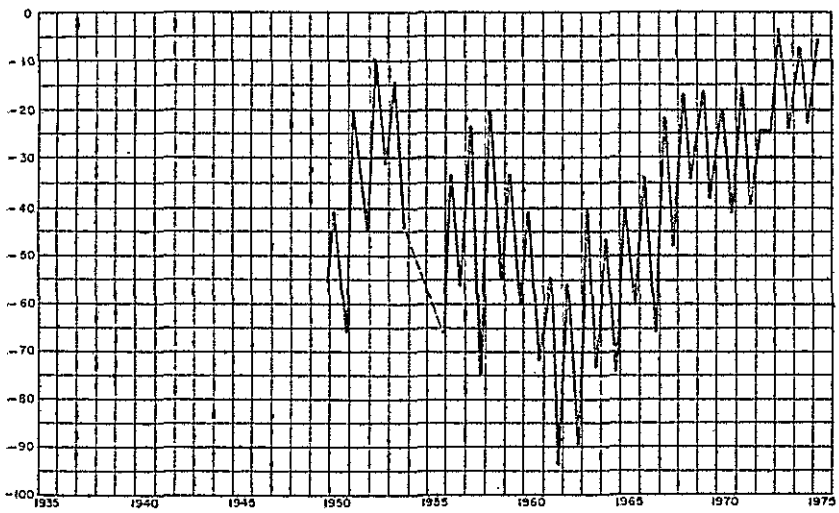
------- CONNECTS MEASUREMENTS MADE AT INTERVALS OF A YEAR OR MORE

FLUCTUATION OF WATER LEVEL IN WELLS

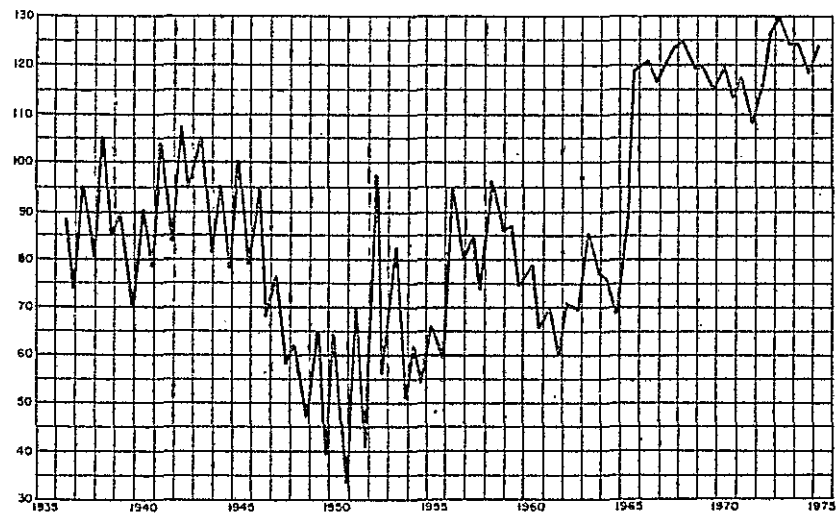
SANTA CLARA VALLEY
EAST BAY AREA - UPPER AQUIFER (2-09.01)
WELL NUMBERS 4S/1W-29C4, 20E1
GROUND SURFACE ELEVATION 55'



ELEVATION IN FEET - USGS DATUM



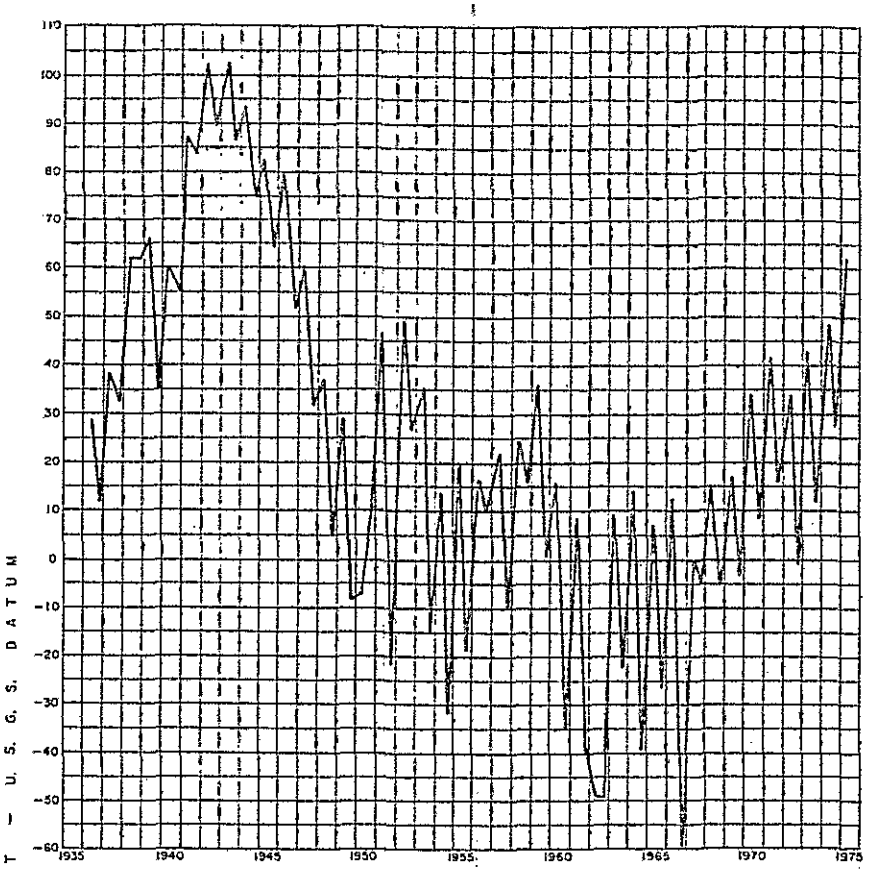
SANTA CLARA VALLEY
EAST BAY AREA
LOWER AQUIFER (2-09.01)
WELL NUMBER 5S/1W-5F1
GROUND SURFACE ELEVATION 36'



SANTA CLARA VALLEY
SOUTH BAY AREA (2-09.02)
WELL NUMBER 6S/1E-23P2
GROUND SURFACE ELEVATION 240'

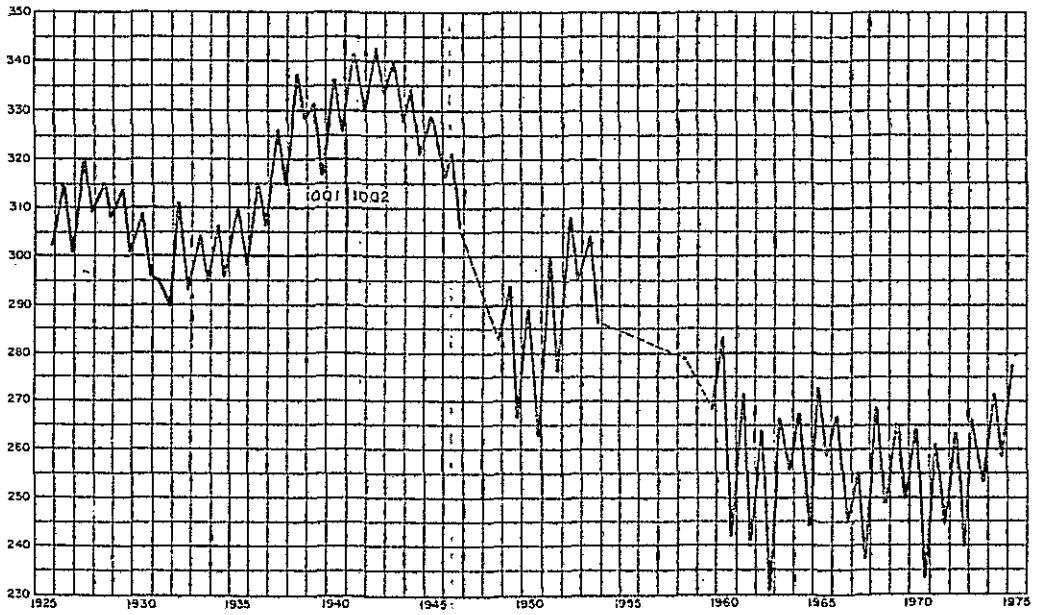
------- CONNECTS MEASUREMENTS MADE AT INTERVALS OF A YEAR OR MORE

FLUCTUATION OF WATER LEVEL IN WELLS



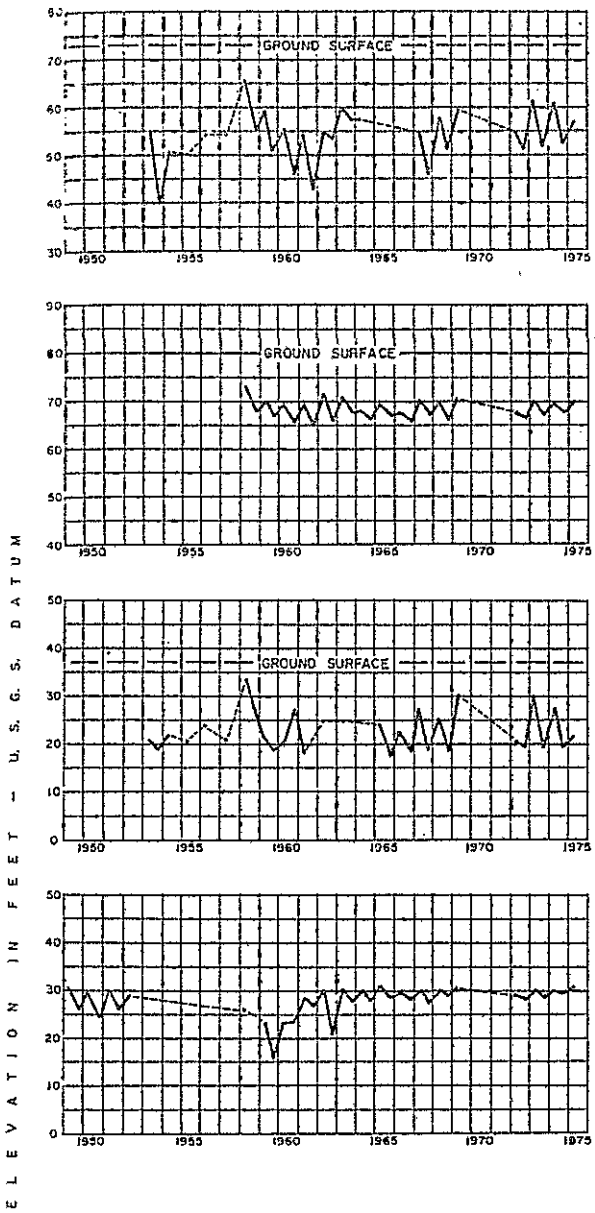
SANTA CLARA VALLEY
SOUTH BAY AREA (2-09.02)
WELL NUMBER 7S/1E-31A2
GROUND SURFACE ELEVATION 152'

LIVERMORE VALLEY (2-10.00)
WELL NUMBERS 3S/1E-1001, 1002
GROUND SURFACE ELEVATION 369'



-------- CONNECTS MEASUREMENTS MADE AT INTERVALS OF A YEAR OR MORE

FLUCTUATION OF WATER LEVEL IN WELLS



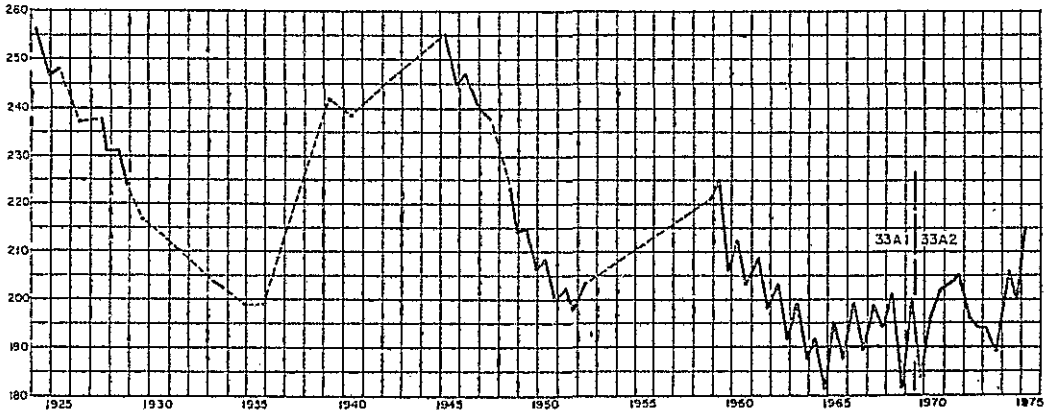
HALF MOON BAY TERRACE (2-22.00)
WELL NUMBER 5S/5W-20L1
GROUND SURFACE ELEVATION 73'

SAN GREGORIO VALLEY (2-24.00)
WELL NUMBER 7S/5W-14C1
GROUND SURFACE ELEVATION 80'

PESCADERO VALLEY (2-26.00)
WELL NUMBER 8S/5W-10K1
GROUND SURFACE ELEVATION 37'

SOQUEL VALLEY (3-01.00)
WELL NUMBER 11S/1W-10C1
GROUND SURFACE ELEVATION 90'

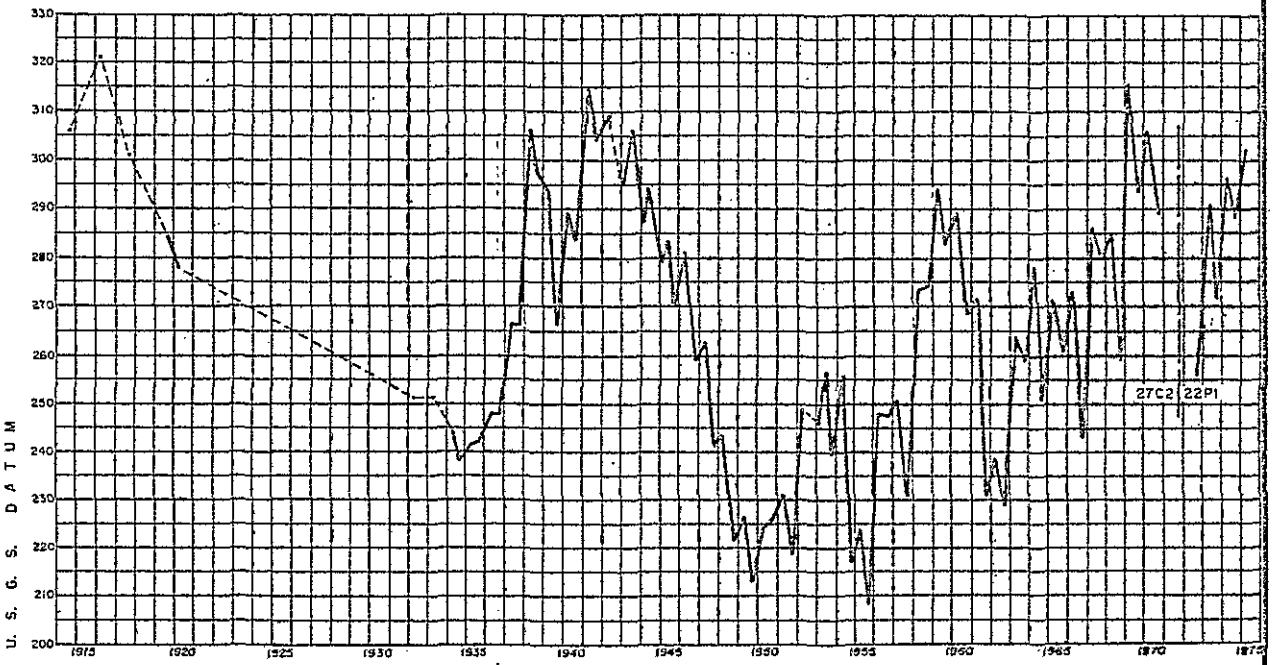
GILROY - HOLLISTER VALLEY
SAN BENITO COUNTY (3-03.02)
WELL NUMBERS 12S/5E-33A1, 33A2
GROUND SURFACE ELEVATION 280'



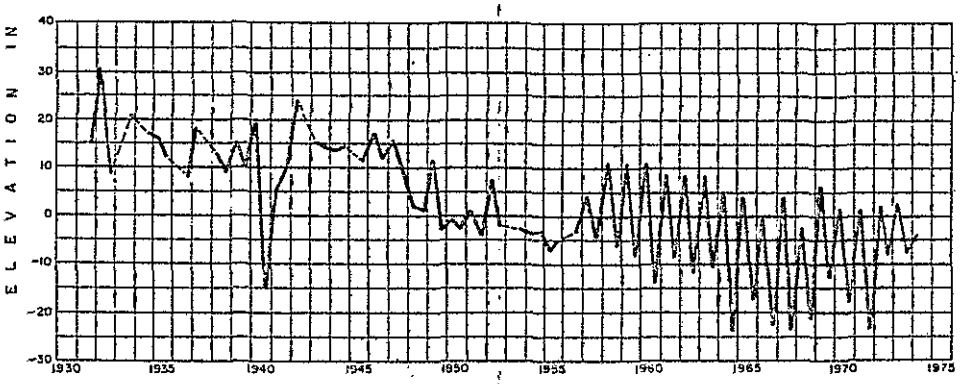
------- CONNECTS MEASUREMENTS MADE AT INTERVALS OF A YEAR OR MORE

FLUCTUATION OF WATER LEVEL IN WELLS

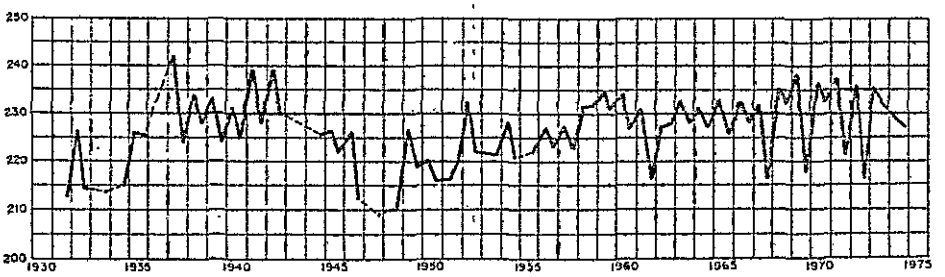
GILROY - HOLLISTER VALLEY
SOUTH SANTA CLARA COUNTY (3-03.01)
WELL NUMBER 9S/3E - 27C2 ,22P1
GROUND SURFACE ELEVATION 347',354'



SALINAS VALLEY
PRESSURE AREA - 400' AQUIFER (3-04.01)
WELL NUMBER 14S/3E - 18J1
GROUND SURFACE ELEVATION 69'



SALINAS VALLEY
UPPER VALLEY AREA (3-04.05)
WELL NUMBER 19S/7E - 10P1
GROUND SURFACE ELEVATION 315'



------- CONNECTS MEASUREMENTS MADE AT INTERVALS OF A YEAR OR MORE

FLUCTUATION OF WATER LEVEL IN WELLS

81. State Department of Water Resources. Bulletin No. 130-75, Hydrologic Data: 1975 Volume IV: San Joaquin Valley, October, 1976

STATE OF CALIFORNIA
The Resources Agency
Department of Water Resources

BULLETIN No. 130-75

HYDROLOGIC DATA: 1975

Volume IV: SAN JOAQUIN VALLEY

CALIFORNIA RESOURCES AGENCY LIBRARY
Resources Building Room 117
1416 9th Street
Sacramento California 95814

OCTOBER 1976

CLAIRE T. DEDRICK
Secretary for Resources
The Resources Agency

EDMUND G. BROWN JR.
Governor
State of California

RONALD B. ROBIE
Director
Department of Water Resources

TABLE OF CONTENTS (Continued)

Page

Appendix C: GROUND WATER MEASUREMENTS 123

Introduction 125

FIGURES

Figure Number

C-1 Fluctuation of Average Water Level in Selected Areas 126

C-2 Fluctuation of Water Levels in Selected Wells 132

TABLES

Table Number

C-1 Change in Average Ground Water Level in Districts or Areas in the San Joaquin Valley . . . 148

C-2 Change in Average Ground Water Level from 1921 to 1951 and 1951 to 1975 in 18 Ground Water Areas in the San Joaquin Valley 151

C-3 Ground Water Levels at Wells 152

Appendix D: SURFACE WATER QUALITY 161

Introduction 163

TABLES

Table Number

D-1 Sampling Station Data and Index for Surface Water 164

D-2 Mineral Analyses of Surface Water 167

D-3 Minor Element Analyses of Surface Water 181

D-4 Miscellaneous Constituents of Surface Water 183

D-5 Nutrient Constituents of Surface Water 192

D-6 Pesticides in Surface Water 199

Appendix E: GROUND WATER QUALITY 201

Introduction 203

TABLES

Table Number

E-1 Mineral Analyses of Ground Water 204

E-2 Minor Element Analyses of Ground Water 231

E-3 Supplemental Minor Element Analyses of Ground Water 240

PLATES
(Bound at end of volume)

Plate Number

1 Ground Water Areas and Selected Observation Wells

2 Map of Selected Ground Water Areas in San Joaquin Valley and Profiles Along Section A-A' Showing Ground Water Levels in 1921, 1951 and 1975

3 Lines of Equal Elevation of Water in Wells, San Joaquin Valley, Spring 1975

4 Lines of Equal Change of Water Levels in Wells, Pressure Surface and Unconfined Aquifers, San Joaquin Valley, Spring 1970 to Spring 1975

TABLE OF CONTENTS

	Page
AREAL COVERAGE OF VOLUMES	ii
FOREWORD	iii
METRIC CONVERSION TABLE	iv
ORGANIZATION, DEPARTMENT OF WATER RESOURCES	vii
ACKNOWLEDGMENTS	ix
ABSTRACT	x

APPENDIXES

Appendix A: CLIMATOLOGICAL DATA	1
Introduction	3

FIGURES

Figure Number		
A-1	Climatological Observation Stations	4

TABLES

Table Number		
A-1	Index of Climatological Stations	11
A-2	Precipitation Data	18
A-3	Storage Gage Precipitation Data	22
Appendix B: SURFACE WATER MEASUREMENTS		23
Introduction		25
Alphabetical Index to Tables		26
Hydrographic Area and Stream Basin Index to Surface Water Measurement Stations		27
Unimpaired Runoff		34
Daily Mean Discharge		37
Diversions		93
Daily Mean Gage Heights		100

FIGURES

Figure Number		
B-1	Surface Water Measurement and Quality Surveillance Stations	28

TABLES

Table Number		
B-1	Annual Unimpaired Runoff	35
B-2	Monthly Unimpaired Runoff	36
B-3	Daily Mean Discharge	38
B-4	Diversions -- San Joaquin River, Fremont Ford Bridge to Gravelly Ford	94
B-5	Diversions and Acreage Irrigated -- Eastside Canals and Irrigation Districts	95
B-6	Deliveries from Central Valley Project Canals	96
B-7	Deliveries from California Aqueduct	98
B-8	Imports and Exports	99
B-9	Daily Mean Gage Heights	101
B-10	Corrections and Revisions to Previously Published Reports	118

INTRODUCTION

The Department of Water Resources cooperates with the U. S. Geological Survey, U. S. Bureau of Reclamation, irrigation and water storage districts, and other local agencies for the systematic observation of ground water levels. The Department obtains approximately 13,000 water level measurements annually on some 7,500 wells in the San Joaquin Valley. The period of record for these wells varies from one to over 40 years. In preparation of the ground water maps most of the well measurements were used. However, because significant trends in water level fluctuations can be indicated by a representative sample, a selection was made of approximately 500 wells for reporting of actual measurements.

This appendix presents ground water measurement data on these wells for the period October 1, 1974, through September 30, 1975. These wells were selected as being representative of all the wells measured in the area and are designated as selected wells. Their selection is based on a number of factors, including areal distribution, length of water level record, frequency of measurements, conformity with respect to water level fluctuation in the ground water basin or area in a confined aquifer, or in a zone of shallow depth, and availability of a log, mineral analyses, and production record.

Two numbering systems are used by the Department to facilitate processing of water level measurement data. The two systems are the Region and Basin Designation and the State Well Numbering System as described below.

The regions used in this report are geographic areas defined in Section 13040 of the Water Code. That portion of California covered by this volume comprises the southern portion of Central Valley Region No. 5. A decimal system of the form 0-00.00 has been selected according to geographic regions, ground water basins, and district or area as follows:

5-22.15

Region (Central Valley Region)

Ground Water Basin (San Joaquin Valley)

District or area (Fresno Irrigation District)

The State Well Numbering System is based on township, range, and section subdivisions of the Public Land Survey. The number of a well, assigned in accordance with this system, is referred to as the State Well Number, as illustrated below:

13S / 19E - 16 K 01 M

Township

Range

Section

Tract

Sequence Number

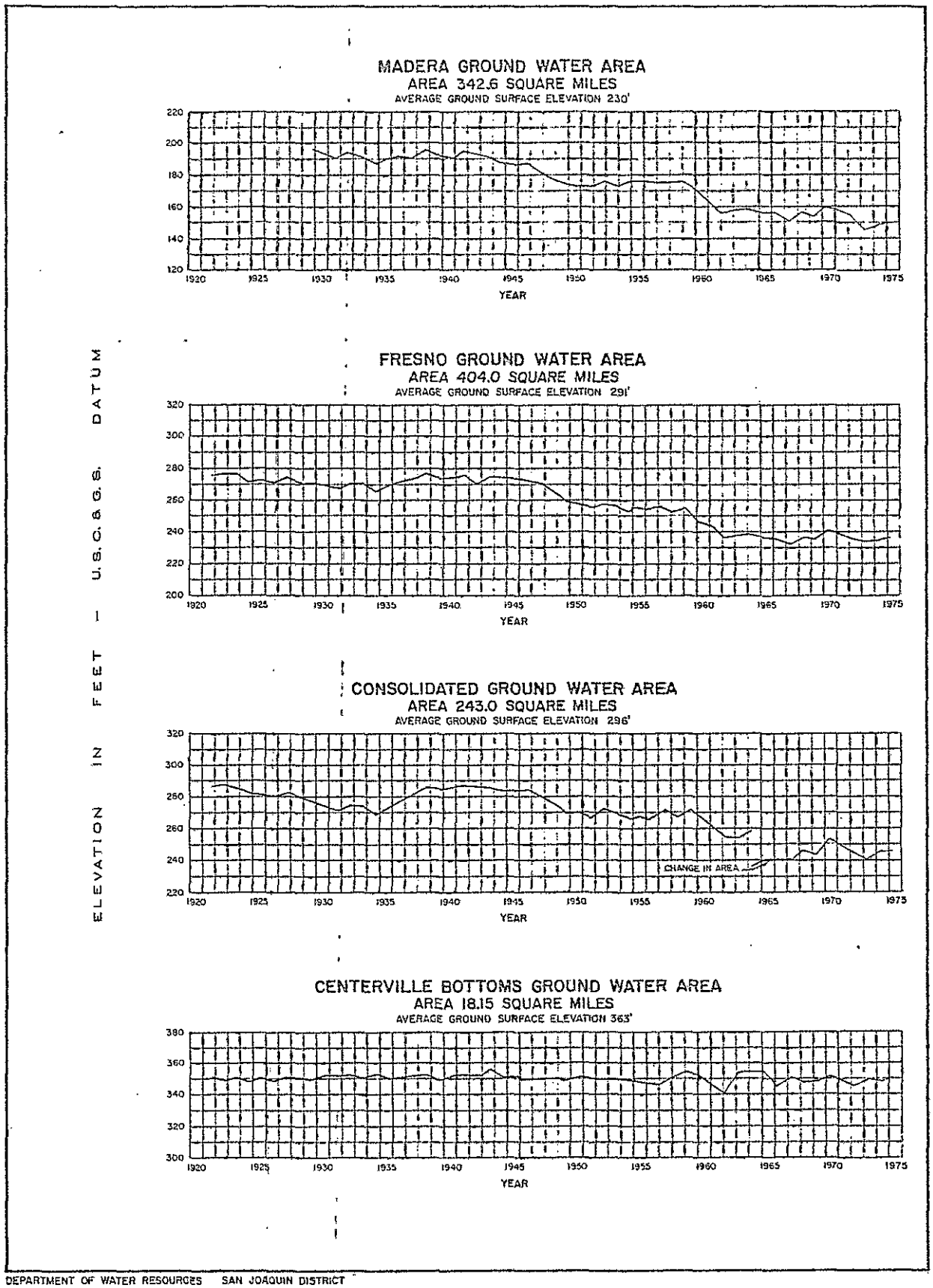
Base and Meridian (M) Mount Diablo (S) San Bernardino

This number identifies and locates the well. In the example, the well is in Township 13 South, Range 19 East, Tract K of Section 16, located in the Mount Diablo Base and Meridian. A section is divided into 40-acre tracts as follows:

D	C	B	A
E	F	G	H
M	L	K	J
N	P	Q	R

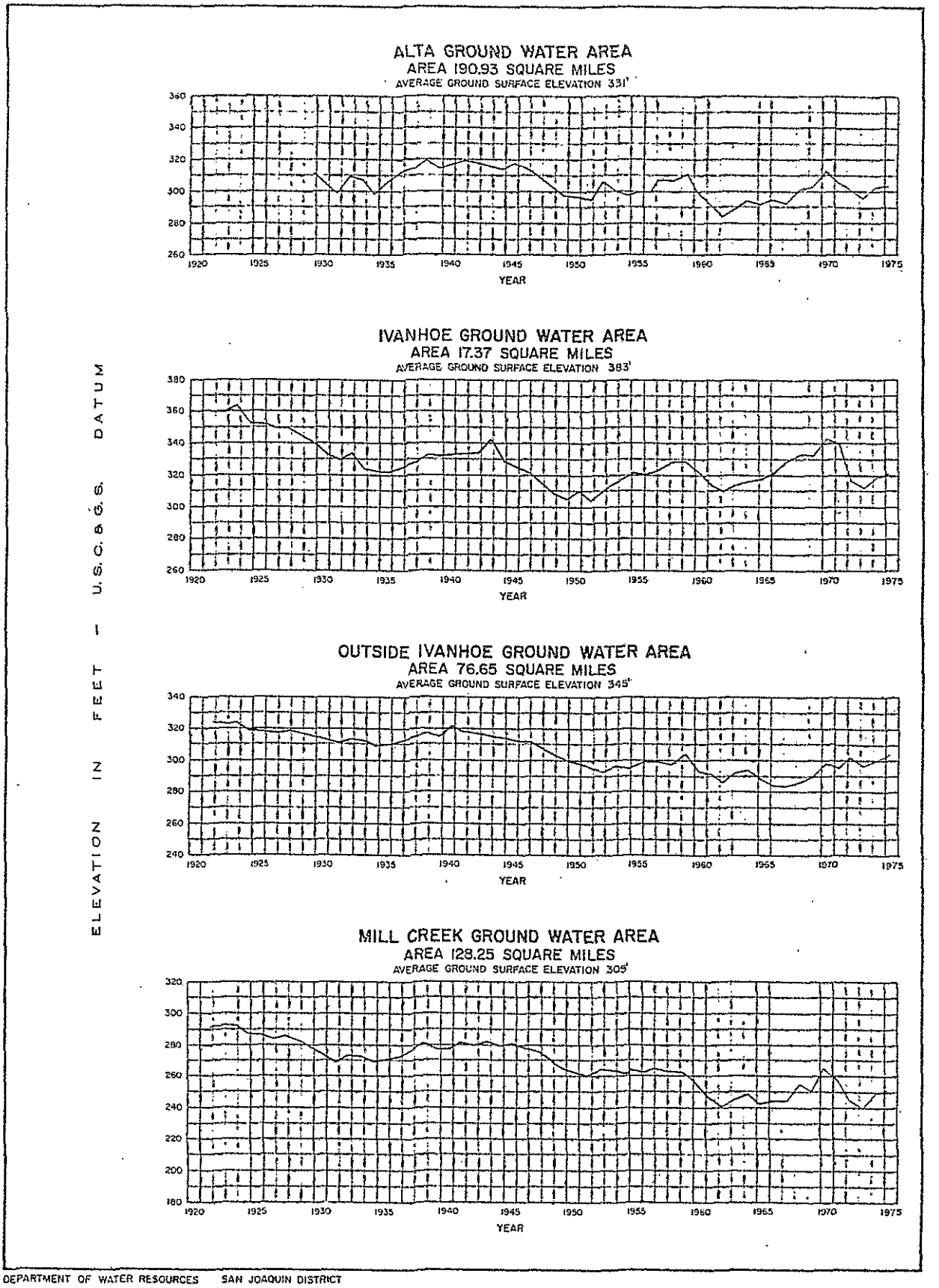
Sequence numbers in a tract are generally assigned in chronological order. The example designates the first well to be assigned a number in Tract K.

Figure C-1. FLUCTUATION OF AVERAGE WATER LEVEL IN SELECTED AREAS



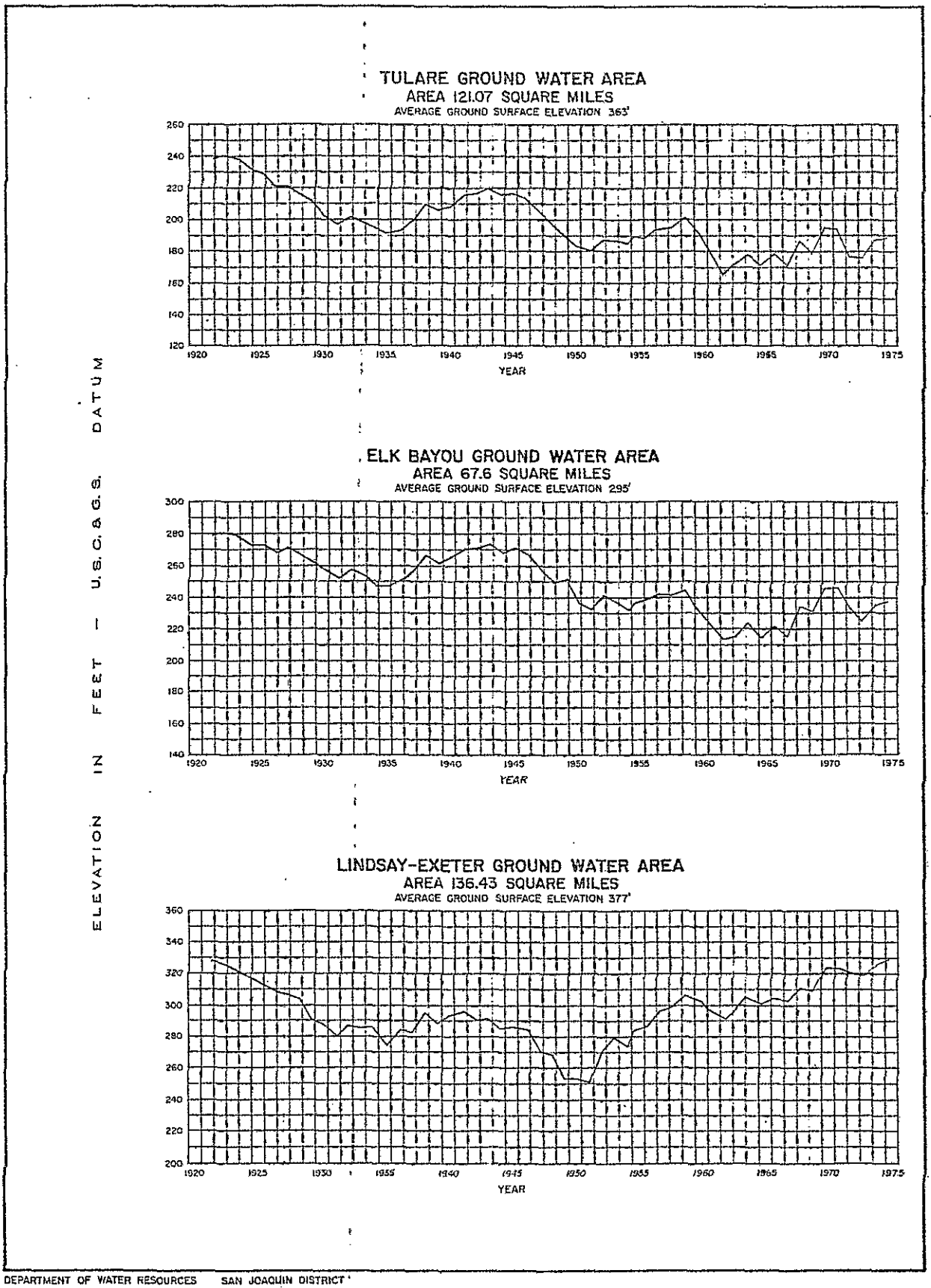
DEPARTMENT OF WATER RESOURCES SAN JOAQUIN DISTRICT

Figure C-1 (Continued). FLUCTUATION OF AVERAGE WATER LEVEL IN SELECTED AREAS



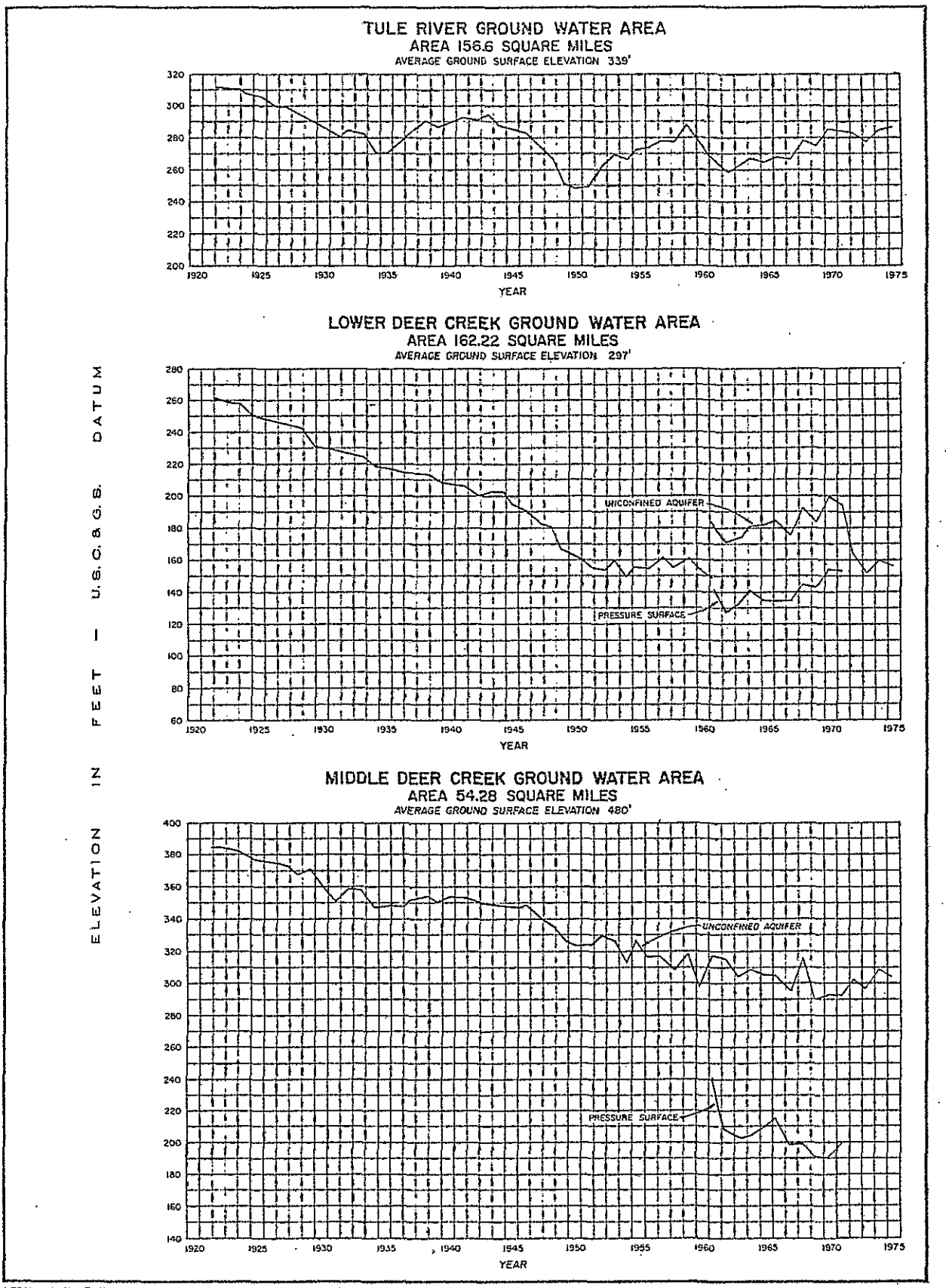
DEPARTMENT OF WATER RESOURCES SAN JOAQUIN DISTRICT

Figure C-1 (Continued). FLUCTUATION OF AVERAGE WATER LEVEL IN SELECTED AREAS



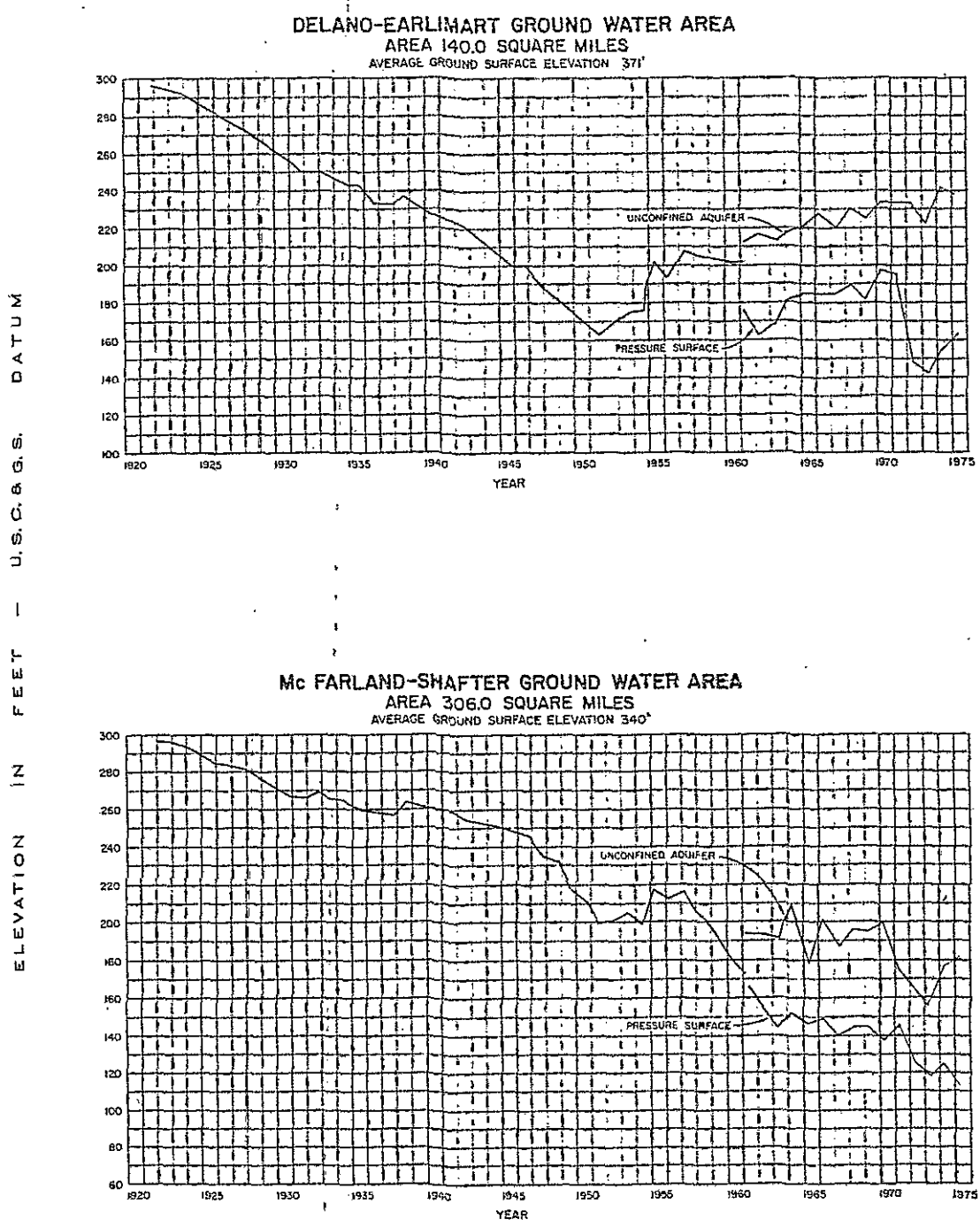
DEPARTMENT OF WATER RESOURCES SAN JOAQUIN DISTRICT

Figure C-I (Continued). FLUCTUATION OF AVERAGE WATER LEVEL IN SELECTED AREAS



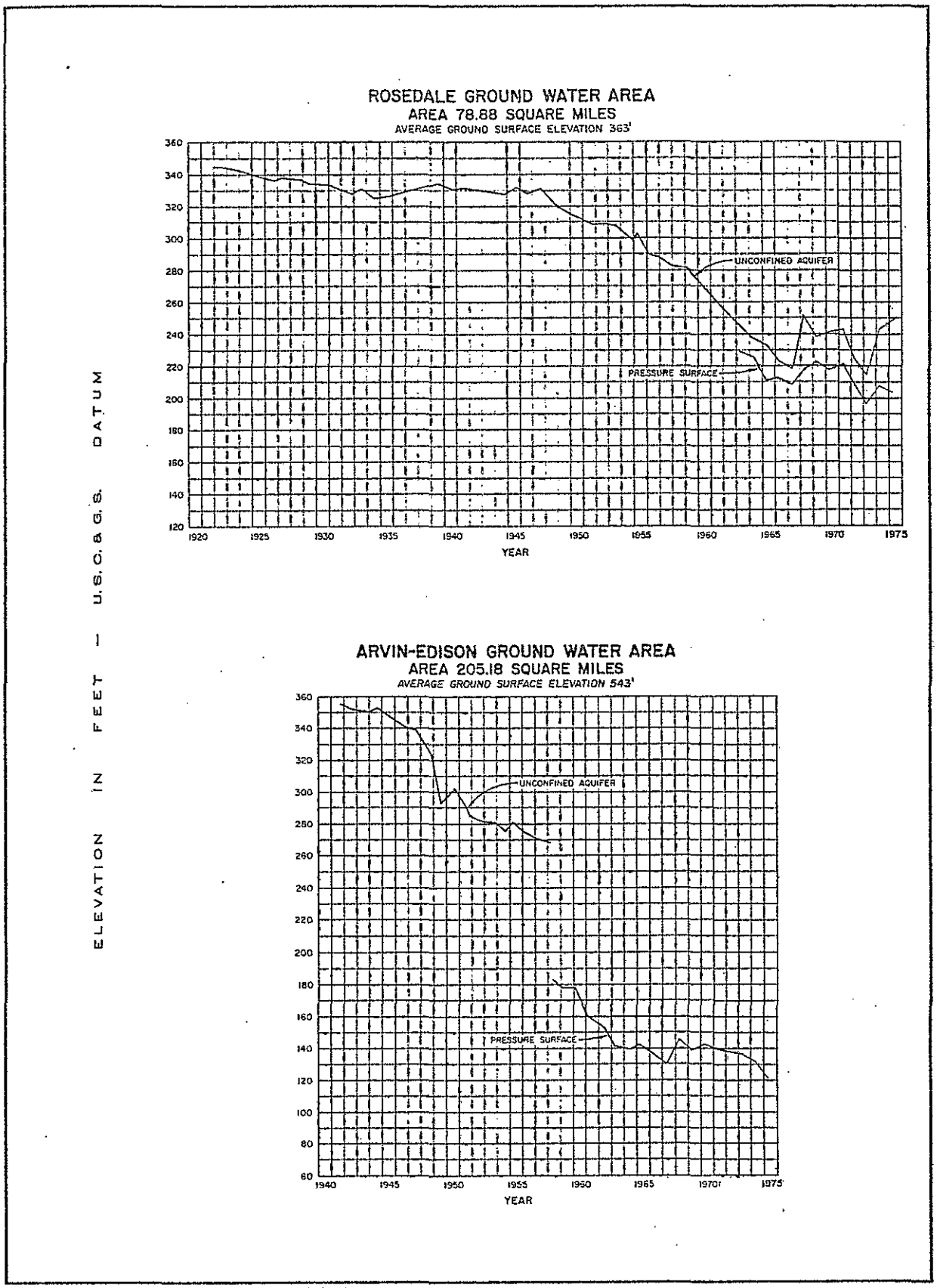
DEPARTMENT OF WATER RESOURCES SAN JOAQUIN DISTRICT

Figure C-I (Continued). FLUCTUATION OF AVERAGE WATER LEVEL IN SELECTED AREAS



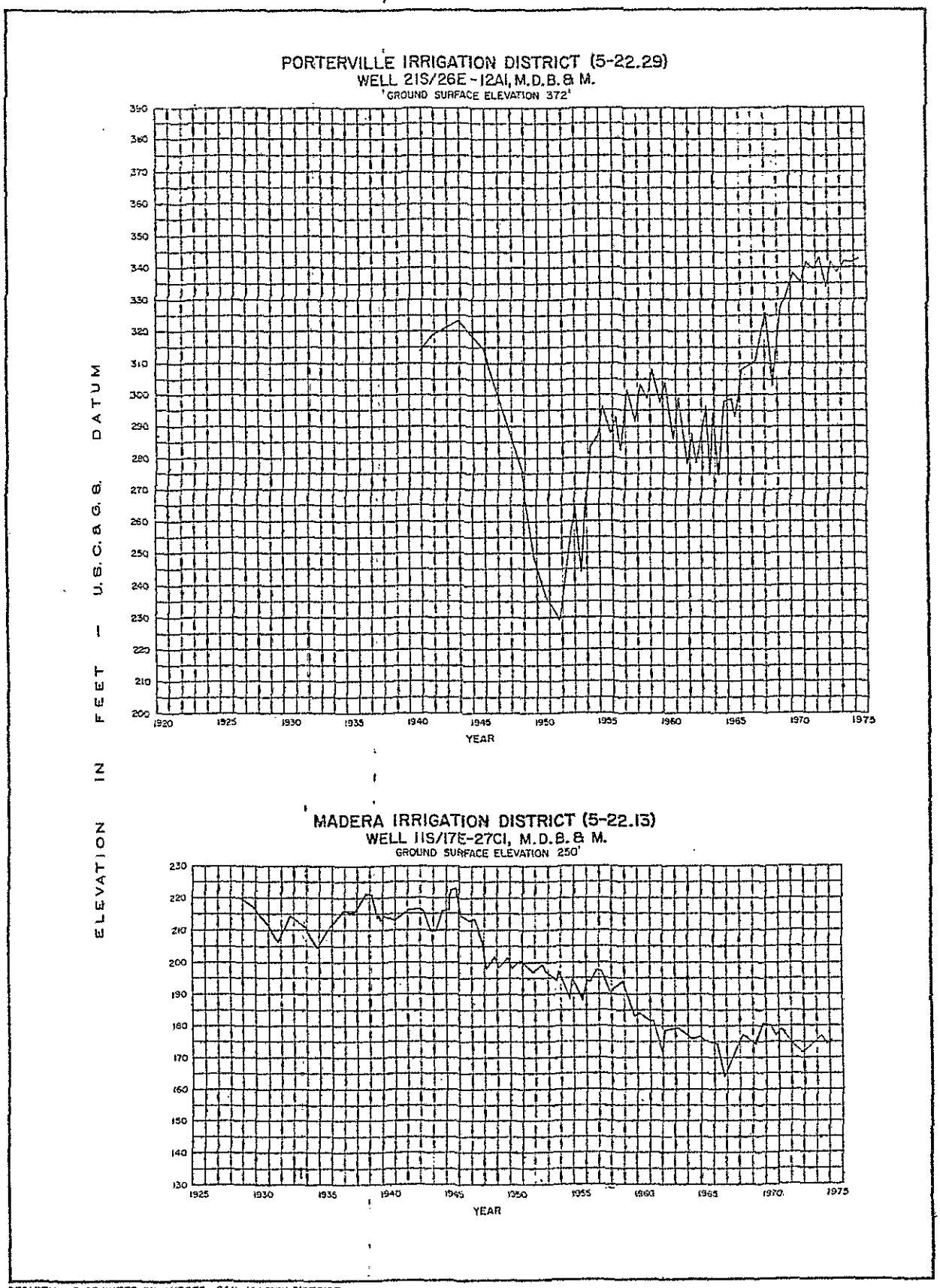
DEPARTMENT OF WATER RESOURCES SAN JOAQUIN DISTRICT

Figure C-I (Continued). FLUCTUATION OF AVERAGE WATER LEVEL IN SELECTED AREAS



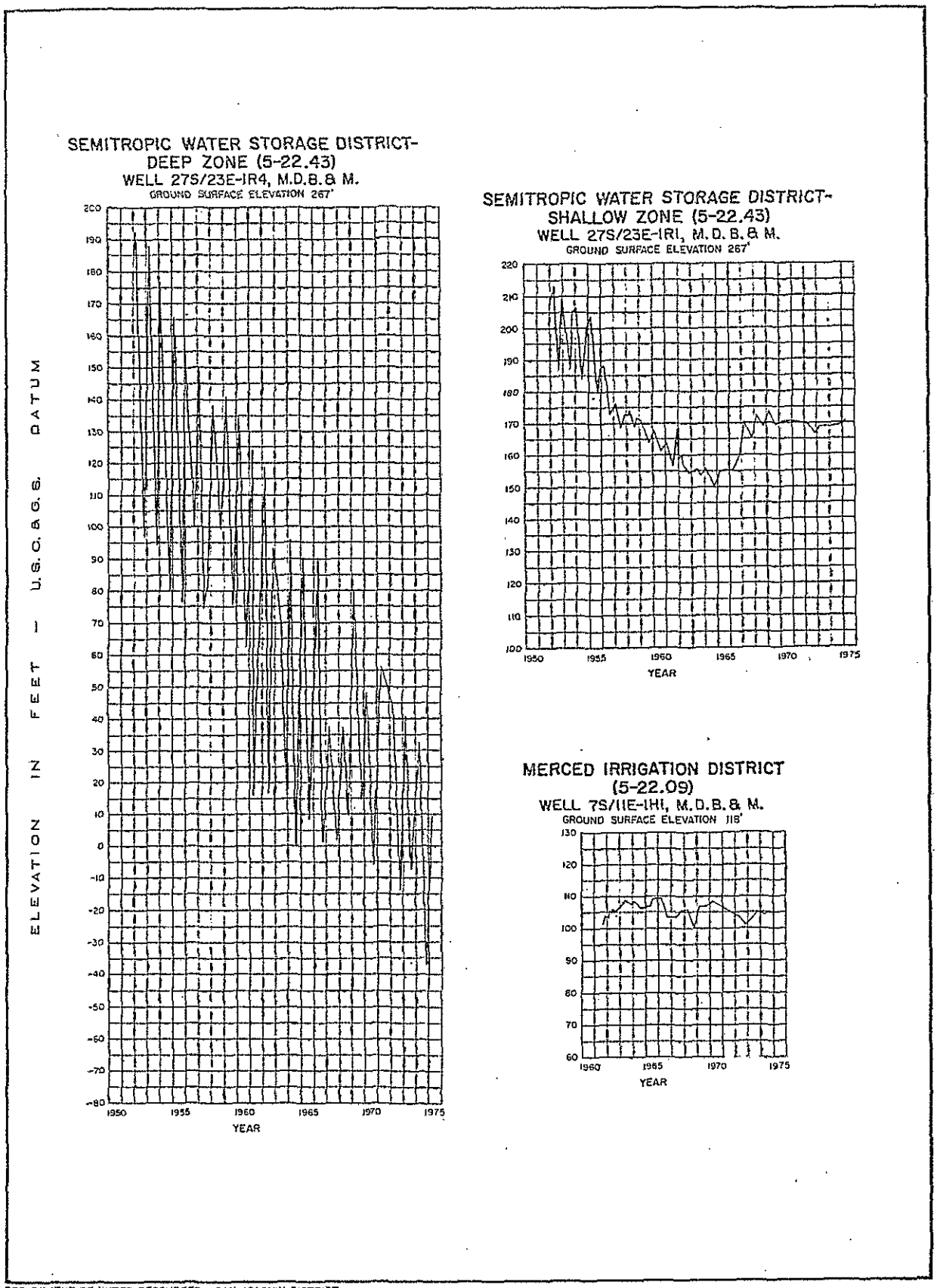
DEPARTMENT OF WATER RESOURCES SAN JOAQUIN DISTRICT

Figure C-2. FLUCTUATION OF WATER LEVELS IN SELECTED WELLS



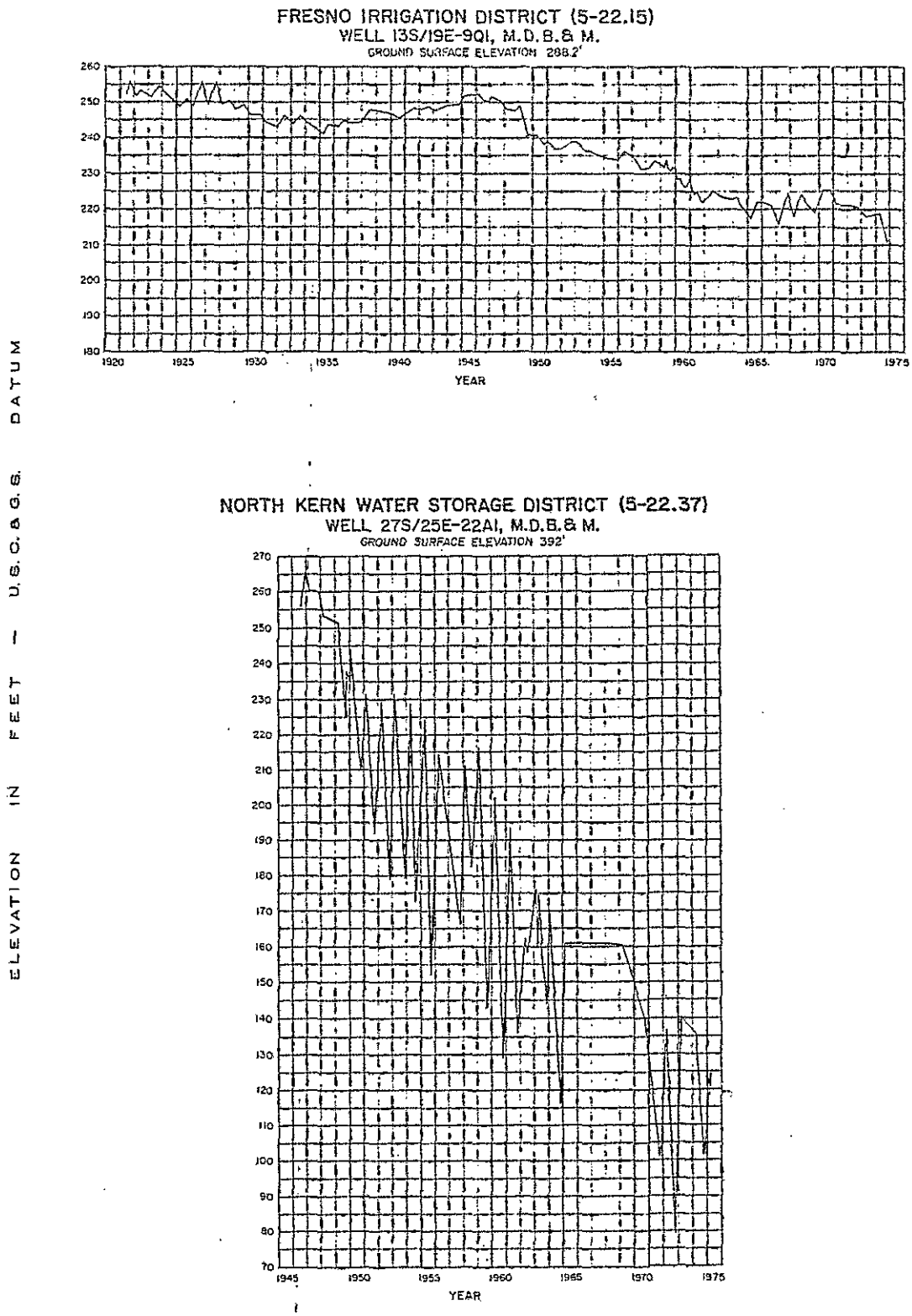
DEPARTMENT OF WATER RESOURCES SAN JOAQUIN DISTRICT

Figure C-2 (Continued). FLUCTUATION OF WATER LEVELS IN SELECTED WELLS



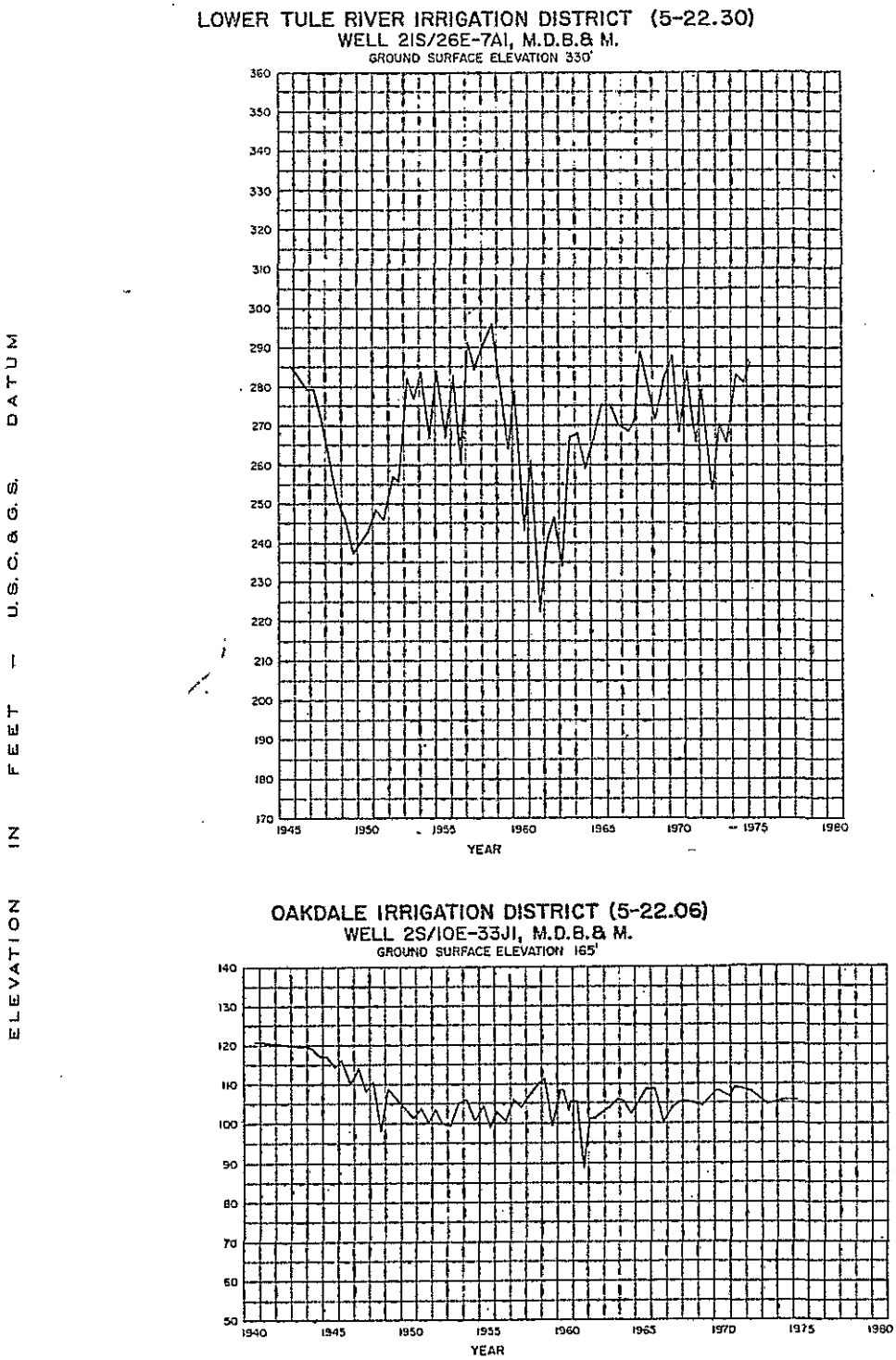
DEPARTMENT OF WATER RESOURCES SAN JOAQUIN DISTRICT

Figure C-2 (Continued). FLUCTUATION OF WATER LEVELS IN SELECTED WELLS



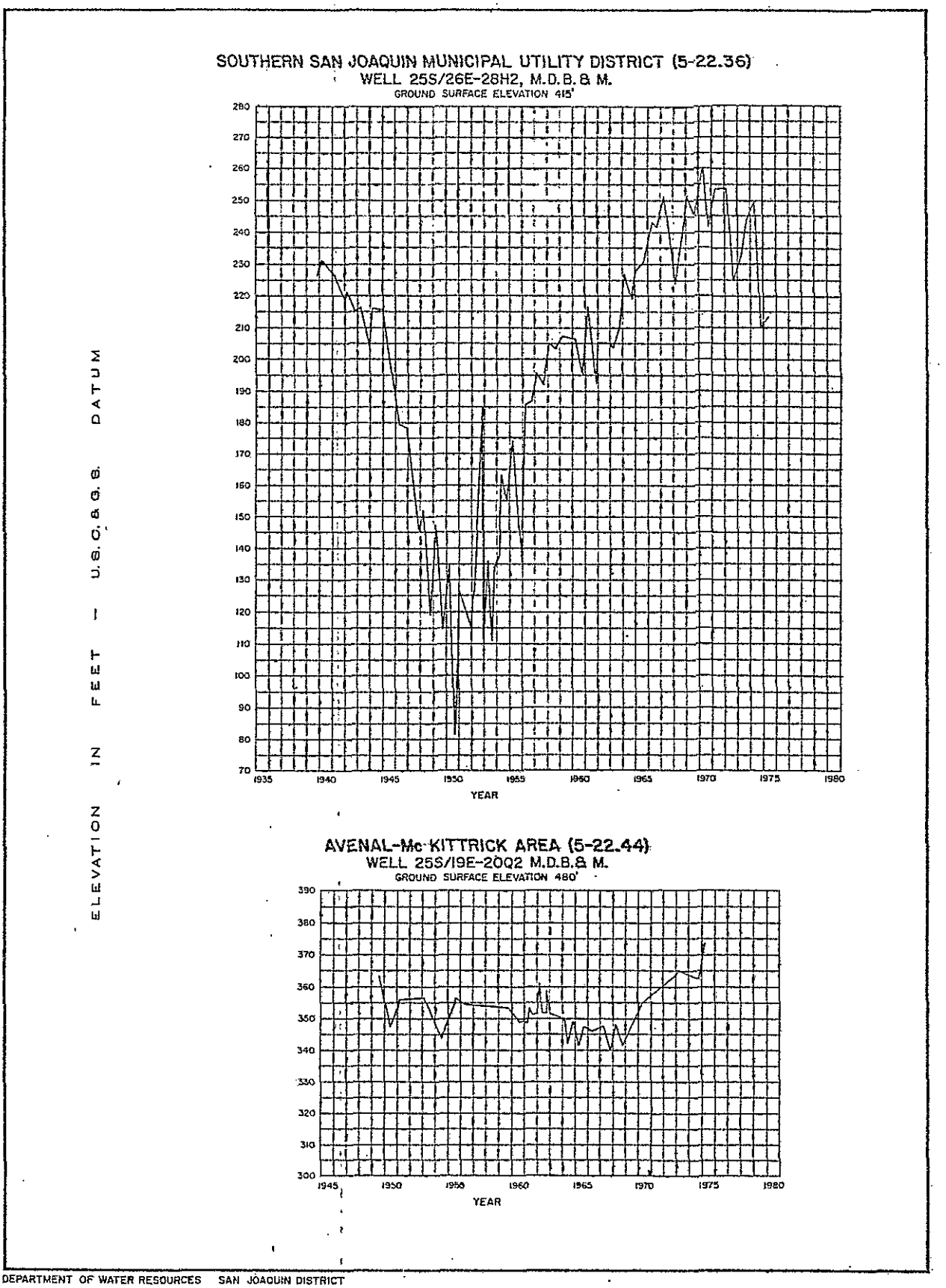
DEPARTMENT OF WATER RESOURCES SAN JOAQUIN DISTRICT

Figure C-2 (Continued). FLUCTUATION OF WATER LEVELS IN SELECTED WELLS



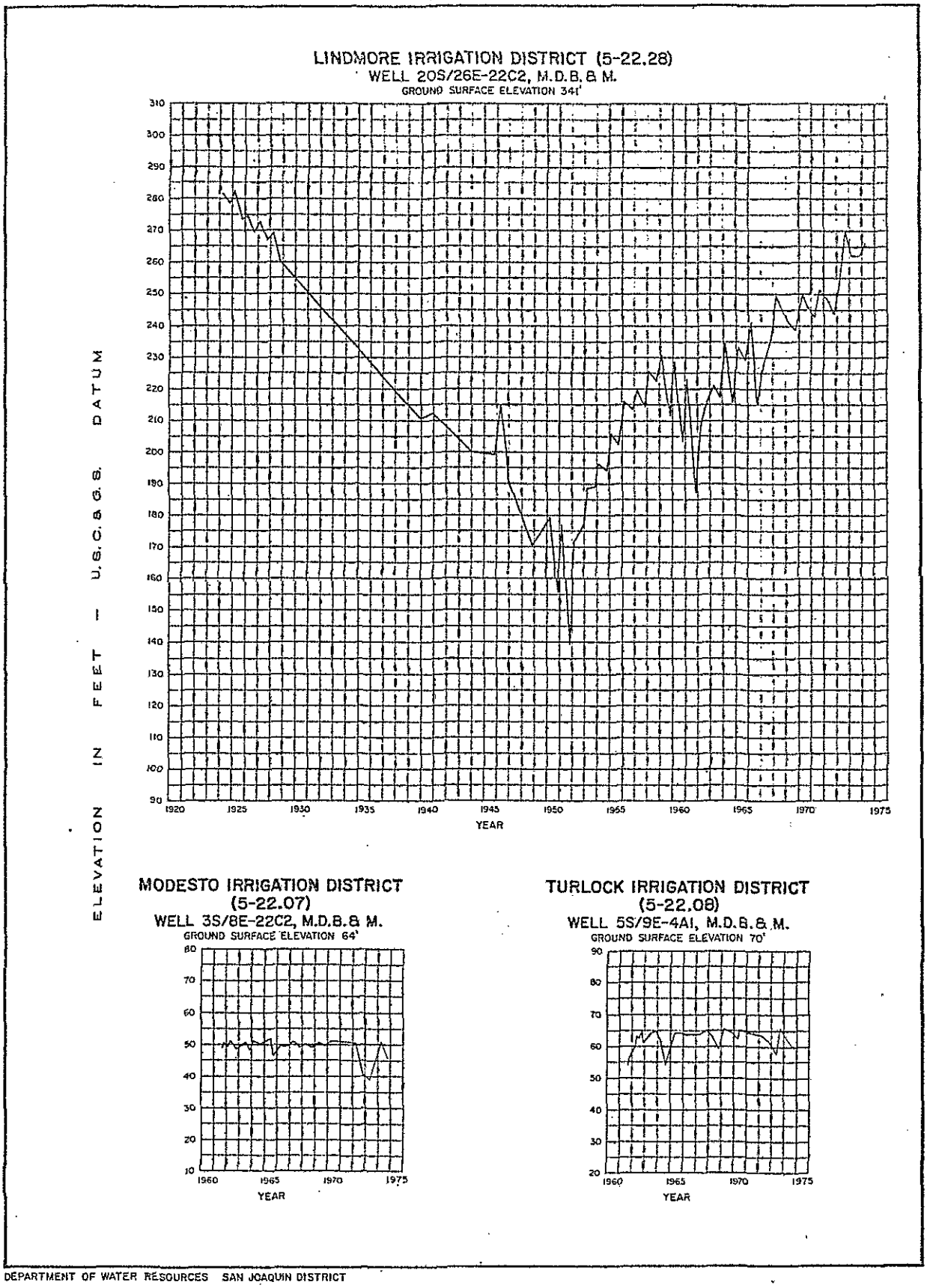
DEPARTMENT OF WATER RESOURCES SAN JOAQUIN DISTRICT

Figure C-2 (Continued). FLUCTUATION OF WATER LEVELS IN SELECTED WELLS



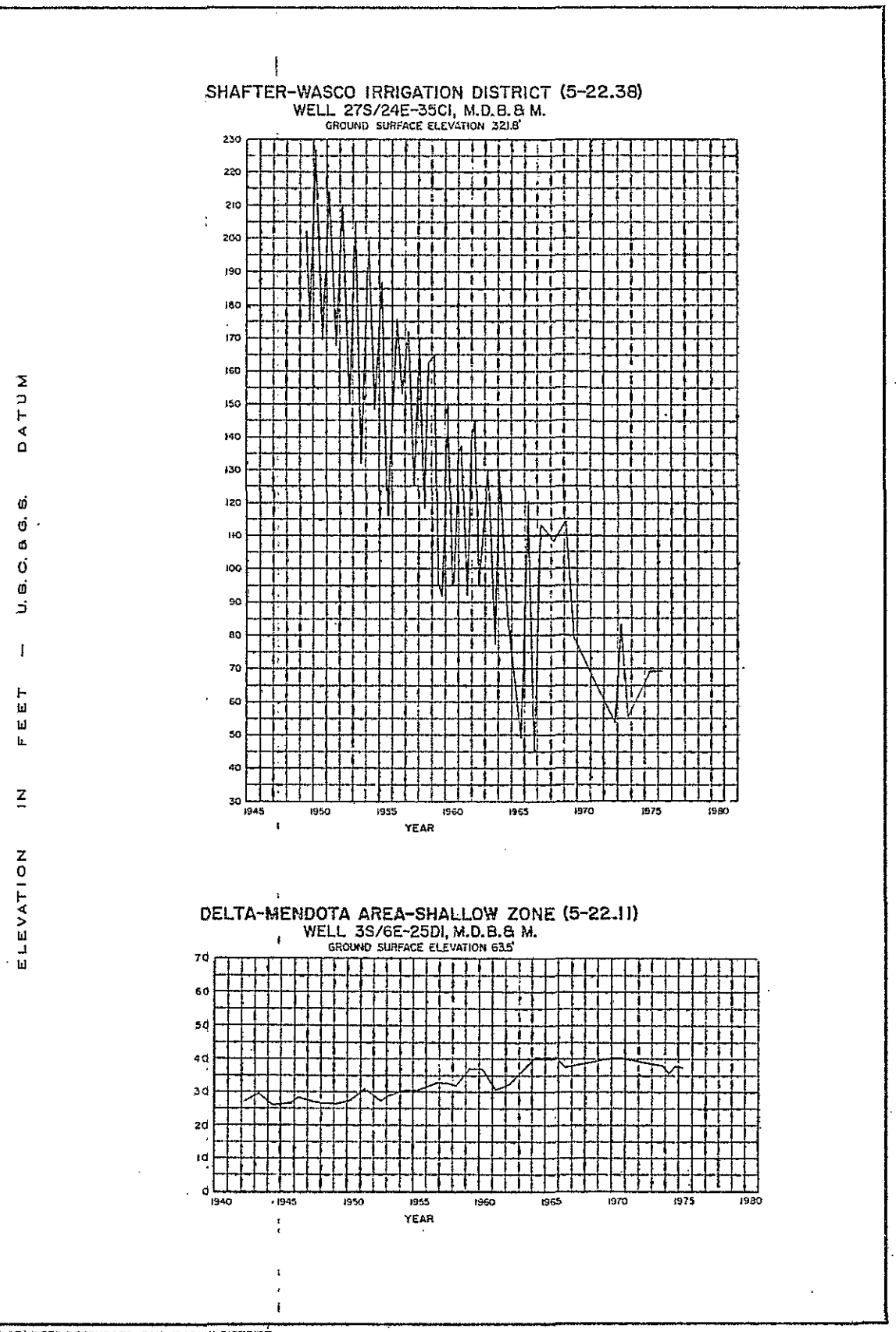
DEPARTMENT OF WATER RESOURCES SAN JOAQUIN DISTRICT

Figure C-2 (Continued). FLUCTUATION OF WATER LEVELS IN SELECTED WELLS



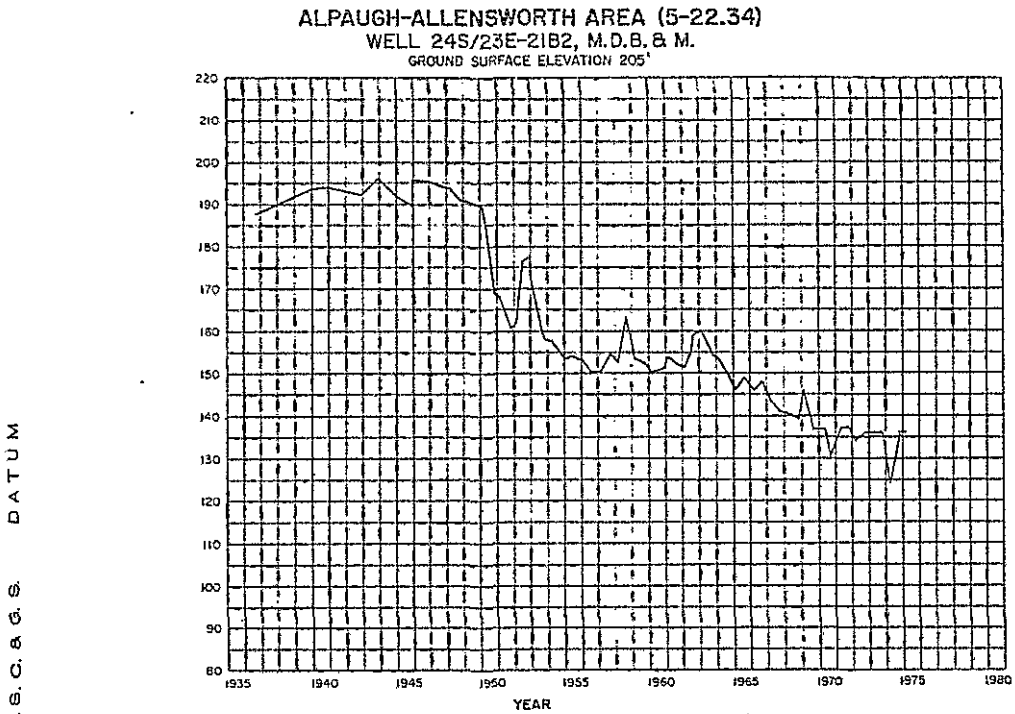
DEPARTMENT OF WATER RESOURCES SAN JOAQUIN DISTRICT

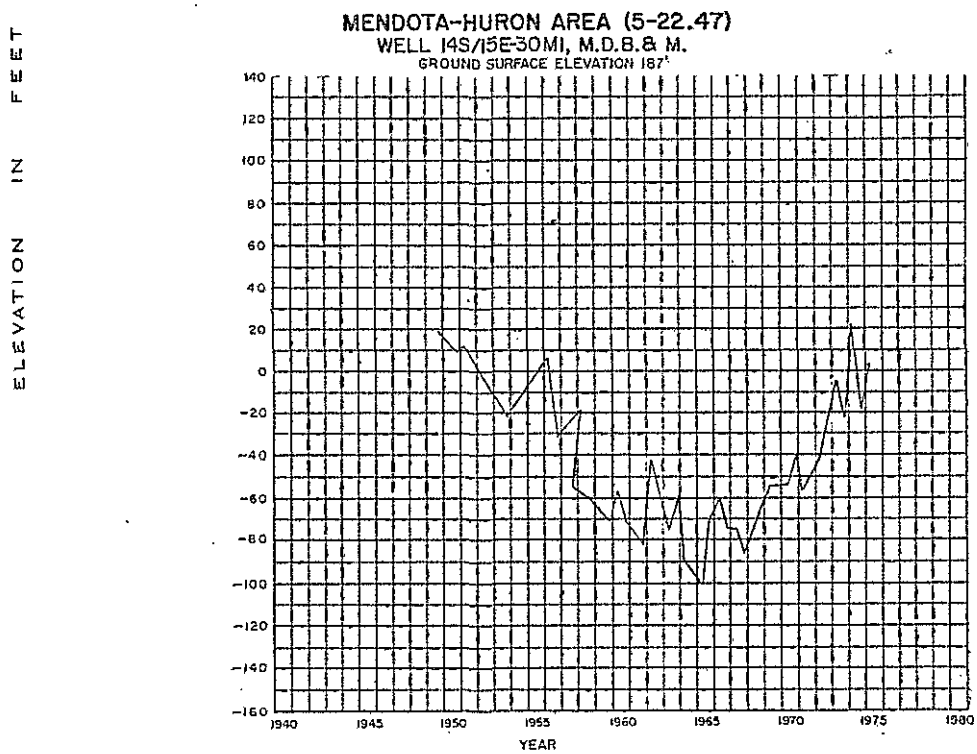
Figure C-2 (Continued). FLUCTUATION OF WATER LEVELS IN SELECTED WELLS



DEPARTMENT OF WATER RESOURCES SAN JOAQUIN DISTRICT

Figure C-2 (Continued). FLUCTUATION OF WATER LEVELS IN SELECTED WELLS

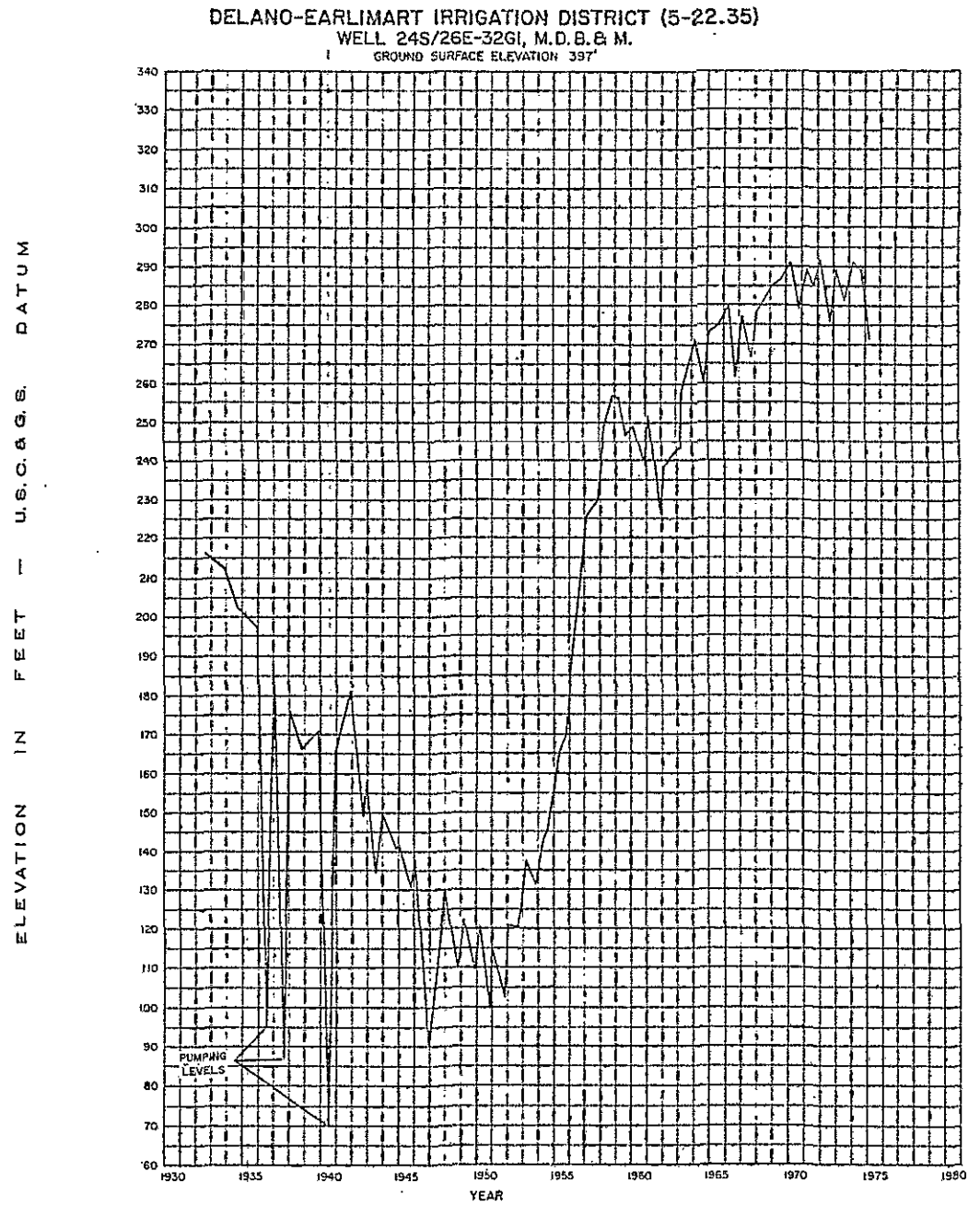




ELEVATION IN FEET - U.S.C.& G.S. DATUM

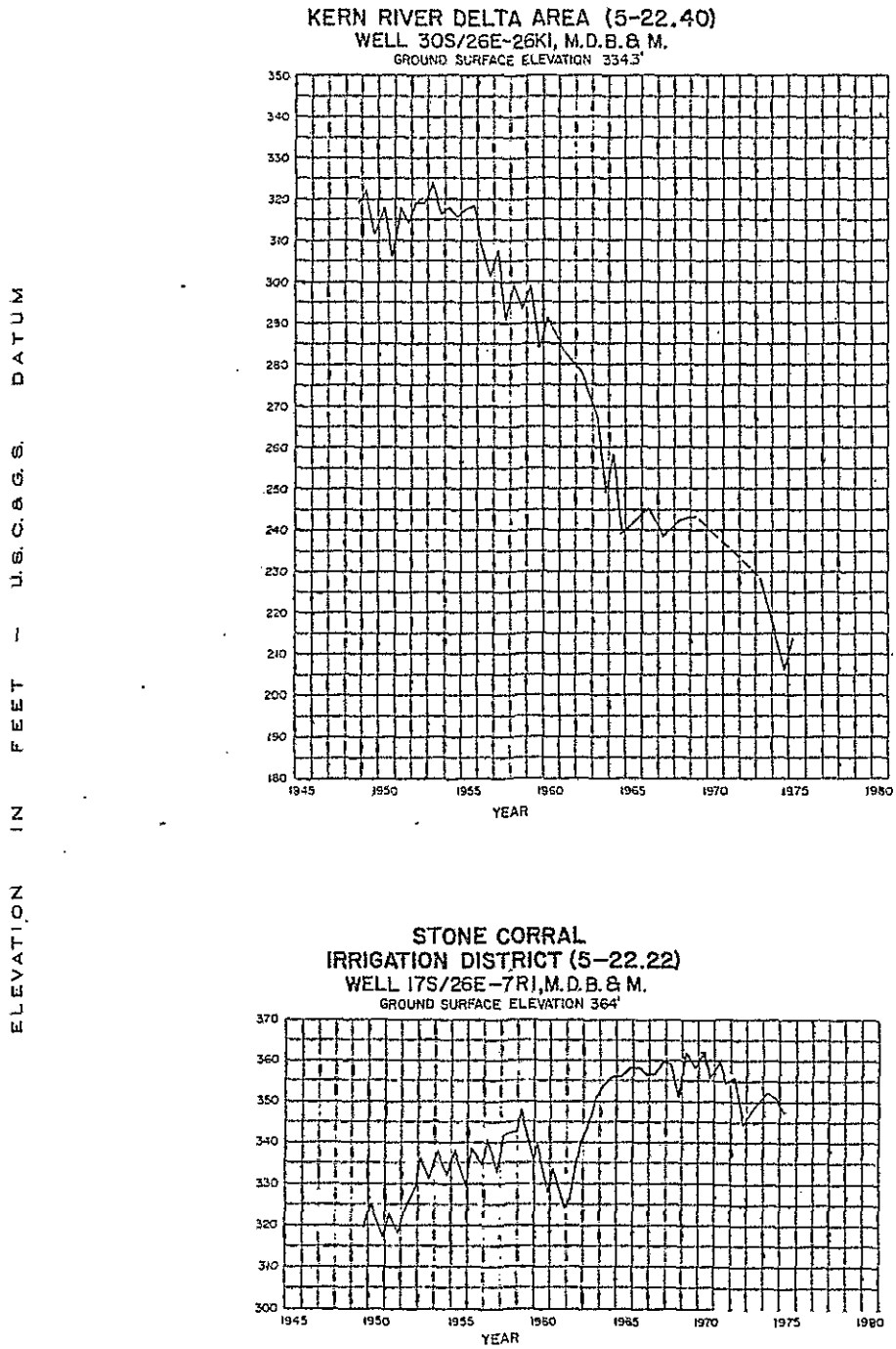
DEPARTMENT OF WATER RESOURCES SAN JOAQUIN DISTRICT

Figure C-2 (Continued). FLUCTUATION OF WATER LEVELS IN SELECTED WELLS



DEPARTMENT OF WATER RESOURCES SAN JOAQUIN DISTRICT

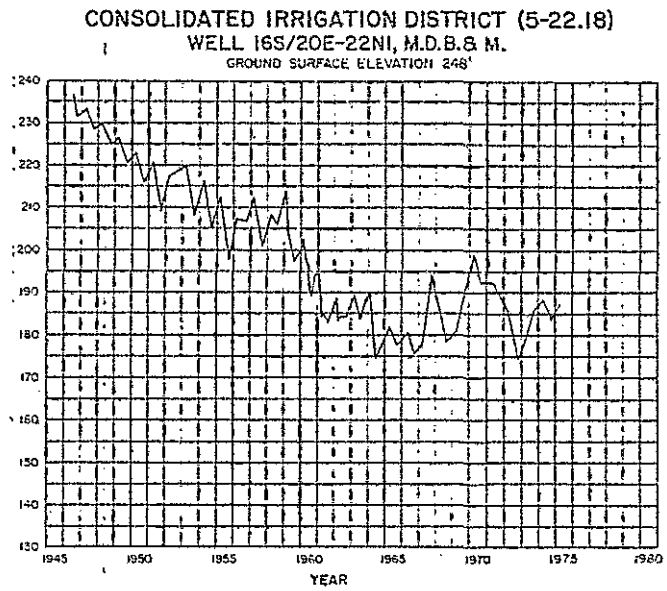
Figure C-2 (Continued). FLUCTUATION OF WATER LEVELS IN SELECTED WELLS

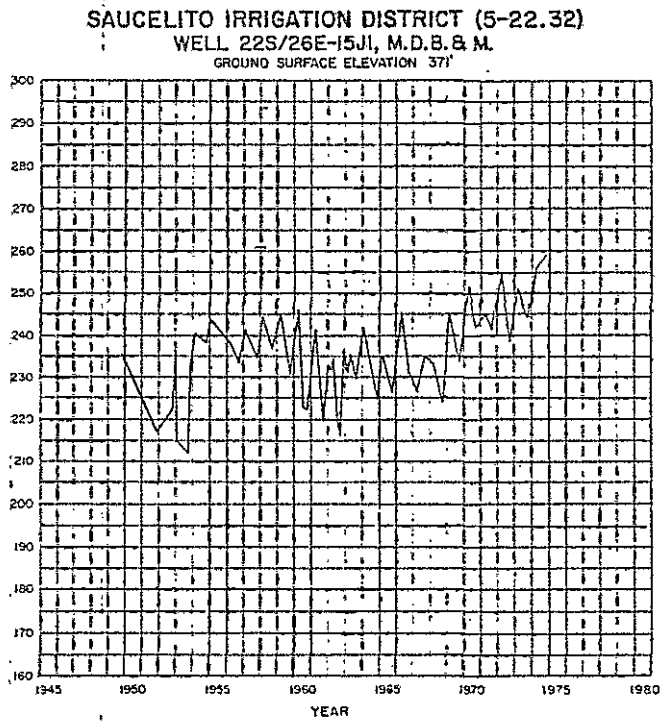


DEPARTMENT OF WATER RESOURCES SAN JOAQUIN DISTRICT

Figure C-2 (Continued). FLUCTUATION OF WATER LEVELS IN SELECTED WELLS

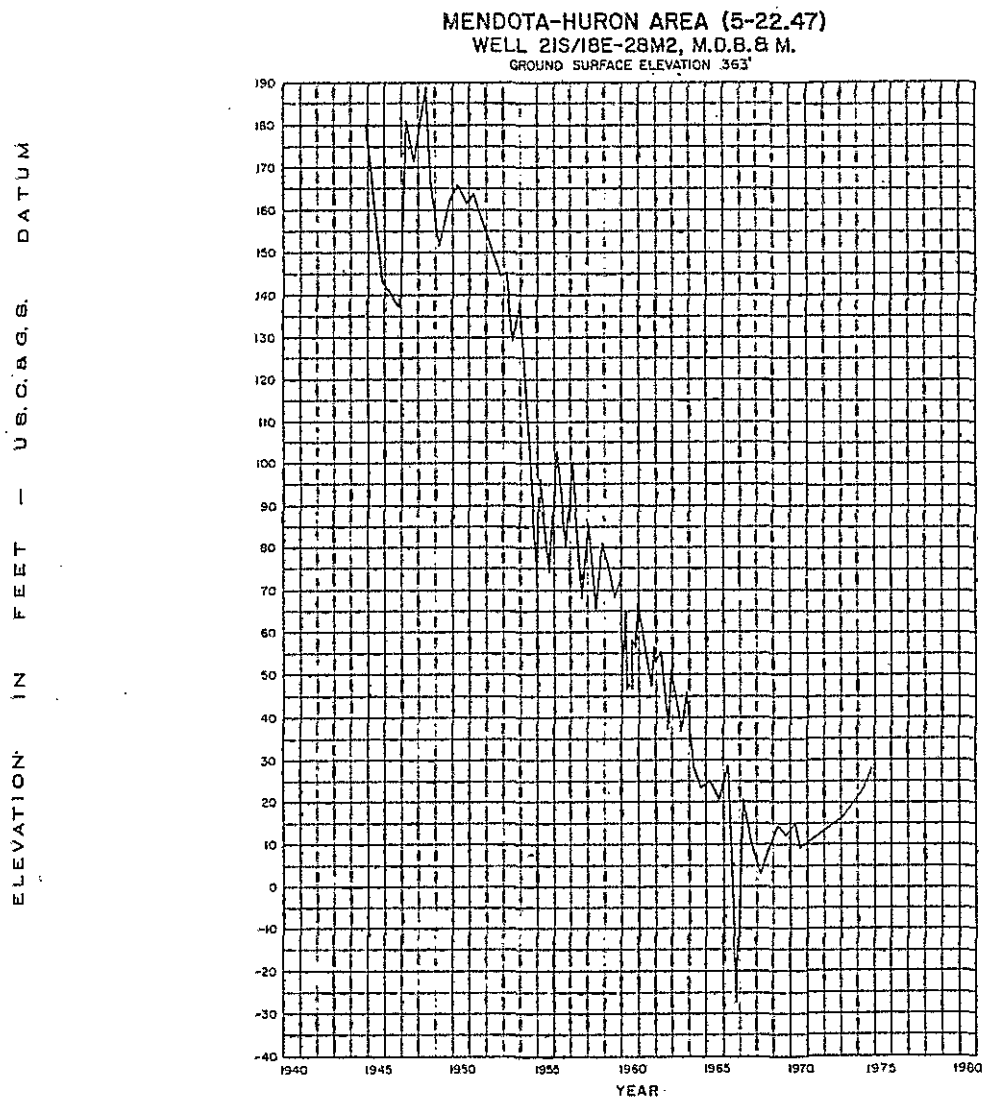
ELEVATION IN FEET - U.S.C.&G.S. DATUM





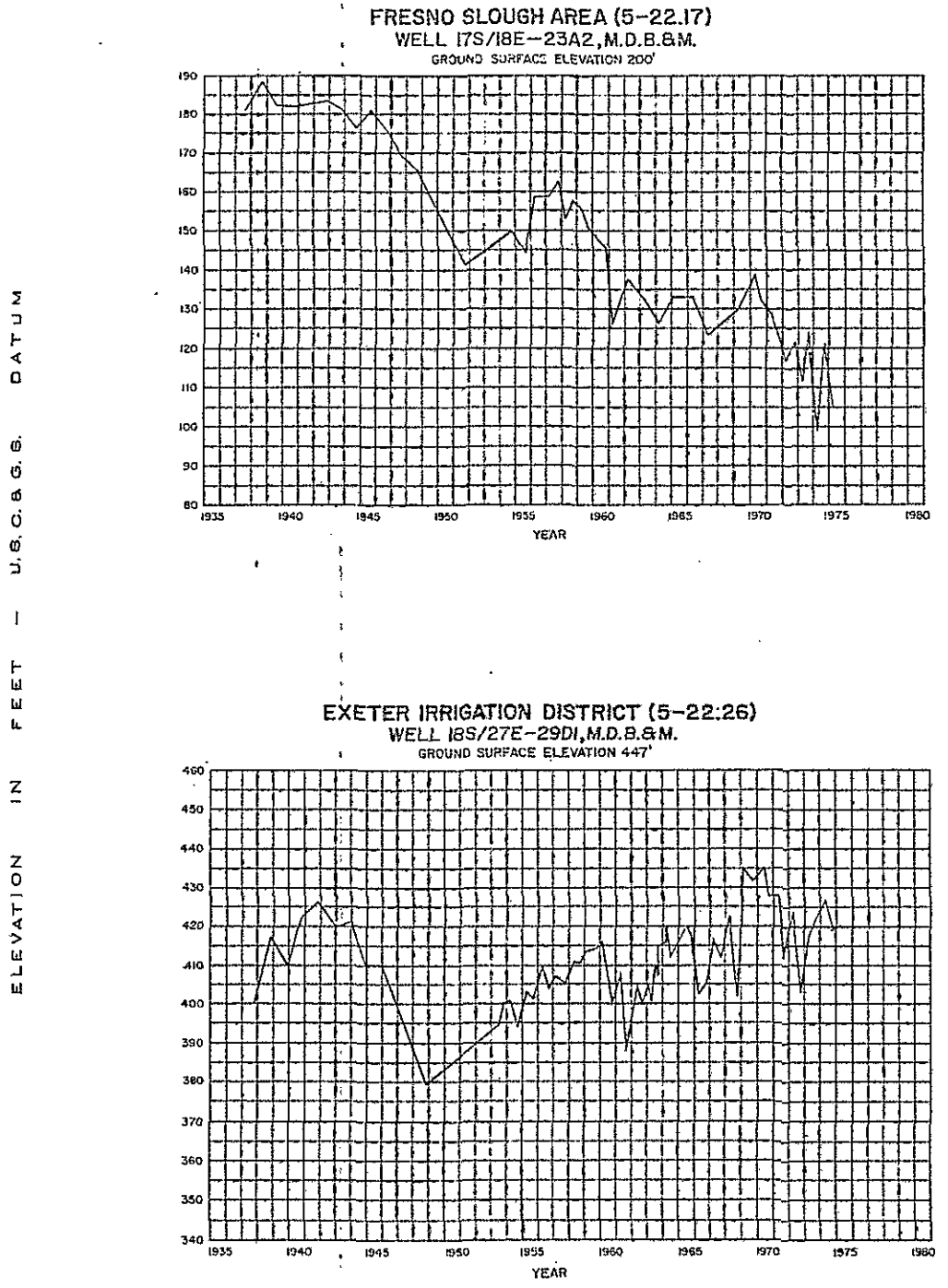
DEPARTMENT OF WATER RESOURCES SAN JOAQUIN DISTRICT

Figure C-2 (Continued). FLUCTUATION OF WATER LEVELS IN SELECTED WELLS



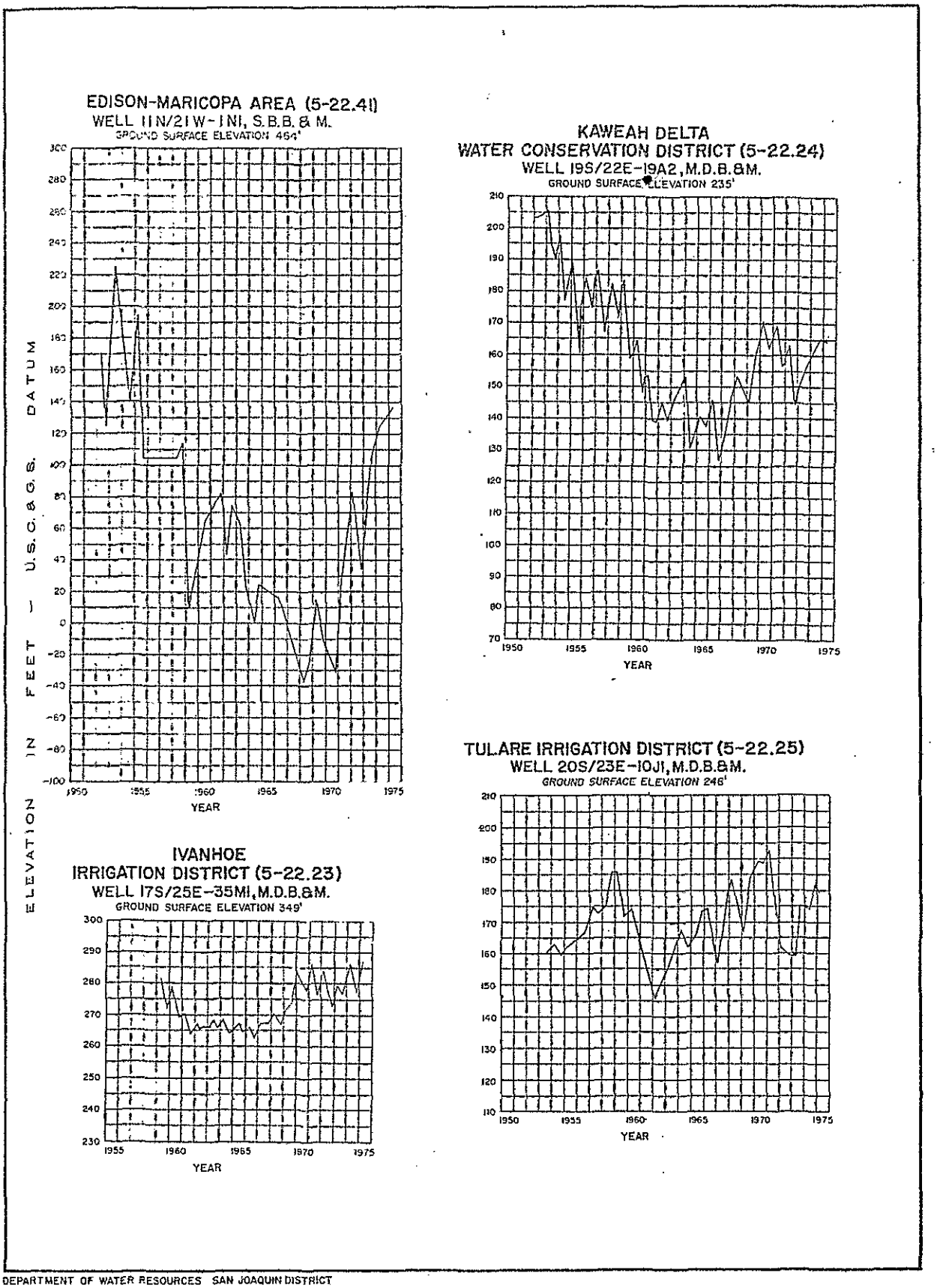
DEPARTMENT OF WATER RESOURCES SAN JOAQUIN DISTRICT

Figure C-2 (Continued). FLUCTUATION OF WATER LEVELS IN SELECTED WELLS



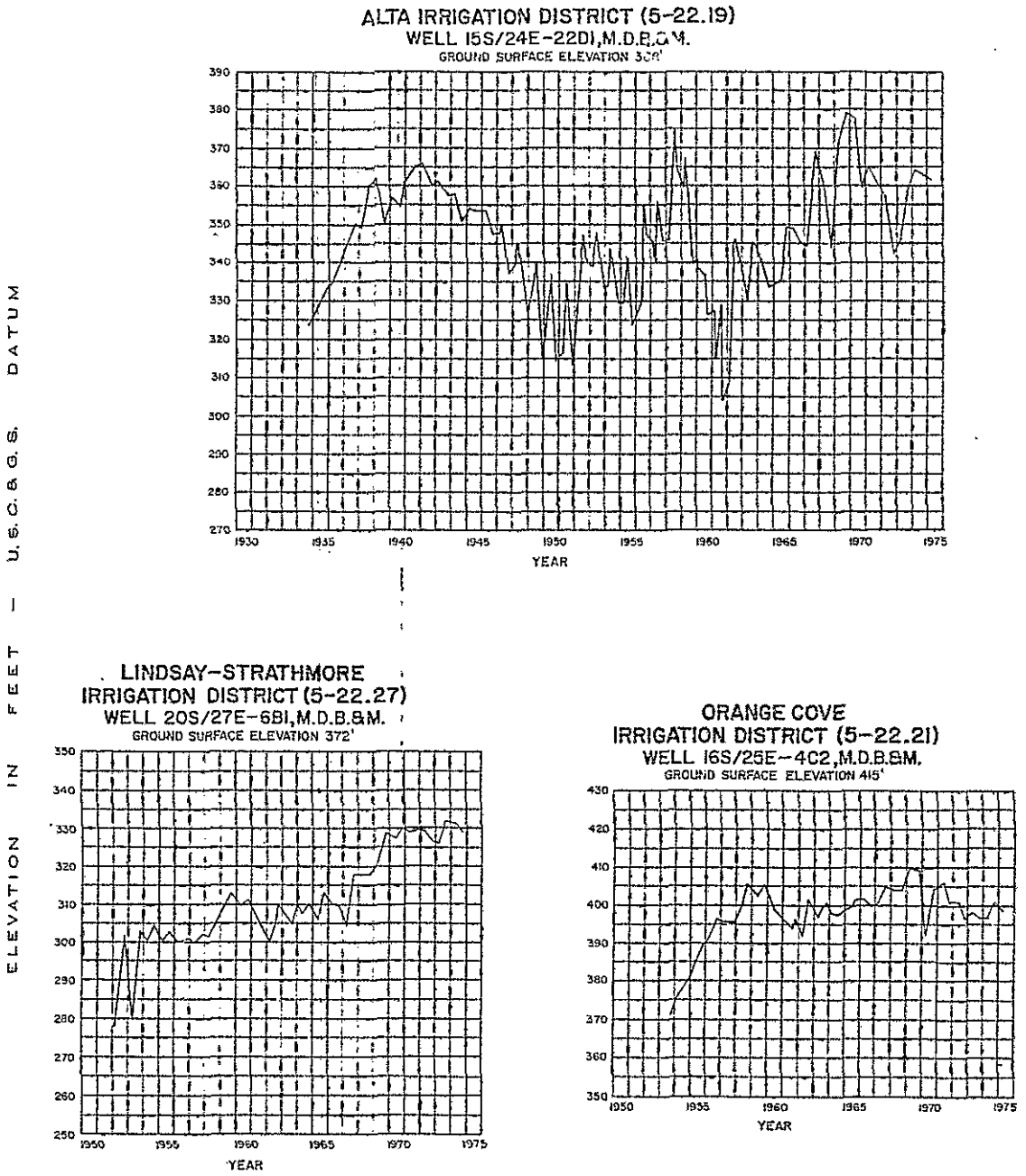
DEPARTMENT OF WATER RESOURCES SAN JOAQUIN DISTRICT

Figure C-2 (Continued). FLUCTUATION OF WATER LEVELS IN SELECTED WELLS



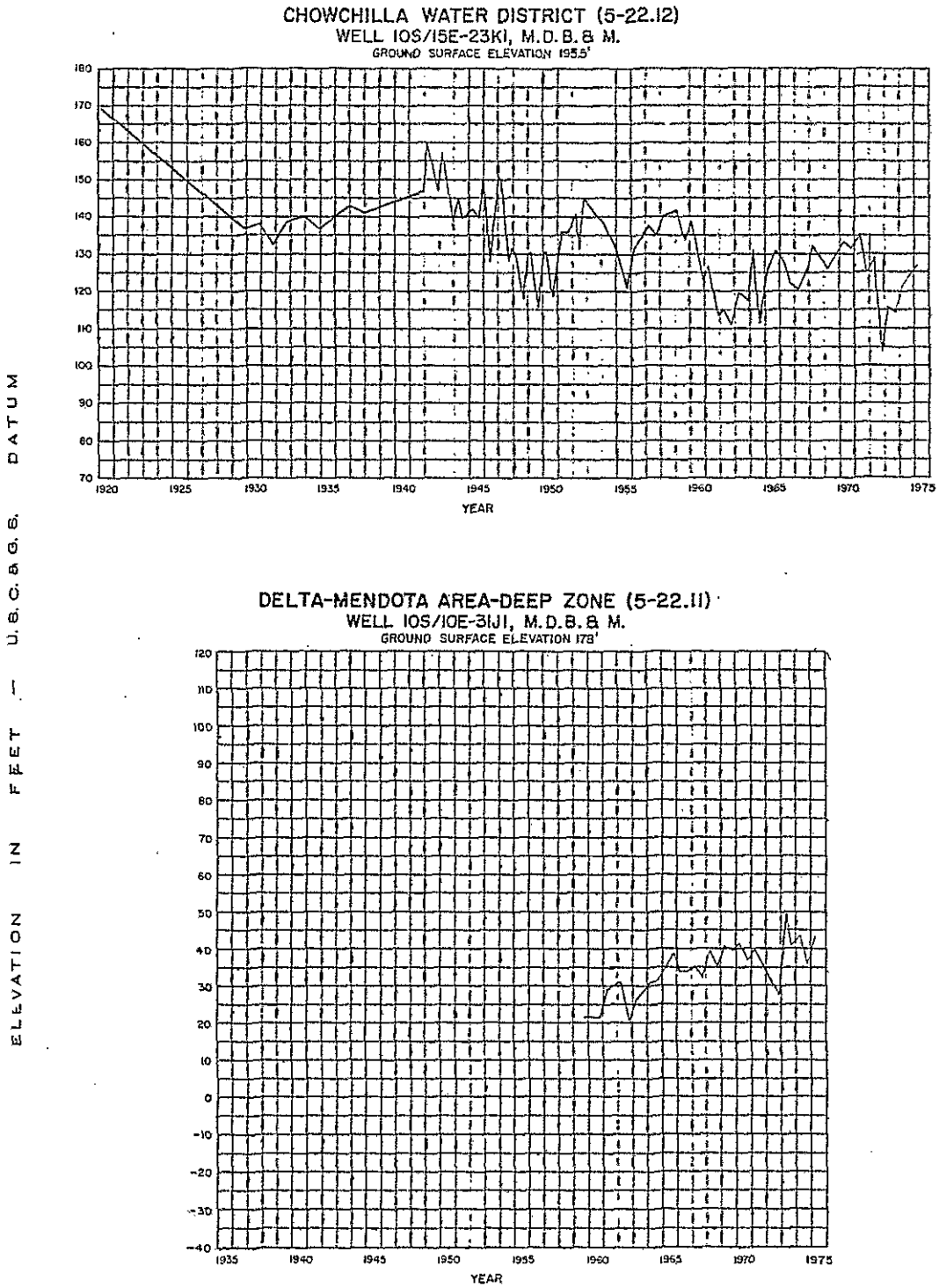
DEPARTMENT OF WATER RESOURCES SAN JOAQUIN DISTRICT

Figure C-2 (Continued). FLUCTUATION OF WATER LEVELS IN SELECTED WELLS



DEPARTMENT OF WATER RESOURCES SAN JOAQUIN DISTRICT

Figure C-2 (Continued). FLUCTUATION OF WATER LEVELS IN SELECTED WELLS



DEPARTMENT OF WATER RESOURCES SAN JOAQUIN DISTRICT

TABLE C-1

CHANGE IN AVERAGE GROUND WATER LEVEL
IN DISTRICTS OR AREAS IN THE SAN JOAQUIN VALLEY
Spring 1974 - Spring 1975

Ground Water Districts or Areas		Number of Wells Considered in Analysis[a]	Change in Feet
Name	Number		
San Joaquin Valley	5-22.00		
Oakdale Irrigation District	5-22.06		- 1.9
Modesto Irrigation District	5-22.07		+ 0.3
Turlock Irrigation District	5-22.08		+ 1.0
Merced Irrigation District	5-22.09		- 0.6
El Nido Irrigation District	5-22.10		- 0.6
Delta-Mendota Area	5-22.11	250	+ 1.2
Chowchilla Water District	5-22.12		+ 1.1
Madera Irrigation District	5-22.13		+ 0.6
West Chowchilla-Madera Area	5-22.14		- 4.4
Fresno Irrigation District	5-22.15		- 0.9
City of Fresno	5-22.16	60	- 0.4
Fresno Slough Area	5-22.17		- 0.3
Consolidated Irrigation District	5-22.18		+ 1.6
Alta Irrigation District	5-22.19		+ 3.6
Lower Kings River Area	5-22.20		
Shallow Zone			0.0
Deep Zone			+ 5.6
Orange Cove Irrigation District	5-22.21	62	- 1.7
Stone Corral Irrigation District	5-22.22	10	- 2.2
Ivanhoe Irrigation District	5-22.23		- 0.5
Kaweah-Delta Water Conservation District	5-22.24		+ 1.9
Tulare Irrigation District	5-22.25		+ 3.2
Exeter Irrigation District	5-22.26		- 1.4
Lindsay-Strathmore Irrigation District	5-22.27		- 3.7
Lindmore Irrigation District	5-22.28		+ 0.8
Porterville Irrigation District	5-22.29	16	- 1.4
Lower Tule River Irrigation District	5-22.30		
Shallow Zone			+ 1.7
Deep Zone		Insufficient data to compute change	
Vandalia Irrigation District	5-22.31	5	- 0.2
Saucelito Irrigation District	5-22.32		
Shallow Zone			+ 0.2
Deep Zone		Insufficient data to compute change	
Pixley Irrigation District	5-22.33		
Shallow Zone			- 5.1
Deep Zone			- 0.1

TABLE C-1 (Cont.)

CHANGE IN AVERAGE GROUND WATER LEVEL
IN DISTRICTS OR AREAS IN THE SAN JOAQUIN VALLEY
Spring 1974 - Spring 1975

Ground Water Districts or Areas		Number of Wells Considered in Analysis[a]	Change in Feet
Name	Number		
San Joaquin Valley (Continued)			
Alpaugh-Allensworth Area	5-22.34		
Shallow Zone			- 5.8
Deep Zone			+ 0.5
Delano-Earlimart Irrigation District	5-22.35		
Shallow Zone			+ 0.9
Deep Zone		Insufficient data to compute change	
Southern San Joaquin Municipal Utility District	5-22.36		
Shallow Zone			+ 8.7
Deep Zone			- 1.9
North Kern Water Storage District	5-22.37		
Shallow Zone			+ 4.1
Deep Zone			-12.6
Shafter-Wasco Irrigation District	5-22.38		
Deep Zone			- 5.7
City of Bakersfield	5-22.39	20	- 2.1
Kern River Delta Area	5-22.40		
Shallow Zone			+ 0.4
Deep Zone			- 3.4
Edison-Maricopa Area	5-22.41		
Deep Zone			- 0.4
Buena Vista Water Storage District	5-22.42		
North Area			-10.3
South Area		Insufficient data to compute change	
Semitropic Water Storage District	5-22.43		
Shallow Zone			- 2.7
Deep Zone			-10.3
Avenal-McKittrick Area	5-22.44	27	- 1.2
Tulare Lake-Lost Hills Area	5-22.45	19	+ 2.8
Corcoran Irrigation District	5-22.46		
Shallow Zone			+ 1.6
Deep Zone			+ 5.8
Mendota-Huron Area	5-22.47		
Deep Zone			+17.8
Poso Resources Conservation District	5-22.48		+ 0.3
San Luis Canal Company	5-22.49		- 0.3

TABLE C-1 (Cont.)

CHANGE IN AVERAGE GROUND WATER LEVEL
IN DISTRICTS OR AREAS IN THE SAN JOAQUIN VALLEY
Spring 1974-- Spring 1975

Ground Water Districts or Areas		Number of Wells Considered in Analysis[a]	Change in Feet
Name	Number		
San Joaquin Valley (Continued)			
Terra Bella Irrigation District	5-22.50	10	+ 0.1
Merced Bottoms	5-22.54		+ 1.1
Centerville Bottoms Area	5-22.64		- 1.9
Garfield Water District	5-22.65	11	+ 0.2
Kings County Water District	5-22.66		
Shallow Zone			+ 0.8
Deep Zone		Insufficient data to compute change	
Pleasant Valley Area	5-22.69	18	+ 8.3

a/ Average changes were determined by planimetering ground water contour maps. Where numbers appear changes were computed by numerical averages.

TABLE C-2

CHANGE IN AVERAGE GROUND WATER LEVEL FROM
1921 TO 1951 AND 1951 TO 1975
IN 18 GROUND WATER AREAS IN THE SAN JOAQUIN VALLEY

Name of Ground Water Area*	Area in square miles	Irrigation and Other Water Districts Included in the Ground Water Area	Net change in water level 1921-51 a/ in feet	Net change in water level 1951-75 b/ in feet
Madera	342.6	Madera Irrigation District and Chowchilla Water District	- 24.1 c/	-22.3
Fresno	404.0	Fresno Irrigation District and City of Fresno	- 22.4	-16.8
Consolidated	243.0	Consolidated Irrigation District	- 19.0	+ 3.8
Centerville Bottoms	18.1	-----	+ 1.0	- 0.1
Alta	190.9	Alta Irrigation District	- 17.2 c/	+ 9.1
Ivanhoe	17.4	Ivanhoe Irrigation District	- 55.9	+18.2
Outside Ivanhoe	76.6	Stone Corral Irrigation District and a portion of Alta Irrigation District	- 28.5	+ 9.1
Mill Creek	128.2	Portions of Kings County Water District and Kaweah Delta Water Conservation District	- 31.1	-10.1
Tulare	121.1	Tulare Irrigation District	- 59.1	+ 9.4
Elk Bayou	67.6	Portion of Kaweah Delta Water Conservation District	- 47.8	+ 5.0
Lindsay-Exeter	136.4	Exeter Irrigation District, Lindsay-Strathmore Irrigation District, and Lindmore Irrigation District	- 77.7	+82.7
Tule River	156.6	Porterville Irrigation District, portions of Lower Tule River Irrigation District, and Saucelito Irrigation District	- 62.5	+42.6
Lower Deer Creek	162.2	Portions of Lower Tule River Irrigation District, Saucelito Irrigation District, and Delano-Earlimart Irrigation District	-106.7	-27.3 e/ -10.2 f/
Middle Deer Creek	54.3	Terra Bella Irrigation District	- 61.8	- 3.4 e/ -40.6 f/
Delano-Earlimart	140.0	Portions of Delano-Earlimart Irrigation District and Southern San Joaquin Municipal Utility District	-133.8	+28.0 e/ +32.3 g/
McFarland-Shafter	306.0	North Kern Water Storage District, Shafter-Wasco Irrigation District, and a portion of Southern San Joaquin Municipal Utility District	- 99.0	-12.3 e/ -54.1 g/
Rosedale	78.9	-----	- 36.3	-46.2 -25.7 g/
Arvin-Edison	205.2	Arvin-Edison Water Storage District	- 69.9 d/	-49.7 g/

a/ 1951 was the first year of substantial deliveries from the Friant-Kern Canal.
b/ Fall 1951 to spring 1975.
c/ Fall 1929 to fall 1951.
d/ Fall 1941 to fall 1951.
e/ Unconfined aquifer, spring 1961 to spring 1975; only one aquifer reported prior to 1961.
f/ Change shown for 1951 to 1971; insufficient data in pressure aquifer to compute changes for 1971-75.
g/ Pressure surface, spring 1961 to spring 1975; only one aquifer reported prior to 1961.

* These areas are shown on Plate 2.

TABLE C-3

GROUND WATER LEVELS AT WELLS

An explanation of the column headings and the code symbols follows:

State Well Number--refer to the explanation under Introduction, page 125.

Aquifer--Qualifications are based on the latest geologic knowledge of the aquifer system and construction of individual wells. The code symbols are as follows:

0	Unqualified due to lack of well construction and/or geology information.	4	Unconfined, outside Corcoran Clay area.
1	Unconfined, perforated above the Corcoran Clay.	5	Confined, aquitard other than Corcoran Clay.
2	Confined, perforated below the Corcoran Clay.	6	Composite, perforated above and below aquitard outside Corcoran Clay area.
3	Composite, perforated above and below the Corcoran Clay.		

Ground surface elevation represents the elevation in feet above mean sea level (U.S.G.S. and U.S.C. & G.S. datum) of the ground surface at the well. Elevations are usually taken from topographic maps and the accuracy is controlled by topographic standards.

Date is the date the depth measurement was made. Where 00 appears in the date, day of measurement is unknown.

Ground surface to water surface in feet is the measured depth in feet from the ground surface to the water surface in the well.

Other code symbols used in this column are as follows:

NO MEASUREMENT (NM)

0	Measurement discontinued	5	Unable to locate well
1	Pumping	6	Well has been destroyed
2	Pump house locked	7	Special
3	Tape hung up	8	Casing leaking or wet
4	Can't get tape in casing	9	Temporarily inaccessible

The words FLOW and DRY are shown in this column to indicate a flowing or dry well.

Water surface elevation is the elevation in feet above mean sea level (U.S.G.S. and U.S.C. & G.S. datum) of the water surface in the well. It was derived by machine computation by subtraction of the depth measurement from the reference point elevation.

Agency supplying data represents the code numbers for the agencies supplying water level data.

In this list of water levels, the agency furnishing the measurement is noted. The agencies and code numbers assigned to them are as follows:

Agency Code	Agency	Agency Code	Agency
5001	U. S. Bureau of Reclamation	5605	Exeter Irrigation District
5050	Department of Water Resources	5606	Lindsay-Strathmore Irrigation District
5129	Kings County Water District	5607	Lindmore Irrigation District
5133	Kern County Water Agency	5608	Porterville Irrigation District
5200	City of Fresno	5609	Lower Tule Irrigation District
5520	Oakdale Irrigation District	5611	Saucelito Irrigation District
5521	Modesto Irrigation District	5612	Pixley Irrigation District
5524	Turlock Irrigation District	5613	Delano-Earlimart Irrigation District
5525	Merced Irrigation District	5614	Southern San Joaquin Municipal Utility District
5527	El Nido Irrigation District	5616	Shafter-Wasco Irrigation District
5528	Chowchilla Water District	5619	Terra Bella Irrigation District
5529	Poso Resources Conservation District	5620	James Irrigation District
5530	Madera Irrigation District	5622	Garfield Water District
5531	San Luis Canal Company	5631	Fresno Irrigation District
5600	Orange Cove Irrigation District	5636	Consolidated Irrigation District
5601	Stone Corral Irrigation District	5637	Alta Irrigation District
5602	Ivanhoe Irrigation District	5640	Buena Vista Water Storage District
5603	Kaweah Delta Water Conservation District	5644	Arvin-Edison Water Storage District
5604	Tulare Irrigation District		

TABLE C-3 (Cont.)
GROUND WATER LEVELS AT WELLS

STATE WELL NUMBER	AQUIFER	GROUND WATER ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEVATION IN FEET	AGENCY CODE
OAKDALE I.D.				5-22.06		
01S/09E-16J01 M		119.0	4-18-75	65.6	53.4	5520
01S/09E-36A01 M		143.0	4-18-75	55.9	89.1	5520
01S/10E-19L01 M		146.5	4-18-75	57.8	888.7	5520
01S/10E-24J01 M		193.0	4-18-75	84.6	108.4	5520
02S/09E-26F01 M		132.0	4-18-75	54.6	77.4	5520
02S/10E-04H01 M		185.5	4-18-75	78.2	107.3	5520
02S/10E-33J01 M		165.0	4-18-75	59.2	105.8	5520
02S/11E-29B01 M		218.0	4-18-75	90.5	127.5	5520
02S/11E-31N01 M		192.0	4-18-75	77.2	114.8	5520
02S/12E-31K01 M		190.0	4-18-75	41.4	148.6	5520
03S/10E-15A01 M		152.0	4-18-75	44.9	107.1	5520
03S/11E-18D01 M		162.0	4-18-75	NM-1		5520
MODESTO I.D.				5-22.07		
02S/08E-25P01 M		94.0	3-04-75	37.6	56.4	5521
02S/09E-30F01 M		93.0	11-13-74 3-26-75	24.0 28.5	69.0 64.5	5050
02S/09E-31G01 M		97.0	3-04-75	34.2	62.8	5521
03S/07E-12C01 M		47.0	11-13-74 3-26-75	9.8 NM-0	37.2	5050
03S/07E-35A02 M		40.0	11-13-74 3-26-75	4.1 NM-0	35.9	5050
03S/08E-01S01 M		65.0	3-04-75	16.9	48.1	5521
03S/08E-24C02 M		73.0	3-04-75	20.0	53.0	5521
03S/09E-08D01 M		92.0	3-04-75	28.2	63.8	5521
03S/09E-11M01 M		99.0	3-04-75	23.2	75.8	5521
03S/09E-26F01 M		100.0	3-26-75	NM-0		5050
03S/10E-06G01 M		133.1	3-04-75	35.2	97.9	5521
03S/10E-29K01 M		118.0	3-04-75	47.9	70.1	5521
03S/10E-32G01 M		120.0	3-04-75	58.7	61.3	5521
03S/10E-34D01 M		125.0	3-26-75	NM-6		5050
04S/08E-03F01 M		60.0	3-04-75	16.7	43.3	5521
TURLOCK I.D.				5-22.08		
04S/08E-22R01 M	1	55.0	11-13-74 3-26-75	10.0 NM-0	45.0	5050
04S/08E-27D01 M		55.0	3-05-75	10.8	44.2	5524
04S/09E-21N01 M		75.0	3-05-75	9.7	65.3	5524
04S/10E-21R01 M	1	109.0	3-05-75	15.1	93.9	5524
04S/11E-29N01 M	1	131.0	3-05-75	DRY		5524
04S/11E-31R01 M		128.0	3-05-75	12.1	115.9	5524
05S/08E-01N01 M		53.0	3-05-75	5.7	47.3	5524
05S/08E-10A01 M		44.0	3-05-75	12.3	31.7	5524
05S/09E-04A01 M		70.0	11-13-74 3-26-75	10.0 NM-0	60.0	5050
05S/09E-14R01 M		75.0	3-05-75	7.2	67.8	5524
05S/09E-24N01 M		75.0	3-05-75	8.3	66.7	5524
05S/09E-28A01 M		63.0	3-05-75	4.7	58.3	5524
05S/09E-34J01 M		64.0	11-13-74 3-26-75	14.3 NM-0	49.7	5050
05S/10E-19R01 M		82.0	3-05-75	6.7	75.3	5524
05S/10E-21R01 M		92.0	3-05-75	10.7	81.3	5524
05S/11E-06J02 M	1	124.0	11-13-74 3-26-75	7.0 NM-0	117.0	5050
05S/11E-21N01 M		125.0	3-05-75	10.1	114.9	5524
05S/11E-30A01 M		117.0	3-05-75	13.4	103.6	5524
05S/11E-33L01 M		115.5	3-05-75	8.8	106.7	5524
06S/09E-15R01 M		60.0	3-05-75	3.8	56.2	5524

STATE WELL NUMBER	AQUIFER	GROUND WATER ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEVATION IN FEET	AGENCY CODE
TURLOCK I.D.				5-22.08		
06S/10E-21A01 M		85.6	3-05-75	3.7	81.9	5524
06S/10E-29D01 M		83.6	3-05-75	10.1	73.5	5524
06S/11E-06N01 M		106.2	3-05-75	9.1	97.1	5524
06S/11E-08R01 M		116.2	3-05-75	11.5	104.7	5524
MERCED I.D.				5-22-09		
06S/12E-22N01 M	1	150.0	11-13-74 3-03-75	19.0 15.3	131.0 134.7	5050 5525
06S/14E-32K01 M	1	178.1	3-04-75	15.1	163.0	5525
07S/10E-01N01 M	1	90.7	3-04-75	7.8	82.9	5525
07S/11E-01H01 M		118.0	11-12-74 2-28-75	13.0 NM-0	105.0	5050
07S/11E-13N01 M	1	106.6	3-03-75	8.7	97.9	5525
07S/12E-12D01 M	1	144.0	11-12-74 3-03-75	1.0 14.1	143.0 129.9	5050 5525
07S/12E-12R01 M	1	147.3	3-03-75	16.9	130.4	5525
07S/13E-26D01 M	1	155.8	11-12-74 3-03-75	11.1 12.1	144.7 143.7	5050 5525
07S/14E-11N01 M	1	191.8	11-12-74 3-04-75	13.4 13.8	178.4 178.0	5050 5525
07S/14E-16R01 M	1	187.3	3-05-75	16.5	170.8	5525
08S/12E-01D01 M	1	120.1	3-03-75	7.9	112.2	5525
08S/13E-09R01 M	1	135.0	3-03-75	5.4	129.6	5525
08S/14E-01A01 M	1	197.5	3-04-75	11.9	185.6	5525
08S/14E-10N01 M	1	172.6	11-12-74 3-03-75	8.1 7.4	164.5 165.2	5050 5525
EL NIDO I.D.				5-22.10		
09S/13E-14H01 M		133.0	10-07-74 2-05-75	NM-7 74.7	58.3	5527
09S/14E-20B01 M		152.0	10-07-74 2-05-75	82.4 66.0	69.6 86.0	5527
DELTA-MENDOTA AREA				5-22.11		
04S/06E-04N01 M	2	196.0	10-18-74 4-07-75	164.3 151.1	31.7 44.9	5607 5001
04S/06E-09R01 M	1	166.3	10-19-74 4-07-75	118.4 115.3	47.9 51.0	5607 5001
04S/07E-27M01 M	1	68.0	10-23-74 4-14-75	22.6 22.9	45.4 45.1	5607 5001
05S/07E-14D01 M	1	130.4	10-22-74 4-08-75	79.1 73.6	51.3 56.8	5607 5001
05S/07E-23L01 M		138.0	10-22-74 4-08-75	82.1 NM-9	55.9	5607 5001
05S/08E-32K01 M	1	90.9	10-22-74 4-08-75	7.4 7.4	83.5 83.5	5607 5001
06S/07E-12P01 M		248.3	10-17-74 3-26-75	13.2 14.5	235.1 233.8	5050
06S/08E-21R02 M	2	133.5	10-17-74 3-26-75	34.0 32.0	99.5 101.5	5050
06S/08E-27J01 M	1	114.5	10-17-74 3-26-75	41.0 46.0	73.5 68.5	5050
06S/08E-29J01 M	2	190.0	3-26-75	93.0	97.0	5050
07S/08E-22L01 M	1	127.9	10-18-74 3-27-75	43.3 45.0	84.6 82.9	5050
07S/09E-04R01 M	1	65.5	10-18-74 3-27-75	17.0 12.0	48.5 53.5	5050
07S/09E-26N01 M	1	68.4	10-16-74 3-28-75	9.2 5.0	59.2 63.4	5050
08S/08E-01N01 M	1	123.2	10-15-74 3-25-75	15.5 18.5	107.7 104.7	5050
08S/08E-15J01 M	2	172.8	3-25-75	25.5	147.1	5050
08S/09E-26H01 M	2	75.0	10-15-74 3-27-75	38.9 14.0	36.1 61.0	5050
08S/09E-26H03 M	1	75.0	10-15-74 3-27-75	5.5 1.0	69.5 74.0	5050
08S/10E-21L04 M		75.0	10-15-74 3-27-75	6.4 1.0	68.6 74.0	5050

TABLE C-3 (Cont.)
GROUND WATER LEVELS AT WELLS

STATE WELL NUMBER	AQUIFER	GROUND WATER ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEVATION IN FEET	AGENCY CODE
DELTA-MENDOTA AREA				5-22.11		
09S/08E-24A01 M	1	157.0	10-17-74 3-25-75	9.0 19.0	148.0 138.0	5050
09S/09E-14N01 M		96.0	10-17-74 3-28-75	60.0 35.0	36.0 61.0	5050
09S/09E-18N01 M	2	153.6	10-17-74 3-27-75	32.0 29.0	121.6 124.6	5050
09S/09E-23L01 M	2	100.0	10-17-74 3-28-74	65.0 47.0	35.0 53.0	5050
09S/10E-19B01 M	3	84.0	10-17-74 3-28-75	NM-5 NM-0		5050
09S/10E-23J01 M	2	87.0	10-16-74 3-28-75	45.0 34.0	42.0 53.0	5050
09S/11E-09A01 M	1	85.0	3-00-74	6.0	79.0	5631
09S/11E-29R01 M	1	90.0	10-16-74 3-26-75	NM-1 4.0	86.0	5050
10S/10E-02R01 M	1	99.5	10-16-74 3-26-75	18.0 12.0	81.5 87.5	5050
10S/10E-31G01 M	2	191.1	10-16-74 3-26-75	152.0 162.0	39.1 29.1	5050
10S/10E-32N01 M	1	189.5	10-16-74 3-26-75	80.0 75.0	109.5 114.5	5050
10S/11E-27E02 M	2	101.3	10-16-74 3-27-75	65.0 55.0	36.3 46.3	5050
11S/10E-11J01 M	1	157.3	10-15-74 3-25-75	12.0 10.0	145.3 147.3	5050
11S/10E-22Q01 M		246.8	10-15-74 3-26-75	98.0 100.0	148.8 146.8	5050
11S/11E-02J02 M	1	106.0	10-15-74 3-25-75	2.0 2.0	104.0 104.0	5050
11S/11E-22Q01 M	2	114.0	10-15-74 3-25-75	9.5 12.0	104.5 102.0	5050
11S/11E-22Q03 M	2	114.0	10-15-74 3-25-75	13.0 12.0	101.0 102.0	5050
12S/12E-06D01 M		144.0	10-16-74 3-24-75	6.4 5.7	137.6 138.3	5607 5001
12S/12E-25J01 M		181.1	10-17-74 3-25-75	5.7 3.5	175.4 177.6	5607 5001
12S/13E-14N01 M		150.0	10-16-74 3-26-75	23.5 22.1	126.5 127.9	5607 5001
CHOWCHILLA W.D.				5-22.12		
09S/14E-25R01 M	1	185.0	10-07-74 1-31-75	67.5 64.5	117.5 120.5	5528
09S/15E-25J02 M	1	230.0	10-01-74 1-31-75	40.0 41.5	190.0 188.5	5528
09S/15E-27A01 M		216.5	11-12-74 3-12-75	119.0 NM-0	97.5	5050
09S/16E-22R01 M		267.0	10-03-74 1-30-75	45.5 47.0	221.5 220.0	5528
09S/17E-19L01 M	1	292.0	10-03-74 1-30-75	113.5 112.5	178.5 179.5	5528
09S/17E-25B01 M	1	338.0	9-27-74 1-21-75	76.2 63.9	261.8 274.1	5001
09S/18E-33Q01 M	4	362.0	9-27-74 1-21-75	58.5 54.8	303.5 307.2	5001
10S/14E-01A01 M		179.0	10-07-74 1-31-75	75.7 75.0	103.3 104.0	5528
10S/14E-01R02 M		177.0	10-07-74 1-31-75	68.5 68.0	108.5 109.0	5528
10S/14E-24R01 M		167.0	10-07-74 2-04-75	86.5 85.0	80.5 82.0	5528
10S/15E-02Q01 M		212.5	10-02-74 1-31-75	114.0 110.5	98.5 102.0	5528
10S/15E-23K01 M		195.5	10-02-74 2-05-75	71.5 69.0	124.0 126.5	5528
10S/15E-27D03 M		184.0	10-02-74 2-05-75	79.5 72.5	104.5 111.5	5528
10S/16E-09E01 M		232.0	10-10-74 2-04-75	95.0 92.9	137.0 139.1	5528
10S/16E-29R01 M	1	208.0	10-02-74 2-05-75	84.0 77.5	124.0 130.5	5528
MADERA I.D.				5-22.13		
10S/19E-16D01 M	4	390.0	9-27-74 1-21-75	16.7 23.1	373.3 366.9	5001
MADERA I.D.				5-22.13		
11S/16E-06A01 M		196.0	10-07-74 2-06-75	77.4 66.8	118.6 129.2	5530
11S/16E-10N01 M		204.0	10-07-74 2-06-75	72.0 68.3	135.7 135.7	5530
11S/17E-27C01 M	1	250.0	10-04-74 2-05-75	75.4 74.7	174.6 175.3	5530
11S/18E-20N01 M	1	272.5	10-01-74 1-30-75	88.2 71.4	184.3 201.1	5530
11S/18E-27M01 M	1	284.0	10-01-74 1-30-75	86.3 82.5	197.7 201.5	5530
12S/16E-23A01 M		205.0	10-03-74 2-03-75	96.7 84.8	108.3 120.2	5530
12S/17E-08G01 M		230.0	10-03-74 2-04-75	90.2 83.6	139.8 146.4	5530
12S/17E-21H01 M	1	228.0	10-03-74 2-03-75	72.3 69.0	155.7 159.0	5530
12S/17E-26C01 M		235.0	10-03-74 2-03-75	60.6 57.2	174.4 177.8	5530
12S/17E-34R01 M		234.0	10-03-74 2-03-75	60.9 50.0	173.1 184.0	5530
12S/18E-13R01 M		288.0	10-01-74 1-30-75	82.2 80.0	205.8 208.0	5530
12S/18E-21G01 M	1	265.0	10-02-74 1-31-75	74.6 71.1	190.4 193.9	5530
12S/18E-21H01 M		267.0	10-02-74 1-31-75	70.3 66.9	196.7 200.1	5530
12S/19E-28A01 M	4	307.5	10-09-74 1-27-75	91.2 90.5	216.3 217.0	5001
WEST CHOWCHILLA-MADERA AREA				5-22.14		
10S/13E-22R01 M		119.0	9-24-74 1-21-75	26.2 24.1	92.8 94.9	5001
10S/14E-08B03 M		147.0	10-08-74 2-06-75	99.5 90.5	47.5 56.5	5528
10S/14E-31H01 M		130.0	9-24-74 1-21-75	45.8 40.0	84.2 90.0	5001
10S/14E-35F01 M		151.0	10-07-74 1-21-75	93.3 79.5	57.7 71.5	5001
11S/14E-13R01 M		150.0	9-25-74 1-21-75	NM-1 NM-1		5001
11S/15E-33E01 M		156.0	9-25-74 1-21-75	82.6 60.5	73.4 95.5	5001
11S/15E-33P01 M		158.0	9-25-74 1-21-75	80.4 57.8	77.6 100.2	5001
12S/15E-14L01 M	1	167.0	9-28-74 1-23-75	NM-7 67.3	99.7	5001
13S/16E-02C01 M		194.0	10-02-74 2-03-75	89.5 71.3	104.5 122.7	5530
FRESNO I.D.				5-22.15		
12S/20E-14A01 M	4	365.0	9-27-74 2-04-75	NM-9 92.0	273.0	5001
12S/21E-34D01 M	4	387.7	10-01-74 2-01-75	44.4 42.3	343.3 345.4	5631
12S/22E-21E01 M	4	473.0	9-24-74 1-23-75	15.3 15.0	457.7 458.0	5001
13S/17E-22B01 M	4	220.8	10-01-74 2-01-75	34.0 37.3	186.8 183.5	5631
13S/17E-33D01 M		211.0	10-10-74 1-23-75	56.0 53.1	155.0 157.9	5001
13S/18E-10F01 M		258.0	10-10-74 1-24-75	46.5 49.0	211.5 209.0	5001
13S/18E-34D01 M		245.0	10-10-74 1-24-75	55.9 56.0	188.1 189.0	5001
13S/19E-09Q01 M	4	288.2	10-01-74 2-01-75	77.0 NM-0	211.2	5631
13S/19E-16K01 M		290.0	10-10-74 1-24-75	81.5 76.5	208.5 213.5	5001
13S/20E-12H01 M		343.4	10-01-74 2-01-75	NM-1 76.5	266.9	5631
13S/23E-31P01 M	4	406.5	10-01-74 2-01-75	30.9 34.5	375.6 372.0	5631
14S/18E-08J01 M	4	227.4	10-02-74 2-01-75	72.8 65.9	154.6 161.5	5631
14S/19E-20B02 M	4	245.0	10-02-74 2-01-75	48.5 NM-6	196.5	5631
14S/20E-06J01 M	1	279.4	2-01-75	NM-1		5631

TABLE C-3 (Cont.)
GROUND WATER LEVELS AT WELLS

STATE WELL NUMBER	AQUIFER	GROUND ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEVATION IN FEET	AGENCY CODE
FRESNO I.D.				5-22.15		
15S/20E-13E02 M		282.5	10-02-74 2-01-75	32.8 36.1	249.7 246.4	5631
CITY OF FRESNO				5-22.16		
13S/20E-21J01 M		310.0	4-00-75	96.3	213.7	5200
13S/20E-23B01 M		325.0	4-00-75	93.2	231.8	5200
13S/20E-28E01 M		299.3	10-03-74 4-01-75	87.0 91.5	212.3 207.8	5200
13S/20E-35H02 M		305.3	4-00-75	80.5	224.8	5200
14S/20E-10M01 M		291.4	10-03-74 4-00-75	76.1 74.5	215.3 216.9	5200
FRESNO SLOUGH AREA				5-22.17		
14S/15E-25H02 M		160.0	10-11-74 1-23-75	30.5 20.4	129.5 139.6	5001
14S/16E-03C01 M		177.0	10-10-74 1-22-75	76.5 67.5	100.5 109.5	5001
14S/16E-08D01 M		165.0	10-11-74 1-22-75	NM-1 42.2	122.8	5001
14S/16E-22N01 M	1	164.0	10-11-74 1-13-75	33.0 28.3	131.0 135.7	5001
14S/17E-25A01 M	1	210.0	10-15-74 1-13-75	113.3 101.9	96.7 108.1	5620
15S/16E-12C03 M		169.5	11-07-74 1-16-75	40.0 39.8	129.5 129.7	5050 5620
15S/17E-22R01 M	1	185.0	10-02-74	NM-6		5620
15S/18E-07A02 M		204.0	10-17-74 1-15-75	126.3 NM-5	77.7	5620
16S/18E-03J01 M		206.0	2-24-75	NM-1		5050
16S/18E-33P01 M		195.0	2-21-75	152.0	43.0	5050
16S/19E-34P01 M		220.0	11-07-74 2-21-75	125.0 115.0	95.0 105.0	5050
17S/17E-12H01 M	1	199.0	12-19-74	150.0	49.0	5050
17S/18E-23A02 M	1	200.0	11-07-74 2-20-75	79.0 95.0	121.0 105.0	5050
CONSOLIDATED I.D.				5-22.18		
14S/22E-22N01 M	4	355.7	10-01-74 2-03-75	27.7 27.8	328.0 327.9	5601 5636
15S/19E-34N01 M	4	245.7	10-01-74 2-03-75	83.9 81.2	161.8 164.5	5601 5636
15S/20E-28A01 M		264.0	11-00-75	NM-0		5636
15S/21E-15D01 M	4	301.0	10-01-74 2-03-75	26.8 24.6	274.2 276.4	5601 5636
15S/22E-16A01 M	4	337.0	10-01-74 2-04-75	24.6 25.2	312.4 311.8	5601 5636
15S/22E-29D01 M	4	321.0	10-01-74 2-04-75	24.3 25.9	296.7 295.1	5601 5636
16S/19E-14A01 M	4	235.0	10-01-74 2-04-75	109.5 99.4	125.5 135.6	5601 5636
16S/20E-22N01 M	4	248.0	10-02-74 2-04-75	64.2 60.5	183.8 187.5	5601 5636
16S/21E-22N01 M	4	271.0	10-02-74 2-04-75	43.1 40.3	227.9 230.7	5636
16S/22E-23R01 M	4	297.0	10-02-74 2-04-75	21.5 21.9	275.5 275.1	5636
17S/22E-03C01 M	4	286.0	10-02-74 2-04-75	19.2 20.6	266.8 265.4	5636
ALTA I.D.				5-22.19		
14S/23E-36R01 M	4	391.0	10-01-74 1-31-75	46.8 47.3	344.2 343.7	5637
14S/24E-31P01 M	4	395.0	10-01-74 1-31-75	39.0 46.8	356.0 348.2	5637
15S/23E-23A02 M	4	358.0	10-01-74 1-31-75	43.5 42.4	314.5 315.6	5637
15S/24E-22D01 M	4	388.0	10-01-74 1-31-75	25.4 26.3	362.6 361.7	5637
16S/23E-23E01 M	4	314.0	10-04-74 2-05-75	21.0 21.6	293.0 292.4	5637

STATE WELL NUMBER	AQUIFER	GROUND ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEVATION IN FEET	AGENCY CODE
ALTA I.D.				5-22.19		
16S/24E-21J01 M	1	336.0	10-01-74 2-03-75	NM-1 27.1	308.9	5637
16S/24E-29A01 M	4	364.0	10-02-74 2-03-75	36.1 29.3	327.9 334.7	5637
17S/22E-25A01 M	4	275.0	10-02-74 2-04-75	47.9 38.1	227.1 236.9	5637
17S/22E-25J01 M	4	275.0	10-02-74 2-04-75	44.3 42.9	230.7 232.1	5637
17S/24E-15A03 M		302.0	10-03-74 1-22-75	30.1 22.2	271.9 279.8	5001
17S/25E-10C01 M	4	335.0	10-03-74 2-03-75	31.3 31.4	303.7 303.6	5637
17S/25E-18R01 M	4	321.0	10-03-74 2-03-75	51.8 49.6	269.2 271.4	5637
LOWER KINGS RIVER AREA				5-22.20		
17S/19E-14J01 M		217.0	11-07-74 2-21-75	81.0 84.0	136.0 133.0	5050
17S/20E-20D01 M	1	223.0	11-07-74 2-21-75	68.0 72.0	155.0 151.0	5050
17S/21E-11K01 M		257.0	11-06-74 2-19-75	37.0 23.0	220.0 234.0	5050
18S/19E-35J02 M	3	211.0	11-06-74 2-18-75	116.0 110.0	95.0 101.0	5050
18S/20E-16A01 M	1	230.0	11-06-74 2-19-75	7.5 8.0	222.5 222.0	5050
18S/21E-10R01 M		254.0	11-06-74 1-30-75	64.0 62.7	190.0 191.3	5050 5129
19S/19E-25A01 M	1	208.0	11-06-74 2-18-75	5.4 2.0	202.6 206.0	5050
ORANGE COVE I.D.				5-22.21		
14S/24E-29C02 M	4	430.5	10-03-74 2-04-75	NM-1 41.5	389.0	5600
14S/25E-30D01 M	1	510.0	9-30-74 1-20-75	24.0 24.1	486.0 485.9	5001
15S/24E-14H01 M	4	415.0	10-01-74 2-04-75	24.8 27.4	390.2 387.6	5000
16S/25E-04C02 M	4	415.0	10-04-74 2-05-75	14.0 16.2	401.0 398.8	5600
STONE CORRAL I.D.				5-22.22		
17S/25E-01D01 M	1	355.0	10-03-74 2-03-75	NM-1 NM-9		5637
17S/26E-07R01 M		364.0	10-07-74 1-23-75	13.1 16.3	350.9 347.7	5619 5601
IVANHOE I.D.				5-22.23		
17S/25E-27R01 M	4	350.0	10-01-74 2-04-75	77.2 71.7	272.8 278.3	5602
17S/25E-35M01 M	4	349.0	10-01-74 2-04-75	70.9 61.5	278.1 287.5	5602
17S/25E-36G01 M	4	365.0	10-01-74 2-04-75	63.4 61.5	301.6 303.5	5602
17S/26E-32N01 M	4	385.0	10-01-74 2-04-75	62.5 57.1	322.5 327.9	5602
17S/26E-34D01 M	4	416.0	10-01-74 2-04-75	62.2 60.5	353.8 355.5	5602
KAWEAH-DELTA W.C.D.				5-22.24		
17S/25E-15P01 M	1	340.0	10-03-74 1-22-75	82.4 75.2	257.6 264.8	5001
17S/26E-17P02 M	1	385.0	10-03-74 1-23-75	16.7 22.0	368.3 363.0	5001
17S/27E-34P01 M	1	470.0	10-04-74 1-23-75	12.7 13.0	457.3 457.0	5001
18S/22E-30E02 M	3	248.0	10-01-74 2-13-75	95.0 89.0	153.0 159.0	5603
18S/23E-12H01 M		282.5	10-02-74 2-20-75	NM-9 47.5	235.0	5603
18S/23E-34A01 M		271.0	9-23-74 2-11-75	112.7 96.7	158.3 174.3	5129
18S/24E-26A01 M	4	312.0	10-12-74 2-21-75	11.0 NM-1	301.0	5603

TABLE C-3 (Cont.)
GROUND WATER LEVELS AT WELLS

STATE WELL NUMBER	AQUIFER	GROUND ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEVATION IN FEET	AGENCY CODE
KAWEAH-DELTA W.C.D.				5-22.24		
18S/25E-12Q01 M	4	363.0	10-04-74 2-11-75	61.5 45.5	301.5 317.5	5603
18S/25E-33F01 M	4	334.0	10-04-74 2-26-75	33.0 24.0	305.0 314.0	5603
18S/26E-27E01 M	4	390.0	10-04-74 2-25-75	NM-1 23.0	367.0	5603
18S/26E-30N01 M		367.0	10-04-74 2-25-75	15.5 19.5	351.5 347.5	5603
19S/22E-01N02 M	1	243.0	10-10-74 2-20-75	61.5 64.5	181.5 180.5	5603
19S/22E-36Z01 M	1	234.3	9-19-74 2-06-75	75.3 75.0	159.0 159.3	5129
19S/25E-07K01 M		318.0	10-07-74 2-21-75	67.0 68.0	251.0 250.0	5603
19S/26E-34R02 M	1	341.0	9-23-74 1-20-75	90.1 63.5	250.9 277.5	5001
20S/22E-10C01 M	1	227.0	10-10-74	88.0	139.0	5603
TULARE I.D.				5-22.25		
19S/23E-14R01 M	1	270.0	10-03-74 2-11-75	NM-1 70.0	200.0	5604
19S/23E-32H01 M	1	250.5	10-03-74 2-11-75	75.0 74.0	175.5 176.5	5604
19S/24E-16P01 M		290.0	10-03-74 2-12-75	87.0 76.0	203.0 214.0	5604
19S/24E-27Q01 M	1	290.0	10-01-74 2-12-75	82.5 NM-1	207.5	5604
19S/25E-17A02 M	4	328.0	10-01-74 2-06-75	47.5 49.5	280.5 278.5	5604
20S/23E-08B02 M	1	241.0	10-04-74 2-11-75	82.5 76.5	158.5 164.5	5603 5604
20S/24E-16H01 M		273.0	10-01-74 2-10-75	95.0 81.0	178.0 192.0	5603
20S/24E-30J02 M	1	250.0	10-02-74 2-10-75	101.0 79.5	149.0 170.5	5603 5604
21S/23E-05R01 M	1	222.0	10-02-74 2-10-75	68.0 NM-1	154.0	5604
EXETER I.D.				5-22.26		
18S/26E-25K01 M	4	436.0	10-01-74	NM-6		5605
18S/26E-34F02 M	4	391.0	10-01-74 2-03-75	45.3 42.5	345.7 348.5	5605
18S/27E-29D01 M	4	447.0	10-01-74 2-03-75	27.4 26.8	419.6 420.2	5605
19S/26E-14E01 M	4	375.0	10-01-74 2-03-75	66.3 62.8	308.7 312.2	5605
19S/26E-23E01 M	4	359.5	10-01-74 2-03-75	65.2 59.8	294.3 299.7	5605
LINDSAY-STRATHMORE I.D.				5-22.27		
19S/27E-29D01 M	4	385.0	10-03-74 2-05-75	46.3 45.9	338.7 339.1	5606
20S/27E-06B01 M	4	372.0	10-03-74 2-05-75	42.7 NM-4	329.3	5606
20S/27E-16A01 M	4	426.0	10-03-74 2-05-75	23.8 26.8	402.2 399.2	5006
20S/27E-21F01 M	4	414.0	10-03-74 2-05-75	26.2 28.2	387.8 385.8	5006
20S/27E-29J01 M	4	406.0	10-03-74 2-05-75	NM-1 21.0	385.0	5006
LINDMORE I.D.				5-22.28		
20S/26E-01F01 M	4	360.0	9-30-74 2-03-75	68.2 57.9	291.8 302.1	5607
20S/26E-22C02 M	4	341.0	10-01-74 2-04-75	79.0 75.0	262.0 266.0	5607
20S/26E-24K01 M		362.5	10-01-74 2-04-75	44.5 40.0	318.0 322.5	5607
20S/26E-32A01 M	4	331.5	10-02-74 10-09-74 2-05-75 2-13-75	NM-1 82.6 65.0 76.9	244.9 266.5 254.6	5607 5609 5607 5609
20S/27E-29E01 M	4	392.0	10-02-74 2-06-75	25.5 18.0	366.5 374.0	5607
PORTERVILLE I.D.				5-22.29		
21S/26E-12A01 M		372.0	10-01-74 2-07-75	30.3 29.1	341.7 342.9	5604
21S/27E-21C01 M		409.0	10-01-74 2-07-75	17.5 NM-5	391.5	5606
21S/27E-23E01 M	4	420.0	10-01-74 2-07-75	24.1 19.9	395.9 400.1	5608
22S/26E-01J01 M	4	395.0	10-02-74 2-07-75	72.8 69.1	322.2 325.9	5608
22S/27E-06D01 M	4	397.0	2-07-75	50.5	346.5	5609
22S/27E-10A01 M	4	455.0	10-02-74	NM-0		5608
22S/27E-04A01 M	4	432.0	10-01-74 2-06-75	15.9 18.2	416.1 413.8	5609
LOWER TULE RIVER I.D.				5-22.30		
21S/23E-22F01 M	1	221.5	10-09-74 2-24-75	59.0 57.0	162.5 164.5	5603
21S/24E-15R01 M	1	253.0	10-17-74 2-19-75	NM-4 NM-1		5609
21S/24E-31D01 M		230.0	10-17-74 2-18-75	62.5 65.1	167.5 164.9	5609
21S/24E-35M01 M		251.0	10-15-74 2-18-75	82.2 75.0	168.8 176.0	5609
21S/25E-08H01 M		286.0	10-18-74 2-14-75	83.9 62.5	200.1 223.5	5609
21S/26E-06G02 M		322.0	10-09-74 2-12-75	66.4 56.0	255.6 266.0	5609
21S/26E-10E01 M		350.0	10-08-74 2-12-75	36.7 36.1	313.3 313.9	5609
22S/24E-09A01 M		245.0	10-11-74 2-19-75	124.1 123.7	119.9 120.3	5609
22S/24E-15A01 M	1	253.0	10-11-74 2-19-75	134.0 129.6	119.0 123.4	5609
22S/25E-10E01 M		296.0	10-10-74 2-10-75	91.7 90.6	204.3 205.4	5609
22S/25E-15A01 M	1	303.0	10-10-74 2-10-75	129.1 127.9	173.9 175.1	5609
22S/26E-06A01 M	4	337.0	10-01-74 1-29-75	106.0 98.5	231.0 238.5	5611
VANDALIA I.D.				5-22.31		
22S/28E-07Q01 M		524.0	10-01-74 1-21-75	NM-1 119.0	405.0	5001
22S/28E-17N01 M		577.0	10-01-74 1-21-75	165.7 NM-6	411.3	5001
22S/28E-19A01 M		535.0	10-01-74 1-21-75	132.6 105.6	402.4 429.4	5001
SAUCELITO I.D.				5-22.32		
22S/26E-15J01 M	4	371.0	10-01-74 1-30-75	112.0 NM-1	259.0	5611
23S/26E-02R01 M	4	396.0	10-04-74 1-29-75	167.5 149.0	228.5 247.0	5611
23S/26E-10F01 M		373.0	10-03-74 1-29-75	173.5 NM-1	201.5	5611
PIXLEY I.D.				5-22.33		
22S/25E-25H01 M		310.0	9-26-74 2-07-75	NM-1 NM-7		5612
23S/24E-16R01 M		222.0	9-30-74 2-05-75	138.4 104.5	83.6 117.5	5612
23S/25E-14C01 M	4	300.0	9-24-74 2-03-75	63.8 NM-9	236.2	5612
23S/26E-08R01 M		345.0	9-24-74 2-03-75	180.4 168.0	164.6 177.0	5612
ALPAUGH-ALLENSWORTH AREA				5-22.34		
23S/24E-35A02 M		235.0	9-24-74 1-24-75	204.9 NM-1	30.1	5001
24S/23E-05R02 M		210.0	9-25-74 1-24-75	281.7 228.3	- 71.7 - 18.3	5001
24S/23E-21B02 M		205.0	9-25-74 1-24-75	68.9 68.7	136.1 136.3	5001
24S/23E-34R01 M	3	205.0	9-25-74 1-24-75	NM-1 236.2	- 31.2	5001

TABLE C-3 (Cont.)
GROUND WATER LEVELS AT WELLS

STATE WELL NUMBER	AQUIFER	GROUND ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEVATION IN FEET	AGENCY CODE
ALPAUGH-ALLENSWORTH AREA				5-22.34		
24S/24E-30P01 M		218.0	9-24-74 1-24-75	NM-1 215.5	2.5	5001
24S/24E-22R01 M		233.0	9-24-74 1-23-75	240.1 163.0	7.1 70.0	5001
24S/24E-34F01 M		232.0	9-24-74 1-24-75	98.7 86.2	133.3 145.8	5001
24S/25E-17P01 M	3	269.0	9-24-74 1-23-75	118.0 108.5	150.0 161.5	5001
DELANO-EARLIMART I.D.				5-22.35		
23S/25E-25K01 M	1	303.0	10-04-74 1-30-75	164.0 141.0	139.0 162.0	5613
23S/26E-29P01 M		357.0	10-07-74 1-30-75	167.5 NM-1	189.5	5613
23S/27E-27G01 M	4	552.0	9-26-74 1-22-75	NM-1 277.0	275.0 275.0	5001
24S/25E-10A01 M	3	304.0	9-30-74 1-29-75	123.5 109.5	180.5 194.5	5613
24S/25E-33J01 M		292.0	9-30-74 1-28-75	44.5 45.5	247.5 246.5	5613
24S/26E-03R01 M	4	376.0	10-04-74 1-30-75	166.0 158.0	210.0 218.0	5613
24S/26E-20E01 M	4	378.0	10-03-74 1-29-75	134.0 124.0	244.0 254.0	5613
24S/26E-29R02 M	1	401.0	10-04-74 1-28-75	126.0 120.0	275.0 280.0	5613
24S/26E-32G01 M	1	397.0	10-03-74 1-28-75	108.0 125.0	289.0 272.0	5613
25S/26E-10B03 M	4	430.0	10-02-74 1-27-75	176.5 163.5	253.5 266.5	5613
25S/26E-16P01 M		388.0	9-23-74 1-23-75	99.2 89.5	288.8 298.5	5001
25S/27E-22R01 M	4	750.0	9-23-74 1-20-75	474.0 NM-1	276.0	5001
SOUTHERN SAN JOAQUIN M.U.D.				5-22.36		
25S/25E-36P02 M		335.0	9-26-74 1-30-75	205.4 160.0	129.6 175.0	5614
25S/26E-28H02 M		415.0	9-27-74 1-31-75	204.6 201.6	210.4 213.4	5614
26S/26E-16P01 M		443.0	9-26-74 1-31-75	NM-3 NM-3		5614
NORTH KERN W.S.D.				5-22.37		
26S/25E-15P01 M	3	340.0	9-23-74 1-27-75	243.0 195.0	109.0 153.0	5050
26S/25E-15R01 M	3	352.3	9-23-74 1-27-75	195.0 195.0	157.3 157.3	5050
26S/26E-30F01 M	2	392.0	1-30-75	255.0	137.0	5050
27S/25E-01N01 M	3	394.0	9-25-74 1-31-75	117.0 106.0	277.0 288.0	5050
27S/25E-01N03 M	2	394.0	9-25-74 1-31-75	301.0 271.0	93.0 123.0	5050
27S/26E-20D01 M	1	445.3	9-25-74 1-31-75	340.0 NM-1	105.3	5050
27S/27E-30H02 M	4	525.0	9-23-74 1-20-75	479.0 324.0	46.0 201.0	5001
28S/25E-13L01 M	3	361.1	9-24-74 1-28-75	240.0 218.0	121.1 143.1	5050
28S/26E-21H01 M	3	388.0	9-23-74 1-28-75	181.0 179.0	207.0 209.0	5050
28S/26E-21H03 M	2	388.0	9-23-74 1-28-75	275.0 250.0	113.0 138.0	5050
SHAFTER-WASCO I.D.				5-22.38		
27S/24E-01L02 M		322.0	9-23-74 1-27-75	295.1 250.5	26.9 71.5	5616
27S/24E-35C01 M	3	321.8	9-24-74 1-29-75	NM-1 252.0	69.8	5050
27S/25E-28A01 M	3	375.0	9-26-74 1-28-75	283.0 260.0	92.0 115.0	5050
28S/25E-16P01 M		329.0	9-25-74 2-03-75	240.5 217.0	88.5 112.0	5616
KERN RIVER DELTA AREA				5-22.40		
28S/26E-29L01 M	3	350.0	9-26-74 2-04-75	201.5 NM-1	148.5	5616
KERN RIVER DELTA AREA				5-22.40		
29S/25E-12M03 M	2	330.0	9-30-74 2-05-75	188.5 181.0	141.5 149.0	5133
30S/25E-10R01 M		300.0	9-25-74 1-29-75	100.0 102.0	200.0 198.0	5050
30S/25E-22D01 M		308.5	10-01-74 2-01-75	91.4 92.1	217.1 216.4	5640
30S/26E-22P02 M	2	338.0	10-01-74 2-04-75	120.5 108.5	217.5 229.5	5133
30S/28E-32B01 M	1	353.0	9-26-74 1-23-75	114.0 110.4	240.4 244.0	5001
31S/27E-04J02 M		340.0	10-01-74 2-04-75	149.0 141.5	191.0 198.5	5133
31S/27E-28J01 M	1	312.1	10-01-74 2-04-75	81.5 93.5	230.6 218.6	5133
31S/28E-30H01 M	3	314.7	9-27-74 1-30-75	90.0 75.0	224.7 239.7	5050
32S/27E-18E01 M	3	292.6	9-27-74 1-30-75	145.0 125.0	147.6 167.6	5050
32S/28E-04B01 M		301.0	9-24-75 1-20-75	NM-1 NM-1		5001
EDISON-MARICOPA AREA				5-22.41		
11N/19W-24H01 S		737.0	9-30-74 2-06-75	589.4 582.3	147.6 154.7	5644
11N/19W-10A01 S	1	612.0	9-30-74 2-11-75	472.9 479.9	139.1 136.1	5644
11N/20W-07Q01 S	3	452.3	1-31-75	283.0	169.3	5050
11N/20W-24E01 S		740.0	2-01-74	585.0	155.0	5050
11N/21W-05M01 S	3	515.9	1-31-75	420.0	95.9	5050
11N/22W-04H01 S	3	529.0	1-31-75	400.0	129.0	5050
29S/29E-31N01 M	4	580.0	9-17-74 1-21-75	442.3 426.3	137.7 153.7	5644
30S/28E-02R01 M	4	411.0	9-26-74 1-24-75	244.0 228.0	167.0 182.0	5001
30S/28E-10N01 M		373.0	9-26-74 1-23-75	56.0 57.2	317.0 315.8	5001
30S/28E-10N04 M		373.0	9-26-74 1-23-75	207.5 197.5	165.5 175.5	5001
30S/29E-05F01 M		515.0	9-18-74 1-21-75	375.2 NM-3	139.8	5644
30S/29E-27A01 M	1	575.0	9-20-74 1-27-75	447.0 442.5	128.0 132.5	5644
30S/30E-20R01 M	4	794.0	10-17-74 2-26-75	232.3 NM-1	561.7	5644
31S/29E-04P01 M		459.0	9-23-74 1-29-75	332.5 292.5	126.5 166.5	5644
31S/29E-29A01 M		400.0	9-24-74 1-20-75	154.5 144.9	245.5 255.1	5001
31S/30E-21G01 M	4	536.0	10-10-74 2-19-75	364.2 358.5	171.8 177.5	5644
32S/28E-23R01 M		386.0	10-10-74 2-20-75	255.6 260.4	130.4 125.6	5644
32S/29E-19H02 M		416.0	10-15-74 2-26-75	199.9 197.8	216.1 218.2	5644
32S/29E-19H03 M		416.0	10-15-74 2-26-75	339.0 322.3	77.0 93.7	5644
BUENA VISTA W.S.D.				5-22.42		
27S/22E-21F02 M		240.0	9-27-74 1-29-75	16.0 18.0	224.0 222.0	5133
27S/22E-32H01 M	1	241.0	9-27-74 1-29-75	141.0 136.0	100.0 105.0	5133
28S/22E-09D01 M	3	240.0	9-27-74 1-29-75	12.5 12.5	227.5 227.5	5133
29S/23E-31R01 M		257.8	10-01-74 2-01-75	26.2 36.1	231.6 221.7	5640
29S/23E-08A01 M		259.0	10-01-74 2-01-75	37.7 48.8	221.3 210.2	5640
29S/23E-27H01 M	1	270.0	9-27-74 1-31-75	55.5 59.5	214.5 210.5	5133
30S/23E-01D01 M		276.8	0-01-74 2-01-75	73.0 84.7	203.8 192.1	5640

TABLE C-3 (Cont.)
GROUND WATER LEVELS AT WELLS

STATE WELL NUMBER	AQUIFER	GROUND ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEVATION IN FEET	AGENCY CODE
BUENA VISTA W.S.D.				5-22.42		
30S/24E-02C01 M		288.7	10-01-74 2-01-75	112.6 107.5	176.1 181.2	5640
30S/24E-04C01 M	1	282.0	9-27-74 1-31-75	87.5 91.5	194.5 190.5	5133
31S/25E-26A01 M		289.0	10-02-74 1-30-75	84.0 66.0	205.0 223.0	5133
SEMITROPIC W.S.D.				5-22.43		
25S/22E-02N02 M	1	212.0	9-25-74	NM-6		5133
25S/22E-14G01 M		215.0	9-25-74 1-28-75	256.5 195.5	- 41.5 19.5	5133
25S/23E-28D01 M		217.0	9-26-74 1-29-75	111.0 103.0	106.0 114.0	5133
25S/23E-28D03 M	2	217.0	9-26-74 1-29-75	NM-3 NM-3		5133
25S/24E-10K01 M	1	240.0	9-25-74 1-23-75	57.6 56.0	182.4 184.0	5001
25S/24E-15H01 M		248.0	9-25-74 1-23-75	75.3 73.2	172.7 174.8	5001
25S/24E-30H01 M		238.0	9-25-74 1-28-75	NM-3 NM-4		5133
26S/21E-14J01 M	1	237.0	9-23-74 1-27-75	28.0 36.0	209.0 201.0	5133
26S/22E-21D01 M	2	240.0	9-23-74 1-28-75	35.0 36.0	205.0 204.0	5133
26S/23E-02R01 M	2	234.9	9-26-74 1-29-75	NM-7 NM-9		5133 5121
26S/24E-23H01 M	2	295.5	9-27-74 1-30-75	322.0 249.0	- 26.5 46.5	5050
27S/23E-01R01 M	1	267.0	9-24-74 1-28-75	97.5 96.5	169.5 170.5	5133
27S/23E-01R04 M	2	267.0	9-24-74 1-28-75	303.5 257.5	- 36.5 9.5	5133
27S/23E-01R05 M	2	267.0	9-24-74 1-28-75	294.5 249.5	- 27.5 17.5	5133
27S/23E-09C01 M		260.0	9-26-74 1-31-75	289.0 283.0	- 29.0 - 23.0	5133
28S/23E-11E01 M		255.0	10-01-74 2-01-75	39.0 43.5	216.0 211.5	5640
29S/24E-14N01 M	1	290.0	10-00-74	NM-0		5133
AVENAL-MCKITTRICK AREA				5-22.44		
24S/19E-10P01 M		330.0	2-19-74 5-20-74	24.1 24.0	305.9 306.0	5050
25S/19E-20Q02 M	1	480.0	9-23-74 1-27-75	117.6 106.6	362.4 373.4	5133
25S/20E-04C01 M	1	268.0	8-26-74 11-19-74	45.5 NM-6	222.5	5050
26S/18E-19B02 M	1	875.0	9-23-74 1-27-75	165.0 164.0	710.0 711.0	5133
28S/22E-20M01 M		290.0	11-19-74 3-18-75	67.0 68.0	223.0 222.0	5050
TULARE LAKE-LOST HILLS AREA				5-22.45		
22S/19E-18P02 M	1	255.0	11-18-74 3-17-75	176.0 175.0	79.0 80.0	5050
22S/21E-01J01 M	2	185.5	2-20-75	94.0	91.5	5050
23S/19E-14R01 M	1	235.0	11-18-74 3-17-75	32.0 33.5	203.0 201.5	5050
24S/20E-21N02 M	1	233.0	3-17-75	NM-0		5050
24S/21E-15J01 M		211.0	2-19-75	19.5	191.5	5050
24S/21E-36B01 M		210.0	2-19-75	17.5	192.5	5050
24S/22E-28A02 M		207.0	11-06-74 2-19-75	233.0 197.0	- 26.0 10.0	5050
24S/22E-35E01 M		213.0	11-06-74 2-19-75	263.0 212.0	- 50.0 1.0	5050
26S/22E-30K01 M	1	237.5	8-27-74 11-19-74	35.5 NM-6	202.0	5050

STATE WELL NUMBER	AQUIFER	GROUND ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEVATION IN FEET	AGENCY CODE
CORCORAN I.D.				5-22.46		
20S/22E-35R01 M		216.0	11-06-74 2-20-75	45.0 55.0	171.0 161.0	5050
21S/22E-27A01 M		196.0	11-06-74 2-20-75	10.0 9.5	186.0 186.5	5050
22S/22E-01B02 M		201.0	11-06-74 2-20-75	5.2 6.5	195.8 194.5	5050
22S/22E-05L01 M	2	188.0	2-20-75	NM-6		5050
22S/22E-09L01 M		189.0	2-20-75	99.0	90.0	5050
22S/22E-10A01 M	2	192.0	11-06-74 2-20-75	117.0 102.0	75.0 90.0	5050
22S/22E-13R01 M	1	193.0	11-06-74 2-20-75	NM-5 NM-6		5050
22S/22E-22H01 M	2	191.0	11-06-74	NM-6		5050
MENDOTA-HURON AREA				5-22.47		
13S/12E-22N01 M	2	280.0	10-17-74 3-25-75	90.4 90.0	189.6 190.0	5607
14S/15E-18E02 M		178.0	12-19-74	NM-6		5050
15S/14E-15E04 M		236.0	12-17-74 1-27-75	NM-4 NM-6		5050
15S/15E-22D01 M		175.0	10-16-74 1-27-75	72.7 81.0	102.3 94.0	5001
15S/16E-17L01 M		165.0	10-17-74 1-16-75	42.7 42.6	122.3 122.4	5621
15S/16E-28A04 M		164.0	12-20-74 1-16-75	130.0 129.7	34.0 34.3	5050 5620
17S/14E-13R01 M	1	457.0	12-23-74	630.0	-173.0	5050
17S/16E-24R01 M		232.5	11-20-74	NM-6		5050
17S/16E-30A03 M		290.0	10-16-74 1-17-75	60.0 58.5	230.0 231.5	5001
17S/16E-30A05 M		290.0	10-16-74 1-17-75	349.2 358.7	- 59.2 - 68.7	5001
17S/17E-20N01 M	3	228.0	12-19-74	NM-1		5050
18S/17E-12N01 M	2	253.0	12-19-74	245.0	8.0	5050
19S/18E-15M01 M	2	274.0	2-06-75	245.0	29.0	5050
20S/17E-32F01 M		447.0	12-19-74	607.0	-160.0	5050
20S/18E-11N01 M	3	277.0	12-16-74	NM-6		5050
20S/18E-16D01 M		260.0	12-17-74	198.0	62.0	5050
21S/18E-28N02 M		363.0	12-17-74	335.0	28.0	5050
POSO RESOURCES C.D.				5-22.48		
11S/13E-05Q01 M		117.0	3-18-75	8.8	108.2	5529
TERRA BELLA I.D.				5-22.50		
22S/27E-25J03 M		532.0	9-14-74 2-20-75	108.0 87.0	424.0 445.0	5619
23S/27E-05A01 M	4	450.0	9-30-74 1-22-75	NM-1 147.1	302.9	5001
23S/28E-06A02 M	1	550.0	9-14-74 2-20-75	101.0 99.0	449.0 451.0	5619
MERCED BOTTOMS				5-22.54		
07S/10E-23K01 M		80.0	11-12-74 3-03-75	16.0 4.5	64.0 75.5	5050
07S/10E-27K02 M		80.0	11-12-74 3-03-75	4.3 3.5	75.7 76.5	5050
07S/12E-27F01 M		110.5	11-12-74 2-28-75	12.0 10.0	98.5 100.5	5050
08S/12E-19D01 M		90.0	2-27-75	12.0	78.0	5050
09S/12E-01C01 M	1	110.5	11-12-74 2-26-75	NM-1 47.0	63.5	5050
09S/14E-01B01 M		180.0	11-12-74 2-26-75	89.0 69.0	91.0 111.0	5050
09S/14E-01B02 M		180.0	11-12-74 2-26-75	85.0 66.0	95.0 114.0	5050

TABLE C-3 (Cont.)
GROUND WATER LEVELS AT WELLS

STATE WELL NUMBER	AQUIFER	GROUND ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEVATION IN FEET	AGENCY CODE
MERCED BOTTOMS				5-22.54		
09S/14E-01B03 M		180.0	11-12-74	40.0	140.0	5050
			2-26-75	39.0	141.0	
09S/14E-06D01 M		141.0	11-12-74	48.0	93.0	5050
			1-20-75	43.4	97.6	5001
GARFIELD W.D.				5-22.65		
12S/20E-13H01 M	4	387.0	10-03-74	97.6	289.4	5622
			2-03-75	96.4	290.6	
12S/21E-07A02 M	4	405.5	10-03-74	120.8	284.7	5622
			2-03-75	120.0	285.5	
12S/21E-18A03 M	4	390.5	10-03-74	94.4	296.1	5622
			2-03-75	94.0	296.5	
KINGS COUNTY W.D.				5-22.66		
17S/20E-36R02 M	1	243.0	9-18-74	17.3	225.7	5129
			1-30-75	16.1	226.9	
17S/22E-11P01 M	1	283.0	9-18-74	22.3	260.7	5129
			1-30-75	22.9	260.1	
17S/22E-35N01 M	1	266.0	9-18-74	43.1	222.9	5129
			1-30-75	35.9	230.1	
18S/21E-17N01 M	1	238.0	9-18-74	11.1	226.9	5129
			1-30-75	10.9	227.1	
18S/22E-21M01 M	1	258.0	9-18-74	85.1	172.9	5129
			1-30-75	NM-6		
18S/22E-36P01 M		245.0	10-09-74	73.7	171.3	5129
			1-30-75	83.5	161.5	5601
18S/23E-28B01 M	1	263.0	9-20-74	112.2	150.8	5129
			1-30-75	111.9	151.1	
19S/21E-20N01 M	1	225.0	9-20-74	10.3	214.7	5129
			2-06-75	10.7	214.3	
19S/22E-04B01 M	1	245.0	9-19-74	129.4	115.6	5129
			1-30-75	127.3	117.7	
19S/22E-19A01 M	2	235.0	9-19-74	75.4	159.6	5129
			2-06-75	71.2	163.8	
19S/22E-23A01 M		240.5	9-19-74	78.6	161.9	5129
			2-06-75	77.1	163.4	
20S/21E-01A01 M		220.0	10-10-74	9.5	210.5	5603
			2-20-75	14.5	205.5	
20S/21E-05E01 M	2	219.0	9-20-74	155.6	63.4	5129
			2-06-75	153.1	65.9	
20S/22E-10H02 M	2	225.0	9-24-74	117.5	107.5	5129
			2-07-75	NM-9		
PLEASANT VALLEY				5-22.69		
20S/15E-25D01 M	1	619.0	1-03-75	DRY		5050
20S/15E-32A01 M	1	675.0	1-03-75	247.0	428.0	5050
21S/16E-02N01 M	1	570.0	1-02-75	258.0	312.0	5050
21S/16E-08E01 M	1	604.0	1-02-75	234.0	361.0	5050
21S/16E-35D01 M	1	682.0	1-02-75	363.0	319.0	5050

STATE WELL NUMBER	AQUIFER	GROUND ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEVATION IN FEET	AGENCY CODE

82. State Department of Water Resources. Bulletin No. 130-75, Hydrologic Data: 1975 Volume V: Southern California, March 1977

SECTION 5
TITLE V.5
TREAT 1

STATE OF CALIFORNIA
The Resources Agency
Department of Water Resources

BULLETIN No. 130-75

HYDROLOGIC DATA: 1975

Volume V: SOUTHERN CALIFORNIA

CALIFORNIA RESOURCES AGENCY LIBRARY
Resources Building, Room 117
1416 - 9th Street
Sacramento, California 95814

MARCH 1977

CLAIRE T. DEDRICK
Secretary for Resources
The Resources Agency

EDMUND G. BROWN JR.
Governor
State of California

RONALD B. ROBIE
Director
Department of Water Resources

STATE OF CALIFORNIA

The Resources Agency

Department of Water Resources

BULLETIN No. 130-75

HYDROLOGIC DATA: 1975

Volume V: SOUTHERN CALIFORNIA

Copies of this bulletin at $7.00 each may be ordered from:
State of California
DEPARTMENT OF WATER RESOURCES
P.O. Box 388
Sacramento, California 95802

Make checks payable to STATE OF CALIFORNIA
California residents add sales tax

MARCH 1977

CLAIRE T. DEDRICK
Secretary for Resources
The Resources Agency

EDMUND G. BROWN JR.
Governor
State of California

RONALD B. ROBIE
Director
Department of Water Resources

BULLETIN No. 130
HYDROLOGIC DATA
AREAL COVERAGE OF VOLUMES
Each Volume Contains
Appendix A: Climatological Data
Appendix B: Surface Water Measurements
Appendix C: Ground Water Measurements
Appendix D: Surface Water Quality Data
Appendix E: Ground Water Quality Data
This Volume
OREGON
NEVADA
ARIZONA
MEXICO
PACIFIC OCEAN
VOLUME I
NORTH COASTAL AREA
VOLUME II
NORTHEASTERN CALIFORNIA
VOLUME III
CENTRAL COASTAL AREA
VOLUME IV
SAN JOAQUIN VALLEY
VOLUME V
SOUTHERN CALIFORNIA
DEL NORTE
SISKIYOU
MODOC
HUMBOLDT
TRINITY
SHASTA
LASSEN
TEHAMA
PLUMAS
GLENN
BUTTE
SIERRA
MENDOCINO
COLUSA
SUTTER
YUBA
NEVADA
LAKE
PLACER
YOLO
EL DORADO
NAPA
SONOMA
SOLANO
SACRAMENTO
AMADOR
ALPINE
MARIN
CONTRA COSTA
SAN JOAQUIN
CALAVERAS
TUOLUMNE
MONO
SAN FRANCISCO
ALAMEDA
STANISLAUS
MARIPOSA
SAN MATEO
SANTA CLARA
MERCED
MADERA
SANTA CRUZ
SAN BENITO
FRESNO
INYO
MONTEREY
TULARE
KINGS
SAN LUIS OBISPO
KERN
SAN BERNARDINO
SANTA BARBARA
VENTURA
LOS ANGELES
ORANGE
RIVERSIDE
SAN DIEGO
IMPERIAL

TABLE OF CONTENTS

	Page
AREAL COVERAGE OF VOLUMES	ii
FOREWORD	iii
CONVERSION TABLE	iv
ORGANIZATION	ix
ACKNOWLEDGMENTS	x

APPENDIXES

Appendix A: CLIMATOLOGICAL DATA	1

FIGURES

A	Representative Precipitation Characteristics	
A-1	For San Luis Obispo	4
A-2	For Los Angeles	5
A-3	For San Diego	6
A-4	For Barstow	7

TABLES

A-1	Monthly Precipitation	8
Appendix B:	SURFACE WATER MEASUREMENTS	17

FIGURES

B	Location of Surface Water Measurement Stations	
B-1	Central Coastal Area	21
B-2	Los Angeles Area	23
B-3	South Lahontan Area	25
B-4	Colorado River Basin Area	27
B-5	Santa Ana Area	29
B-6	San Diego Area	31
B-7	Historical Net Diversions of Water to Southern California from the Colorado River	32
B-8	Historical Importations of Water to Coastal Southern California	33

TABLES

		Page
B-1	Annual Unimpaired Runoff at Selected Stations in Southern California	34
B-2	Daily Mean Discharge	35
	California Aqueduct, Inlet to Silverwood Lake	36
	East Fork of the West Fork of Mojave River Below Confluence With Seely Creek	37
	East Fork of the West Fork of Mojave River Above Cedar Springs	38
	Sawpit Canyon Creek Above Cedar Springs	39
	West Fork Mojave River at Highway 138 Bridge	40
	West Fork Mojave River Above Cedar Springs	41
	Piru Creek Above Frenchmans Flat	42
	Canada De Los Alamos Above Pyramid Lake	43
	Piru Creek Below Buck Creek	44
	Elizabeth Lake Canyon Creek Above Castaic Creek	45
	Necktie Canyon Creek Above Castaic Creek	46
	Fish Creek Above Castaic Creek	47
	Castaic Creek One Mile Above Fish Creek	48
	Castaic Lagoon Parshall Flume	49
B-3	Monthly Water Content of Selected Surface Reservoirs in or Supplying Water to Southern California, October 1, 1974, to September 30, 1975	50
Appendix C. GROUND WATER MEASUREMENTS		51

FIGURES

C	Names and Areal Code Numbers of Hydrologic Areas	
C-1	Central Coastal Drainage Province (T)	55
C-2	Los Angeles Drainage Province (U)	57
C-3	Lahontan Drainage Province (W)	59
C-4	Colorado River Basin Drainage Province (X)	61
C-5	Santa Ana Drainage Province (Y)	63
C-6	San Diego Drainage Province (Z)	65
C-7	Fluctuation of Water Levels in Wells	66

TABLES

C-1	Ground Water Levels at Wells	79
	Central Coastal Drainage Province (T)	81
	Los Angeles Drainage Province (U)	104
	Lahontan Drainage Province (W)	201
	Colorado River Basin Drainage Province (X)	209
	Santa Ana Drainage Province (Y)	220
	San Diego Drainage Province (Z)	257

TABLES (Continued)

Page

C-2 Ground Water Replenishment in Southern California During the 1974-75 Water Year 268

Appendix D. SURFACE WATER QUALITY DATA 269

FIGURES

D Location of Surface Water Sampling Stations
D-1 Central Coastal Area 273
D-2 Los Angeles Area 275
D-3 South Lahontan Area 277
D-4 Colorado River Basin 279
D-5 Santa Ana Area 281
D-6 San Diego Area 283

TABLES

D-1 Sampling Stations Data and Index 284
D-2 Mineral Analyses of Surface Water 291
D-3 Minor Element Analyses of Surface Water 334
D-4 Supplemental Minor Element Analyses of Surface Water 351
D-5 Miscellaneous Constituents in Surface Water 356
D-6 Nutrient Analyses of Surface Water 378
D-7 Pesticide Analyses of Surface Water 404

Appendix E. GROUND WATER QUALITY DATA 409

TABLES

E-1 Mineral Analyses of Ground Water 412
Central Coastal Drainage Province (T) 413
Los Angeles Drainage Province (U) 417
Lahontan Drainage Province (W) 437
Colorado River Basin Drainage Province (X) 443
Santa Ana Drainage Province (Y) 447
San Diego Drainage Province (Z) 454

E-2 Minor Element Analyses of Ground Water 455

E-3 Supplemental Minor Element Analyses of Ground Water 471

E-4 Miscellaneous Constituents in Ground Water 473

E-5 Nutrient Analyses of Ground Water 477

Appendix C
GROUND WATER MEASUREMENTS

Appendix C

GROUND WATER MEASUREMENTS

This appendix contains ground water level measurements (Table C–1) for approximately 6,000 wells for the period October 1, 1974, through September 30, 1975. It also contains hydrographs of selected wells (Figure C–7) and a tabulation of ground water replenishment (Table C–2).

Two numbering systems are used by the Department to facilitate processing of water level measurement data. The two systems are the *Areal Designation* and the *State Well Numbering System* as described below.

The *Areal Designation System* comprises a series of major drainage provinces which are further subdivided into hydrologic units, hydrologic subunits, and hydrologic subareas. A coding system of the form *U–04.A2* has been developed as follows:

U – 04 A 2

Drainage Province (Los Angeles)
Hydrologic Unit (Malibu)
Hydrologic Subunit (Topanga)
Hydrologic Subarea (Tuna Canyon)

Figures C–1 through C–6 show the location and code number of each hydrologic subdivision in each drainage province, as well as the location of wells for which hydrographs are shown in Figure C–7.

The *State Well Numbering System* is based on township, range, and section subdivisions of the Public Land Survey. The number of a well, assigned in accordance with this system, is referred to as the *State Well Number*, as illustrated below:

39N / 13E – 08 K 04 M

Township
Range
Section
Tract
Sequence Number
Base and Meridian (M) Mount Diablo (S) San Bernardino

This number identifies and locates the well. In the example, the well is in Township 39 North, Range 13 East, Tract K of Section 8, located in the Mount Diablo Base and Meridian. A section is divided into 40–acre tracts as shown:

D	C	B	A
E	F	G	H
M	L	K	J
N	P	Q	R

Sequence numbers in a tract are generally assigned in chronological order. The example designates the fourth well to be assigned a number in Tract K.

AREAL DESIGNATIONS
HYDROLOGIC UNITS SUBUNITS AND SUBAREAS
CENTRAL COASTAL DRAINAGE PROVINCE

T–09.00 SALINAS HYDROLOGIC UNIT
- T–09.H0 Paso Robles Hydrologic Subunit
- T–09.I0 Pozo Hydrologic Subunit

T–10.00 SAN LUIS OBISPO HYDROLOGIC UNIT
- T–10.A0 Cambria Hydrologic Subunit
  - T–10.A1 San Carpoforo Hydrologic Subarea
  - T–10.A2 Arroyo De La Cruz Hydrologic Subarea
  - T–10.A3 San Simeon Hydrologic Subarea
  - T–10.A4 Santa Rosa Hydrologic Subarea
  - T–10.A5 Villa Hydrologic Subarea
  - T–10.A6 Cayucos Hydrologic Subarea
  - T–10.A7 Old Hydrologic Subarea
  - T–10.A8 Toro Hydrologic Subarea
- T–10.B0 San Luis Obispo Hydrologic Subunit
  - T–10.B1 Morro Hydrologic Subarea
  - T–10.B2 Chorro Hydrologic Subarea
  - T–10.B3 Los Osos Hydrologic Subarea
  - T–10.B4 San Luis Obispo Creek Hydrologic Subarea
  - T–10.B5 Point San Luis Hydrologic Subarea
  - T–10.B6 Pismo Hydrologic Subarea
- T–10.C0 Arroyo Grande Hydrologic Subunit
  - T–10.C1 Arroyo Grande Hydrologic Subarea
  - T–10.C2 Nipomo Mesa Hydrologic Subarea

T–11.00 CARRIZO PLAIN HYDROLOGIC UNIT

T–12.00 SANTA MARIA–CUYAMA HYDROLOGIC UNIT
- T–12.A0 Santa Maria Hydrologic Subunit
- T–12.B0 Sisquoc Hydrologic Subunit
- T–12.C0 Cuyama Valley Hydrologic Subunit

T–13.00 SAN ANTONIO HYDROLOGIC UNIT

T–14.00 SANTA YNEZ HYDROLOGIC UNIT
- T–14.A0 Lompoc Hydrologic Subunit
- T–14.B0 Santa Rita Hydrologic Subunit
- T–14.C0 Buellton Hydrologic Subunit
- T–14.D0 Santa Ynez Hydrologic Subunit
- T–14.E0 Headwater Hydrologic Subunit

T–15.00 SANTA BARBARA HYDROLOGIC UNIT
- T–15.A0 Arguello Hydrologic Subunit
- T–15.C0 South Coast Hydrologic Subunit
  - T–15.C1 Goleta Hydrologic Subarea
  - T–15.C2 Santa Barbara Hydrologic Subarea
  - T–15.C3 Montecito Hydrologic Subarea
  - T–15.C4 Carpinteria Hydrologic Subarea

NAMES AND AREAL CODE NUMBERS OF HYDROLOGIC AREAS
CENTRAL COASTAL DRAINAGE PROVINCE (T)

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1975

AREAL DESIGNATIONS
HYDROLOGIC UNITS SUBUNITS AND SUBAREAS
LOS ANGELES DRAINAGE PROVINCE

U-01.00 RINCON CREEK HYDROLOGIC UNIT

U-02.00 VENTURA RIVER HYDROLOGIC UNIT
- U-02 A0 Lower Ventura River Hydrologic Subunit
- U-02.B0 Upper Ventura River Hydrologic Subunit
- U-02.C0 Ojai Hydrologic Subunit
  - U-02.C1 Upper Ojai Hydrologic Subarea
  - U-02.C2 Ojai Hydrologic Subarea

U-03.00 SANTA CLARA-CALLEGUAS HYDROLOGIC UNIT
- U-03.A0 Oxnard Plain Hydrologic Subunit
  - U-03.A1 Oxnard Hydrologic Subarea
  - U-03.A2 Pleasant Valley Hydrologic Subarea
- U-03.B0 Santa Paula Hydrologic Subunit
  - U-03.B1 Santa Paula Hydrologic Subarea
  - U-03.B2 Sisar Hydrologic Subarea
- U-03.C0 Sespe Hydrologic Subunit
  - U-03 C1 Fillmore Hydrologic Subarea
  - U-03 C2 Sespe Hydrologic Subarea
- U-03.D0 Piru Hydrologic Subunit
  - U-03.D1 Piru Hydrologic Subarea
  - U-03.D2 Upper Piru Hydrologic Subarea
  - U-03.D3 Hungry Valley Hydrologic Subarea
  - U-03.D4 Stauffer Hydrologic Subarea
- U-03.E0 Upper Santa Clara River Hydrologic Subunit
  - U-03.E1 Eastern Hydrologic Subarea
  - U-03.E2 Bouquet Hydrologic Subarea
  - U-03.E3 Mint Canyon Hydrologic Subarea
  - U-03.E4 Sierra Pelona Hydrologic Subarea
  - U-03.E5 Acton Hydrologic Subarea
- U-03 F0 Calleguas-Conejo Hydrologic Subunit
  - U-03.F1 West Las Posas Hydrologic Subarea
  - U-03.F2 East Las Posas Hydrologic Subarea
  - U-03.F3 Arroyo Santa Rosa Hydrologic Subarea
  - U-03.F4 Conejo Valley Hydrologic Subarea
  - U-03.F5 Tierra Rejada Valley Hydrologic Subarea
  - U-03.F6 Gillibrand Hydrologic Subarea
  - U-03.F7 Simi Valley Hydrologic Subarea
  - U-03.F8 Thousand Oaks Hydrologic Subarea

U-04.00 MALIBU HYDROLOGIC UNIT
- U-04.A0 Topanga Hydrologic Subunit
  - U-04.A1 Topanga Canyon Hydrologic Subarea
  - U-04.A2 Tuna Canyon Hydrologic Subarea
  - U-04.A3 Pena Canyon Hydrologic Subarea
  - U-04.A4 Piedra Gorda Canyon Hydrologic Subarea
  - U-04.A5 Las Flores Canyon Hydrologic Subarea
  - U-04.A6 Carbon Canyon Hydrologic Subarea
- U-04 B0 Malibu Creek Hydrologic Subunit
  - U-04.B1 Malibu Creek Hydrologic Subarea
  - U-04.B2 Las Virgenes Canyon Hydrologic Subarea
  - U-04.B3 Lindero Canyon Hydrologic Subarea
  - U-04.B4 Triunfo Canyon Hydrologic Subarea
  - U-04.B5 Russell Valley Hydrologic Subarea
  - U-04.B6 Sherwood Hydrologic Subarea
- U-04.C0 Point Dume Hydrologic Subunit
  - U-04 C1 Corral Canyon Hydrologic Subarea
  - U-04 C2 Solstice Canyon Hydrologic Subarea
  - U-04.C3 Latigo Canyon Hydrologic Subarea
  - U-04 C4 Escondido Canyon Hydrologic Subarea
  - U-04.C5 Ramera Canyon Hydrologic Subarea
  - U-04.C6 Zuma Canyon Hydrologic Subarea
  - U-04.C7 Trancas Canyon Hydrologic Subarea
- U-04.D0 Camarillo Hydrologic Subunit
  - U-04 D1 Encinal Canyon Hydrologic Subarea
  - U-04.D2 Los Alisos Canyon Hydrologic Subarea
  - U-04.D3 Nicholas Canyon Hydrologic Subarea
  - U-04.D4 Arroyo Sequit Hydrologic Subarea
  - U-04.D5 Little Sycamore Canyon Hydrologic Subarea
  - U-04.D6 Deer Canyon Hydrologic Subarea
  - U-04.D7 Big Sycamore Canyon Hydrologic Subarea
  - U-04.D8 La Jolla Valley Hydrologic Subarea

U-05.00 LOS ANGELES-SAN GABRIEL RIVER HYDROLOGIC UNIT
- U-05.A0 Coastal Plain of Los Angeles County Hydrologic Subunit
  - U-05.A1 Palos Verdes Hydrologic Subarea
  - U-05.A2 West Coast Hydrologic Subarea
  - U-05.A3 Santa Monica Hydrologic Subarea
  - U-05.A4 Hollywood Hydrologic Subarea
  - U-05.A5 Central Hydrologic Subarea
- U-05.B0 San Fernando Hydrologic Subunit
  - U-05.B1 San Fernando Hydrologic Subarea
  - U-05.B2 Sylmar Hydrologic Subarea
  - U-05.B3 Tujunga Hydrologic Subarea
  - U-05.B4 Verdugo Hydrologic Subarea
  - U-05.B5 Eagle Rock Hydrologic Subarea
- U-05.C0 Raymond Hydrologic Subunit
  - U-05.C1 Pasadena Hydrologic Subarea
  - U-05.C2 Monk Hill Hydrologic Subarea
  - U-05.C3 Santa Anita Hydrologic Subarea
- U-05.D0 San Gabriel Valley Hydrologic Subunit
  - U-05.D1 Main San Gabriel Hydrologic Subarea
  - U-05.D2 Lower Canyon Hydrologic Subarea
  - U-05.D3 Upper Canyon Hydrologic Subarea
  - U-05.D4 Foothill Hydrologic Subarea
- U-05.E0 Spadra Hydrologic Subunit
  - U-05 E1 Spadra Hydrologic Subarea
  - U-05.E2 Pomona Hydrologic Subarea
  - U-05.E3 Live Oak Hydrologic Subarea
- U-05.F0 Anaheim Hydrologic Subunit
  - U-05.F1 Anaheim Hydrologic Subarea
  - U-05.F2 La Habra Hydrologic Subarea
  - U-05.F3 Yorba Linda Hydrologic Subarea

NAMES AND AREAL CODE NUMBERS OF HYDROLOGIC AREAS
LOS ANGELES DRAINAGE PROVINCE (U)

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1978

AREAL DESIGNATIONS
HYDROLOGIC UNITS SUBUNITS AND SUBAREAS
LAHONTAN DRAINAGE PROVINCE

W-01.00 MONO HYDROLOGIC UNIT

W-02.00 ADOBE HYDROLOGIC UNIT

W-03.00 OWENS HYDROLOGIC UNIT
- W-03.A0 Long Hydrologic Subunit
- W-03 B0 Upper Owens Hydrologic Subunit
- W-03.C0 Lower Owens Hydrologic Subunit
- W-03.D0 Centennial Hydrologic Subunit

W-04.00 FISH LAKE HYDROLOGIC UNIT

W-05.00 DEEP SPRINGS HYDROLOGIC UNIT

W-06.00 EUREKA HYDROLOGIC UNIT
- W-06.A0 Marble Bath Hydrologic Subunit
- W-06.B0 Eureka Hydrologic Subunit

W-07.00 SALINE HYDROLOGIC UNIT
- W-07.A0 Saline Hydrologic Subunit
- W-07.B0 Cameo Hydrologic Subunit

W-08.00 RACE TRACK HYDROLOGIC UNIT
- W-08.A0 Race Track Hydrologic Subunit
- W-08.B0 Hidden Valley Hydrologic Subunit
- W-08.C0 Ulida Hydrologic Subunit
- W-08.D0 Sand Flat Hydrologic Subunit

W-09.00 AMARGOSA HYDROLOGIC UNIT
- W-09.A0 Death Valley Hydrologic Subunit
  - W-09.A1 Death Valley Hydrologic Subarea
  - W-09.A2 Harrisburgh Hydrologic Subarea
  - W-09.A3 Wingate Wash Hydrologic Subarea
- W-09.B0 Valjean Hydrologic Subunit
  - W-09.B1 Avawatz Hydrologic Subarea
  - W-09.B2 Red Pass Hydrologic Subarea
  - W-09.B3 Valjean Hydrologic Subarea
  - W-09.B4 Shadow Hydrologic Subarea
- W-09.C0 Furnace Creek Hydrologic Subunit
  - W-09.C1 Furnace Creek Hydrologic Subarea
  - W-09.C2 Greenwater Hydrologic Subarea
- W-09.D0 Amargosa Hydrologic Subunit
  - W-09.D1 Calico Hydrologic Subarea
  - W-09.D2 Amargosa Hydrologic Subarea
  - W-09.D3 Chicago Hydrologic Subarea
  - W-09.D4 California Hydrologic Subarea

W-10.00 PAHRUMP HYDROLOGIC UNIT

W-11.00 MESQUITE HYDROLOGIC UNIT

W-12.00 IVANPAH HYDROLOGIC UNIT

W-13.00 OWLSHEAD HYDROLOGIC UNIT
- W-13.A0 Lost Lake Hydrologic Subunit
- W-13.B0 Owlshead Hydrologic Subunit

W-14.00 LEACH HYDROLOGIC UNIT

W-15.00 NELSON HYDROLOGIC UNIT
- W-15.A0 McLean Hydrologic Subunit
- W-15.B0 Nelson Hydrologic Subunit

W-16.00 BICYCLE HYDROLOGIC UNIT

W-17.00 GOLDSTONE HYDROLOGIC UNIT

W-18.00 COYOTE HYDROLOGIC UNIT

W-19.00 SUPERIOR HYDROLOGIC UNIT

W-20.00 PANAMINT HYDROLOGIC UNIT
- W-20.A0 Wingate Pass Hydrologic Subunit
- W-20.B0 Wild Rose Hydrologic Subunit
  - W-20.B1 White Sage Hydrologic Subarea
  - W-20.B2 Wild Rose Hydrologic Subarea
- W-20.C0 Lee Flat Hydrologic Subunit
- W-20.D0 Santa Rosa Flat Hydrologic Subunit
  - W-20.D1 Santa Rosa Flat Hydrologic Subarea
  - W-20.D2 Rainbow Hydrologic Subarea
  - W-20.D3 Silver Dollar Hydrologic Subarea
- W-20.E0 Darwin Hydrologic Subunit
- W-20.F0 Panamint Hydrologic Subunit
- W-20.G0 Brown Hydrologic Subunit
- W-20.H0 Robbers Hydrologic Subunit

W-21.00 SEARLES HYDROLOGIC UNIT
- W-21.A0 Searles Hydrologic Subunit
- W-21.B0 Salt Wells Hydrologic Subunit
- W-21.C0 Pilot Knob Hydrologic Subunit

W-22.00 COSO HYDROLOGIC UNIT
- W-22.A0 Wild Horse Hydrologic Subunit
- W-22 B0 Coso Hydrologic Subunit

W-23.00 UPPER CACTUS HYDROLOGIC UNIT

W-24.00 INDIAN WELLS HYDROLOGIC UNIT
- W-24.A0 Rose Hydrologic Subunit
- W-24.B0 Indian Wells Hydrologic Subunit

W-25.00 FREMONT HYDROLOGIC UNIT
- W-25.A0 Dove Springs Hydrologic Subunit
- W-25.B0 Kelso Landis Hydrologic Subunit
- W-25.C0 East Tehachapi Hydrologic Subunit
- W-25.D0 Koehn Hydrologic Subunit

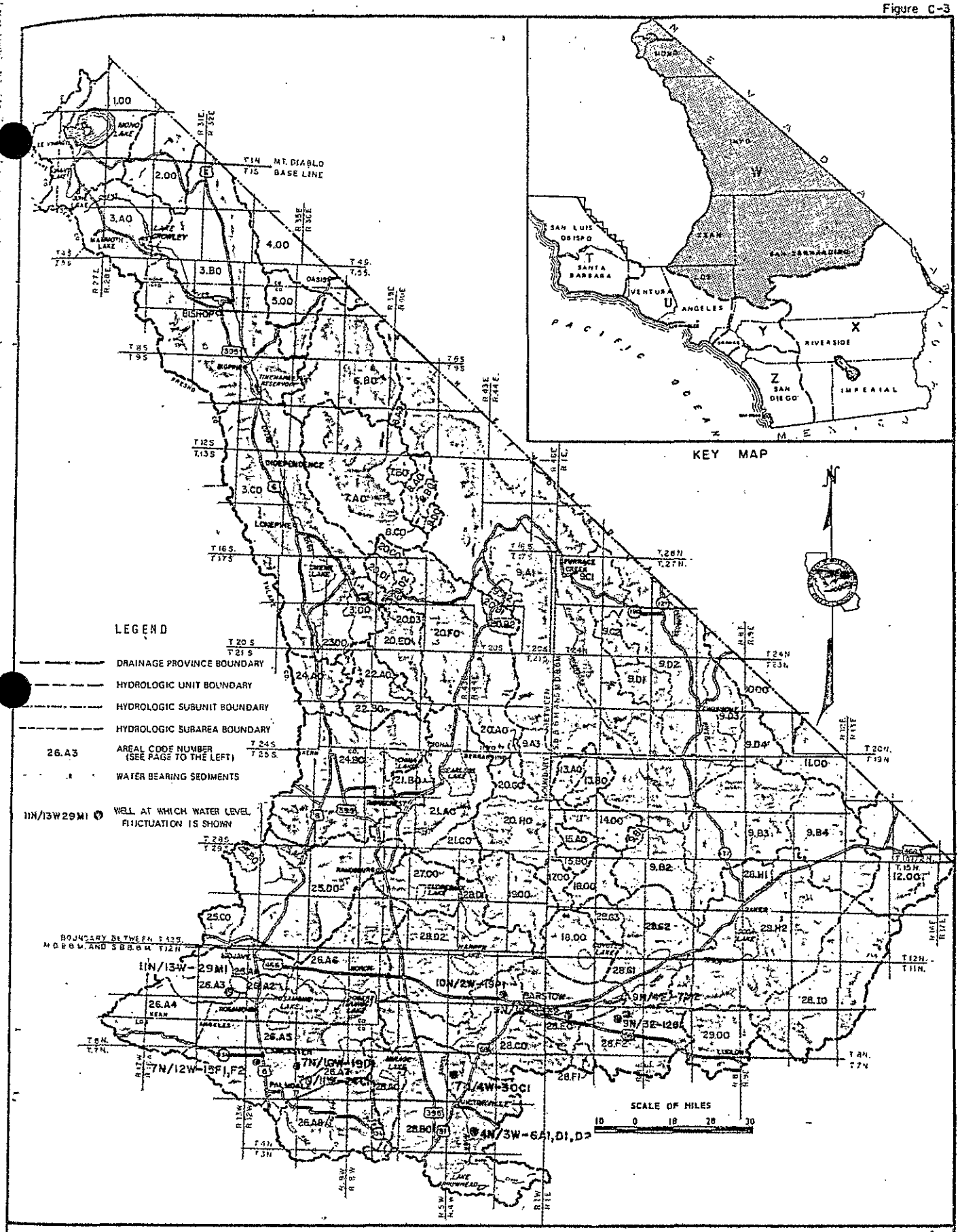
W-26.00 ANTELOPE HYDROLOGIC UNIT
- W-26.A0 Antelope Hydrologic Subunit
  - W-26.A1 Chafee Hydrologic Subarea
  - W-26.A2 Gloster Hydrologic Subarea
  - W-26.A3 Willow Springs Hydrologic Subarea
  - W-26.A4 Neenach Hydrologic Subarea
  - W-26.A5 Lancaster Hydrologic Subarea
  - W-26.A6 North Muroc Hydrologic Subarea
  - W-26.A7 Buttes Hydrologic Subarea
  - W-26.A8 Rock Creek Hydrologic Subarea

W-27.00 CUDDEBACK HYDROLOGIC UNIT

W-28.00 MOJAVE HYDROLOGIC UNIT
- W-28.A0 El Mirage Hydrologic Subunit
- W-28.B0 Upper Mojave Hydrologic Subunit
- W-28.C0 Middle Mojave Hydrologic Subunit
- W-28.D0 Harper Hydrologic Subunit
  - W-28.D1 Grass Valley Hydrologic Subarea
  - W-28.D2 Harper Hydrologic Subarea
- W-28.E0 Lower Mojave Hydrologic Subunit
- W-28.F0 Troy Hydrologic Subunit
  - W-28.F1 Kane Wash Hydrologic Subarea
  - W-28.F2 Troy Hydrologic Subarea
- W-28.G0 Afton Hydrologic Subunit
  - W-28.G1 Caves Hydrologic Subarea
  - W-28.G2 Cronese Hydrologic Subarea
  - W-28.G3 Langford Hydrologic Subarea
- W-28.H0 Baker Hydrologic Subunit
  - W-28.H1 Silver Lake Hydrologic Subarea
  - W-28.H2 Soda Lake Hydrologic Subarea
- W-28.I0 Kelso Hydrologic Subunit

W-29.00 BROADWELL HYDROLOGIC UNIT

Figure C-3



NAMES AND AREAL CODE NUMBERS OF HYDROLOGIC AREAS
LAHONTAN DRAINAGE PROVINCE (W)

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1975

AREAL DESIGNATIONS
HYDROLOGIC UNITS SUBUNITS AND SUBAREAS
COLORADO RIVER BASIN DRAINAGE PROVINCE

X–1.00 LUCERNE HYDROLOGIC UNIT

X–2.00 JOHNSON HYDROLOGIC UNIT

X–3.00 BESSEMER HYDROLOGIC UNIT

X–4.00 MEANS HYDROLOGIC UNIT

X–5.00 EMERSON HYDROLOGIC UNIT

X–6.00 LAVIC HYDROLOGIC UNIT

X–7.00 DEADMAN HYDROLOGIC UNIT

X–8.00 JOSHUA TREE HYDROLOGIC UNIT
- X–8.A0 Warren Hydrologic Subunit
- X–8.B0 Copper Mountain Hydrologic Subunit

X–9.00 DALE HYDROLOGIC UNIT
- X–9.A0 Twentynine Palms Hydrologic Subunit
- X–9.B0 Dale Hydrologic Subunit

X–10.00 BRISTOL HYDROLOGIC UNIT
- X–10.A0 Bristol Hydrologic Subunit
- X–10 B0 Fenner Hydrologic Subunit

X–11.00 CADIZ HYDROLOGIC UNIT

X–12.00 WARD HYDROLOGIC UNIT

X–13.00 PIUTE HYDROLOGIC UNIT
- X–13.A0 Lanfair Hydrologic Subunit
- X–13.B0 Piute Hydrologic Subunit
- X–13.C0 Needles Hydrologic Subunit

X–14.00 CHEMEHUEVI HYDROLOGIC UNIT

X–15.00 COLORADO HYDROLOGIC UNIT
- X–15.A0 Vidal Hydrologic Subunit
- X–15.B0 Big Wash Hydrologic Subunit
- X–15.C0 Quien Sabe Hydrologic Subunit
- X–15.D0 Palo Verde Hydrologic Subunit
- X–15.E0 Arroyo Seco Hydrologic Subunit

X–16.00 RICE HYDROLOGIC UNIT

X–17.00 CHUCKWALLA HYDROLOGIC UNIT
- X–17.A0 Ford Hydrologic Subunit
- X–17.B0 Palen Hydrologic Subunit
- X–17.C0 Pinto Hydrologic Subunit
- X–17.D0 Pleasant Hydrologic Subunit

X–18.00 HAYFIELD HYDROLOGIC UNIT

X–19.00 WHITEWATER HYDROLOGIC UNIT
- X–19.A0 Morongo Hydrologic Subunit
- X–19.B0 Shavers Hydrologic Subunit
- X–19.C0 San Gorgonio Hydrologic Subunit
  - X–19.C1 Beaumont Hydrologic Subarea
  - X–19.C2 San Gorgonio Hydrologic Subarea
- X–19.D0 Coachella Hydrologic Subunit
  - X–19.D1 Garnet Hill Hydrologic Subarea
  - X–19.D2 Mission Creek Hydrologic Subarea
  - X–19.D3 Miracle Hill Hydrologic Subarea
  - X–19.D4 Sky Valley Hydrologic Subarea
  - X–19.D5 Fargo Canyon Hydrologic Subarea
  - X–19.D6 Thousand Palms Hydrologic Subarea
  - X–19.D7 Indio Hydrologic Subarea

X–20.00 CLARK HYDROLOGIC UNIT

X–21.00 WEST SALTON SEA HYDROLOGIC UNIT

X–22.00 ANZA–BORREGO HYDROLOGIC UNIT
- X–22.A0 Borrego Hydrologic Subunit
  - X–22.A1 Terwilliger Hydrologic Subarea
  - X–22.A2 Collins Hydrologic Subarea
  - X–22.A3 Borrego Hydrologic Subarea
- X–22.B0 Ocotillo–Lower San Felipe Hydrologic Subunit
- X–22.C0 Mescal Bajada Hydrologic Subunit
- X–22.D0 San Felipe Hydrologic Subunit
- X–22.E0 Mason Hydrologic Subunit
- X–22.F0 Vallecito–Carrizo Hydrologic Subunit
  - X–22.F1 Carrizo Hydrologic Subarea
  - X–22.F2 Vallecito Hydrologic Subarea
  - X–22.F3 Canebrake Hydrologic Subarea
- X–22.G0 Jacumba Hydrologic Subunit
  - X–22.G1 McCain Hydrologic Subarea
  - X–22.G2 Jacumba Hydrologic Subarea

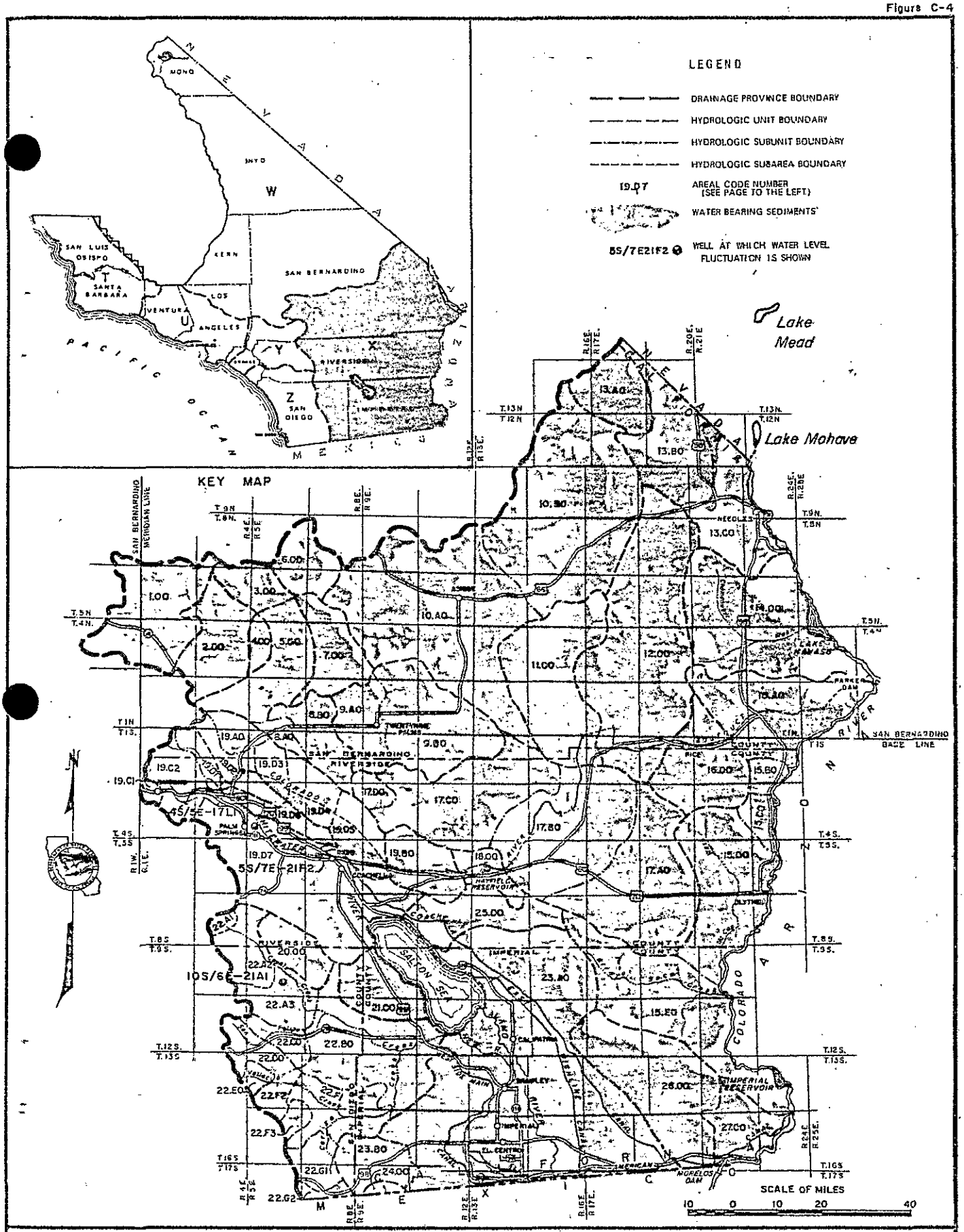
X–23.00 IMPERIAL HYDROLOGIC UNIT
- X–23.A0 Imperial Hydrologic Subunit
- X–23.B0 Coyote Wells Hydrologic Subunit

X–24.00 DAVIES HYDROLOGIC UNIT

X–25.00 EAST SALTON SEA HYDROLOGIC UNIT

X–26.00 AMOS–OGILBY HYDROLOGIC UNIT

X–27.00 YUMA HYDROLOGIC UNIT

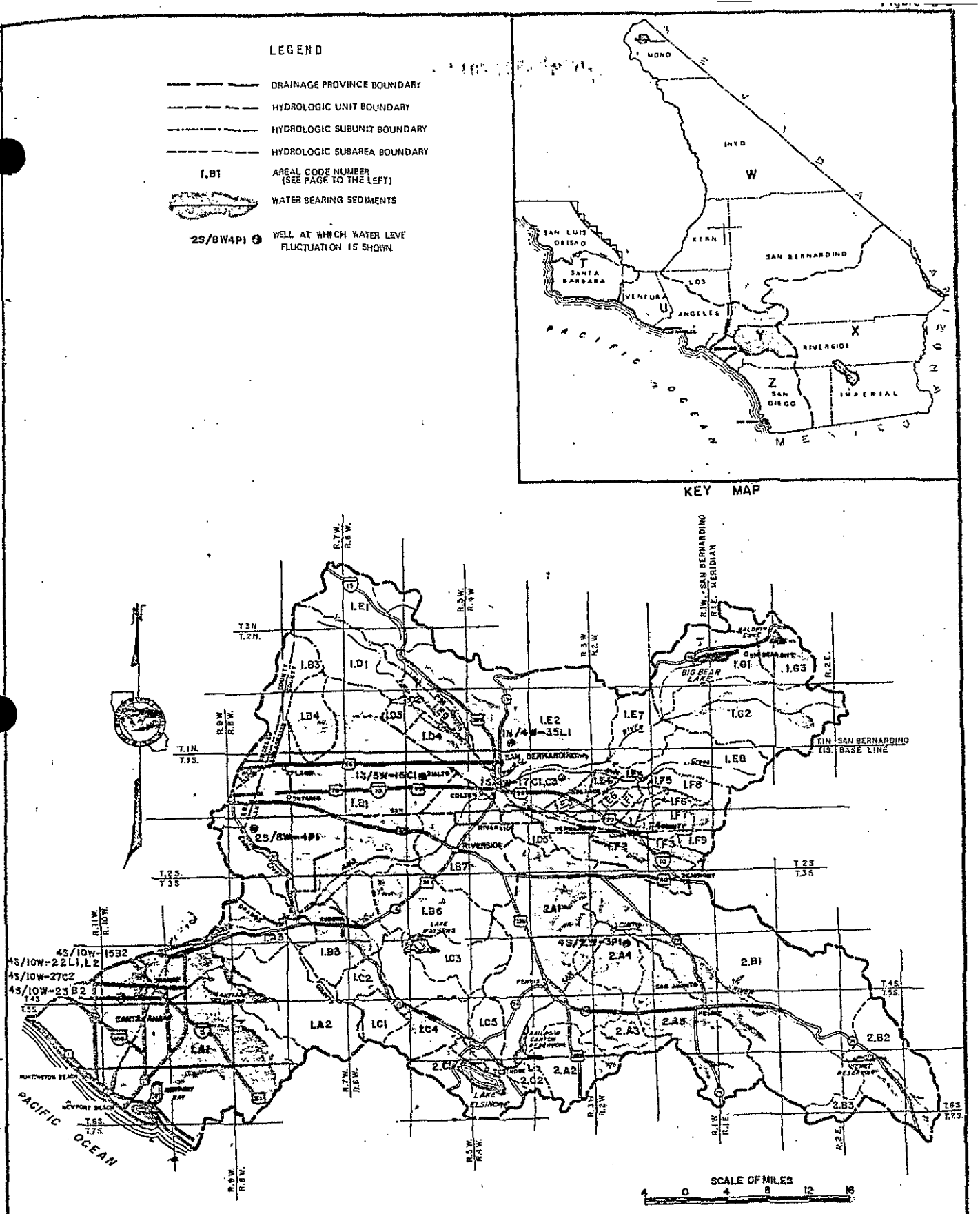


NAMES AND AREAL CODE NUMBERS OF HYDROLOGIC AREAS
COLORADO RIVER BASIN DRAINAGE PROVINCE (X)

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1975

AREAL DESIGNATIONS
HYDROLOGIC UNITS SUBUNITS AND SUBAREAS
SANTA ANA DRAINAGE PROVINCE

Y–01.00	SANTA ANA RIVER HYDROLOGIC UNIT
Y–01.A0	Lower Santa Ana River Hydrologic Subunit
Y–01.A1	East Coastal Plain Hydrologic Subarea
Y–01.A2	Santiago Hydrologic Subarea
Y–01.A3	Santa Ana Narrows Hydrologic Subarea
Y–01.B0	Middle Santa Ana River Hydrologic Subunit
Y–01.B1	Chino Hydrologic Subarea
Y–01.B2	Harrison Hydrologic Subarea
Y–01.B3	Claremont Heights Hydrologic Subarea
Y–01.B4	Cucamonga Hydrologic Subarea
Y–01.B5	Temescal Hydrologic Subarea
Y–01.B6	Arlington Hydrologic Subarea
Y–01.B7	Riverside Hydrologic Subarea
Y–01.C0	Lake Mathews Hydrologic Subunit
Y–01.C1	Coldwater Hydrologic Subarea
Y–01.C2	Bedford Hydrologic Subarea
Y–01.C3	Cajalco Hydrologic Subarea
Y–01.C4	Lee Lake Hydrologic Subarea
Y–01.C5	Terra Cotta Hydrologic Subarea
Y–01.D0	Colton–Rialto Hydrologic Subunit
Y–01.D1	Upper Lytle Hydrologic Subarea
Y–01.D2	Lower Lytle Hydrologic Subarea
Y–01.D3	Upper Colton–Rialto Hydrologic Subarea
Y–01.D4	Colton–Rialto Hydrologic Subarea
Y–01.D5	Reche Hydrologic Subarea
Y–01.E0	Upper Santa Ana River Hydrologic Subunit
Y–01.E1	Cajon Hydrologic Subarea
Y–01.E2	Bunker Hill Hydrologic Subarea
Y–01.E3	Redlands Hydrologic Subarea
Y–01.E4	Mentone Hydrologic Subarea
Y–01.E5	Reservoir Hydrologic Subarea
Y–01.E6	Crafton Hydrologic Subarea
Y–01.E7	Santa Ana Canyon Hydrologic Subarea
Y–01.E8	Mill Creek Hydrologic Subarea
Y–01.E9	Sycamore Hydrologic Subarea
Y–01.F0	San Timoteo Hydrologic Subunit
Y–01.F1	Yucaipa Hydrologic Subarea
Y–01.F2	San Timoteo Hydrologic Subarea
Y–01.F3	Cherry Valley Hydrologic Subarea
Y–01.F4	Chicken Hill Hydrologic Subarea
Y–01.F5	Gateway Hydrologic Subarea
Y–01.F6	Oak Glen Hydrologic Subarea
Y–01.F7	South Mesa Hydrologic Subarea
Y–01.F8	Triple Falls Creek Hydrologic Subarea
Y–01.F9	Noble Creek Hydrologic Subarea
Y–01.G0	San Bernardino Mountain Hydrologic Subunit
Y–01.G1	Bear Valley Hydrologic Subarea
Y–01.G2	Seven Oaks Hydrologic Subarea
Y–01.G3	Baldwin Hydrologic Subarea
Y–02.00	SAN JACINTO VALLEY HYDROLOGIC UNIT
Y–02.A0	Perris Hydrologic Subunit
Y–02.A1	Perris Valley Hydrologic Subarea
Y–02.A2	Menifee Hydrologic Subarea
Y–02.A3	Winchester Hydrologic Subarea
Y–02.A4	Lakeview Hydrologic Subarea
Y–02.A5	Hemet Hydrologic Subarea
Y–02.B0	San Jacinto Hydrologic Subunit
Y–02.B1	San Jacinto Hydrologic Subarea
Y–02.B2	Hemet Lake Hydrologic Subarea
Y–02.B3	Bautista Hydrologic Subarea
Y–02.C0	Elsinore Hydrologic Subunit
Y–02.C1	Elsinore Hydrologic Subarea
Y–02.C2	Railroad Hydrologic Subarea



NAMES AND AREAL CODE NUMBERS OF HYDROLOGIC AREAS
SANTA ANA DRAINAGE PROVINCE (Y)

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1975

AREAL DESIGNATIONS
HYDROLOGIC UNITS SUBUNITS AND SUBAREAS

SAN DIEGO DRAINAGE PROVINCE

Z-01.00 SAN JUAN HYDROLOGIC UNIT
- Z-01.A0 Laguna Hydrologic Subunit
  - Z-01.A1 San Joaquin Hydrologic Subarea
  - Z-01.A2 Laguna Hydrologic Subarea
  - Z-01.A3 Aliso Hydrologic Subarea
  - Z-01.A4 Dana Point Hydrologic Subarea
- Z-01.B0 San Juan Hydrologic Subunit
- Z-01.C0 San Clemente Hydrologic Subunit
- Z-01.D0 San Mateo Hydrologic Subunit
- Z-01.E0 San Onofre Hydrologic Subunit
  - Z-01.E1 San Onofre Hydrologic Subarea
  - Z-01.E2 Las Pulgas Hydrologic Subarea
  - Z-01.E3 Stuart Hydrologic Subarea

Z-02.00 SANTA MARGARITA HYDROLOGIC UNIT
- Z-02.A0 Ysidora Hydrologic Subunit
  - Z-02.A1 Ysidora Hydrologic Subarea
  - Z-02.A2 Chappo Hydrologic Subarea
  - Z-02.A3 Upper Ysidora Hydrologic Subarea
- Z-02.B0 De Luz Hydrologic Subunit
  - Z-02.B1 De Luz Hydrologic Subarea
  - Z-02.B2 Gavilan Hydrologic Subarea
  - Z-02.B3 Vallecitos Hydrologic Subarea
- Z-02.C0 Murrieta Hydrologic Subunit
  - Z-02.C1 Wildomar Hydrologic Subarea
  - Z-02.C2 Murrieta Hydrologic Subarea
  - Z-02.C3 French Hydrologic Subarea
  - Z-02.C4 Lower Domenigoni Hydrologic Subarea
  - Z-02.C5 Domenigoni Hydrologic Subarea
  - Z-02.C6 Diamond Hydrologic Subarea
- Z-02.D0 Auld Hydrologic Subunit
  - Z-02.D1 Auld Hydrologic Subarea
  - Z-02.D2 Gertrudis Hydrologic Subarea
  - Z-02.D3 Lower Tucalota Hydrologic Subarea
  - Z-02.D4 Tucalota Hydrologic Subarea
- Z-02.E0 Pechanga Hydrologic Subunit
  - Z-02.E1 Pauba Hydrologic Subarea
  - Z-02.E2 Pechanga Hydrologic Subarea
- Z-02.F0 Wilson Hydrologic Subunit
  - Z-02.F1 Lancaster Valley Hydrologic Subarea
  - Z-02.F2 Lewis Hydrologic Subarea
  - Z-02.F3 Wilson Hydrologic Subarea
- Z-02.G0 Anza Hydrologic Subunit
  - Z-02.G1 Lower Coahuila Hydrologic Subarea
  - Z-02.G2 Upper Coahuila Hydrologic Subarea
  - Z-02.G3 Anza Hydrologic Subarea
  - Z-02.G4 Burnt Hydrologic Subarea
- Z-02.H0 Aguanga Hydrologic Subunit
  - Z-02.H1 Vail Hydrologic Subarea
  - Z-02.H2 Devils Hole Hydrologic Subarea
  - Z-02.H3 Redec Hydrologic Subarea
  - Z-02.H4 Aguanga Hydrologic Subarea
- Z-02.I0 Oakgrove Hydrologic Subunit
  - Z-02.I1 Lower Culp Hydrologic Subarea
  - Z-02.I2 Oakgrove Hydrologic Subarea
  - Z-02.I3 Dodge Hydrologic Subarea
  - Z-02.I4 Chihuahua Hydrologic Subarea

Z-03.00 SAN LUIS REY HYDROLOGIC UNIT
- Z-03.A0 Bonsall Hydrologic Subunit
  - Z-03.A1 Mission Hydrologic Subarea
  - Z-03.A2 Bonsall Hydrologic Subarea
  - Z-03.A3 Moosa Hydrologic Subarea
  - Z-03.A4 Valley Center Hydrologic Subarea
  - Z-03.A5 Woods Hydrologic Subarea
  - Z-03.A6 Rincon Hydrologic Subarea
- Z-03.B0 Monserate Hydrologic Subunit
  - Z-03.B1 Pala Hydrologic Subarea
  - Z-03.B2 Pauma Hydrologic Subarea
  - Z-03.B3 San Luis Rey Hydrologic Subarea
- Z-03.C0 Warner Hydrologic Subunit
  - Z-03 C1 Warner Hydrologic Subarea
  - Z-03.C2 Combs Hydrologic Subarea

Z-04.00 CARLSBAD HYDROLOGIC UNIT
- Z-04.A0 Loma Alta Hydrologic Subunit
- Z-04.B0 Vista Hydrologic Subunit
  - Z-04 B1 Carlsbad Hydrologic Subarea
  - Z-04.B2 Vista Hydrologic Subarea
- Z-04.C0 Agua Hedionda Hydrologic Subunit
  - Z-04.C1 Agua Hedionda Hydrologic Subarea
  - Z-04 C2 Buena Hydrologic Subarea
- Z-04.D0 Encinas Hydrologic Subunit
- Z-04.E0 San Marcos Hydrologic Subunit
  - Z-04.E1 Batiquitos Hydrologic Subarea
  - Z-04.E2 San Marcos Hydrologic Subarea
  - Z-04.E3 Twin Oaks Hydrologic Subarea
- Z-04.F0 Escondido Hydrologic Subunit
  - Z-04.F1 San Elijo Hydrologic Subarea
  - Z-04.F2 Escondido Hydrologic Subarea
  - Z-04.F3 Lake Wohlford Hydrologic Subarea

Z-05.00 SAN DIEGUITO HYDROLOGIC UNIT
- Z-05.A0 San Dieguito Hydrologic Subunit
  - Z-05.A1 San Dieguito Hydrologic Subarea
  - Z-05.A2 La Jolla Hydrologic Subarea
- Z-05.B0 Hodges Hydrologic Subunit
  - Z-05.B1 Hodges Hydrologic Subarea
  - Z-05.B2 Green Hydrologic Subarea
  - Z-05 B3 Felicita Hydrologic Subarea
  - Z-05 B4 Bear Hydrologic Subarea
- Z-05.C0 San Pasqual Hydrologic Subunit
  - Z-05 C1 Highland Hydrologic Subarea
  - Z-05.C2 San Pasqual Hydrologic Subarea
  - Z-05.C3 Reed Hydrologic Subarea
  - Z-05.C4 Hidden Hydrologic Subarea
  - Z-05.C5 Guejito Hydrologic Subarea
  - Z-05.C6 Vineyard Hydrologic Subarea
- Z-05 D0 Santa Maria Valley Hydrologic Subunit
  - Z-05 D1 Ramona Hydrologic Subarea
  - Z-05.D2 Lower Hatfield Hydrologic Subarea
  - Z-05.D3 Wash Hollow Hydrologic Subarea
  - Z-05.D4 Upper Hatfield Hydrologic Subarea
  - Z-05.D5 Ballena Hydrologic Subarea
  - Z-05.D6 East Santa Teresa Hydrologic Subarea
  - Z-05 D7 West Santa Teresa Hydrologic Subarea
- Z-05.E0 Santa Ysabel Hydrologic Subunit
  - Z-05.E1 Boden Hydrologic Subarea
  - Z-05 E2 Pamo Hydrologic Subarea
  - Z-05 E3 Sutherland Hydrologic Subarea
  - Z-05 E4 Santa Ysabel Hydrologic Subarea

Z-06.00 PENASQUITOS HYDROLOGIC UNIT
- Z-06 A0 Soledad Hydrologic Subunit
- Z-06.B0 Poway Hydrologic Subunit
- Z-06.C0 Scripps Hydrologic Subunit
- Z-06.D0 Miramar Hydrologic Subunit
- Z-06.E0 Tecolote Hydrologic Subunit

Z-07.00 SAN DIEGO HYDROLOGIC UNIT
- Z-07.A0 Lower San Diego Hydrologic Subunit
  - Z-07.A1 Mission San Diego Hydrologic Subarea
  - Z-07.A2 Santee Hydrologic Subarea
  - Z-07.A3 El Cajon Hydrologic Subarea
  - Z-07.A4 Cochea Hydrologic Subarea
  - Z-07.A5 El Monte Hydrologic Subarea
- Z-07.B0 San Vicente Hydrologic Subunit
  - Z-07.B1 San Vicente Hydrologic Subarea
  - Z-07.B2 Kimball Hydrologic Subarea
  - Z-07.B3 Gower Hydrologic Subarea
  - Z-07.B4 Barona Hydrologic Subarea
- Z-07.C0 El Capitan Hydrologic Subunit
  - Z-07.C1 El Capitan Hydrologic Subarea
  - Z-07.C2 Glen Oaks Hydrologic Subarea
  - Z-07.C3 Alpine Hydrologic Subarea
- Z-07.D0 Cuyamaca Hydrologic Subunit
  - Z-07.D1 Inaja Hydrologic Subarea
  - Z-07.D2 Spencer Hydrologic Subarea
  - Z-07.D3 Cuyamaca Hydrologic Subarea

Z-08.00 CORONADO HYDROLOGIC UNIT
- Z-08.A0 Point Loma Hydrologic Subunit
- Z-08.B0 San Diego Mesa Hydrologic Subunit
  - Z-08.B1 Lindbergh Hydrologic Subarea
  - Z-08.B2 Chollas Hydrologic Subarea
- Z-08.C0 Paradise Hydrologic Subunit
  - Z-08.C1 El Toyan Hydrologic Subarea
  - Z-08.C2 Paradise Hydrologic Subarea

Z-09.00 SWEETWATER HYDROLOGIC UNIT
- Z-09.A0 Lower Sweetwater Hydrologic Subunit
  - Z-09.A1 Telegraph Hydrologic Subarea
  - Z-09.A2 Sweetwater Hydrologic Subarea
- Z-09.B0 Middle Sweetwater Hydrologic Subunit
  - Z-09.B1 Jamacha Hydrologic Subarea
  - Z-09.B2 Hillsdale Hydrologic Subarea
  - Z-09.B3 Dehesa Hydrologic Subarea
  - Z-09.B4 Galloway Hydrologic Subarea
  - Z-09.B5 Sequan Hydrologic Subarea
  - Z-09 B6 Alpine Heights Hydrologic Subarea
- Z-09.C0 Upper Sweetwater Hydrologic Subunit
  - Z-09.C1 Loveland Hydrologic Subarea
  - Z-09.C2 Japatul Hydrologic Subarea
  - Z-09.C3 Viejas Hydrologic Subarea
  - Z-09.C4 Descanso Hydrologic Subarea
  - Z-09.C5 Garnet Hydrologic Subarea

Z-10.00 OTAY HYDROLOGIC UNIT
- Z-10.A0 Coronado Hydrologic Subunit
- Z-10.B0 Otay Hydrologic Subunit
- Z-10.C0 Dulzura Hydrologic Subunit
  - Z-10.C1 Savage Hydrologic Subarea
  - Z-10.C2 Proctor Hydrologic Subarea
  - Z-10.C3 Jamul Hydrologic Subarea
  - Z-10.C4 Lee Hydrologic Subarea
  - Z-10.C5 Lyon Hydrologic Subarea
  - Z-10.C6 Dulzura Hydrologic Subarea
  - Z-10.C7 Engineer Springs Hydrologic Subarea

Z-11.00 TIA JUANA HYDROLOGIC UNIT
- Z-11.A0 Tia Juana Hydrologic Subunit
  - Z-11.A1 Tia Juana Hydrologic Subarea
  - Z-11.A2 San Ysidro Hydrologic Subarea
- Z-11.B0 Potrero Hydrologic Subunit
  - Z-11.B1 Marron Hydrologic Subarea
  - Z-11.B2 Bee Canyon Hydrologic Subarea
  - Z-11.B3 Barrett Hydrologic Subarea
  - Z-11.B4 Round Potrero Hydrologic Subarea
  - Z-11.B5 Potrero Hydrologic Subarea
- Z-11.C0 Barrett Lake Hydrologic Subunit
- Z-11.D0 Monument Hydrologic Subunit
  - Z-11.D1 Pine Hydrologic Subarea
  - Z-11.D2 Monument Hydrologic Subarea
- Z-11.E0 Morena Hydrologic Subunit
- Z-11.F0 Cottonwood Hydrologic Subunit
- Z-11.G0 Cameron Hydrologic Subunit
- Z-11.H0 Campo Hydrologic Subunit
  - Z-11.H1 Tecate Hydrologic Subarea
  - Z-11.H2 Campo Hydrologic Subarea
  - Z-11.H3 Clover Flat Hydrologic Subarea
  - Z-11.H4 Hill Hydrologic Subarea
  - Z-11.H5 Hipass Hydrologic Subarea

Figure C-6

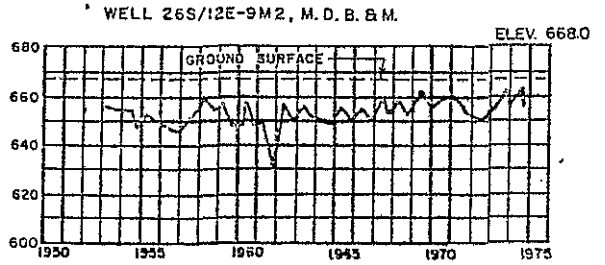
NAMES AND AREAL CODE NUMBERS OF HYDROLOGIC AREAS
SAN DIEGO DRAINAGE PROVINCE (Z)

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1975

ELEVATION IN FEET U. S. G. S. DATUM

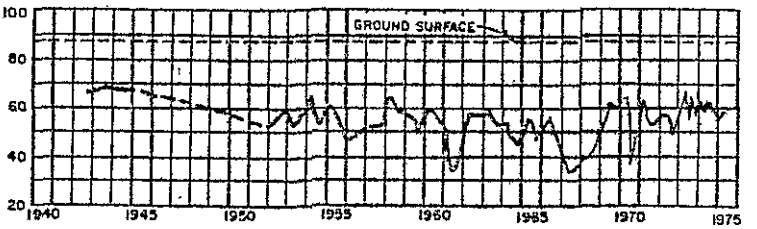
PASO ROBLES HYDROLOGIC SUBUNIT (T-09.HO)

WELL 26S/12E-9M2, M. D. B. & M.



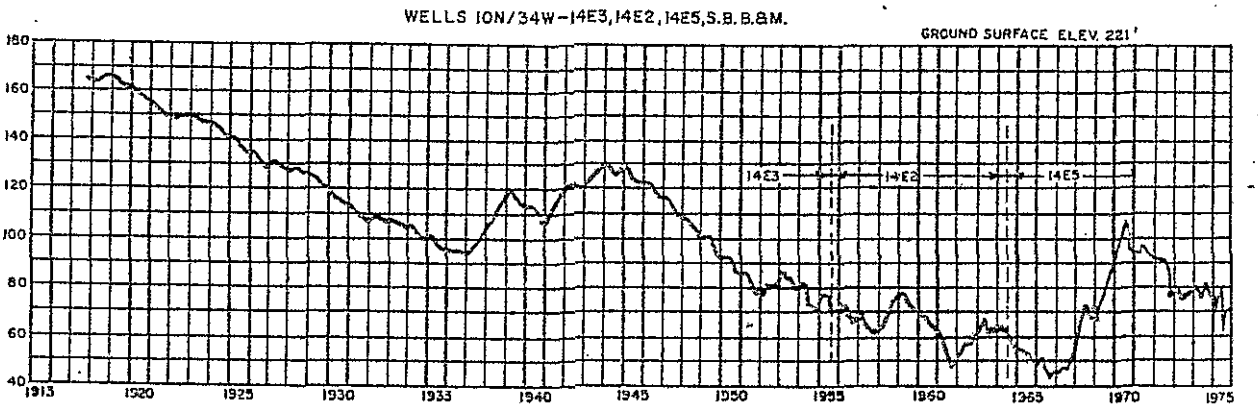
ARROYO GRANDE HYDROLOGIC SUBUNIT (T-10.CO)

WELL 32S/13E-28G1, M.D.B.&M.

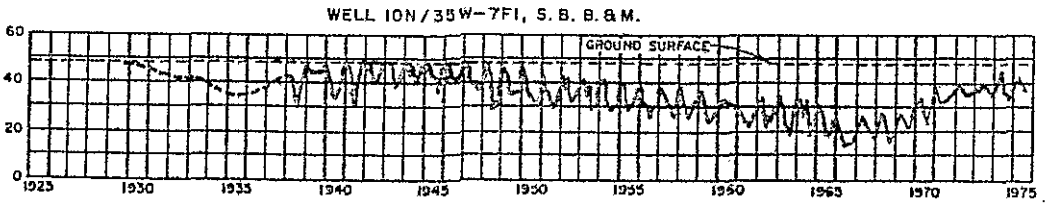


SANTA MARIA HYDROLOGIC SUBUNIT (T-12.AO)

WELLS 10N/34W-14E3, 14E2, 14E5, S.B.B.&M.



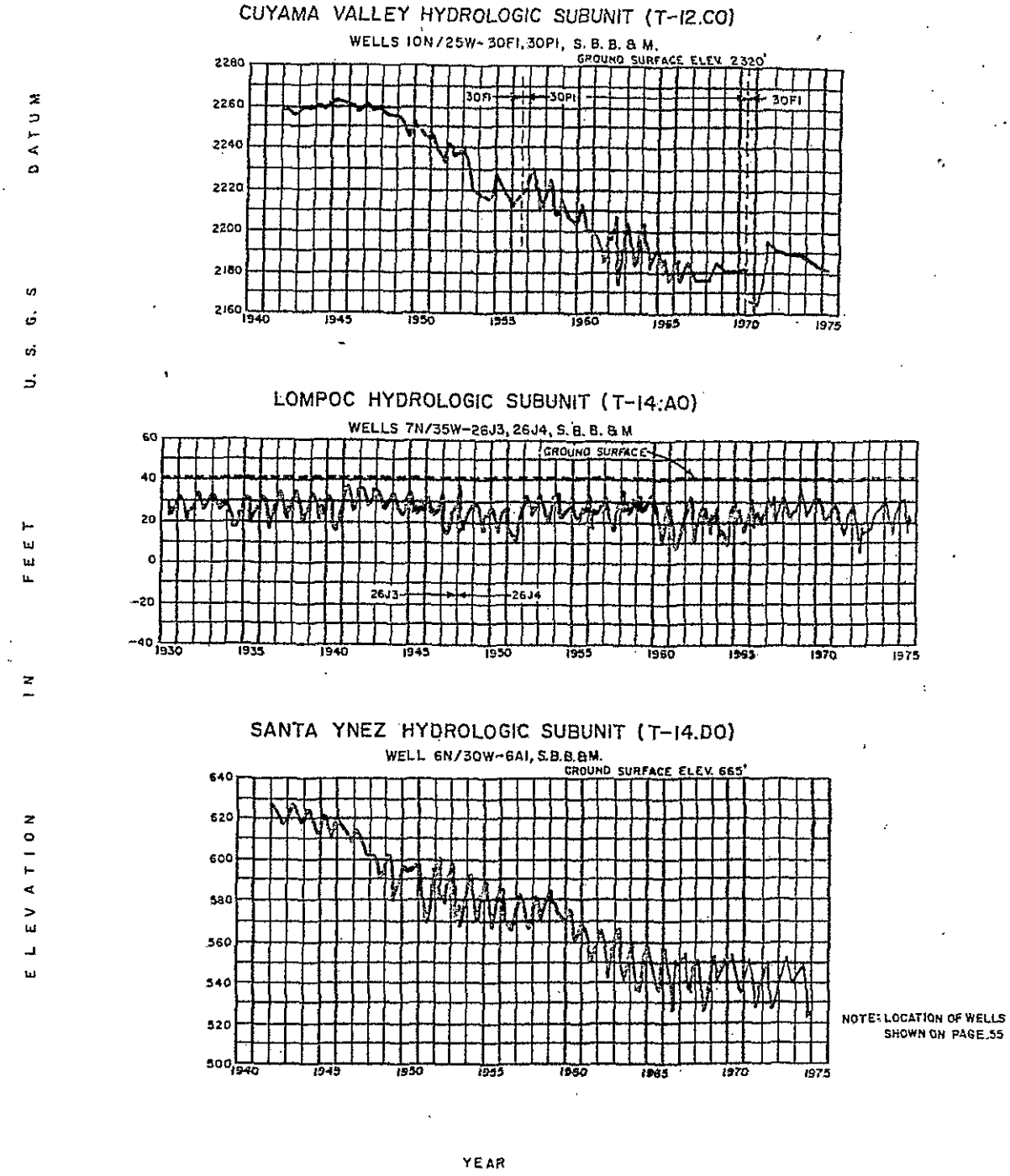
WELL 10N/35W-7F1, S. B. B. & M.



YEAR

NOTE. LOCATION OF WELLS SHOWN ON PAGE 55

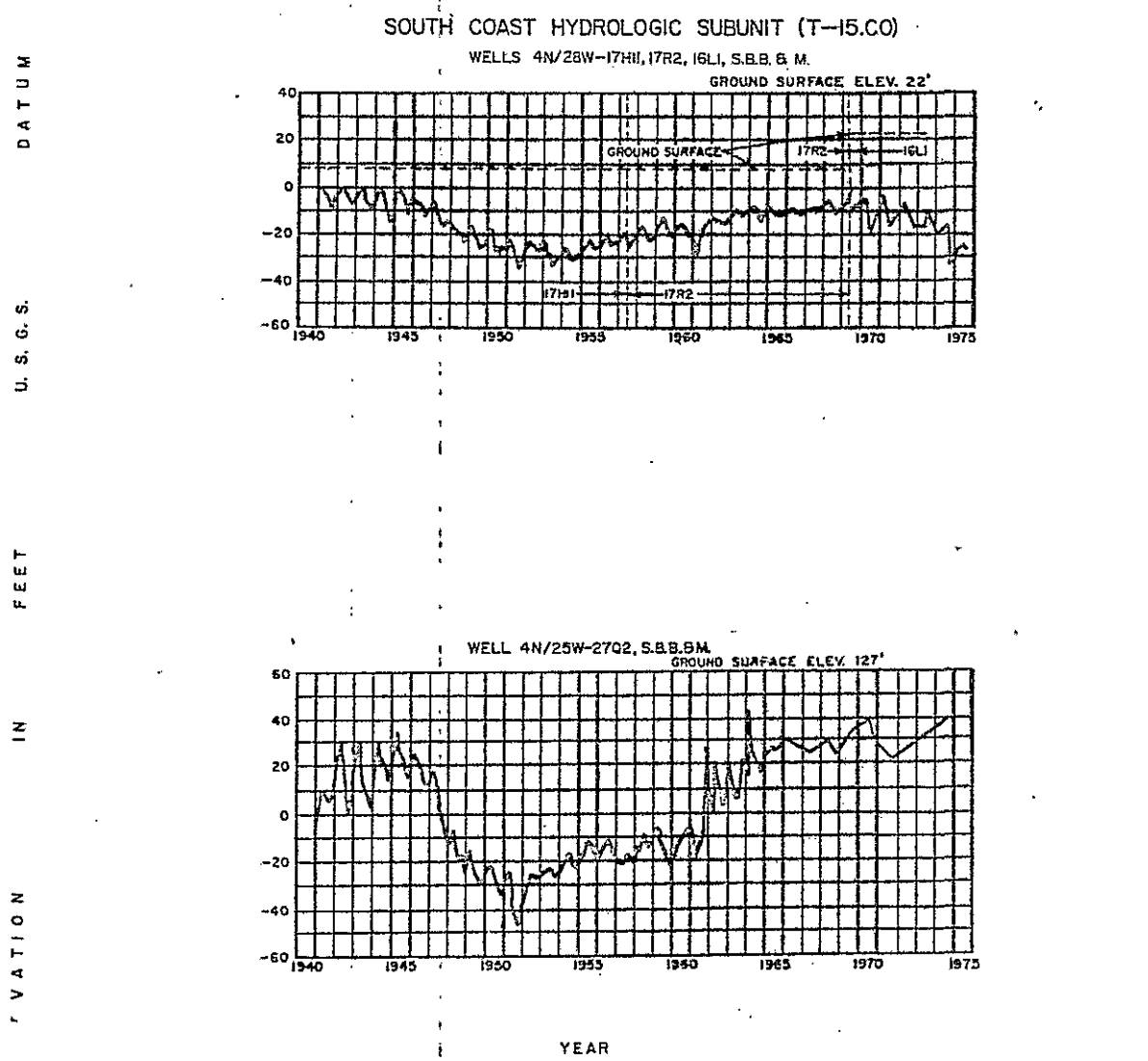
FLUCTUATION OF WATER LEVEL IN WELLS



NOTE: LOCATION OF WELLS SHOWN ON PAGE 55

FLUCTUATION OF WATER LEVEL IN WELLS

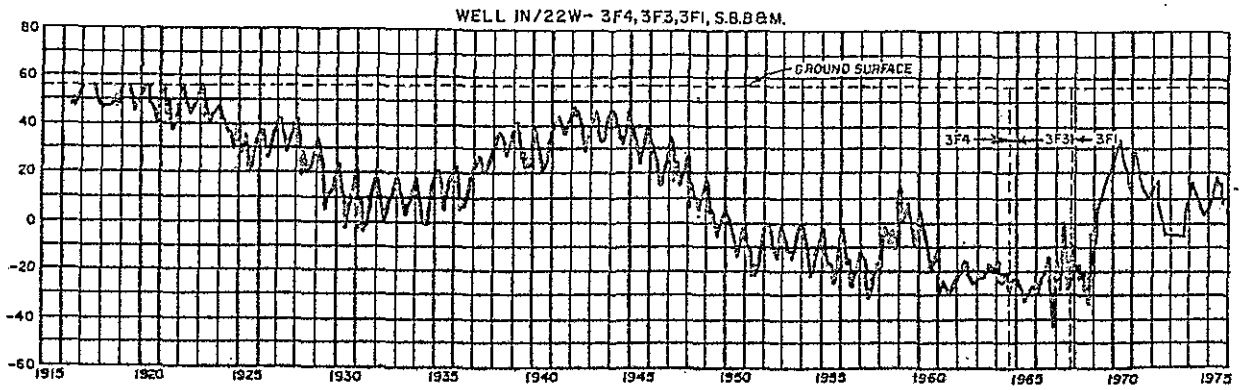
DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1976

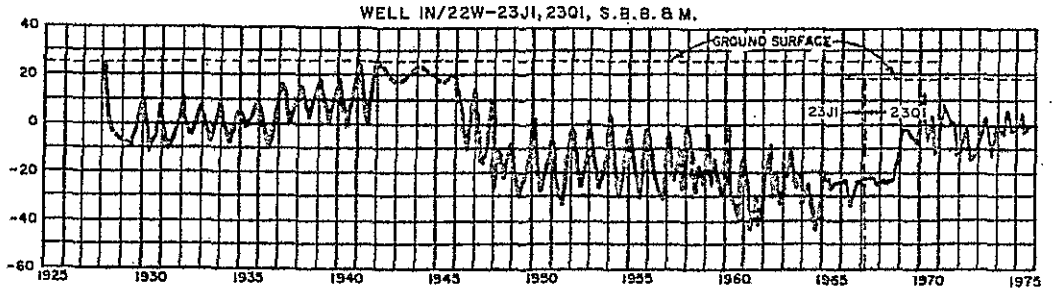


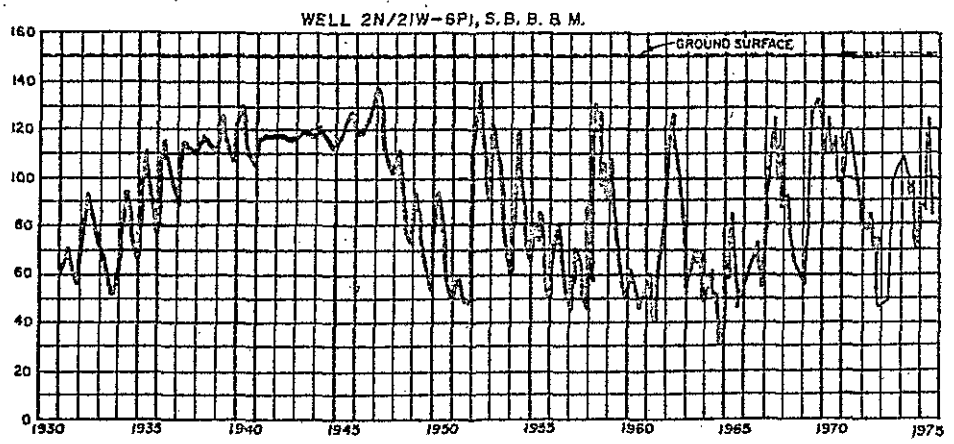
NOTE: LOCATION OF WELLS SHOWN ON PAGE 55

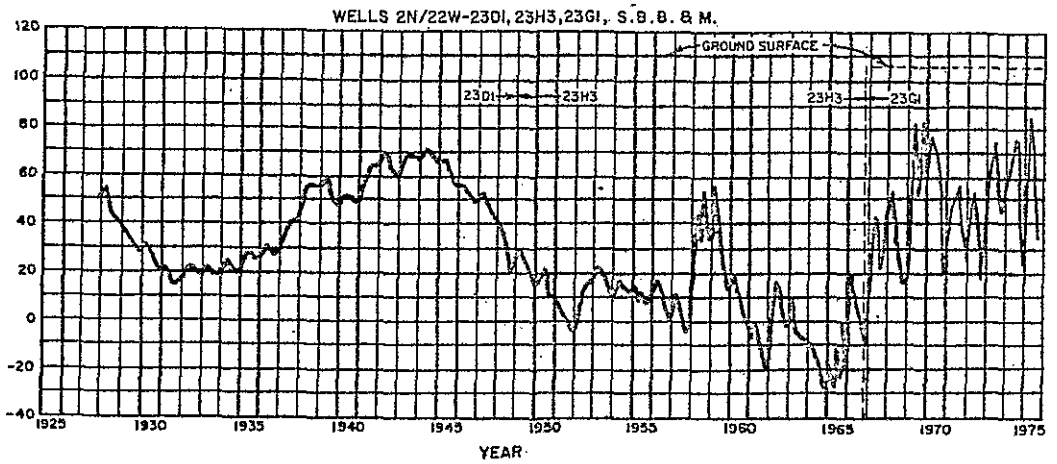
FLUCTUATION OF WATER LEVEL IN WELLS

OXNARD PLAIN HYDROLOGIC SUBUNIT (U-03.A0)









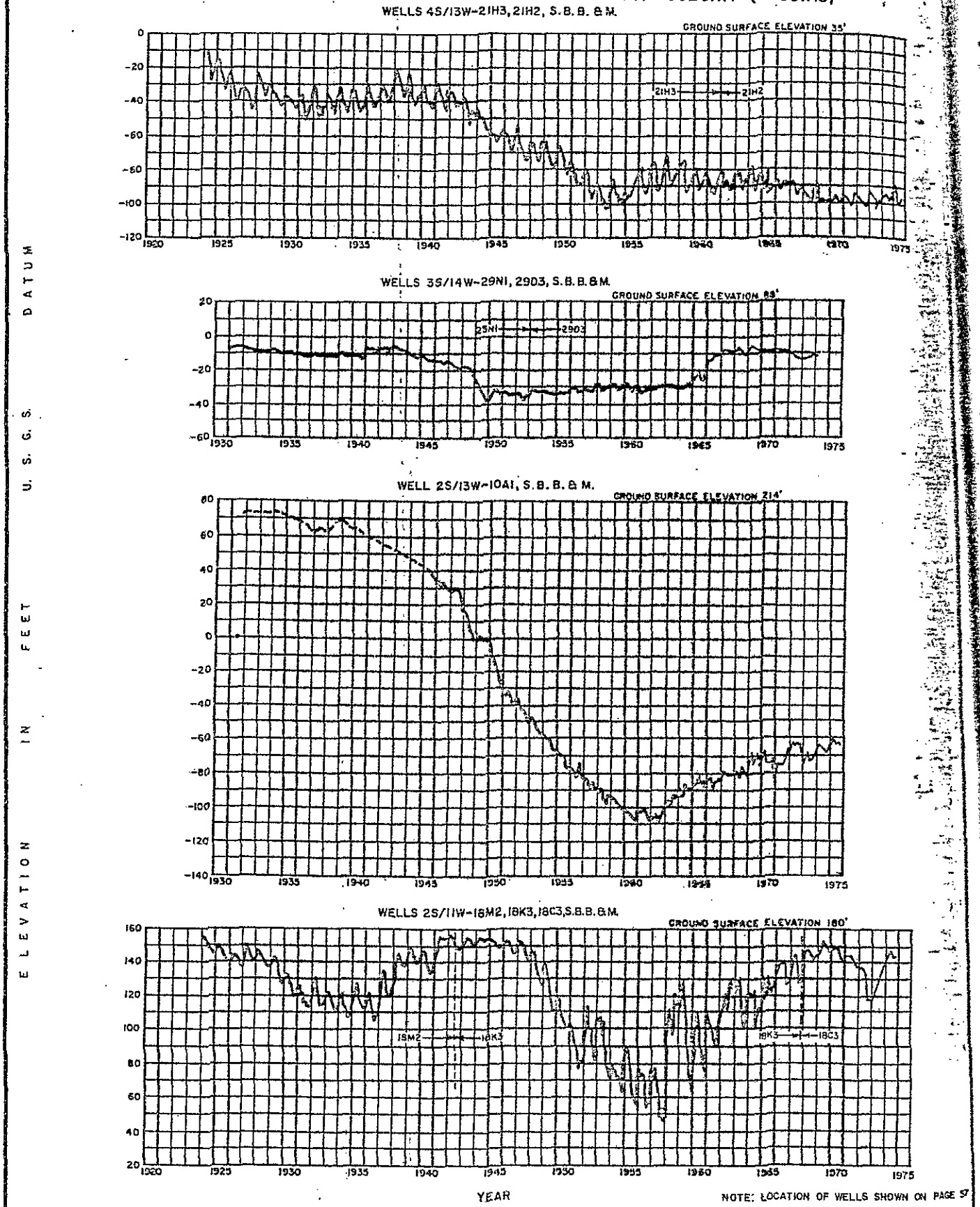
ELEVATION IN FEET U. S. G. S. DATUM

NOTE: LOCATION OF WELLS SHOWN ON PAGE 57

FLUCTUATION OF WATER LEVEL IN WELLS

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1976

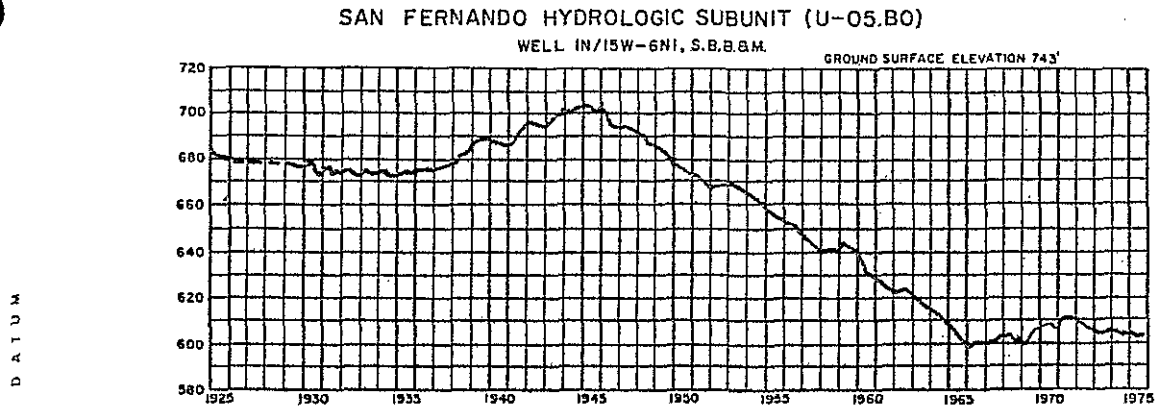
COASTAL PLAIN OF LOS ANGELES COUNTY HYDROLOGIC SUBUNIT (U-05.A0)

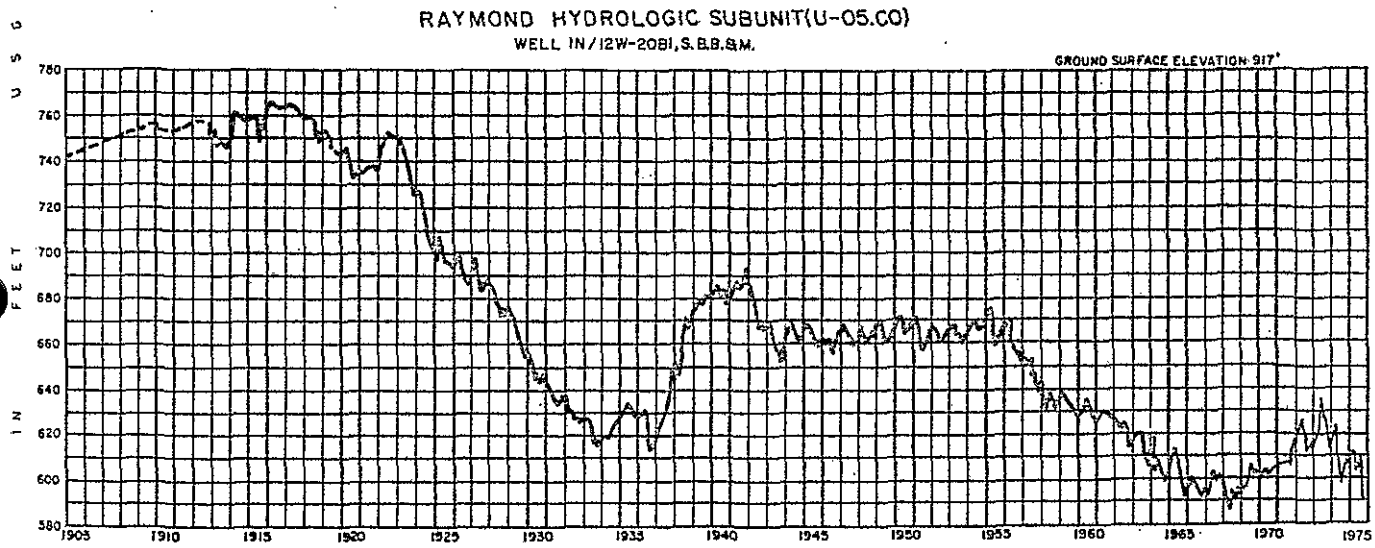


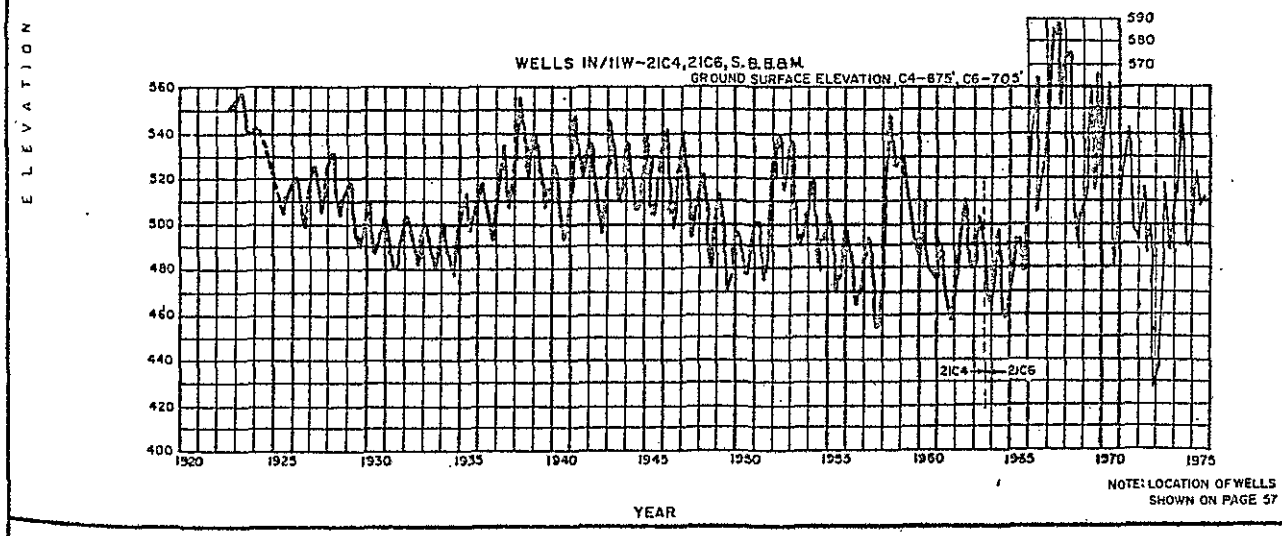
NOTE: LOCATION OF WELLS SHOWN ON PAGE 57

FLUCTUATION OF WATER LEVEL IN WELLS

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1976





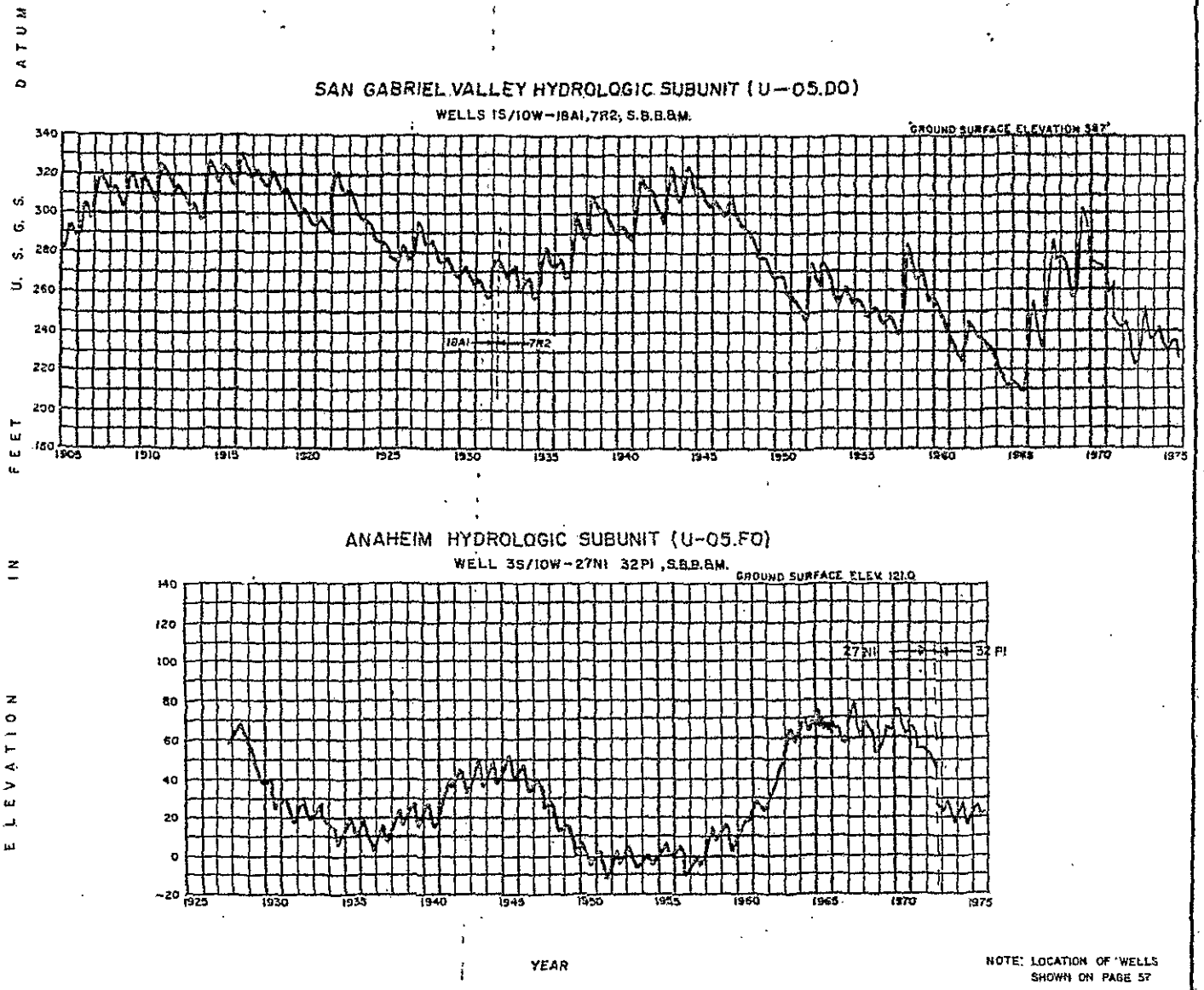


NOTE: LOCATION OF WELLS SHOWN ON PAGE 57

FLUCTUATION OF WATER LEVEL IN WELLS

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1976

Figure C-7 Sheet 7 of 13

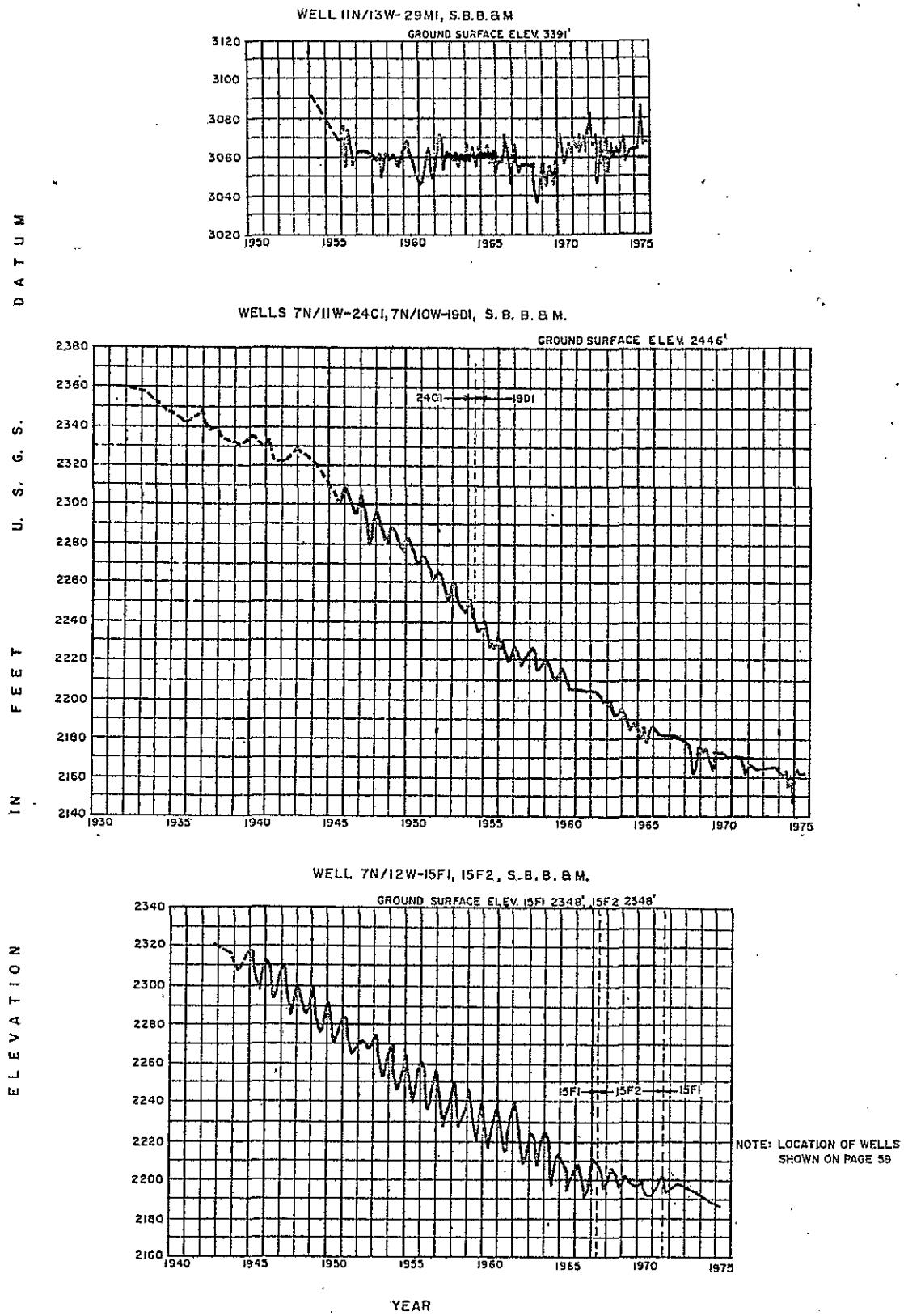


NOTE: LOCATION OF WELLS SHOWN ON PAGE 57

FLUCTUATION OF WATER LEVEL IN WELLS

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1976

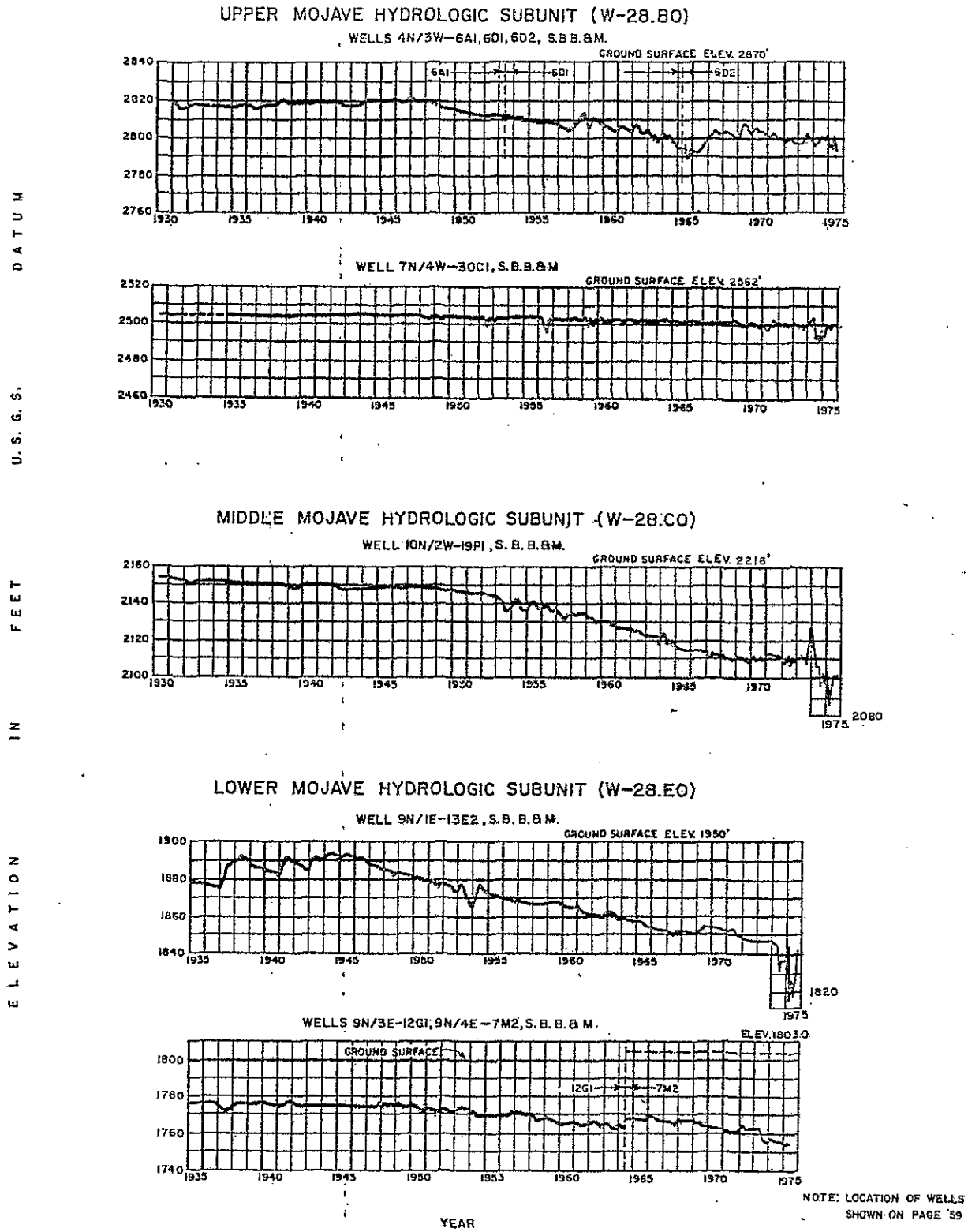
ANTELOPE HYDROLOGIC SUBUNIT (W-26.A0)



NOTE: LOCATION OF WELLS SHOWN ON PAGE 59

FLUCTUATION OF WATER LEVEL IN WELLS

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1976



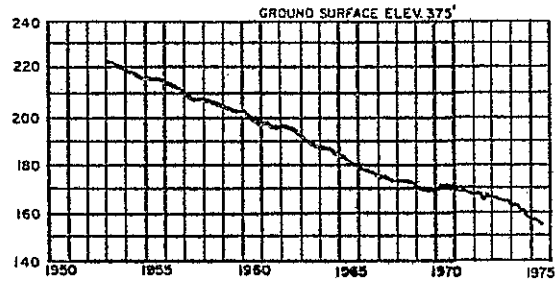
FLUCTUATION OF WATER LEVEL IN WELLS

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1976

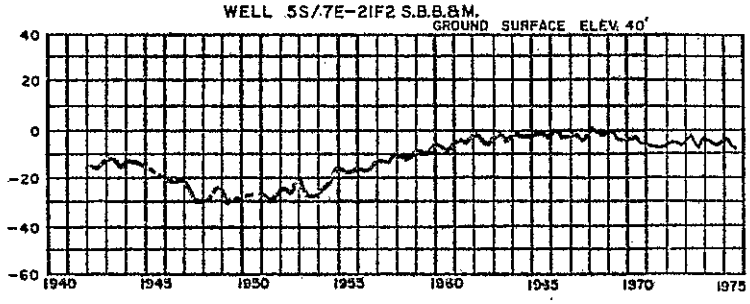
ELEVATION IN FEET U.S.G.S. DATUM

COACHELLA HYDROLOGIC SUBUNIT (X-19.DO)

WELL 4S/5E-17L1 S.B.B.&M.

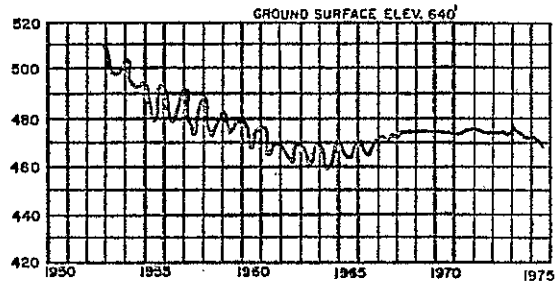


WELL 5S/7E-21F2 S.B.B.&M.



BORREGO HYDROLOGIC SUBUNIT (X-22.AO)

WELL 10S/6E-21A1 S.B.B.&M.



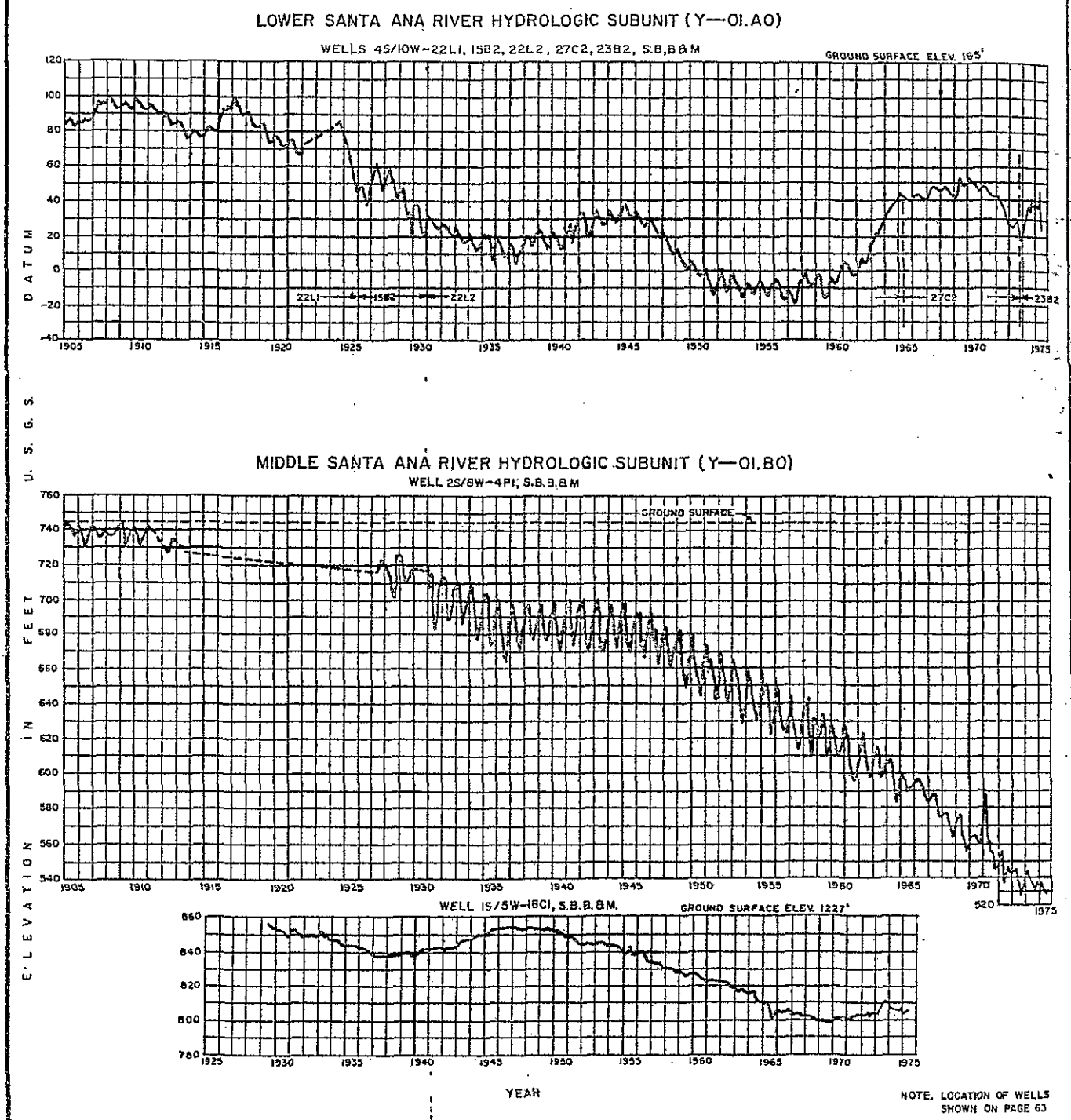
NOTE: LOCATION OF WELLS SHOWN ON PAGE 61

YEAR

FLUCTUATION OF WATER LEVEL IN WELLS

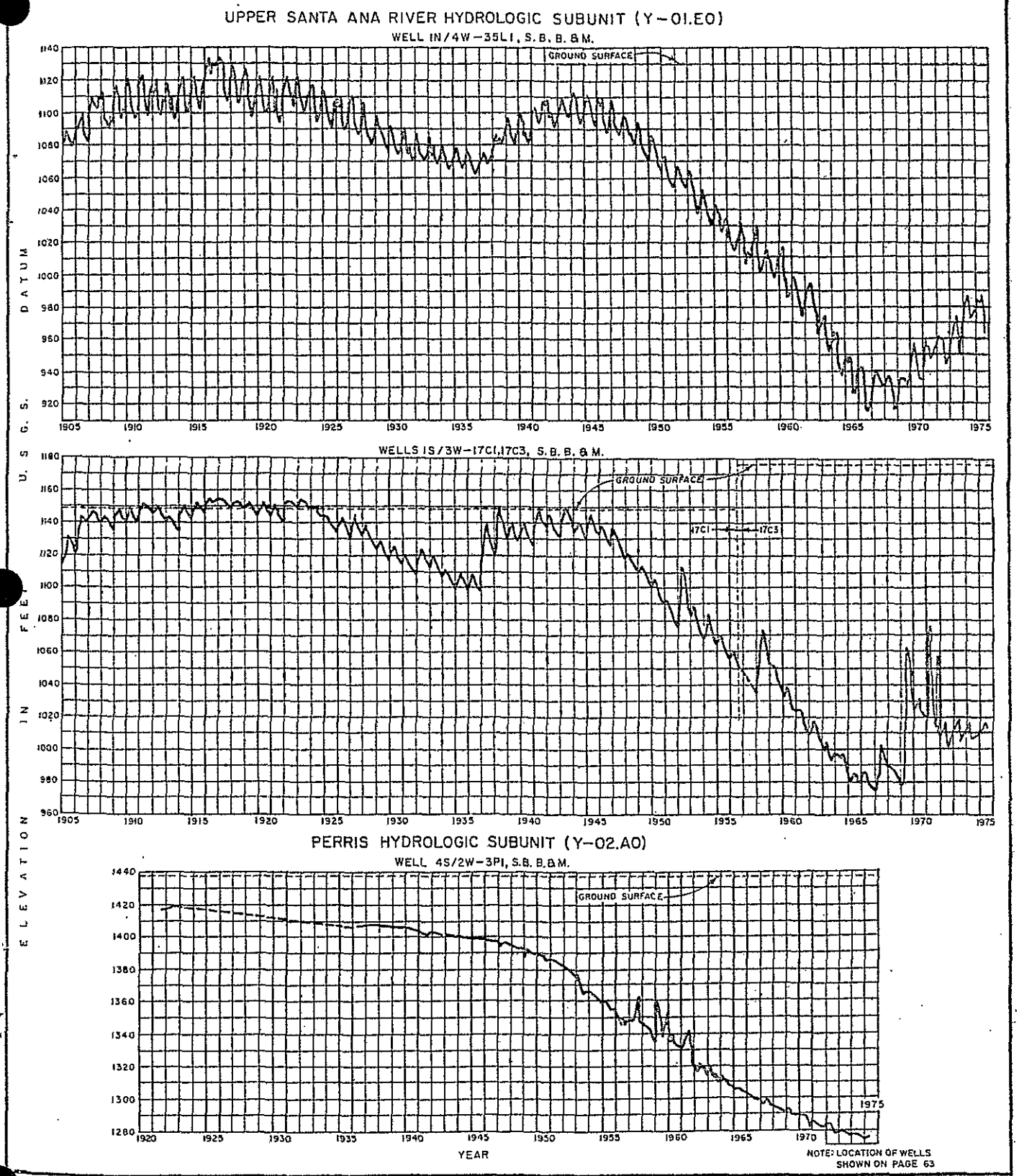
DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1976

Figure C-7 Sheet 11 of 13



FLUCTUATION OF WATER LEVEL IN WELLS

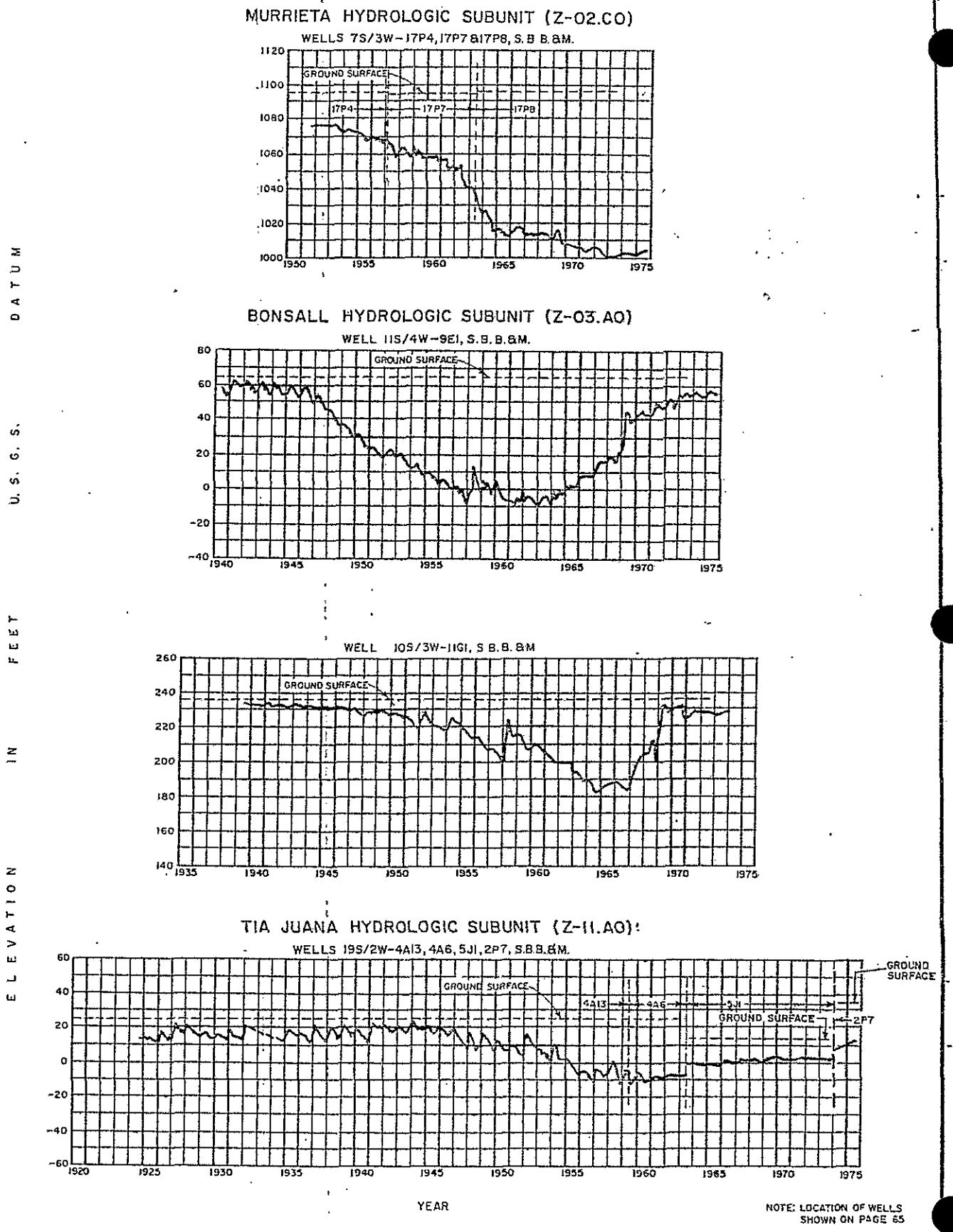
DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1976



FLUCTUATION OF WATER LEVEL IN WELLS

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1976

Figure C-7 Sheet 13 of 13



FLUCTUATION OF WATER LEVEL IN WELLS

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1976

Table C-1
GROUND WATER LEVELS AT WELLS

An explanation of the column headings and the code symbols follows:

State Well Number – Refer to the explanation at the beginning of Appendix C.

Ground Surface Elevation – The numbers in this column are the elevation in feet above mean sea level (USGS Datum) of the ground surface at the well. Elevations are usually taken from topographic maps and the accuracy is controlled by topographic standards.

Date – The date shown in the column is the date when the well was visited to obtain a measurement. Where 00 appears in the date, day of measurement is unknown.

Ground Surface to Water Surface – This is the measured depth in feet from the ground surface to the water surface in the well; certain of the depth measurements in the column may be followed by a number in parentheses to indicate a questionable measurement. The code applicable to these "questionable measurements" is as follows:

(1) Pumping
(2) Nearby pump operating
(3) Casing leaking or wet
(4) Pumped recently
(5) Air or pressure gage measurement
(6) Other
(7) Recharge operation at or near well
(8) Oil in casing
(9) Caved or deepened

When no measurement was obtained, then only a number in parentheses is shown in the column. The code applicable to these "no measurements" is as follows:

(1) Pumping
(2) Pump house locked
(3) Tape hung up
(4) Cannot get tape in casing
(5) Unable to locate well
(6) Well has been destroyed
(7) Special
(8) Casing leaking or wet
(9) Temporarily inaccessible
(0) Measurements discontinued

The words *flow* and *dry* are shown in this column to indicate a flowing or dry well, respectively. A minus preceding the number in this column indicates that the static water level in the well is this distance in feet above the ground surface.

Water Surface Elevation – This is the elevation in feet above mean sea level (USGS Datum) of the water surface in the well. It was derived by subtraction of the depth measurement from the ground surface elevation.

Agency Supplying Data – Each number in this column is the code number for the agency supplying data for that measurement. The agencies supplying data for this report and the code numbers assigned to them are as follows:

Agency code	*Agency name*
1101	Los Angeles County Flood Control District
1200	Los Angeles City, Department of Water and Power
1437	Chino, City
1733	San Gabriel Valley Protective Association
2225	Santa Paula Water Works Limited (Incl. Limoneira Water Co.)
2980	Western Municipal Water District
3230	San Bernardino, City
3400	San Bernardino Valley Water Conservation District
3718	Webb, A. A., Associates Company
3719	West End Consolidated Water Company
3847	Gage Canal Company
4104	San Bernardino, East, County Water District
4124	San Bernardino, West, County Water District
4201	Colton, City
4205	Upland, City
4206	Long Beach, City
4209	Oxnard, City
4210	Anaheim, City
4228	Ontario, City
4402	Ramona Municipal Water District
4405	Vista Irrigation District
4412	Metropolitan Water District of Southern California, The
4700	Palm Springs Water Company
4701	Corona Foothill Lemon Company
4702	Cucamonga County Water District

Continued

Table C-1 (continued)
GROUND WATER LEVELS AT WELLS

Agency code	Agency name
4706	Fontana Union Water Company
4709	Irvine Company
4715	Santa Ana Valley Irrigation Company
4742	Yorba Linda County Water District
4748	San Antonio Water Company
4750	San Luis Rey Heights Mutual Water Company
4776	Southern California Water Company
4785	California Portland Cement Company
4793	Muscoy Water Company
4829	Banning Water Company
4850	Kaiser Industries Corporation
5000	U. S. Geological Survey
5001	U. S. Bureau of Reclamation
5015	U. S. International Boundary and Water Commission
5050	California Department of Water Resources
5060	California Department of Health
5061	Watermaster West Coast Basin Party Association
5062	Watermaster Raymond Basin Party Association
5101	San Bernardino County Flood Control District
5102	Orange County Flood Control District
5103	Riverside County Flood Control and Water Conservation District
5117	San Luis Obispo County Flood Control and Water Conservation District
5121	Ventura County Flood Control District
5125	Monte Vista County Water District
5135	Coachella Valley County Water District
5202	Oceanside, City
5205	Carlsbad Municipal Water District
5206	Redlands, City
5208	Riverside, City
5229	San Diego, City
5272	Corona, City
5400	Helix Water District
5404	Santa Maria Valley Water Conservation District
5407	Beaumont Irrigation District
5408	Fallbrook Public Utility District
5411	United Water Conservation District
5412	San Bernardino Valley Municipal Water District
5419	Yucaipa Valley County Water District
5703	California-American Water Company (Calif. W. and T. Co.)
5708	Vail Company
5710	Green Mutual Water Company
5711	Escondido Mutual Water Company
5713	Rowe, W. P. & Son
5716	Elsinore, South, Mutual Water Company
5717	Temescal Water Company
5720	Riverside Water Company
5721	Frances Mutual Water Company
5723	Pine Valley Mutual Water Company
5724	Del Dios Mutual Water Company
5727	Julian Mutual Water Company
5783	Riverside Highland Water Company
5881	Dulin Ranch Company
6224	Mesa, South, Mutual Water Company
8027	Norco City
8208	Glenn Avon Heights, Mutual Water Company of

COUNTY WHERE WELL IS LOCATED

County	Code	County	Code
Imperial	13	Riverside	33
Inyo	14	San Bernardino	36
Kern	15	San Diego	37
Los Angeles	19	San Luis Obispo	40
Mono	26	Santa Barbara	42
Monterey	27*	Ventura	56
Orange	30		

* Portion of Paso Robles Hydro Subunit in Monterey County

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
CENTRAL COASTAL DRAINAGE PROVINCE SALINAS HYDRO UNIT PASO ROBLES HYDRO SUBUNIT						T T-09 T-09.H	
23S/14E-35F01 M	27		1490.0	10/24/74	37.4	1452.6	5117
24S/11E-25N01 M	27		603.3	11/14/74	41.4	561.9	5117
				4/15/75	39.8	563.5	
24S/11E-33R01 M	27		565.0	11/14/74	32.4	532.6	5117
				4/15/75	33.0	532.0	
24S/11E-35D01 M	40		570.6	11/14/74	32.7	537.9	5117
				4/15/75	32.6	538.0	
24S/11E-35J01 M	27		616.8	11/14/74	60.1	556.7	5117
24S/12E-23G01 M	27		1160.0	10/23/74	99.5	1060.5	5117
				4/17/75	99.1	1060.9	
24S/12E-23G02 M	27		1160.0	10/23/74	99.5	1060.5	5117
24S/14E-17C01 M	27		2300.0	10/24/74	92.0	2208.0	5117
				4/22/75	83.4	2216.6	
24S/15E-17F01 M	27		1320.0	10/24/74	82.6	1237.4	5117
				4/22/75	NM-1		
24S/15E-17F02 M	27		1310.0	10/24/74	79.3	1230.7	5117
				4/22/75	77.0	1233.0	
24S/15E-27L01 M	27		1211.5	10/24/74	8.8	1202.7	5117
				4/22/75	5.7	1205.8	
24S/15E-33C02 M	27		1225.0	10/24/74	30.4(1)	1194.6	5117
				12/06/74	21.5	1203.5	
				4/22/75	16.8	1208.2	
25S/11E-09H01 M	40		600.0	11/14/74	52.8	547.2	5117
				4/15/75	53.5	546.5	
25S/11E-35G01 M	40		880.0	10/21/74	42.5	837.5	5117
				11/19/74	42.4	837.6	
				4/17/75	41.6	838.4	
25S/11E-36N02 M	40		836.0	10/24/74	NM-1		5117
				11/13/74	42.9	793.1	
				4/17/75	39.1	796.9	
25S/12E-08G01 M	40		585.0	10/22/74	55.7(1)	529.3	5117
				4/15/75	26.2	558.8	
25S/12E-08R01 M	40		598.0	10/22/74	9.9	588.1	5117
				4/15/75	5.7	592.3	
25S/12E-16D01 M	40		605.0	10/22/74	61.5	543.5	5117
				4/15/75	32.7	572.3	
				6/19/75	DRY		
25S/12E-16N01 M	40		620.0	10/22/74	NM-1		5117
25S/12E-17J01 M	40		640.0	10/23/74	75.6	564.4	5117
				4/17/75	60.1	579.9	
25S/12E-17R01 M	40		640.0	10/23/74	71.0	569.0	5117
				4/17/75	NM-1		
25S/12E-20K03 M	40		624.0	10/21/74	20.2	603.8	5117
				4/17/75	26.6	597.4	
25S/12E-20Q02 M	40		680.0	12/02/74	75.9	604.1	5117
				4/15/75	71.7	608.3	
25S/12E-26K01 M	40		749.0	10/24/74	132.0	617.0	5117
				1/09/75	123.0	626.0	
				4/02/75	130.0	619.0	
25S/12E-26K02 M	40		749.0	10/24/74	142.8	606.2	5117
				1/09/75	132.6	616.4	
				2/20/75	138.1	610.9	
				7/24/75	145.5	603.5	
				9/24/75	190.0(1)	559.0	
25S/12E-26L01 M	40		878.0	10/24/74	179.2	698.8	5117
				1/09/75	153.9	724.1	
				2/20/75	151.3	726.7	
				4/02/75	148.5	729.5	
				7/24/75	188.5	689.5	
				9/24/75	196.0	682.0	
25S/12E-28N01 M	40		639.0	10/24/74	NM-7		5117
				4/17/75	10.9	628.1	
25S/12E-29N01 M	40		695.0	12/02/74	84.7	610.3	5117
				4/17/75	117.4	577.6	
25S/12E-31G01 M	40		700.0	10/23/74	152.5	547.5	5117
25S/12E-32K01 M	40		680.0	4/17/75	59.8	620.2	5117
25S/13E-11E01 M	40		1185.0	10/24/74	41.6	1143.4	5117
				4/17/75	42.2	1142.8	
25S/13E-19C01 M	40		908.0	10/24/74	295.5	612.5	5117
				4/17/75	294.7	613.3	
25S/13E-19R01 M	40		915.0	10/24/74	176.3	738.7	5117
SALINAS HYDRO UNIT PASO ROBLES HYDRO SUBUNIT						T-09 T-09.H	
25S/13E-19R01 M	40		915.0	4/17/75	176.6	738.4	5117
25S/13E-32N01 M	40		744.0	4/17/75	53.8	690.2	5117
25S/15E-02C01 M	40		1165.0	10/24/74	FLOW		5117
				4/22/75	FLOW		
25S/15E-11C03 M	40		1155.0	10/24/74	32.5	1122.5	5117
				4/22/75	21.3	1133.7	
25S/15E-13B01 M	40		1139.0	10/24/74	NM-1		5117
				12/06/74	4.0	1135.0	
				4/22/75	3.6	1135.4	
25S/16E-17L01 M	40		1165.0	10/24/74	NM-1		5117
				12/06/74	29.9	1135.1	
				4/22/75	28.1	1136.9	
25S/16E-30H01 M	40		1218.0	10/24/74	65.7	1152.3	5117
				4/22/75	65.9	1152.1	
26S/12E-01L01 M	40		844.0	11/19/74	209.7	634.3	5117
				4/21/75	193.0	651.0	
26S/12E-04N01 M	40		675.0	10/23/74	46.5	628.5	5117
				4/21/75	42.2	632.8	
26S/12E-05J01 M	40		696.0	12/02/74	68.5	627.5	5117
				4/15/75	68.6	627.4	
26S/12E-06B02 M	40		680.0	12/02/74	21.9	658.1	5117
				4/17/75	10.1	669.9	
26S/12E-07F02 M	40		867.0	4/21/75	33.4	833.6	5117
26S/12E-09H02 M	40		668.0	10/23/74	14.2	653.8	5117
				4/21/75	NM-7		
26S/12E-11D01 M	40		761.0	10/17/74	147.7	613.3	5117
				1/09/75	135.0	626.0	
				2/20/75	132.8	628.2	
				4/02/75	133.3	627.7	
				7/24/75	168.3	592.7	
26S/12E-11K01 M	40		775.0	10/23/74	132.7	642.3	5117
				4/21/75	121.6	653.4	
26S/12E-15N01 M	40		770.0	10/17/74	153.3	616.7	5117
				1/09/75	130.6	639.4	
				2/20/75	125.5	644.5	
				4/02/75	122.4	647.6	
				7/24/75	158.7	611.3	
				9/24/75	148.9	621.1	
26S/12E-21D06 M	40		1000.0	10/22/74	NM-1		5117
				11/19/74	3.4	996.6	
				4/21/75	NM-1		
26S/12E-21L01 M	40		660.0	10/13/74	9.9	650.1	5117
				4/21/75	9.6	650.4	
26S/12E-22K01 M	40		810.0	11/15/74	155.6	654.4	5117
				4/21/75	146.7	663.3	
26S/12E-22P02 M	40		820.0	10/23/74	157.0	663.0	5117
				4/21/75	155.3	664.7	
26S/12E-26D01 M	40		829.0	10/17/74	201.5	627.5	5117
				1/09/75	194.1	634.9	
				2/20/75	191.2	637.8	
				4/02/75	197.3	631.7	
				7/24/75	193.5	635.5	
				9/24/75	198.2	630.8	
26S/12E-26E01 M	40		840.0	10/23/74	186.9	653.1	5117
				4/21/75	NM-1		
26S/12E-26E07 M	40		834.0	10/17/74	170.0	664.0	5117
				1/09/75	168.3	665.7	
				2/20/75	168.5	665.5	
				4/02/75	NM-1		
				7/24/75	170.5	663.5	
				9/24/75	170.1	663.9	
26S/12E-35P02 M	40		840.0	10/22/74	188.0	652.0	5117
				4/21/75	157.3	682.7	
26S/13E-05F01 M	40		739.0	10/24/74	17.6	721.4	5117
				4/17/75	15.9	723.1	
26S/13E-07Q01 M	40		799.0	10/23/74	113.7	685.3	5117
				4/21/75	107.5	691.5	
26S/13E-10D01 M	40		800.0	10/24/74	77.8	722.2	5117
				4/17/75	113.6(1)	686.4	
26S/13E-11F02 M	40		820.0	11/20/74	44.8	775.2	5117
				4/17/75	27.6	792.4	
26S/13E-28L03 M	40		979.5	10/30/74	188.7	790.8	5117
				1/06/75	193.4	786.1	
				2/20/75	187.8	791.7	
				4/02/75	188.2	791.3	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SALINAS HYDRO UNIT PASO ROBLES HYDRO SUBUNIT						T-09 T-09.H	
26S/13E-28L03 M (CONTINUED)	40		979.5	7/24/75	196.5	783.0	5117
				9/24/75	199.3	780.2	
26S/13E-30R01 M	40		934.0	11/20/74	212.0	722.0	5117
				4/21/75	208.9	725.1	
26S/13E-34B01 M	40		1005.0	10/30/74	172.2	832.8	5117
				1/06/75	172.1	832.9	
				2/20/75	171.6	833.4	
				4/02/75	172.9	832.1	
				7/24/75	177.0	828.0	
				9/24/75	164.4	840.6	
26S/14E-09N01 M	40		1140.0	7/24/75	298.0(1)	842.0	5117
				9/25/75	236.3	903.7	
26S/14E-17E01 M	40		1000.0	10/30/74	98.3	901.7	5117
				12/06/74	85.7	914.3	
				7/24/75	NH-1		
				9/25/75	110.6	889.4	
26S/14E-17L01 M	40		949.0	10/30/74	45.3	903.7	5117
				12/06/74	32.1	916.9	
				1/09/75	26.8	922.2	
				4/03/75	27.5	921.5	
				7/24/75	69.0	880.0	
				9/25/75	52.2	896.8	
26S/14E-18J01 M	40		979.5	10/30/74	88.0	891.5	5117
				1/09/75	67.7	911.8	
				2/20/75	65.1	914.4	
				4/02/75	67.5	912.0	
				9/24/75	96.7(1)	882.8	
26S/14E-18Q01 M	40		930.0	10/30/74	NH-7		5117
				12/06/74	39.6	890.4	
				4/22/75	43.8	886.2	
26S/14E-24B01 M	40		1000.0	10/30/74	65.9	934.1	5117
				4/22/75	NH-1		
26S/14E-35D01 M	40		1135.0	10/30/74	119.3	1015.7	5117
				4/24/75	121.0(1)	1014.0	
26S/15E-02R02 M	40		1115.0	10/24/74	29.8	1085.2	5117
26S/15E-02N01 M	40		1093.0	10/17/74	113.1	979.9	5117
				1/06/75	77.3	1015.7	
				2/20/75	70.9	1022.1	
				4/02/75	70.1	1022.9	
				7/23/75	129.3	963.7	
				9/25/75	144.9	948.1	
26S/15E-16R02 M	40		1068.0	10/24/74	83.1	984.9	5117
26S/15E-16R03 M	40		1068.0	10/24/74	82.8	985.2	5117
26S/15E-16P02 M	40		1050.0	10/24/74	72.7	977.3	5117
				4/23/75	34.0	1016.0	
26S/15E-20F01 M	40		1057.7	10/24/74	114.7(1)	943.0	5117
				2/20/75	45.0	1012.7	
				4/02/75	70.1(1)	987.6	
				7/23/75	165.0(1)	892.7	
26S/15E-20L01 M	40		1095.0	10/30/74	85.0	1010.0	5117
				12/06/74	60.6	1034.4	
				1/06/75	55.7	1039.3	
				2/20/75	54.5	1040.5	
				4/02/75	72.9	1022.1	
				7/23/75	138.0(1)	957.0	
				9/25/75	81.0	1014.0	
26S/15E-21E01 M	40		1040.0	7/23/75	179.3(1)	860.7	5117
				9/25/75	112.8	927.2	
26S/15E-21G02 M	40		1800.0	12/06/74	40.4	1759.6	5117
				1/06/75	34.0	1766.0	
				2/20/75	31.7	1768.3	
				4/03/75	43.0	1757.0	
26S/15E-21P01 M	40		1071.5	10/17/74	67.1	1004.4	5117
				1/06/75	40.7	1030.8	
				2/20/75	38.1	1033.4	
				7/23/75	118.5(1)	953.0	
				9/25/75	111.5(1)	960.0	
26S/15E-28Q01 M	40		1090.0	1/06/75	55.1	1034.9	5117
				2/20/75	50.7	1039.3	
				4/03/75	74.3(1)	1015.7	
				7/23/75	135.0	955.0	
				9/26/75	105.2(1)	984.8	
26S/15E-29H01 M	40		1113.0	10/30/74	115.1	997.9	5117
				1/06/75	76.5	1036.5	
				4/02/75	102.7	1010.3	
				7/23/75	185.0(1)	928.0	
				9/26/75	179.7(1)	933.3	
26S/15E-29N01 M	40		1133.0	10/30/74	103.0	1030.0	5117
				1/06/75	87.3	1045.7	
				4/02/75	99.7	1033.3	
				7/23/75	NH-7		
SALINAS HYDRO UNIT PASO ROBLES HYDRO SUBUNIT						T-09 T-09.H	
26S/15E-29N01 M	40		1133.0	9/26/75	NH-7		5117
26S/15E-30J01 M	40		1123.0	10/30/74	111.7	1011.3	5117
				1/06/75	85.1	1037.9	
				4/03/75	NH-1		
				7/23/75	NH-1		
				9/26/75	176.9	946.1	
26S/15E-33C01 M	40		1100.0	11/01/74	64.3	1035.7	5117
				4/23/75	NH-1		
26S/15E-33Q01 M	40		1101.5	11/01/74	59.4	1042.1	5117
27S/12E-02D01 M	40		810.0	10/18/74	125.5	684.5	5117
				11/15/74	119.5	690.5	
				12/06/74	112.7	697.3	
				1/03/75	113.5	696.5	
				2/07/75	122.6	687.4	
				3/07/75	119.5	690.5	
				4/11/75	121.5	688.5	
				6/06/75	130.5	679.5	
				7/11/75	129.5	680.5	
				8/15/75	123.5	686.5	
				9/05/75	123.1	686.9	
27S/12E-02E01 M	40		799.0	10/18/74	115.0	684.0	5117
				12/06/74	114.7	684.3	
				1/03/75	111.5	687.5	
				2/07/75	123.8	675.2	
				3/07/75	100.6	698.4	
				4/04/75	100.4	698.6	
				6/06/75	127.6	671.4	
				7/04/75	121.0	678.0	
				8/15/75	130.0(1)	669.0	
				9/05/75	129.8(1)	669.2	
27S/12E-03C02 M	40		780.0	10/23/74	NH-7		5117
27S/12E-03J01 M	40		785.0	10/22/74	NH-1		5117
27S/12E-04F04 M	40		700.0	10/22/74	NH-1		5117
				4/21/75	13.9	686.1	
27S/12E-04K02 M	40		741.2	10/04/74	105.5(1)	635.7	5117
				11/15/74	52.0	689.2	
				12/06/74	47.2	694.0	
				1/10/75	42.6	698.6	
				2/21/75	48.6	692.6	
				3/14/75	48.3	692.9	
				4/04/75	47.9	693.3	
				6/06/75	138.5(1)	602.7	
				7/03/75	51.0	690.2	
				8/15/75	148.6(1)	592.6	
				9/05/75	149.6(1)	591.6	
27S/12E-16J01 M	40		720.0	10/21/74	13.0	707.0	5117
				4/21/75	7.0	713.0	
27S/12E-21B01 M	40		745.0	10/21/74	13.3	731.7	5117
				4/21/75	NH-7		
27S/12E-21C01 M	40		740.0	10/21/74	12.3	727.7	5117
				4/21/75	NH-1		
27S/12E-21N04 M	40		750.0	10/21/74	8.6	741.4	5117
				4/21/75	1.6	748.4	
27S/12E-21N05 M	40		737.0	10/21/74	11.3	725.7	5117
				4/21/75	NH-7		
27S/12E-22M01 M	40		850.0	11/05/74	128.4	721.6	5117
				1/09/75	114.6	735.4	
				4/03/75	104.4	745.6	
				9/23/75	190.5(1)	659.5	
27S/12E-29N01 M	40		838.5	7/25/75	47.8	790.7	5117
				9/20/75	47.9	790.6	
27S/12E-29P04 M	40		750.0	10/21/74	14.5	735.5	5117
				4/21/75	7.1	742.9	
				9/31/75	14.2	735.8	
27S/12E-29P06 M	40		743.2	10/21/74	FLOW		5117
27S/12E-32C06 M	40		760.0	10/21/74	14.6	745.4	5117
27S/12E-32P04 M	40		810.0	10/21/74	14.8	795.2	5117
				4/22/75	4.3	805.7	
27S/12E-32P07 M	40		930.0	10/21/74	10.5	919.5	5117
27S/12E-32P08 M	40		810.0	10/21/74	NH-7		5117
27S/12E-32Q04 M	40		768.0	10/21/74	12.8	755.2	5117
				4/18/75	NH-1		
				9/30/75	NH-1		
27S/12E-33F01 M	40		900.0	11/05/74	138.2	761.8	5117
				1/09/75	122.2	777.8	
				7/25/75	299.5(1)	600.5	
				9/23/75	299.5(1)	600.5	
27S/12E-33G01 M	40		860.0	10/05/74	158.2	701.8	5117

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SALINAS HYDRO UNIT PASO ROBLES HYDRO SUBUNIT						T-09 T-09.H	
27S/12E-33G01 M (CONTINUED)	40		860.0	11/05/74	158.2	701.8	5117
				1/09/75	138.0	722.0	
				7/25/75	218.5(1)	641.5	
				9/23/75	259.5(1)	600.5	
27S/12E-34P01 M	40		880.0	11/05/74	96.0	784.0	5117
				1/09/75	75.6	804.4	
				4/03/75	60.9	819.1	
				7/25/75	240.0(1)	640.0	
27S/13E-09K01 M	40		885.0	11/01/74	FLOW		5117
				4/24/75	FLOW		
27S/13E-22D01 M	40		1043.0	11/25/74	92.1	950.9	5117
				4/24/75	85.6	957.4	
27S/13E-23R02 M	40		1040.0	11/25/74	37.0	1003.0	5117
				4/24/75	44.2	995.8	
27S/13E-27P02 M	40		1054.5	4/24/75	107.0	947.5	5117
27S/13E-28F01 M	40		1072.0	11/04/74	125.3	946.7	5117
				1/09/75	120.5	951.5	
				4/03/75	115.2	956.8	
				7/25/75	123.4	948.6	
				9/26/75	127.8	944.2	
27S/13E-33L01 M	40		1180.0	11/04/74	117.0	1063.0	5117
				1/09/75	148.0	1032.0	
				4/03/75	113.4	1066.6	
				7/25/75	127.0	1053.0	
				9/26/75	299.5(1)	880.5	
27S/13E-36R01 M	40		1098.5	4/24/75	16.8	1081.7	5117
27S/14E-11G02 M	40		1121.0	10/30/74	117.2	1003.8	5117
				4/24/75	106.6	1014.4	
27S/14E-11R01 M	40		1150.0	10/30/74	87.5	1062.5	5117
				4/24/75	NM-1		
27S/14E-19M01 M	40		1260.0	10/30/74	157.5	1102.5	5117
27S/14E-24B01 M	40		1180.0	10/30/74	125.7	1054.3	5117
				4/24/75	116.8	1063.2	
27S/14E-25A01 M	40		1225.0	10/30/74	117.9	1107.1	5117
				4/24/75	116.1	1108.9	
27S/14E-25J01 M	40		1250.8	10/30/74	88.8	1161.2	5117
				4/24/75	82.9	1167.1	
27S/14E-29G01 M	40		1200.0	11/25/74	142.8	1057.2	5117
				4/24/75	138.9	1061.1	
27S/15E-03E01 M	40		1120.0	10/17/74	75.2	1044.8	5117
				1/06/75	63.3	1056.7	
				2/20/75	62.0	1058.0	
				4/03/75	67.3	1052.7	
				7/23/75	148.1(1)	971.9	
				9/26/75	89.3	1030.7	
27S/15E-10A02 M	40		1119.4	12/06/74	54.7	1064.7	5117
				1/06/75	53.2	1066.2	
				2/20/75	52.1	1067.3	
				4/03/75	55.4	1064.0	
				7/23/75	77.9	1041.5	
27S/15E-10R02 M	40		1130.0	4/25/75	NM-1		5117
27S/15E-14H01 M	40		1159.5	10/17/74	71.5	1088.0	5117
				11/01/74	86.0	1073.5	
				12/06/74	84.0	1075.5	
				1/06/75	82.6	1076.9	
				4/03/75	82.4	1077.1	
				7/23/75	134.5(1)	1025.0	
				9/26/75	136.7(1)	1022.8	
27S/15E-35F01 M	40		1230.0	11/01/74	NM-1		5117
				4/25/75	60.2	1169.8	
27S/16E-07P01 M	40		1224.5	11/01/74	65.5	1159.0	5117
				4/23/75	61.9	1162.6	
27S/16E-21E01 M	40		1260.0	11/01/74	64.7	1195.3	5117
				4/23/75	71.3	1188.7	
27S/16E-35Q01 M	40		1281.0	11/01/74	13.0	1268.0	5117
				4/23/75	12.1	1268.9	
28S/12E-03R01 M	40		860.0	11/04/74	84.6	775.4	5117
				1/09/75	76.5	783.5	
				4/03/75	64.9	795.1	
				7/25/75	101.5	758.5	
				9/26/75	98.7	761.3	
28S/12E-04J02 M	40		792.0	10/21/74	15.1	776.9	5117
				4/18/75	2.3	789.7	
				9/30/75	13.9	778.1	
28S/12E-05B01 M	40		770.0	10/21/74	NM-1		5117
				4/18/75	3.9	766.1	
				9/30/75	NM-7		
SALINAS HYDRO UNIT PASO ROBLES HYDRO SUBUNIT						T-09 T-09.H	
28S/12E-10A03 M	40		815.0	10/21/74	NM-1		5117
				4/18/75	7.2	807.8	
28S/12E-10H04 M	40		820.0	10/21/74	102.4(1)	717.6	5117
				4/18/75	19.5	800.5	
28S/12E-10R01 M	40		816.0	10/18/74	28.5	787.5	5117
				4/18/75	NM-1		
				9/30/75	NM-1		
28S/12E-10R02 M	40		805.0	10/21/74	29.9	775.1	5117
				4/18/75	11.2	793.8	
				9/30/75	30.9	774.1	
28S/12E-11N06 M	40		820.0	10/18/74	NM-1		5117
				4/18/75	NM-1		
28S/12E-13P02 M	40		900.0	10/18/74	48.5	851.5	5117
				4/18/75	51.9	848.1	
				9/29/75	54.6	845.4	
28S/12E-13Q02 M	40		960.0	10/18/74	104.0	856.0	5117
				4/18/75	103.3	856.7	
				9/29/75	106.3	853.7	
28S/12E-14B03 M	40		828.0	10/18/74	19.4	808.6	5117
				4/18/75	12.6	815.4	
				9/30/75	19.2	808.8	
28S/12E-14R04 M	40		840.0	11/22/74	22.0	818.0	5117
				4/18/75	NM-1		
				9/29/75	NM-7		
28S/12E-14K01 M	40		845.0	10/18/74	28.3	816.7	5117
				4/18/75	14.6	830.4	
				9/30/75	21.8(1)	823.2	
28S/12E-24B02 M	40		920.0	10/18/74	95.5	824.5	5117
				4/18/75	93.7	826.3	
				9/29/75	100.7	819.3	
28S/12E-24C01 M	40		852.6	10/18/74	NM-1		5117
				4/18/75	4.7	847.9	
				9/29/75	10.5(1)	842.1	
28S/12E-24C02 M	40		850.0	10/13/74	16.6	833.4	5117
			861.7	4/18/75	10.7	851.0	
				9/29/75	13.7	848.0	
28S/12E-24J02 M	40		860.0	10/01/74	11.2	848.8	5117
				4/18/75	4.4	855.6	
				9/30/75	11.8(1)	848.2	
28S/12E-25R01 M	40		877.0	10/18/74	21.0	856.0	5117
				4/18/75	10.8	866.2	
				9/29/75	17.7	859.3	
28S/12E-34B01 M	40		860.0	10/21/74	74.6	785.4	5117
28S/13E-04K01 M	40		1199.5	11/05/74	44.6	1154.9	5117
				4/24/75	45.1	1154.4	
28S/13E-04K02 M	40		1195.0	11/04/74	75.7	1119.3	5117
				4/24/75	74.5	1120.5	
28S/13E-04K03 M	40		1185.0	11/04/74	181.3	1003.7	5117
				1/09/75	200.5	984.5	
				4/03/75	198.3	986.7	
				7/25/75	205.1	979.9	
28S/13E-12H01 M	40		1150.0	11/04/74	14.8	1135.2	5117
				4/24/75	NM-1		
28S/13E-13D01 M	40		1180.0	11/04/74	6.6	1173.4	5117
				4/24/75	4.1	1175.9	
28S/13E-14J01 M	40		1190.0	11/04/74	12.1	1177.9	5117
				4/24/75	11.6	1178.4	
28S/13E-31F01 M	40		920.0	10/18/74	75.5	844.5	5117
				4/18/75	62.2	857.8	
				9/29/75	79.0	841.0	
28S/13E-31F02 M	40		880.0	11/26/74	21.6	858.4	5117
				4/18/75	7.4	872.6	
				9/29/75	19.5	860.5	
28S/13E-31J01 M	40		886.0	10/18/74	NM-1		5117
28S/13E-31K01 M	40		884.8	10/18/74	17.2	867.6	5117
				4/18/75	4.7	880.1	
28S/13E-31L01 M	40		921.0	10/18/74	72.0	849.0	5117
				4/18/75	58.0	863.0	
				9/29/75	70.3	850.7	
28S/13E-31L02 M	40		885.0	10/18/74	76.2	808.8	5117
				4/18/75	60.8	824.2	
				9/29/75	75.9	809.1	
28S/13E-31H01 M	40		890.0	10/18/74	NM-1		5117
				4/18/75	56.4	833.6	

See page 79 for key to terms a abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SALINAS HYDRO UNIT						T-09	
PASO ROBLES HYDRO SUBUNIT						T-09.H	
28S/13E-31M01 M	40		890.0	9/29/75	62.3	827.7	5117
28S/13E-31R02 M	40		893.7	10/18/74	23.7	870.0	5117
				4/18/75	12.5	881.2	
				9/29/75	23.1	870.6	
28S/13E-32N05 M	40		888.5	10/18/74	21.2(1)	867.3	5117
				11/18/74	21.2(1)	867.3	
				4/18/75	14.9	873.6	
				9/29/75	19.7	868.8	
28S/14E-12M01 M	40		1150.0	11/04/74	14.8	1135.2	5117
28S/14E-19B01 M	40		1190.0	11/01/74	8.7	1181.3	5117
				4/24/75	9.8	1180.2	
28S/15E-24E02 M	40		1338.5	4/25/75	43.8	1294.7	5117
28S/16E-14N01 M	40		1440.0	11/01/74	55.1	1384.9	5117
				4/23/75	NM-1		
28S/16E-14Q01 M	40		1440.0	11/01/74	50.0	1390.0	5117
				4/23/75	NM-1		
28S/16E-23M01 M	40		1440.0	11/01/74	40.7	1399.3	5117
				4/23/75	39.8	1400.2	
28S/16E-35F01 M	40		1474.0	11/01/74	22.1	1451.9	5117
				4/23/75	22.5	1451.5	
29S/13E-05F03 M	40		916.1	10/18/74	18.8	897.3	5117
				4/18/75	13.2	902.9	
				9/29/75	19.4	896.7	
29S/13E-05K02 M	40		928.5	10/16/74	14.7	913.8	5117
				4/18/75	8.1	920.4	
				9/29/75	14.2	914.3	
29S/13E-06A01 M	40		920.0	10/18/74	57.0	863.0	5117
				4/18/75	32.0	888.0	
29S/13E-08F01 M	40		950.0	10/16/74	16.9	933.1	5117
				4/18/75	16.9	933.1	
				9/30/75	16.9	933.1	
29S/13E-08M01 M	40		945.0	10/16/74	10.3	934.7	5117
				4/18/75	4.5	940.5	
				9/30/75	10.9	934.1	
29S/13E-08N05 M	40		1002.6	10/16/74	10.3	992.3	5117
				4/18/75	3.4	999.2	
				9/30/75	10.7	991.9	
29S/13E-19H01 M	40		1002.0	10/16/74	18.1(1)	983.9	5117
				4/18/75	3.6	998.4	
29S/14E-04E01 M	40		1387.0	11/05/74	NM-9		5117
29S/14E-04E02 M	40		1387.0	11/05/74	12.8	1374.2	5117
				4/24/75	7.9	1379.1	
29S/14E-04P01 M	40		1410.0	11/05/74	16.1	1393.9	5117
				4/24/75	16.7	1393.3	
29S/14E-04P02 M	40		1410.0	11/05/74	16.2	1393.8	5117
				4/24/75	14.9	1395.1	
29S/14E-05F01 M	40		1378.0	11/05/74	15.2	1362.8	5117
				4/24/75	14.6	1363.4	
29S/14E-05F02 M	40		1383.0	11/05/74	17.3	1365.7	5117
				4/24/75	16.7	1366.3	
29S/14E-05H01 M	40		1400.0	11/05/74	14.0	1386.0	5117
				4/25/75	8.6	1391.4	
29S/14E-09R02 M	40		1435.0	11/05/74	18.2	1416.8	5117
				4/25/75	27.5	1407.5	
29S/16E-02R01 M	40		1541.0	11/01/74	NM-1		5117
				4/23/75	23.5	1517.5	
POZO HYDRO SUBUNIT						T-09.1	
30S/15E-21C01 M	40		1465.0	10/29/74	11.7	1453.3	5117
				4/25/75	8.4	1456.6	
30S/15E-21D01 M	40		1450.0	10/29/74	10.8	1439.2	5117
				4/25/75	8.8	1441.2	

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SAN LUIS OBISPO HYDRO UNIT						T-10	
CAMBRIA HYDRO SUBUNIT						T-10.A	
SAN CARPOFORO HYDRO SUBAREA						T-10.A1	
25S/06E-16A02 M	40		30.0	10/15/74	11.7	18.3	5117
				4/10/75	8.5	21.5	
ARROYO DE LA CRUZ HYDRO SUBAREA						T-10.A2	
25S/06E-35N01 M	40		20.0	10/15/74	14.8	5.2	5117
				4/10/75	10.6	9.4	
SAN SIMEON HYDRO SUBAREA						T-10.A3	
27S/08E-06G01 M	40		20.0	10/15/74	12.3	7.7	5117
				4/10/75	9.2	10.8	
27S/08E-06G02 M	40		20.0	10/15/74	12.5	7.5	5117
				4/10/75	9.5	10.5	
27S/08E-08R02 M	40		21.0	10/15/74	5.2	15.8	5117
				4/10/75	3.4	17.6	
27S/08E-09L01 M	40		30.0	10/15/74	15.2(1)	14.8	5117
				4/10/75	NM-1		
27S/08E-10G01 M	40		50.0	10/15/74	16.9	33.1	5117
				4/10/75	13.4	36.6	
27S/08E-11B01 M	40		119.5	4/10/75	15.3	104.2	5117
SANTA ROSA HYDRO SUBAREA						T-10.A4	
27S/08E-21R03 M	40		13.0	10/15/74	5.3	7.7	5117
27S/08E-23R01 M	40		82.0	10/15/74	29.3	52.7	5117
27S/08E-24J01 M	40		82.0	10/15/74	24.8	57.2	5117
				4/10/75	22.1	59.9	
27S/08E-24L01 M	40		80.0	12/18/74	24.3	55.7	5117
				4/10/75	23.5	56.5	
27S/08E-26C04 M	40		50.0	5/05/75	22.0	28.0	5117
27S/09E-19J01 M	40		160.0	12/18/74	10.7	149.3	5117
				4/10/75	9.7	150.3	
27S/09E-19H02 M	40		140.0	12/18/74	23.8	116.2	5117
				4/10/75	19.6	120.4	
27S/09E-20E01 M	40		200.0	12/18/74	28.4	171.6	5117
				4/10/75	27.5	172.5	
27S/09E-20G01 M	40		200.0	12/18/74	17.2	182.8	5117
				4/11/75	14.1	185.9	
27S/09E-20G02 M	40		200.0	4/11/75	14.0	186.0	5117
27S/09E-25G01 M	40		559.0	12/18/74	15.5	543.5	5117
				4/11/75	13.7	545.3	
VILLA HYDRO SUBAREA						T-10.A5	
28S/09E-10J01 M	40		218.5	12/12/74	7.8	210.7	5117
				4/11/75	6.6	211.9	
28S/09E-10K01 M	40		199.0	12/12/74	7.8	191.2	5117
				4/11/75	6.8	192.2	
28S/09E-11E01 M	40		240.0	12/12/74	13.0	227.0	5117
				4/11/75	12.5	227.5	
28S/09E-15J01 M	40		120.0	12/12/74	19.0	101.0	5117
				4/11/75	15.6	104.4	
28S/09E-23D01 M	40		160.0	12/12/74	14.4	145.6	5117
				4/11/75	13.9	146.1	
28S/09E-23M01 M	40		70.0	10/15/74	19.3	50.7	5117
				4/11/75	18.8	51.2	
28S/09E-26D01 M	40		49.0	12/12/74	6.5	42.5	5117
				4/11/75	5.2	43.8	
OLD HYDRO SUBAREA						T-10.A7	
28S/10E-34N03 M	40		47.0	10/16/74	18.2	28.8	5117
				4/09/75	18.3	28.7	
29S/10E-03C05 M	40		35.0	10/16/74	16.6	18.4	5117
				4/09/75	10.2	24.8	
29S/10E-03C07 M	40		35.0	10/16/74	NM-1		5117
				4/09/75	9.7	25.3	
TORO HYDRO SUBAREA						T-10.A8	
29S/10E-01P01 M	40		130.0	10/16/74	9.3	120.7	5117
				4/10/75	9.2	120.8	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SAN LUIS OBISPO HYDRO UNIT						T-10	
SAN LUIS OBISPO HYDRO SUBUNIT						T-10.8	
MORRO HYDRO SUBAREA						T-10.81	
29S/10E-11H01 M	40		63.5	10/16/74	NM-7		5117
				4/10/75	7.7	54.9	
29S/10E-24R02 M	40		59.5	12/10/74	21.0	38.5	5117
				4/09/75	20.9	38.6	
29S/10E-25C01 M	40		29.0	10/14/74	22.0	7.0	5117
				3/31/75	19.0	10.0	
				9/29/75	23.0	6.0	
29S/10E-25C02 M	40		20.1	10/14/74	16.5	3.6	5117
				3/31/75	13.5	6.6	
				9/29/75	18.5	1.6	
29S/10E-25C03 M	40		20.0	3/31/75	12.0	8.0	5117
				9/29/75	18.0	2.0	
29S/10E-25C04 M	40		40.0	10/14/74	17.5	22.5	5117
				3/31/75	14.5	25.5	
				9/29/75	18.5	21.5	
29S/10E-25E02 M	40		20.0	10/14/74	11.0	9.0	5117
				3/31/75	10.0	10.0	
				9/29/75	13.0	7.0	
29S/11E-09J01 M	40		299.5	12/10/74	36.8	262.7	5117
				4/09/75	36.0	263.5	
29S/11E-17A01 M	40		210.0	10/16/74	NM-1		5117
				4/09/75	17.6	192.4	
29S/11E-17A02 M	40		219.0	10/16/74	NM-1		5117
				4/09/75	26.9	192.1	
29S/11E-17A03 M	40		219.0	10/16/74	38.9	180.1	5117
				4/09/75	27.0	192.0	
29S/11E-19B02 M	40		120.0	10/16/74	27.8	92.2	5117
				4/11/75	27.5	92.5	
29S/11E-19B03 M	40		120.0	10/15/74	28.8	91.2	5117
				4/11/75	28.6	91.4	
29S/11E-19P01 M	40		78.1	10/16/74	29.4	48.7	5117
				4/09/75	22.7	55.4	
29S/11E-30D01 M	40		61.5	10/16/74	14.6	46.9	5117
				4/09/75	11.1	50.4	
CHORRO HYDRO SUBAREA						T-10.82	
29S/11E-19J01 M	40		120.0	12/10/74	3.1	116.9	5117
				4/09/75	2.8	117.2	
29S/11E-32F01 M	40		22.0	12/10/74	6.2	15.8	5117
				4/11/75	4.7	17.3	
29S/11E-32J01 M	40		32.0	10/14/74	11.7	20.3	5117
29S/11E-32J02 M	40		34.6	10/11/74	17.5	17.1	5117
				4/11/75	15.4	19.2	
29S/11E-32J04 M	40		30.0	10/14/74	7.0	23.0	5117
				3/31/75	4.0	26.0	
				9/29/75	6.0	24.0	
29S/11E-32J06 M	40		40.0	10/14/74	13.0	27.0	5117
29S/11E-32J08 M	40		37.5	10/14/74	11.5	26.0	5117
				12/30/74	11.5	26.0	
				3/31/75	10.5	27.0	
				9/29/75	12.5	25.0	
29S/11E-32M01 M	40		20.0	10/10/74	7.1	12.9	5117
				4/09/75	3.3	16.7	
29S/11E-33E02 M	40		45.0	12/10/74	25.6(1)	19.4	5117
				4/11/75	23.3	21.7	
29S/11E-33N01 M	40		40.0	12/10/74	5.1	34.9	5117
				4/11/75	4.9	35.1	
30S/11E-03D02 M	40		75.0	10/14/74	22.0	53.0	5117
				3/31/75	20.0	55.0	
30S/11E-11J01 M	40		165.0	10/11/74	26.2	138.8	5117
				4/11/75	23.6	141.4	
30S/11E-12N01 M	40		180.0	10/11/74	32.8	147.2	5117
				4/11/75	32.2	147.8	
30S/11E-18K06 M	40		120.0	10/11/74	54.1	65.9	5117
				4/08/75	53.5	66.5	
30S/12E-17D01 M	40		330.0	10/11/74	16.6	313.4	5117
				11/14/74	18.0	312.0	
				2/06/75	11.7(1)	318.3	
				4/11/75	4.2	325.8	
				6/02/75	6.7	323.3	
				8/27/75	15.9	314.1	

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SAN LUIS OBISPO HYDRO UNIT						T-10	
SAN LUIS OBISPO HYDRO SUBUNIT						T-10.8	
LOS OSOS HYDRO SUBAREA						T-10.83	
30S/10E-13A02 M	40		30.0	10/10/74	8.1	21.9	5117
				4/07/75	7.1	22.9	
30S/10E-13G02 M	40		20.0	10/10/74	11.2	8.8	5117
				4/07/75	11.0	9.0	
30S/10E-13H01 M	40		20.0	10/10/74	9.5	10.5	5117
				4/07/75	8.0	12.0	
30S/10E-13L01 M	40		50.0	10/10/74	33.5	16.5	5117
				4/07/75	33.1	16.9	
30S/10E-13L02 M	40		46.0	10/10/74	31.2	14.8	5117
				4/07/75	27.6	18.4	
30S/10E-13L03 M	40		21.0	4/07/75	18.4	2.6	5117
30S/10E-13P01 M	40		90.0	10/10/74	70.0	20.0	5117
				4/08/75	68.7	21.3	
30S/10E-13P02 M	40		90.0	10/10/74	109.0	-19.0	5117
				4/08/75	104.2	-14.2	
30S/10E-24A01 M	40		22.5	3/31/75	163.0	-140.5	5117
30S/11E-07K01 M	40		50.0	10/10/74	40.5	9.5	5117
				4/07/75	38.7	11.3	
30S/11E-07N01 M	40		6.0	10/01/74	8.7	-2.7	5117
				4/02/75	7.3	-1.3	
30S/11E-07Q01 M	40		44.5	10/01/74	13.8	30.7	5117
				4/02/75	13.2	31.3	
30S/11E-08M02 M	40		100.0	10/10/74	63.7	36.3	5117
				4/07/75	61.9	38.1	
30S/11E-08R01 M	40		100.0	10/10/74	5.6	94.4	5117
				4/07/75	3.5	96.5	
30S/11E-17A01 M	40		25.0	10/10/74	34.3(1)	-9.3	5117
				4/07/75	4.5	20.5	
30S/11E-17B01 M	40		21.2	10/10/74	50.5(1)	-29.3	5117
				4/07/75	2.1	19.1	
30S/11E-17E01 M	40		100.0	10/11/74	91.7	8.3	5117
				4/08/75	90.6	9.4	
30S/11E-17E02 M	40		100.0	10/11/74	79.0	21.0	5117
30S/11E-17E04 M	40		120.0	10/11/74	98.3	21.7	5117
				4/08/75	93.6	26.4	
30S/11E-17F02 M	40		80.0	10/11/74	66.2	13.8	5117
				4/08/75	63.8	16.2	
30S/11E-17F03 M	40		81.0	10/11/74	68.7	12.3	5117
				4/08/75	67.3	13.7	
30S/11E-17F04 M	40		80.0	10/11/74	47.7	32.3	5117
				4/08/75	49.6	30.4	
30S/11E-17H01 M	40		24.0	10/10/74	153.9(1)	-129.9	5117
				4/07/75	8.1	15.9	
30S/11E-17H02 M	40		30.0	10/10/74	11.4	18.6	5117
				4/07/75	8.4	21.6	
30S/11E-18F01 M	40		100.0	10/01/74	105.0	-5.0	5117
				4/03/75	98.0	2.0	
30S/11E-18H01 M	40		120.0	10/01/74	101.2	18.8	5117
				4/02/75	99.1	20.9	
30S/11E-18H04 M	40		120.0	10/11/74	62.7	57.3	5117
				4/08/75	60.8	59.2	
30S/11E-18J03 M	40		60.0	10/11/74	-2.5	62.5	5117
				4/08/75	-3.6	63.6	
30S/11E-18K01 M	40		122.0	10/01/74	133.0	-11.0	5117
				4/02/75	135.0	-13.0	
30S/11E-18K02 M	40		104.5	10/10/74	114.5	-10.0	5117
				4/08/75	118.0	-13.5	
30S/11E-18K03 M	40		120.0	3/25/75	120.0	0.0	5117
30S/11E-18M01 M	40		110.0	3/25/75	103.4	6.6	5117
30S/11E-18Q01 M	40		129.5	10/10/74	59.5	70.0	5117
				4/08/75	54.7	74.8	
30S/11E-20A01 M	40		80.0	10/10/74	22.6	57.4	5117
				4/07/75	17.7	62.3	
30S/11E-20A02 M	40		80.0	10/10/74	16.3	63.7	5117
				4/07/75	13.6	66.4	
30S/11E-20B01 M	40		250.0	10/10/74	46.6	203.4	5117
				4/07/75	42.6	207.4	

See page 79 for key to terms a abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SAN LUIS OBISPO HYDRO UNIT						T-10	
SAN LUIS OBISPO HYDRO SUBUNIT						T-10.B	
LOS OSOS HYDRO SUBAREA						T-10.B3	
30S/11E-21E01 M	40		76.9	10/10/74	12.9	64.0	5117
				4/07/75	9.3	67.6	
30S/11E-21E03 M	40		80.0	4/07/75	9.1	70.9	5117
SAN LUIS OBISPO CR HYDRO SUBAREA						T-10.B4	
30S/12E-32J01 M	40		128.7	10/05/74	11.2	117.5	5117
				5/06/75	6.8	121.9	
31S/12E-03P02 M	40		125.0	10/09/74	4.9	120.1	5117
				5/06/75	3.6	121.4	
31S/12E-10F03 M	40		115.0	10/09/74	3.1	111.9	5117
				5/06/75	1.5	113.5	
31S/12E-10G02 M	40		125.0	10/03/74	15.1	109.9	5117
				5/06/75	NM-2		
31S/12E-12E03 M	40		165.0	10/09/74	20.2	144.8	5117
				5/06/75	17.3	147.7	
31S/12E-12G03 M	40		200.0	10/09/74	39.0(1)	161.0	5117
				5/06/75	37.2(1)	162.8	
31S/12E-13J01 M	40		200.0	5/06/75	0.3	199.7	5117
31S/12E-14C01 M	40		135.0	10/09/74	14.1	120.9	5117
				5/06/75	12.3	122.7	
31S/12E-15R01 M	40		125.0	10/09/74	15.1	109.9	5117
				5/06/75	13.4	111.6	
31S/12E-28C01 M	40		45.0	5/08/75	11.7	33.3	5117
31S/12E-32C01 M	40		45.0	5/08/75	12.0	33.0	5117
31S/12E-32D01 M	40		42.0	5/08/75	12.3	29.7	5117
31S/12E-32D02 M	40		42.0	5/08/75	17.9	24.1	5117
31S/12E-33E02 M	40		27.0	5/08/75	6.8	20.2	5117
31S/12E-34N01 M	40		255.0	5/08/75	111.5	143.5	5117
31S/13E-17B01 M	40		358.0	12/11/74	4.5	353.5	5117
				5/06/75	3.7	354.3	
31S/13E-18J02 M	40		240.0	12/10/74	13.8	226.2	5117
				5/06/75	8.9	231.1	
31S/13E-18J03 M	40		260.0	5/06/75	19.4(1)	240.6	5117
31S/13E-18N01 M	40		192.0	5/06/75	21.6	170.4	5117
31S/13E-18P01 M	40		240.0	12/10/74	16.5	223.5	5117
				5/06/75	20.4	219.6	
31S/13E-18P02 M	40		240.0	12/10/74	18.0	222.0	5117
				5/06/75	26.9	213.1	
31S/13E-19P01 M	40		240.0	12/10/74	40.5	199.5	5117
				5/06/75	71.3(1)	168.7	
PISMO HYDRO SUBAREA						T-10.B6	
31S/13E-16N01 M	40		324.5	5/06/75	11.9	312.6	5117
31S/13E-17Q04 M	40		350.0	12/11/74	20.5	329.5	5117
				5/06/75	15.6	334.4	
31S/13E-18J01 M	40		240.0	12/10/74	12.3	227.7	5117
				5/06/75	5.9	234.1	
31S/13E-19A03 M	40		249.0	12/10/74	30.6	218.4	5117
				5/06/75	26.9	222.1	
31S/13E-19H01 M	40		262.0	5/06/75	10.0	252.0	5117
31S/13E-20G01 M	40		275.0	12/10/74	12.6	262.4	5117
				5/06/75	11.6	263.4	
31S/13E-20K01 M	40		275.0	12/10/74	12.1	262.9	5117
				5/06/75	10.7	264.3	
31S/13E-27D03 M	40		300.0	5/06/75	3.8	296.2	5117
31S/13E-27H02 M	40		280.0	12/11/74	6.0	274.0	5117
				5/06/75	2.5	277.5	
31S/13E-29B03 M	40		250.0	5/06/75	0.4	249.6	5117
31S/13E-29C01 M	40		255.0	5/08/75	6.9	248.1	5117
31S/13E-34P01 M	40		249.0	12/11/74	8.0	241.0	5117
				5/06/75	6.4	242.6	
SAN LUIS OBISPO HYDRO UNIT						T-10	
ARROYO GRANDE HYDRO SUBUNIT						T-10.C	
32S/13E-12D03 M	40		237.5	11/06/74	25.5	212.0	5117
				5/03/75	26.6	210.9	
11N/35W-07F01 S	40		48.0	10/01/74	16.4	31.6	5444
11N/35W-09N01 S	40		87.0	10/01/74	NM-6		5434
11N/35W-21B01 S	40		94.0	10/01/74	47.5	46.5	5444
11N/35W-24B01 S	40		144.0	10/01/74	93.8	50.2	5444
ARROYO GRANDE HYDRO SUBAREA						T-10.C1	
26S/17E-35P01 M	40		830.0	10/22/74	188.0	642.0	5117
31S/13E-36R01 M	40		395.0	10/07/74	NM-1		5117
				11/06/74	9.9	385.1	
				1/02/75	10.7	384.3	
				4/04/75	11.0	384.0	
				5/03/75	52.0(1)	343.0	
				7/29/75	16.2	378.8	
				9/23/75	NM-1		
31S/14E-31N02 M	40		320.0	10/07/74	NM-1		5117
				11/06/74	7.5	312.5	
				1/02/75	7.4	312.6	
				4/04/75	7.9	312.1	
				5/03/75	64.0(1)	256.0	
				7/29/75	NM-1		
				9/23/75	45.1(1)	274.9	
31S/14E-32G03 M	40		365.5	10/02/74	NM-1		5117
				11/06/74	39.1	326.4	
				1/03/75	47.0	318.5	
				4/04/75	35.9	329.6	
				5/03/75	30.1(1)	335.4	
				7/29/75	23.0	342.5	
				9/23/75	33.7(1)	331.8	
31S/14E-32H02 M	40		365.0	10/07/74	25.5	339.5	5117
				11/06/74	32.4	332.6	
				1/03/75	39.8	325.2	
				4/04/75	37.0	328.0	
				5/03/75	23.2	341.8	
				7/29/75	24.0	341.0	
				9/23/75	25.4	339.6	
31S/14E-33H03 M	40		365.0	1/02/75	26.0	339.0	5117
				5/03/75	22.5	342.5	
				7/29/75	22.3	342.7	
				9/23/75	24.3	340.7	
32S/12E-24B01 M	40		10.0	4/01/75	2.1	7.9	5117
				7/07/75	2.4	7.6	
32S/12E-24B02 M	40		10.0	7/07/75	3.6	6.4	5117
32S/12E-24R01 M	40		10.0	4/01/75	16.5	-6.5	5117
				7/07/75	16.7	-6.7	
32S/12E-24R02 M	40		10.0	4/01/75	17.0	-7.0	5117
				7/07/75	17.1	-7.1	
32S/13E-01G01 M	40		305.0	10/07/74	NM-1		5117
				11/06/74	23.9	281.1	
				1/02/75	22.0	283.0	
				4/04/75	NM-1		
				5/03/75	NM-1		
				7/29/75	24.5	280.5	
				9/23/75	24.0(1)	281.0	
32S/13E-12C03 M	40		271.0	10/08/74	27.1	243.9	5117
				11/06/74	25.0	246.0	
				1/02/75	21.9	249.1	
				4/04/75	21.5	249.5	
				5/03/75	25.3	245.7	
				7/29/75	39.6(1)	231.4	
				9/23/75	41.0(1)	230.0	
32S/13E-12C04 M	40		260.0	11/06/74	25.8	234.2	5117
				5/03/75	24.4	235.6	
32S/13E-12F04 M	40		250.0	10/08/74	26.6	223.4	5117
				11/06/74	23.1	226.9	
				1/02/75	19.3	230.7	
				4/04/75	19.3	230.7	
				5/03/75	19.3	230.7	
				7/29/75	24.2	225.8	
				9/23/75	27.6	222.4	
32S/13E-12N01 M	40		231.0	10/08/74	24.8	206.2	5117
				11/06/74	23.7	207.3	
				1/02/75	22.1	208.9	
				4/04/75	21.4	209.6	
				5/03/75	22.2	208.8	
				7/29/75	30.6(1)	200.4	
32S/13E-14Q02 M	40		174.0	10/08/74	62.0	112.0	5117
				11/06/74	52.5	121.5	
				1/02/75	30.1	143.9	
				4/04/75	NM-1		
				5/03/75	33.6	140.4	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SAN LUIS OBISPO HYDRO UNIT ARROYO GRANDE HYDRO SUBUNIT ARROYO GRANDE HYDRO SUBAREA						T-10 T-10.C T-10.C1	
32S/13E-14Q02 M (CONTINUED)	40		174.0	7/29/75	54.9	119.1	5117
				9/23/75	71.5	102.5	
32S/13E-14R01 M	40		200.0	10/08/74	74.2	125.8	5117
				11/06/74	67.0	133.0	
				1/02/75	44.0	156.0	
				4/04/75	41.6	158.4	
				5/03/75	45.1	154.9	
				7/29/75	69.8	130.2	
				9/23/75	81.7(1)	118.3	
32S/13E-14R02 M	40		197.6	10/08/74	70.9	126.7	5117
				11/06/74	64.5	133.1	
				1/02/75	39.8	157.8	
				4/04/75	37.9	159.7	
				5/03/75	41.5	156.1	
				7/29/75	72.6(1)	125.0	
				9/23/75	71.5	126.1	
32S/13E-14R03 M	40		180.0	10/08/74	70.4	109.6	5117
				11/06/74	60.3	119.7	
				1/02/75	35.9	144.1	
				4/04/75	38.7	141.3	
				5/03/75	38.6	141.4	
				7/29/75	75.0(1)	105.0	
				9/23/75	82.5(1)	97.5	
32S/13E-22R02 M	40		139.0	10/08/74	17.7	121.3	5117
				11/06/74	14.3	124.7	
				1/02/75	12.3	126.7	
				4/04/75	21.1	117.9	
				5/05/75	24.3	114.7	
				7/29/75	36.0	103.0	
				9/23/75	36.0	103.0	
32S/13E-22R03 M	40		100.0	10/08/74	20.1	79.9	5117
				11/06/74	17.0	83.0	
				1/02/75	15.8	84.2	
				4/04/75	NM-1		
				5/05/75	25.9	74.1	
				7/29/75	NM-1		
				9/23/75	35.9	64.1	
32S/13E-23C01 M	40		185.0	10/08/74	NM-1		5117
				11/06/74	29.0	156.0	
				1/02/75	26.9	158.1	
				4/04/75	NM-1		
				5/03/75	28.0	157.0	
				7/29/75	58.0(1)	127.0	
				9/23/75	30.0	155.0	
32S/13E-23F01 M	40		161.2	10/08/74	13.9	147.3	5117
				11/06/74	14.2	147.0	
				1/02/75	15.2	146.0	
				4/04/75	NM-1		
				5/03/75	15.2	146.0	
				7/29/75	25.5	135.7	
				9/23/75	17.8	143.4	
32S/13E-23H07 M	40		140.0	10/08/74	20.0	120.0	5117
				11/06/74	19.5	120.5	
				1/02/75	19.1	120.9	
				4/04/75	24.7(1)	115.3	
				5/03/75	21.1	118.9	
				7/29/75	23.5	116.5	
				9/23/75	47.3(1)	92.7	
32S/13E-27D03 M	40		103.5	10/08/74	32.6	70.9	5117
				11/06/74	32.2	71.3	
				1/02/75	21.4	82.1	
				4/04/75	31.1	72.4	
				5/05/75	32.1	71.4	
				7/29/75	39.4	64.1	
				9/23/75	39.4	64.1	
32S/13E-28G01 M	40		86.2	10/08/74	27.9(1)	58.3	5117
				11/06/74	26.9	59.3	
				1/02/75	31.7	54.5	
				4/04/75	NM-1		
				5/05/75	26.7	59.5	
				7/29/75	NM-1		
				9/23/75	46.8(1)	39.4	
32S/13E-28K01 M	40		82.0	11/08/74	39.6	42.4	5117
				5/05/75	73.7(1)	8.3	
32S/13E-28L01 M	40		90.0	11/07/74	25.5	64.5	5117
				5/05/75	85.0	5.0	
32S/13E-28N02 M	40		72.9	10/08/74	42.2	30.7	5117
				11/06/74	41.0	31.9	
				1/02/75	39.4	33.5	
				4/04/75	41.7	31.2	
				5/05/75	42.1	30.8	
				7/29/75	50.7	22.2	
				9/23/75	NM-1		
32S/13E-28N06 M	40		75.0	10/08/74	41.8	33.2	5117
				11/06/74	40.0	35.0	
				1/02/75	37.4	37.6	
				4/04/75	40.1	34.9	
				5/05/75	40.2	34.8	
SAN LUIS OBISPO HYDRO UNIT ARROYO GRANDE HYDRO SUBUNIT ARROYO GRANDE HYDRO SUBAREA						T-10 T-10.C T-10.C1	
32S/13E-28N06 M (CONTINUED)	40		75.0	7/29/75	49.0	26.0	5117
				9/23/75	53.6	21.4	
32S/13E-29R01 M	40		81.4	11/07/74	70.5	10.9	5117
				5/05/75	NM-1		
32S/13E-29C02 M	40		71.6	10/08/74	NM-1		5117
				11/07/74	NM-1		
				1/02/75	64.1(1)	7.5	
				4/04/75	68.3(1)	3.3	
				5/05/75	68.1	3.5	
				7/29/75	70.1	1.5	
				9/24/75	69.1	2.5	
32S/13E-29D04 M	40		54.0	10/08/74	43.0	11.0	5117
				11/07/74	42.3	11.7	
				1/02/75	41.0	13.0	
				4/04/75	41.6	12.4	
				5/05/75	42.3	11.7	
				7/29/75	NM-1		
				9/24/75	45.0	9.0	
32S/13E-29E02 M	40		50.5	10/08/74	44.5	6.0	5117
				11/07/74	45.0	5.5	
				1/02/75	42.2	8.3	
				4/04/75	44.1	6.4	
				5/05/75	43.5	7.0	
				7/29/75	46.0	4.5	
				9/25/75	45.9	4.6	
32S/13E-29G07 M	40		80.0	10/08/74	70.3	9.7	5117
				11/07/74	65.7	14.3	
				1/03/75	64.7	15.3	
				4/04/75	65.1	14.9	
				5/05/75	66.0	14.0	
				7/29/75	68.5	11.5	
				9/24/75	68.6	11.4	
32S/13E-29J02 M	40		82.6	11/07/74	67.5	15.1	5117
				5/05/75	69.4	13.2	
32S/13E-29J03 M	40		89.0	10/08/74	76.1	12.9	5117
				11/07/74	75.1	13.9	
				1/02/75	73.4	15.6	
				4/04/75	74.1	14.9	
				5/05/75	75.3	13.7	
				7/29/75	79.1	9.9	
				9/24/75	79.0	10.0	
32S/13E-29L06 M	40		71.0	10/08/74	61.4	9.6	5117
				11/07/74	61.5	9.5	
				1/02/75	53.2	17.8	
				5/05/75	62.6	8.4	
				7/29/75	64.5	6.5	
				9/24/75	64.6	6.4	
32S/13E-29M04 M	40		61.2	10/08/74	45.1	16.1	5117
				11/07/74	46.4	14.8	
				1/02/75	41.6	19.6	
				4/04/75	42.9	18.3	
				5/05/75	43.7	17.5	
				7/29/75	45.3	15.9	
				9/24/75	46.1	15.1	
32S/13E-29N01 M	40		79.0	10/09/74	71.6	7.4	5117
				11/07/74	71.0	8.0	
				1/02/75	69.0	10.0	
				4/04/75	83.2(1)	-4.2	
				5/05/75	82.9(1)	-3.9	
				7/29/75	73.6	5.4	
				9/25/75	73.2	5.8	
32S/13E-30F01 M	40		20.0	7/07/75	11.8	8.2	5117
32S/13E-30F02 M	40		30.0	7/07/75	12.6	17.4	5117
32S/13E-30F03 M	40		30.0	7/07/75	8.4	21.6	5117
32S/13E-30J08 M	40		42.0	11/07/74	33.5	8.5	5117
				5/05/75	33.2	8.8	
32S/13E-30K04 M	40		30.0	10/09/74	15.7	14.3	5117
				11/07/74	15.3	14.7	
				1/02/75	NM-2		
				4/04/75	NM-2		
				9/29/75	17.1	12.9	
32S/13E-30K06 M	40		30.0	10/03/74	14.5	15.5	5117
				11/07/74	14.1	15.9	
				1/02/75	13.2	16.8	
				4/04/75	13.6	16.4	
				5/05/75	14.2	15.8	
				7/29/75	15.6	14.4	
				9/26/75	16.0	14.0	
32S/13E-30K11 M	40		29.2	11/07/74	20.6	8.6	5117
				5/05/75	23.3(1)	5.9	
32S/13E-30K14 M	40		41.0	10/08/74	32.0	9.0	5117
				11/07/74	31.5	9.5	
				1/02/75	30.1	10.9	
				4/04/75	30.9	10.1	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SAN LUIS OBISPO HYDRO UNIT ARROYO GRANDE HYDRO SUBUNIT ARROYO GRANDE HYDRO SUBAREA						T-10 T-10.C T-10.C1	
32S/13E-30K14 M (CONTINUED)	40		41.0	5/05/75	31.5	9.5	5117
				7/29/75	33.2	7.8	
				9/25/75	33.8	7.2	
32S/13E-30K16 M	40		30.0	10/09/74	15.8	14.2	5117
				11/07/74	15.7	14.3	
				1/02/75	14.3	15.7	
				4/04/75	15.2	14.8	
				5/05/75	16.1	13.9	
				7/29/75	16.9	13.1	
				9/26/75	17.0	13.0	
32S/13E-30L02 M	40		15.0	11/07/74	8.5	6.5	5117
				5/05/75	9.5	5.5	
				9/25/75	10.1	4.9	
32S/13E-30N01 M	40		30.0	4/01/75	6.2	23.8	5117
				7/07/75	6.3	23.7	
32S/13E-30N03 M	40		30.0	4/01/75	4.2	25.8	5117
				7/07/75	5.7	24.3	
32S/13E-30P02 M	40		28.3	11/08/74	20.4	7.9	5117
				5/05/75	21.1	7.2	
				9/26/75	21.6	6.7	
32S/13E-30R02 M	40		46.5	10/09/74	36.6	9.9	5117
				11/07/74	37.5	9.0	
				1/02/75	35.8	10.7	
				4/04/75	39.4(1)	7.1	
				5/05/75	39.5	7.0	
				7/29/75	NM-1		
				9/24/75	40.7	5.8	
32S/13E-31A02 M	40		51.0	11/08/74	44.5	6.5	5117
				5/05/75	63.1(1)	-12.1	
				9/25/75	65.5(1)	-14.5	
32S/13E-31B03 M	40		8.5	10/04/74	8.2	0.3	5117
				11/07/74	1.4	7.1	
				5/06/75	1.4	7.1	
				9/29/75	NM-9		
32S/13E-31G01 M	40		12.0	11/08/74	2.9	9.1	5117
				5/06/75	2.8	9.2	
				9/29/75	3.4	8.6	
32S/13E-31G02 M	40		19.9	11/08/74	10.5	9.4	5117
				5/06/75	10.2	9.7	
				9/29/75	11.5	8.4	
32S/13E-31H07 M	40		19.0	11/08/74	7.5	11.5	5117
				5/06/75	7.2	11.8	
				9/29/75	8.5	10.5	
32S/13E-32B03 M	40		70.0	11/08/74	56.0	14.0	5117
				5/06/75	56.5	13.5	
				9/29/75	58.7	11.3	
32S/13E-32C02 M	40		60.0	11/08/74	54.7	5.3	5117
				5/06/75	59.7(1)	0.3	
				9/26/75	NM-1		
32S/13E-32D03 M	40		81.4	11/18/74	71.8	9.6	5117
				12/12/74	71.1	10.3	
				2/07/75	69.1	12.3	
				4/07/75	70.5	10.9	
				7/02/75	76.0	5.4	
				9/06/75	74.1	7.3	
32S/13E-32D09 M	40		72.0	11/08/74	68.6(1)	3.4	5117
				5/06/75	61.6	10.4	
				9/26/75	66.0	6.0	
32S/13E-32J02 M	40		39.9	10/03/74	26.8	13.1	5117
				11/07/74	24.4	15.5	
				1/02/75	21.7	18.2	
				4/04/75	24.9	15.0	
				5/05/75	40.1	-0.2	
				7/29/75	34.9	5.0	
				9/24/75	46.5(1)	-6.6	
32S/13E-32L07 M	40		20.0	11/08/74	12.7	7.3	5117
				5/06/75	12.9	7.1	
				9/26/75	14.3(1)	5.7	
32S/13E-32M03 M	40		20.0	11/08/74	6.0	14.0	5117
				5/06/75	11.0	9.0	
				9/26/75	15.0	5.0	
32S/13E-33C04 M	40		61.5	10/08/74	41.4	20.1	5117
				11/07/74	37.5	24.0	
				1/02/75	35.3	26.2	
				4/04/75	38.5	23.0	
				9/24/75	46.8	14.7	
32S/13E-33E03 M	40		53.2	11/06/74	27.2	26.0	5117
				5/05/75	26.2	27.0	
				9/30/75	33.4	19.8	
32S/13E-33F01 M	40		48.0	11/06/74	24.1	23.9	5117
				5/05/75	25.9	22.1	
SAN LUIS OBISPO HYDRO UNIT ARROYO GRANDE HYDRO SUBUNIT ARROYO GRANDE HYDRO SUBAREA						T-10 T-10.C T-10.C1	
32S/13E-33F01 M	40		48.0	9/30/75	32.9	15.1	5117
32S/13E-33K03 M	40		52.3	10/08/74	31.4	20.9	5117
				11/06/74	27.6	24.7	
				1/02/75	25.4	26.9	
				5/05/75	69.0(1)	-16.7	
				9/24/75	37.1	15.2	
32S/13E-33L02 M	40		42.1	11/07/74	18.2	23.9	5117
				5/05/75	40.5(1)	1.6	
				9/30/75	26.9	15.2	
32S/13E-33M02 M	40		47.7	11/07/74	13.1	34.6	5117
				5/05/75	54.2(1)	-6.5	
				9/30/75	21.7	26.0	
32S/14E-19A01 M	40		289.9	11/06/74	NM-1		5117
				5/03/75	8.1	281.8	
32S/14E-19D01 M	40		275.0	11/06/74	NM-1		5117
				5/03/75	15.2	259.8	
12N/35W-27N02 S	40		170.0	10/09/74	8.8	161.2	5117
				5/01/75	8.2	161.8	
12N/35W-28J02 S	40		180.0	5/09/75	35.7	144.3	5117
12N/35W-28J06 S	40		170.0	5/09/75	69.2	100.8	5117
12N/35W-28J07 S	40		170.0	5/09/75	29.1(1)	140.9	5117
12N/35W-29L01 S	40		40.0	11/07/74	15.8	24.2	5117
				5/05/75	30.9(1)	9.1	
				9/30/75	24.6	15.4	
12N/35W-29L02 S	40		38.0	10/08/74	13.1	24.9	5117
				11/07/74	14.3	23.7	
				1/02/75	11.9	26.1	
				4/04/75	17.1	20.9	
				7/09/75	25.3	12.7	
				9/24/75	26.6	11.4	
12N/35W-29N01 S	40		35.0	11/07/74	7.9	27.1	5117
				5/05/75	15.0	20.0	
				9/25/75	22.8(1)	12.2	
12N/35W-30K02 S	40		27.5	11/07/74	11.0	16.5	5117
				5/05/75	22.0(1)	5.5	
				9/29/75	17.7	9.8	
12N/35W-30K03 S	40		30.0	11/07/74	6.7	23.3	5117
				5/05/75	10.7	19.3	
				9/29/75	15.0	15.0	
12N/35W-30M02 S	40		21.8	11/08/74	9.0	12.8	5117
				5/08/75	8.8	13.0	
				9/26/75	15.4	6.4	
12N/35W-30P02 S	40		26.0	11/07/74	4.6	21.4	5117
				5/05/75	11.2	14.8	
				9/29/75	15.1	10.9	
12N/35W-33J02 S	40		300.0	11/27/74	249.0	51.0	5117
				3/01/75	245.5	54.5	
				5/01/75	249.0(1)	51.0	
12N/35W-33M01 S	40		246.0	5/12/75	NM-1		5117
12N/35W-33Q02 S	40		339.0	5/12/75	178.3	160.7	5117
12N/35W-34C03 S	40		158.0	10/09/74	25.2(1)	132.8	5117
				5/01/75	16.3	141.7	
12N/35W-34G03 S	40		187.9	10/09/74	21.3	166.6	5117
				5/01/75	19.6	168.3	
12N/35W-34G06 S	40		198.0	10/09/74	18.9	179.1	5117
				5/01/75	14.8	183.2	
12N/35W-34L01 S	40		320.0	11/27/74	290.5	29.5	5117
				5/01/75	290.0	30.0	
12N/35W-34P01 S	40		300.0	11/27/74	191.9	108.1	5117
				5/01/75	190.0	110.0	
12N/35W-35K02 S	40		245.0	10/09/74	42.6	202.4	5117
				5/01/75	42.0	203.0	
12N/35W-35P01 S	40		390.0	11/11/74	163.9	226.1	5117
				5/08/75	169.4	220.6	
NIPOMO MESA HYDRO SUBAREA						T-10.C2	
32S/13E-19Q02 M	40		58.0	10/08/74	46.1	11.9	5117
				11/07/74	45.3	12.7	
				1/02/75	44.5	13.5	
				4/04/75	45.0	13.0	
				5/05/75	45.8	12.2	
				7/29/75	47.2	10.8	
				9/25/75	118.2(1)	-60.2	
11N/34W-17B04 S	40		325.0	11/08/74	20.3	304.7	5117

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SAN LUIS OBISPO HYDRO UNIT ARROYO GRANDE HYDRO SUBUNIT NIPOMO MESA HYDRO SUBAREA						T-10 T-10.C T-10.C2	
11N/34W-17R04	S	40	325.0	5/01/75	16.1	308.9	5117
11N/34W-17N03	S	40	370.0	11/08/74	156.7	213.3	5117
				4/03/75	NM-0		5000
11N/34W-18P01	S	40	295.0	11/08/74	275.2	19.8	5117
				5/01/75	275.0	20.0	
11N/34W-18P02	S	40	350.0	4/03/75	273.8	76.2	5000
11N/34W-19Q01	S	40	305.0	11/12/74	264.8	40.2	5117
				4/03/75	277.4	27.6	5000
11N/34W-28F01	S	40	316.0	11/08/74	211.0	105.0	5117
				4/03/75	213.4	102.6	5000
11N/35W-02F01	S	40	380.0	11/11/74	331.8	48.2	5117
				5/08/75	332.3	47.7	
11N/35W-02F02	S	40	390.0	11/18/74	337.1	52.9	5117
				5/08/75	365.0(1)	25.0	
11N/35W-02G01	S	40	399.5	11/20/74	97.8	301.7	5117
				5/08/75	97.5	302.0	
11N/35W-02G02	S	40	399.5	11/20/74	228.8	170.7	5117
				5/08/75	232.0	167.5	
11N/35W-02H01	S	40	399.0	11/20/74	229.5	169.5	5117
				5/09/75	238.4(1)	160.6	
11N/35W-02N01	S	40	248.0	11/22/74	203.2	44.8	5117
				5/01/75	203.0	45.0	
11N/35W-03B01	S	40	320.0	11/27/74	222.6	97.4	5117
				5/01/75	219.7	100.3	
11N/35W-03C01	S	40	330.0	11/00/74	208.5	121.5	5117
				5/08/75	206.6	123.4	
11N/35W-05B01	S	40	139.0	2/26/75	114.1	24.9	5117
11N/35W-05G01	S	40	210.0	11/06/74	113.0	96.0	5117
				4/30/75	109.2	99.8	
11N/35W-05L01	S	40	108.0	11/06/74	103.3	4.7	5117
				4/30/75	102.3	5.7	
11N/35W-05N02	S	40	99.5	2/26/75	79.5	20.0	5117
				9/30/75	88.5	11.0	
11N/35W-06J01	S	40	100.0	5/12/75	74.8	25.2	5117
11N/35W-07A01	S	40	100.0	11/27/74	83.2	16.8	5117
				4/30/75	82.9	17.1	
				9/30/75	86.8	13.2	
11N/35W-07R01	S	40	95.0	11/07/74	75.0(1)	20.0	5117
			100.0	4/03/75	82.1(1)	17.9	5000
			95.0	9/30/75	95.5(1)	-0.5	5117
11N/35W-08C01	S	40	100.0	2/26/75	85.6	14.4	5117
				4/30/75	88.9	11.1	
11N/35W-09G01	S	40	200.0	11/07/74	245.5	-45.5	5117
				5/01/75	212.2	-12.2	
11N/35W-09K02	S	40	190.0	11/07/74	134.1	55.9	5117
				4/03/75	127.9	62.1	5000
				5/01/75	133.1	56.9	5117
11N/35W-09K04	S	40	182.0	11/07/74	145.5	36.5	5117
				4/03/75	137.4	44.6	5000
11N/35W-09P01	S	40	170.0	11/07/74	120.7	49.3	5117
			165.0	4/08/75	NM-4		5000
11N/35W-10J01	S	40	319.5	11/08/74	294.5	25.0	5117
11N/35W-10R01	S	40	277.0	11/07/74	178.6(1)	98.4	5117
				4/03/75	176.7	100.3	5000
				5/01/75	179.3(1)	97.7	5117
11N/35W-11A01	S	40	385.0	11/08/74	336.5	48.5	5117
				4/03/75	336.2	48.8	5000
				5/08/75	336.9	48.1	5117
11N/35W-11C01	S	40	267.0	11/08/74	221.6	45.4	5117
				4/03/75	244.4(1)	22.6	5000
				5/01/75	NM-1		5117
11N/35W-11J01	S	40	352.0	11/08/74	280.0	72.0	5117
				4/03/75	274.1	77.9	5000
				5/01/75	280.1	71.9	5117
11N/35W-11J02	S	40	362.0	11/08/74	346.3	15.7	5117
				5/02/75	350.4	11.6	
11N/35W-12E02	S	40	360.0	11/20/74	326.4	33.6	5117
				5/08/75	326.4	33.6	
11N/35W-13C01	S	40	345.0	11/08/74	283.5	61.5	5117
SAN LUIS OBISPO HYDRO UNIT ARROYO GRANDE HYDRO SUBUNIT NIPOMO MESA HYDRO SUBAREA						T-10 T-10.C T-10.C2	
11N/35W-13C01 (CONTINUED)	S	40	345.0	4/03/75	281.3	63.7	5000
				5/01/75	289.0(1)	56.0	5117
11N/35W-13F02	S	40	305.0	11/12/74	262.2	42.8	5117
				4/03/75	237.6	67.4	5000
				5/01/75	243.1	61.9	5117
11N/35W-13E03	S	40	305.0	11/12/74	246.3	58.7	5117
				4/03/75	238.0	67.0	5000
				5/01/75	246.0	59.0	5117
11N/35W-16B01	S	40	193.0	11/07/74	191.7	1.3	5117
				5/01/75	182.1	10.9	
11N/35W-17E01	S	40	89.0	4/30/75	NM-1		5117
				9/30/75	67.0(1)	22.0	
11N/35W-22C01	S	40	238.0	11/12/74	NM-7		5117
11N/35W-23B01	S	40	275.0	11/08/74	244.2	30.8	5117
				5/01/75	NM-1		
11N/35W-24D01	S	40	321.0	11/08/74	190.5	130.5	5117
				4/03/75	186.6	134.4	5000
				5/01/75	190.2(1)	130.8	5117
12N/35W-29R03	S	40	235.0	11/06/74	201.3	33.7	5117
				4/30/75	194.6	40.4	
12N/35W-32F01	S	40	200.0	5/12/75	155.6	44.4	5117
12N/35W-32G01	S	40	153.0	5/17/75	174.0	-21.0	5117
12N/35W-32J02	S	40	245.0	5/12/75	169.1	75.9	5117
12N/35W-33E01	S	40	258.5	5/09/75	135.1	123.4	5117
12N/35W-33L01	S	40	304.5	5/09/75	278.6	25.9	5117
12N/35W-33P01	S	40	339.0	5/09/75	211.3	127.7	5117
12N/35W-35P02	S	40	390.0	11/19/74	190.8	199.2	5117
				5/08/75	191.7	198.3	

See page 79 for key to terms a abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
CARRIZO PLAIN HYDRO UNIT						T-11	
29S/17E-13R02 M	40		2037.9	11/04/74	44.1(1)	1993.8	5117
				4/28/75	82.6(1)	1955.3	
29S/18E-28G01 M	40		2022.0	11/04/74	59.6	1962.4	5117
				4/28/75	NM-7		
29S/18E-28K01 M	40		2020.0	11/04/74	29.5	1990.5	5117
				4/28/75	30.3	1989.7	
29S/18E-28L01 M	40		2020.0	11/04/74	26.1	1993.9	5117
				4/28/75	27.2	1992.8	
30S/18E-01R02 M	40		2020.0	11/04/74	43.0	1977.0	5117
				4/28/75	43.1	1976.9	
30S/18E-02N01 M	40		1984.0	11/04/74	13.6	1970.4	5117
				4/28/75	10.6	1973.4	
30S/18E-03D01 M	40		2000.0	11/04/74	34.0	1966.0	5117
				4/28/75	NM-1		
30S/18E-12N01 M	40		1970.0	11/04/74	74.2(1)	1895.8	5117
				4/28/75	13.0	1957.0	
30S/19E-29M02 M	40		1943.0	11/04/74	10.4	1932.6	5117
				4/28/75	10.1	1932.9	
31S/21E-31B01 M	40		1994.0	11/04/74	52.0	1942.0	5117
				4/28/75	52.1	1941.9	
31S/21E-33J01 M	40		2200.0	4/28/75	140.3	2059.7	5117
32S/20E-12P01 M	40		1955.0	11/04/74	49.1	1905.9	5117
				4/28/75	35.9	1919.1	
32S/21E-22M02 M	40		2044.0	11/04/74	78.1	1965.9	5117
				4/29/75	77.7	1966.3	
32S/21E-23L02 M	40		2034.0	11/04/74	69.9	1964.1	5117
				4/28/75	68.2	1965.8	
12N/26W-32M02 S	40		2150.0	11/04/74	163.2	1986.8	5117
				4/28/75	NM-1		
12N/27W-36E01 S	42		2248.0	11/04/74	101.9	2146.1	5117
				4/28/75	123.1(1)	2124.9	

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA MARIA-CUYAMA HYDRO UNIT SANTA MARIA HYDRO SUBUNIT						T-12 T-12-A	
09N/33W-08L01 S	42		700.0	4/03/75	NM-4		5000
09N/33W-24L01 S	42		531.0	4/03/75	199.5	331.5	5000
09N/33W-28M01 S	42		903.0	4/02/75	213.7	689.3	5000
09N/34W-03A02 S	42		270.0	3/20/75	206.1	63.9	5000
09N/34W-03F01 S	42		265.0	4/02/75	NM-1		5000
09N/34W-03N01 S	42		258.0	4/02/75	186.7	71.3	5000
09N/34W-06C01 S	42		131.6	2/25/75	77.3	54.3	5000
09N/34W-06K02 S	42		161.0	2/24/75	91.8	69.2	5000
09N/34W-08H01 S	42		222.0	2/25/75	NM-1		5000
				4/04/75	149.5	72.5	
09N/34W-09R01 S	42		275.0	3/04/75	194.9	80.1	5000
10N/33W-07H01 S	42		255.0	4/02/75	122.0	133.0	5000
10N/33W-07Q02 S	42		270.0	4/02/75	109.5	160.5	5000
10N/33W-16N01 S	42		292.0	4/02/75	69.8	222.2	5000
10N/33W-16N02 S	42		292.0	4/03/75	72.6	219.4	5000
10N/33W-17J02 S	42		300.0	4/02/75	67.6	232.4	5000
10N/33W-18G01 S	42		273.0	10/01/74	99.5	173.5	5000
				1/20/75	102.0	171.0	
				4/01/75	105.5	167.5	
				7/01/75	108.7	164.3	
10N/33W-19R01 S	42		275.0	10/01/74	121.3	153.7	5000
				1/20/75	122.5	152.5	
				4/02/75	117.5	157.5	
				7/01/75	150.5	124.5	
10N/33W-19K01 S	42		280.0	4/02/75	149.9	130.1	5000
10N/33W-20H01 S	42		300.0	3/20/75	102.0	198.0	5000
10N/33W-20L01 S	42		294.0	10/29/74	106.3	187.7	5000
				11/27/74	105.1	188.9	
				12/24/74	105.4	188.6	
				1/27/75	106.3	187.7	
				2/24/75	107.7	186.3	
				3/26/75	109.2	184.8	
				4/24/75	111.2	182.8	
				5/27/75	116.5	177.5	
				6/26/75	124.8	169.2	
				7/28/75	135.1	158.9	
				8/27/75	139.0	155.0	
				9/24/75	140.3	153.7	
10N/33W-21F04 S	42		308.0	3/11/75	91.4	216.6	5000
10N/33W-21R01 S	42		319.0	3/14/75	NM-1		5000
10N/33W-27G01 S	42		338.0	10/01/74	58.8	279.2	5000
				3/14/75	66.7	271.3	
10N/33W-27K02 S	42		335.0	4/03/75	93.6	241.4	5000
10N/33W-27R01 S	42		352.0	3/13/75	81.2	270.8	5000
10N/33W-28A01 S	42		325.0	1/20/75	69.3	255.7	5000
				2/24/75	67.7	257.3	
				3/14/75	67.4	257.6	
				4/01/75	75.5	249.5	
				5/27/75	72.3	252.7	
				6/26/75	73.5	251.5	
				7/01/75	78.3	246.7	
				8/27/75	81.0	244.0	
				9/24/75	83.5	241.5	
10N/33W-28F01 S	42		316.0	3/14/75	139.0	177.0	5000
10N/33W-29F01 S	42		315.0	3/12/75	170.7	144.3	5000
10N/33W-30G01 S	42		320.0	10/01/74	NM-9		5404
				1/20/75	197.0	123.0	5000
				3/12/75	194.3	125.7	
				4/01/75	200.9	119.1	
				7/01/75	212.0	108.0	
10N/33W-30H01 S	42		310.0	10/01/74	206.3	103.7	5404
				1/20/75	208.4	101.6	5000
				4/01/75	211.6	98.4	
				7/01/75	222.3	87.7	
10N/33W-30R01 S	42		335.0	10/01/74	192.5	142.5	5404
			310.0	1/20/75	194.6	115.4	5000
				3/12/75	191.2	118.8	
				4/01/75	196.6	113.4	
				7/01/75	198.0	112.0	
10N/33W-33H01 S	42		402.0	4/03/75	232.5	169.5	5000
10N/33W-35C01 S	42		348.0	3/06/75	58.8	289.2	5000

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA MARIA-CUYAMA HYDRO UNIT SANTA MARIA HYDRO SUBUNIT						T-12 T-12.A	
10N/34W-02R01 S	42		230.0	10/01/74	121.9	108.1	5000
				1/20/75	122.4	107.6	
				4/01/75	120.9	109.1	
				7/01/75	123.2	106.8	
10N/34W-04R01 S	42		192.0	4/02/75	NM-1		5000
10N/34W-06N01 S	42		152.0	10/01/74	102.1	49.9	5000
				1/20/75	98.0	54.0	
				3/12/75	NM-1		
				4/01/75	98.7	53.3	
				7/01/75	99.6	52.4	
10N/34W-09L02 S	42		189.0	10/01/74	NM-9		5404
10N/34W-12P01 S	42		244.0	4/02/75	NM-4		5000
10N/34W-12P02 S	42		245.0	3/21/75	131.6	113.4	5000
10N/34W-13C01 S	42		249.0	3/20/75	132.9	116.1	5000
10N/34W-13G01 S	42		253.0	4/02/75	134.6	118.4	5000
10N/34W-13J01 S	42		260.0	3/20/75	145.3	114.7	5000
10N/34W-14E05 S	42		221.0	10/29/74	144.2	76.8	5000
				11/22/74	143.7	77.3	
				12/26/74	144.3	76.7	
				1/27/75	147.1	73.9	
				2/24/75	142.9	78.1	
				3/18/75	151.1(4)	69.9	
				4/24/75	142.5	78.5	
				5/27/75	143.7	77.3	
				6/26/75	151.4	69.6	
				7/28/75	160.5	60.5	
				8/27/75	152.9	68.1	
				9/24/75	150.8	70.2	
10N/34W-20H03 S	42		180.0	3/19/75	115.3	64.7	5000
10N/34W-22R01 S	42		217.0	10/01/74	151.1	65.9	5000
				1/20/75	149.1	67.9	
				4/01/75	150.4	66.6	
				7/01/75	151.1	65.9	
10N/34W-23H01 S	42		242.0	10/01/74	155.0	87.0	5000
				1/20/75	153.0	89.0	
				3/17/75	176.2	65.8	
				4/01/75	158.1	83.9	
				7/01/75	163.4	78.6	
10N/34W-24K01 S	42		254.0	10/15/74	156.2	97.8	5000
				1/20/75	153.3	100.7	
				4/01/75	158.2	95.8	
				7/01/75	166.1	87.9	
10N/34W-24K02 S	42		244.0	10/01/74	156.4	87.6	5404
10N/34W-24K03 S	42		245.0	10/01/74	143.7	101.3	5404
			254.0	1/20/75	160.0	94.0	5000
				4/01/75	161.0	93.0	
				7/01/75	164.0	90.0	
10N/34W-26H02 S	42		260.0	4/02/75	196.8	63.2	5000
10N/34W-31F02 S	42		182.0	3/04/75	122.2	59.8	5000
10N/34W-31L02 S	42		175.0	3/04/75	125.2	49.8	5000
10N/34W-34G02 S	42		263.0	3/20/75	NM-1		5000
10N/35W-06A01 S	40		72.0	11/12/74	10.5	61.5	5117
				3/03/75	9.8	62.2	5000
				4/30/75	9.6	62.4	5117
				7/07/75	10.4	61.6	
10N/35W-06A02 S	40		72.0	11/12/74	10.8	61.2	5117
				3/03/75	10.1	61.9	5000
				4/03/75	9.9	62.1	5117
				7/07/75	10.6	61.4	
10N/35W-06A03 S	40		72.0	11/12/74	26.9	45.1	5117
				3/03/75	25.1	46.9	5000
				4/30/75	29.5	42.5	5117
				7/07/75	32.9	39.1	
10N/35W-07F01 S	42		48.0	10/15/74	14.6	33.4	5000
				1/20/75	7.8	40.2	
				2/26/75	5.9	42.1	
				4/01/75	8.6	39.4	
				7/01/75	10.5	37.5	
10N/35W-09F01 S	42		88.0	4/02/75	NM-1		5000
10N/35W-09N03 S	42		87.0	4/02/75	13.1(2)	73.9	5000
10N/35W-09N05 S	42		87.0	10/00/74	NM-0		5000
				2/25/75	34.0	53.0	
10N/35W-11F02 S	42		122.0	3/03/75	72.0	50.0	5000
10N/35W-12H01 S	42		138.0	10/01/74	99.4	38.6	5000

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA MARIA-CUYAMA HYDRO UNIT SANTA MARIA HYDRO SUBUNIT						T-12 T-12.A	
10N/35W-12H01 S (CONTINUED)	42		138.0	1/20/75	84.4	53.6	5000
				3/03/75	92.1	45.9	
				4/01/75	85.8	52.2	
				7/01/75	88.2	49.8	
10N/35W-14L01 S	42		102.0	2/27/75	45.6	56.4	5000
10N/35W-18F02 S	42		49.0	2/26/75	13.8	35.2	5000
10N/35W-21R01 S	42		94.0	10/15/74	47.2	46.8	5000
				11/27/74	54.1(4)	39.9	
				12/24/74	55.2	38.8	
				1/20/75	51.7	42.3	
				2/24/75	43.6	50.4	
				3/26/75	42.4	51.6	
				4/01/75	54.9	39.1	
				5/27/75	50.1	43.9	
				6/26/75	NM-1		
				7/01/75	58.6	35.4	
				8/28/75	NM-1		
				9/24/75	NM-1		
10N/35W-23H02 S	42		125.0	4/02/75	59.5	65.5	5000
10N/35W-24R01 S	42		145.0	10/15/74	93.6	51.4	5000
				1/20/75	91.2	53.8	
				2/12/75	85.9	59.1	
				4/01/75	93.8	51.2	
				7/01/75	96.1	48.9	
10N/35W-24Q01 S	42		162.0	2/14/75	104.1	57.9	5000
10N/36W-01H01 S	40		139.2	11/12/74	113.3(1)	25.9	5117
			139.1	3/03/75	126.5	12.6	5000
			139.2	4/30/75	113.2	26.0	5117
				7/07/75	115.4	23.8	
10N/36W-02Q01 S	42		10.0	5/01/75	FLOW		5117
				7/07/75	FLOW		
10N/36W-02Q02 S	42		10.0	5/01/75	FLOW		5117
				7/07/75	FLOW		
10N/36W-02Q04 S	42		10.0	5/01/75	FLOW		5117
				7/07/75	FLOW		
10N/36W-02Q06 S	42		10.0	5/01/75	FLOW		5117
				7/07/75	FLOW		
10N/36W-02Q07 S	42		10.0	5/01/75	6.4	3.6	5117
				7/07/75	6.8	3.2	
10N/36W-12P01 S	42		28.0	4/02/75	0.6	27.4	5000
11N/34W-05G01 S	40		425.0	12/09/74	14.5	410.5	5117
				4/29/75	13.6	411.4	
11N/34W-05Q01 S	40		375.0	12/09/74	2.5	372.5	5117
				4/29/75	0.0	375.0	
11N/34W-05Q02 S	40		375.0	12/09/74	26.7	348.3	5117
				4/29/75	22.4	352.6	
11N/34W-06G01 S	40		370.0	12/09/74	62.2	307.8	5117
				4/29/75	47.4	322.6	
11N/34W-08P01 S	40		340.0	12/09/74	19.7	320.3	5117
				4/29/75	14.7	325.3	
11N/34W-09P01 S	40		375.0	12/04/74	72.8	302.2	5117
				4/29/75	67.5	307.5	
11N/34W-21P01 S	40		300.0	11/08/74	88.9	211.1	5117
				4/03/75	95.6	204.4	5000
11N/34W-27D01 S	40		295.0	11/08/74	120.1	174.9	5117
				4/03/75	128.8	166.2	5000
11N/34W-27E01 S	40		303.5	11/30/74	175.0	128.5	5117
11N/34W-27G02 S	40		255.0	11/08/74	66.5	188.5	5117
				4/03/75	86.6(1)	168.4	5000
11N/34W-27P01 S	40		287.0	11/08/74	128.9	158.1	5117
				4/03/75	135.9	151.1	5000
11N/34W-29R01 S	40		164.0	11/12/74	92.2	71.8	5117
				4/03/75	101.4	62.6	5000
11N/34W-30Q02 S	40		145.0	11/12/74	104.7	40.3	5117
				4/03/75	96.1	48.9	5000
11N/34W-30Q01 S	40		148.0	10/01/74	95.5	52.5	5000
				1/20/75	92.9	55.1	
				4/01/75	92.1	55.9	
				7/01/75	95.8	52.2	
11N/35W-18H01 S	40		24.0	11/12/74	10.5	13.5	5117
				4/03/75	6.6	17.4	5000
11N/35W-19C01 S	40		37.0	11/12/74	16.0	21.0	5117
				4/03/75	9.7	27.3	5000
11N/35W-19C02 S	40		37.0	11/12/74	5.3	31.7	5117

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA MARIA-CUYAMA HYDRO UNIT SANTA MARIA HYDRO SUBUNIT						T-12 T-12.A	
11N/35W-19C02 S	40		37.0	4/03/75	5.6	31.4	5000
11N/35W-20E01 S	40		49.0	10/01/74	24.4	24.6	5404
			48.7	1/20/75	15.8	32.9	5000
				3/25/75	15.5	33.2	
				4/01/75	14.1	34.6	
				7/01/75	18.1	30.6	
11N/35W-21K01 S	40		80.0	11/12/74	42.9	37.1	5117
				4/03/75	34.7	45.3	5000
11N/35W-26H02 S	40		106.0	11/12/74	NM-1		5117
				4/03/75	115.1(1)	-9.1	5000
11N/35W-28F02 S	40		80.0	11/12/74	15.7	64.3	5117
				4/03/75	16.5	63.5	5000
11N/35W-28H01 S	40		77.0	10/01/74	42.0	35.0	5000
				1/20/75	38.7	38.3	
				4/01/75	39.3	37.7	
				7/01/75	40.8	36.2	
11N/35W-29D01 S	40		60.0	11/12/74	NM-1		5117
				4/03/75	37.5	22.5	5000
11N/35W-33C04 S	40		80.0	11/12/74	16.7	63.3	5117
				4/03/75	NM-6		5000
11N/35W-33G01 S	40		91.0	10/01/74	51.0	40.0	5404
			90.0	11/12/74	54.1	35.9	5117
				1/20/75	57.9	32.1	5000
				3/25/75	50.3	39.7	
				4/01/75	59.4	30.6	
				7/01/75	58.4	31.6	
11N/35W-35A01 S	40		123.0	10/01/74	78.2	44.8	5404
				1/20/75	72.3	50.7	5000
				3/25/75	68.9(2)	54.1	
				4/01/75	75.5	47.5	
				7/01/75	79.6	43.4	
11N/36W-13K02 S	40		25.0	4/01/75	20.9	4.1	5117
				7/07/75	21.2	3.8	
11N/36W-13K03 S	40		25.0	4/01/75	21.0	4.0	5117
				7/07/75	21.4	3.6	
11N/36W-13K04 S	40		25.0	4/01/75	20.8	4.2	5117
				7/07/75	21.9	3.1	
11N/36W-13K05 S	40		25.0	4/01/75	16.4	8.6	5117
				7/07/75	21.1	3.9	
11N/36W-13K06 S	40		25.0	4/01/75	16.0	9.0	5117
				7/07/75	21.4	3.6	
11N/36W-35J02 S	40		30.0	5/01/75	FLOW		5117
				7/07/75	FLOW		
11N/36W-35J03 S	40		30.0	5/01/75	1.0	29.0	5117
				7/07/75	4.2	25.8	
11N/36W-35J04 S	40		30.0	5/01/75	1.2	28.8	5117
				7/07/75	4.4	25.6	
11N/36W-35J05 S	40		30.0	5/01/75	0.8	29.2	5117
				7/07/75	4.1	25.9	
11N/36W-35J06 S	40		30.0	5/01/75	6.4	23.6	5117
				7/07/75	6.5	23.5	
12N/34W-31F01 S	40		440.0	4/23/75	64.7	375.3	5117
SISQUOC HYDRO SUBUNIT						T-12.B	
09N/32W-06D01 S	42		435.0	4/03/75	88.1	346.9	5000
09N/32W-06G02 S	42		505.0	4/03/75	NM-1		5000
09N/32W-07A01 S	42		490.0	4/03/75	129.0	361.0	5000
09N/32W-07N01 S	42		422.0	10/01/74	83.5	338.5	5000
				1/20/75	84.5	337.5	
				4/01/75	85.0	337.0	
				7/01/75	86.3	335.7	
09N/32W-07Q01 S	42		421.0	3/17/75	57.9	363.1	5000
09N/32W-08N01 S	42		420.0	4/03/75	NM-1		5000
09N/32W-16L01 S	42		468.0	4/03/75	29.7	438.3	5000
09N/32W-17G01 S	42		447.0	4/03/75	41.9	405.1	5000
09N/32W-18H01 S	42		443.0	3/17/75	48.8	394.2	5000
09N/32W-19A01 S	42		728.0	4/04/75	358.0	370.0	5000
09N/32W-20E01 S	42		638.0	4/04/75	NM-4		5000
09N/32W-22D01 S	42		495.0	4/03/75	11.1	483.9	5000
09N/32W-23K01 S	42		532.0	4/03/75	13.6	518.4	5000
SANTA MARIA-CUYAMA HYDRO UNIT SISQUOC HYDRO SUBUNIT						T-12 T-12.B	
09N/32W-32K01 S	42		725.0	4/04/75	22.3	702.7	5000
09N/32W-33H01 S	42		745.0	4/04/75	62.2	682.8	5000
09N/33W-02A01 S	42		378.7	10/01/74	83.5	295.2	5404
09N/33W-02H09 S	42		380.0	10/01/74	83.6	296.4	5000
				1/20/75	84.8	295.2	
				3/14/75	97.9	282.1	
09N/33W-12C01 S	42		395.0	4/03/75	107.1	287.9	5000
CUYAMA VALLEY HYDRO SUBUNIT						T-12.C	
07N/23W-15P02 S	56		3746.0	4/14/75	42.9	3703.1	5121
				6/17/75	NM-1		
				9/19/75	41.7	3704.3	
07N/23W-21D01 S	56		3672.0	4/14/75	13.9	3658.1	5121
				6/17/75	14.5	3657.5	
				9/30/75	15.3	3656.7	
07N/23W-23G01 S	56		3845.0	4/14/75	49.7	3795.3	5121
				6/17/75	41.8	3803.2	
				9/19/75	45.4	3799.6	
07N/24W-13C02 S	56		3418.0	4/02/75	21.9	3396.1	5000
08N/24W-06R02 S	56		2994.0	4/15/75	NM-1		5121
				6/26/75	NM-1		
08N/24W-08L01 S	56		3050.0	10/29/74	126.0	2924.0	5000
				11/25/74	126.1	2923.9	
				12/26/74	126.3	2923.7	
				1/27/75	126.3	2923.7	
				2/24/75	126.5	2923.5	
				3/26/75	125.6	2924.4	
				4/15/75	116.4	2933.6	5121
				5/27/75	126.5	2923.5	5000
				6/26/75	124.1(2)	2925.9	
				7/28/75	128.7	2921.3	
				8/26/75	130.1	2919.9	
				9/25/75	131.6	2918.4	
09N/23W-29P01 S	56		3708.0	4/15/75	54.8	3645.2	5121
				6/17/75	56.0	3644.0	
09N/23W-30G01 S	56		3611.0	4/15/75	107.2	3503.8	5121
				6/17/75	107.8	3503.2	
09N/23W-30M01 S	56		3526.0	4/15/75	120.5	3405.5	5121
				6/26/75	132.5	3393.5	
09N/24W-33M01 S	42		3049.0	4/02/75	197.4	2851.6	5000
09N/25W-13B01 S	42		2681.0	4/02/75	104.1	2576.9	5000
09N/26W-01F02 S	42		2683.0	4/02/75	NM-4		5000
09N/26W-04J01 S	42		2575.0	4/02/75	298.9	2276.1	5000
10N/25W-08P01 S	42		2293.0	4/02/75	88.1	2204.9	5000
10N/25W-24E01 S	40		2475.0	10/29/74	346.0	2129.0	5000
				11/25/74	345.9	2129.1	
				12/26/74	346.0	2129.0	
				1/27/75	347.5	2127.5	
				2/24/75	347.2	2127.8	
				3/26/75	348.6	2126.4	
				4/24/75	349.4	2125.6	
				5/27/75	350.2	2124.8	
				6/26/75	352.0	2123.0	
				7/28/75	352.2	2122.8	
				8/26/75	354.1	2120.9	
				9/25/75	354.6	2120.4	
10N/25W-30F01 S	42		2320.0	4/02/75	137.2(2)	2182.8	5000
10N/26W-04R01 S	42		2116.0	4/02/75	59.5	2056.5	5000
10N/26W-16Q01 S	42		2205.0	4/02/75	88.7	2116.3	5000
10N/26W-22A01 S	42		2219.0	4/02/75	80.1	2138.9	5000
10N/26W-27N01 S	42		2362.0	4/02/75	170.6	2191.4	5000
10N/27W-11A03 S	42		1978.0	10/29/74	72.1	1905.9	5000
				11/25/74	67.6	1910.4	
				12/26/74	60.4	1917.6	
				1/27/75	70.4(2)	1907.6	
				2/24/75	70.8(2)	1907.2	
				3/26/75	73.4(2)	1904.6	
				4/24/75	71.4(2)	1906.6	
				5/27/75	72.4(2)	1905.6	
				6/26/75	73.6(2)	1904.4	
				7/28/75	74.3(2)	1903.7	
				8/26/75	74.9(2)	1903.1	
				9/25/75	75.4(2)	1902.6	
10N/27W-11C01 S	42		1963.0	4/02/75	47.4	1915.6	5000
10N/27W-12P01 S	42		2045.0	4/02/75	DRY		5000

See page 79 for key to terms & abbreviations

TABLE C-1.

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA MARIA-CUYAMA HYDRO UNIT						T-12	
CUYAMA VALLEY HYDRO SUBUNIT						T-12.C	
10N/32W-19E01	S	42	380.0	4/03/75	8.5	371.5	5000
10N/32W-19E02	S	42	380.0	4/03/75	11.2	368.8	5000
10N/32W-19M01	S	42	380.0	4/03/75	NM-1		5000
10N/33W-36A01	S	42	372.0	4/03/75	22.5	349.5	5000

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SAN ANTONIO HYDRO UNIT						T-13	
08N/32W-30H07	S	42	563.0	4/01/75	26.6	536.4	5000
08N/33W-20D01	S	42	408.0	10/31/74	32.4	375.6	5000
				12/24/74	33.9	374.1	
				1/27/75	NM-0		
08N/33W-20D02	S	42	408.0	10/31/74	21.1	386.9	5000
				12/24/74	23.8	384.2	
				1/27/75	37.9(4)	370.1	
				2/24/75	17.0	391.0	
				3/26/75	18.0	390.0	
				4/24/75	19.8	388.2	
				5/27/75	NM-1		
				7/29/75	60.6	347.4	
				8/28/75	33.9	374.1	
				9/24/75	26.5	381.5	
08N/33W-20R01	S	42	408.0	4/01/75	27.0	381.0	5000
08N/34W-04N01	S	42	460.0	4/15/75	139.4	320.6	5000
08N/34W-07Q01	S	42	280.0	4/15/75	3.0	277.0	5000
08N/34W-16G01	S	42	291.0	4/15/75	-3.7	294.7	5000
08N/34W-16G02	S	42	305.6	4/15/75	15.7	289.9	5000
08N/34W-16J01	S	42	300.4	4/15/75	8.8	291.6	5000
08N/34W-23B01	S	42	315.0	4/01/75	22.8	292.2	5000
09N/34W-32P01	S	42	480.0	4/15/75	14.2	465.8	5000
09N/35W-18L01	S	42	80.0	4/15/75	76.5	3.5	5000

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA YNEZ HYDRO UNIT LOMPOC HYDRO SUBUNIT						T-14 T-14.A	
06N/34W-04G03 S	42		97.0	10/23/74	NM-6		5001
				11/29/74	NM-6		
			100.0	4/09/75	NM-6		5000
06N/34W-04G04 S	42		97.5	12/02/74	52.8	44.7	5001
				1/28/75	52.0	45.5	
				2/25/75	51.3	46.2	
				3/25/75	50.4	47.1	
				4/22/75	50.1	47.4	
				5/22/75	49.9	47.6	
				6/27/75	49.7	47.8	
				7/26/75	50.1	47.4	
				8/27/75	49.9	47.6	
				9/24/75	49.6	47.9	
07N/33W-17N02 S	42		360.0	4/11/75	276.0	84.0	5000
07N/33W-19D01 S	42		270.0	4/11/75	190.6	79.4	5000
07N/33W-30C01 S	42		235.2	4/11/75	169.6	65.6	5000
07N/34W-09H05 S	42		275.0	4/10/75	254.6	20.4	5000
07N/34W-09H06 S	42		275.0	4/10/75	245.7	29.3	5000
07N/34W-12F01 S	42		385.8	10/30/74	316.7	69.1	5000
				11/27/74	317.2	68.6	
				12/23/74	317.3	68.5	
				1/29/75	317.4	68.4	
				2/27/75	318.0	67.8	
				4/02/75	317.4	68.4	
				5/29/75	317.3	68.5	
				7/01/75	317.4	68.4	
				8/28/75	317.7	68.1	
07N/34W-14F03 S	42		268.0	4/11/75	NM-4		5000
07N/34W-15D01 S	42		180.0	4/10/75	NM-1		5000
07N/34W-15E01 S	42		180.0	4/10/75	125.1	54.9	5000
07N/34W-15P01 S	42		300.0	4/10/75	273.0	27.0	5000
07N/34W-19J03 S	42		60.0	4/14/75	32.0	28.0	5000
07N/34W-20K04 S	42		75.0	4/14/75	29.5	45.5	5000
07N/34W-20H02 S	42		70.0	4/14/75	40.6	29.4	5000
07N/34W-21N01 S	42		81.3	10/30/74	35.0	46.3	5000
				11/27/74	35.2	46.1	
				12/23/74	32.7	48.6	
				1/29/75	34.1	47.2	
				2/26/75	31.4	49.9	
				3/27/75	26.6	54.7	
				4/30/75	26.9	54.4	
				5/29/75	NM-1		
				7/01/75	28.9	52.4	
				8/28/75	30.6	50.7	
07N/34W-22F02 S	42		89.9	10/23/74	NM-1		5001
				11/29/74	41.5	48.4	
				12/30/74	40.8	49.1	
				1/29/75	NM-1		5000
				2/26/75	39.8	50.1	
				4/24/75	38.6	51.3	
				5/22/75	NM-1		5001
				6/27/75	39.4	50.5	
				7/26/75	39.8	50.1	
				8/27/75	40.1	49.8	
				9/24/75	40.3	49.6	
07N/34W-22J06 S	42		97.0	4/11/75	40.3	56.7	5000
07N/34W-22M06 S	42		150.0	10/23/74	39.9	110.1	5001
				11/29/74	39.6	110.4	
				12/30/74	38.5	111.5	
			100.0	1/29/75	NM-1		5000
				2/26/75	36.6	63.4	
				3/25/75	35.3	64.7	
				4/24/75	34.8	65.2	
			150.0	5/22/75	35.7(4)	114.3	5001
				6/27/75	36.4	113.6	
				7/26/75	36.5	113.5	
				8/27/75	37.3	112.7	
				9/24/75	37.5	112.5	
07N/34W-23L01 S	42		103.4	10/23/74	44.3(8)	59.1	5001
				11/29/74	43.6(8)	59.8	
				12/30/74	43.3(8)	60.1	
				1/29/75	45.1	58.3	5000
				2/26/75	42.9	60.5	
				4/24/75	44.5	58.9	
				5/22/75	NM-1		5001
				6/27/75	44.9(8)	58.5	
				7/26/75	44.7(8)	58.7	
				8/27/75	44.2(8)	59.2	
				9/24/75	44.0(8)	59.4	
07N/34W-23D02 S	42		112.8	10/23/74	52.3	59.7	5001
				11/29/74	52.1	59.9	
				12/30/74	51.3	60.7	
SANTA YNEZ HYDRO UNIT LOMPOC HYDRO SUBUNIT						T-14 T-14.A	
07N/34W-23D02 S (CONTINUED)	42		109.6	1/29/75	51.8	57.8	5000
				2/26/75	50.8	58.8	
				4/24/75	52.8	56.8	
			112.0	5/22/75	52.8	59.2	5001
				6/27/75	53.0	59.0	
				7/26/75	59.2(2)	52.8	
				8/27/75	54.5	57.5	
				9/24/75	52.5	59.5	
07N/34W-24N01 S	42		130.4	4/11/75	69.5	60.9	5000
07N/34W-25D01 S	42		127.0	10/23/74	70.7	56.3	5001
				11/29/74	68.8	58.2	
				12/30/74	67.9	59.1	
			127.3	1/29/75	67.5	59.8	5000
				2/26/75	67.4	59.9	
				4/24/75	69.5(2)	57.8	
			127.0	5/22/75	69.5	57.5	5001
				6/27/75	70.3	56.7	
				7/26/75	74.7(2)	52.3	
				8/27/75	74.9(2)	52.1	
				9/24/75	75.1(2)	51.9	
07N/34W-25F01 S	42		136.6	10/23/74	80.4	56.2	5001
				11/29/74	77.9	58.7	
				12/31/74	77.1	59.5	
				1/29/75	76.6	60.0	5000
				2/26/75	76.4	60.2	
				3/25/75	75.8	60.8	
				4/24/75	75.9	60.7	
				5/22/75	79.1(2)	57.5	5001
				6/27/75	79.6(2)	57.0	
				7/26/75	82.8(2)	53.8	
				8/27/75	80.4	56.2	
				9/24/75	80.4	56.2	
07N/34W-25P01 S	42		119.8	10/23/74	57.6	62.2	5001
				11/26/74	57.0	62.8	
				12/31/74	NM-9		
			119.2	1/28/75	56.6	62.6	5000
				2/26/75	56.0	63.2	
				4/24/75	54.3	64.9	
			119.8	5/22/75	54.3	65.5	5001
				6/28/75	55.1	64.7	
				7/26/75	55.0	64.8	
				8/27/75	55.6	64.2	
				9/24/75	56.8	63.0	
07N/34W-26C03 S	42		104.0	10/23/74	36.9	67.1	5001
				11/29/74	37.2	66.8	
				12/30/74	37.8	66.2	
			105.0	1/29/75	37.9	67.1	5000
				2/26/75	37.8	67.2	
				3/25/75	37.5	67.5	
				4/24/75	37.2	67.8	
			104.0	5/22/75	36.3	67.7	5001
				6/27/75	36.8	67.2	
				7/26/75	36.8	67.2	
				8/27/75	37.1	66.9	
				9/24/75	37.3	66.7	
07N/34W-26F06 S	42		108.6	10/23/74	45.6	63.0	5001
				11/29/74	45.1(2)	63.5	
				12/30/74	45.1	63.5	
				1/29/75	45.5	63.1	5000
				2/26/75	44.6	64.0	
				4/24/75	43.5	65.1	
				5/22/75	43.6	65.0	5001
				6/27/75	43.1	65.5	
				7/26/75	43.4	65.2	
				8/27/75	44.3(2)	64.3	
				9/24/75	44.4	64.2	
07N/34W-26H02 S	42		109.9	10/23/74	54.6(8)	55.3	5001
				11/26/74	54.7(8)	55.2	
				12/31/74	51.6(8)	58.3	
			109.8	1/29/75	52.3	57.5	5000
				2/26/75	51.7	58.1	
				4/24/75	50.2	59.6	
			109.9	5/22/75	50.8(8)	59.1	5001
				6/28/75	48.8(8)	61.1	
				7/26/75	NM-1		
				8/27/75	NM-1		
				9/24/75	52.9(8)	57.0	
07N/34W-26H03 S	42		112.9	10/23/74	55.6	57.3	5001
				11/26/74	54.7	58.2	
				12/31/74	53.8	59.1	
				1/29/75	53.6	59.3	5000
				2/26/75	53.1	59.8	
				3/26/75	52.2	60.7	
				4/11/75	51.9	61.0	
				5/22/75	53.0	59.9	5001
				6/28/75	53.1	59.8	
				7/26/75	54.6(2)	58.3	
				8/27/75	55.0	57.9	
				9/24/75	54.7	58.2	
07N/34W-26P01 S	42		91.8	10/23/74	DRY		5001
				11/26/74	NM-7		
				12/31/74	NM-7		
			91.7	1/28/75	18.3	73.4	5000
				2/26/75	15.4	76.3	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA YNEZ HYDRO UNIT LOMPOC HYDRO SUBUNIT						T-14 T-14.A	
07N/34W-26P01 S (CONTINUED)	42		91.7	4/24/75	13.1	78.6	5000
			91.8	5/22/75	13.5	78.3	5001
				6/28/75	15.6	76.2	
				7/26/75	18.2	73.6	
				8/27/75	21.1	70.7	
				9/24/75	23.2	68.6	
07N/34W-26Q04 S	42		91.0	10/23/74	36.2	54.8	5001
				11/26/74	32.6	58.4	
				12/31/74	28.8	62.2	
			98.0	1/29/75	27.1	70.9	5000
				2/26/75	26.4	71.6	
				4/24/75	20.9	77.1	
			91.0	5/22/75	NM-1		5001
				6/28/75	NM-1		
				7/26/75	31.0(4)	60.0	
				8/27/75	29.0	62.0	
				9/24/75	32.6	58.4	
07N/34W-26Q05 S	42		91.0	10/23/74	57.0(1)	34.0	5001
				11/26/74	53.7	37.3	
				12/31/74	50.0	41.0	
				1/29/75	48.5	42.5	
				2/26/75	47.8	43.2	
				3/26/75	43.3	47.7	
				4/24/75	42.7	48.3	
				5/22/75	52.1(4)	38.9	
				6/28/75	53.0	38.0	
				7/26/75	51.3	39.7	
				8/27/75	49.6	41.4	
				9/24/75	52.7	38.3	
07N/34W-27F04 S	42		96.8	10/23/74	48.2(8)	48.6	5001
				11/29/74	47.3(8)	49.5	
				12/30/74	44.5(8)	52.3	
			96.7	1/29/75	NM-1		5000
				2/26/75	44.3	52.4	
				3/25/75	38.2	58.5	
				4/10/75	39.4	57.3	
			96.8	5/22/75	NM-1		5001
				6/27/75	NM-1		
				7/26/75	43.0(8)	53.8	
				8/27/75	NM-1		
				9/24/75	44.1(8)	52.7	
07N/34W-27L01 S	42		97.0	10/19/74	53.4(5)	43.6	5001
				11/26/74	54.4(5)	42.6	
				12/30/74	51.4(5)	45.6	
			98.5	1/28/75	49.4	49.1	5000
				2/19/75	46.4	52.1	
				3/25/75	44.4	54.1	
				4/19/75	44.4	54.1	
			97.0	5/22/75	44.4(5)	52.6	5001
				6/17/75	46.4(5)	50.6	
				7/20/75	48.4(5)	48.6	
				8/17/75	49.4(5)	47.6	
				9/17/75	50.4(5)	46.6	
07N/34W-27P05 S	42		92.0	10/21/74	47.2(5)	44.8	5001
				11/28/74	47.2(5)	44.8	
				12/30/74	45.2(5)	46.8	
				1/28/75	44.2	47.8	5000
				2/17/75	41.2	50.8	
				3/25/75	36.2	55.8	
				4/23/75	40.2	51.8	
				5/22/75	38.2(5)	53.8	5001
				6/27/75	47.2(5)	44.8	
				7/22/75	44.2(5)	47.8	
				8/26/75	47.2(5)	44.8	
				9/23/75	48.2(5)	43.8	
07N/34W-29E04 S	42		67.7	4/10/75	27.1	40.6	5000
07N/34W-29E06 S	42		65.0	4/10/75	30.3	34.7	5000
07N/34W-29H01 S	42		78.0	4/10/75	NM-6		5000
07N/34W-29R01 S	42		77.0	4/10/75	33.6	43.4	5000
07N/34W-30L03 S	42		58.7	4/10/75	19.5	39.2	5000
07N/34W-30L08 S	42		59.0	4/10/75	18.7(2)	40.3	5000
07N/34W-31C02 S	42		64.7	4/09/75	28.9	35.8	5000
07N/34W-31C03 S	42		64.6	4/09/75	18.8	45.8	5000
07N/34W-31C04 S	42		64.6	4/09/75	NM-4		5000
07N/34W-31P03 S	42		70.0	4/09/75	DRY		5000
07N/34W-34A05 S	42		111.0	10/22/74	53.5(5)	57.5	5001
				11/29/74	53.5(5)	57.5	
				12/21/74	50.5(5)	60.5	
				1/28/75	46.5	64.5	5000
				2/15/75	43.5	67.5	
				3/11/75	41.5	69.5	
				4/23/75	39.5	71.5	
				5/22/75	39.5(5)	71.5	5001
				6/27/75	40.5(5)	70.5	
				7/18/75	42.5(5)	68.5	
				8/17/75	44.5(5)	66.5	
				9/23/75	46.5(5)	64.5	

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA YNEZ HYDRO UNIT LOMPOC HYDRO SUBUNIT						T-14 T-14.A	
07N/34W-34R01 S	42		102.0	10/22/74	57.7(5)	44.3	5001
				11/28/74	56.7(5)	45.3	
				12/29/74	53.7(5)	48.3	
				1/28/75	51.7	50.3	5000
				2/19/75	50.7	51.3	
				3/15/75	50.7	51.3	
				4/23/75	40.7	61.3	
				5/22/75	45.7(5)	56.3	5001
				6/26/75	47.7(5)	54.3	
				7/25/75	48.7(5)	53.3	
				8/26/75	51.7(5)	50.3	
				9/23/75	51.7(5)	50.3	
07N/34W-34F06 S	42		101.0	10/22/74	57.0(5)	44.0	5001
				11/29/74	57.0(5)	44.0	
				12/30/74	56.0(5)	45.0	
				1/28/75	55.0	46.0	5000
				2/19/75	55.0	46.0	
				3/25/75	NM-9		5001
				4/24/75	NM-9		
				5/22/75	53.0(5)	48.0	
				6/26/75	53.0(5)	48.0	
				7/25/75	53.0(5)	48.0	
				8/26/75	53.0(5)	48.0	
				9/23/75	53.0(5)	48.0	
07N/34W-34Q01 S	42		107.0	10/23/74	49.5	57.5	5001
				11/29/74	49.7	57.3	
				12/30/74	49.8	57.2	
			106.6	1/28/75	50.0	56.6	5000
				2/25/75	49.8	56.8	
				3/25/75	49.2	57.4	
				4/22/75	49.1	57.5	
			107.0	5/22/75	48.5	58.5	5001
				6/27/75	48.2	58.8	
				7/26/75	48.2	58.8	
				8/27/75	48.0	59.0	
				9/24/75	48.0	59.0	
07N/34W-35F16 S	42		119.5	10/30/74	52.1(2)	67.4	5000
				11/27/74	54.0(2)	65.5	
				12/23/74	46.3	73.2	
				1/29/75	NM-1		
				2/26/75	NM-1		
				4/02/75	38.5	81.0	
				5/29/75	NM-1		
				7/01/75	39.8	79.7	
				8/27/75	45.1	74.4	
				9/30/75	47.6	71.9	
07N/34W-35K09 S	42		101.0	10/23/74	31.5	69.5	5001
				11/26/74	31.8	69.2	
				12/30/74	20.1	80.9	
				1/28/75	20.2	80.8	5000
				2/25/75	19.6	81.4	
				3/25/75	18.8	82.2	
				4/11/75	18.7	82.3	
				5/22/75	NM-9		5001
				6/27/75	NM-7		
				7/26/75	NM-7		
				8/27/75	25.6	75.4	
				9/24/75	NM-7		
07N/35W-17K01 S	42		10.0	4/14/75	3.8	6.2	5000
07N/35W-17M01 S	42		9.7	10/30/74	2.2	7.5	5000
				11/27/74	3.0	6.7	
				12/23/74	3.3	6.4	
				1/29/75	2.6	7.1	
				2/26/75	4.2	5.5	
				3/27/75	3.9	5.8	
				4/30/75	4.5	5.2	
				5/29/75	4.6	5.1	
				7/01/75	4.3	5.4	
				8/27/75	3.7	6.0	
				9/30/75	3.7	6.0	
07N/35W-18H01 S	42		5.8	4/09/75	2.3	3.5	5000
07N/35W-18J02 S	42		7.2	4/09/75	4.5	2.7	5000
07N/35W-21L04 S	42		20.0	4/14/75	9.5	10.5	5000
07N/35W-22J01 S	42		31.7	4/09/75	12.9	18.8	5000
07N/35W-22L01 S	42		30.0	4/14/75	NM-4		5000
07N/35W-22H01 S	42		28.8	4/14/75	7.5	21.3	5000
07N/35W-22N02 S	42		24.0	4/14/75	5.0	19.0	5000
07N/35W-23E02 S	42		36.1	4/09/75	15.1	21.0	5000
07N/35W-23F04 S	42		36.9	4/09/75	NM-4		5000
07N/35W-23J05 S	42		43.0	4/09/75	20.7	22.3	5000
07N/35W-24H01 S	42		48.0	4/14/75	15.1	32.9	5000
07N/35W-24J04 S	42		52.0	4/10/75	25.5	26.5	5000
07N/35W-25F06 S	42		47.7	4/09/75	9.8	37.9	5000

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA YNEZ HYDRO UNIT LOMPOC HYDRO SUBUNIT						T-14 T-14.A	
07N/35W-25F07 S	42		46.9	4/09/75	9.2	37.7	5000
07N/35W-26F04 S	42		35.0	4/09/75	22.9(4)	12.1	5000
07N/35W-26J04 S	42		40.8	10/25/74	17.5	23.3	5000
				11/22/74	13.7	27.1	
				12/23/74	10.9	29.9	
				1/27/75	11.2	29.6	
				2/25/75	9.8	31.0	
				3/27/75	9.7	31.1	
				4/25/75	17.3	23.5	
				5/27/75	18.3	22.5	
				6/25/75	25.5	15.3	
				7/25/75	22.3	18.5	
				8/25/75	15.0	25.8	
				9/25/75	20.2	20.6	
07N/35W-27F01 S	42		27.6	4/14/75	7.9	19.7	5000
07N/35W-27H01 S	42		27.0	4/14/75	5.0	22.0	5000
07N/35W-27P01 S	42		260.0	4/14/75	225.2	34.8	5000
07N/35W-28R01 S	42		120.0	11/27/74	NM-0		5000
07N/35W-30G01 S	42		130.0	4/14/75	97.4	32.6	5000
07N/35W-33J01 S	42		177.0	4/14/75	129.6	47.4	5000
07N/35W-33J02 S	42		177.0	4/14/75	134.1	42.9	5000
07N/35W-33J03 S	42		220.0	4/14/75	137.7(2)	82.3	5000
07N/35W-33R01 S	42		216.0	10/30/74	113.3	102.7	5000
				11/27/74	113.1	102.9	
				12/20/74	112.5	103.5	
				1/27/75	112.8	103.2	
				2/26/75	112.6	103.4	
				3/27/75	112.1	103.9	
				4/30/75	112.0	104.0	
				5/29/75	112.4	103.6	
				7/01/75	112.5	103.5	
				8/27/75	112.7	103.3	
				9/30/75	112.8	103.2	
07N/35W-35A03 S	42		45.7	4/09/75	10.5	35.2	5000
07N/35W-35D02 S	42		70.0	4/14/75	11.2	58.8	5000
07N/35W-36J03 S	42		58.7	10/30/74	24.0	34.7	5000
				11/27/74	23.9	34.8	
				12/23/74	23.4	35.3	
				1/29/75	22.7	36.0	
				2/26/75	21.8	36.9	
				3/27/75	21.2	37.5	
				4/30/75	24.2	34.5	
				5/29/75	24.7	34.0	
				7/01/75	24.9	33.8	
				8/27/75	25.2	33.5	
				9/30/75	23.5	35.2	
SANTA RITA HYDRO SUBUNIT						T-14.B	
06N/32W-06K01 S	42		383.5	4/08/75	27.5	356.0	5000
06N/32W-08N03 S	42		246.1	10/22/74	16.4	229.7	5001
				11/26/74	16.2	229.9	
				12/27/74	14.2	231.9	
				1/28/75	14.1	232.0	5000
				2/25/75	13.6	232.5	
				3/25/75	12.4	233.7	
				4/21/75	13.0	233.1	
				5/21/75	13.9	232.2	5001
				6/24/75	14.4	231.7	
				7/25/75	15.2	230.9	
				8/26/75	16.1	230.0	
				9/23/75	16.3	229.8	
06N/32W-16G02 S	42		273.6	10/21/74	22.4	251.2	5001
				11/25/74	22.2	251.4	
				12/27/74	16.3	257.3	
				1/27/75	16.0	257.6	5000
				2/24/75	16.0	257.6	
				3/24/75	15.2	258.4	
				4/21/75	15.7	257.9	
				5/21/75	16.4	257.2	5001
				6/23/75	16.9	256.7	
				7/24/75	19.7	253.9	
				8/25/75	23.2(2)	250.4	
				9/22/75	22.6	251.0	
06N/32W-16K01 S	42		260.2	10/21/74	12.2	248.0	5001
				11/25/74	12.0	248.2	
				12/27/74	8.3	251.9	
				1/27/75	7.9	252.3	5000
				2/24/75	7.4	252.8	
				3/24/75	6.6	253.6	
				4/21/75	7.2	253.0	
				5/21/75	7.9	252.3	5001
				6/23/75	8.4	251.8	
				7/24/75	9.6	250.6	
				8/25/75	11.6	248.6	
SANTA YNEZ HYDRO UNIT SANTA RITA HYDRO SUBUNIT						T-14 T-14.B	
06N/32W-16K01 S	42		260.2	9/22/75	12.3	247.9	5001
06N/32W-16P03 S	42		293.1	4/08/75	42.0	251.1	5000
06N/32W-17E02 S	42		245.0	10/22/74	16.2	228.8	5001
				11/26/74	16.2	228.8	
				12/30/74	12.8	232.2	
			250.0	1/28/75	13.2	236.8	5000
				2/25/75	13.0	237.0	
				3/25/75	12.7	237.3	
				4/22/75	13.1	236.9	
			245.0	5/21/75	13.6	231.4	5001
				6/24/75	13.9	231.1	
				7/25/75	14.8	230.2	
				8/26/75	NM-1		
				9/23/75	13.7(7)	231.3	
06N/32W-17J02 S	42		256.0	10/22/74	9.8(8)	246.2	5001
				11/26/74	9.6(8)	246.4	
				12/27/74	8.3	247.7	
				1/28/75	8.1	247.9	5000
				2/25/75	7.6	248.4	
				3/25/75	6.8	249.2	
				4/22/75	7.2	248.8	
				5/21/75	8.6(8)	247.4	5001
				6/24/75	8.4	247.6	
				7/25/75	9.0	247.0	
				8/26/75	9.4	246.6	
				9/23/75	9.3	246.7	
06N/32W-17L01 S	42		249.4	10/22/74	13.0	236.4	5001
				11/26/74	12.6	236.8	
				12/27/74	11.8	237.6	
			249.3	1/28/75	11.5	237.8	5000
				2/25/75	10.8	238.5	
				3/25/75	9.6	239.7	
				4/22/75	10.1	239.2	
			249.4	5/21/75	10.7	238.7	5001
				6/24/75	11.2	238.2	
				7/25/75	12.1	237.3	
				8/26/75	12.8	236.6	
				9/23/75	13.0	236.4	
06N/32W-18C02 S	42		237.7	10/22/74	11.7	226.0	5001
				11/26/74	11.7	226.0	
				12/30/74	11.1	226.6	
				1/28/75	11.1	226.6	5000
				2/25/75	10.0	227.7	
				3/25/75	8.3	229.4	
				4/22/75	NM-1		
				5/21/75	NM-1		5001
				6/24/75	NM-1		
				7/25/75	NM-1		
				8/27/75	10.0(4)	227.7	
				9/23/75	11.0	226.7	
06N/32W-18H01 S	42		267.0	4/08/75	32.1(4)	234.9	5000
06N/33W-06D03 S	42		150.0	10/22/74	3.6	146.4	5001
				11/26/74	3.4	146.6	
				12/27/74	1.3	148.7	
				1/28/75	1.2	148.8	5000
				2/25/75	0.9	149.1	
				3/25/75	1.4	148.6	
				4/22/75	1.3	148.7	
				5/21/75	2.1	147.9	5001
				6/24/75	2.6	147.4	
				7/25/75	NM-1		
				8/26/75	3.7	146.3	
				9/23/75	3.4	146.6	
06N/33W-06K01 S	42		186.0	10/22/74	47.4	138.6	5001
				11/26/74	47.2	138.8	
				12/27/74	46.4	139.6	
			187.1	1/28/75	45.5	141.6	5000
				2/25/75	44.9	142.2	
				3/25/75	44.1	143.0	
				4/22/75	43.5	143.6	
			186.0	5/21/75	NM-9		5001
				6/24/75	NM-7		
				7/25/75	NM-1		
				8/26/75	47.4	138.6	
				9/23/75	47.1	138.9	
06N/33W-07A01 S	42		180.0	10/22/74	47.7	132.3	5001
				11/26/74	47.5	132.5	
				12/27/74	46.8	133.2	
			182.0	1/28/75	45.8	136.2	5000
				2/25/75	45.4	136.6	
				3/25/75	44.3	137.7	
				4/22/75	45.3	136.7	
			180.0	5/21/75	46.0	134.0	5001
				6/24/75	46.6	133.4	
				7/25/75	47.3	132.7	
				8/26/75	48.3	131.7	
				9/23/75	48.6	131.4	
06N/33W-07E01 S	42		130.2	11/26/74	17.2	113.0	5001
				12/27/74	14.8	115.4	
				1/28/75	14.5	115.7	
				2/25/75	13.6	116.6	
				3/25/75	12.5	117.7	
				4/22/75	13.1	117.1	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT W

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA YNEZ HYDRO UNIT						T-14	
SANTA RITA HYDRO SUBUNIT						T-14.B	
06N/33W-07E01 S (CONTINUED)	42		130.2	5/21/75	14.9	115.3	5001
				6/24/75	15.5	114.7	
				7/25/75	16.2	114.0	
				8/26/75	17.0	113.2	
				9/23/75	17.1	113.1	
06N/33W-08F02 S	42		190.0	10/23/74	26.3(4)	163.7	5001
				11/29/74	25.8(4)	164.2	
				12/30/74	23.1	166.9	
			175.0	1/28/75	23.4	151.6	5000
				2/25/75	23.4(4)	151.6	
				3/25/75	22.6	152.4	
				4/22/75	23.5	151.5	
			190.0	5/21/75	NM-1		5001
				6/24/75	25.0	165.0	
				7/25/75	NM-1		
				8/26/75	28.9	161.1	
				9/23/75	27.3	162.7	
06N/33W-08G02 S	42		198.4	10/22/74	43.6	154.8	5001
				11/26/74	43.5	154.9	
				12/30/74	41.3	157.1	
			198.3	1/28/75	41.7	156.6	5000
				2/25/75	41.2	157.1	
				4/22/75	41.1	157.2	
			198.4	5/21/75	42.1	156.3	5001
				6/24/75	42.9(4)	155.5	
				7/25/75	43.1	155.3	
				8/26/75	44.0	154.4	
				9/23/75	44.1	154.3	
06N/33W-08J01 S	42		200.6	10/22/74	40.3	160.3	5001
				11/26/74	40.3(0)	160.3	
				12/30/74	36.7	163.9	
			200.5	1/28/75	36.7	163.8	5000
				2/25/75	36.2	164.3	
				3/25/75	35.2	165.3	
				4/08/75	35.5	165.0	
			200.6	5/21/75	36.6	164.0	5001
				6/24/75	37.1	163.5	
				7/25/75	38.6	162.0	
				8/26/75	39.7	160.9	
				9/23/75	40.5	160.1	
06N/33W-09P01 S	42		203.0	10/30/74	38.7	164.3	5000
				11/27/74	40.0	163.0	
				12/23/74	37.5	165.5	
				1/30/75	NM-6		
06N/33W-09Q01 S	42		217.7	10/22/74	47.6	170.1	5001
				11/26/74	47.7	170.0	
				12/30/74	47.1	170.6	
			215.6	1/28/75	46.6	169.0	5000
				2/25/75	45.7	169.9	
				3/25/75	44.9	170.7	
				4/22/75	44.1	171.5	
			217.7	5/21/75	44.6	173.1	5001
				6/24/75	45.6	172.1	
				7/25/75	46.6	171.1	
				8/26/75	47.9	169.8	
				9/23/75	48.6	169.1	
06N/33W-10H01 S	42		200.0	10/22/74	40.3	159.7	5001
				11/26/74	40.3	159.7	
				12/30/74	38.5	161.5	
			225.0	1/28/75	39.0	186.0	5000
				2/25/75	38.7	186.3	
				3/25/75	37.6	187.4	
				4/22/75	38.0	187.0	
			200.0	5/21/75	38.7	161.3	5001
				6/24/75	39.1	160.9	
				7/25/75	39.3	160.7	
				8/26/75	39.9	160.1	
				9/23/75	39.9	160.1	
06N/33W-11H01 S	42		203.8	10/22/74	12.0	191.8	5001
				11/26/74	11.7	192.1	
				12/30/74	9.8	194.0	
				1/28/75	10.0	193.8	5000
				2/25/75	9.3	194.5	
				3/25/75	7.4	196.4	
				4/08/75	6.7	197.1	
				5/21/75	10.7(8)	193.1	5001
				6/24/75	NM-7		
				7/25/75	12.6	191.2	
				8/27/75	12.1(4)	191.7	
				9/23/75	11.0	192.8	
06N/33W-12L01 S	42		223.6	10/22/74	16.7	206.9	5001
				11/26/74	15.8	207.8	
				12/27/74	13.6	210.0	
			223.5	1/28/75	13.5	210.0	5000
				2/25/75	12.9	210.6	
				3/25/75	11.3	212.2	
				4/22/75	12.3	211.2	
			223.6	5/21/75	13.9	209.7	5001
				6/24/75	13.9	209.7	
				7/25/75	14.6	209.0	
				8/26/75	15.2	208.4	
				9/23/75	15.0(1)	208.6	
06N/34W-01G02 S	42		116.7	10/22/74	9.6	107.1	5001
				11/26/74	9.3	107.4	

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA						T-14	
						T-14.0	
06N/34W-01[illegible] (CONTINU						418.8	5000
						419.0	
						420.5	
						420.1	
						[illegible].7	5001
06N/34W-01K01 S							
			122.0				
				2/[illegible]			
				3/25/75			
				4/22/75	14.[illegible]		
			122.1	5/22/75	15.8		
				6/24/75	16.5	105.[illegible]	
				7/25/75	16.8	105.3	
				8/26/75	16.7	105.4	
				9/23/75	17.0(8)	105.1	
06N/34W-01P01 S	42		150.3	4/08/75	39.6(6)	110.7	5000
06N/34W-01R01 S	42		140.3	10/22/74	26.0(8)	114.3	5001
				11/26/74	25.9(8)	114.4	
				12/27/74	23.3(8)	117.0	
			139.8	1/28/75	23.1	116.7	5000
				2/25/75	22.6	117.2	
				4/22/75	22.3	117.5	
			140.3	5/22/75	23.4(8)	116.9	5001
				6/24/75	23.9(8)	116.4	
				7/25/75	25.9(8)	114.4	
				8/26/75	25.7(8)	114.6	
				9/23/75	25.8(8)	114.5	
06N/34W-02A06 S	42		129.9	10/22/74	40.7	89.2	5001
				11/26/74	41.2	88.7	
				12/30/74	37.9	92.0	
			129.8	1/28/75	38.2	91.6	5000
				2/25/75	37.8	92.0	
				3/25/75	36.9	92.9	
				4/22/75	37.3	92.5	
			129.9	5/22/75	38.5	91.4	5001
				6/24/75	39.1(4)	90.8	
				7/25/75	38.1	91.8	
				8/26/75	38.6	91.3	
				9/23/75	38.7	91.2	
06N/34W-12C01 S	42		153.4	10/22/74	39.6	113.8	5001
				11/26/74	40.0	113.4	
				12/27/74	39.1	114.3	
				1/28/75	38.9	114.5	5000
				2/25/75	43.8	109.6	
				4/22/75	39.8	113.6	
				5/21/75	41.7	111.7	5001
				6/24/75	45.9(2)	107.5	
				7/25/75	46.8(2)	106.6	
				8/26/75	46.2(2)	107.2	
				9/23/75	45.6(2)	107.8	
07N/32W-31H01 S	42		450.0	4/09/75	65.4	384.6	5000
07N/33W-13E01 S	42		838.0	4/09/75	87.4	750.6	5000
07N/33W-21N01 S	42		360.0	4/09/75	283.0	77.0	5000
07N/33W-27G01 S	42		432.0	4/09/75	348.3	83.7	5000
07N/33W-27J01 S	42		458.2	4/09/75	NM-1		5000
07N/33W-36J01 S	42		495.0	4/09/75	147.1	347.9	5000
07N/33W-36J02 S	42		478.0	4/09/75	60.4	417.6	5000
07N/33W-36J03 S	42		490.0	4/09/75	137.4	352.6	5000
BUELLTON HYDRO SUBUNIT						T-14.C	
06N/31W-03A01 S	42		760.0	4/02/75	153.3(1)	606.7	5000
06N/31W-04A01 S	42		615.0	4/08/75	83.3	531.7	5000
06N/31W-06F01 S	42		425.0	4/09/75	NM-6		5000
06N/31W-10F01 S	42		540.0	4/08/75	65.7	474.3	5000
06N/31W-16N02 S	42		366.2	4/08/75	15.9	350.3	5000
06N/31W-17D01 S	42		340.8	10/21/74	19.3(4)	321.5	5001
				11/25/74	18.8(8)	322.0	
				12/27/74	17.0	323.8	
			340.6	1/27/75	16.3	324.3	5000
				2/24/75	15.3	325.3	
				3/24/75	14.1	326.5	
				4/21/75	14.5	326.1	
			340.8	5/20/75	15.3	325.5	5001
				6/28/75	17.8	323.0	
				7/24/75	18.0	322.8	
				8/25/75	20.3	320.5	

See page 79 for key to terms a abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA YNEZ HYDRO UNIT BUELLTON HYDRO SUBUNIT						T-14 T-14.C	
06N/31W-17D01 S	42		340.8	9/22/75	21.6(4)	319.2	5001
06N/31W-17F01 S	42		362.9	4/08/75	31.8	331.1	5000
06N/31W-17N02 S	42		347.0	10/21/74	21.2	325.8	5001
				11/25/74	19.9	327.1	
				12/27/74	18.4	328.6	
				1/27/75	18.1	328.9	
				2/24/75	17.5	329.5	
				3/24/75	16.0	331.0	
				4/21/75	16.5	330.5	
				5/20/75	17.1	329.9	
				6/23/75	NM-1		
				7/24/75	21.0(1)	326.0	
				8/25/75	19.9(1)	327.1	
				9/22/75	20.9(1)	326.1	
06N/31W-17R01 S	42		364.8	10/21/74	31.1	333.7	5001
				11/25/74	30.4	334.4	
				12/26/74	26.6	338.2	
			364.2	1/27/75	23.2	341.0	5000
				2/24/75	22.5	341.7	
				3/24/75	21.8	342.4	
				4/21/75	22.4	341.8	
			364.8	5/20/75	22.4	342.4	5001
				6/23/75	24.5	340.3	
				7/24/75	26.6	338.2	
				8/25/75	28.8	336.0	
				9/22/75	29.7	335.1	
06N/31W-18G01 S	42		334.7	10/21/74	17.2	317.5	5001
				11/25/74	17.2	317.5	
				12/27/74	14.7	320.0	
				1/27/75	NM-1		
				2/24/75	NM-1		
			334.3	3/24/75	11.9	322.4	5000
				4/21/75	NM-1		
			334.7	5/20/75	NM-1		5001
				6/23/75	NM-1		
				7/24/75	NM-1		
				8/25/75	NM-1		
				9/22/75	10.3(7)	324.4	
06N/32W-09A02 S	42		308.0	4/08/75	34.2	273.8	5000
06N/32W-09G01 S	42		305.0	10/21/74	36.2	268.8	5001
				11/25/74	34.4	270.6	
				12/27/74	33.5	271.5	
				1/27/75	33.2	271.8	5000
				2/24/75	32.6	272.4	
				3/24/75	32.0	273.0	
				4/21/75	32.6	272.4	
				5/21/75	34.7	270.3	5001
				6/23/75	34.1	270.9	
				7/24/75	35.2	269.8	
				8/26/75	36.7(4)	268.3	
				9/22/75	35.9	269.1	
06N/32W-09J02 S	42		275.5	10/21/74	13.5	262.0	5001
				11/25/74	NM-1		
				12/30/74	9.2	266.3	
				1/28/75	9.5	266.0	
				2/25/75	9.2	266.3	
				4/22/75	8.2	267.3	
				5/21/75	11.0	264.5	
				6/24/75	10.1	265.4	
				7/24/75	NM-1		
				8/25/75	11.6	263.9	
				9/23/75	11.8	263.7	
06N/32W-10J01 S	42		317.2	10/21/74	32.8	284.4	5001
				11/25/74	32.1	285.1	
				12/30/74	31.1	286.1	
				1/28/75	30.8	286.4	5000
				2/25/75	30.4	286.8	
				4/22/75	29.6	287.6	
				5/21/75	30.0	287.2	5001
				6/24/75	31.0	286.2	
				7/24/75	31.6	285.6	
				8/25/75	32.2	285.0	
				9/23/75	32.5	284.7	
06N/32W-11D01 S	42		298.0	10/21/74	10.8	287.2	5001
				11/25/74	10.1	287.9	
				12/27/74	9.3	288.7	
			298.5	1/27/75	9.0	289.5	5000
				2/24/75	8.9	289.6	
				3/24/75	7.9	290.6	
				4/21/75	9.1	289.4	
			298.0	5/20/75	8.7	289.3	5001
				6/23/75	9.1	288.9	
				7/24/75	11.1	286.9	
				8/25/75	11.8	286.2	
				9/22/75	10.4	287.6	
06N/32W-11L02 S	42		300.4	10/21/74	NM-1		5001
				11/25/74	6.9	293.5	
				12/27/74	5.9	294.5	
			300.3	1/28/75	5.5	294.8	5000
				2/25/75	4.9	295.4	
				4/22/75	NM-1		
			300.4	5/21/75	4.8	295.6	5001
				6/24/75	NM-1		
SANTA YNEZ HYDRO UNIT BUELLTON HYDRO SUBUNIT						T-14 T-14.C	
06N/32W-11L02 S (CONTINUED)	42		300.4	7/24/75	6.8	293.6	5001
				8/25/75	NM-1		
				9/23/75	7.1	293.3	
06N/32W-11L03 S	42		302.3	4/08/75	NM-6		5000
06N/32W-12J11 S	42		351.8	4/08/75	34.0	317.8	5000
06N/32W-12001 S	42		317.6	10/21/74	12.1	305.5	5001
				11/25/74	11.5	306.1	
				12/27/74	10.8	306.8	
			317.7	1/27/75	10.7	307.0	5000
				2/24/75	10.3	307.4	
				3/24/75	9.2	308.5	
				4/08/75	58.1	259.6	
			317.6	5/20/75	10.3	307.3	5001
				6/23/75	10.8	306.8	
				7/24/75	12.0	305.6	
				8/25/75	13.1	304.5	
				9/22/75	12.6	305.0	
06N/32W-13G01 S	42		317.9	10/21/74	10.5	307.4	5001
				11/25/74	10.1	307.8	
				12/27/74	9.1	308.8	
			317.8	1/28/75	8.9	308.9	5000
				2/25/75	8.4	309.4	
				3/25/75	7.7	310.1	
				4/22/75	8.1	309.7	
			317.9	5/21/75	8.7	309.2	5001
				6/24/75	9.3	308.6	
				7/24/75	10.4	307.5	
				8/25/75	10.9	307.0	
				9/23/75	10.6	307.3	
07N/31W-34H01 S	42		670.0	4/08/75	135.4	534.6	5000
07N/32W-07R01 S	42		1030.0	4/09/75	43.1	986.9	5000
SANTA YNEZ HYDRO SUBUNIT						T-14.D	
06N/30W-03A01 S	42		710.0	10/30/74	153.4	556.6	5000
				11/27/74	151.6	558.4	
				12/23/74	150.1	559.9	
06N/30W-06A01 S	42		665.2	10/30/74	138.9	526.3	5000
				11/27/74	NM-0		
06N/30W-14N01 S	42		513.5	10/21/74	5.2	508.3	5001
				11/25/74	6.8	506.7	
				12/26/74	5.0	508.5	
				1/26/75	4.8	508.7	5000
				2/24/75	3.1	510.4	
				3/24/75	0.9	512.6	
				4/21/75	1.5	512.0	
				5/20/75	2.5	511.0	5001
				6/23/75	3.6	509.9	
				7/24/75	5.0	508.5	
				8/25/75	6.5	507.0	
				9/22/75	7.6	505.9	
06N/30W-19002 S	42		458.3	10/21/74	18.0	440.3	5001
				11/25/74	16.9	441.4	
				12/26/74	14.7	443.6	
			456.3	1/27/75	13.5	442.8	5000
				2/24/75	11.3	445.0	
				3/24/75	8.9	447.4	
				4/21/75	9.6	446.7	
			458.3	5/20/75	11.8	446.5	5001
				6/23/75	12.4	445.9	
				7/24/75	14.3	444.0	
				8/25/75	15.9	442.4	
				9/22/75	NM-1		
06N/30W-20H02 S	42		476.4	10/21/74	20.2(2)	456.2	5001
				11/25/74	17.4	459.0	
				12/26/74	14.0	462.4	
				1/27/75	13.2	463.2	5000
				2/24/75	8.7	467.7	
				3/24/75	7.3	469.1	
				4/21/75	8.3(2)	468.1	
				5/20/75	9.6	466.8	5001
				6/23/75	13.4(2)	463.0	
				7/24/75	17.5(2)	458.9	
				8/25/75	21.2(2)	455.2	
				9/22/75	22.4	454.0	
06N/30W-20H05 S	42		476.0	10/21/74	16.4	459.6	5001
				11/25/74	14.5	461.5	
				12/26/74	NM-1		
			477.6	1/27/75	10.5	467.1	5000
				2/24/75	6.4	471.2	
				3/24/75	4.1	473.5	
				4/21/75	5.5	472.1	
			476.0	5/20/75	7.4	468.6	5001
				6/23/75	11.2	464.8	
				7/24/75	NM-1		
				8/25/75	18.4	457.6	
				9/22/75	20.6	455.4	
06N/30W-21B02 S	42		498.7	10/21/74	NM-1		5001
				11/25/74	13.6	485.1	
				12/26/74	10.7	488.0	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA YNEZ HYDRO UNIT SANTA YNEZ HYDRO SUBUNIT						T-14 T-14.D	
06N/30W-21B02 S (CONTINUED)	42		498.7	1/27/75	10.9	487.8	5000
				2/24/75	9.5	489.2	
				3/24/75	8.0	490.7	
				4/21/75	8.5	490.2	
				5/20/75	NM-1		5001
				6/23/75	13.8	484.9	
				7/24/75	16.1	482.6	
				8/25/75	NM-1		
				9/22/75	21.3	477.4	
06N/30W-21E01 S	42		490.7	10/21/74	25.2	465.5	5001
				11/25/74	22.8	467.9	
				12/26/74	19.0	471.7	
				1/27/75	18.4	472.3	5000
				2/24/75	15.5	475.2	
				3/24/75	13.5	477.2	
				4/21/75	14.1	476.6	
				5/20/75	15.1	475.6	5001
				6/23/75	18.5	472.2	
				7/24/75	22.2	468.5	
				8/25/75	25.7	465.0	
				9/22/75	28.6	462.1	
06N/30W-22G01 S	42		513.5	10/21/74	10.5	503.0	5001
				11/25/74	13.4	500.1	
				12/26/74	11.2	502.3	
				1/27/75	11.6	501.9	5000
				2/24/75	8.5	505.0	
				3/24/75	7.0	506.5	
				4/21/75	7.3	506.2	
				5/20/75	8.2	505.3	5001
				6/23/75	8.9	504.6	
				7/24/75	11.1	502.4	
				8/25/75	13.5	500.0	
				9/22/75	15.1	498.4	
06N/30W-24E02 S	42		539.3	10/21/74	6.3	533.0	5001
				11/25/74	7.2	532.1	
				12/26/74	5.2	534.1	
				1/26/75	6.3	533.0	
				2/24/75	3.7	535.6	
				3/24/75	1.8	537.5	
				4/21/75	2.5	536.8	
				5/20/75	8.9(2)	530.4	
				6/23/75	NM-7		
				7/24/75	DRY		
				8/25/75	DRY		
				9/22/75	DRY		
06N/30W-24E05 S	42		550.4	10/21/74	16.0	534.4	5001
				11/25/74	17.0	533.4	
				12/26/74	15.1	535.3	
				1/26/75	16.2	534.2	
				2/24/75	13.7	536.7	
				3/24/75	11.8	538.6	
				4/21/75	12.5	537.9	
				5/20/75	17.6	532.8	
				6/23/75	24.1	526.3	
				7/24/75	29.9	520.5	
				8/25/75	25.8	524.6	
				9/22/75	28.2	522.2	
06N/30W-29E01 S	42		465.0	10/21/74	24.0	441.0	5001
				11/25/74	24.3	440.7	
				12/26/74	24.5	440.5	
				1/27/75	24.5	440.5	5000
				2/24/75	21.4	443.6	
				3/24/75	14.6	450.4	
				4/21/75	14.6	450.4	
				5/20/75	15.7	449.3	5001
				6/23/75	19.0	446.0	
				7/24/75	21.5	443.5	
				8/25/75	22.4	442.6	
				9/22/75	23.0	442.0	
06N/31W-01P02 S	42		620.0	4/08/75	55.7	564.3	5000
06N/31W-01P03 S	42		640.0	4/08/75	80.4	559.6	5000
06N/31W-02K01 S	42		627.0	4/02/75	40.3	586.7	5000
06N/31W-11D04 S	42		558.5	4/02/75	41.4	517.1	5000
06N/31W-13D01 S	42		608.0	4/08/75	111.8	496.2	5000
06N/31W-15A05 S	42		502.0	4/08/75	7.7	494.3	5000
06N/31W-22F01 S	42		400.0	10/21/74	13.3	386.7	5001
				11/25/74	13.9	386.1	
				12/26/74	10.2	389.8	
			390.0	1/27/75	10.0	380.0	5000
				2/24/75	9.4	380.6	
			400.0	3/24/75	NM-9		5001
				4/21/75	NM-9		
				5/20/75	10.0	390.0	
				6/23/75	10.4	389.6	
				7/24/75	10.8	389.2	
				8/25/75	11.0	389.0	
				9/22/75	12.1	387.9	
06N/31W-24F01 S	42		429.0	10/21/74	16.9	412.1	5001
				11/25/74	13.1	415.9	
				12/26/74	10.3	418.7	
SANTA YNEZ HYDRO UNIT SANTA YNEZ HYDRO SUBUNIT						T-14 T-14.D	
06N/31W-24F01 S (CONTINUED)	42		429.0	1/27/75	10.2	418.8	5000
				2/24/75	10.0	419.0	
				3/24/75	8.5	420.5	
				4/21/75	8.9	420.1	
				5/28/75	10.3	418.7	5001
				6/23/75	11.3	417.7	
				7/24/75	13.1	415.9	
				8/25/75	14.8	414.2	
				9/22/75	14.9	414.1	
06N/31W-24K01 S	42		427.0	10/21/74	12.7	414.3	5001
				11/25/74	6.2	420.8	
				12/26/74	2.8	424.2	
				1/27/75	2.9	424.1	5000
				2/24/75	2.3	424.7	
				3/24/75	1.8	425.2	
				4/21/75	2.1	424.9	
				5/20/75	3.5	423.5	5001
				6/23/75	3.8	423.2	
				7/24/75	8.3	418.7	
				8/25/75	9.3	417.7	
				9/22/75	9.0	418.0	
07N/29W-28D01 S	42		1130.0	4/02/75	34.6	1095.4	5000
07N/29W-29R02 S	42		1050.0	4/02/75	54.8(4)	995.2	5000
07N/30W-16B01 S	42		1077.0	4/03/75	23.0	1054.0	5000
07N/30W-19H01 S	42		1120.0	4/03/75	189.7	930.3	5000
07N/30W-19P01 S	42		920.0	4/03/75	85.0	835.0	5000
07N/30W-22E01 S	42		920.0	4/02/75	7.0	913.0	5000
07N/30W-24Q01 S	42		1190.0	4/02/75	48.9	1141.1	5000
07N/30W-27H01 S	42		852.0	4/03/75	5.4	846.6	5000
07N/30W-27Q01 S	42		789.0	4/03/75	31.0	758.0	5000
07N/30W-29D01 S	42		910.0	4/03/75	NM-1		5000
07N/30W-29N02 S	42		820.3	4/03/75	273.6	546.7	5000
07N/30W-30H01 S	42		795.0	4/03/75	NM-1		5000
07N/30W-33H02 S	42		746.3	4/03/75	197.1	549.2	5000
07N/30W-35R01 S	42		760.0	4/02/75	229.3	530.7	5000
07N/31W-22A03 S	42		865.0	4/03/75	60.7	804.3	5000
07N/31W-23P01 S	42		821.8	10/30/74	44.5	777.3	5000
				11/27/74	43.1	778.7	
				12/23/74	41.8	780.0	
				1/28/75	40.3	781.5	
				2/24/75	38.2	783.6	
				3/31/75	38.9	782.9	
				4/28/75	39.7	782.1	
				5/28/75	40.9	780.9	
				6/30/75	44.0	777.8	
				7/28/75	46.1	775.7	
				8/27/75	50.9	770.9	
				9/26/75	51.9	769.9	
07N/31W-25L01 S	42		806.0	4/03/75	101.4	704.6	5000
07N/31W-26P01 S	42		743.0	4/02/75	15.1	727.9	5000
07N/31W-35K01 S	42		683.0	4/09/75	62.1	620.9	5000
07N/31W-36L02 S	42		720.6	4/08/75	78.9	641.7	5000
08N/30W-30F01 S	42		1380.0	4/03/75	25.0	1355.0	5000
08N/31W-25Q01 S	42		1220.0	4/03/75	45.8	1174.2	5000
HEADWATER HYDRO SUBUNIT						T-14.E	
07N/29W-29R01 S	42		1050.0	4/02/75	NM-1		5000

See page 79 for key to terms a abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA BARBARA HYDRO UNIT ARGUELLO HYDRO SUBUNIT						T-15 T-15.A	
04N/29W-33D03 S	56		478.4	8/06/75	8.1	470.3	5121
				9/25/75	10.4	468.0	
04N/30W-01G01 S	42		180.0	10/01/74	115.6	64.4	5000
				11/26/74	NM-1		
				1/09/75	107.4	72.6	
				2/26/75	104.7	75.3	
				3/23/75	104.3	75.7	
				4/28/75	103.2	76.8	
				5/27/75	NM-1		
				6/30/75	NM-1		
				7/28/75	NM-1		
				9/08/75	114.9	65.1	
05N/32W-34H01 S	42		100.0	10/01/74	48.3	51.7	5000
				11/26/74	49.5	50.5	
				12/31/74	50.5	49.5	
06N/35W-31N01 S	42		74.0	4/14/75	60.5	13.5	5000
06N/36W-26C01 S	42		170.0	4/14/75	78.3	91.7	5000
06N/36W-26F01 S	42		150.0	4/14/75	147.6	2.4	5000
06N/36W-26G01 S	42		330.0	4/14/75	99.6	230.4	5000
07N/35W-31J01 S	42		160.0	4/14/75	53.1	106.9	5000
07N/35W-31M02 S	42		200.0	4/14/75	6.7	193.3	5000
07N/35W-32N01 S	42		175.0	4/14/75	5.0	170.0	5000
SOUTH COAST HYDRO SUBUNIT GOLETA HYDRO SUBAREA						T-15.C T-15.C1	
04N/27W-06G09 S	42		325.0	10/03/74	205.8	119.2	5000
				11/06/74	206.6	118.4	
				12/03/74	206.5	118.5	
04N/27W-07H06 S	42		195.0	10/04/74	93.9	101.1	5000
				11/06/74	93.2	101.8	
				12/03/74	92.5	102.5	
				1/09/75	91.4	103.6	
				2/06/75	90.9	104.1	
				3/05/75	89.0	106.0	
				4/10/75	88.8	106.2	
				5/06/75	88.6	106.4	
				6/04/75	87.8	107.2	
				7/10/75	89.3	105.7	
				8/08/75	89.4	105.6	
				9/09/75	87.6	107.4	
04N/28W-02N02 S	42		177.9	10/03/74	34.9	143.0	5000
				11/06/74	37.1	140.8	
				12/03/74	38.7	139.2	
				1/09/75	38.8	139.1	
				2/06/75	38.8	139.1	
				3/04/75	36.1	141.8	
				4/10/75	33.2	144.7	
				5/07/75	32.0	145.9	
				6/04/75	31.0	146.9	
				7/10/75	30.2	147.7	
				8/08/75	30.6	147.3	
				9/09/75	31.3	146.6	
04N/28W-02P03 S	42		180.0	4/07/75	59.8	120.2	5000
04N/28W-03D02 S	42		120.0	10/04/74	21.7	98.3	5000
				11/06/74	21.6	98.4	
				1/09/75	21.2	98.8	
				3/05/75	20.4	99.6	
				4/10/75	20.1	99.9	
				5/07/75	19.9	100.1	
				6/04/75	20.1	99.9	
				7/10/75	20.4	99.6	
				8/08/75	20.4	99.6	
				9/09/75	20.5	99.5	
04N/28W-03E01 S	42		100.0	10/04/74	11.5	88.5	5000
				11/06/74	11.6	88.4	
				12/04/74	11.1	88.9	
04N/28W-03N03 S	42		118.4	10/04/74	77.7	40.7	5000
				11/06/74	77.2	41.2	
				12/04/74	76.9	41.5	
				1/09/75	77.8	40.6	
				2/06/75	78.1	40.3	
				3/04/75	78.3	40.1	
				4/10/75	78.0	40.4	
				5/07/75	78.1	40.3	
				6/04/75	78.2	40.2	
				7/10/75	78.2	40.2	
				8/08/75	78.3	40.1	
				9/09/75	78.1	40.3	
04N/28W-03P05 S	42		120.0	10/04/74	49.1	70.9	5000
				11/06/74	49.6	70.4	
				1/09/75	51.1	68.9	
				2/06/75	51.6	68.4	
				3/04/75	51.5	68.5	
				4/10/75	51.0	69.0	
SANTA BARBARA HYDRO UNIT SOUTH COAST HYDRO SUBUNIT GOLETA HYDRO SUBAREA						T-15 T-15.C T-15.C1	
04N/28W-03P05 S (CONTINUED)	42		120.0	5/07/75	51.1	68.9	
				6/04/75	51.9	68.1	
				7/10/75	52.0	68.0	
				8/08/75	52.1	67.9	
				9/09/75	53.7	66.3	
04N/28W-03Q03 S	42		120.0	10/04/74	90.9	29.1	
				11/06/74	91.1	28.9	
				12/04/74	93.1	26.9	
				1/09/75	93.7	26.3	
				2/06/75	93.8	26.2	
				3/04/75	94.2	25.8	
				4/10/75	93.4	26.6	
				5/07/75	93.7	26.3	
				6/04/75	94.0	26.0	
				7/10/75	94.1	25.9	
				8/08/75	94.0	26.0	
				9/09/75	95.5	24.5	
04N/28W-03Q09 S	42		125.0	10/04/74	86.5	38.5	5000
				11/06/74	85.4	39.6	
				12/04/74	88.1	36.9	
04N/28W-03R02 S	42		123.9	10/04/74	141.5	-17.6	5000
				11/07/74	141.5	-17.6	
				12/09/74	142.5	-18.6	
				1/10/75	144.5	-20.6	
				2/07/75	143.5	-19.6	
				3/05/75	142.5	-18.6	
				4/14/75	140.5	-16.6	
				5/07/75	143.5	-19.6	
				6/04/75	143.5	-19.6	
				7/10/75	143.5	-19.6	
				8/08/75	143.5	-19.6	
				9/10/75	144.5	-20.6	
04N/28W-03R07 S	42		128.0	10/03/74	83.0	45.0	5000
				11/06/74	83.5	44.5	
				12/03/74	83.8	44.2	
04N/28W-05R01 S	42		62.0	11/06/74	12.8	49.2	5000
				1/09/75	14.3	47.7	
				2/07/75	13.6	48.4	
				3/04/75	13.3	48.7	
				4/10/75	12.6	49.4	
				5/07/75	11.7	50.3	
				6/05/75	12.0	50.0	
				7/10/75	12.7	49.3	
				8/08/75	12.7	49.3	
				9/09/75	12.9	49.1	
04N/28W-05R04 S	42		57.1	10/04/74	10.2	46.9	5000
				11/06/74	10.5	46.6	
				1/09/75	9.9	47.2	
				2/07/75	9.2	47.9	
				3/04/75	8.6	48.5	
				4/10/75	8.1	49.0	
				5/07/75	7.2	49.9	
				6/05/75	7.5	49.6	
				7/10/75	8.5	48.6	
				8/08/75	8.6	48.5	
				9/09/75	8.8	48.3	
04N/28W-08K0A S	42		25.0	10/03/74	39.0	-14.0	5000
				11/07/74	34.0	-9.0	
				12/09/74	35.0	-10.0	
			27.0	1/10/75	36.0	-9.0	
				2/06/75	35.0	-8.0	
				3/05/75	35.0	-8.0	
				4/10/75	34.0	-7.0	
				5/07/75	33.0	-6.0	
				6/04/75	33.0	-6.0	
				7/11/75	34.0	-7.0	
				8/08/75	34.0	-7.0	
				9/10/75	36.0	-9.0	
04N/28W-08N03 S	42		28.0	10/03/74	16.3	11.7	5000
				11/07/74	17.5	10.5	
				12/04/74	18.0	10.0	
			23.0	1/10/74	17.9	5.1	
				2/06/75	17.9	5.1	
				3/04/75	17.0	6.0	
				4/14/75	15.6	7.4	
				5/06/75	15.5	7.5	
				6/04/75	16.6	6.4	
				7/11/75	16.5	6.5	
				8/08/75	16.6	6.4	
				9/09/75	18.1	4.9	
04N/28W-08P02 S	42		20.0	10/03/74	19.4	0.6	5000
				11/07/74	19.7	0.3	
				12/04/74	18.7	1.3	
				1/09/75	18.7	1.3	
				2/06/75	19.0	1.0	
				3/04/75	18.4	1.6	
				4/14/75	17.7	2.3	
				5/06/75	17.0	3.0	
				6/05/75	17.3	2.7	
				7/11/75	17.5	2.5	
				8/08/75	17.6	2.4	
				9/10/75	17.4	2.6	
04N/28W-08P03 S	42		25.0	10/03/74	46.3	-21.3	5000

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

SANTA BARBARA HYDRO UNIT
SOUTH COAST HYDRO SUBUNIT
GOLETA HYDRO SUBAREA

T-15
T-15.C
T-15.C1

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
04N/28W-08R03 S (CONTINUED)	42		25.0	11/07/74	47.6	-22.6	5000
				12/04/74	46.7	-21.7	
			26.0	1/10/75	50.2	-24.2	
				2/07/75	51.1	-25.1	
				3/06/75	51.8	-25.8	
				4/14/75	50.9	-24.9	
				5/06/75	48.5	-22.5	
				6/05/75	47.6	-21.6	
				7/11/75	46.4	-20.4	
				8/08/75	46.6	-20.6	
				9/10/75	45.2	-19.2	
04N/28W-09A03 S	42		85.0	10/04/74	44.1	40.9	5000
				11/06/74	45.1	39.9	
				12/04/74	45.6	39.4	
				1/09/75	45.8	39.2	
				2/06/75	45.8	39.2	
				3/04/75	45.6	39.4	
				4/10/75	45.2	39.8	
				5/07/75	44.6	40.4	
				6/04/75	44.5	40.5	
				7/11/75	45.2	39.8	
				8/08/75	44.1	40.9	
				9/09/75	43.7	41.3	
04N/28W-09G02 S	42		64.0	10/04/74	75.0	-11.0	5000
				11/06/74	74.4	-10.4	
				12/04/74	76.5	-12.5	
			60.0	1/09/75	77.6	-17.6	
				3/04/75	77.5	-17.5	
				4/10/75	76.9	-16.9	
				5/06/75	76.7	-16.7	
				6/04/75	76.8	-16.8	
				7/10/75	77.4	-17.4	
				8/08/75	77.5	-17.5	
				9/09/75	73.2	-13.2	
04N/28W-09G03 S	42		60.1	10/04/74	60.4	-0.3	5000
				11/04/74	60.5	-0.4	
				1/16/75	62.6	-2.5	
				2/10/75	63.1	-3.0	
				3/05/75	63.0	-2.9	
				5/14/75	62.8	-2.7	
				6/05/75	63.4	-3.3	
				7/25/75	64.3	-4.2	
				9/10/75	59.5	0.6	
04N/28W-09H03 S	42		75.0	10/04/74	98.7	-23.7	5000
				11/07/74	103.7	-28.7	
				12/09/74	106.7	-31.7	
				1/10/75	108.7	-33.7	
				2/07/75	109.7	-34.7	
				3/05/75	108.7	-33.7	
				4/14/75	106.7	-31.7	
				5/07/75	105.7	-30.7	
				6/05/75	105.7	-30.7	
				7/10/75	106.7	-31.7	
				8/07/75	106.7	-31.7	
				9/10/75	105.7	-30.7	
04N/28W-09K02 S	42		50.0	10/09/74	71.5	-21.5	5000
				11/07/74	71.5	-21.5	
				12/09/74	72.5	-22.5	
				1/10/75	73.5	-23.5	
				2/07/75	73.5	-23.5	
				3/05/75	72.5	-22.5	
				4/14/75	69.5	-19.5	
				5/07/75	68.5	-18.5	
				6/04/75	69.5	-19.5	
				7/11/75	69.5	-19.5	
				8/08/75	69.5	-19.5	
				9/09/75	70.5	-20.5	
04N/28W-09Q06 S	42		42.0	10/03/74	81.2	-39.2	5000
				11/07/74	81.5	-39.5	
				12/04/74	82.8	-40.8	
				1/10/75	84.1	-42.1	
				2/07/75	85.1	-43.1	
				3/06/75	85.4	-43.4	
				4/14/75	84.8	-42.8	
				5/06/75	80.0	-38.0	
				6/05/75	79.3	-37.3	
				7/11/75	78.3	-36.3	
				8/08/75	78.5	-36.5	
				9/10/75	77.6	-35.6	
04N/28W-10F03 S	42		90.6	10/04/74	130.1	-39.5	5000
				11/08/74	130.1	-39.5	
				2/21/75	132.7	-42.1	
				3/17/75	135.4	-44.8	
				4/16/75	129.8	-39.2	
				5/09/75	128.7	-38.1	
				6/10/75	125.6	-35.0	
				7/09/75	123.0	-32.4	
				8/09/75	120.9	-30.3	
				9/04/75	119.4	-28.8	
04N/28W-10Q02 S	42		70.0	10/03/74	124.5	-54.5	5000
				11/08/74	122.9	-52.9	
				12/04/74	122.0	-52.0	
04N/28W-11F01 S	42		133.4	10/03/74	159.9	-26.5	5000

SANTA BARBARA HYDRO UNIT
SOUTH COAST HYDRO SUBUNIT
GOLETA HYDRO SUBAREA

T-15
T-15.C
T-15.C1

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
04N/28W-11F01 S (CONTINUED)	42		133.4	11/06/74	161.5	-28.1	5000
				12/03/74	161.7	-28.3	
			123.0	1/09/75	160.9	-37.9	
				3/04/75	160.4	-37.4	
				4/10/75	159.5	-36.5	
				5/07/75	159.2	-36.2	
				6/04/75	159.4	-36.4	
				7/10/75	159.8	-36.8	
				8/08/75	160.1	-37.1	
				9/09/75	160.0	-37.0	
04N/28W-11L01 S	42		75.2	10/04/74	85.8	-10.6	5000
				11/06/74	85.7	-10.5	
				12/03/74	85.7	-10.5	
				1/09/75	86.1	-10.9	
				2/06/75	86.3	-11.1	
				3/05/75	86.1	-10.9	
				5/07/75	86.3	-11.1	
				6/04/75	85.7	-10.5	
				7/10/75	86.0	-10.8	
				8/08/75	86.2	-11.0	
				9/09/75	86.0	-10.8	
04N/28W-11P03 S	42		39.9	10/04/74	45.3	-5.4	5000
				1/16/75	61.6	-21.7	
				2/10/75	54.6	-14.7	
				3/05/75	54.0	-14.1	
				4/15/75	47.8	-7.9	
				5/06/75	52.8	-12.9	
				6/09/75	46.8	-6.9	
				7/14/75	44.8	-4.9	
				8/04/75	43.8	-3.9	
				9/08/75	42.8	-2.9	
04N/28W-12B01 S	42		203.0	10/03/74	93.0	110.0	5000
				11/06/74	90.7	112.3	
				12/03/74	90.1	112.9	
				1/09/75	91.1	111.9	
				2/06/75	90.4	112.6	
				3/05/75	86.8	116.2	
				4/10/75	88.1	114.9	
				5/07/75	87.8	115.2	
				6/04/75	87.5	115.5	
				7/10/75	87.5	115.5	
				8/04/75	87.6	115.4	
				9/09/75	87.0	116.0	
04N/28W-12L05 S	42		140.0	10/03/74	48.8	91.2	5000
				11/06/74	48.2	91.8	
				12/03/74	48.0	92.0	
04N/28W-12P03 S	42		80.0	10/04/74	188.5(2)	-108.5	5000
				11/11/74	186.5(2)	-106.5	
				12/04/74	194.5(2)	-114.5	
				1/13/75	183.5(2)	-103.5	
				2/07/75	186.5(2)	-106.5	
				3/05/75	194.5	-114.5	
				4/10/75	93.5	-13.5	
				5/06/75	185.5	-105.5	
				6/09/75	180.5	-100.5	
				7/14/75	188.5	-108.5	
				8/04/75	197.5	-117.5	
				9/08/75	197.5	-117.5	
04N/28W-12P05 S	42		100.0	10/03/74	161.2	-61.2	5000
				11/06/74	159.4	-59.4	
				12/03/74	159.5	-59.5	
			105.0	1/09/75	157.3	-52.3	
				2/06/75	156.8	-51.8	
				3/05/75	156.3	-51.3	
				4/10/75	155.2	-50.2	
				5/07/75	155.0	-50.0	
				6/04/75	155.3	-50.3	
				7/10/75	155.1	-50.1	
				8/08/75	155.2	-50.2	
				9/09/75	158.6	-53.6	
04N/28W-14C01 S	42		40.0	10/04/74	184.1	-144.1	5000
				11/11/74	173.1	-133.1	
				12/04/74	166.1	-126.1	
				1/13/75	154.1	-114.1	
				2/07/75	149.1	-109.1	
				3/21/75	77.1	-37.1	
				4/15/75	78.1	-38.1	
				5/06/75	77.1	-37.1	
				6/09/75	194.1	-154.1	
				7/14/75	190.1	-150.1	
				8/04/75	77.6	-37.6	
				9/08/75	74.1	-34.1	
04N/28W-14F01 S	42		40.0	10/03/74	FLOW		5000
				11/06/74	FLOW		
				12/04/74	FLOW		
04N/28W-15B01 S	42		50.0	10/03/74	101.3	-51.3	5000
				11/08/74	101.6	-51.6	
				12/04/74	101.8	-51.8	
				1/10/75	100.6	-50.6	
				2/07/75	99.8	-49.8	
				3/07/75	99.5	-49.5	
				4/14/75	98.2	-48.2	
				5/06/75	97.1	-47.1	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA BARBARA HYDRO UNIT SOUTH COAST HYDRO SUBUNIT GOLETA HYDRO SUBAREA						T-15 T-15.C T-15.C1	
04N/28W-15R01 S (CONTINUED)	42		50.0	6/05/75	97.7	-47.7	5000
				7/11/75	97.4	-47.4	
				8/08/75	97.4	-47.4	
				9/10/75	98.3	-48.3	
04N/28W-15F04 S	42		32.8	10/03/74	97.7	-64.9	5000
				11/05/74	93.4	-60.6	
				1/16/75	88.1	-55.3	
				2/10/75	87.7	-54.9	
				3/21/75	87.0	-54.2	
				5/14/75	87.4	-54.6	
				6/05/75	88.2	-55.4	
				7/25/75	88.9	-56.1	
				9/10/75	89.1	-56.3	
04N/28W-15H04 S	42		42.1	10/03/74	179.4(1)	-137.3	5000
				11/07/74	100.4	-58.3	
				12/09/74	118.4	-76.3	
				1/10/75	93.4	-51.3	
				2/07/75	93.4	-51.3	
				3/07/75	91.4	-49.3	
				4/14/75	87.4	-45.3	
				5/07/75	83.4	-41.3	
				6/05/75	89.4	-47.3	
				7/11/75	88.4	-46.3	
				9/10/75	88.2	-46.1	
04N/28W-16C01 S	42		30.0	10/03/74	48.2	-18.2	5000
				11/07/74	48.7	-18.7	
				12/04/74	46.1	-16.1	
				1/10/75	48.5	-18.5	
				2/07/75	48.6	-18.6	
				3/07/75	48.6	-18.6	
				4/14/75	48.4	-18.4	
				5/06/75	46.8	-16.8	
				6/05/75	47.6	-17.6	
				7/11/75	47.0	-17.0	
				8/08/75	47.0	-17.0	
				9/10/75	46.4	-16.4	
04N/28W-16H02 S	42		20.0	10/03/74	64.8	-44.8	5000
				11/08/74	62.9	-42.9	
				12/04/74	63.0	-43.0	
				1/10/75	61.0	-41.0	
				2/07/75	58.7	-38.7	
				3/04/75	60.8	-40.8	
				4/10/75	56.6	-36.6	
				5/06/75	53.9	-33.9	
				6/04/75	54.0	-34.0	
				7/10/75	NM-1		
				8/08/75	NM-1		
				9/09/75	53.6	-33.6	
04N/28W-16J02 S	42		26.0	10/03/74	82.4	-56.4	5000
				11/07/74	80.0	-54.0	
				12/04/74	78.5	-52.5	
				1/10/75	76.2	-50.2	
				2/06/75	76.1	-50.1	
				3/04/75	76.5	-50.5	
				4/10/75	68.4	-42.4	
				5/06/75	65.6	-39.6	
				6/04/75	66.4	-40.4	
				7/10/75	67.8	-41.8	
				8/08/75	73.6	-47.6	
				9/10/75	66.2	-40.2	
04N/28W-16J05 S	42		25.0	4/07/75	4.9	20.1	5000
04N/28W-16L01 S	42		22.0	10/03/74	56.0	-34.0	5000
				11/07/74	53.4	-31.4	
				12/04/74	54.5	-32.5	
				1/10/75	50.7	-28.7	
				2/07/75	50.8	-28.8	
				3/07/75	50.2	-28.2	
				4/14/75	49.7	-27.7	
				5/06/75	47.6	-25.6	
				6/05/75	48.5	-26.5	
				7/11/75	48.6	-26.6	
				8/08/75	48.9	-26.9	
				9/10/75	48.1	-26.1	
04N/28W-16Q02 S	42		15.0	1/10/75	18.1	-3.1	5000
				2/07/75	17.5	-2.5	
				3/07/75	17.1	-2.1	
				5/06/75	14.8	0.2	
				6/05/75	15.1	-0.1	
				7/11/75	15.2	-0.2	
				8/08/75	15.2	-0.2	
				9/10/75	14.4	0.6	
04N/28W-18F02 S	42		9.0	10/03/74	FLOW		5000
				11/07/74	FLOW		
				1/10/75	1.0	8.0	
				2/06/75	0.8	8.2	
				4/14/75	FLOW		
				5/06/75	FLOW		
				6/05/75	FLOW		
				7/11/75	FLOW		
				8/08/75	FLOW		
				9/09/75	FLOW		
04N/29W-01F01 S	42		180.0	10/03/74	7.7	172.3	5000

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA BARBARA HYDRO UNIT SOUTH COAST HYDRO SUBUNIT GOLETA HYDRO SUBAREA						T-15 T-15.C T-15.C1	
04N/29W-01E01 S (CONTINUED)	42		180.0	11/06/74	7.6	172.4	5000
				1/10/75	6.9	173.1	
				2/06/75	5.4	174.6	
				3/04/75	5.3	174.7	
				4/10/75	4.5	175.5	
				5/06/75	5.3	174.7	
				6/04/75	6.0	174.0	
				7/10/75	6.3	173.7	
				8/07/75	6.4	173.6	
				9/09/75	6.8	173.2	
04N/29W-12D03 S	42		100.0	10/03/74	15.8	84.2	5000
				11/06/74	16.0	84.0	
				12/04/74	15.6	84.4	
				1/09/75	14.8	85.2	
				2/07/75	14.3	85.7	
				3/04/75	13.3	86.7	
				4/10/75	11.9	88.1	
				5/06/75	12.4	87.6	
				6/04/75	13.2	86.8	
				7/10/75	13.6	86.4	
				8/07/75	13.6	86.4	
				9/09/75	14.7	85.3	
04N/29W-13G03 S	42		41.0	10/03/74	17.2	23.8	5000
				11/07/74	17.6	23.4	
				12/04/74	17.3	23.7	
				1/09/75	17.2	23.8	
				2/06/75	17.2	23.8	
				3/04/75	16.8	24.2	
				4/10/75	16.7	24.3	
				5/06/75	16.5	24.5	
				6/04/75	16.4	24.6	
				7/10/75	16.5	24.5	
				8/07/75	16.6	24.4	
				9/09/75	17.2	23.8	
05N/29W-35J01 S	42		570.0	10/03/74	29.0	541.0	5000
				11/06/74	29.9	540.1	
				12/03/74	29.9	540.1	
SANTA BARBARA HYDRO SUBAREA						T-15.C2	
04N/27W-07G07 S	42		250.0	10/04/74	NM-1		5000
				11/06/74	NM-1		
				12/03/74	NM-1		
04N/27W-08E02 S	42		250.0	10/03/74	114.2	135.8	5000
				11/06/74	112.6	137.4	
				12/03/74	111.4	138.6	
04N/27W-13R01 S	42		35.0	4/07/75	29.4	5.6	5000
				7/25/75	28.4	6.6	
				9/10/75	29.0	6.0	
04N/27W-21R01 S	42		68.0	4/08/75	38.8	29.2	5000
MONTECITO HYDRO SUBAREA						T-15.C3	
04N/26W-08P01 S	42		175.0	4/07/75	FLOW		5000
				9/10/75	3.7	171.3	
04N/26W-09P01 S	42		245.0	7/25/75	21.3	223.7	5000
				9/10/75	22.8	222.2	
04N/26W-15Q02 S	42		255.0	8/19/75	16.3	238.7	5000
				9/10/75	17.9	237.1	
04N/26W-16C01 S	42		215.0	7/25/75	7.2	207.8	5000
				9/10/75	8.4	206.6	
04N/26W-16C02 S	42		225.0	7/25/75	8.9	216.1	5000
				9/10/75	10.1	214.9	
04N/26W-16F01 S	42		170.0	7/25/75	16.8	153.2	5000
				9/10/75	17.5	152.5	
04N/26W-16K01 S	42		185.0	7/25/75	4.1	180.9	5000
				9/10/75	4.2	180.8	
04N/26W-16N01 S	42		50.0	4/07/75	40.8	9.2	5000
				7/25/75	40.2	9.8	
				9/10/75	41.1	8.9	
04N/26W-16P01 S	42		100.0	7/25/75	23.1	76.9	5000
				9/10/75	24.8	75.2	
04N/26W-17N01 S	42		75.0	4/07/75	NM-4		5000
				8/01/75	NM-1		
				9/10/75	84.6	-9.6	
04N/26W-18B01 S	42		245.0	7/25/75	11.3	233.7	5000
				9/10/75	12.1	232.9	
CARPINTERIA HYDRO SUBAREA						T-15.C4	
04N/25W-19F04 S	42		106.0	4/08/75	73.3	32.7	5000
04N/25W-20L04 S	42		111.0	10/02/74	98.6	12.4	5000
				11/27/74	94.3	16.7	
				1/09/75	90.3	20.7	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA BARBARA HYDRO UNIT						T-15	
SOUTH COAST HYDRO SUBUNIT						T-15.C	
CARPINTERIA HYDRO SUBAREA						T-15.C4	
04N/25W-20L04 S (CONTINUED)	42		111.0	2/24/75	86.8	24.2	5000
				4/28/75	82.6	28.4	
				6/02/75	87.8	23.2	
				7/28/75	89.3	21.7	
				9/09/75	91.9	19.1	
04N/25W-21R01 S	42		127.0	4/08/75	45.2	81.8	5000
04N/25W-22R01 S	42		170.8	4/08/75	22.0	148.8	5000
04N/25W-25L01 S	42		227.0	4/08/75	12.5	214.5	5000
04N/25W-26A01 S	42		420.0	4/08/75	185.7	234.3	5000
04N/25W-26C02 S	42		432.0	4/08/75	184.0	248.0	5000
04N/25W-27D02 S	42		127.0	4/08/75	NM-6		5000
04N/25W-27R02 S	42		132.0	10/02/74	NM-1		5000
				12/02/74	NM-4		
				1/09/75	NM-4		
				2/24/75	69.2	62.8	
				3/24/75	67.1	64.9	
				4/28/75	NM-4		
				6/02/75	NM-4		
				7/28/75	NM-4		
				9/09/75	NM-1		
04N/25W-28J01 S	42		89.0	10/02/74	42.6	46.4	5000
				12/02/74	41.4	47.6	
				1/09/75	38.3	50.7	
				2/24/75	37.1	51.9	
				3/24/75	35.0	54.0	
				4/28/75	36.9	52.1	
				6/02/75	41.7	47.3	
				7/28/75	35.3	53.7	
				9/09/75	NM-1		
04N/25W-28M01 S	42		57.0	4/07/75	1.3	55.7	5000
04N/25W-29D01 S	42		17.0	10/02/74	10.9	6.1	5000
				11/27/74	3.4	13.6	
				1/09/75	FLOW		
				2/24/75	FLOW		
				3/25/75	FLOW		
				4/28/75	FLOW		
				6/02/75	FLOW		
				7/28/75	FLOW		
				9/09/75	0.4	16.6	
04N/25W-29L01 S	42		18.0	4/08/75	FLOW		5000
04N/25W-29R01 S	42		32.0	4/08/75	14.7	17.3	5000
04N/25W-30D01 S	42		7.4	4/08/75	FLOW		5000
04N/25W-35A03 S	42		147.0	4/08/75	19.7	127.3	5000
04N/26W-23A02 S	42		63.0	4/07/75	NM-4		5000
04N/26W-23R01 S	42		75.0	7/25/75	10.6	64.4	5000
				9/10/75	11.7	63.3	
04N/26W-23F05 S	42		40.0	7/25/75	41.5	-1.5	5000
				9/10/75	39.0	1.0	
04N/26W-23G02 S	42		40.0	7/25/75	33.8	6.2	5000
				9/10/75	32.5	7.5	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LOS ANGELES DRAINAGE PROVINCE						U	
VENTURA RIVER HYDRO UNIT						U-02	
UPPER VENTURA RIVER HYDRO SUBUNIT						U-02.B	
03N/23W-05B01 S	56		291.9	1/21/75	31.4	260.5	5121
				3/27/75	25.2	266.7	
				6/10/75	25.7	266.2	
				8/01/75	27.2	264.7	
				9/29/75	29.5	262.4	
03N/23W-06K01 S	56		298.8	1/21/75	15.0	283.8	5121
				3/27/75	14.4	284.4	
				6/10/75	14.1	284.7	
				8/01/75	17.2	281.6	
				9/29/75	18.2	280.6	
03N/23W-08B02 S	56		246.2	1/21/75	13.0	233.2	5121
				3/27/75	12.7	233.5	
				6/10/75	NM-1.		
				8/11/75	NM-1		
03N/23W-08R07 S	56		239.6	1/21/75	14.2	225.4	5121
				3/27/75	13.6	226.0	
				6/11/75	15.0	224.6	
				8/01/75	15.1	224.5	
				9/29/75	16.6	223.0	
04N/23W-02K01 S	56		869.5	1/23/75	2.0	867.5	5121
				8/06/75	1.1	868.4	
				9/30/75	1.7	867.8	
04N/23W-03M01 S	56		759.4	1/22/75	92.8	666.6	5121
				3/27/75	86.8	672.6	
				6/11/75	85.8	673.6	
				7/31/75	91.4	668.0	
				9/29/75	96.0	663.4	
04N/23W-04J01 S	56		700.0	1/22/75	41.8	658.2	5121
				3/27/75	27.0	673.0	
				6/11/75	29.5	670.5	
				8/01/75	46.5	653.5	
				9/30/75	52.8	647.2	
04N/23W-09R01 S	56		658.1	1/22/75	23.0	635.1	5121
				3/27/75	18.1	640.0	
				6/11/75	13.8	644.3	
				7/31/75	30.4	627.7	
				9/29/75	51.0	607.1	
04N/23W-11D01 S	56		780.9	1/22/75	41.4	739.5	5121
				3/27/75	38.7	742.2	
				6/16/75	38.3	742.6	
				8/01/75	39.2	741.7	
				9/29/75	43.5	737.4	
04N/23W-15A02 S	56		679.9	1/22/75	105.0	574.9	5121
				3/27/75	103.6	576.3	
				6/17/75	111.9	568.0	
				8/01/75	109.0	570.9	
				9/29/75	105.0	574.9	
04N/23W-15D01 S	56		637.0	1/22/75	117.8	519.2	5121
				3/27/75	104.8	532.2	
				6/11/75	98.5	538.5	
				7/31/75	102.7	534.3	
				9/29/75	113.0	524.0	
04N/23W-16C04 S	56		557.3	1/22/75	32.7	524.6	5121
				3/27/75	17.8	539.5	
				6/11/75	18.9(2)	538.4	
				7/31/75	26.4	530.9	
				9/29/75	38.0	519.3	
04N/23W-16P01 S	56		619.1	1/22/75	75.4	543.7	5121
				3/27/75	73.1	546.0	
				7/01/75	76.6	542.5	
04N/23W-18G01 S	56		673.1	1/22/75	28.6	644.5	5121
				3/27/75	25.7	647.4	
				6/11/75	26.3	646.8	
				7/31/75	27.5	645.6	
				9/29/75	28.6	644.5	
04N/23W-20A01 S	56		488.5	1/22/75	16.6	471.9	5121
				3/27/75	6.5	482.0	
				6/10/75	6.7	481.8	
				8/01/75	9.6	478.9	
				9/29/75	24.1	464.4	
04N/23W-20J02 S	56		456.1	1/22/75	26.5	429.6	5121
				3/27/75	25.1	431.0	
				6/11/75	NM-1		
				8/01/75	17.7	438.4	
				9/29/75	29.0	427.1	
04N/23W-20Q02 S	56		425.6	1/22/75	15.1	410.5	5121
				3/27/75	3.8	421.8	
				6/11/75	4.4	421.2	
				8/01/75	6.1	419.5	
				9/29/75	15.2	410.4	
04N/23W-22R01 S	56		498.5	1/22/75	15.5	483.0	5121
				3/27/75	14.6	483.9	
				6/12/75	14.9	483.6	
				8/01/75	15.2	483.3	
				9/30/75	15.4	483.1	
VENTURA RIVER HYDRO UNIT						U-02	
UPPER VENTURA RIVER HYDRO SUBUNIT						U-02.B	
04N/23W-28G01 S	56		402.2	1/22/75	12.3	389.9	5121
				3/27/75	11.7	390.5	
				6/16/75	9.4	392.8	
				8/01/75	12.2	390.0	
				9/30/75	14.2	388.0	
04N/23W-29F02 S	56		394.1	1/22/75	27.5	366.6	5121
				3/27/75	11.1	383.0	
				6/10/75	11.4	382.7	
				8/01/75	14.9	379.2	
				9/29/75	23.4	370.5	
04N/23W-29H04 S	56		446.7	1/22/75	75.0	371.7	5121
				3/27/75	55.1	391.6	
				6/10/75	51.2	395.5	
				8/01/75	55.0	391.7	
				9/29/75	66.5	380.2	
04N/23W-29L01 S	56		372.0	1/22/75	17.1	354.9	5121
				3/27/75	6.2	365.8	
				6/11/75	6.1	365.9	
				8/01/75	8.7	363.3	
				9/29/75	13.4	358.6	
04N/23W-33M03 S	56		331.4	1/22/75	14.0	317.4	5121
				3/27/75	13.4	318.0	
				6/10/75	15.1	316.3	
				8/01/75	15.9	315.5	
				9/29/75	16.2	315.2	
04N/24W-13J04 S	56		625.8	1/22/75	6.4	619.4	5121
				3/27/75	5.8	620.0	
				6/11/75	6.3	619.5	
				7/31/75	7.0	618.8	
				9/29/75	10.4	615.4	
04N/24W-13N01 S	56		640.4	6/11/75	-1.6	642.0	5121
				7/31/75	-1.0	641.4	
				9/29/75	-0.3	640.7	
05N/23W-33R03 S	56		816.8	1/22/75	3.0	813.8	5121
				3/27/75	2.1	814.7	
				6/17/75	NM-1		
				8/01/75	5.8	811.0	
				9/30/75	9.0	807.8	
05N/23W-33G01 S	56		806.4	1/22/75	4.4	802.0	5121
				3/27/75	4.5	801.9	
				6/17/75	4.6	801.8	
				8/11/75	NM-1		
				9/30/75	5.6	800.8	
OJAI HYDRO SUBUNIT						U-02.C	
UPPER OJAI HYDRO SUBAREA						U-02.C1	
04N/22W-09Q02 S	56		1278.8	1/22/75	20.4	1258.4	5121
				3/27/75	16.2	1262.6	
				6/10/75	17.5	1261.3	
				8/06/75	20.0	1258.8	
				9/30/75	19.7	1259.1	
04N/22W-10K02 S	56		1324.9	1/22/75	19.8	1305.1	5121
				3/27/75	16.7	1308.2	
				6/10/75	18.9	1306.0	
				8/06/75	16.5	1308.4	
				9/30/75	10.6	1314.3	
04N/22W-11P02 S	56		1418.9	1/22/75	12.2	1406.7	5121
				3/27/75	7.3	1411.6	
				6/11/75	12.2	1406.7	
				8/06/75	13.3	1405.6	
				9/30/75	12.6	1406.3	
04N/22W-17G01 S	56		1246.9	1/22/75	57.6	1189.3	5121
				3/27/75	40.9	1206.0	
				6/23/75	-37.4	1284.3	
				8/06/75	35.8	1211.1	
				9/30/75	39.0	1207.9	
OJAI HYDRO SUBAREA						U-02.C2	
04N/22W-03F02 S	56		1211.4	3/28/75	129.4	1082.0	5121
				6/11/75	132.9	1078.5	
				8/06/75	144.1	1067.3	
				9/30/75	140.9	1070.5	
04N/22W-03F02 S	56		1211.4	1/22/75	140.0	1071.4	5121
04N/22W-04Q01 S	56		1040.0	1/22/75	84.6	955.4	5121
				3/28/75	67.5	972.5	
				6/11/75	75.5	964.5	
				8/06/75	84.5	955.5	
04N/22W-05D03 S	56		895.5	1/23/75	135.5	760.0	5121
				3/28/75	99.5	796.0	
				6/11/75	118.1	777.4	
				8/06/75	123.1	772.4	
				9/30/75	140.7	754.8	
04N/22W-05H04 S	56		949.3	1/23/75	185.6	763.7	5121
				3/28/75	172.6	776.7	
				6/11/75	169.3	780.0	

See page 79 for key to terms a abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
VENTURA RIVER HYDRO UNIT OJAI HYDRO SUBUNIT OJAI HYDRO SUBAREA						U-02 U-02.C U-02.C2	
04N/22W-05H04 S (CONTINUED)	56		949.3	8/06/75	165.4	783.9	5121
				9/30/75	176.0	773.3	
04N/22W-05L08 S	56		890.7	1/23/75	126.7	764.0	5121
				3/28/75	115.0	775.7	
				6/11/75	98.8	791.9	
				8/06/75	112.7	778.0	
				9/30/75	126.2	764.5	
04N/22W-05H01 S	56		842.4	1/23/75	83.2	759.2	5121
				3/28/75	52.4	790.0	
				6/11/75	NM-1		
				8/06/75	74.9	767.5	
				9/30/75	90.5	751.9	
04N/22W-06D01 S	56		844.7	1/23/75	79.9	764.8	5121
				3/28/75	50.9	793.8	
				6/11/75	36.2	808.5	
				8/06/75	63.5	781.2	
				9/30/75	77.1	767.6	
04N/22W-06K03 S	56		801.1	1/23/75	53.6	747.5	5121
				3/28/75	20.0	781.1	
				6/11/75	48.2	752.9	
				8/06/75	67.5	733.6	
				9/30/75	75.4	725.7	
04N/22W-06M01 S	56		794.4	1/23/75	40.6	753.8	5121
				3/28/75	13.7	780.7	
				6/11/75	19.2	775.2	
				8/06/75	33.6	760.8	
				9/30/75	42.4	752.0	
04N/22W-07A01 S	56		798.5	1/22/75	48.4	750.1	5121
				3/27/75	28.0	770.5	
				6/10/75	32.4	766.1	
				8/06/75	56.9	741.6	
04N/22W-07B02 S	56		772.6	1/22/75	24.1	748.5	5121
				3/27/75	6.9	765.7	
				6/03/75	15.4	757.2	
				8/06/75	32.0	740.6	
				9/30/75	40.2	732.4	
04N/22W-07B05 S	56		786.0	1/22/75	37.5	748.5	5121
				3/27/75	24.9	761.1	
				6/10/75	21.4	764.6	
04N/22W-07C05 S	56		763.4	1/22/75	17.3	746.1	5121
				6/03/75	11.7	751.7	
				8/11/75	NM-1		
				9/30/75	49.0	714.4	
04N/22W-07G01 S	56		769.0	1/22/75	21.9	747.1	5121
				3/27/75	14.3	754.7	
				6/10/75	NM-1		
				8/06/75	16.3	752.7	
				9/30/75	22.7	746.3	
04N/22W-08B02 S	56		868.7	1/22/75	102.1	766.6	5121
				3/28/75	80.8	787.9	
				6/11/75	77.4	791.3	
				8/06/75	86.2	782.5	
				9/30/75	98.4	770.3	
04N/23W-01K02 S	56		786.4	1/23/75	15.4	771.0	5121
				3/28/75	11.0	775.4	
				6/11/75	9.4	777.0	
				8/06/75	11.2	775.2	
				9/30/75	13.5	772.9	
04N/23W-12K02 S	56		688.0	1/22/75	3.4	684.6	5121
				3/27/75	2.1	685.9	
				6/17/75	2.6(4)	685.4	
				8/01/75	1.9	686.1	
				9/30/75	2.1	685.9	
04N/23W-14M03 S	56		540.2	1/22/75	13.0	527.2	5121
				3/27/75	12.6	527.6	
				6/17/75	12.9	527.3	
				8/01/75	13.0	527.2	
				9/30/75	13.0	527.2	
05N/22W-32J01 S	56		1162.6	1/23/75	38.2	1124.4	5121
				3/28/75	35.6	1127.0	
				6/11/75	NM-1		
				8/06/75	37.2	1125.4	
				9/30/75	38.1	1124.5	

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA CLARA-CALLEGUAS HYDRO UNIT OXNARD PLAIN HYDRO SUBUNIT OXNARD HYDRO SUBAREA						U-03 U-03.A U-03.A1	
01N/21W-04H01 S	56		50.4	1/22/75	NM-1		5121
				4/02/75	99.7	-49.3	
			54.1	5/22/75	112.0	-57.9	
01N/21W-04N02 S	56		44.8	1/22/75	NM-1		5121
				4/14/75	NM-1		
				5/28/75	NM-1		
				7/31/75	NM-1		
01N/21W-05A02 S	56		56.0	1/22/75	32.6	23.4	5121
				4/14/75	26.2	29.8	
				5/22/75	31.2	24.8	
				7/24/75	33.4(4)	22.6	
01N/21W-06L02 S	56		47.0	1/22/75	NM-1		5121
				4/03/75	38.3	8.7	
				5/28/75	45.2	1.8	
				7/25/75	45.0	2.0	
01N/21W-07H01 S	56		39.6	1/22/75	38.2	1.4	5121
				4/02/75	38.7	0.9	
				5/28/75	NM-7		
01N/21W-08F01 S	56		34.0	1/20/75	90.0	-56.0	5121
				4/14/75	74.0	-40.0	
				5/28/75	NM-1		
				7/24/75	78.8	-44.8	
01N/21W-08L01 S	56		8.9	5/23/75	37.7	-28.8	5121
				7/25/75	38.5	-29.6	
01N/21W-17D02 S	56		33.0	1/22/75	37.5	-4.5	5121
				4/02/75	28.9	4.1	
				5/28/75	42.5	-9.5	
				7/24/75	39.2	-6.2	
01N/21W-17G01 S	56		24.0	1/21/75	31.0	-7.0	5121
				4/02/75	23.2	0.8	
				5/22/75	33.0	-9.0	
				7/24/75	37.9(2)	-13.9	
01N/21W-19A01 S	56		21.8	10/01/74	57.6	-35.8	5411
				11/01/74	43.7	-21.9	
				1/02/75	25.5	-3.7	
				3/03/75	25.2	-3.4	
				4/01/75	23.7	-1.9	
01N/21W-20N07 S	56		18.1	1/22/75	25.2	-7.1	5121
				4/02/75	18.7	-0.6	
				5/22/75	28.1(4)	-10.0	
				7/24/75	28.0(4)	-9.9	
01N/21W-21N01 S	56		15.2	1/22/75	61.7	-46.5	5121
				4/02/75	47.6	-32.4	
				5/22/75	59.4	-44.2	
				7/24/75	62.6	-47.4	
01N/21W-29R03 S	56		17.9	1/22/75	30.7	-12.8	5121
				4/02/75	26.8	-8.9	
				5/28/75	45.7	-27.8	
				7/24/75	46.2	-28.3	
01N/21W-30F02 S	56		16.1	1/24/75	45.6	-29.5	5121
				4/04/75	34.1	-18.0	
				5/26/75	45.0	-28.9	
				7/25/75	43.5	-27.4	
01N/21W-31L01 S	56		8.6	1/22/75	62.0	-53.4	5121
				4/11/75	43.0	-34.4	
				5/11/75	42.0	-33.4	
				7/20/75	45.0	-36.4	
01N/21W-32A01 S	56		10.0	1/24/75	53.5	-43.5	5121
				4/11/75	54.5	-44.5	
				5/11/75	51.5	-41.5	
				7/20/75	46.5	-36.5	
01N/21W-32A02 S	56		12.8	1/22/75	19.0	-6.2	5121
				4/02/75	NM-6		
				5/22/75	NM-6		
				7/24/75	NM-6		
01N/21W-32G01 S	56		10.0	1/24/75	19.8	-9.8	5121
				4/11/75	13.2	-3.2	
				5/23/75	19.4	-9.4	
				7/25/75	19.0	-9.0	
01N/21W-32K01 S	56		10.1	4/11/75	43.0	-32.9	5121
				5/11/75	42.0	-31.9	
				7/20/75	46.0	-35.9	
01N/21W-32L01 S	56		9.6	1/24/75	9.0	0.6	5121
				4/11/75	7.2	2.4	
				5/23/75	9.0	0.6	
				7/25/75	9.6	0.0	
01N/21W-32Q01 S	56		9.5	1/24/75	42.0	-32.5	5121
				4/11/75	34.0	-24.5	
				5/23/75	40.5	-31.0	
				7/25/75	38.4	-28.9	
01N/22W-01A01 S	56		53.6	1/22/75	47.9	5.7	5121

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

SANTA CLARA-CALLEGUAS HYDRO UNIT
OXNARD PLAIN HYDRO SUBUNIT
OXNARD HYDRO SUBAREA

U-03
U-03.A
U-03.A1

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
01N/22W-01A01 S (CONTINUED)	56		53.6	4/14/75	27.9	25.7	5121
				5/22/75	41.1	12.5	
				7/25/75	NM-1		
01N/22W-01P01 S	56		51.7	10/25/74	52.2	-0.5	5411
				1/02/75	39.3	12.4	
				2/28/75	42.1	9.6	
				4/04/75	38.4	13.3	
				5/02/75	44.3	7.4	
				6/06/75	42.2	9.5	
				7/03/75	52.4	-0.7	
				8/01/75	40.0	11.7	
				9/26/75	NM-2		
01N/22W-03F01 S	56		55.7	10/03/74	96.7(1)	-41.0	5411
				11/04/74	60.7	-5.0	
				12/05/74	50.6	5.1	4209
				1/02/75	94.7(1)	-39.0	5411
				2/06/75	46.6	9.1	4209
				3/06/75	43.6	12.1	
				4/03/75	37.6	18.1	
				5/01/75	42.6	13.1	
				6/05/75	40.6	15.1	
				7/03/75	39.6	16.1	
				8/07/75	41.6	14.1	
				9/04/75	47.6	8.1	
01N/22W-05G02 S	56		25.0	1/23/75	24.3	0.7	5121
01N/22W-06J01 S	56		20.8	10/01/74	6.9	13.1	5411
				12/31/74	4.0	16.0	
				3/03/75	3.4	16.6	
				4/01/75	2.3	17.7	
				6/04/75	2.3	17.7	
				7/31/75	2.4	17.6	
				8/27/75	4.1	15.9	
01N/22W-07H01 S	56		17.0	1/31/75	12.7	4.3	5121
				5/23/75	4.7	12.3	
				8/05/75	3.8	13.2	
				9/22/75	10.1	6.9	
01N/22W-07M01 S	56		18.6	1/23/75	20.4	-1.8	5121
				3/25/75	11.6	7.0	
				5/23/75	14.8	3.8	
				8/05/75	13.5	5.1	
				9/22/75	19.2	-0.6	
01N/22W-08Q01 S	56		18.1	10/01/74	NM-1		5411
				11/12/74	16.1	2.0	
				12/31/74	9.5	8.6	
				1/29/75	11.9	6.2	
				3/03/75	7.8	10.3	
				4/01/75	5.5	12.6	
				6/04/75	6.4	11.7	
				7/31/75	4.7	13.4	
				8/27/75	11.0	7.1	
01N/22W-10R03 S	56		44.0	10/10/74	50.0	-6.0	4209
				11/07/74	52.0	-8.0	
				12/05/74	49.0	-5.0	
				1/03/75	44.0	0.0	
				2/06/75	43.0	1.0	
				3/06/75	41.0	3.0	
				4/03/75	35.0	9.0	
				5/01/75	35.0	9.0	
				6/05/75	35.0	9.0	
				7/03/75	35.0	9.0	
				8/07/75	38.0	6.0	
				9/04/75	44.0	0.0	
01N/22W-11D02 S	56		51.0	10/11/74	44.3	6.7	5411
				11/01/74	45.1	5.9	
				12/27/74	45.5	5.5	
				1/03/75	45.4	5.6	
				2/07/75	45.1	5.9	
				3/07/75	43.9	7.1	
				4/04/75	42.5	8.5	
				5/02/75	41.2	9.8	
				6/06/75	40.5	10.5	
				7/03/75	39.9	11.1	
				8/01/75	39.5	11.5	
				9/05/75	40.3	10.7	
01N/22W-13D02 S	56		41.7	1/22/75	43.6	-1.9	5121
				4/03/75	37.1	4.6	
				5/22/75	43.2	-1.5	
				7/25/75	39.1	2.6	
01N/22W-13K02 S	56		37.0	1/22/75	46.1	-9.1	5121
				4/02/75	36.9	0.1	
				5/22/75	47.0	-10.0	
				7/24/75	49.1	-12.1	
01N/22W-14Q01 S	56		36.1	11/01/74	38.4	-2.3	5411
				1/02/75	28.8	7.3	
				3/03/75	27.3	8.8	
				4/01/75	24.1	12.0	
				6/04/75	28.5	7.6	
				7/31/75	28.6	7.5	
				8/27/75	38.8	-2.7	
01N/22W-14K01 S	56		32.9	1/22/75	30.9	2.0	5121

SANTA CLARA-CALLEGUAS HYDRO UNIT
OXNARD PLAIN HYDRO SUBUNIT
OXNARD HYDRO SUBAREA

U-03
U-03.A
U-03.A1

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
01N/22W-14K01 S (CONTINUED)	56		32.9	4/03/75	23.2	9.7	5121
				5/22/75	31.7	1.2	
				7/25/75	27.4	5.5	
01N/22W-14R02 S	56		32.9	10/01/74	45.2	-12.3	5411
				11/01/74	41.2	-8.3	
				12/05/74	38.4	-5.5	
				1/02/75	31.4	1.5	
				3/03/75	30.9	2.0	
				4/01/75	26.6	6.3	
				6/04/75	34.2	-1.3	
				7/31/75	31.8	1.1	
				8/27/75	45.3	-12.4	
01N/22W-15C01 S	56		31.9	1/22/75	26.1	5.8	5121
				4/03/75	17.9	14.0	
				5/22/75	20.6	11.3	
				7/25/75	19.3	12.6	
01N/22W-17H03 S	56		9.0	10/01/74	4.8	4.2	5411
				11/12/74	7.1	1.9	
				1/02/75	0.5	8.5	
				8/29/75	1.4	7.6	
01N/22W-18L02 S	56		11.3	1/23/75	-1.0	12.3	5121
				9/22/75	-0.1	11.4	
01N/22W-20E01 S	56		10.7	10/01/74	5.1	5.6	5411
01N/22W-20N02 S	56		8.4	10/11/74	5.1	3.3	5411
				11/08/74	5.2	3.2	
				12/27/74	5.2	3.2	
				1/03/75	2.3	6.1	
				2/07/75	4.4	4.0	
				5/16/75	0.2	8.2	
				8/15/75	1.4	7.0	
				9/05/75	4.2	4.2	
01N/22W-21R03 S	56		18.0	1/23/75	18.8	-0.8	5121
				3/25/75	10.9	7.1	
				5/23/75	14.0	4.0	
				8/05/75	14.4	3.6	
				9/22/75	21.7	-3.7	
01N/22W-21L02 S	56		11.4	1/23/75	6.8	4.6	5121
				3/25/75	3.1	8.3	
				5/23/75	5.6	5.8	
				8/05/75	5.2	6.2	
				9/22/75	10.8	0.6	
01N/22W-22M05 S	56		16.4	1/22/75	14.7	1.7	5121
				4/03/75	12.6	3.8	
				5/23/75	12.7	3.7	
				7/25/75	11.2	5.2	
01N/22W-23Q01 S	56		18.8	1/22/75	20.5	-1.7	5121
				4/04/75	14.3	4.5	
				5/23/75	20.8	-2.0	
				7/25/75	20.1	-1.3	
01N/22W-25C02 S	56		18.3	1/22/75	NM-1		5121
				4/14/75	NM-2		
				5/28/75	NM-2		
				7/25/75	NM-2		
01N/22W-26K01 S	56		13.9	1/22/75	18.7	-4.8	5121
				4/03/75	14.4	-0.5	
				5/23/75	18.3	-4.4	
				7/25/75	NM-7		
01N/22W-26K04 S	56		13.8	1/22/75	NM-1		5121
				4/11/75	23.0	-10.0	
				5/28/75	40.7(4)	-27.7	
				7/25/75	37.3	-24.3	
01N/22W-26M01 S	56		12.0	1/22/75	15.4	-3.4	5121
				4/03/75	13.0	-1.0	
				5/23/75	15.9	-3.9	
				7/25/75	14.0	-2.0	
01N/22W-26M03 S	56		13.0	1/22/75	37.0	-24.0	5121
				4/03/75	26.0	-13.0	
				5/23/75	30.2	-17.2	
				7/25/75	30.5	-17.5	
01N/22W-27R04 S	56		14.0	1/22/75	28.5	-14.5	5121
				4/03/75	18.7	-4.7	
				5/23/75	24.9	-10.9	
				7/25/75	23.1	-9.1	
01N/22W-36R02 S	56		10.8	1/22/75	42.7	-31.9	5121
				4/14/75	NM-1		
				5/23/75	35.4	-24.6	
				7/25/75	35.3	-24.5	
01N/22W-36L01 S	56		6.9	1/22/75	13.1	-6.2	5121
				4/04/75	7.2	-0.3	
				5/23/75	12.7	-5.8	
				7/25/75	13.1	-6.2	
01N/23W-01H01 S	56		20.0	1/23/75	9.4	10.6	5121
				3/25/75	8.9(4)	11.1	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA CLARA-CALLEGUAS HYDRO UNIT OXNARD PLAIN HYDRO SUBUNIT OXNARD HYDRO SUBAREA					U-03 U-03.A U-03.A1		
01N/23W-01H01 S (CONTINUED)	56		20.0	5/23/75	6.2	13.8	5121
				8/05/75	5.3	14.7	
				9/22/75	8.7	11.3	
02N/21W-06F01 S	56		148.4	10/11/74	28.2	120.2	5411
02N/21W-06L01 S	56		149.0	10/11/74	66.4	82.6	5411
				11/12/74	73.4	75.6	
				1/02/75	57.1	91.9	
				2/27/75	58.6	90.4	
				3/26/75	40.8	108.2	
				5/02/75	26.4	122.6	
				6/03/75	31.4	117.6	
				7/03/75	38.5	110.5	
02N/21W-06P01 S	56		150.1	10/11/74	76.7	73.4	5411
				11/12/74	80.2	69.9	
				1/02/75	62.0	88.1	
				2/27/75	64.7	85.4	
				3/26/75	44.8	105.3	
				5/02/75	27.2	122.9	
				7/03/75	43.9	106.2	
02N/21W-18A01 S	56		118.4	1/21/75	62.7	55.7	5121
				3/31/75	52.0	66.4	
				5/21/75	38.5	79.9	
				7/31/75	56.4(5)	62.0	
02N/21W-18H01 S	56		115.0	5/21/75	NM-1		5121
				7/31/75	NM-1		
02N/21W-18R01 S	56		108.2	10/01/74	NM-1		5411
02N/21W-19L01 S	56		89.7	1/21/75	50.9	38.8	5121
				3/31/75	40.7	49.0	
				5/30/75	NM-1		
				7/23/75	NM-4		
02N/21W-29L03 S	56		77.0	11/12/74	94.2	-17.2	5411
				1/02/75	90.0	-13.0	
				3/03/75	90.1	-13.1	
				4/01/75	88.5	-11.5	
				6/04/75	88.4	-11.4	
				7/31/75	NM-8		
				8/27/75	NM-1		
02N/21W-30P02 S	56		64.2	1/21/75	NM-1		5121
				4/14/75	NM-1		
				5/21/75	28.3	35.9	
				7/23/75	-19.3	83.5	
02N/21W-31P02 S	56		56.5	1/22/75	44.5	12.0	5121
				4/03/75	36.6	19.9	
				5/22/75	39.0	17.5	
				7/25/75	37.7	18.8	
02N/21W-31P03 S	56		57.3	1/22/75	NM-1		5121
				4/03/75	85.9	-28.6	
				5/28/75	74.9	-17.6	
				7/25/75	73.9	-16.6	
02N/22W-08N01 S	56		203.8	1/22/75	157.0	46.8	5121
				3/20/75	157.6	46.2	
				5/23/75	158.4	45.4	
				8/04/75	161.4	42.4	
				9/22/75	164.0	39.8	
02N/22W-08P01 S	56		214.6	1/22/75	NM-4		5121
				3/20/75	NM-4		
				5/23/75	NM-4		
				8/04/75	NM-4		
				9/22/75	NM-4		
02N/22W-09J01 S	56		238.5	1/22/75	171.2	67.3	5121
				3/20/75	165.3	73.2	
				5/23/75	164.0	74.5	
				8/04/75	164.4	74.1	
				9/22/75	164.0	74.5	
02N/22W-09K04 S	56		246.6	10/01/74	197.8	48.8	5411
				12/05/74	197.6	49.0	
				1/29/75	194.8	51.8	
				2/26/75	193.3	53.3	
				3/26/75	192.3	54.3	
				4/29/75	191.3	55.3	
				6/04/75	191.6	55.0	
				7/30/75	193.8	52.8	
				8/26/75	193.9	52.7	
02N/22W-12R01 S	56		141.0	10/11/74	69.0	72.0	5411
				11/12/74	50.3	90.7	
				1/02/75	54.3	86.7	
				2/27/75	55.8	85.2	
				3/26/75	55.2	85.8	
				5/02/75	49.5	91.5	
				7/03/75	42.0	99.0	
02N/22W-12E01 S	56		128.0	10/11/74	76.1(2)	51.9	5411
				11/12/74	80.8(2)	47.2	
				1/02/75	79.1(2)	48.9	
				3/03/75	74.7(2)	53.3	
				5/05/75	55.8(2)	72.2	
SANTA CLARA-CALLEGUAS HYDRO UNIT OXNARD PLAIN HYDRO SUBUNIT OXNARD HYDRO SUBAREA					U-03 U-03.A U-03.A1		
02N/22W-12E01 S	56		128.0	7/03/75	57.9(2)	70.1	5411
02N/22W-12N03 S	56		125.0	10/11/74	71.2	53.8	5411
				1/02/75	76.7	48.3	
				3/03/75	NM-1		
				5/05/75	NM-1		
				6/04/75	NM-1		
				7/03/75	NM-1		
02N/22W-12P01 S	56		135.1	10/11/74	69.0	66.1	5411
				11/01/74	67.6	67.5	
				12/06/74	80.8	54.3	
				1/03/75	76.4	58.7	
				2/07/75	74.4	60.7	
				3/28/75	56.7	78.4	
				5/05/75	41.8	93.3	
				6/04/75	43.9	91.2	
				7/03/75	49.8	85.3	
				8/01/75	55.2	79.9	
02N/22W-13G07 S	56		127.8	1/03/75	80.8	47.0	5411
				2/27/75	77.8	50.0	
				3/28/75	72.2	55.6	
				5/05/75	58.8	69.0	
				6/04/75	NM-1		
				7/03/75	NM-1		
				8/01/75	NM-1		
02N/22W-14P02 S	56		108.0	10/10/74	76.0	32.0	5411
				11/07/74	81.0	27.0	
				12/06/74	80.0	28.0	
				1/02/75	77.0	31.0	
				2/07/75	67.0	41.0	
				3/11/75	66.0	42.0	
				4/03/75	52.0	56.0	
02N/22W-16K01 S	56		150.0	1/22/75	119.5	30.5	5121
				3/20/75	99.3	50.7	
				6/10/75	NM-1		
				8/11/75	NM-1		
02N/22W-18N01 S	56		80.0	1/22/75	55.9	24.1	5121
				3/20/75	54.0	26.0	
				6/10/75	NM-1		
				8/04/75	44.3	35.7	
				9/22/75	44.9	35.1	
02N/22W-20H05 S	56		41.0	10/01/74	34.8	6.2	5411
				12/31/74	27.8	13.2	
				1/29/75	28.3	12.7	
				2/26/75	20.6	20.4	
				3/26/75	16.6	24.4	
				4/29/75	15.6	25.4	
				6/04/75	26.9	14.1	
				7/30/75	29.4	11.6	
				8/27/75	34.4	6.6	
02N/22W-21Q01 S	56		68.5	1/31/75	46.5	22.0	5121
				3/24/75	36.3	32.2	
				6/10/75	NM-1		
				8/11/75	NM-1		
02N/22W-22H01 S	56		109.4	1/21/75	71.3	38.1	5121
				3/31/75	54.8	54.6	
				5/21/75	53.4	56.0	
				7/31/75	66.7	42.7	
02N/22W-22M04 S	56		80.4	1/21/75	59.9	20.5	5121
				3/31/75	48.5	31.9	
				5/28/75	46.7	33.7	
				7/23/75	49.6	30.8	
02N/22W-22R01 S	56		92.2	10/04/74	67.1	25.1	5411
				11/01/74	69.7	22.5	
				12/27/74	71.2	21.0	
				1/03/75	70.6	21.6	
				2/07/75	66.0	26.2	
				3/07/75	58.5	33.7	
				4/04/75	51.7	40.5	
				5/02/75	47.6	44.6	
				6/06/75	52.0	40.2	
				7/03/75	55.7	36.5	
				8/01/75	58.2	34.0	
				9/05/75	61.6	30.6	
02N/22W-23R01 S	56		109.0	10/10/74	77.5	31.5	5411
				11/07/74	83.5	25.5	
				12/06/74	85.5	23.5	
				1/02/75	74.5	34.5	
				2/07/75	68.5	40.5	
				3/11/75	64.5	44.5	
				4/03/75	50.5	58.5	
				5/29/75	61.5	47.5	
				6/13/75	62.5	46.5	
				7/10/75	67.5	41.5	
				8/14/75	71.5	37.5	
				9/15/75	73.5	35.5	
02N/22W-23R02 S	56		108.0	10/10/74	76.0	32.0	5411
				11/07/74	89.0	19.0	
				12/06/74	84.0	24.0	
				1/02/75	76.0	32.0	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

SANTA CLARA-CALLEGUAS HYDRO UNIT — U-03
OXNARD PLAIN HYDRO SUBUNIT — U-03.A
OXNARD HYDRO SUBAREA — U-03.A1

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
02N/22W-23B02 S (CONTINUED)	56		108.0	2/07/75	68.0	40.0	5411
				3/11/75	68.0	40.0	
				4/03/75	54.0	54.0	
				5/02/75	57.0	51.0	
				6/13/75	63.0	45.0	
				9/15/75	73.0	35.0	
02N/22W-23C01 S	56		107.0	10/24/74	79.0	28.0	5411
				11/22/74	84.0	23.0	
				12/06/74	81.0	26.0	
				1/02/75	77.0	30.0	
				2/07/75	66.0	41.0	
				3/11/75	65.0	42.0	
				4/03/75	52.0	55.0	
02N/22W-23C02 S	56		107.0	1/14/75	72.0	35.0	5411
				2/07/75	70.0	37.0	
				3/11/75	67.0	40.0	
				4/11/75	56.0	51.0	
				5/02/75	59.0	48.0	
				6/13/75	66.0	41.0	
				7/10/75	70.0	37.0	
				8/14/75	73.0	34.0	
				9/15/75	75.0	32.0	
02N/22W-23C03 S	56		107.0	10/10/74	81.1	25.9	5411
				11/07/74	89.1	17.9	
				12/06/74	85.1	21.9	
				1/02/75	83.1	23.9	
				2/07/75	82.1	24.9	
				3/11/75	78.1	28.9	
				4/03/75	80.1	26.9	
				5/02/75	71.1	35.9	
				6/13/75	69.1	37.9	
				7/10/75	70.1	36.9	
				8/14/75	73.1	33.9	
				9/15/75	74.1	32.9	
02N/22W-23G01 S	56		106.5	11/22/74	81.0	25.5	5411
				12/06/74	83.0	23.5	
				1/02/75	72.0	34.5	
				2/07/75	63.0	43.5	
				3/11/75	56.0	50.5	
				4/03/75	24.0	82.5	
				5/02/75	38.0	68.5	
				6/13/75	61.0	45.5	
				7/10/75	65.0	41.5	
				8/14/75	69.0	37.5	
				9/15/75	72.0	34.5	
02N/22W-23G02 S	56		106.5	10/10/74	79.0	27.5	5411
				11/07/74	81.0	25.5	
				12/06/74	82.0	24.5	
				1/02/75	74.0	32.5	
				2/07/75	66.0	40.5	
				3/11/75	60.0	46.5	
				4/03/75	43.0	63.5	
				6/13/75	62.0	44.5	
02N/22W-23K01 S	56		105.0	10/10/74	78.8	26.2	5411
				11/07/74	81.8	23.2	
				12/06/74	79.8	25.2	
				1/02/75	75.8	29.2	
				2/07/75	71.8	33.2	
				3/11/75	46.8	58.2	
				4/03/75	31.8	73.2	
				5/02/75	38.8	66.2	
				6/13/75	59.8	45.2	
				7/10/75	62.8	42.2	
				8/14/75	67.8	37.2	
				9/15/75	69.8	35.2	
02N/22W-23K04 S	56		105.8	10/10/74	89.7	16.1	5411
				11/07/74	95.7	10.1	
				12/06/74	92.7	13.1	
				1/02/75	90.7	15.1	
				2/07/75	88.7	17.1	
				3/11/75	79.7	26.1	
				4/11/75	89.7	16.1	
				5/02/75	84.7	21.1	
				6/13/75	78.7	27.1	
				7/10/75	78.7	27.1	
				8/14/75	84.7	21.1	
				9/15/75	75.7	30.1	
02N/22W-23K05 S	56		100.0	11/07/74	78.0	22.0	5411
				12/06/74	78.0	22.0	
				1/02/75	76.0	24.0	
				2/07/75	68.0	32.0	
02N/22W-24P01 S	56		100.0	1/21/75	63.7	36.3	5121
				3/31/75	49.3	50.7	
				5/21/75	58.2	41.8	
				7/31/75	NM-1		
02N/22W-25N02 S	56		76.2	10/11/74	55.1	21.1	5411
				11/01/74	55.5	20.7	
				12/27/74	55.6	20.6	
				1/03/75	54.9	21.3	
				2/07/75	53.0	23.2	
				3/07/75	48.7	27.5	
				4/04/75	42.7	33.5	

SANTA CLARA-CALLEGUAS HYDRO UNIT — U-03
OXNARD PLAIN HYDRO SUBUNIT — U-03.A
OXNARD HYDRO SUBAREA — U-03.A1

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
02N/22W-25N02 S (CONTINUED)	56		76.2	5/02/75	38.1	38.1	5411
				6/06/75	40.1	36.1	
				7/03/75	42.1	34.1	
				8/01/75	43.1	33.1	
				9/05/75	49.0	27.2	
02N/22W-26E01 S	56		88.0	1/21/75	65.6	22.4	5121
				3/31/75	51.2	36.8	
				5/28/75	48.8	39.2	
				7/31/75	NM-1		
02N/22W-28L01 S	56		66.4	1/23/75	48.5	17.9	5121
				3/25/75	38.2	28.2	
				6/10/75	NM-1		
				8/05/75	39.7	26.7	
				9/22/75	46.8	19.6	
02N/22W-31A01 S	56		41.7	1/23/75	31.6	10.1	5121
				3/25/75	20.8	20.9	
				5/23/75	29.3	12.4	
				8/05/75	26.3	15.4	
				9/22/75	34.4	7.3	
02N/22W-33H01 S	56		49.0	10/11/74	42.3	6.7	5411
				11/01/74	41.6	7.4	
				12/27/74	38.6	10.4	
				1/03/75	35.1	13.9	
				2/07/75	34.2	14.8	
				3/07/75	30.2	18.8	
				4/04/75	28.3	20.7	
				5/02/75	28.9	20.1	
				6/06/75	28.4	20.6	
				7/03/75	26.6	22.4	
				8/01/75	27.5	21.5	
				9/05/75	35.7	13.3	
02N/22W-35C01 S	56		75.2	1/21/75	59.7	15.5	5121
				3/31/75	45.1	30.1	
				5/21/75	45.2	30.0	
				7/31/75	NM-2		
02N/22W-36H02 S	56		67.0	10/25/74	53.7	13.3	5411
				1/03/75	48.7	18.3	
				4/04/75	37.7	29.3	
				5/02/75	36.2	30.8	
				6/06/75	32.7	34.3	
				7/03/75	39.9	27.1	
				8/01/75	37.2	29.8	
02N/23W-01P01 S	56		231.0	1/22/75	12.1(3)	218.9	5121
				3/20/75	5.7(3)	225.3	
				5/23/75	7.9(3)	223.1	
				8/04/75	16.6	214.4	
				9/22/75	20.4	210.6	
02N/23W-13K02 S	56		64.1	1/22/75	34.3	29.8	5121
				3/20/75	30.7	33.4	
				5/23/75	31.6	32.5	
				8/04/75	31.3	32.8	
				9/22/75	33.1	31.0	
02N/23W-14K01 S	56		32.1	10/01/74	NM-1		5411
02N/23W-24G01 S	56		27.1	10/01/74	8.2	18.9	5411
				12/04/74	5.9	21.2	
				1/29/75	NM-1		
				2/26/75	NM-1		
				3/26/75	NM-1		
				4/29/75	NM-1		
				6/04/75	9.7	17.4	
				7/01/75	5.3	21.8	
				8/27/75	7.5	19.6	
02N/23W-25C02 S	56		23.0	8/05/75	14.2	8.8	5121
02N/23W-25G02 S	56		27.0	1/23/75	16.2	10.8	5121
			23.0	3/25/75	3.8	19.2	
				5/23/75	13.4	9.6	
				9/22/75	16.7	6.3	
02N/23W-35H01 S	56		10.6	10/01/74	NM-1		5411
				12/31/74	-0.8	11.4	
				1/29/75	3.2	7.4	
				2/26/75	0.1	10.5	
				4/29/75	1.2	9.4	
				8/27/75	7.2	3.4	
02N/23W-36C04 S	56		28.0	1/23/75	21.0	7.0	5121
				3/25/75	13.9	14.1	
				5/23/75	20.5	7.5	
				8/05/75	17.2	10.8	
				9/22/75	22.1	5.9	
01S/21W-08L01 S	56		10.0	1/24/75	43.6	-33.6	5121
				4/11/75	34.1	-24.1	
01S/21W-08L02 S	56		10.0	1/24/75	15.2	-5.2	5121
				4/11/75	14.4	-4.4	
				5/23/75	14.5	-4.5	
				7/25/75	13.9	-3.9	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA CLARA-CALLEGUAS HYDRO UNIT OXNARD PLAIN HYDRO SUBUNIT PLEASANT VALLEY HYDRO SUBAREA						U-03 U-03.A U-03.A2	
01N/20W-06A01 S	56		119.6	1/21/75	50.3	69.3	5121
				3/31/75	49.8	69.8	
				5/22/75	50.1	69.5	
				7/24/75	50.5	69.1	
01N/20W-06C01 S	56		124.5	1/21/75	NM-7		5121
				3/31/75	105.0	19.5	
				5/22/75	114.3	10.2	
				7/24/75	128.2	-3.7	
01N/20W-06J01 S	56		190.0	1/21/75	40.0	150.0	5121
				5/22/75	42.6	147.4	
				7/24/75	NM-3		
01N/21W-02J02 S	56		90.0	1/21/75	145.5	-55.5	5121
				3/31/75	122.1	-32.1	
				5/22/75	134.4	-44.4	
				7/24/75	119.8	-29.8	
01N/21W-02P01 S	56		66.6	1/21/75	110.1	-43.5	5121
				4/02/75	103.3	-36.7	
				5/22/75	103.5	-36.9	
				7/24/75	101.1	-34.5	
01N/21W-03C01 S	56		72.3	1/20/75	153.0	-80.7	5121
				3/31/75	137.6	-65.3	
				5/22/75	155.2	-82.9	
				7/24/75	155.7	-83.4	
01N/21W-03L02 S	56		59.0	1/21/75	NM-1		5121
				4/02/75	98.0	-39.0	
				5/28/75	NM-3		
				7/24/75	99.0	-40.0	
01N/21W-10E01 S	56		34.0	1/21/75	NM-1		5121
				4/14/75	81.3	-47.3	
				6/19/75	81.2	-47.2	
				8/01/75	104.5	-70.5	
01N/21W-10F01 S	56		38.2	1/21/75	DRY		5121
				7/24/75	66.0	-27.8	
01N/21W-10G01 S	56		39.1	4/02/75	59.9	-20.8	5121
				5/22/75	67.4	-28.3	
01N/21W-12F03 S	56		75.0	1/21/75	52.7	22.3	5121
				4/02/75	51.5	23.5	
				5/22/75	51.5	23.5	
				7/24/75	53.4	21.6	
01N/21W-14A01 S	56		53.0	1/21/75	45.3	7.7	5121
				4/02/75	42.3	10.7	
				5/22/75	43.7	9.3	
				7/24/75	51.6	1.4	
01N/21W-15H01 S	56		35.0	1/21/75	30.0	5.0	5121
				4/02/75	25.0	10.0	
				5/22/75	28.1	6.9	
				7/24/75	34.3(4)	0.7	
01N/21W-15P02 S	56		26.0	1/22/75	NM-1		5121
				4/02/75	79.0	-53.0	
				5/22/75	NM-1		
				7/31/75	NM-1		
01N/21W-15Q02 S	56		23.7	10/01/74	99.0	-75.3	5411
				11/12/74	91.7	-68.0	
				12/15/74	87.7	-64.0	
				1/02/75	73.8	-50.1	
				3/03/75	73.1	-49.4	
				4/01/75	70.4	-46.7	
				6/04/75	79.1	-55.4	
				7/31/75	82.6	-58.9	
				8/27/75	91.4	-67.7	
01N/21W-16A02 S	56		27.8	1/21/75	75.9	-48.1	5121
				4/02/75	NM-6		
01N/21W-16H01 S	56		25.0	1/20/75	79.5	-54.5	5121
				4/02/75	71.1	-46.1	
				5/22/75	76.8	-51.8	
				7/24/75	80.8	-55.8	
01N/21W-16P03 S	56		22.0	1/20/75	87.1	-65.1	5121
				4/02/75	53.1	-31.1	
				5/22/75	52.6	-30.6	
				7/31/75	48.6	-26.6	
01N/21W-22H01 S	56		23.3	1/22/75	33.7	-10.4	5121
				4/14/75	23.8	-0.5	
				5/22/75	22.9	0.4	
				7/24/75	20.8(4)	2.5	
01N/21W-27F01 S	56		13.7	1/22/75	68.4	-54.7	5121
				4/02/75	50.0	-36.3	
				5/22/75	75.0	-61.3	
				7/24/75	67.9	-54.2	
02N/20W-17J02 S	56		282.0	4/10/75	241.0	41.0	5121
02N/20W-19F01 S	56		206.0	4/01/75	322.0	-116.0	5121
02N/20W-19F02 S	56		204.0	4/01/75	319.0	-115.0	5121
SANTA CLARA-CALLEGUAS HYDRO UNIT OXNARD PLAIN HYDRO SUBUNIT PLEASANT VALLEY HYDRO SUBAREA						U-03 U-03.A U-03.A2	
02N/20W-19H04 S	56		199.0	4/01/75	308.0	-109.0	5121
02N/20W-28G02 S	56		170.0	1/21/75	98.4	71.6	5121
				3/31/75	102.2	67.8	
				5/22/75	99.4	70.6	
				7/24/75	100.3	69.7	
02N/20W-30C01 S	56		189.1	1/21/75	298.6	-109.5	5121
				3/31/75	296.2	-107.1	
				5/22/75	299.8	-110.7	
				7/23/75	306.2	-117.1	
02N/20W-30H01 S	56		189.3	1/20/75	266.9	-77.6	5121
				3/31/75	261.6	-72.3	
				4/02/75	262.7	-73.4	
				5/22/75	275.4	-86.1	
				7/23/75	281.8	-92.5	
02N/20W-31R01 S	56		155.3	1/20/75	167.3	-12.0	5121
				3/31/75	165.7	-10.4	
				4/02/75	167.6	-12.3	
				5/22/75	168.7	-13.4	
				7/24/75	168.4	-13.1	
02N/21W-24G01 S	56		298.4	4/09/75	390.4	-92.0	5121
02N/21W-25B01 S	56		176.3	2/06/75	282.2	-105.9	5121
				4/14/75	280.8	-104.5	
				5/28/75	282.7	-106.4	
				7/23/75	NM-1		
02N/21W-25C01 S	56		171.0	1/24/75	86.0	85.0	5121
				3/31/75	85.4	85.6	
				5/21/75	85.5	85.5	
				7/23/75	85.4	85.6	
02N/21W-26D05 S	56		144.0	4/01/75	NM-1		5121
02N/21W-34D02 S	56		90.0	1/20/75	NM-1		5121
				3/31/75	152.0	-62.0	
				5/21/75	166.4	-76.4	
				7/23/75	170.1	-80.1	
02N/21W-34J01 S	56		82.0	10/01/74	150.5	-68.5	5411
				12/05/74	141.5	-59.5	
				1/02/75	140.6	-58.6	
				3/03/75	127.3	-45.3	
				4/01/75	122.3	-40.3	
				6/04/75	137.9	-55.9	
				7/31/75	136.0	-54.0	
				8/27/75	147.7	-65.7	
02N/21W-35D02 S	56		118.3	1/20/75	NM-1		5121
				3/31/75	185.7	-67.4	
				4/02/75	192.0	-73.7	
				5/28/75	195.3	-77.0	
				7/23/75	NM-1		
02N/21W-36N01 S	56		110.1	1/21/75	147.3	-37.2	5121
				3/31/75	136.4	-26.3	
				5/22/75	146.0	-35.9	
				7/24/75	145.0	-34.9	
SANTA PAULA HYDRO SUBUNIT SANTA PAULA HYDRO SUBAREA						U-03.B U-03.B1	
02N/22W-02C01 S	56		177.4	1/21/75	24.5	152.9	5121
				3/21/75	20.8	156.6	
				5/23/75	21.5	155.9	
				8/07/75	32.9	144.5	
02N/22W-03K02 S	56		248.1	1/21/75	105.2	142.9	5121
				3/21/75	101.9	146.2	
				5/23/75	98.7	149.4	
				8/11/75	NM-1		
02N/22W-03N02 S	56		291.9	1/21/75	178.4	113.5	5121
				3/21/75	171.3	120.6	
				5/23/75	171.2	120.7	
				8/06/75	175.7	116.2	
				9/22/75	182.4	109.5	
02N/22W-03Q02 S	56		214.2	1/21/75	88.4	125.8	5121
				3/21/75	87.4	126.8	
				5/23/75	86.4	127.8	
				8/07/75	91.3	122.9	
				9/22/75	94.5	119.7	
02N/22W-10C02 S	56		238.6	1/21/75	127.5	111.1	5121
				3/21/75	126.3	112.3	
				5/23/75	125.2	113.4	
				8/05/75	127.9	110.7	
				9/22/75	133.5	105.1	
02N/22W-11A01 S	56		129.5	1/21/75	72.5	57.0	5121
				3/25/75	56.8	72.7	
				5/23/75	49.0	80.5	
				8/05/75	53.3	76.2	
				9/22/75	66.0	63.5	
02N/22W-12A01 S	56		148.9	10/04/74	76.6	72.3	5411

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA CLARA-CALLEGUAS HYDRO UNIT SANTA PAULA HYDRO SUBUNIT SANTA PAULA HYDRO SUBAREA						U-03 U-03.8 U-03.81	
02N/22W-12A01 S (CONTINUED)	56		148.9	11/01/74	79.1	69.8	5411
				12/06/74	79.7	69.2	
				1/03/75	58.2	90.7	
				2/07/75	61.9	87.0	
				3/07/75	65.2	83.7	
				4/04/75	40.2	108.7	
				5/02/75	17.1	131.8	
				6/06/75	30.0	118.9	
				7/03/75	43.7	105.2	
				8/01/75	51.3	97.6	
				9/05/75	62.7	86.2	
03N/21W-02D01 S	56		347.6	1/22/75	99.1	248.5	5121
				3/21/75	96.2	251.4	
				5/20/75	104.7	242.9	
				8/12/75	NM-1		
03N/21W-03R02 S	56		369.0	10/13/74	162.8	206.2	2225
				11/22/74	169.5	199.5	
				12/10/74	170.1	198.9	
				1/03/75	157.0	212.0	
				2/06/75	162.9	206.1	
				3/12/75	160.3	208.7	
				4/04/75	153.3	215.7	
				6/08/75	169.5	199.5	
				8/01/75	171.1	197.9	
03N/21W-09K02 S	56		361.6	1/21/75	155.6	206.0	5121
				3/21/75	151.6	210.0	
				6/10/75	NM-1		
				8/12/75	167.9	193.7	
				9/23/75	169.4	192.2	
03N/21W-09P03 S	56		295.0	10/10/74	104.1	190.9	2225
				11/08/74	98.4	196.6	
				12/10/74	101.3	193.7	
				1/03/75	87.7	207.3	
				2/06/75	87.0	208.0	
				3/12/75	83.4	211.6	
				4/04/75	83.1	211.9	
				6/08/75	91.9	203.1	
				7/07/75	91.8	203.2	
				9/04/75	96.3	198.7	
03N/21W-09R04 S	56		292.0	10/10/74	94.9	197.1	2225
				11/08/74	104.4	187.6	
				12/10/74	90.6	201.4	
				1/03/75	84.6	207.4	
				2/06/75	94.1	197.9	
				3/12/75	81.6	210.4	
				4/04/75	81.5	210.5	
				6/08/75	99.3	192.7	
				7/07/75	100.8	191.2	
				8/03/75	93.7	198.3	
				9/04/75	95.2	196.8	
03N/21W-10A01 S	56		359.2	10/11/74	148.3	210.9	2225
				11/08/74	149.7	209.5	
				12/01/74	147.0	212.2	
				1/03/75	149.7	209.5	
				2/06/75	137.7	221.5	
				3/12/75	134.9	224.3	
				4/04/75	135.1	224.1	
				6/08/75	154.7	204.5	
				7/07/75	145.1	214.1	
				8/08/75	147.6	211.6	
				9/04/75	196.6(1)	162.6	
03N/21W-11D02 S	56		329.9	10/11/74	111.6	218.3	2225
				11/08/74	179.3(1)	150.6	
				12/01/74	172.7(1)	157.2	
				1/03/75	100.9	229.0	
				2/06/75	100.2	229.7	
				3/12/75	97.5	232.4	
				4/04/75	149.5	180.4	
				6/08/75	182.9	147.0	
				7/02/75	169.3	160.6	
				8/04/75	172.1	157.8	
				9/04/75	179.0(1)	150.9	
03N/21W-11F03 S	56		315.0	10/11/74	89.1	225.9	2225
				11/08/74	88.0	227.0	
				12/01/74	87.0	228.0	
				1/03/75	81.8	233.2	
				2/06/75	71.3	243.7	
				3/12/75	70.8	244.2	
				4/04/75	76.3	238.7	
				6/08/75	81.1	233.9	
				7/02/75	84.8	230.2	
				8/04/75	86.3	228.7	
				9/04/75	98.1	216.9	
03N/21W-11F03 S	56		306.0	10/13/74	86.7	219.3	2225
				11/08/74	78.9	227.1	
				12/01/74	77.9	228.1	
				1/03/75	72.9	233.1	
				2/06/75	71.0	235.0	
				3/12/75	68.5	237.5	
				4/04/75	69.2	236.8	
				6/08/75	70.6	235.4	
				7/07/75	74.6	231.4	
				8/04/75	77.2	228.8	

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA CLARA-CALLEGUAS HYDRO. UNIT SANTA PAULA HYDRO SUBUNIT SANTA PAULA HYDRO SUBAREA						U-03 U-03.8 U-03.81	
03N/21W-11F03 S	56		306.0	9/04/75	77.4	228.6	2225
03N/21W-11P01 S	56		251.0	10/08/74	26.8	224.2	5411
				12/30/74	21.0	230.0	
				3/31/75	21.6	229.4	
				4/29/75	20.4	230.6	
				6/02/75	21.2	229.8	
				7/30/75	24.1	226.9	
				8/26/75	28.1	222.9	
				9/30/75	26.9	224.1	
03N/21W-12E01 S	56		278.0	10/10/74	52.3	225.7	2225
				11/08/74	53.1	224.9	
				12/01/74	47.1	230.9	
				1/03/75	16.1	261.9	
				2/03/75	15.5	262.5	
				3/12/75	14.4	263.6	
				4/04/75	14.8	263.2	
				6/08/75	23.9	254.1	
				7/01/75	52.3(1)	225.7	
				8/08/75	27.4	250.6	
				9/04/75	50.1(1)	227.9	
03N/21W-12E04 S	56		276.0	10/10/74	68.3	207.7	2225
				11/08/74	66.8	209.2	
				12/01/74	22.5	253.5	
				1/03/75	12.9	263.1	
				2/06/75	10.4	265.6	
				3/12/75	11.2	264.8	
				4/04/75	11.3	264.7	
				6/08/75	55.0(1)	221.0	
				7/01/75	66.1(1)	209.9	
				8/03/75	59.6(1)	216.4	
				9/04/75	23.6	252.4	
03N/21W-12F03 S	56		277.0	10/10/74	26.0	251.0	2225
				11/08/74	25.5	251.5	
				12/01/74	20.2	256.8	
				1/03/75	11.9	265.1	
				2/06/75	11.3	265.7	
				3/12/75	10.3	266.7	
				4/04/75	10.4	266.6	
				6/08/75	19.1	257.9	
				7/01/75	58.7(1)	218.3	
				8/03/75	22.2	254.8	
				9/04/75	23.4	253.6	
03N/21W-15C02 S	56		242.0	10/10/74	40.3	201.7	2225
03N/21W-15C03 S	56		242.2	10/10/74	69.3	172.9	2225
03N/21W-15C04 S	56		241.4	10/10/74	38.8	202.6	2225
				11/08/74	36.5	204.9	
				12/10/74	35.7	205.7	
				1/03/75	30.5	210.9	
				2/06/75	29.7	211.7	
				3/12/75	27.8	213.6	
				4/04/75	27.4	214.0	
				6/08/75	30.5	210.9	
				7/02/75	45.3(1)	196.1	
				8/06/75	49.2(1)	192.2	
				9/04/75	37.1	204.3	
03N/21W-16G01 S	56		244.1	10/10/74	57.6	186.5	2225
				11/08/74	49.4	194.7	
				12/10/74	46.5	197.6	
				1/02/75	43.3	200.8	
				2/06/75	41.4	202.7	
				3/12/75	41.6	202.5	
				4/04/75	38.1	206.0	
				6/08/75	42.9	201.2	
				7/08/75	48.8	195.3	
				8/03/75	49.0	195.1	
				9/04/75	50.2	193.9	
03N/21W-16K01 S	56		232.0	10/10/74	64.4	167.6	2225
				11/08/74	37.7	194.3	
				12/10/74	41.1	190.9	
				1/02/75	31.7	200.3	
				2/06/75	30.0	202.0	
				3/12/75	27.9	204.1	
				4/04/75	27.1	204.9	
				6/08/75	31.2	200.8	
				7/02/75	60.1(1)	171.9	
				8/03/75	38.0	194.0	
03N/21W-16K02 S	56		228.0	10/10/74	40.1	187.9	2225
				11/08/74	39.9	188.1	
				12/10/74	34.3	193.7	
				1/02/75	27.7	200.3	
				2/06/75	27.1	200.9	
				3/12/75	24.7	203.3	
				4/04/75	26.4	201.6	
				6/08/75	27.3	200.7	
				7/02/75	33.4	194.6	
				8/03/75	33.3	194.7	
				9/04/75	34.2	193.8	
03N/21W-16K03 S	56		228.7	10/10/74	34.0	194.7	2225
				11/08/74	34.1	194.6	
				12/10/74	31.9	196.8	
				1/02/75	28.8	199.9	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA CLARA-CALLEGUAS HYDRO UNIT						U-03	
SANTA PAULA HYDRO SUBUNIT						U-03.B	
SANTA PAULA HYDRO SUBAREA						U-03.B1	
03N/21W-16K03 S (CONTINUED)	56		228.7	2/06/75	27.4	201.3	2225
				3/12/75	28.5	200.2	
				4/04/75	22.7	206.0	
				6/08/75	27.8	200.9	
				7/02/75	33.4	195.3	
				8/03/75	33.9	194.8	
				9/04/75	34.7	194.0	
03N/21W-17Q01 S	56		284.0	1/21/75	86.2	197.8	5121
				3/21/75	82.7	201.3	
				5/20/75	85.0	199.0	
				8/06/75	96.9	187.1	
				9/23/75	95.8	188.2	
03N/21W-19G01 S	56		250.8	10/10/74	82.0	168.8	2225
				11/08/74	82.4	168.4	
				12/02/74	81.6	169.2	
				1/02/75	68.1	182.7	
				2/06/75	67.2	183.6	
				3/12/75	64.4	186.4	
				4/04/75	70.8	180.0	
				6/08/75	70.1	180.7	
				7/07/75	75.4	175.4	
				8/03/75	74.8	176.0	
03N/21W-19H06 S	56		248.0	10/10/74	153.8	94.2	2225
				11/08/74	163.1	84.9	
				12/02/74	153.7	94.3	
				1/02/75	67.6	180.4	
				2/06/75	64.6	183.4	
				3/12/75	62.2	185.8	
				4/04/75	120.8	127.2	
				6/08/75	81.3	166.7	
				7/20/75	74.2	173.8	
				8/03/75	81.6	166.4	
				9/04/75	75.4	172.6	
03N/21W-19R01 S	56		235.9	1/21/75	50.2	185.7	5121
				3/21/75	46.3	189.6	
				6/10/75	NM-1		
				8/07/75	59.0	176.9	
				9/23/75	57.2	178.7	
03N/21W-21B01 S	56		220.8	10/31/74	28.1	192.7	5411
				12/04/74	29.4	191.4	
				1/27/75	23.6	197.2	
				2/26/75	21.0	199.8	
				3/26/75	19.4	201.4	
				4/27/75	17.0	203.8	
				6/02/75	21.7	199.1	
				7/30/75	NM-1		
				8/26/75	NM-1		
				9/30/75	NM-1		
03N/21W-21F01 S	56		210.9	10/31/74	28.0	182.9	5411
				12/27/74	27.8	183.1	
				1/29/75	21.8	189.1	
				2/26/75	20.2	190.7	
				3/26/75	18.3	192.6	
				4/27/75	17.6	193.3	
				6/02/75	NM-1		
				7/30/75	26.3	184.6	
				8/26/75	27.4	183.5	
				9/30/75	29.0	181.9	
03N/21W-29B01 S	56		192.0	10/31/74	19.2	172.8	5411
				12/27/74	16.6	175.4	
				1/29/75	13.6	178.4	
				2/26/75	11.6	180.4	
				3/26/75	10.1	181.9	
				4/27/75	9.6	182.4	
				6/02/75	10.8	181.2	
				7/30/75	14.8	177.2	
				8/27/75	18.5	173.5	
				9/30/75	NM-1		
03N/21W-30B01 S	56		222.8	2/07/75	43.6	179.2	5121
				3/21/75	44.9	177.9	
				5/21/75	48.0	174.8	
				8/07/75	57.4	165.4	
				9/23/75	57.2	165.6	
03N/21W-30F01 S	56		220.7	3/21/75	46.9	173.8	5121
				6/10/75	NM-1		
				8/12/75	NM-1		
03N/21W-30H04 S	56		208.0	3/21/75	30.7	177.3	5121
				5/21/75	32.9	175.1	
				8/12/75	NM-1		
03N/21W-31B01 S	56		174.7	10/31/74	17.0	157.7	5411
				12/30/74	13.8	160.9	
				1/29/75	12.3	162.4	
				2/26/75	10.9	163.8	
				3/26/75	9.7	165.0	
				4/27/75	9.2	165.5	
				6/03/75	10.5	164.2	
				7/30/75	15.5	159.2	
				8/27/75	16.6	158.1	
				9/30/75	17.5	157.2	
03N/21W-31K02 S	56		620.0	4/01/75	604.0	16.0	5121
SANTA CLARA-CALLEGUAS HYDRO UNIT						U-03	
SANTA PAULA HYDRO SUBUNIT						U-03.B	
SANTA PAULA HYDRO SUBAREA						U-03.B1	
03N/21W-35R01 S	56		630.0	4/01/75	526.0	104.0	5121
03N/22W-03K02 S	56		250.6	9/25/75	112.6	138.0	5121
03N/22W-34R01 S	56		266.2	1/21/75	108.7	157.5	5121
				3/21/75	105.0	161.2	
				5/23/75	105.1	161.1	
				8/11/75	118.5	147.7	
03N/22W-36K02 S	56		180.6	1/21/75	19.5	161.1	5121
				3/21/75	15.5	165.1	
				5/23/75	16.3	164.3	
				8/07/75	31.5(2)	149.1	
				9/22/75	24.1	156.5	
SISAR HYDRO SUBAREA						U-03.B2	
04N/22W-12F01 S	56		1616.0	1/22/75	143.8	1472.2	5121
				3/27/75	134.4	1481.6	
				6/11/75	128.8	1487.2	
				8/06/75	137.5	1478.5	
				9/30/75	138.3	1477.7	
SFSPE HYDRO SUBUNIT						U-03.C	
FILLMORE HYDRO SUBAREA						U-03.C1	
03N/19W-06D02 S	56		433.3	1/22/75	43.8	389.5	5121
				3/21/75	42.3	391.0	
				5/28/75	43.7	389.6	
				8/06/75	44.1	389.2	
03N/20W-01C04 S	56		404.2	1/22/75	26.4	377.8	5121
				3/21/75	24.5	379.7	
				5/21/75	25.1	379.1	
				8/12/75	NM-1		
03N/20W-02A01 S	56		375.6	10/30/74	19.6	356.0	5411
				12/30/74	17.5	358.1	
				1/28/75	17.4	358.2	
				2/27/75	16.2	359.4	
				3/31/75	16.5	359.1	
				4/29/75	14.8	360.8	
				6/03/75	16.6	359.0	
				7/30/75	17.1	358.5	
				8/26/75	18.8	356.8	
				9/29/75	19.8	355.8	
03N/20W-03D01 S	56		345.5	9/23/75	-0.3	345.8	5121
03N/20W-03N01 S	56		341.8	10/31/74	13.5	328.3	5411
				12/30/74	13.9	327.9	
				1/28/75	13.1	328.7	
				2/27/75	11.5	330.3	
				3/31/75	10.0	331.8	
				4/29/75	12.4	329.4	
				6/03/75	11.9	329.9	
				7/30/75	14.4	327.4	
				8/26/75	15.5	326.3	
				9/29/75	NM-1		
03N/20W-05D01 S	56		437.8	8/06/75	153.7(2)	284.1	5121
				9/23/75	153.2	284.6	
03N/20W-06P01 S	56		300.0	1/22/75	3.7	296.3	5121
			298.0	5/28/75	4.3	293.7	
				8/06/75	7.5	290.5	
				9/23/75	7.2	290.8	
03N/20W-08A01 S	56		319.6	10/31/74	NM-9		5411
				12/30/74	10.0	309.6	
				1/28/75	10.3	309.3	
				2/27/75	9.6	310.0	
				3/31/75	9.3	310.3	
				6/03/75	11.0	308.6	
				7/30/75	NM-9		
				9/29/75	16.8	302.8	
03N/20W-09F01 S	56		335.0	1/22/75	19.0	316.0	5121
				3/21/75	17.4	317.6	
				5/21/75	18.7	316.3	
				8/06/75	20.6	314.4	
				9/25/75	21.8	313.2	
03N/20W-11C01 S	56		397.4	1/22/75	43.0	354.4	5121
				3/21/75	43.4	354.0	
				5/21/75	42.6	354.8	
				8/12/75	50.5	346.9	
				9/25/75	47.2	350.2	
03N/20W-27B01 S	56		900.0	4/01/75	NM-1		5121
03N/21W-01N01 S	56		320.3	1/22/75	64.2	256.1	5121
				3/21/75	54.4	265.9	
				5/20/75	68.2(2)	252.1	
				8/06/75	73.8(2)	246.5	
				9/23/75	70.7	249.4	
03N/21W-12R01 S	56		279.0	10/04/74	10.4	268.6	5411
				11/01/74	10.3	268.7	
				12/06/74	9.4	269.6	
				1/03/75	8.2	270.8	

See page 79 for key to terms a abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA CLARA-CALLEGUAS HYDRO UNIT SESPE HYDRO SUBUNIT FILLMORE HYDRO SUBAREA						U-03 U-03.C U-03.C1	
03N/21W-12B01 S (CONTINUED)	56		279.0	2/07/75	7.2	271.8	5411
				3/07/75	6.3	272.7	
				4/04/75	5.6	273.4	
				5/02/75	5.6	273.4	
				6/06/75	6.2	272.8	
				7/03/75	7.1	271.9	
				8/01/75	8.0	271.0	
				9/05/75	8.4	270.6	
04N/19W-25N01 S	56		582.0	10/30/74	58.8	523.2	5411
				12/30/74	57.7	524.3	
				1/27/75	NM-1		
				2/27/75	58.8	523.2	
				3/27/75	55.3	526.7	
				4/28/75	58.2	523.8	
				6/02/75	NM-1		
				7/30/75	NM-1		
				8/26/75	69.1	512.9	
				9/29/75	NM-1		
04N/19W-30D01 S	56		437.6	1/22/75	36.4	401.2	5121
				3/21/75	32.3	405.3	
				6/06/75	NM-1		
				8/06/75	37.8	399.8	
				9/23/75	37.3	400.3	
04N/19W-30P01 S	56		441.9	1/22/75	25.1	416.8	5121
				3/21/75	23.0	418.9	
				5/28/75	26.4	415.5	
				8/06/75	23.1	418.8	
				9/23/75	27.7	414.2	
04N/19W-31E01 S	56		417.8	10/31/74	16.2	401.6	5411
				12/04/74	16.6	401.2	
				1/28/75	13.5	404.3	
				2/27/75	12.8	405.0	
				3/31/75	11.8	406.0	
				4/29/75	12.3	405.5	
				6/03/75	NM-1		
				7/30/75	NM-1		
				8/26/75	14.0	403.8	
				9/29/75	17.1	400.7	
04N/19W-31P01 S	56		448.0	1/30/75	43.1	404.9	5121
				3/21/75	41.5	406.5	
				5/28/75	42.4	405.6	
				8/12/75	54.0	394.0	
04N/19W-32A01 S	56		468.0	10/04/74	4.2	463.8	5411
				11/01/74	4.1	463.9	
				12/06/74	4.1	463.9	
				1/03/75	4.0	464.0	
				2/07/75	4.0	464.0	
				3/07/75	3.9	464.1	
				4/04/75	4.4	463.6	
				5/02/75	4.2	463.8	
				6/06/75	5.2	462.8	
				7/03/75	3.6	464.4	
				8/01/75	1.9	466.1	
				9/05/75	4.9	463.1	
04N/19W-32M02 S	56		447.3	1/22/75	19.1	428.2	5121
				3/21/75	10.7	436.6	
				5/28/75	12.9	434.4	
				8/06/75	17.8	429.5	
				9/25/75	22.3	425.0	
04N/19W-32R01 S	56		470.0 469.0	1/22/75	6.9	463.1	5121
				3/21/75	6.3	462.7	
				5/21/75	6.8	462.2	
				8/06/75	6.6	462.4	
				9/25/75	7.4	461.6	
04N/19W-33D03 S	56		474.3	3/20/75	3.2	471.1	5121
				5/21/75	NM-1		
04N/19W-33D04 S	56		474.3	1/21/75	NM-1		5121
				3/20/75	NM-1		
				5/21/75	5.3	469.0	
				8/06/75	NM-1		
				9/25/75	NM-1		
04N/19W-33K03 S	56		478.4	1/21/75	7.1	471.3	5121
04N/20W-23N02 S	56		558.0	3/21/75	160.0	398.0	5121
				6/06/75	NM-1		
				8/12/75	NM-1		
04N/20W-26A02 S	56		430.7	1/31/75	NM-1		5121
				3/21/75	28.2	402.5	
				5/21/75	33.0	397.7	
				8/12/75	NM-1		
04N/20W-26D01 S	56		538.6	1/22/75	151.3	387.3	5121
				3/21/75	145.5	393.1	
				6/06/75	NM-1		
				8/12/75	NM-1		
04N/20W-26L01 S	56		428.0	10/30/74	48.6	379.4	5411
				12/30/74	42.6	385.4	
				1/27/75	41.6	386.4	
				2/27/75	39.7	388.3	
SANTA CLARA-CALLEGUAS HYDRO UNIT SESPE HYDRO SUBUNIT FILLMORE HYDRO SUBAREA						U-03 U-03.C U-03.C1	
04N/20W-26L01 S (CONTINUED)	56		428.0	3/27/75	36.6	391.4	5411
				4/28/75	36.9	391.1	
				6/02/75	39.8	388.2	
				7/30/75	45.6	382.4	
				8/26/75	45.3	382.7	
				9/29/75	48.9	379.1	
04N/20W-27N01 S	56		527.3	1/22/75	134.7	392.6	5121
				3/21/75	135.5	391.8	
				5/20/75	130.1	397.2	
				8/06/75	144.9	382.4	
				9/23/75	148.0	379.3	
04N/20W-33C03 S	56		526.0	1/22/75	144.6	381.4	5121
				3/21/75	142.0	384.0	
				6/06/75	NM-1		
				8/12/75	NM-1		
04N/20W-36D04 S	56		401.0	1/22/75	14.1	386.9	5121
				3/21/75	12.0	389.0	
				5/21/75	11.3	389.7	
				8/06/75	15.2	385.8	
				9/23/75	16.4	384.6	
PIRU HYDRO SUBUNIT PIRU HYDRO SUBAREA						U-03.D U-03.D1	
04N/18W-19P02 S	56		663.9	10/30/74	114.8	549.1	5411
04N/18W-19R01 S	56		655.5	1/21/75	109.1	546.4	5121
				3/20/75	111.6	543.9	
				5/28/75	109.3	546.2	
				8/06/75	107.3	548.2	
				9/25/75	113.3	542.2	
04N/18W-20K01 S	56		676.9	10/15/74	96.1	580.8	5411
				1/28/75	115.2	561.7	
				2/27/75	118.7	558.2	
				3/27/75	120.5	556.4	
				4/28/75	121.8	555.1	
				6/02/75	117.2	559.7	
				7/30/75	115.6	561.3	
				8/26/75	110.2	566.7	
				9/29/75	117.0	559.9	
04N/18W-20N01 S	56		662.0	10/09/74	93.8	568.2	5411
				11/01/74	71.0	591.0	
				12/02/74	107.2	554.8	
				1/02/75	109.1	552.9	
				2/04/75	113.9	548.1	
				3/03/75	113.5	548.5	
				4/07/75	112.8	549.2	
				5/02/75	110.7	551.3	
				6/01/75	109.0	553.0	
				7/01/75	109.8	552.2	
04N/18W-20R01 S	56		659.7	1/21/75	102.2	557.5	5121
				3/20/75	102.9	556.8	
				5/21/75	100.4	559.3	
				8/04/75	101.6	558.1	
				9/29/75	107.5	552.2	
04N/18W-27B02 S	56		713.0	10/30/74	84.7	628.3	5411
				12/30/74	77.7	635.3	
				1/28/75	70.5	642.5	
				2/27/75	64.7	648.3	
				3/27/75	56.3	656.7	
				4/28/75	55.8	657.2	
				6/02/75	64.8	648.2	
				7/30/75	81.7	631.3	
				8/26/75	91.5	621.5	
				9/29/75	97.7	615.3	
04N/18W-28C02 S	56		676.0	1/30/75	115.2	560.8	5121
				3/20/75	117.2	558.8	
				5/28/75	114.3	561.7	
				8/04/75	115.7	560.3	
04N/18W-29M02 S	56		635.9	10/05/74	66.5	569.3	5411
				11/10/74	79.0	556.8	
				12/01/74	83.1	552.7	
				1/05/75	86.3	549.5	
				2/02/75	89.4	546.4	
				3/02/75	90.5	545.3	
				4/06/75	89.7	546.1	
				5/04/75	89.7	546.1	
				6/01/75	88.2	547.6	
				7/06/75	88.3	547.5	
				8/03/75	87.3	548.5	
				9/07/75	89.6	546.2	
04N/18W-29P01 S	56		642.9	10/30/74	77.8	565.1	5411
				12/30/74	79.3	563.6	
				1/28/75	80.7	562.2	
				2/27/75	82.4	560.5	
				3/27/75	83.7	559.2	
				4/28/75	85.3	557.6	
				6/02/75	86.5	556.4	
				7/30/75	93.5	549.4	
				8/26/75	87.8	555.1	
				9/29/75	95.3	547.6	
04N/18W-30K01 S	56		626.1	10/30/74	74.0	552.1	5411

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA CLARA-CALLEGUAS HYDRO UNIT						U-03	
PIRU HYDRO SUBUNIT						U-03.D	
PIRU HYDRO SUBAREA						U-03.D1	
04N/18W-30K01 S (CONTINUED)	56		626.1	12/04/74	79.6	546.5	5411
				1/27/75	83.3	542.8	
				2/27/75	NM-1		
				3/27/75	84.8	541.3	
				4/28/75	86.2	539.9	
				6/03/75	85.3	540.8	
				7/30/75	82.5	543.6	
				8/26/75	81.8	544.3	
				9/29/75	87.4	538.7	
04N/18W-31C01 S	56		607.0	10/30/74	56.3	550.7	5411
				12/30/74	62.4	544.6	
				1/28/75	65.6	541.4	
				2/27/75	78.0	529.0	
				3/27/75	67.2	539.8	
				4/28/75	69.2	537.8	
				6/02/75	72.0	535.0	
				7/30/75	61.9	545.1	
				8/26/75	63.9	543.1	
				9/29/75	75.9	531.1	
04N/19W-25C02 S	56		610.4	1/21/75	96.5	513.9	5121
				3/20/75	84.6	525.8	
				5/28/75	88.5	521.9	
				8/12/75	NM-1		
04N/19W-25K02 S	56		593.7	1/21/75	58.9	534.8	5121
				3/20/75	57.3	536.4	
				5/28/75	63.6	530.1	
				8/12/75	NM-1		
				9/25/75	62.8	530.9	
04N/19W-26P01 S	56		565.0	1/30/75	45.3	519.7	5121
				3/20/75	42.8	522.2	
				5/21/75	47.7	517.3	
				8/12/75	NM-1		
04N/19W-34D02 S	56		501.7	10/30/74	8.9	492.8	5411
04N/19W-34K01 S	56		522.8	1/21/75	19.8	503.0	5121
				3/20/75	19.5	503.3	
				5/21/75	23.1	499.7	
				8/06/75	12.0	510.8	
				9/25/75	22.3	500.5	
04N/19W-34M02 S	56		501.2	10/30/74	8.4	492.8	5411
				12/30/74	8.7	492.5	
				1/28/75	9.7	491.5	
				2/27/75	9.9	491.3	
				3/27/75	9.2	492.0	
				4/28/75	10.3	490.9	
				6/03/75	NM-1		
				7/30/75	6.4	494.8	
				8/26/75	8.3	492.9	
				9/29/75	12.2	489.0	
04N/19W-35L02 S	56		540.1	10/30/74	22.2	517.9	5411
				12/30/74	23.0	517.1	
				1/28/75	24.2	515.9	
				2/27/75	26.0	514.1	
				3/27/75	25.4	514.7	
				4/28/75	27.0	513.1	
				6/03/75	NM-1		
				7/30/75	NM-1		
				8/26/75	NM-1		
				9/26/75	NM-1		
HUNGRY VALLEY HYDRO SUBAREA						U-03.D3	
07N/18W-07E01 S	56		3100.0	4/01/75	97.7	3002.3	5121
				6/17/75	97.8	3002.2	
08N/19W-35P01 S	56		3460.0	4/01/75	152.1	3307.9	5121
				6/17/75	152.1	3307.9	
STAUFFER HYDRO SUBAREA						U-03.D4	
08N/20W-08F01 S	56		5345.0	4/01/75	35.7	5309.3	5121
				6/17/75	35.6	5309.4	
08N/21W-24J02 S	56		5240.0	4/01/75	19.6	5220.4	5121
				6/25/75	9.9	5230.1	
08N/21W-26N01 S	56		5190.0	6/25/75	54.5	5135.5	5121
08N/21W-27R01 S	56		5190.0	4/09/75	53.5	5136.5	5121
				6/25/75	52.5	5137.5	
08N/21W-33R03 S	56		5150.0	4/16/75	45.1	5104.9	5121
				6/25/75	45.5	5104.5	
08N/21W-35R01 S	56		5043.0	4/16/75	54.2	4988.8	5121
				6/25/75	56.0	4987.0	
08N/21W-35K01 S	56		5003.0	4/16/75	42.5	4960.5	5121
				6/25/75	42.8	4960.2	
08N/21W-36G02 S	56		4922.0	4/16/75	18.4	4903.6	5121
				6/25/75	18.6	4903.4	
08N/23W-11P01 S	56		4381.1	4/17/75	115.8	4265.3	5121
				6/26/75	117.3	4263.8	

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA CLARA-CALLEGUAS HYDRO UNIT						U-03	
UPPER SANTA CLARA R HYDRO SUBUNIT						U-03.E	
EASTERN HYDRO SUBAREA						U-03.E1	
03N/15W-02A01 S	19		1843.0	11/22/74	DRY		1101
				4/16/75	NM-3		
03N/15W-05D02 S	19		1467.0	11/27/74	NM-1		1101
				4/16/75	21.9	1445.1	
03N/15W-06A01 S	19		1447.0	11/27/74	29.5	1417.5	1101
				4/16/75	22.1	1424.9	
03N/16W-01M01 S	19		1309.4	11/27/74	93.0	1216.4	1101
				4/16/75	86.5	1222.9	
03N/16W-01Q05 S	19		1336.2	11/04/74	2.1	1334.1	1101
				1/06/75	1.2	1335.0	
				3/04/75	1.3	1334.9	
				5/09/75	1.4	1334.8	
				7/01/75	NM-2		
				9/05/75	4.0	1332.2	
03N/16W-02J01 S	19		1318.0	11/22/74	NM-2		1101
				12/18/74	105.8	1212.2	
				4/02/75	98.6	1219.4	
03N/16W-02P02 S	19		1354.0	1/13/75	94.5	1259.5	1101
03N/14W-03H02 S	19		1300.0	11/22/74	88.8	1211.2	1101
				4/02/75	90.0	1210.0	
03N/16W-03R01 S	19		1325.0	11/22/74	NM-3		1101
				4/02/75	145.5	1179.5	
03N/14W-04A01 S	19		1238.5	10/31/74	115.4	1123.1	1101
				11/22/74	121.4	1117.1	
				12/17/74	120.3	1118.2	
				1/23/75	122.8	1115.7	
				3/05/75	124.2(3)	1114.3	
				4/02/75	122.9	1115.6	
				5/09/75	123.6	1114.9	
				6/11/75	120.5	1118.0	
				7/02/75	121.1	1117.4	
				8/07/75	120.7	1117.8	
				9/05/75	121.0	1117.5	
03N/16W-04A02 S	19		1273.0	4/02/75	NM-1		1101
03N/16W-04J01 S	19		1280.3	11/22/74	80.1	1200.2	1101
				4/02/75	56.1	1224.2	
03N/16W-11A01 S	19		1388.0	11/22/74	62.4	1325.6	1101
				4/02/75	65.9	1322.1	
03N/16W-11A02 S	19		1400.0	11/22/74	NM-5		1101
				4/02/75	45.2	1354.8	
03N/16W-11D02 S	19		1377.0	11/22/74	31.4	1345.6	1101
				4/02/75	31.9	1345.1	
03N/16W-11H02 S	19		1417.0	11/27/74	NM-1		1101
				12/18/74	153.1	1263.9	
				4/02/75	NM-1		
03N/16W-12A03 S	19		1400.0	11/27/74	19.7	1380.3	1101
				4/16/75	18.0	1382.0	
03N/16W-12G02 S	19		1401.3	11/27/74	NM-6		1101
03N/16W-13A01 S	19		1600.0	11/27/74	84.8	1515.2	1101
				4/16/75	86.0	1514.0	
04N/14W-17E01 S	19		1690.0	11/19/74	62.1(2)	1627.9	1101
				12/18/74	64.1(2)	1625.9	
				4/22/75	58.0(2)	1632.0	
04N/14W-17H01 S	19		1725.0	11/19/74	23.0	1702.0	1101
				4/22/75	22.6	1702.4	
04N/14W-18F01 S	19		1632.0	11/19/74	43.6	1588.4	1101
				4/22/75	46.0	1586.0	
04N/14W-31E01 S	19		2075.0	11/27/74	FLOW		1101
04N/15W-01A02 S	19		1851.0	11/19/74	51.6	1799.4	1101
				4/21/75	54.2	1796.8	
04N/15W-01B02 S	19		1825.0	11/19/74	48.5	1776.5	1101
04N/15W-01C01 S	19		1795.5	11/19/74	59.0	1736.5	1101
				4/21/75	61.0	1734.5	
04N/15W-01F01 S	19		1775.0	11/19/74	78.4	1696.6	1101
				4/30/75	68.0	1707.0	
04N/15W-02J01 S	19		1730.0	11/19/74	47.3	1682.7	1101
				4/21/75	48.2	1681.8	
04N/15W-02J02 S	19		1735.0	11/19/74	47.3	1687.7	1101
				4/21/75	48.8	1686.2	
04N/15W-05R01 S	19		1482.0	11/06/74	40.5	1441.5	1101
				4/28/75	NM-1		
04N/15W-05C01 S	19		1437.0	11/06/74	29.2	1407.8	1101

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

SANTA CLARA-CALLEGUAS HYDRO UNIT — U-03
UPPER SANTA CLARA R HYDRO SUBUNIT — U-03.E
EASTERN HYDRO SUBAREA — U-03.E1

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
04N/15W-05C01 S	19		1437.0	4/28/75	33.0	1404.0	1101
04N/15W-06F02 S	19		1381.0	11/06/74	22.3	1358.7	1101
				4/28/75	21.0	1360.0	
04N/15W-06H01 S	19		1420.0	11/06/74	21.5	1398.5	1101
				4/28/75	22.1	1397.9	
04N/15W-06K01 S	19		1396.0	11/06/74	15.1	1380.9	1101
				4/28/75	15.9	1380.1	
04N/15W-07E01 S	19		1326.7	11/04/74	72.8	1253.9	1101
				1/06/75	73.7	1253.0	
				3/04/75	72.7	1254.0	
				4/28/75	71.7	1255.0	
04N/15W-11R01 S	19		1690.0	11/19/74	57.0	1633.0	1101
				4/30/75	59.0	1631.0	
04N/15W-11R02 S	19		1703.0	11/19/74	53.6	1649.4	1101
				4/30/75	60.5	1642.5	
04N/15W-11F01 S	19		1652.0	11/04/74	42.8	1609.2	1101
				1/06/75	43.0	1609.0	
				3/04/75	43.3	1608.7	
				5/09/75	43.7	1608.3	
				7/01/75	43.9	1608.1	
				9/05/75	43.9(2)	1608.1	
04N/15W-11N01 S	19		1609.0	11/19/74	49.7	1559.3	1101
				4/30/75	52.4(4)	1556.6	
04N/15W-11N03 S	19		1621.0	11/19/74	50.2	1570.8	1101
				4/30/75	58.2(4)	1562.8	
04N/15W-13P01 S	19		1573.0	11/04/74	39.8	1533.2	1101
				1/06/75	41.7	1531.3	
				3/04/75	43.7	1529.3	
				5/09/75	45.3	1527.7	
				7/01/75	48.2	1524.8	
				9/05/75	52.4	1520.6	
04N/15W-13P02 S	19		1577.0	1/13/75	30.0	1547.0	1101
04N/15W-13Q04 S	19		1595.0	1/13/75	33.5	1561.5	1101
04N/15W-14J01 S	19		1558.0	11/19/74	NM-1		1101
				12/18/74	37.8	1520.2	
				4/24/75	41.1	1516.9	
04N/15W-14P01 S	19		1545.0	12/17/74	NM-3		1101
04N/15W-14R01 S	19		1554.0	11/19/74	41.2	1512.8	1101
				4/22/75	45.0(6)	1509.0	
04N/15W-14R03 S	19		1560.0	1/13/75	38.5	1521.5	1101
04N/15W-15A01 S	19		1600.0	11/19/74	50.7	1549.3	1101
				4/30/75	51.9	1548.1	
04N/15W-15G01 S	19		1575.0	11/19/74	62.6	1512.4	1101
				4/30/75	57.8	1517.2	
04N/15W-15G02 S	19		1573.0	11/19/74	47.4	1525.6	1101
				4/30/75	50.8	1522.2	
04N/15W-15N01 S	19		1525.0	4/30/75	NM-7		1101
04N/15W-15N02 S	19		1505.0	11/06/74	41.6	1463.4	1101
				4/30/75	41.4	1463.6	
04N/15W-16N01 S	19		1377.0	11/06/74	77.6	1299.4	1101
				4/30/75	86.5(1)	1290.5	
04N/15W-17N02 S	19		1322.0	11/06/74	NM-1		1101
				12/18/74	NM-1		
04N/15W-17P01 S	19		1323.5	11/06/74	51.9	1271.6	1101
				4/28/75	NM-5		
04N/15W-18N02 S	19		1278.0	11/06/74	NM-1		1101
				12/18/74	44.0	1234.0	
				5/01/75	NM-1		
04N/15W-18P01 S	19		1291.0	11/06/74	49.6	1241.4	1101
				5/01/75	52.3	1238.7	
04N/15W-19R01 S	19		1275.0	11/04/74	44.5	1230.5	1101
				1/06/75	46.2	1228.8	
				3/04/75	47.8	1227.2	
				5/06/75	48.4	1226.6	
				7/01/75	48.2	1226.8	
				9/05/75	53.4	1221.6	
04N/15W-20R01 S	19		1331.4	3/04/75	61.3	1270.1	1101
				4/16/75	61.0	1270.4	
				5/06/75	60.9	1270.5	
				6/11/75	62.2	1269.2	
				7/01/75	62.8	1268.6	
				8/07/75	63.7	1267.7	
				9/05/75	64.8	1266.6	
04N/15W-20K01 S	19		1362.0	10/18/74	NM-3		1101

SANTA CLARA-CALLEGUAS HYDRO UNIT — U-03
UPPER SANTA CLARA R HYDRO SUBUNIT — U-03.E
EASTERN HYDRO SUBAREA — U-03.E1

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
04N/15W-20R01 S	19		1385.0	11/06/74	65.3	1319.7	1101
				5/01/75	62.4	1322.6	
04N/15W-20R02 S	19		1387.5	11/06/74	54.4	1333.1	1101
				5/01/75	60.2	1327.3	
04N/15W-21A01 S	19		1460.0	11/06/74	66.6	1393.4	1101
				4/30/75	66.9	1393.1	
04N/15W-21G01 S	19		1441.0	11/06/74	56.6	1384.4	1101
				4/30/75	54.8	1386.2	
04N/15W-21J01 S	19		1431.0	11/06/74	46.5	1384.5	1101
				4/30/75	46.9	1384.1	
04N/15W-21J02 S	19		1440.0	11/06/74	46.5	1393.5	1101
				6/12/75	46.3	1393.7	
04N/15W-21M01 S	19		1390.0	11/06/74	41.8	1348.2	1101
				4/30/75	41.5	1348.5	
04N/15W-21Q02 S	19		1418.0	11/06/74	45.9	1372.1	1101
				5/09/75	46.4	1371.6	
04N/15W-22F01 S	19		1463.0	11/06/74	32.6	1430.4	1101
04N/15W-22L01 S	19		1464.0	11/06/74	34.6	1429.4	1101
				4/30/75	33.5	1430.5	
04N/15W-22L02 S	19		1461.0	3/04/75	54.4	1406.6	1101
				5/09/75	57.0	1404.0	
				7/01/75	59.0	1402.0	
				9/05/75	60.8	1400.2	
04N/15W-23R02 S	19		1530.0	11/19/74	30.3	1499.7	1101
				5/01/75	32.5	1497.5	
04N/15W-23R03 S	19		1550.0	11/19/74	42.6	1507.4	1101
				5/09/75	43.1	1506.9	
04N/15W-23F01 S	19		1515.0	11/19/74	36.1	1478.9	1101
				5/01/75	36.8	1478.2	
04N/15W-23F01 S	19		1528.5	11/19/74	NM-1		1101
				5/01/75	NM-5		
04N/15W-23F02 S	19		1553.0	11/19/74	46.7	1506.3	1101
				5/01/75	NM-5		
04N/15W-23F04 S	19		1530.0	11/16/74	33.5	1496.5	1101
				5/01/75	NM-1		
04N/15W-23F05 S	19		1552.0	5/01/75	50.3	1501.7	1101
04N/15W-23K03 S	19		1570.0	11/19/74	46.7	1523.3	1101
				5/01/75	50.6	1519.4	
04N/15W-23Q02 S	19		1587.0	11/19/74	47.0	1540.0	1101
				4/21/75	53.0	1534.0	
04N/15W-24C01 S	19		1580.8	11/19/74	38.8	1541.2	1101
				4/22/75	47.6	1532.4	
04N/15W-26G01 S	19		1640.0	11/19/74	49.0	1591.0	1101
				5/01/75	59.5	1580.5	
04N/15W-26K01 S	19		1678.0	11/19/74	66.9(4)	1611.1	1101
				5/01/75	83.6	1594.4	
04N/15W-26R02 S	19		1686.0	11/04/74	40.1	1645.9	1101
				1/06/75	41.2	1644.8	
				3/04/75	42.2	1643.8	
				4/16/75	42.5	1643.5	
				5/09/75	42.8	1643.2	
				7/01/75	42.7	1643.3	
				9/05/75	42.8	1643.2	
04N/15W-26R04 S	19		1715.0	11/22/74	83.5	1631.5	1101
				4/16/75	NM-3		
04N/15W-31G01 S	19		1506.5	11/27/74	2.5	1504.0	1101
04N/15W-31N02 S	19		1375.0	11/27/74	43.5	1331.5	1101
				4/16/75	NM-8		
04N/15W-31P02 S	19		1385.8	11/04/74	45.0	1340.8	1101
				1/06/75	39.7	1346.1	
				3/04/75	43.6	1342.2	
				5/09/75	36.8	1349.0	
				7/01/75	38.7	1347.1	
				9/05/75	39.7	1346.1	
04N/15W-35J02 S	19		1779.0	11/27/74	67.7	1711.3	1101
				4/16/75	66.0	1713.0	
04N/15W-35P01 S	19		1812.5	11/22/74	NM-9		1101
				12/18/74	87.3	1725.2	
				4/16/75	86.1	1726.4	
04N/15W-35R02 S	19		1800.0	11/27/74	80.0	1720.0	1101
				4/16/75	88.5(6)	1711.5	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

SANTA CLARA-CALLEGUAS HYDRO UNIT U-03
UPPER SANTA CLARA R HYDRO SUBUNIT U-03.E
EASTERN HYDRO SUBAREA U-03.E1

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
04N/15W-36C01 S	19		1776.0	11/27/74	32.0	1744.0	1101
				4/16/75	31.5	1744.5	
04N/15W-36E01 S	19		1770.0	11/22/74	NM-3		1101
				4/16/75	NM-3		
04N/15W-36F03 S	19		1821.0	11/27/74	NM-5		1101
				12/18/74	NM-2		
				4/16/75	NM-2		
				5/09/75	NM-2		
04N/15W-36H01 S	19		2075.0	11/27/74	40.2	2034.8	1101
04N/16W-01B01 S	19		1377.3	11/04/74	67.0	1310.3	1101
				4/28/75	68.4	1308.9	
04N/16W-01K01 S	19		1333.0	11/04/74	69.1	1263.9	1101
				4/28/75	70.1	1262.9	
04N/16W-01P03 S	19		1329.0	11/04/74	DRY		1101
04N/16W-01Q01 S	19		1330.0	11/04/74	80.0	1250.0	1101
				4/28/75	NM-5		
04N/16W-02M01 S	19		1330.0	11/04/74	90.7	1239.3	1101
				4/28/75	95.0	1235.0	
04N/16W-03E01 S	19		1196.3	11/04/74	18.0	1178.3	1101
				4/28/75	19.6	1176.7	
04N/16W-04H01 S	19		1201.0	11/04/74	24.4	1176.6	1101
				4/28/75	25.4	1175.6	
04N/16W-06A01 S	19		1063.0	12/09/74	27.0(8)	1036.0	1101
				4/03/75	27.1(8)	1035.9	
04N/16W-07Q01 S	19		1027.0	12/12/74	8.2	1018.8	1101
				4/03/75	10.0	1017.0	
04N/16W-09H01 S	19		1153.5	11/04/74	13.4	1140.1	1101
				4/28/75	15.0	1138.5	
04N/16W-09M02 S	19		1155.0	11/04/74	20.2	1134.8	1101
				4/28/75	21.0	1134.0	
04N/16W-12C03 S	19		1030.2	12/09/74	20.0	1010.2	1101
04N/16W-12H01 S	19		1315.0	11/04/74	53.3	1261.7	1101
				1/06/75	66.1	1248.9	
				3/04/75	NM-9		
				5/06/75	NM-9		
				7/01/75	66.3	1248.7	
				9/05/75	NM-9		
04N/16W-12K01 S	19		1281.0	11/04/74	54.2	1226.8	1101
				4/28/75	58.6	1222.4	
04N/16W-12M01 S	19		1265.0	11/04/74	NM-6		1101
04N/16W-12N02 S	19		1253.0	11/04/74	49.8	1203.2	1101
				4/28/75	NM-9		
04N/16W-13D01 S	19		1240.0	11/04/74	47.7	1192.3	1101
				4/28/75	NM-7		
				6/30/75	49.0	1191.0	
04N/16W-14E02 S	19		1178.8	11/04/74	40.0	1138.8	1101
				4/28/75	NM-2		
04N/16W-14H01 S	19		1223.0	11/04/74	53.9(2)	1169.1	1101
				6/30/75	45.5	1177.5	
04N/16W-15Q03 S	19		1153.0	11/04/74	38.5	1114.5	1101
				4/28/75	NM-1		
04N/16W-15R01 S	19		1155.0	11/04/74	34.3	1120.7	1101
				4/28/75	NM-1		
04N/16W-16D02 S	19		1096.0	12/12/74	NM-5		1101
				4/03/75	18.9(8)	1077.1	
04N/16W-16E01 S	19		1102.4	10/04/74	22.4	1080.0	1101
				11/04/74	21.6	1080.8	
				12/09/74	20.8	1081.6	
				1/06/75	20.2	1082.2	
				2/14/75	19.5	1082.9	
				3/04/75	NM-9		
				4/03/75	18.8	1083.6	
				5/06/75	18.6	1083.8	
				6/11/75	19.5	1082.9	
				7/01/75	20.2	1082.2	
				8/07/75	22.9	1079.5	
				9/05/75	NM-9		
04N/16W-16G03 S	19		1115.8	11/04/74	30.0	1085.8	1101
				1/06/75	27.4	1088.4	
				3/04/75	26.0	1089.8	
				4/28/75	24.5	1091.3	
04N/16W-16R01 S	19		1127.0	11/04/74	34.7	1092.3	1101
				4/28/75	28.5	1098.5	

SANTA CLARA-CALLEGUAS HYDRO UNIT U-03
UPPER SANTA CLARA R HYDRO SUBUNIT U-03.E
EASTERN HYDRO SUBAREA U-03.E1

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
04N/16W-17A05 S	19		1089.0	12/12/74	15.0(8)	1074.0	1101
				4/03/75	NM-1		
04N/16W-17C01 S	19		1056.0	12/12/74	10.5	1045.5	1101
				4/03/75	9.5	1046.5	
04N/16W-17D01 S	19		1048.0	12/12/74	14.6	1033.4	1101
				4/03/75	14.0	1034.0	
04N/16W-17J02 S	19		1095.0	12/12/74	NM-4		1101
				4/03/75	59.2	1035.8	
04N/16W-18A02 S	19		1043.8	10/04/74	13.7	1030.1	1101
				11/04/74	13.4	1030.4	
				12/09/74	13.2	1030.6	
				1/06/75	12.8	1031.0	
				2/14/75	12.5	1031.3	
				3/04/75	12.7	1031.1	
				4/03/75	12.6	1031.2	
				5/06/75	13.7	1030.1	
				6/11/75	14.8	1029.0	
				7/01/75	NM-1		
				8/07/75	17.4	1026.4	
				9/05/75	16.1	1027.7	
04N/16W-18R01 S	19		1030.0	12/12/74	8.9	1021.1	1101
				4/03/75	8.5	1021.5	
04N/16W-18F04 S	19		1022.6	12/17/74	NM-3		1101
				4/03/75	NM-3		
04N/16W-20R02 S	19		1092.0	12/12/74	16.0	1076.0	1101
				4/09/75	14.0(8)	1078.0	
04N/16W-21D01 S	19		1100.0	12/12/74	NM-1		1101
				4/09/75	NM-4		
04N/16W-21H02 S	19		1133.0	10/04/74	NM-3		1101
				11/04/74	NM-3		
				12/09/74	NM-3		
				1/06/75	40.2	1092.8	
				2/14/75	38.9	1094.1	
				3/04/75	39.0	1094.0	
				4/16/75	37.0	1096.0	
				5/06/75	37.0	1096.0	
				6/11/75	41.3	1091.7	
				7/01/75	44.4	1088.6	
				8/07/75	49.4	1083.6	
				9/05/75	49.7	1083.3	
04N/16W-22C07 S	19		1130.0	11/04/74	37.6	1092.4	1101
				4/30/75	27.6	1102.4	
04N/16W-22D02 S	19		1128.0	11/04/74	NM-1		1101
			1128.5	12/18/74	31.2	1097.3	
04N/16W-22D03 S	19		1136.7	11/04/74	45.4	1091.3	1101
				4/28/75	37.2	1099.5	
04N/16W-22M01 S	19		1148.0	11/04/74	NM-1		1101
				12/18/74	NM-1		
				1/15/75	NM-3		
				4/28/75	NM-1		
04N/16W-23A02 S	19		1198.9	11/04/74	24.7	1174.2	1101
				4/30/75	25.5	1173.4	
04N/16W-23G01 S	19		1195.0	11/06/74	25.5	1169.5	1101
				4/30/75	NM-1		
04N/16W-23H01 S	19		1205.4	11/04/74	27.6	1177.8	1101
				4/30/75	29.5	1175.9	
04N/16W-24A05 S	19		1260.1	11/06/74	36.4	1223.7	1101
				5/01/75	39.3	1220.8	
04N/16W-24B03 S	19		1241.0	11/06/74	29.1	1211.9	1101
				5/01/75	32.6	1208.4	
04N/16W-24H01 S	19		1269.0	11/04/74	29.3(6)	1239.7	1101
				4/30/75	DRY		
04N/16W-27H07 S	19		1191.0	11/22/74	98.9	1092.1	1101
				4/02/75	87.5	1103.5	
04N/16W-27J01 S	19		1188.0	11/04/74	91.8	1096.2	1101
				1/06/75	91.9	1096.1	
				3/04/75	90.7	1097.3	
				5/09/75	88.1	1099.9	
				7/01/75	90.0	1098.0	
				9/05/75	93.0	1095.0	
04N/16W-27J03 S	19		1185.0	1/21/75	NM-0		1101
04N/16W-28A01 S	19		1169.5	11/04/74	76.8	1092.7	1101
				4/30/75	73.7	1095.8	
04N/16W-32Q01 S	19		1350.0	11/04/74	69.3	1280.7	1101
				1/06/75	71.7	1278.3	
				3/04/75	72.9	1277.1	
				5/06/75	67.8	1282.2	

See page 79 for key to terms a abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

SANTA CLARA-CALLEGUAS HYDRO UNIT
UPPER SANTA CLARA R HYDRO SUBUNIT
EASTERN HYDRO SUBAREA

U-03
U-03.E
U-03.E1

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
04N/16W-32D01 S (CONTINUED)	19		1350.0	7/01/75	69.7	1280.3	1101
				9/05/75	72.5	1277.5	
04N/16W-33H01 S	19		1257.0	11/04/74	148.7	1108.3	1101
				1/06/75	148.2	1108.8	
				3/04/75	151.5	1105.5	
				4/02/75	151.5	1105.5	
04N/16W-33L01 S	19		1285.0	11/22/74	148.0(8)	1117.0	1101
				4/02/75	151.5(8)	1133.5	
04N/16W-34A03 S	19		1200.0	1/13/75	103.0	1097.0	1101
04N/16W-34J01 S	19		1230.6	11/22/74	NM-8		1101
				1/16/75	NM-1		
				5/01/75	NM-1		
04N/16W-34J02 S	19		1232.0	1/14/75	145.0(2)	1087.0	1101
				5/01/75	130.0(2)	1102.0	
04N/16W-34L01 S	19		1226.4	10/04/74	126.5	1099.9	1101
				11/04/74	126.0	1100.4	
				12/09/74	127.7	1098.7	
				1/06/75	127.5	1098.9	
				2/14/75	127.5	1098.9	
				3/05/75	127.5	1098.9	
				4/02/75	127.2	1099.2	
				5/09/75	125.7	1100.7	
				6/11/75	126.0	1100.4	
				7/02/75	127.0	1099.4	
				8/07/75	127.9	1098.5	
				9/05/75	128.5	1097.9	
04N/16W-34L02 S	19		1227.1	10/04/74	122.7	1104.4	1101
				11/04/74	125.7	1101.4	
				12/09/74	126.4	1100.7	
				1/06/75	125.2	1101.9	
				2/14/75	126.8	1100.3	
				3/05/75	126.4	1100.7	
				4/02/75	125.1	1102.0	
				5/09/75	122.7	1104.4	
				6/11/75	123.2	1103.9	
				7/02/75	122.9	1104.2	
				8/07/75	124.9	1102.2	
				9/05/75	125.8	1101.3	
04N/16W-35K01 S	19		1270.0	11/22/74	167.0	1103.0	1101
				4/16/75	161.0	1109.0	
04N/16W-35L01 S	19		1249.0	1/21/75	NM-0		1101
04N/16W-35M02 S	19		1236.5	1/13/75	236.0(1)	1000.5	1101
04N/16W-36M04 S	19		1286.0	11/22/74	164.7	1121.3	1101
				6/12/75	170.4	1115.6	
04N/16W-36M05 S	19		1286.0	11/22/74	163.0	1123.0	1101
				6/12/75	170.0	1116.0	
04N/16W-36Q01 S	19		1330.0	11/22/74	122.5	1207.5	1101
				4/15/75	125.5	1204.5	
04N/16W-36R01 S	19		1350.0	11/22/74	94.5	1255.5	1101
				4/15/75	94.2	1255.8	
04N/17W-01A01 S	19		1043.4	12/09/74	12.3	1031.1	1101
				4/03/75	NM-1		
04N/17W-01C01 S	19		1060.0	12/09/74	NM-4		1101
				4/03/75	NM-4		
04N/17W-03K02 S	19		1261.0	1/06/75	107.5	1153.5	1101
				4/30/75	NM-1		
				5/01/75	120.5	1140.5	
04N/17W-12B02 S	19		1039.0	12/09/74	20.0	1019.0	1101
				4/03/75	NM-1		
04N/17W-12B03 S	19		1028.5	12/09/74	19.5	1009.0	1101
				4/03/75	19.5	1009.0	
04N/17W-12G01 S	19		1020.6	12/09/74	27.6	993.0	1101
				4/03/75	24.6	996.0	
04N/17W-12P01 S	19		991.9	12/09/74	14.6	977.3	1101
				4/03/75	14.9	977.0	
04N/17W-12P01 S	19		1012.0	12/09/74	19.8	992.2	1101
				4/03/75	19.8	992.2	
04N/17W-12P03 S	19		1013.4	10/04/74	13.5	999.9	1101
				11/04/74	13.5	999.9	
				12/09/74	12.7	1000.7	
				1/06/75	13.4	1000.0	
				2/14/75	13.0	1000.4	
				3/04/75	13.5	999.9	
				4/03/75	13.5	999.9	
				5/06/75	13.0	1000.4	
				6/11/75	12.1	1001.3	
				7/01/75	11.7	1001.7	
				8/07/75	11.7	1001.7	
				9/05/75	12.5	1000.9	

SANTA CLARA-CALLEGUAS HYDRO UNIT
UPPER SANTA CLARA R HYDRO SUBUNIT
EASTERN HYDRO SUBAREA

U-03
U-03.E
U-03.E1

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
04N/17W-13C01 S	19		981.9	12/09/74	8.2	973.7	1101
04N/17W-13C02 S	19		983.8	11/04/74	16.0	967.8	1101
				1/06/75	12.0	971.8	
				3/04/75	13.7	970.1	
				5/06/75	14.0	969.8	
				7/01/75	17.0	966.8	
				9/05/75	19.1	964.7	
04N/17W-13F01 S	19		985.0	12/09/74	NM-5		1101
04N/17W-13E02 S	19		982.0	12/09/74	20.7	961.3	1101
				4/03/75	19.9(8)	962.1	
04N/17W-13J01 S	19		1036.0	12/12/74	NM-5		1101
				4/03/75	66.0	970.0	
04N/17W-14Q02 S	19		958.0	4/03/75	17.7	940.3	1101
04N/17W-14Q03 S	19		957.4	4/03/75	15.9	941.5	1101
04N/17W-15N01 S	19		996.0	12/12/74	FLOW		1101
				4/03/75	FLOW		
04N/17W-22E01 S	19		897.6	12/12/74	1.5	896.1	1101
				4/03/75	1.2	896.4	
04N/17W-22F04 S	19		900.6	12/12/74	7.0	893.6	1101
				4/03/75	6.9	893.7	
04N/17W-23D01 S	19		949.7	12/12/74	18.6	931.1	1101
				4/03/75	18.1	931.6	
04N/17W-28L01 S	19		971.0	11/22/74	5.5	965.5	1101
				4/02/75	1.2	969.8	
05N/14W-29P01 S	19		2265.0	11/19/74	45.4	2219.6	1101
				4/21/75	45.0	2220.0	
05N/14W-30R02 S	19		2040.0	11/19/74	NM-1		1101
				4/27/75	NM-5		
05N/14W-31C02 S	19		1953.0	11/19/74	63.1	1889.9	1101
				4/21/75	64.7	1888.3	
05N/14W-31F04 S	19		1950.0	11/19/74	32.2	1917.8	1101
				4/21/75	33.0	1917.0	
05N/14W-31L01 S	19		1920.0	11/19/74	NM-2		1101
05N/15W-05M01 S	19		1412.0	11/06/74	20.9	1391.1	1101
				4/28/75	21.5	1390.5	
05N/15W-21Q01 S	19		1627.5	11/06/74	25.4	1602.1	1101
				4/28/75	NM-1		
				9/17/75	4.8	1622.7	
05N/15W-28F01 S	19		1600.0	11/06/74	47.5	1552.5	1101
				4/28/75	62.4	1537.6	
05N/15W-28G01 S	19		1625.0	11/06/74	57.4	1567.6	1101
				4/28/75	72.0	1553.0	
05N/15W-32R02 S	19		1492.0	11/06/74	31.7	1460.3	1101
				4/28/75	38.7	1453.3	
05N/15W-33E04 S	19		1513.0	11/06/74	35.6	1477.4	1101
				4/28/75	44.7	1468.3	
05N/15W-33E05 S	19		1528.0	11/06/74	41.3	1486.7	1101
				4/28/75	55.5	1472.5	
05N/15W-33E06 S	19		1495.0	11/06/74	39.9	1455.1	1101
				4/28/75	44.9	1450.1	
05N/15W-33K01 S	19		1610.0	11/06/74	76.4	1533.6	1101
				4/28/75	76.3	1533.7	
05N/16W-34P01 S	19		1233.0	11/04/74	30.7	1202.3	1101
				4/28/75	33.8(8)	1199.2	
05N/16W-34P02 S	19		1235.0	11/04/74	42.5(8)	1192.5	1101
				1/06/75	36.6(8)	1198.4	
				3/04/75	37.6(8)	1197.4	
				5/06/75	39.7(8)	1195.3	
				7/01/75	NM-1		
				9/05/75	45.8	1189.2	
05N/16W-36R03 S	19		1475.0	11/04/74	31.1	1443.9	1101
				4/28/75	NM-7		
05N/17W-24Q01 S	19		1150.0	12/09/74	35.0	1115.0	1101
				4/03/75	37.5	1112.5	
05N/17W-25R02 S	19		1140.0	1/13/75	35.0(1)	1105.0	1101
05N/17W-25B07 S	19		1140.0	4/03/75	NM-2		1101
05N/17W-25B08 S	19		1150.0	12/09/74	38.4	1111.6	1101
				4/03/75	40.6	1109.4	
05N/17W-25G03 S	19		1129.5	11/04/74	26.2	1103.3	1101

See page 79 for key to terms a abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA CLARA-CALLEGUAS HYDRO UNIT						U-03	
UPPER SANTA CLARA R HYDRO SUBUNIT						U-03.E	
EASTERN HYDRO SUBAREA						U-03.E1	
05N/17W-25G03 S (CONTINUED)	19		1129.5	1/06/75	25.3	1104.2	1101
				3/04/75	26.9	1102.6	
				5/06/75	26.6	1102.9	
				7/01/75	21.4	1108.1	
				9/05/75	24.0	1105.5	
05N/17W-25G04 S	19		1135.0	12/09/74	NM-1		1101
				1/06/75	30.9	1104.1	
				4/03/75	NM-9		
05N/17W-25G05 S	19		1129.0	1/17/75	55.5(1)	1073.5	1101
05N/17W-25M02 S	19		1235.0	12/09/74	110.3	1124.7	1101
				4/03/75	112.3	1122.7	
05N/17W-36A03 S	19		1109.0	12/09/74	23.3	1085.7	1101
				4/03/75	23.1	1085.9	
05N/17W-36G03 S	19		1090.0	12/09/74	11.5	1078.5	1101
				4/03/75	11.3	1078.7	
05N/17W-36H04 S	19		1086.2	12/09/74	14.0	1072.2	1101
				4/03/75	NM-1		
05N/17W-36H05 S	19		1099.6	12/09/74	21.0(8)	1078.6	1101
				4/03/75	NM-1		
05N/17W-36J01 S	19		1088.2	12/09/74	14.7	1073.5	1101
				4/03/75	NM-1		
SIERRA PELONA HYDRO SUBAREA						U-03.E4	
05N/14W-13C01 S	19		2825.0	11/26/74	56.9	2768.1	1101
				4/21/75	57.0	2768.0	
05N/14W-14A01 S	19		2825.0	4/21/75	37.8	2787.2	1101
05N/14W-14A02 S	19		2820.0	11/26/74	31.6	2788.4	1101
				4/21/75	32.0	2788.0	
05N/14W-14F02 S	19		2705.0	11/26/74	NM-1		1101
				4/21/75	40.0	2665.0	
05N/14W-22J01 S	19		2575.0	11/26/74	85.3	2489.7	1101
				4/18/75	90.5	2484.5	
05N/14W-23B01 S	19		2653.0	8/26/75	112.7	2540.3	1101
05N/14W-23E01 S	19		2570.0	11/26/74	79.8	2490.2	1101
				4/18/75	80.4	2489.6	
05N/14W-23N02 S	19		2525.0	11/26/74	51.7	2473.3	1101
				4/18/75	49.0	2476.0	
05N/14W-24C01 S	19		2666.7	11/26/74	125.5	2541.2	1101
				4/21/75	NM-5		
05N/14W-25D01 S	19		2664.0	4/18/75	26.2	2637.8	1101
05N/14W-26D02 S	19		2500.0	11/26/74	33.7	2466.3	1101
				4/18/75	32.7	2467.3	
05N/14W-26E01 S	19		2483.0	11/26/74	29.2	2453.8	1101
				4/18/75	NM-4		
05N/14W-26E02 S	19		2490.0	11/26/74	38.3(4)	2451.7	1101
				4/18/75	33.5(4)	2456.5	
05N/14W-26E03 S	19		2480.0	11/26/74	21.6	2458.4	1101
				4/18/75	19.0	2461.0	
05N/14W-26G01 S	19		2565.0	11/26/74	44.5	2520.5	1101
				4/18/75	43.3	2521.7	
05N/14W-27H01 S	19		2500.5	11/26/74	NM-2		1101
				4/18/75	NM-1		
05N/14W-27K01 S	19		2480.0	11/26/74	NM-2		1101
				4/18/75	33.5	2446.5	
ACTON HYDROLOGIC SUBAREA						U-03.E5	
04N/12W-02E02 S	19		3520.0	11/26/74	NM-2		1101
				4/24/75	154.5	3365.5	
04N/12W-11G01 S	19		3735.0	11/26/74	58.5	3676.5	1101
				4/23/75	NM-5		
				8/14/75	65.4	3669.6	
04N/13W-01C02 S	19		2698.0	7/15/75	49.5(5)	2648.5	1101
				8/05/75	49.5(5)	2648.5	
				9/05/75	55.5(5)	2642.5	
04N/13W-07N02 S	19		2155.0	2/20/75	[illegible]-1		5000
04N/13W-10Q01 S	19		2465.0	2/20/75	20.3	2444.7	5000
04N/13W-12C03 S	19		2635.0	2/20/75	24.7	2610.3	5000
04N/13W-13L01 S	19		2960.0	2/20/75	14.0	2946.0	5000
05N/12W-29R02 S	19		2962.0	2/20/75	208.5	2753.5	5000
SANTA CLARA-CALLEGUAS HYDRO UNIT						U-03	
UPPER SANTA CLARA R HYDRO SUBUNIT						U-03.E	
ACTON HYDROLOGIC SUBAREA						U-03.E5	
05N/14W-27R01 S	19		2480.0	11/26/74	17.5	2462.5	1101
				4/18/75	17.5	2462.5	
CALLEGUAS-CONEJO HYDRO SUBUNIT						U-03.F	
WEST LAS POSAS HYDRO SUBAREA						U-03.F1	
02N/21W-01A01 S	56		605.0	4/02/75	526.0	79.0	5121
02N/21W-08G01 S	56		338.0	4/02/75	309.5	28.5	5121
02N/21W-09D01 S	56		350.0	1/27/75	367.4	-17.4	5121
			345.0	3/24/75	351.5	-6.5	
				6/18/75	358.5	-13.5	
				7/28/75	NM-1		
02N/21W-10H01 S	56		329.6	1/27/75	220.1	109.5	5121
				3/24/75	216.5	113.1	
				4/01/75	211.1	118.5	
				5/20/75	210.9	118.7	
				7/28/75	224.7	104.9	
				9/30/75	240.2	89.4	
02N/21W-11J01 S	56		385.8	1/27/75	334.3	51.5	5121
				3/24/75	331.0	54.8	
				5/20/75	331.6	54.2	
				7/28/75	351.8	34.0	
				9/30/75	349.1	36.7	
02N/21W-12F01 S	56		404.6	1/27/75	308.6	96.0	5121
				3/24/75	305.6	99.0	
				5/20/75	307.4	97.2	
				7/28/75	313.8	90.8	
02N/21W-12H01 S	56		413.0	2/11/75	426.4	-13.4	5121
				3/24/75	422.2	-9.2	
				6/06/75	NM-1		
				7/28/75	NM-1		
02N/21W-15A01 S	56		308.5	1/27/75	333.4	-24.9	5121
				3/24/75	334.0	-25.5	
				6/06/75	NM-1		
				7/28/75	335.9	-27.4	
				9/30/75	336.4	-27.9	
02N/21W-15P01 S	56		330.2	1/27/75	380.2	-50.0	5121
				3/24/75	365.2	-35.0	
				5/20/75	381.9	-51.7	
				7/28/75	400.9	-70.7	
				9/30/75	413.1	-82.9	
02N/21W-16J01 S	56		259.4	1/27/75	56.0	203.4	5121
				3/24/75	56.3	203.1	
				5/20/75	54.0	205.4	
				7/28/75	53.2	206.2	
				9/30/75	51.9	207.5	
02N/21W-20J01 S	56		152.0	4/10/75	156.0	-4.0	5121
02N/21W-20Q03 S	56		112.1	1/22/75	NM-6		5121
				3/24/75	NM-6		
				5/20/75	NM-6		
EAST LAS POSAS HYDRO SUBAREA						U-03.F2	
02N/19W-03A01 S	56		582.3	2/11/75	5.0	577.3	5121
				3/25/75	5.1	577.2	
				5/21/75	5.3	577.0	
				7/24/75	5.3	577.0	
02N/19W-04K01 S	56		526.7	2/11/75	71.7	455.0	5121
				3/25/75	69.1	457.6	
				5/21/75	67.1	459.6	
				7/29/75	65.6	461.1	
02N/19W-05H01 S	56		477.6	1/27/75	190.8	286.8	5121
				3/25/75	188.4	289.2	
				5/21/75	186.4	291.2	
				7/29/75	184.7	292.9	
02N/19W-06F01 S	56		615.8	2/11/75	NM-3		5121
02N/19W-06N03 S	56		442.8	2/11/75	76.3	366.5	5121
				3/25/75	75.3	367.5	
				5/21/75	76.5	366.3	
				8/08/75	NM-1		
02N/19W-07A03 S	56		457.0	1/27/75	86.7	370.3	5121
				3/25/75	86.1	370.9	
				5/21/75	85.5	371.5	
				7/28/75	88.4	368.6	
02N/19W-08G03 S	56		491.4	2/11/75	111.5	379.9	5121
				3/25/75	107.7	383.7	
				5/21/75	106.5	384.9	
				7/29/75	NM-1		
02N/20W-02D01 S	56		546.0	4/17/75	446.0	100.0	5121
02N/20W-03B01 S	56		564.0	4/17/75	455.0	109.0	5121
02N/20W-06B01 S	56		557.1	1/27/75	156.5	400.6	5121

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA CLARA-CALLEGUAS HYDRO UNIT						U-03	
CALLEGUAS-CONEJO HYDRO SUBUNIT						U-03.F	
EAST LAS POSAS HYDRO SUBAREA						U-03.F2	
02N/20W-06R01 S (CONTINUED)	56		557.1	3/25/75	156.6	400.5	5121
				5/20/75	156.7	400.4	
				7/28/75	156.9	400.2	
				9/30/75	157.1	400.0	
02N/20W-10G01 S	56		415.1	1/27/75	NM-1		5121
				3/25/75	299.4	115.7	
				6/27/75	296.2	118.9	
				7/28/75	NM-1		
02N/20W-10J01 S	56		400.0	1/27/75	286.1	113.9	5121
			405.0	3/25/75	283.0	122.0	
				5/20/75	277.8	127.2	
				7/28/75	281.4	123.6	
02N/20W-12G02 S	56		420.0	1/27/75	65.3	354.7	5121
				3/25/75	64.2	355.8	
				5/20/75	64.1	355.9	
				7/28/75	68.0	352.0	
02N/20W-12J01 S	56		428.7	1/27/75	189.9	238.8	5121
				3/25/75	188.7	240.0	
				5/20/75	187.3	241.4	
				7/28/75	186.5	242.2	
02N/20W-18A01 S	56		374.6	4/09/75	409.0	-34.4	5121
03N/19W-19J01 S	56		1060.0	3/26/75	768.0	292.0	5121
03N/19W-29E02 S	56		852.0	2/11/75	280.1	571.9	5121
				3/25/75	260.4	591.6	
				5/21/75	262.9	589.1	
				7/29/75	270.1	581.9	
03N/19W-29K04 S	56		852.0	2/11/75	NM-3		5121
				4/01/75	448.0	404.0	
03N/19W-32A01 S	56		815.2	4/02/75	550.0	265.2	5121
03N/19W-32D01 S	56		890.6	4/02/75	623.0	267.6	5121
03N/19W-32G01 S	56		840.0	4/02/75	573.0	267.0	5121
03N/20W-23L01 S	56		1000.0	4/01/75	697.0	303.0	5121
03N/20W-24J01 S	56		1040.0	4/18/75	800.0	240.0	5121
03N/20W-25H01 S	56		835.0	2/11/75	220.5	614.5	5121
			832.0	3/25/75	219.0	613.0	
				5/21/75	220.7	611.3	
				7/29/75	221.8	610.2	
03N/20W-34G01 S	56		690.0	2/11/75	FLOW		5121
ARROYO SANTA ROSA HYDRO SUBAREA						U-03.F3	
02N/19W-19L01 S	56		346.0	1/22/75	62.8	283.2	5121
				3/26/75	65.0	281.0	
				5/27/75	65.1	280.9	
				7/23/75	65.2	280.8	
02N/19W-19R02 S	56		291.4	1/22/75	115.8	175.6	5121
				3/26/75	111.4	180.0	
				5/27/75	113.6	177.8	
				7/29/75	125.7	165.7	
02N/19W-20L01 S	56		304.5	1/22/75	145.3	159.2	5121
				3/26/75	139.5	165.0	
				5/27/75	136.1	168.4	
				7/23/75	144.2	160.3	
02N/19W-21C02 S	56		489.6	1/22/75	75.2	414.4	5121
				3/26/75	73.8	415.8	
				5/27/75	72.7	416.9	
				7/23/75	75.1	414.5	
02N/20W-22H01 S	56		281.6	1/22/75	196.7	84.9	5121
				3/26/75	192.8	88.8	
				5/27/75	190.1	91.5	
02N/20W-23K01 S	56		272.7	1/22/75	180.0	92.7	5121
				3/26/75	170.7	102.0	
				5/27/75	177.6	95.1	
				7/29/75	NM-1		
02N/20W-23P01 S	56		234.6	1/22/75	42.8	191.8	5121
				3/26/75	40.2	194.4	
				5/27/75	44.4	190.2	
				7/23/75	NM-1		
02N/20W-25L01 S	56		235.2	1/22/75	23.9	211.3	5121
				3/26/75	23.0	212.2	
				5/27/75	25.2	210.0	
				7/23/75	29.0	206.2	
02N/20W-26R03 S	56		205.5	1/22/75	15.9	189.6	5121
				3/26/75	15.3	190.2	
				5/27/75	24.0	181.5	
				7/29/75	22.9	182.6	
SANTA CLARA-CALLEGUAS HYDRO UNIT						U-03	
CALLEGUAS-CONEJO HYDRO SUBUNIT						U-03.F	
CONEJO VALLEY HYDRO SUBAREA						U-03.F4	
01N/19W-05N02 S	56		653.7	1/20/75	12.2	641.5	5121
				7/23/75	11.6	642.1	
01N/20W-03J01 S	56		762.9	1/20/75	64.1	698.8	5121
				3/27/75	48.8	714.1	
				5/22/75	54.2	708.7	
				7/23/75	56.0	706.9	
01N/20W-15R03 S	56		720.0	1/20/75	12.2	707.8	5121
				3/27/75	12.2	707.8	
				5/22/75	12.2	707.8	
				7/23/75	12.2	707.8	
TIERRA REJADA VALLEY HYDR SUBAREA						U-03.F5	
02N/19W-10R01 S	56		618.6	1/21/75	190.1	428.5	5121
				3/26/75	189.6	429.0	
				5/22/75	188.8	429.8	
				7/29/75	188.0	430.6	
02N/19W-11J02 S	56		717.2	1/21/75	143.5	573.7	5121
				3/26/75	143.4	573.8	
				5/22/75	145.2	572.0	
				7/29/75	145.5	571.7	
02N/19W-14R01 S	56		677.4	1/22/75	35.5	641.9	5121
				3/26/75	33.5	643.9	
				5/22/75	33.5	643.9	
				7/29/75	NM-1		
02N/19W-15F02 S	56		500.0	1/21/75	172.5	327.5	5121
SIMI VALLEY HYDRO SUBAREA						U-03.F7	
02N/17W-06J01 S	56		1039.4	1/21/75	59.7	979.7	5121
				3/26/75	59.3	980.1	
				5/21/75	57.5	981.9	
				7/24/75	57.5	981.9	
02N/17W-08J03 S	56		1015.5	1/23/75	14.2	1001.3	5121
				3/26/75	13.1	1002.4	
				5/21/75	13.3	1002.2	
				7/24/75	13.7	1001.8	
02N/17W-09N05 S	56		1047.8	1/21/75	16.9	1030.9	5121
				3/26/75	15.0	1032.8	
				5/21/75	15.1	1032.7	
				7/24/75	15.7	1032.1	
02N/18W-07F04 S	56		753.4	1/21/75	65.9	687.5	5121
				3/26/75	66.1	687.3	
				5/22/75	65.3	688.1	
				7/29/75	66.4	687.0	
02N/18W-08C02 S	56		746.4	1/21/75	0.8	745.6	5121
02N/18W-09H01 S	56		777.7	1/21/75	10.6	767.1	5121
				3/26/75	22.3	755.4	
				5/21/75	24.8	752.9	
				7/24/75	29.0	748.7	
02N/18W-09N01 S	56		787.0	1/21/75	25.8	761.2	5121
				3/26/75	26.1	760.9	
				5/21/75	26.3	760.7	
				7/24/75	28.5	758.5	
02N/18W-13C01 S	56		939.2	1/21/75	62.0	877.2	5121
				3/26/75	59.8	879.4	
				5/21/75	58.3	880.9	
				7/24/75	61.3	877.9	
02N/18W-14C03 S	56		883.2	1/25/75	64.2	819.0	5121
				3/26/75	67.0	816.2	
				5/21/75	63.5	819.7	
				7/24/75	63.8	819.4	
THOUSAND OAKS HYDRO SUBAREA						U-03.F8	
01N/19W-02L01 S	56		945.2	1/20/75	70.2	875.0	5121
				3/27/75	69.3	875.9	
				5/22/75	68.5	876.7	
				7/23/75	71.1	874.1	
01N/19W-09H02 S	56		764.0	1/20/75	64.2	699.8	5121
				3/27/75	61.8	702.2	
				5/22/75	61.4	702.6	
				7/23/75	61.5	702.5	
01N/19W-14K04 S	56		907.9	1/20/75	33.5	874.4	5121
				7/23/75	31.0	876.9	
01N/19W-15E01 S	56		902.6	1/20/75	29.9	872.7	5121
				3/27/75	18.2	884.4	
				5/22/75	21.5	881.1	
				7/23/75	28.0	874.6	
02N/18W-31K01 S	56		1148.5	1/20/75	NM-1		5121
				3/27/75	NM-1		
				5/22/75	29.0	1119.5	
				7/23/75	NM-1		
02N/19W-35J01 S	56		1001.4	1/20/75	38.5	962.9	5121

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA CLARA-CALLEGUAS HYDRO UNIT						U-03	
CALLEGUAS-CONEJO HYDRO SUBUNIT						U-03.F	
THOUSAND OAKS HYDRO SUBAREA						U-03.F8	
02N/19W-35J01 S (CONTINUED)	56		1001.4	3/27/75	37.6	963.8	5121
				5/22/75	37.0	964.4	
				7/23/75	39.0	962.4	
MALIBU HYDRO UNIT						U-04	
TOPANGA HYDRO SUBUNIT						U-04.A	
TOPANGA CANYON HYDRO SUBAREA						U-04.A1	
01S/18W-18L02 S			921.0	11/19/74	53.0	868.0	1101
				4/14/75	42.5	878.5	
PIEDRA GORDA CANYON HYDRO SUBAREA						U-04.A4	
01S/17W-36G01 S	19		825.0	11/19/74	350.9	474.1	1101
				4/11/75	350.6	474.4	
01S/17W-36G05 S	19		218.0	11/19/74	NM-1		1101
				12/10/74	NM-1		
				1/08/75	NM-1		
				3/27/75	63.5	154.5	
				4/11/75	63.3	154.7	
				5/07/75	63.5	154.5	
				6/04/75	63.5	154.5	
				7/09/75	63.6	154.4	
				8/06/75	63.5	154.5	
				9/02/75	63.0	155.0	
01S/17W-36H02 S	19		250.0	11/19/74	34.9	215.1	1101
				4/11/75	34.5	215.5	
01S/17W-36K01 S	19		310.0	10/08/74	59.4	250.6	1101
				11/19/74	60.1	249.9	
				12/10/74	60.2	249.8	
				1/08/75	60.4	249.6	
				2/14/75	61.0	249.0	
				3/27/75	60.3	249.7	
				4/11/75	60.6	249.4	
				5/02/75	60.9	249.1	
				6/04/75	60.8	249.2	
				7/09/75	61.1	248.9	
				8/06/75	61.0	249.0	
				9/02/75	61.0	249.0	
LAS FLORES CANYON HYDRO SUBAREA						U-04.A5	
01S/17W-26F01 S			325.0	11/19/74	FLOW		1101
				4/11/75	FLOW		
MALIBU CREEK HYDRO SUBUNIT						U-04.B	
MALIBU CREEK HYDRO SUBAREA						U-04.B1	
01S/17W-29E01 S	19		80.0	11/20/74	7.8	72.2	1101
				4/11/75	10.0	70.0	
01S/17W-29N01 S	19		59.4	11/20/74	15.4	44.0	1101
				4/11/75	15.0	44.4	
01S/17W-29N02 S	19		63.8	11/20/74	12.1	51.7	1101
				4/11/75	11.8	52.0	
01S/17W-29P01 S	19		35.0	11/20/74	17.6	17.4	1101
				4/11/75	17.2	17.8	
01S/17W-32F01 S	19		19.7	11/20/74	11.6	8.1	1101
				4/11/75	11.7	8.0	
01S/17W-32F02 S	19		21.9	11/20/74	12.6	9.3	1101
				4/11/75	12.8	9.1	
01S/17W-32F03 S	19		16.3	11/20/74	9.0	7.3	1101
				4/11/75	9.2	7.1	
01S/17W-32G01 S	19		12.5	11/20/74	7.4	5.1	1101
				4/11/75	7.6	4.9	
01S/17W-32L04 S	19		15.2	11/20/74	8.8	6.4	1101
				4/11/75	8.6	6.6	
01S/17W-32L05 S	19		21.0	11/20/74	13.6	7.4	1101
				4/11/75	13.6	7.4	
01S/17W-32L06 S	19		14.0	11/20/74	6.1	7.9	1101
				4/11/75	6.0	8.0	
01S/17W-32L07 S	19		13.0	11/20/74	7.5	5.5	1101
				4/11/75	7.3	5.7	
01S/17W-32M01 S	19		12.5	11/20/74	2.9	9.6	1101
				4/11/75	0.4(6)	12.1	
LAS VIRGENES CANYON HYDRO SUBAREA						U-04.B2	
01N/17W-30P02 S	19		703.0	11/20/74	24.0	679.0	1101
				4/11/75	24.0	679.0	
01N/17W-31C01 S	19		703.0	11/20/74	24.3	678.7	1101
				4/11/75	24.3	678.7	
01N/18W-24J01 S	19		1120.5	11/20/74	212.9	907.6	1101
				4/11/75	217.0	903.5	
01N/18W-24J02 S	19		1106.4	11/20/74	130.1	976.3	1101
				4/11/75	216.5	889.9	
SHEPWOOD HYDRO SUBAREA						U-04.B6	
01N/19W-19L02 S	19		1082.0	1/20/75	77.6	1004.4	5121
				3/27/75	73.0	1009.0	
				5/22/75	78.5	1003.5	
				7/23/75	76.3	1005.7	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
MALIBU HYDRO UNIT						U-04	
MALIBU CREEK HYDRO SUBUNIT						U-04.B	
SHERWOOD HYDRO SUBAREA						U-04.B6	
01N/19W-28A01 S	19		963.3	1/20/75	19.2	944.1	5121
				3/27/75	2.6	960.7	
				5/22/75	9.2	954.1	
				7/23/75	13.4	949.9	
01N/19W-30A01 S	19		998.2	1/20/75	17.8	980.4	5121
				3/27/75	12.9	985.3	
				5/22/75	NM-1		
				7/23/75	NM-1		
01N/20W-24H02 S	19		1126.0	1/20/75	NM-3		5121
				3/27/75	60.7	1065.3	
				5/22/75	NM-3		
				7/23/75	60.0	1066.0	
POINT DUME HYDRO SUBUNIT						U-04.C	
RAMERA CANYON HYDRO SUBAREA						U-04.C5	
01S/18W-32P01 S	19		120.0	11/19/74	18.5	101.5	1101
				4/14/75	8.5	111.5	
01S/18W-32P02 S	19		135.0	11/19/74	20.6	114.4	1101
				4/14/75	15.7	119.3	
01S/18W-34H01 S	19		125.0	11/20/74	45.4	79.6	1101
				4/14/75	45.3	79.7	
02S/18W-05R01 S	19		100.0	11/19/74	25.3	74.7	1101
				4/14/75	9.4	90.6	
02S/18W-05C02 S	19		100.0	11/19/74	4.7	95.3	1101
				4/14/75	4.1	95.9	
02S/18W-05C04 S	19		100.0	11/19/74	21.8	78.2	1101
				4/14/75	6.8	93.2	
02S/18W-05C05 S	19		125.0	11/19/74	21.9	103.1	1101
				4/14/75	5.8	119.2	
02S/18W-05E01 S	19		200.0	11/19/74	61.4	138.6	1101
				4/14/75	61.6	138.4	
ZUMA CANYON HYDRO SUBAREA						U-04.C6	
01S/18W-31N01 S	19		90.0	11/19/74	65.0	25.0	1101
				4/14/75	42.4	47.6	
02S/18W-06E01 S	19		66.6	11/19/74	42.8	23.8	1101
				4/14/75	31.6	35.0	
02S/18W-06E02 S	19		66.0	11/17/74	46.7	19.3	1101
				4/14/75	35.6	30.4	
02S/18W-06H01 S	19		54.0	11/19/74	32.8	21.2	1101
				4/14/75	31.6	22.4	
02S/18W-06H02 S	19		45.0	11/19/74	27.2	17.8	1101
				4/14/75	14.2	30.8	
TRANCAS CANYON HYDRO SUBAREA						U-04.C7	
01S/19W-29P01 S	19		275.0	11/19/74	9.9	265.1	1101
				4/14/75	7.0	268.0	
01S/19W-35P01 S	19		25.0	11/19/74	21.9	3.1	1101
				4/14/75	13.6	11.4	
01S/19W-35Q02 S	19		23.0	11/19/74	15.8	7.2	1101
				4/14/75	9.2	13.8	
CAMARILLO HYDRO SUBUNIT						U-04.D	
NICHOLAS CANYON HYDRO SUBAREA						U-04.D3	
01S/19W-30N01 S	19		400.0	11/19/74	122.8	277.2	1101
				4/14/75	114.8	285.2	
ARROYO SEQUIT HYDRO SUBAREA						U-04.D4	
01S/20W-25E01 S	19		54.0	11/19/74	24.6(8)	29.4	1101
				4/14/75	7.5(8)	46.5	

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT						U-05	
COASTAL PL OF LA CO HYDRO SUBUNIT						U-05.A	
WEST COAST HYDRO SUBAREA						U-05.A2	
02N/20W-20H03 S	56		218.0	1/20/75	310.4	-92.4	5121
02S/14W-19K02 S	19		57.0	10/30/74	75.9	-18.9	5050
02S/14W-19K03 S	19		57.0	10/30/74	80.8	-23.8	5050
02S/14W-19H02 S	19		30.0	11/08/74	52.4	-22.4	1101
				4/22/75	47.2	-17.2	
02S/14W-19H03 S	19		30.0	11/08/74	DRY (6)		1101
				4/22/75	DRY (6)		
02S/14W-19Q01 S	19		48.9	10/30/74	69.2	-20.3	5050
02S/14W-27H01 S	19		155.0	10/30/74	216.9	-61.9	5050
02S/14W-27P02 S	19		162.0	11/12/74	NM-5		1101
02S/14W-28L01 S	19		124.0	10/23/74	155.3	-31.3	5050
02S/14W-29H01 S	19		90.0	10/30/74	116.5	-26.5	5050
02S/14W-31H01 S	19		91.1	7/08/75	115.9	-24.8	1101
				8/13/75	116.5	-25.4	
02S/14W-31H02 S	19		91.1	7/08/75	107.4	-16.3	1101
02S/14W-32C02 S	19		102.0	10/23/74	124.9	-22.9	5050
02S/14W-32F01 S	19		99.0	10/23/74	122.7	-23.7	5050
02S/14W-34C01 S	19		142.0	10/23/74	218.1	-76.1	5050
02S/14W-34C02 S	19		147.0	10/23/74	223.1	-76.1	5050
02S/14W-34F01 S	19		152.0	10/23/74	226.7	-74.7	5050
02S/14W-34L02 S	19		137.0	10/23/74	224.5	-87.5	5050
02S/15W-34F01 S	19		60.8	11/07/74	61.9	-1.1	1101
				4/22/75	61.5	-0.7	
02S/15W-36H01 S	19		105.2	8/08/75	127.3	-22.1	1101
03S/13W-18G02 S	19		131.2	10/23/74	200.3	-69.1	5050
03S/13W-19D01 S	19		70.0	11/12/74	105.0	-35.0	1101
				4/15/75	105.9	-35.9	
03S/13W-19J03 S	19		72.3	11/12/74	109.8	-37.5	1101
				4/04/75	110.6	-38.3	
03S/13W-19K02 S	19		45.0	10/23/74	78.9	-33.9	5050
03S/13W-29A02 S	19		67.0	10/23/74	106.0	-39.0	5050
03S/13W-29C08 S	19		53.7	10/29/74	128.5	-74.8	5050
03S/13W-29D06 S	19		49.0	10/23/74	117.5	-68.5	5050
03S/13W-29D07 S	19		49.0	10/23/74	118.0	-69.0	5050
03S/13W-29F11 S	19		50.0	10/29/74	85.8(6)	-35.8	5050
03S/13W-29G03 S	19		61.0	10/29/74	100.8	-39.8	5050
03S/13W-29G08 S	19		61.0	10/29/74	123.4	-62.4	5050
03S/13W-30A10 S	19		43.0	10/23/74	112.1	-69.1	5050
03S/13W-30H02 S	19		41.6	11/12/74	69.6	-28.0	1101
				4/04/75	72.0	-30.4	
03S/13W-30J01 S	19		36.2	10/29/74	103.5	-67.3	5050
03S/13W-30J05 S	19		35.0	10/29/74	69.8	-34.8	5050
03S/13W-30K01 S	19		39.5	10/29/74	70.9	-31.4	5050
03S/13W-30Q01 S	19		33.0	10/30/74	48.7	-15.7	5050
03S/13W-30Q07 S	19		30.5	11/12/74	63.3	-32.8	1101
				4/04/75	62.6	-32.1	
03S/13W-31R07 S	19		26.0	10/29/74	70.5	-44.5	5050
03S/13W-31C02 S	19		27.0	11/01/74	75.5	-48.5	5050
03S/13W-31K01 S	19		20.0	10/30/74	NM-7		5050
03S/13W-31H01 S	19		35.0	11/01/74	104.6	-69.6	5050
03S/13W-32C01 S	19		34.9	10/30/74	65.9	-31.0	5050
03S/13W-32E02 S	19		25.0	10/29/74	NM-6		5050
03S/13W-32F02 S	19		46.0	10/30/74	112.9	-66.9	5050
03S/14W-02D01 S	19		136.0	10/22/74	200.7	-64.7	5050
03S/14W-03H01 S	19		91.0	10/22/74	163.1	-72.1	5050
03S/14W-03K01 S	19		76.0	10/22/74	133.0(2)	-57.0	5050

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
COASTAL PL OF LA CO HYDRO SUBUNIT — U-05.A
WEST COAST HYDRO SUBAREA — U-05.A2

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
03S/14W-03K02 S	19		76.0	10/22/74	291.5(1)	-215.5	5050
03S/14W-03K03 S	19		76.0	10/22/74	NH-1		5050
03S/14W-04N01 S	19		74.0	10/22/74	121.6	-47.6	5050
03S/14W-04N02 S	19		74.0	10/03/74	136.1	-62.1	1101
				11/06/74	132.8	-58.8	
				12/03/74	133.4	-59.4	
				1/06/75	130.1	-56.1	
				2/05/75	128.0	-54.0	
				3/12/75	125.6	-51.6	
				4/14/75	124.8	-50.8	
				5/06/75	126.5	-52.5	
				6/09/75	127.9	-53.9	
				7/08/75	130.2	-56.2	
				8/08/75	133.0	-59.0	
				9/05/75	131.9	-57.9	
03S/14W-07R01 S	19		97.7	1/03/75	124.8	-27.1	1101
				8/07/75	126.4	-28.7	
03S/14W-07R02 S	19		97.7	1/03/75	105.7	-8.0	1101
				8/07/75	104.9	-7.2	
03S/14W-07R03 S	19		98.5	8/07/75	104.8	-6.3	1101
03S/14W-07D01 S	19		104.2	7/08/75	103.0	1.2	1101
03S/14W-07D02 S	19		104.2	7/08/75	101.1	3.1	1101
				8/07/75	99.1	5.1	
03S/14W-07H02 S	19		111.2	8/07/75	105.4	5.8	1101
03S/14W-07N01 S	19		125.4	1/06/75	108.9	16.5	1101
				8/13/75	108.3	17.1	
03S/14W-07P01 S	19		104.6	1/06/75	100.0	4.6	1101
				8/07/75	102.0	2.6	
03S/14W-07P02 S	19		104.6	8/07/75	99.4	5.2	1101
03S/14W-07P03 S	19		93.9	8/01/75	123.2	-29.3	1101
03S/14W-07P04 S	19		93.9	8/01/75	98.0	-4.1	1101
03S/14W-07P05 S	19		93.9	8/01/75	98.0	-4.1	1101
03S/14W-09N03 S	19		79.8	10/22/74	120.3	-40.5	5050
03S/14W-09N04 S	19		80.1	10/22/74	NH-1		5050
03S/14W-09N05 S	19		96.4	10/22/74	NH-1		5050
03S/14W-09P01 S	19		81.2	10/22/74	NH-1		5050
03S/14W-10G02 S	19		62.0	10/22/74	121.4	-59.4	5050
03S/14W-11D01 S	19		116.0	10/02/74	146.9	-30.9	1101
				11/04/74	146.3	-30.3	
03S/14W-11G02 S	19		150.0	10/28/74	NH-9		5061
				11/06/74	231.3	-81.3	5050
03S/14W-11J02 S	19		160.0	10/23/74	237.2	-77.2	5050
03S/14W-11N01 S	19		50.0	11/08/74	74.9	-24.9	1101
				4/14/75	74.2	-24.2	
03S/14W-13B02 S	19			10/06/74	227.0	-100.0	5050
03S/14W-13J03 S	19		86.0	10/28/74	162.7(5)	-76.7	5061
				11/06/74	160.1	-77.1	5050
03S/14W-13J04 S	19		82.0	10/28/74	169.5(5)	-87.5	5061
			98.0	11/06/74	185.5	-87.5	5050
03S/14W-14A01 S	19		84.0	10/28/74	140.7(1)	-56.7	5061
				11/06/74	124.4	-40.4	5050
03S/14W-14D01 S	19			11/06/74	111.5	-61.5	5050
03S/14W-15B01 S	19		52.0	11/12/74	89.2(8)	-37.2	1101
03S/14W-17F02 S	19		90.0	11/12/74	105.1	-15.1	1101
				4/14/75	104.7	-14.7	
03S/14W-17G02 S	19		87.0	10/22/74	117.1	-30.1	5050
03S/14W-18B01 S	19		93.7	10/22/74	94.1	-0.4	5050
				7/15/75	92.7	1.0	1101
03S/14W-18C01 S	19		102.0	10/22/74	96.9	5.1	5050
			98.8	8/01/75	93.2	5.6	1101
03S/14W-18K01 S	19		93.0	10/29/74	NH-7		5050
03S/14W-18K04 S	19		87.6	10/22/74	90.2	-2.6	5050
03S/14W-18M02 S	19		98.8	10/02/74	88.9	9.9	1101
				11/26/74	89.3	9.5	

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
COASTAL PL OF LA CO HYDRO SUBUNIT — U-05.A
WEST COAST HYDRO SUBAREA — U-05.A2

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
03S/14W-18M02 S (CONTINUED)	19		98.8	12/26/74	89.7	9.1	1101
				1/29/75	89.8	9.0	
				2/26/75	89.9	8.9	
				3/25/75	89.6	9.2	
				4/30/75	89.3	9.5	
				5/28/75	90.1	8.7	
				6/24/75	91.4	7.4	
				7/29/75	89.9	8.9	
				8/26/75	89.0	9.8	
03S/14W-18N04 S	19		110.0	10/21/74	103.7	6.3	5050
03S/14W-18N05 S	19		112.0	10/21/74	104.3	7.7	5050
03S/14W-19R01 S	19		88.8	8/01/75	94.4	-5.6	1101
03S/14W-19R02 S	19		88.8	8/01/75	90.4	-1.6	1101
03S/14W-19R03 S	19		88.8	8/01/75	91.5	-2.7	1101
03S/14W-19C02 S	19		85.8	10/21/74	75.6	10.2	5050
				8/05/75	82.9	2.9	1101
03S/14W-19C04 S	19		85.8	8/01/75	77.4	8.4	1101
03S/14W-19E01 S	19		148.7	12/23/74	142.7	6.0	1101
				8/01/75	142.2	6.5	
03S/14W-19F02 S	19		148.7	10/31/74	142.7	6.0	5050
				8/01/75	142.2	6.5	1101
03S/14W-19E03 S	19		148.7	8/01/75	136.5	12.2	1101
03S/14W-20P01 S	19		73.8	10/31/74	84.3	-10.5	5050
03S/14W-21R02 S	19		60.5	10/03/74	93.3	-32.8	1101
				11/06/74	93.8	-33.3	
				12/03/74	93.8	-33.3	
				1/06/75	94.2	-33.7	
				2/05/75	94.6	-34.1	
				3/12/75	93.8	-33.3	
				4/23/75	95.0	-34.5	
				5/06/75	94.5	-34.0	
				6/09/75	95.6	-35.1	
				7/08/75	96.2	-35.7	
				8/08/75	98.4	-37.9	
				9/05/75	96.1	-35.6	
03S/14W-21M01 S	19		62.0	10/28/74	NH-9		5061
03S/14W-21R02 S	19		52.0	10/29/74	82.8	-30.8	5050
03S/14W-22A01 S	19		48.0	10/28/74	94.0(5)	-46.0	5061
				11/07/74	87.5	-39.5	5050
03S/14W-22A02 S	19		50.0	10/28/74	209.0(1)	-159.0	5061
				11/07/74	98.2	-48.2	5050
03S/14W-22K01 S	19		50.0	10/29/74	81.9	-31.9	5050
03S/14W-22L01 S	19		51.0	10/28/74	126.2(1)	-75.2	5061
03S/14W-22Q01 S	19		45.0	10/29/74	78.7	-33.7	5050
03S/14W-22P02 S	19		52.0	10/29/74	80.3	-28.3	5050
03S/14W-24F05 S	19		54.5	11/12/74	85.8	-31.3	1101
				4/04/75	84.9	-30.4	
03S/14W-25F03 S	19		38.7	10/23/74	70.5	-31.8	5050
03S/14W-25K06 S	19		30.0	11/18/74	61.5	-31.5	1101
				4/04/75	62.4(4)	-32.4	
03S/14W-25N02 S	19		39.2	11/01/74	69.4	-30.2	5050
03S/14W-25P04 S	19		25.0	10/28/74	154.0(1)	-129.0	5061
				11/06/74	97.0	-72.0	5050
03S/14W-25Q02 S	19		20.6	11/18/74	10.4	10.2	1101
				4/04/75	10.6	10.0	
03S/14W-27C01 S	19		45.0	11/08/74	76.6	-31.6	5050
03S/14W-27Q05 S	19		56.3	10/29/74	84.7	-28.4	5050
03S/14W-29Q03 S	19		88.0	11/06/74	NH-1		5050
03S/14W-29F01 S	19		77.3	10/30/74	91.0(5)	-13.7	1101
				12/04/74	112.0(1)	-34.7	
				2/11/75	113.0(1)	-35.7	
				3/03/75	91.0(5)	-13.7	
				4/07/75	111.0(1)	-33.7	
				5/30/75	113.0(1)	-35.7	
				7/02/75	91.0(5)	-13.7	
				9/08/75	91.0(5)	-13.7	
03S/14W-29J01 S	19		95.0	10/30/74	107.7(5)	-12.7	1101
				12/04/74	132.7(1)	-37.7	
				2/11/75	130.7(1)	-35.7	
				3/03/75	106.7(5)	-11.7	
				4/07/75	129.7(5)	-34.7	

See page 79 for key to terms a abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GARRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT WEST COAST HYDRO SUBAREA						U-05 U-05.A U-05.A2	
03S/14W-29J01 S (CONTINUED)	19		95.0	5/30/75	130.7(1)	-35.7	1101
				7/02/75	105.7(5)	-10.7	
				9/08/75	109.7(5)	-14.7	
03S/14W-29M01 S	19		114.2	11/06/74	124.7	-10.5	5050
03S/14W-29N01 S	19		112.8	11/06/74	122.1	-9.3	5050
03S/14W-30D02 S	19		116.7	11/06/74	117.6	-0.9	5050
				8/13/75	118.9	-2.2	1101
03S/14W-30E01 S	19		156.5	7/15/75	152.3	4.2	1101
03S/14W-30F02 S	19		180.0	10/02/74	182.5	-2.5	1101
				11/26/74	183.5	-3.5	
				12/26/74	181.8	-1.8	
				1/29/75	181.6	-1.6	
				2/26/75	182.0	-2.0	
				3/25/75	181.6	-1.6	
				4/30/75	181.6	-1.6	
				5/28/75	182.6	-2.6	
				6/24/75	183.6	-3.6	
				7/29/75	182.8	-2.8	
				8/26/75	185.0	-5.0	
03S/14W-30G01 S	19		126.0	11/06/74	129.5	-3.5	5050
03S/14W-30H02 S	19		126.0	11/06/74	134.9	-8.9	5050
03S/14W-30H02 S	19		175.6	11/06/74	171.1	4.5	5050
03S/14W-30H03 S	19		226.0	11/06/74	219.1	6.9	5050
			226.1	7/15/75	220.6	5.5	1101
03S/14W-30N01 S	19		182.1	11/06/74	179.0	3.1	5050
03S/14W-31D01 S	19		117.8	11/04/74	112.9	4.9	5050
03S/14W-31E02 S	19		96.9	10/02/74	92.3	4.6	1101
				11/26/74	91.3	5.6	
				12/26/74	91.2	5.7	
				1/29/75	91.1	5.8	
				2/26/75	91.5	5.4	
				3/25/75	91.0	5.9	
				4/30/75	90.4	6.5	
				5/28/75	91.2	5.7	
				6/24/75	92.2	4.7	
				7/29/75	92.3	4.6	
				8/26/75	99.9	-3.0	
03S/14W-31L02 S	19		135.7	7/08/75	129.8	5.9	1101
03S/14W-31L03 S	19		169.0	10/02/74	163.1	5.9	1101
			151.0	11/06/74	146.2	4.8	5050
			169.0	12/26/74	163.1	5.9	1101
				1/29/75	163.0	6.0	
				2/26/75	164.2	4.8	
				3/25/75	162.5	6.5	
			151.0	6/24/75	163.3	5.7	
				7/29/75	164.1	4.9	
				8/26/75	172.5	-3.5	
03S/14W-31L04 S	19		178.3	7/30/75	174.6	3.7	1101
03S/14W-31L05 S	19		152.2	10/02/74	147.5	4.7	1101
				11/26/74	146.6	5.6	
				12/26/74	146.4	5.8	
				1/29/75	146.4	5.8	
				2/26/75	146.7	5.5	
				3/25/75	146.2	6.0	
				4/30/75	145.7	6.5	
				5/28/75	146.4	5.8	
				6/24/75	147.4	4.8	
				7/29/75	147.5	4.7	
				8/26/75	155.4	-3.2	
03S/14W-31Q02 S	19		171.0	11/12/74	DRY		1101
03S/14W-32A02 S	19		95.6	10/30/74	111.8(5)	-16.2	1101
				12/04/74	115.8(1)	-20.2	
				2/11/75	115.8(1)	-20.2	
				3/03/75	110.8(5)	-15.2	
				4/07/75	115.8(1)	-20.2	
				5/30/75	115.8(1)	-20.2	
				7/02/75	111.8(5)	-16.2	
				9/08/75	112.8(5)	-17.2	
03S/14W-32E02 S	19		100.0	10/03/74	23.7	76.3	1101
				11/06/74	23.4	76.6	
				4/14/75	123.3	-23.3	
03S/14W-32P02 S	19		90.0	11/12/74	98.8	-8.8	1101
				3/31/75	97.9	-7.9	
03S/14W-33F01 S	19		120.0	10/29/74	137.9	-17.9	5050
03S/14W-33L01 S	19		90.0	11/08/74	NM-2		5050
03S/14W-33R04 S	19		78.5	11/12/74	99.7	-21.2	1101
				4/04/75	94.2	-15.7	
03S/14W-34R02 S	19		65.0	10/29/74	103.7	-38.7	5050

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GARRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT WEST COAST HYDRO SUBAREA						U-05 U-05.A U-05.A2	
03S/14W-34G02 S	19		63.0	10/01/74	129.5(1)	-66.5	5061
				11/01/74	99.5(5)	-36.5	
03S/14W-34N04 S	19		70.0	10/29/74	103.5	-33.5	5050
03S/14W-35B03 S	19		46.0	11/01/74	72.8	-26.8	5050
03S/14W-35M07 S	19		66.0	10/28/74	95.9	-29.9	5050
03S/15W-01L01 S	19		115.0	10/22/74	113.9	1.1	5050
			121.0	11/14/74	119.5	1.5	1101
03S/15W-01R01 S	19		112.3	10/02/74	105.9	6.4	1101
				11/26/74	105.7	6.6	
				12/26/74	105.3	7.0	
				1/29/75	105.7	6.6	
				2/26/75	105.6	6.7	
				3/25/75	105.4	6.9	
				4/30/75	105.2	7.1	
				5/28/75	109.0	3.3	
				6/24/75	111.3	1.0	
				7/29/75	105.3	7.0	
				8/26/75	105.0	7.3	
03S/15W-02P01 S	19		67.9	11/07/74	NM-5		1101
				4/23/75	62.9	5.0	
03S/15W-02P02 S	19		68.4	11/07/74	NM-5		1101
				4/23/75	62.5	5.9	
03S/15W-11H05 S	19		30.0	10/22/74	25.3	4.7	5050
03S/15W-11H06 S	19		31.0	10/22/74	28.5	2.5	5050
03S/15W-11H07 S	19		39.2	8/08/75	34.9	4.3	1101
03S/15W-11H12 S	19		61.6	8/08/75	56.4	5.2	1101
03S/15W-11H15 S	19		77.3	10/22/74	74.6	2.7	5050
03S/15W-11P01 S	19		114.3	11/07/74	57.0	57.3	1101
03S/15W-11Q01 S	19		106.2	10/22/74	101.2	5.0	5050
				7/08/75	100.4	5.8	1101
03S/15W-12A01 S	19		127.1	10/02/74	116.2	10.9	1101
				11/26/74	115.8	11.3	
				12/26/74	115.7	11.4	
				1/29/75	115.8	11.3	
				2/26/75	115.7	11.4	
				3/25/75	115.4	11.7	
				4/30/75	115.3	11.8	
				5/28/75	122.6	4.5	
				6/24/75	125.1	2.0	
				7/29/75	115.1	12.0	
				8/26/75	114.8	12.3	
03S/15W-12A02 S	19		127.1	10/02/74	122.3	4.8	1101
				11/26/74	122.1	5.0	
				12/26/74	122.1	5.0	
				1/29/75	121.9	5.2	
				2/26/75	122.0	5.1	
				3/25/75	121.7	5.4	
				4/30/75	121.8	5.3	
				5/28/75	122.1	5.0	
				6/24/75	123.3	3.8	
				7/29/75	122.1	5.0	
				8/26/75	121.2	5.9	
03S/15W-12A03 S	19		121.5	10/02/74	111.9	9.6	1101
				11/26/74	111.7	9.8	
				12/26/74	111.4	10.1	
				1/29/75	111.7	9.8	
				2/26/75	111.4	10.1	
				3/25/75	111.2	10.3	
				4/30/75	111.2	10.3	
				5/28/75	117.3	4.2	
				6/24/75	119.8	1.7	
				7/29/75	111.2	10.3	
				8/26/75	111.1	10.4	
03S/15W-12B01 S	19		109.3	10/22/74	99.3	10.0	5050
03S/15W-12G01 S	19		112.6	10/22/74	106.5	6.1	5050
03S/15W-12G02 S	19		107.6	10/22/74	99.1	8.5	5050
03S/15W-12H02 S	19		126.2	10/22/74	114.1	12.1	5050
03S/15W-12H03 S	19		129.9	10/22/74	118.6	11.3	5050
03S/15W-12H04 S	19		119.3	1/02/75	106.9	12.4	1101
				8/20/75	106.0	13.3	
03S/15W-12H05 S	19		119.3	10/02/74	106.9	12.4	1101
				11/26/74	106.6	12.7	
				12/26/74	106.7	12.6	
				1/29/75	106.9	12.4	
				2/26/75	107.7	11.6	
				3/25/75	107.4	11.9	
				4/30/75	106.2	13.1	

See page 79 for key to terms & abbreviations

TABLE C-1
GROUND WATER LEVELS AT WELLS
SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT WEST COAST HYDRO SUBAREA						U-05 U-05.A U-05.A2	
03S/15W-12H05 S (CONTINUED)	19		119.3	5/28/75	113.2	6.1	1101
				6/24/75	116.4	2.9	
				7/29/75	106.0	13.3	
				8/26/75	105.5	13.8	
03S/15W-12H06 S	19		119.3	10/02/74	113.0	6.3	1101
				11/26/74	112.9	6.4	
				12/26/74	113.8	5.5	
				1/29/75	112.7	6.6	
				2/26/75	114.1	5.2	
				3/25/75	112.6	6.7	
				4/30/75	112.6	6.7	
				5/28/75	114.6	4.7	
				6/24/75	114.4	4.9	
				7/29/75	112.8	6.5	
				8/26/75	112.4	6.9	
03S/15W-12J01 S	19		111.2	10/02/74	99.3	11.9	1101
				11/26/74	99.2	12.0	
				12/26/74	99.5	11.7	
				1/29/75	99.7	11.5	
				2/26/75	99.5	11.7	
				3/25/75	99.3	11.9	
				4/30/75	98.9	12.3	
				5/28/75	104.0	7.2	
				6/24/75	106.5	4.7	
				7/29/75	98.3	12.9	
				8/26/75	98.2	13.0	
03S/15W-12J02 S	19		111.2	10/02/74	99.1	12.1	1101
				11/26/74	99.2	12.0	
				12/26/74	99.8	11.4	
				1/29/75	99.9	11.3	
				2/26/75	99.8	11.4	
				3/25/75	99.5	11.7	
				4/30/75	99.3	11.9	
				5/28/75	103.2	8.0	
				6/24/75	105.6	5.6	
				7/29/75	98.8	12.4	
				8/05/75	98.7	12.5	
03S/15W-12J03 S	19		114.5	10/02/74	101.4	13.1	1101
				11/26/74	101.3	13.2	
				12/26/74	101.5	13.0	
				1/29/75	101.9	12.6	
				2/26/75	101.8	12.7	
				3/25/75	101.4	13.1	
				4/30/75	101.2	13.3	
				5/28/75	107.6	6.9	
				6/24/75	110.1	4.4	
				7/29/75	100.5	14.0	
				8/26/75	100.3	14.2	
03S/15W-12J04 S	19		114.5	10/02/74	105.6	8.9	1101
				11/26/74	105.5	9.0	
				12/26/74	105.5	9.0	
				1/29/75	105.5	9.0	
				2/26/75	105.6	8.9	
				3/25/75	105.4	9.1	
				4/30/75	105.3	9.2	
				5/28/75	107.2	7.3	
				6/24/75	109.0	5.5	
				7/29/75	105.2	9.3	
				8/26/75	104.8	9.7	
03S/15W-12P02 S	19		95.9	10/02/74	84.4	11.5	1101
				11/26/74	84.6	11.3	
				12/26/74	85.6	10.3	
				1/29/75	85.6	10.3	
				2/26/75	85.6	10.3	
				3/25/75	85.4	10.5	
				4/30/75	85.0	10.9	
				5/28/75	87.2	8.7	
				6/24/75	89.2	6.7	
				7/29/75	84.3	11.6	
				8/26/75	84.3	11.6	
03S/15W-12R03 S	19		95.9	8/06/75	81.9	14.0	1101
03S/15W-12R04 S	19		95.9	10/02/74	82.3	13.6	1101
				11/26/74	82.4	13.5	
				12/26/74	82.6	13.3	
				1/29/75	82.4	13.5	
				2/26/75	82.7	13.2	
				3/25/75	82.4	13.5	
				4/30/75	82.4	13.5	
				5/28/75	83.1	12.8	
				6/24/75	85.3	10.6	
				7/29/75	82.2	13.7	
				8/26/75	82.0	13.9	
03S/15W-13A04 S	19		122.1	10/21/74	102.5	19.6	5050
03S/15W-13A06 S	19		99.4	10/30/74	88.3	11.1	1101
				11/26/74	88.2	11.2	
				1/29/75	89.4	10.0	
				2/26/75	89.5	9.9	
				3/25/75	89.3	10.1	
				4/30/75	88.8	10.6	
				5/28/75	90.5	8.9	
				6/24/75	92.3	7.1	
				7/29/75	88.1	11.3	

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT WEST COAST HYDRO SUBAREA						U-05 U-05.A U-05.A2	
03S/15W-13A07 S	19		99.4	10/30/74	87.8	11.6	1101
				11/26/74	87.8	11.6	
				1/29/75	88.2	11.2	
				2/26/75	88.3	11.1	
				3/25/75	88.1	11.3	
				4/30/75	87.8	11.6	
				5/28/75	88.8	10.6	
03S/15W-13H02 S	19		104.3	10/21/74	12.8(7)	91.5	5050
03S/15W-13H03 S	19		103.0	10/21/74	18.9(7)	84.1	5050
03S/15W-13H04 S	19		103.8	7/08/75	94.5	9.3	1101
03S/15W-13H05 S	19		103.8	7/08/75	94.6	9.2	1101
				8/05/75	92.9	10.9	
03S/15W-13H06 S	19		103.8	7/08/75	94.4	9.4	1101
03S/15W-13H07 S	19		103.8	8/05/75	93.2	10.6	1101
03S/15W-13H08 S	19		98.2	10/02/74	87.7	10.5	1101
				11/26/74	88.3	9.9	
				12/26/74	89.5	8.7	
				1/29/75	89.6	8.6	
				2/26/75	89.6	8.6	
				3/25/75	89.4	8.8	
				4/30/75	88.7	9.5	
				5/28/75	90.0	8.2	
				6/24/75	91.6	6.6	
				7/29/75	88.1	10.1	
				8/26/75	88.2	10.0	
03S/15W-13H09 S	19		98.2	10/02/74	87.7	10.5	1101
				11/26/74	88.1	10.1	
				12/26/74	88.8	9.4	
				1/29/75	88.9	9.3	
				2/26/75	89.0	9.2	
				3/25/75	88.9	9.3	
				4/30/75	88.1	10.1	
				5/28/75	89.1	9.1	
				6/24/75	90.5	7.7	
				7/29/75	87.6	10.6	
				8/26/75	87.7	10.5	
03S/15W-13J04 S	19		98.8	10/02/74	90.0	8.8	1101
				11/26/74	90.3	8.5	
				12/26/74	90.7	8.1	
				1/29/75	90.9	7.9	
				2/26/75	91.0	7.8	
				3/25/75	90.8	8.0	
				4/30/75	90.0	8.8	
				5/28/75	90.6	8.2	
				6/24/75	91.8	7.0	
				7/29/75	89.3	9.5	
				8/26/75	89.8	9.0	
03S/15W-13R02 S	19		153.2	10/21/74	86.5(7)	66.7	5050
03S/15W-13R03 S	19		133.9	10/21/74	123.4	10.5	5050
03S/15W-13R06 S	19		149.0	10/21/74	139.6	9.4	5050
03S/15W-13R07 S	19		155.9	1/03/75	146.5	9.4	1101
				8/05/75	145.7	10.2	
03S/15W-13R08 S	19		155.7	10/21/74	145.9	9.8	5050
03S/15W-13R09 S	19		155.7	8/05/75	145.6	10.1	1101
03S/15W-13P10 S	19		158.1	10/02/74	148.3	9.8	1101
				11/26/74	149.1	9.0	
				12/26/74	149.4	8.7	
				1/29/75	148.6	9.5	
				2/26/75	149.5	8.6	
				3/25/75	149.4	8.7	
				4/30/75	148.7	9.4	
				5/28/75	149.6	8.5	
				6/24/75	150.8	7.3	
				7/29/75	148.5	9.6	
				8/26/75	149.3	8.8	
03S/15W-13P12 S	19		158.1	10/02/74	139.5	18.6	1101
				11/26/74	139.8	18.3	
				12/26/74	139.8	18.3	
				1/29/75	139.9	18.2	
				2/26/75	140.0	18.1	
				3/25/75	140.0	18.1	
				4/30/75	139.9	18.2	
				5/28/75	140.3	17.8	
				6/24/75	140.4	17.7	
				7/29/75	139.8	18.3	
				8/26/75	140.9	17.2	
03S/15W-14J01 S	19		154.9	10/21/74	148.0	6.9	5050
03S/15W-24F06 S	19		122.4	10/02/74	114.6	7.8	1101
				11/26/74	113.7	8.7	
				12/26/74	114.1	8.3	
				1/29/75	114.0	8.4	
				2/26/75	114.2	8.2	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
COASTAL PL OF LA CO HYDRO SUBUNIT — U-05.A
WEST COAST HYDRO SUBAREA — U-05.A2

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
03S/15W-24F06 S (CONTINUED)	19		122.4	3/25/75	114.1	8.3	1101
				4/30/75	114.3	8.1	
				5/28/75	115.5	6.9	
				6/24/75	114.5	7.9	
				7/29/75	113.3	9.1	
				8/26/75	114.0	8.4	
03S/15W-24G01 S	19		122.4	10/02/74	114.6	7.8	1101
				11/26/74	108.9	13.5	
				12/26/74	109.0	13.4	
				1/29/75	108.6	13.8	
				2/26/75	109.0	13.4	
				3/25/75	108.9	13.5	
				4/30/75	109.5	12.9	
				5/28/75	110.1	12.3	
				6/24/75	108.9	13.5	
				7/29/75	108.4	14.0	
				8/26/75	108.8	13.6	
03S/15W-24H01 S	19		125.9	10/02/74	111.9	14.0	1101
				11/26/74	111.4	14.5	
				12/26/74	111.3	14.6	
				1/29/75	111.2	14.7	
				2/26/75	111.3	14.6	
				3/25/75	111.2	14.7	
				4/30/75	111.6	14.3	
				5/28/75	111.4	14.5	
				6/24/75	111.3	14.6	
				7/29/75	110.7	15.2	
03S/15W-24H02 S	19		125.9	10/02/74	118.1	7.8	1101
				11/26/74	118.2	7.7	
				12/26/74	118.6	7.3	
				1/29/75	118.6	7.3	
				2/26/75	118.8	7.1	
				3/25/75	118.5	7.4	
				4/30/75	119.9	6.0	
				5/28/75	119.6	6.3	
				6/24/75	119.5	6.4	
				7/29/75	117.8	8.1	
03S/15W-24K01 S	19		123.3	10/29/74	114.4	8.9	5050
03S/15W-24M01 S	19		93.0	10/31/74	84.4	8.6	5050
03S/15W-24N01 S	19		120.6	10/02/74	112.9	7.7	1101
				11/26/74	113.1	7.5	
				12/26/74	112.4	8.2	
				1/29/75	111.9	8.7	
				2/26/75	112.2	8.4	
				3/25/75	112.2	8.4	
				4/30/75	112.2	8.4	
				5/28/75	112.5	8.1	
				6/24/75	113.3	7.3	
				7/29/75	111.9	8.7	
				8/26/75	112.1	8.5	
03S/15W-24P01 S	19		119.9	10/02/74	111.4	8.5	1101
				11/26/74	110.6	9.3	
				12/26/74	111.6	8.3	
				1/29/75	110.6	9.3	
				2/26/75	110.8	9.1	
				3/25/75	110.7	9.2	
				4/30/75	110.7	9.2	
				5/28/75	111.4	8.5	
				6/24/75	111.1	8.8	
				7/29/75	110.3	9.6	
				8/26/75	110.5	9.4	
03S/15W-24P02 S	19		162.9	10/31/74	154.9	8.0	5050
03S/15W-25A03 S	19		156.0	12/12/74	NM-5		1101
				1/14/75	152.9	3.1	
				3/31/75	NM-5		
03S/15W-25B01 S	19		182.7	8/12/75	174.4	8.3	1101
03S/15W-25B02 S	19		126.5	11/04/74	120.6	5.9	5050
03S/15W-25B03 S	19		161.4	7/08/75	154.7	6.7	1101
03S/15W-25C03 S	19		112.9	10/02/74	104.8	8.1	1101
				11/26/74	104.5	8.4	
				12/26/74	104.8	8.1	
				1/29/75	104.0	8.9	
				2/26/75	104.6	8.3	
				3/25/75	104.4	8.5	
				4/30/75	104.3	8.6	
				5/28/75	104.5	8.4	
				6/24/75	104.8	8.1	
				7/29/75	104.4	8.5	
				8/26/75	105.0	7.9	
03S/15W-25C04 S	19		136.8	11/04/74	128.0	8.8	5050
03S/15W-25C05 S	19		103.8	11/04/74	98.2	5.6	5050
03S/15W-25D01 S	19		82.7	11/04/74	78.3	4.4	5050
03S/15W-25D02 S	19		22.6	11/04/74	20.8	1.8	5050
03S/15W-25G03 S	19		90.0	10/02/74	84.3	5.7	1101

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
COASTAL PL OF LA CO HYDRO SUBUNIT — U-05.A
WEST COAST HYDRO SUBAREA — U-05.A2

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
03S/15W-25G03 S (CONTINUED)	19		90.0	11/26/74	83.9	6.1	1101
				12/26/74	84.1	5.9	
				2/26/75	83.8	6.2	
				3/25/75	84.0	6.0	
				4/30/75	83.3	6.7	
				5/28/75	84.7	5.3	
				6/24/75	83.7	6.3	
				7/29/75	83.7	6.3	
				8/26/75	85.3	4.7	
03S/15W-25G07 S	19		145.4	7/15/75	138.0	7.4	1101
03S/15W-25G09 S	19		86.0	11/04/74	78.2	7.8	5050
03S/15W-25G10 S	19		146.5	7/08/75	140.6	5.9	1101
03S/15W-25H03 S	19		209.1	10/02/74	202.4	6.7	1101
				11/04/74	202.1	7.0	5050
				12/26/74	202.1	7.0	1101
				1/29/75	201.7	7.4	
				2/26/75	201.8	7.3	
				3/25/75	201.6	7.5	
				4/30/75	201.3	7.8	
				5/28/75	201.7	7.4	
				6/24/75	202.4	6.7	
				7/29/75	201.9	7.2	
				8/26/75	204.0	5.1	
03S/15W-25K03 S	19		90.0	7/03/75	81.5	8.5	1101
03S/15W-25K07 S	19		135.4	12/18/74	128.3	7.1	1101
				7/08/75	128.8	6.6	
03S/15W-25K14 S	19		71.0	10/02/74	63.7	7.3	1101
				1/29/75	63.9	7.1	
				2/26/75	63.2	7.8	
				3/25/75	62.9	8.1	
				5/28/75	62.8	8.2	
				6/24/75	64.0	7.0	
				7/29/75	63.2	7.8	
				8/26/75	66.9	4.1	
03S/15W-25K18 S	19		78.0	11/26/74	70.3	7.7	1101
				12/12/74	70.6	7.3	
			77.9	3/31/75	69.6	8.3	
				8/26/75	73.8	4.1	
03S/15W-25L01 S	19		73.4	8/12/75	66.6	6.8	1101
03S/15W-25L02 S	19		94.4	10/02/74	87.5	6.9	1101
				11/04/74	87.5	6.9	5050
				1/29/75	87.3	7.1	1101
				2/26/75	87.3	7.1	
				3/25/75	87.0	7.4	
				4/30/75	86.6	7.8	
				5/28/75	86.8	7.6	
				6/24/75	87.8	6.6	
				7/29/75	87.0	7.4	
				8/26/75	90.1	4.3	
03S/15W-25P01 S	19		73.0	11/01/74	67.9	5.1	5050
03S/15W-25Q03 S	19		72.5	11/07/74	65.6	6.9	5050
03S/15W-25R01 S	19		137.8	7/08/75	131.3	6.5	1101
03S/15W-25R02 S	19		76.4	11/07/74	172.3	5.7	5050
03S/15W-25R04 S	19		70.6	10/02/74	62.4	8.2	1101
				11/01/74	62.3	8.3	5050
				12/26/74	61.8	8.8	1101
				1/29/75	61.4	9.2	
				2/26/75	61.5	9.1	
				3/25/75	61.2	9.4	
				4/30/75	60.5	10.1	
				5/28/75	61.1	9.5	
				6/24/75	63.0	7.6	
				7/29/75	62.2	8.4	
03S/15W-27L01 S	19		62.0	11/04/74	74.5	-12.5	1101
				1/02/75	65.5	-3.5	
				3/05/75	67.5	-5.5	
				5/01/75	72.5	-10.5	
				7/07/75	85.5	-23.5	
				9/02/75	136.5(1)	-74.5	
03S/15W-36A02 S	19		64.2	10/02/74	58.4	5.8	1101
				11/01/74	58.3	5.9	5050
				12/26/74	57.5	6.7	1101
				2/26/75	57.5	6.7	
				3/25/75	57.1	7.1	
				4/30/75	56.3	7.9	
				5/28/75	56.9	7.3	
				6/24/75	58.2	6.0	
				7/29/75	57.7	6.5	
				8/26/75	63.5	0.7	
03S/15W-36H03 S	19		58.2	10/02/74	53.2	5.0	1101
				11/26/74	52.5	5.7	
				12/26/74	52.3	5.9	
				1/29/75	52.0	6.2	
				2/26/75	52.2	6.0	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT WEST COAST HYDRO SUBAREA						U-05 U-05.A U-05.A2	
03S/15W-36H03 S (CONTINUED)	19		58.2	3/25/75	51.8	6.4	1101
				4/30/75	50.9	7.3	
				5/28/75	51.6	6.6	
				6/24/75	52.8	5.4	
				7/29/75	52.2	6.0	
				8/26/75	58.4	-0.2	
04S/12W-30R01 S	19		15.6	10/26/74	97.6	-82.0	5050
			7.7	11/15/74	16.3	-8.6	1101
04S/12W-32G01 S	19		38.0	10/18/74	44.0	-6.0	4206
				11/29/74	43.2	-5.2	
				12/20/74	44.0	-6.0	
				3/14/75	45.0	-7.0	
				4/25/75	44.1	-6.1	
				5/16/75	44.0	-6.0	
				6/27/75	44.2	-6.2	
				7/18/75	44.2	-6.2	
				8/22/75	44.3	-6.3	
				9/19/75	44.0	-6.0	
04S/13W-02P01 S	19		38.7	10/24/74	66.2	-27.5	5050
04S/13W-05L01 S	19		25.5	10/03/74	101.6(8)	-76.1	1101
				11/06/74	101.7(8)	-76.2	
				12/03/74	102.6(8)	-77.1	
				1/06/75	101.6(8)	-76.1	
				2/05/75	100.6(8)	-75.1	
				3/12/75	98.3(8)	-72.8	
				4/14/75	98.8(8)	-73.3	
				5/06/75	99.0(8)	-73.5	
				6/09/75	97.7(8)	-72.2	
				7/08/75	101.8(8)	-76.3	
				8/07/75	104.1(8)	-78.6	
				9/03/75	103.1(8)	-77.6	
04S/13W-06Q01 S	19		22.0	10/30/74	NM-4		5050
04S/13W-07H01 S	19		20.3	10/03/74	90.1(8)	-69.8	1101
				11/18/74	90.6(8)	-70.3	
04S/13W-08G02 S	19		8.9	11/18/74	50.5	-41.6	1101
				4/07/75	50.3	-41.4	
04S/13W-08J03 S	19		18.0	4/07/75	13.1	4.9	1101
04S/13W-08J04 S	19		18.0	10/03/74	13.3	4.7	1101
				11/18/74	13.4	4.6	
04S/13W-08R01 S	19		12.1	11/18/74	25.0	-12.9	1101
				4/07/75	24.5	-12.4	
04S/13W-08R02 S	19		13.5	4/07/75	62.3	-48.8	1101
04S/13W-09F01 S	19		23.0	10/03/74	10.8	12.2	1101
				11/18/74	11.3	11.7	
				4/07/75	NM-9		
04S/13W-09H02 S	19		25.7	11/12/74	139.8	-114.1	5050
04S/13W-10R02 S	19		30.0	11/08/74	58.9	-28.9	5050
04S/13W-10C02 S	19		27.1	10/01/74	129.0	-101.9	5061
				11/04/74	130.0	-102.9	
04S/13W-10E02 S	19		25.0	11/12/74	61.1	-36.1	5050
04S/13W-10E03 S	19		26.0	11/12/74	83.5	-57.5	5050
04S/13W-10L01 S	19		28.0	11/18/74	16.3	11.7	1101
				4/08/75	NM-9		
04S/13W-11R01 S	19		35.0	10/18/74	62.4	-27.4	4206
				11/23/74	63.0	-28.0	5050
				12/20/74	62.9	-27.9	4206
				1/31/75	62.4	-27.4	
				2/21/75	62.1	-27.1	
				3/14/75	NM-9		
				4/25/75	61.4	-26.4	
				5/16/75	60.4	-25.4	
			33.3	6/27/75	61.0	-27.7	
				7/18/75	61.6	-28.3	
				8/22/75	61.9	-28.6	
				9/19/75	62.8	-29.5	
04S/13W-11E02 S	19		31.0	10/24/74	NM-4		5050
04S/13W-11K01 S	19		34.6	11/15/74	61.6	-27.0	1101
				4/08/75	60.6	-26.0	
04S/13W-11K03 S	19		34.0	10/24/74	68.0	-34.0	5050
04S/13W-14H03 S	19		43.2	11/15/74	73.8	-30.6	1101
				4/07/75	72.5	-29.3	
04S/13W-14L01 S	19		29.0	10/02/74	58.6	-29.6	4206
				11/08/74	64.1	-35.1	5050
				12/20/74	58.5	-29.5	4206
				1/15/75	62.7	-33.7	
			28.5	2/20/75	57.6	-29.1	5000
			29.0	3/19/75	62.6	-33.6	4206
				4/09/75	60.8	-31.8	
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT WEST COAST HYDRO SUBAREA						U-05 U-05.A U-05.A2	
04S/13W-14L01 S (CONTINUED)	19		27.4	5/21/75	56.1	-28.7	4206
				6/25/75	55.9	-28.5	
			28.5	7/29/75	56.8	-28.3	5000
			27.4	8/20/75	55.7	-28.3	4206
				9/24/75	55.8	-28.4	
04S/13W-14Q08 S	19		25.9	11/15/74	5.5	20.4	1101
				4/07/75	2.4	23.5	
04S/13W-15A11 S	19		27.0	11/12/74	125.1	-98.1	5050
04S/13W-15B05 S	19		26.0	11/12/74	128.7	-102.7	5050
04S/13W-15B07 S	19		27.0	11/06/74	133.2	-106.2	5050
04S/13W-15C01 S	19		24.0	11/08/74	128.7	-104.7	5050
04S/13W-15N01 S	19		20.0	10/02/74	167.8	-147.8	5061
				11/02/74	154.8	-134.8	
04S/13W-15Q01 S	19		22.0	11/08/74	59.3	-37.3	5050
04S/13W-15Q05 S	19		25.0	11/15/74	62.4	-37.4	1101
				4/07/75	62.4	-37.4	
04S/13W-15R03 S	19		20.0	11/08/74	53.6	-33.6	5050
04S/13W-16F02 S	19		16.3	11/18/74	44.2	-27.9	1101
				4/07/75	43.6	-27.3	
04S/13W-16J04 S	19		17.2	4/07/75	63.5	-46.3	1101
04S/13W-16R02 S	19		25.0	10/31/74	126.0	-101.0	5061
				11/08/74	126.0	-101.0	5050
04S/13W-17D01 S	19		27.0	11/06/74	130.4(1)	-103.4	5050
04S/13W-19R01 S	19		40.0	10/30/74	99.1	-59.1	5050
04S/13W-19J02 S	19		44.3	10/03/74	105.5	-61.2	1101
				11/06/74	102.5	-58.2	
				12/03/74	107.3	-63.0	
				1/06/75	107.2	-62.9	
				2/05/75	106.6	-62.3	
				3/12/75	105.0	-60.7	
				4/14/75	105.7	-61.4	
				5/08/75	103.3	-59.0	
				6/09/75	102.5	-58.2	
				7/08/75	106.2	-61.9	
				8/07/75	NM-4		
				9/05/75	107.4	-63.1	
04S/13W-19J06 S	19		40.0	10/30/74	99.0(4)	-59.0	5050
04S/13W-20K01 S	19		37.0	11/07/74	104.5	-67.5	5050
04S/13W-21A01 S	19		16.0	11/18/74	40.2	-24.2	1101
				4/07/75	40.4	-24.4	
04S/13W-21H02 S	19		35.0	10/31/74	131.1	-96.1	5061
				11/08/74	131.1	-96.1	5050
04S/13W-21H03 S	19		34.0	11/18/74	81.1(8)	-47.1	1101
04S/13W-21H05 S	19		21.0	10/31/74	116.6	-95.6	5061
				11/08/74	116.6	-95.6	5050
04S/13W-21H06 S	19		20.0	10/31/74	116.8	-96.8	5061
				11/08/74	116.8	-96.8	5050
04S/13W-21H07 S	19		30.0	10/31/74	122.8	-92.8	5061
				11/08/74	122.8	-92.8	5050
04S/13W-21J02 S	19		34.0	10/31/74	129.3	-95.3	5061
				11/08/74	132.1	-98.1	5050
04S/13W-21P01 S	19		31.0	11/07/74	126.5	-95.5	5050
04S/13W-21P02 S	19		39.8	11/07/74	143.0	-103.2	5050
04S/13W-22E01 S	19		20.0	10/31/74	116.2	-96.2	5061
				11/08/74	NM-1		5050
04S/13W-22F01 S	19		20.0	10/31/74	116.2	-96.2	5061
				11/08/74	NM-1		5050
04S/13W-22F02 S	19		19.0	10/01/74	NM-9		5061
				11/05/74	NM-9		
04S/13W-22G05 S	19		18.7	11/15/74	47.7	-27.9	1101
			19.8	4/07/75	48.6	-28.8	
04S/13W-22K14 S	19		17.1	11/15/74	35.4	-18.3	1101
				4/07/75	36.0	-18.9	
04S/13W-22K15 S	19		17.3	11/15/74	47.9	-30.6	1101
				4/07/75	47.6	-30.3	
04S/13W-22K16 S	19		17.0	11/15/74	29.9	-12.9	1101
				4/07/75	30.0	-13.0	
04S/13W-22K19 S	19		16.3	11/15/74	37.9	-21.6	1101

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT WEST COAST HYDRO SUBAREA						U-05 U-05.A U-05.A2	
04S/13W-22K19 S	19		16.3	4/07/75	38.0	-21.7	1101
04S/13W-22K30 S	19		15.9	11/15/74	51.7	-35.8	1101
				4/07/75	51.2	-35.3	
04S/13W-22P01 S	19		16.0	10/01/74	109.8	-93.8	5061
				11/01/74	110.5	-94.5	
04S/13W-22Q03 S	19		15.3	10/23/74	110.2	-94.9	5050
04S/13W-22Q04 S	19		15.5	10/23/74	110.1	-94.6	5050
04S/13W-22Q05 S	19		15.9	10/23/74	47.3	-31.4	5050
04S/13W-22Q06 S	19		13.3	10/29/74	51.9	-38.6	1101
				11/25/74	52.5	-39.2	
				12/23/74	52.6	-39.3	
				1/28/75	52.4	-39.1	
				2/25/75	52.6	-39.3	
				3/24/75	52.3	-39.0	
				4/28/75	52.2	-38.9	
				5/27/75	51.6	-38.3	
				6/23/75	52.1	-38.8	
				7/28/75	52.6	-39.3	
				8/25/75	52.5	-39.2	
				9/30/75	52.8	-39.5	
04S/13W-22Q07 S	19		13.3	10/29/74	51.3	-38.0	1101
				11/25/74	51.7	-38.4	
				12/23/74	51.8	-38.5	
				1/28/75	51.9	-38.6	
				2/25/75	51.7	-38.4	
				3/24/75	51.6	-38.3	
				4/28/75	51.2	-37.9	
				5/27/75	50.7	-37.4	
				6/23/75	51.1	-37.8	
				7/28/75	51.5	-38.2	
				8/25/75	51.5	-38.2	
				9/30/75	51.7	-38.4	
04S/13W-22Q08 S	19		13.3	12/12/74	52.4	-39.1	1101
04S/13W-23A02 S	19		35.7	10/23/74	73.0	-37.3	5050
04S/13W-23B02 S	19		24.5	10/02/74	122.2	-97.7	4206
				11/06/74	122.3	-97.8	
				12/04/74	121.3	-96.8	
				1/08/75	121.8	-97.3	
				2/05/75	118.5	-94.0	
				3/05/75	116.3	-91.8	
				4/02/75	116.3	-91.8	
				5/07/75	117.7	-93.2	
				6/04/75	114.9	-90.4	
				7/02/75	122.1	-97.6	
				8/06/75	125.2	-100.7	
				9/03/75	124.2	-99.7	
04S/13W-23G02 S	19		23.2	1/22/75	121.5	-98.3	5000
				2/20/75	119.3	-96.1	
				3/19/75	115.6	-92.4	
				4/23/75	118.5	-95.3	
				5/21/75	114.7	-91.5	
				6/18/75	118.0	-94.8	
				7/29/75	124.5	-101.3	
				8/20/75	124.4	-101.2	
				9/17/75	125.3	-102.1	
04S/13W-23N03 S	19		17.4	10/23/74	111.5	-94.1	5050
04S/13W-23N04 S	19		17.5	10/23/74	44.6	-27.1	5050
04S/13W-25F01 S	19		13.1	10/28/74	37.3	-24.2	5050
04S/13W-26A02 S	19		32.0	10/28/74	127.3	-95.3	5050
04S/13W-26A03 S	19		32.3	11/15/74	60.0	-27.7	1101
04S/13W-26A04 S	19		31.8	10/28/74	57.4	-25.6	5050
04S/13W-26F05 S	19		12.5	11/12/74	108.0	-95.5	5050
04S/13W-26F07 S	19		12.8	11/12/74	37.5	-24.7	5050
04S/13W-26P02 S	19		10.3	10/18/74	31.9	-21.6	4206
				11/12/74	31.9	-21.6	5050
				12/20/74	32.1	-21.8	4206
				3/14/75	32.3	-22.0	
				4/25/75	32.7	-22.4	
				5/16/75	32.5	-22.2	
			7.0	6/27/75	30.9	-23.9	
				7/18/75	NM-9		
				8/22/75	NM-9		
				9/19/75	NM-9		
04S/13W-26R02 S	19		28.0	10/28/74	122.5	-94.5	5050
04S/13W-26R03 S	19		27.4	10/28/74	50.2	-22.8	5050
04S/13W-27B02 S	19		14.9	10/31/74	48.4	-33.5	1101
				11/26/74	48.9	-34.0	
				1/03/75	50.7	-35.8	
				2/06/75	50.2	-35.3	

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT WEST COAST HYDRO SUBAREA						U-05 U-05.A U-05.A2	
04S/13W-27B02 S (CONTINUED)	19		14.9	3/28/75	49.8	-34.9	1101
				4/22/75	49.9	-35.0	
				5/29/75	49.1	-34.2	
				6/27/75	49.6	-34.7	
				7/29/75	50.0	-35.1	
				8/28/75	50.1	-35.2	
04S/13W-27B03 S	19		14.9	10/31/74	42.4	-27.5	1101
				11/26/74	42.6	-27.7	
				1/03/75	43.1	-28.2	
				2/06/75	43.7	-28.8	
				3/28/75	43.2	-28.3	
				4/22/75	43.4	-28.5	
				5/29/75	42.4	-27.5	
				6/27/75	42.8	-27.9	
				7/29/75	43.2	-28.3	
				8/28/75	43.1	-28.2	
04S/13W-27B04 S	19		14.9	10/31/74	36.9	-22.0	1101
				11/26/74	37.5	-22.6	
				1/03/75	37.7	-22.8	
				2/06/75	41.6	-26.7	
				3/28/75	40.2	-25.3	
				4/22/75	40.8	-25.9	
				5/29/75	39.6	-24.7	
				6/27/75	39.5	-24.6	
				7/29/75	39.9	-25.0	
				8/28/75	39.7	-24.8	
04S/13W-27B05 S	19		14.7	10/29/74	47.3	-32.6	1101
				11/25/74	47.7	-33.0	
				12/23/74	47.9	-33.2	
				1/28/75	47.8	-33.1	
				2/25/75	47.5	-32.8	
				3/24/75	47.2	-32.5	
				4/28/75	47.0	-32.3	
				5/27/75	46.1	-31.4	
				6/23/75	46.5	-31.8	
				7/28/75	46.7	-32.0	
				8/25/75	46.7	-32.0	
				9/30/75	46.9	-32.2	
04S/13W-27D02 S	19		31.3	12/12/74	74.1	-42.8	1101
04S/13W-27D06 S	19		13.7	6/23/75	53.4	-39.7	1101
				7/28/75	54.5	-40.8	
				8/25/75	54.8	-41.1	
				9/30/75	54.9	-41.2	
04S/13W-27E01 S	19		39.2	10/28/74	130.7	-91.5	5050
04S/13W-27E02 S	19		39.0	10/28/74	82.2	-43.2	5050
				11/26/74	82.3	-43.3	1101
				1/03/75	82.7	-43.7	
				6/27/75	82.0	-43.0	
				7/29/75	82.7	-43.7	
				8/28/75	82.8	-43.8	
04S/13W-27H01 S	19		14.0	10/31/74	39.4	-25.4	5050
			11.2	3/14/75	37.6	-26.4	4206
				4/25/75	37.8	-26.6	
			11.6	5/16/75	37.6	-26.0	
			11.2	6/27/75	37.0	-25.8	
				7/18/75	37.4	-26.2	
				8/22/75	37.1	-25.9	
				9/19/75	37.2	-26.0	
04S/13W-27H02 S	19		13.4	6/27/75	47.6	-34.2	1101
				7/29/75	47.9	-34.5	
				8/28/75	47.8	-34.4	
04S/13W-27J02 S	19		8.9	6/27/75	34.9	-26.0	1101
				7/29/75	35.0	-26.1	
				8/28/75	35.1	-26.2	
04S/13W-27K02 S	19		9.8	10/29/74	102.1	-93.1	5050
04S/13W-27K03 S	19		13.8	10/29/74	51.1	-37.3	5050
04S/13W-27K04 S	19		14.2	6/27/75	52.8	-38.6	1101
				7/29/75	53.6	-39.4	
				8/28/75	53.6	-39.4	
04S/13W-27K05 S	19		14.2	6/27/75	37.7	-23.5	1101
				7/29/75	38.1	-23.9	
				8/28/75	37.9	-23.7	
04S/13W-27M01 S	19		30.4	10/01/74	NM-9		5061
				11/05/74	NM-9		
04S/13W-27M03 S	19		31.2	10/01/74	NM-9		5061
				11/05/74	NM-9		
04S/13W-27M04 S	19		32.7	10/01/74	NM-9		5061
				11/05/74	NM-9		
04S/13W-27M05 S	19		21.0	10/01/74	NM-9		5061
				11/05/74	NM-7		
04S/13W-27N04 S	19		28.9	12/12/74	NM-5		1101
04S/13W-27N05 S	19		28.0	10/01/74	122.8	-94.8	5061

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
COASTAL PL OF LA CO HYDRO SUBUNIT — U-05.A
WEST COAST HYDRO SUBAREA — U-05.A2

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
04S/13W-27N05 S	19		28.0	11/05/74	NM-9		5061
04S/13W-27P02 S	19		10.8	10/31/74	102.2	-91.4	5050
04S/13W-27P03 S	19		10.5	10/31/74	53.9	-43.4	5050
04S/13W-27P07 S	19		13.7	6/23/75	49.9	-36.2	1101
				7/28/75	50.7	-37.0	
				8/25/75	51.0	-37.3	
				9/30/75	51.1	-37.4	
04S/13W-27P08 S	19		13.7	6/23/75	35.3	-21.6	1101
				7/28/75	35.3	-21.6	
				8/25/75	35.0	-21.3	
				9/30/75	35.2	-21.5	
04S/13W-28A01 S	19		34.9	10/31/74	88.5	-53.6	1101
				11/26/74	89.4	-54.5	
				1/03/75	89.6	-54.7	
				2/06/75	89.3	-54.4	
				3/28/75	89.3	-54.4	
				4/22/75	88.9	-54.0	
				5/29/75	88.3	-53.4	
				6/27/75	90.1	-55.2	
				7/29/75	91.0	-56.1	
				8/28/75	91.3	-56.4	
04S/13W-28A02 S	19		34.9	12/12/74	86.3	-51.4	1101
04S/13W-28J01 S	19		33.4	10/29/74	77.5	-44.1	1101
				11/25/74	78.7	-45.3	
				12/23/74	79.1	-45.7	
				6/23/75	78.2	-44.8	
				7/28/75	80.2	-46.8	
				8/25/75	80.6	-47.2	
				9/30/75	80.6	-47.2	
04S/13W-28J02 S	19		33.4	10/29/74	74.7	-41.3	1101
				11/25/74	75.3	-41.9	
				12/23/74	79.1	-45.7	
				6/23/75	75.3	-41.9	
				7/28/75	76.1	-42.7	
				8/25/75	76.3	-42.9	
				9/30/75	76.4	-43.0	
04S/13W-28L02 S	19		42.6	12/11/74	88.2	-45.6	1101
04S/13W-28L03 S	19		42.6	12/11/74	87.0	-44.4	1101
04S/13W-28N01 S	19		46.1	10/03/74	95.3	-49.2	1101
				11/06/74	95.0	-48.9	
				12/03/74	95.8	-49.7	
				1/06/75	95.9	-49.8	
				7/08/75	94.6	-48.5	
				8/07/75	NM-9		
				9/05/75	95.4	-49.3	
04S/13W-28N02 S	19		45.0	10/22/74	87.4	-42.4	5050
04S/13W-28N04 S	19		37.0	10/23/74	116.1	-79.1	5050
04S/13W-28N06 S	19		37.7	10/23/74	89.2	-51.5	5050
04S/13W-28R01 S	19		26.1	11/08/74	69.2	-43.1	1101
04S/13W-28R02 S	19		29.3	12/11/74	NM-9		1101
04S/13W-29E03 S	19		41.0	11/07/74	100.3	-59.3	5050
04S/13W-29H02 S	19		40.6	11/07/74	112.5	-71.9	5050
04S/13W-29H03 S	19		40.2	11/07/74	43.7	-3.5	5050
04S/13W-30A05 S	19		35.0	10/31/74	109.5	-74.5	5061
				11/01/74	102.4	-67.4	5050
04S/13W-30G01 S	19		37.1	10/23/74	98.1	-61.0	1200
			37.0	11/01/74	97.1	-60.1	5050
			37.1	12/20/74	101.2	-64.1	1200
				5/30/75	95.3	-58.2	
				6/25/75	100.9	-63.8	
				7/28/75	102.4	-65.3	
				8/27/75	103.0	-65.9	
				9/30/75	101.7	-64.6	
04S/13W-30G03 S	19		26.0	10/31/74	86.9(5)	-60.9	5061
				11/01/74	86.2	-60.2	5050
04S/13W-30K01 S	19		36.0	10/31/74	97.4(5)	-61.4	5061
				11/01/74	97.2	-61.2	5050
04S/13W-31F02 S	19		19.0	10/31/74	80.9	-61.9	5061
				11/01/74	82.6	-63.6	5050
04S/13W-31F04 S	19		22.0	10/23/74	81.9	-59.9	1200
				11/01/74	81.7	-59.7	5050
				12/20/74	84.0	-62.0	1200
				6/25/75	82.6	-60.6	
				7/29/75	83.9	-61.9	
				8/27/75	85.7	-63.7	
				9/24/75	84.4	-62.4	
04S/13W-31J01 S	19		35.2	10/30/74	96.5	-61.3	5050

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
COASTAL PL OF LA CO HYDRO SUBUNIT — U-05.A
WEST COAST HYDRO SUBAREA — U-05.A2

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
04S/13W-31J01 S	19		35.2	12/11/74	56.7	-21.5	1101
04S/13W-31J03 S	19		21.4	10/30/74	47.8	-26.4	5050
04S/13W-31K02 S	19		21.7	12/11/74	51.7	-30.0	1101
04S/13W-31N01 S	19		43.4	10/21/74	4.4	39.0	5050
04S/13W-31N02 S	19		42.6	12/11/74	82.4	-39.8	1101
04S/13W-31P01 S	19		44.7	10/01/74	169.0	-124.3	5061
				11/01/74	169.0	-124.3	
04S/13W-31Q01 S	19		28.5	10/29/74	46.5	-18.0	1101
				11/25/74	46.7	-18.2	
				12/23/74	47.1	-18.6	
				6/23/75	47.6	-19.1	
				7/28/75	47.8	-19.3	
				8/25/75	48.1	-19.6	
				9/30/75	48.4	-19.9	
04S/13W-32B02 S	19		39.1	10/29/74	75.8	-36.7	1101
				11/25/74	75.4	-36.3	
				12/23/74	75.7	-36.6	
				6/23/75	75.3	-36.2	
				7/28/75	75.3	-36.2	
				8/25/75	75.5	-36.4	
				9/30/75	75.7	-36.6	
04S/13W-32G01 S	19		26.6	10/29/74	47.9	-21.3	1101
				11/25/74	48.0	-21.4	
				12/23/74	48.2	-21.6	
				6/23/75	48.6	-22.0	
				7/28/75	48.7	-22.1	
				8/25/75	48.8	-22.2	
				9/30/75	49.0	-22.4	
04S/13W-32K01 S	19		21.6	10/29/74	36.6	-15.0	1101
				11/25/74	36.8	-15.2	
				12/23/74	37.1	-15.5	
				6/23/75	37.8	-16.2	
				7/28/75	37.9	-16.3	
				9/30/75	38.2	-16.6	
04S/13W-32N01 S	19		17.9	11/25/74	25.2	-7.3	1101
				12/23/74	25.9	-8.0	
				6/23/75	26.7	-8.8	
				7/28/75	27.3	-9.4	
				8/25/75	27.5	-9.6	
				9/30/75	27.9	-10.0	
04S/13W-32P01 S	19		14.4	10/29/74	21.8	-7.4	1101
				11/25/74	22.3	-7.9	
				12/23/74	22.7	-8.3	
				6/23/75	21.0	-6.6	
				7/28/75	21.3	-6.9	
				8/25/75	21.5	-7.1	
				9/30/75	21.9	-7.5	
04S/13W-32P02 S	19		14.1	10/31/74	19.8	-5.7	1101
				11/26/74	20.4	-6.3	
				1/03/75	21.8	-7.7	
				6/27/75	19.2	-5.1	
				7/29/75	20.2	-6.1	
				8/28/75	20.4	-6.3	
04S/13W-32P03 S	19		14.1	10/31/74	21.9	-7.8	1101
				11/26/74	22.3	-8.2	
				1/03/75	22.9	-8.8	
				6/27/75	23.4	-9.3	
				7/29/75	23.8	-9.7	
				8/28/75	24.0	-9.9	
04S/13W-32Q01 S	19		14.0	6/23/75	28.2	-14.2	1101
				7/28/75	28.9	-14.9	
				8/25/75	26.3	-12.3	
				9/30/75	26.0	-12.0	
04S/13W-32Q02 S	19		14.0	10/29/74	27.3	-13.3	1101
				11/25/74	27.6	-13.6	
				12/11/74	24.4	-10.4	
04S/13W-32Q03 S	19		14.0	12/11/74	24.7	-10.7	1101
04S/13W-32Q07 S	19		12.6	10/29/74	18.6	-6.0	1101
				11/25/74	19.1	-6.5	
				12/23/74	19.9	-7.3	
				6/23/75	19.9	-7.3	
				7/28/75	20.0	-7.4	
				8/25/75	21.0	-8.4	
				9/30/75	20.9	-8.3	
04S/13W-32R01 S	19		13.0	10/31/74	21.0	-8.0	1101
				11/26/74	21.0	-8.0	
				1/03/75	22.0	-9.0	
				6/27/75	21.7	-8.7	
				7/29/75	21.6	-8.6	
				8/28/75	21.6	-8.6	
04S/13W-32R02 S	19		13.0	10/31/74	21.4	-8.4	1101
				11/26/74	21.6	-8.6	
				1/03/75	22.6	-9.6	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

LA-SAN GABRIEL RIVER HYDRO UNIT
COASTAL PL OF LA CO HYDRO SUBUNIT
WEST COAST HYDRO SUBAREA

U-05
U-05.A
U-05.A2

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
04S/13W-32R02 S (CONTINUED)	19		13.0	6/27/75	22.8	-9.8	1101
				7/29/75	23.1	-10.1	
				8/28/75	23.2	-10.2	
04S/13W-32R03 S	19		13.9	8/25/75	21.1	-7.2	1101
				9/30/75	20.7	-6.8	
04S/13W-32R04 S	19		13.1	10/30/74	19.8	-6.7	1101
				8/26/75	22.8	-9.7	
04S/13W-33B02 S	19		23.5	12/11/74	45.0	-21.5	1101
04S/13W-33B03 S	19		23.5	12/11/74	45.0	-21.5	1101
04S/13W-33G01 S	19		14.5	10/31/74	32.3	-17.8	1101
				11/26/74	32.8	-18.3	
				1/03/75	32.7	-18.2	
				6/27/75	32.6	-18.1	
				7/29/75	33.2	-18.7	
				8/28/75	33.3	-18.8	
04S/13W-33G02 S	19		14.5	10/31/74	32.5	-18.0	1101
				11/26/74	33.0	-18.5	
				1/03/75	32.8	-18.3	
				6/27/75	32.7	-18.2	
				7/29/75	33.3	-18.8	
				8/28/75	33.4	-18.9	
04S/13W-33H02 S	19		17.7	10/31/74	63.1	-45.4	1101
				11/26/74	64.2	-46.5	
				1/03/75	65.5	-47.8	
				6/27/75	64.9	-47.2	
				7/29/75	65.9	-48.2	
				8/28/75	67.0	-49.3	
04S/13W-33H04 S	19		17.7	10/31/74	35.0	-17.3	1101
				11/26/74	35.4	-17.7	
				1/03/75	36.2	-18.5	
				6/27/75	36.0	-18.3	
				7/29/75	36.6	-18.9	
				8/28/75	36.7	-19.0	
04S/13W-33H05 S	19		17.7	10/31/74	35.5	-17.8	1101
				11/26/74	35.8	-18.1	
				1/03/75	36.7	-19.0	
				6/27/75	36.6	-18.9	
				7/29/75	37.2	-19.5	
				8/28/75	37.4	-19.7	
04S/13W-33H06 S	19		17.7	10/31/74	62.9	-45.2	1101
				11/26/74	64.0	-46.3	
				1/03/75	65.2	-47.5	
				6/27/75	64.7	-47.0	
				7/29/75	65.7	-48.0	
				8/28/75	66.1	-48.4	
04S/13W-33K02 S	19		8.0	10/29/74	19.5	-11.5	1101
				11/25/74	20.2	-12.2	
				12/23/74	21.5	-13.5	
				6/23/75	21.7	-13.7	
				7/28/75	22.2	-14.2	
				8/25/75	22.0	-14.0	
				9/30/75	22.3	-14.3	
04S/13W-33K03 S	19		8.0	10/29/74	20.7	-12.7	1101
				11/25/74	20.2	-12.2	
				12/23/74	21.6	-13.6	
				6/23/75	22.1	-14.1	
				7/28/75	22.6	-14.6	
				8/25/75	22.3	-14.3	
				9/30/75	22.7	-14.7	
04S/13W-33K04 S	19		8.0	10/29/74	20.7	-12.7	1101
				11/25/74	21.3	-13.3	
				12/23/74	21.5	-13.5	
				6/23/75	22.1	-14.1	
				7/28/75	22.1	-14.1	
				8/25/75	22.2	-14.2	
				9/30/75	22.7	-14.7	
04S/13W-33L03 S	19		7.0	6/26/75	-42.8	49.8	1101
				7/28/75	-42.8	49.8	
				8/26/75	-42.8	49.8	
04S/13W-33N02 S	19		10.7	10/29/74	18.1	-7.4	1101
				11/25/74	18.7	-8.0	
				12/23/74	19.8	-9.1	
				6/23/75	19.3	-8.6	
				7/28/75	20.4	-9.7	
				8/25/75	20.5	-9.8	
				9/30/75	20.5	-9.8	
04S/13W-33P01 S	19		5.8	10/30/74	14.8	-9.0	1101
				11/27/74	15.2	-9.4	
				1/02/75	15.4	-9.6	
04S/13W-33P06 S	19		10.6	11/08/74	23.4	-12.8	1101
04S/13W-33P07 S	19		10.6	10/31/74	17.1	-6.5	1101
				11/26/74	17.3	-6.7	
				1/03/75	18.7	-8.1	
				6/27/75	20.4	-9.8	

LA-SAN GABRIEL RIVER HYDRO UNIT
COASTAL PL OF LA CO HYDRO SUBUNIT
WEST COAST HYDRO SUBAREA

U-05
U-05.A
U-05.A2

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
04S/13W-33P07 S (CONTINUED)	19		10.6	7/29/75	20.9	-10.3	1101
				8/28/75	21.0	-10.4	
04S/13W-33P08 S	19		10.6	10/31/74	19.0	-8.4	1101
				11/26/74	19.2	-8.6	
				1/03/75	24.8	-14.2	
				6/27/75	20.5	-9.9	
				7/29/75	20.6	-10.0	
				8/28/75	20.8	-10.2	
04S/13W-33P09 S	19		5.8	6/26/75	15.5	-9.7	1101
				7/28/75	9.4	-3.6	
				8/26/75	11.4	-5.6	
04S/13W-34A01 S	19		6.8	10/30/74	99.5	-92.7	5050
04S/13W-34A02 S	19		6.7	10/30/74	29.7	-23.0	5050
04S/13W-34A03 S	19		6.9	10/30/74	38.7	-31.8	5050
04S/13W-34C02 S	19		10.3	11/08/74	50.4	-40.1	1101
04S/13W-34D02 S	19		4.1	6/27/75	45.9	-41.8	1101
				7/29/75	46.7	-42.6	
				8/28/75	47.8	-43.7	
04S/13W-34D03 S	19		4.1	6/27/75	23.1	-19.0	1101
				7/29/75	22.9	-18.8	
				8/28/75	22.7	-18.6	
04S/13W-34D04 S	19		4.1	6/27/75	22.1	-18.0	1101
				7/29/75	21.7	-17.6	
				8/28/75	21.9	-17.8	
04S/13W-34E02 S	19		18.3	10/31/74	60.5	-42.2	1101
				11/26/74	61.6	-43.3	
				1/03/75	63.2	-44.9	
				6/27/75	62.6	-44.3	
				7/29/75	63.6	-45.3	
				8/28/75	64.0	-45.7	
04S/13W-34E03 S	19		18.3	6/27/75	62.5	-44.2	1101
				7/29/75	63.3	-45.0	
				8/28/75	63.8	-45.5	
04S/13W-34E04 S	19		18.3	6/27/75	36.2	-17.9	1101
				7/29/75	36.5	-18.2	
				8/28/75	36.6	-18.3	
04S/13W-34F02 S	19		5.4	6/23/75	43.1	-37.7	1101
				7/28/75	44.1	-38.7	
				8/25/75	44.5	-39.1	
				9/30/75	44.4	-39.0	
04S/13W-34F03 S	19		5.4	6/23/75	43.2	-37.8	1101
				7/28/75	44.1	-38.7	
				8/25/75	44.6	-39.2	
				9/30/75	44.5	-39.1	
04S/13W-34H01 S	19		3.4	10/24/74	79.3	-75.9	5050
04S/13W-34H02 S	19		3.6	10/24/74	19.8	-16.2	5050
04S/13W-34N05 S	19		18.3	6/27/75	36.2	-17.9	1101
				7/29/75	36.6	-18.3	
				8/28/75	36.6	-18.3	
04S/13W-35H01 S	19		9.4	10/18/74	31.5	-22.1	4206
				11/29/74	33.0	-23.6	
				12/20/74	31.5	-22.1	
				3/14/75	31.9	-22.5	
				4/25/75	32.4	-23.0	
				5/16/75	31.3	-21.9	
			7.0	6/27/75	29.0	-22.0	
				7/18/75	29.1	-22.1	
				8/22/75	28.5	-21.5	
				9/19/75	28.9	-21.9	
04S/13W-35B02 S	19		6.7	11/12/74	87.4	-80.7	5050
04S/13W-35R03 S	19		6.7	11/12/74	36.3	-29.6	5050
04S/13W-35R04 S	19		6.7	11/12/74	27.0	-20.3	5050
04S/13W-35F01 S	19		9.0	10/30/74	23.9	-14.9	5050
04S/13W-35J02 S	19		22.7	11/08/74	40.1	-17.4	5050
04S/13W-35M04 S	19		10.1	11/08/74	22.2	-12.1	5050
04S/13W-35M05 S	19		10.1	11/08/74	35.7	-25.6	5050
04S/14W-01F02 S	19		51.0	10/31/74	117.7	-66.7	5050
04S/14W-01F03 S	19		50.8	10/31/74	118.0	-67.2	5050
04S/14W-01P01 S	19		46.0	10/31/74	112.2	-66.2	5050
04S/14W-03L02 S	19		74.0	10/30/74	106.9	-32.9	5050
04S/14W-03L03 S	19		76.0	10/30/74	108.7	-32.7	5050
04S/14W-03L04 S	19		75.0	10/30/74	NM-3		5050

See page 79 for key to terms a abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
COASTAL PL OF LA CO HYDRO SUBUNIT — U-05.A
WEST COAST HYDRO SUBAREA — U-05.A2

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
04S/14W-03M01 S	19		79.1	10/30/74	107.9	-28.8	5050
04S/14W-05A01 S	19		97.5	12/06/74	103.0	-5.5	1101
				7/21/75	110.2	-12.7	
04S/14W-05A02 S	19		97.5	7/21/75	109.8	-12.3	1101
04S/14W-05A03 S	19		105.9	7/21/75	120.2	-14.3	1101
04S/14W-05F01 S	19		92.0	10/22/74	100.8	-8.8	5050
04S/14W-05N02 S	19		151.1	12/12/74	152.5	-1.4	1101
				3/31/75	142.7	8.4	
04S/14W-05N03 S	19		142.0	12/17/74	NM-9		1101
04S/14W-05N06 S	19		145.7	10/03/74	152.1	-6.4	1101
				11/27/74	152.2	-6.5	
				12/27/74	151.0	-5.3	
				1/30/75	150.4	-4.7	
				2/27/75	150.1	-4.4	
				3/26/75	149.3	-3.6	
				5/02/75	148.5	-2.8	
				6/25/75	149.0	-3.3	
				7/30/75	149.2	-3.5	
				8/27/75	154.3	-8.6	
04S/14W-06G02 S	19		174.8	12/11/74	169.0	5.8	1101
04S/14W-06G04 S	19		196.7	10/03/74	192.0	4.7	1101
				11/27/74	191.4	5.3	
				12/27/74	190.7	6.0	
				1/30/75	190.3	6.4	
				2/27/75	189.6	7.1	
				3/26/75	188.7	8.0	
				5/02/75	187.8	8.9	
				6/25/75	189.4	7.3	
				7/30/75	189.1	7.6	
				8/27/75	199.0	-2.3	
04S/14W-06G05 S	19		166.5	10/02/74	163.8	2.7	1101
				11/26/74	160.1	6.4	
				12/26/74	160.2	6.3	
				1/29/75	160.7	5.8	
				2/26/75	160.1	6.4	
				3/25/75	159.0	7.5	
				4/30/75	158.2	8.3	
				5/28/75	158.6	7.9	
				6/24/75	159.6	6.9	
				7/29/75	159.8	6.7	
				8/26/75	169.5	-3.0	
04S/14W-06H01 S	19		165.3	10/22/74	178.2	2.8	5050
04S/14W-06J05 S	19		159.8	1/30/75	164.8	-5.0	1101
				2/27/75	164.5	-4.7	
				3/26/75	163.8	-4.0	
				5/02/75	163.1	-3.3	
				6/25/75	163.7	-3.9	
				7/30/75	163.9	-4.1	
				8/27/75	168.6	-8.8	
04S/14W-06J06 S	19		139.4	10/03/74	135.2	4.2	1101
				11/27/74	134.3	5.1	
				12/27/74	133.9	5.5	
				1/30/75	133.5	5.9	
				2/27/75	132.1	7.3	
				3/26/75	131.2	8.2	
				5/02/75	130.1	9.3	
				6/25/75	131.0	8.4	
				7/30/75	131.3	8.1	
				8/27/75	141.3	-1.9	
04S/14W-06J07 S	19		139.4	10/03/74	146.1	-6.7	1101
				11/27/74	145.1	-5.7	
				12/27/74	145.0	-5.6	
				1/30/75	144.5	-5.1	
				2/27/75	144.3	-4.9	
				3/26/75	143.6	-4.2	
				5/02/75	142.8	-3.4	
				6/25/75	143.6	-4.2	
				7/30/75	143.8	-4.4	
				8/27/75	148.7	-9.3	
04S/14W-06J08 S	19		141.1	1/30/75	135.2	5.9	1101
				2/27/75	133.5	7.6	
				3/26/75	132.3	8.8	
				5/02/75	131.0	10.1	
				6/25/75	131.7	9.4	
				7/30/75	132.1	9.0	
				8/27/75	142.9	-1.8	
04S/14W-06K05 S	19		159.8	10/03/74	166.4	-6.6	1101
				11/27/74	165.4	-5.6	
				12/27/74	165.3	-5.5	
04S/14W-06K08 S	19		141.1	10/03/74	137.0	4.1	1101
				11/27/74	135.9	5.2	
				12/27/74	135.6	5.5	
04S/14W-06L01 S	19		71.3	10/22/74	69.4	1.9	5050

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
COASTAL PL OF LA CO HYDRO SUBUNIT — U-05.A
WEST COAST HYDRO SUBAREA — U-05.A2

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
04S/14W-07C03 S	19		62.2	10/03/74	58.3	3.9	1101
				11/27/74	56.7	5.5	
				12/27/74	56.8	5.4	
				1/30/75	56.3	5.9	
				2/27/75	55.1	7.1	
				3/26/75	54.9	7.3	
				5/02/75	55.0	7.2	
				6/25/75	49.7	12.5	
				7/30/75	52.8	9.4	
				8/27/75	58.1	4.1	
04S/14W-07D01 S	19		13.8	10/03/74	9.2	4.6	1101
				11/27/74	9.1	4.7	
				12/27/74	9.2	4.6	
				1/30/75	8.8	5.0	
				2/27/75	6.7	7.1	
				3/26/75	9.4	4.4	
				5/02/75	8.5	5.3	
				6/25/75	8.3	5.5	
				7/30/75	8.2	5.6	
				8/27/75	8.7	5.1	
04S/14W-07F01 S	19		65.0	10/21/74	64.1	0.9	5050
04S/14W-07J07 S	19		143.0	7/21/75	148.3	-5.3	1101
04S/14W-07J08 S	19		143.0	7/21/75	133.8	9.2	1101
04S/14W-07K02 S	19		87.0	10/21/74	85.0	2.0	5050
				7/23/75	79.1	7.9	1101
04S/14W-07P01 S	19		47.0	10/21/74	49.4	-2.4	5050
04S/14W-07P03 S	19		73.6	10/21/74	72.5	1.1	5050
				7/02/75	68.4	5.2	1101
04S/14W-07P04 S	19		52.1	7/23/75	57.7	-5.6	1101
04S/14W-07P05 S	19		52.1	7/23/75	42.1	10.0	1101
04S/14W-08B01 S	19		97.0	10/03/74	101.5	-4.5	1101
				11/27/74	100.7	-3.7	
				12/27/74	100.5	-3.5	
				1/30/75	100.0	-3.0	
				2/27/75	99.3	-2.3	
				3/26/75	98.4	-1.4	
				5/02/75	97.3	-0.3	
				6/25/75	97.3	-0.3	
				7/21/75	99.6	-2.6	
				8/27/75	102.3	-5.3	
04S/14W-08B02 S	19		94.1	7/22/75	108.6	-14.5	1101
04S/14W-08B03 S	19		94.1	12/10/74	106.2	-12.1	1101
				7/22/75	104.6	-10.5	
04S/14W-08B04 S	19		94.2	7/22/75	101.4	-7.2	1101
04S/14W-08D02 S	19		124.4	11/07/74	NM-7		5050
04S/14W-08D11 S	19		138.2	10/03/74	134.4	3.8	1101
				11/27/74	133.2	5.0	
				12/27/74	133.0	5.2	
				1/30/75	132.5	5.7	
				2/27/75	131.2	7.0	
				3/26/75	129.2	9.0	
				5/02/75	127.5	10.7	
				6/25/75	127.3	10.9	
				7/30/75	127.5	10.7	
				8/27/75	137.3	0.9	
04S/14W-08D12 S	19		139.7	10/03/74	146.8	-7.1	1101
				11/27/74	146.1	-6.4	
				12/27/74	145.4	-5.7	
				1/30/75	145.1	-5.4	
				2/27/75	144.9	-5.2	
				3/26/75	144.3	-4.6	
				5/02/75	143.4	-3.7	
				6/25/75	143.7	-4.0	
				7/30/75	143.8	-4.1	
				8/27/75	149.3	-9.6	
04S/14W-08D15 S	19		146.4	10/03/74	154.1	-7.7	1101
				11/27/74	153.3	-6.9	
				12/27/74	152.3	-5.9	
				1/30/75	151.8	-5.4	
				2/27/75	151.6	-5.2	
				3/26/75	150.9	-4.5	
				5/02/75	150.3	-3.9	
				6/25/75	150.7	-4.3	
				7/30/75	150.7	-4.3	
				8/27/75	156.3	-9.9	
04S/14W-08D17 S	19		138.1	10/03/74	145.2	-7.1	1101
				11/27/74	144.2	-6.1	
				12/27/74	143.7	-5.6	
				1/30/75	143.1	-5.0	
				2/27/75	143.0	-4.9	
				3/26/75	142.2	-4.1	
				5/02/75	141.4	-3.3	
				6/25/75	141.7	-3.6	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT WEST COAST HYDRO SUBAREA						U-05 U-05.A U-05.A2	
04S/14W-08H17 S (CONTINUED)	19		138.1	7/30/75	141.9	-3.8	1101
				8/27/75	147.2	-9.1	
04S/14W-08E03 S	19		135.7	10/22/74	127.2	8.5	5050
04S/14W-08E05 S	19		147.3	10/03/74	143.5	3.8	1101
				11/27/74	141.5	5.8	
				12/27/74	141.3	6.0	
				1/30/75	140.8	6.5	
				2/27/75	138.6	8.7	
				3/26/75	135.0	12.3	
				5/02/75	133.8	14.3	
				6/25/75	132.9	14.4	
				7/30/75	132.9	14.4	
				8/27/75	145.3	2.0	
04S/14W-08E15 S	19		143.3	10/03/74	139.4	3.9	1101
				11/27/74	137.7	5.6	
				12/27/74	137.7	5.6	
				1/30/75	137.3	6.0	
				2/27/75	135.2	8.1	
				3/26/75	132.8	10.5	
				5/02/75	130.6	12.7	
				6/25/75	130.3	13.0	
				7/30/75	130.4	12.9	
				8/27/75	141.1	2.2	
04S/14W-08E16 S	19		142.3	10/03/74	138.5	3.8	1101
				11/27/74	137.4	4.9	
				12/27/74	136.6	5.7	
				1/30/75	136.0	6.3	
				2/27/75	133.8	8.5	
				3/26/75	130.5	11.8	
				5/02/75	128.3	14.0	
				6/25/75	128.1	14.2	
				8/27/75	139.9	2.4	
04S/14W-08E17 S	19		143.0	10/03/74	151.5	-8.5	1101
				11/27/74	150.6	-7.6	
				12/27/74	149.7	-6.7	
				1/30/75	149.2	-6.2	
				2/27/75	148.5	-5.5	
				3/26/75	148.2	-5.2	
				5/02/75	147.8	-4.8	
				6/25/75	148.1	-5.1	
				7/30/75	148.1	-5.1	
				8/27/75	153.2	-10.2	
04S/14W-08E18 S	19		150.0	11/27/74	143.8	6.2	1101
				4/02/75	137.1	12.9	
				7/02/75	135.6	14.4	
04S/14W-08F19 S	19		153.2	11/27/74	147.2	6.0	1101
				4/03/75	140.0	13.2	
04S/14W-08E20 S	19		154.6	10/03/74	163.1	-8.5	1101
				11/27/74	162.8	-8.2	
				12/27/74	162.1	-7.5	
				1/30/75	161.5	-6.9	
				2/27/75	161.3	-6.7	
				3/26/75	160.7	-6.1	
				5/02/75	160.2	-5.6	
				6/25/75	160.5	-5.9	
				7/30/75	160.4	-5.8	
				8/27/75	165.3	-10.7	
04S/14W-08G01 S	19		97.0	10/22/74	107.9	-10.9	5050
04S/14W-08J01 S	19		103.7	7/22/75	117.8	-14.1	1101
04S/14W-08J02 S	19		103.7	7/22/75	116.9	-13.2	1101
04S/14W-08M03 S	19		139.0	4/04/75	126.7	12.3	1101
04S/14W-08M04 S	19		138.8	7/29/75	142.6	-3.8	1101
04S/14W-08M06 S	19		144.3	10/03/74	140.7	3.6	1101
				11/27/74	139.9	4.4	
				12/27/74	136.2	8.1	
				1/30/75	136.1	8.2	
				2/27/75	134.6	9.7	
				3/26/75	132.1	12.2	
				5/02/75	131.1	13.2	
				6/25/75	129.6	14.7	
				7/30/75	129.2	15.1	
				8/27/75	140.4	3.9	
04S/14W-08M07 S	19		152.5	10/03/74	150.2	2.3	1101
				11/27/74	146.7	5.8	
				12/27/74	146.2	6.3	
				1/30/75	146.6	5.9	
				3/26/75	146.4	6.1	
				5/02/75	144.1	8.4	
				6/25/75	140.3	12.2	
				7/30/75	138.5	14.0	
				8/27/75	150.2	2.3	
04S/14W-08M11 S	19		144.3	12/17/74	NM-9		1101
				4/04/75	132.6	11.7	
04S/14W-08M12 S	19		137.1	10/03/74	146.9	-9.8	1101
				11/27/74	145.2	-8.1	
04S/14W-08M12 S (CONTINUED)	19		137.1	12/27/74	144.5	-7.4	1101
				1/30/75	144.0	-6.9	
				2/27/75	143.8	-6.7	
				3/26/75	143.2	-6.1	
				5/02/75	142.9	-5.8	
				6/25/75	143.1	-6.0	
				7/30/75	143.1	-6.0	
				8/27/75	147.8	-10.7	
04S/14W-08M13 S	19		137.0	10/03/74	134.2	2.8	1101
				11/27/74	130.4	6.6	
				12/27/74	129.3	7.7	
				1/30/75	129.9	7.1	
				2/27/75	128.8	8.2	
				3/26/75	125.7	11.3	
				5/02/75	124.3	12.7	
				6/25/75	124.8	12.2	
				7/30/75	124.4	12.6	
				8/27/75	134.2	2.8	
04S/14W-08N03 S	19		158.0	10/03/74	159.1	-1.1	1101
				11/27/74	155.3	2.7	
				12/27/74	154.3	3.7	
				1/30/75	154.3	3.7	
				2/27/75	154.0	4.0	
				3/26/75	151.8	6.2	
				5/02/75	151.2	6.8	
				6/25/75	152.1	5.9	
				7/30/75	151.9	6.1	
				8/27/75	159.2	-1.2	
04S/14W-08N04 S	19		160.0	10/03/74	171.0	-11.0	1101
				11/27/74	169.3	-9.3	
				12/27/74	168.5	-8.5	
				1/30/75	168.1	-8.1	
				2/27/75	167.6	-7.6	
				3/26/75	167.1	-7.1	
				5/02/75	166.5	-6.5	
				6/25/75	166.7	-6.7	
				7/30/75	166.7	-6.7	
				8/27/75	171.5	-11.5	
04S/14W-08N05 S	19		140.0	10/03/74	139.3	0.7	1101
				11/27/74	132.6	7.4	
				12/27/74	132.1	7.9	
				2/27/75	131.2	8.8	
				3/26/75	129.1	10.9	
				5/02/75	128.3	11.7	
				6/25/75	128.9	11.1	
				7/30/75	127.9	12.1	
				8/27/75	140.3	-0.3	
04S/14W-08N07 S	19		141.8	10/03/74	139.6	2.2	1101
				11/27/74	138.0	3.8	
				12/27/74	137.9	3.9	
				1/30/75	137.4	4.4	
				2/27/75	135.7	6.1	
				3/26/75	134.1	7.7	
				5/02/75	132.6	9.2	
				6/25/75	132.8	9.0	
				7/30/75	132.9	8.9	
				8/27/75	137.5	4.3	
04S/14W-08P01 S	19		108.0	7/22/75	115.2	-7.2	1101
04S/14W-08P02 S	19		108.0	10/21/74	119.0	-11.0	5050
				7/22/75	116.4	-8.4	1101
04S/14W-09D01 S	19		113.0	7/21/75	127.8	-14.8	1101
04S/14W-09D02 S	19		113.0	10/03/74	129.7	-16.7	1101
				11/27/74	129.7	-16.7	
				12/27/74	128.5	-15.5	
				1/30/75	128.1	-15.1	
				2/27/75	127.9	-14.9	
				3/26/75	127.3	-14.3	
				5/02/75	127.0	-14.0	
				6/25/75	127.6	-14.6	
				7/30/75	128.0	-15.0	
				8/27/75	130.0	-17.0	
04S/14W-09D01 S	19		106.0	10/22/74	126.3	-20.3	5050
			100.6	11/12/74	120.4	-19.8	1101
04S/14W-10D02 S	19		107.0	10/24/74	135.8(2)	-28.8	5050
04S/14W-10D03 S	19		108.7	10/28/74	141.5(1)	-32.8	5050
04S/14W-10J01 S	19		93.0	10/28/74	117.3(5)	-24.3	5050
04S/14W-10K02 S	19		94.0	10/01/74	136.6(5)	-42.6	5061
				11/01/74	189.6(1)	-95.6	
04S/14W-10K03 S	19		90.0	10/01/74	114.3(5)	-24.3	5061
				11/01/74	112.3(5)	-22.3	
04S/14W-11F01 S	19		68.0	10/31/74	104.1	-36.1	5050
04S/14W-11G04 S	19		68.1	10/31/74	103.3	-35.2	5050
04S/14W-11L01 S	19		69.8	10/31/74	104.3	-34.5	5050
04S/14W-12D02 S	19		18.0	11/12/74	57.7	-39.7	1101

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
COASTAL PL OF LA CO HYDRO SUBUNIT — U-05.A
WEST COAST HYDRO SUBAREA — U-05.A2

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
04S/14W-12Q02 S	19		18.0	4/04/75	57.5	-39.5	1101
04S/14W-15N01 S	19		78.2	10/03/74	103.9	-25.7	1101
				11/06/74	104.1	-25.9	
				12/03/74	103.8	-25.6	
				1/06/75	103.5	-25.3	
				2/05/75	103.1	-24.9	
				3/12/75	102.8	-24.6	
				4/14/75	103.0	-24.8	
				5/06/75	102.9	-24.7	
				6/09/75	102.3	-24.1	
				7/08/75	103.3	-25.1	
				8/07/75	103.0	-24.8	
				9/05/75	103.4	-25.2	
04S/14W-16F01 S	19		81.0	10/30/74	103.6(5)	-22.6	1101
				12/30/74	103.6(5)	-22.6	
				3/03/75	100.6(5)	-19.6	
				4/30/75	112.6(5)	-31.6	
				7/02/75	113.6(5)	-32.6	
				9/08/75	112.6(5)	-31.6	
04S/14W-16L04 S	19		77.0	10/01/74	92.5(5)	-15.5	5061
				11/01/74	94.5(5)	-17.5	
04S/14W-16Q01 S	19		77.0	10/28/74	95.1	-18.1	5050
04S/14W-17D01 S	19		150.4	10/31/74	154.6	-4.2	1101
				11/27/74	154.6	-4.2	
				12/13/74	156.7	-6.3	
				1/30/75	156.5	-6.1	
				2/27/75	156.1	-5.7	
				3/26/75	155.8	-5.4	
				5/02/75	155.7	-5.3	
			156.4	6/25/75	162.2	-5.8	
04S/14W-17D02 S	19		156.4	10/31/74	145.6	10.8	5050
04S/14W-17D04 S	19		129.2	7/28/75	136.2	-7.0	1101
04S/14W-17D05 S	19		129.3	10/31/74	122.0	7.3	5050
04S/14W-17D06 S	19		128.0	4/04/75	119.9	8.1	1101
04S/14W-17D10 S	19		146.0	10/03/74	145.3	0.7	1101
				11/27/74	138.7	7.3	
				12/27/74	137.5	8.5	
				1/30/75	137.5	8.5	
				2/27/75	137.0	9.0	
				3/26/75	135.0	11.0	
				5/02/75	134.6	11.4	
				7/30/75	133.6	12.4	
				8/27/75	144.5	1.5	
04S/14W-17E05 S	19		137.4	7/28/75	134.1	3.3	1101
04S/14W-17E06 S	19		112.0	10/03/74	111.3	0.7	1101
				11/27/74	104.5	7.5	
				12/27/74	103.1	8.9	
				1/30/75	103.2	8.8	
				3/26/75	101.1	10.9	
				5/02/75	101.1	10.9	
				6/25/75	101.9	10.1	
				7/30/75	99.9	12.1	
				8/27/75	110.5	1.5	
04S/14W-17F02 S	19		180.5	10/31/74	188.3	-7.8	5050
04S/14W-17H01 S	19		96.0	10/30/74	105.6(5)	-9.6	1101
				12/30/74	105.6(5)	-9.6	
				3/03/75	104.6(5)	-8.6	
				4/30/75	101.6(5)	-5.6	
				7/02/75	101.6(5)	-5.6	
				9/08/75	105.6(5)	-9.6	
04S/14W-17H02 S	19		92.0	10/30/74	105.5(5)	-13.5	1101
				12/30/74	104.5(5)	-12.5	
				3/03/75	106.5(5)	-14.5	
				4/30/75	105.5(5)	-13.5	
				7/02/75	105.5(5)	-13.5	
				9/08/75	105.5(5)	-13.5	
04S/14W-17M01 S	19		115.0	10/03/74	114.8	0.2	1101
				11/27/74	108.1	6.9	
				12/27/74	106.3	8.7	
				1/30/75	106.6	8.4	
				2/27/75	106.0	9.0	
				3/26/75	104.7	10.3	
				5/02/75	104.8	10.2	
				6/25/75	105.7	9.3	
				7/30/75	103.4	11.6	
				8/27/75	114.3	0.7	
04S/14W-17M02 S	19		97.0	10/03/74	98.2	-1.2	1101
				11/27/74	90.3	6.7	
				12/27/74	88.4	8.6	
				1/30/75	89.0	8.0	
				2/27/75	88.5	8.5	
				3/26/75	88.1	8.9	
				5/02/75	88.3	8.7	
				6/25/75	88.2	8.8	
				7/30/75	85.4	11.6	

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
COASTAL PL OF LA CO HYDRO SUBUNIT — U-05.A
WEST COAST HYDRO SUBAREA — U-05.A2

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
04S/14W-17M02 S	19		97.0	8/27/75	96.4	0.6	1101
04S/14W-17N02 S	19		88.0	10/03/74	99.2	-11.2	1101
				11/27/74	95.9	-7.9	
				12/27/74	95.2	-7.2	
				1/30/75	95.1	-7.1	
				2/27/75	94.3	-6.3	
				3/26/75	93.8	-5.8	
				5/02/75	95.1	-7.1	
				6/25/75	95.5	-7.5	
				7/30/75	93.7	-5.7	
				8/27/75	99.4	-11.4	
04S/14W-17N03 S	19		95.0	10/03/74	101.8	-6.8	1101
				11/27/74	94.0	1.0	
				12/27/74	92.7	2.3	
				1/30/75	91.1	3.9	
				2/27/75	90.4	4.6	
				3/26/75	90.0	5.0	
				5/02/75	94.0	1.0	
				6/25/75	94.8	0.2	
				7/30/75	90.4	4.6	
				8/27/75	100.6	-5.6	
04S/14W-17P01 S	19		75.0	7/16/75	83.2	-8.2	1101
04S/14W-17P02 S	19		74.3	11/07/74	83.6	-9.3	5050
				7/16/75	82.0	-7.7	1101
04S/14W-17R01 S	19		77.1	7/23/75	91.4	-14.3	1101
04S/14W-17R02 S	19		77.1	12/10/74	89.4	-12.3	1101
				7/23/75	89.3	-12.2	
04S/14W-17R03 S	19		77.1	12/10/74	89.3	-12.2	1101
				7/23/75	89.2	-12.1	
04S/14W-18A02 S	19		146.4	12/11/74	138.6	7.8	1101
				7/28/75	135.0	11.4	
04S/14W-18A03 S	19		147.7	7/28/75	146.3	1.4	1101
04S/14W-18B01 S	19		87.0	10/24/74	85.0	2.0	5050
				7/28/75	83.1	3.9	1101
04S/14W-18F01 S	19		14.0	10/21/74	14.2	-0.2	5050
			15.3	7/29/75	13.7	1.6	1101
04S/14W-18H02 S	19		147.2	10/24/74	NH-7		5050
04S/14W-18H04 S	19		133.8	7/02/75	139.0	-5.2	1101
04S/14W-18H05 S	19		134.5	8/21/75	134.4	0.1	1101
04S/14W-18H06 S	19		133.5	8/21/75	131.1	2.4	1101
04S/14W-18H07 S	19		123.0	7/02/75	117.0	6.0	1101
04S/14W-18H08 S	19		122.0	7/02/75	100.1	21.9	1101
04S/14W-18J01 S	19		133.0	10/24/74	132.0	1.0	5050
				7/24/75	127.2	5.8	1101
04S/14W-18J02 S	19		133.0	10/24/74	141.7	-8.7	5050
				7/02/75	142.3	-9.3	1101
04S/14W-18K01 S	19		73.0	10/24/74	80.2	-7.2	5050
				7/24/75	70.2	2.8	1101
04S/14W-18P01 S	19		47.5	10/21/74	49.6	-2.1	5050
04S/14W-18Q01 S	19		100.0	10/24/74	100.2	-0.2	5050
				7/24/75	95.5	4.5	1101
04S/14W-18Q02 S	19		101.0	12/13/74	98.2	2.8	1101
04S/14W-18Q03 S	19		102.0	10/24/74	107.4	-5.4	5050
			101.0	4/04/75	97.8	3.2	1101
				7/24/75	101.9	1.1	
04S/14W-18R02 S	19		102.7	7/23/75	100.3	2.4	1101
04S/14W-18R03 S	19		102.7	7/23/75	110.9	-8.2	1101
04S/14W-20D02 S	19		116.5	11/01/74	131.8	-15.3	5050
04S/14W-20D03 S	19		116.4	11/01/74	119.9	-3.5	5050
04S/14W-20D05 S	19		116.5	11/12/74	114.1	2.4	1101
				4/04/75	114.3	2.2	
04S/14W-20D06 S	19		125.0	10/03/74	134.5	-9.5	1101
				11/01/74	127.0	-2.0	5050
				12/27/74	124.5	0.5	1101
				1/30/75	122.8	2.2	
				2/27/75	122.1	2.9	
				3/26/75	121.7	3.3	
				5/02/75	126.3	-1.3	
				6/25/75	126.9	-1.9	
				7/30/75	121.9	3.1	
				8/27/75	131.4	-6.4	
04S/14W-20D07 S	19		120.0	10/31/74	129.2	-9.2	1101

See page 79 for key to terms a abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
COASTAL PL OF LA CO HYDRO SUBUNIT — U-05.A
WEST COAST HYDRO SUBAREA — U-05.A2

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
04S/14W-20D07 S (CONTINUED)	19		120.0	11/27/74	127.7	-7.7	1101
				12/27/74	126.5	-6.5	
				1/30/75	125.4	-5.4	
				2/27/75	126.7	-6.7	
				3/26/75	126.1	-6.1	
				5/02/75	127.8	-7.8	
				6/25/75	128.7	-8.7	
				7/30/75	126.1	-6.1	
				8/27/75	131.7	-11.7	
04S/14W-20D08 S	19		145.0	10/03/74	152.6	-7.6	1101
				11/01/74	147.9	-2.9	5050
				12/27/74	145.1	-0.1	1101
				1/30/75	143.9	1.1	
				2/27/75	143.1	1.9	
				3/26/75	142.7	2.3	
				5/02/75	147.3	-2.3	
				6/25/75	147.9	-2.9	
				7/30/75	143.1	1.9	
				8/27/75	151.9	-6.9	
04S/14W-20E01 S	19		157.0	10/03/74	171.0	-14.0	1101
				11/27/74	167.9	-10.9	
				12/27/74	167.3	-10.3	
				1/30/75	167.0	-10.0	
				2/27/75	166.3	-9.3	
				3/26/75	165.8	-8.8	
				5/02/75	168.4	-11.4	
				6/25/75	168.0	-11.0	
				7/30/75	165.8	-8.8	
				8/27/75	171.2	-14.2	
04S/14W-20E02 S	19		199.0	10/03/74	206.9	-7.9	1101
				11/27/74	201.0	-2.0	
				12/27/74	199.9	-0.9	
				1/30/75	199.2	-0.2	
				2/27/75	198.1	0.9	
				3/26/75	197.6	1.4	
				5/02/75	202.0	-3.0	
				6/25/75	202.2	-3.2	
				7/30/75	197.9	1.1	
				8/27/75	206.2	-7.2	
04S/14W-20G02 S	19		90.9	11/01/74	91.6	-0.7	5050
				7/02/75	97.4	-6.5	1101
04S/14W-20G03 S	19		90.1	11/01/74	95.0	-4.9	5050
04S/14W-20G04 S	19		89.9	7/02/75	89.8	0.1	1101
04S/14W-20J02 S	19		83.0	7/24/75	99.0	-16.0	1101
04S/14W-20J04 S	19		83.0	7/02/75	90.1	-7.1	1101
04S/14W-21F01 S	19		72.0	10/31/74	83.5	-11.5	5050
04S/14W-21F02 S	19		76.0	10/03/74	94.7	-18.7	1101
				11/12/74	94.1	-18.1	
				3/31/75	91.7	-15.7	
04S/14W-21G01 S	19		71.0	10/31/74	90.2	-19.2	5050
04S/14W-21L02 S	19		73.2	10/03/74	91.6(8)	-18.4	1101
				11/12/74	91.1(8)	-17.9	
04S/14W-21N01 S	19		101.3	11/01/74	120.5	-19.2	5050
04S/14W-22N01 S	19		79.0	11/08/74	113.3	-34.3	5050
04S/14W-22Q01 S	19		74.3	10/03/74	106.0	-31.7	1101
				11/06/74	105.9	-31.6	
				12/03/74	105.7	-31.4	
				1/06/75	105.5	-31.2	
				2/05/75	105.4	-31.1	
04S/14W-24A01 S	19		58.0	11/04/74	115.0	-57.0	5050
04S/14W-25G04 S	19		70.3	10/03/74	119.3	-49.0	1101
			70.1	11/01/74	119.1	-49.0	5050
			70.3	12/03/74	119.5	-49.2	1101
				1/06/75	119.2	-48.9	
				2/05/75	119.0	-48.7	
				3/12/75	118.6	-48.3	
				4/14/75	118.6	-48.3	
				5/06/75	118.5	-48.2	
				6/09/75	118.1	-47.8	
				7/08/75	118.5	-48.2	
				8/07/75	118.6	-48.3	
				9/05/75	117.6	-47.3	
04S/14W-27B01 S	19		81.0	11/12/74	111.7	-30.7	1101
				4/04/75	110.9(8)	-29.9	
04S/14W-27N01 S	19		200.0	11/06/74	NM-6		5050
04S/14W-28G01 S	19		168.0	10/31/74	180.1	-12.1	5050
04S/14W-28J01 S	19		184.0	11/06/74	NM-6		5050
04S/14W-35F02 S	19		180.0	11/07/74	227.8	-47.8	5050
04S/14W-35F06 S	19		178.4	11/06/74	230.3	-51.9	5050

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
COASTAL PL OF LA CO HYDRO SUBUNIT — U-05.A
WEST COAST HYDRO SUBAREA — U-05.A2

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
04S/14W-35E07 S	19		184.9	11/06/74	237.6	-52.7	5050
04S/14W-35F08 S	19		176.8	11/07/74	223.8	-47.0	5050
04S/14W-35F02 S	19		200.0	11/06/74	234.8	-34.8	5050
04S/14W-36G02 S	19		39.9	10/21/74	95.9	-56.0	5050
04S/14W-36G03 S	19		40.6	10/21/74	98.4	-57.8	5050
04S/14W-36G04 S	19		41.0	10/21/74	98.4	-57.4	5050
04S/14W-36H01 S	19		44.0	10/21/74	101.1	-57.1	5050
04S/14W-36J01 S	19		47.0	10/21/74	105.6	-58.6	5050
04S/15W-20F02 S			1338.2	10/04/74	49.6	1288.6	1101
				11/04/74	50.3	1287.9	
				12/09/74	51.0	1287.2	
				1/06/75	51.1	1287.1	
				2/14/75	50.9	1287.3	
				3/04/75	51.2	1287.0	
				4/16/75	51.4	1286.8	
				5/06/75	51.4	1286.8	
				8/07/75	53.2	1285.0	
				9/05/75	53.0	1285.2	
05S/12W-10P01 S	19		5.0	10/24/74	3.8	1.2	5050
05S/13W-01M02 S	19		11.6	11/08/74	14.3	-2.7	1101
05S/13W-02B01 S	19		7.2	11/08/74	20.8	-13.6	1101
05S/13W-02G01 S	19		3.2	11/08/74	8.8	-5.6	1101
05S/13W-02G03 S	19		3.2	11/08/74	6.8	-3.6	1101
05S/13W-02J03 S	19		14.7	10/28/74	35.1	-20.4	5050
05S/13W-02K02 S	19		23.9	11/21/74	22.4	1.5	1101
05S/13W-02K03 S	19		23.9	11/21/74	12.0	11.9	1101
05S/13W-02K05 S	19		23.9	11/21/74	18.3	5.6	1101
05S/13W-03C01 S	19		11.8	12/12/74	12.8	-1.0	1101
05S/13W-03C08 S	19		-5.6	11/08/74	17.8	-23.4	5050
05S/13W-03F01 S	19		10.7	12/12/74	14.0	-3.3	1101
05S/13W-03L01 S	19		11.6	10/28/74	-4.8	16.4	5050
05S/13W-03P17 S	19		16.0	10/28/74	NM-5		5050
05S/13W-03P19 S	19		15.3	10/28/74	25.0	-9.7	5050
05S/13W-03Q02 S	19		-14.8	11/08/74	5.2	-20.0	1101
05S/13W-04E01 S	19		-0.6	10/28/74	10.9	-11.5	5050
05S/13W-04E02 S	19		-0.2	10/28/74	9.4	-9.6	5050
05S/13W-05A01 S	19		3.3	10/29/74	16.0	-7.5	1101
				11/25/74	16.4	-7.9	
				12/23/74	16.8	-8.3	
				1/02/75	11.0	-7.7	
05S/13W-05A02 S	19		8.5	10/29/74	15.6	-7.1	1101
				11/25/74	16.1	-7.6	
				12/23/74	16.4	-7.9	
				6/23/75	16.8	-8.3	
				7/28/75	16.6	-8.1	
				8/25/75	16.3	-7.8	
				9/30/75	16.4	-7.9	
05S/13W-05A03 S	19		3.3	6/26/75	12.1	-8.8	1101
				7/28/75	12.0	-8.7	
				8/26/75	11.5	-8.2	
05S/13W-05C02 S	19		12.7	10/31/74	17.1	-4.4	1101
				11/26/74	17.3	-4.6	
				1/03/75	17.9	-5.2	
				6/27/75	17.8	-5.1	
				7/29/75	17.9	-5.2	
				8/28/75	18.2	-5.5	
05S/13W-06B01 S	19		15.1	10/21/74	77.6	-62.5	5050
05S/13W-06B02 S	19		15.2	10/21/74	20.3	-5.1	5050
				11/25/74	21.1	-5.9	1101
				12/23/74	21.5	-6.3	
				6/23/75	22.5	-7.3	
				7/28/75	22.9	-7.7	
				8/25/75	23.2	-8.0	
				9/30/75	24.0	-8.8	
05S/13W-06B05 S	19		24.0	10/31/74	29.6	-5.6	1101
				11/26/74	30.2	-6.2	
				1/03/75	31.1	-7.1	
				6/27/75	32.7	-8.7	

See page 79 for key to terms & abbreviations

TABLE G-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT WEST COAST HYDRO SUBAREA						U-05 U-05.A U-05.A2	
05S/13W-06B05 S (CONTINUED)	19		24.0	7/29/75	33.6	-9.6	1101
				8/28/75	33.9	-9.9	
05S/13W-06B06 S	19		24.0	10/31/74	31.0	-7.0	1101
				11/26/74	31.5	-7.5	
				1/03/75	32.3	-8.3	
				6/27/75	34.0	-10.0	
				7/29/75	34.6	-10.6	
				8/28/75	35.0	-11.0	
05S/13W-11H02 S	19		21.4	11/08/74	44.9	-23.5	1101
SANTA MONICA HYDRO SUBAREA						U-05.A3	
01S/15W-12N01 S	19		470.0	11/15/74	NM-2		1101
				4/21/75	60.2	409.8	
01S/15W-23J01 S	19		308.3	11/15/74	FLOW		1101
				4/21/75	FLOW		
01S/15W-28G01 S	19		334.0	11/15/74	70.3	263.7	1101
				4/21/75	70.1	263.9	
01S/15W-29G01 S	19		353.0	11/15/74	71.7	281.3	1101
				4/21/75	74.3	278.7	
01S/15W-30K01 S	19		390.0	11/15/74	DRY (6)		1101
				4/21/75	DRY (6)		
01S/15W-30M01 S	19		315.4	11/14/74	75.6	239.8	1101
				4/21/75	74.4	241.0	
01S/15W-31E01 S	19		310.0	10/02/74	95.8	214.2	1101
				11/04/74	95.9	214.1	
				12/03/74	96.0	214.0	
				1/06/75	96.0	214.0	
				2/05/75	96.2	213.8	
				3/12/75	95.8	214.2	
				4/21/75	95.2	214.8	
				5/06/75	94.9	215.1	
				6/04/75	94.3	215.7	
				7/08/75	94.0	216.0	
				8/08/75	94.1	215.9	
				9/02/75	94.1	215.9	
01S/15W-32A05 S	19		235.6	11/18/74	42.1(5)	193.5	1101
			236.4	6/16/75	14.4	222.0	
01S/15W-33D02 S	19		247.2	11/18/74	55.0(5)	192.2	1101
01S/15W-33Q05 S	19		160.0	11/15/74	40.4	119.6	1101
				4/22/75	41.0	119.0	
01S/16W-34D01 S	19		128.9	10/15/74	28.5	100.4	1101
01S/16W-34D02 S	19		134.1	10/18/74	31.6	102.5	1101
01S/16W-34D04 S	19		142.2	10/18/74	32.2	110.0	1101
01S/16W-34D05 S	19		139.8	10/18/74	32.0	107.8	1101
01S/16W-34D06 S	19		142.9	10/18/74	28.2	114.7	1101
01S/16W-36K01 S	19		265.0	11/04/74	NM-7		1101
				4/14/75	102.0	163.0	
02S/14W-19C02 S	19		48.5	10/30/74	78.3	-29.8	5050
02S/15W-01P02 S	19		83.7	10/02/74	67.8	15.9	1101
				11/04/74	67.9	15.8	
				4/21/75	68.3	15.4	
02S/15W-04C02 S	19		154.0	6/16/75	121.3	32.7	1101
02S/15W-04E02 S	19		152.5	11/15/74	129.7	22.8	1101
				4/22/75	129.4	23.1	
				6/16/75	129.6	22.9	
02S/15W-09N09 S	19		26.0	10/02/74	15.6	10.4	1101
				11/04/74	15.7	10.3	
				4/21/75	15.7	10.3	
02S/15W-11C07 S	19		98.8	10/02/74	162.0	-63.2	1101
				11/04/74	158.9	-60.1	
				12/03/74	158.4	-59.6	
				1/06/75	164.5	-65.7	
				2/05/75	166.5	-67.7	
				6/16/75	151.5	-52.7	
02S/15W-11E05 S	19		93.7	10/14/74	189.0(1)	-95.3	1101
				6/17/75	NM-0		
02S/15W-11F05 S	19		91.0	10/14/74	159.5(1)	-68.5	1101
				11/14/74	139.5(5)	-48.5	
				12/14/74	144.5(5)	-53.5	
				1/14/75	146.5(5)	-55.5	
				2/14/75	141.5(5)	-50.5	
				4/14/75	144.5(5)	-53.5	
				5/21/75	144.5(5)	-53.5	
				6/14/75	139.5(5)	-48.5	
				7/14/75	165.5(1)	-74.5	
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT SANTA MONICA HYDRO SUBAREA						U-05 U-05.A U-05.A3	
02S/15W-11F05 S (CONTINUED)	19		91.0	8/14/75	139.5(5)	-48.5	1101
				9/14/75	141.5(5)	-50.5	
02S/15W-13P07 S	19		33.7	11/08/74	66.0	-32.3	1101
				4/22/75	65.7	-32.0	
02S/15W-15F01 S	19		34.0	10/02/74	28.9	5.1	1101
				11/04/74	NM-9		
				12/03/74	29.0	5.0	
				1/06/75	29.0	5.0	
				2/05/75	29.0	5.0	
				3/12/75	29.0	5.0	
				4/21/75	28.8	5.2	
				5/06/75	28.8	5.2	
				6/04/75	28.9	5.1	
				7/08/75	29.0	5.0	
				8/08/75	29.1	4.9	
				9/02/75	29.9	4.1	
02S/15W-16N01 S	19		7.0	11/06/74	10.7	-3.7	1101
				4/21/75	9.7	-2.7	
02S/15W-21C01 S	19		2.0	11/06/74	2.8	-0.8	1101
				4/21/75	3.3	-1.3	
				5/06/75	7.8	-5.8	
				6/05/75	3.8	-1.8	
02S/15W-21D01 S	19		3.5	4/21/75	5.6	-2.1	1101
02S/15W-21D02 S	19		3.5	11/06/74	5.1	-1.6	1101
02S/15W-22A07 S	19		15.0	11/08/74	13.2	1.8	1101
				4/22/75	12.3	2.7	
02S/15W-22B08 S	19		22.5	11/06/74	21.0	1.5	1101
				4/22/75	20.9	1.6	
02S/15W-22D04 S	19		13.5	10/02/74	9.4	4.1	1101
				11/04/74	9.3	4.2	
				4/21/75	9.0	4.5	
02S/15W-22E03 S	19		10.0	10/30/74	7.7	2.3	5050
02S/15W-22E05 S	19		10.0	10/30/74	7.8	2.2	5050
02S/15W-22G01 S	19		11.0	11/06/74	7.0	4.0	1101
				4/22/75	6.9	4.1	
02S/15W-22R03 S	19		9.0	10/30/74	10.8	-1.8	5050
02S/15W-23A03 S	19		17.4	11/08/74	17.4	0.0	1101
				4/22/75	17.0	0.4	
02S/15W-23G03 S	19		22.6	10/03/74	22.6	0.0	1101
				11/06/74	22.5	0.1	
				4/22/75	22.3	0.3	
02S/15W-23H05 S	19		10.0	11/06/74	6.5	3.5	1101
				4/22/75	NM-9		
02S/15W-23Q04 S	19		10.6	11/07/74	10.6(8)	0.0	1101
				4/22/75	10.2(8)	0.4	
02S/15W-23R01 S	19		11.3	4/22/75	11.9	-0.6	1101
02S/15W-27F02 S	19		15.5	11/06/74	14.0	1.5	1101
				4/23/75	14.2	1.3	
02S/15W-27L01 S	19		4.0	10/30/74	-0.7	4.7	5050
02S/15W-27L02 S	19		4.0	10/30/74	2.6	1.4	5050
02S/15W-28J01 S	19		10.0	11/07/74	7.6	2.4	1101
				4/22/75	8.1	1.9	
02S/15W-28Q01 S	19		12.9	11/07/74	9.9	3.0	1101
				4/22/75	NM-7		
02S/15W-28P02 S	19		10.1	11/07/74	7.4	2.7	1101
				4/22/75	7.6	2.5	
HOLLYWOOD HYDRO SUBAREA						U-05.A4	
01S/14W-14E01 S	19		280.0	10/02/74	18.6	261.4	1101
				11/04/74	18.8	261.2	
				12/03/74	18.8	261.2	
				1/06/75	19.0	261.0	
				2/05/75	19.0	261.0	
				3/12/75	18.4	261.6	
				4/17/75	18.2	261.8	
				5/06/75	18.5	261.5	
				6/09/75	19.3	260.7	
				7/08/75	NM-9		
				8/08/75	18.7	261.3	
				9/04/75	18.9	261.1	
01S/14W-17E02 S	19		188.0	10/19/74	179.0(5)	9.0	1101
				11/16/74	178.0(5)	10.0	
				12/14/74	178.0(5)	10.0	
				1/18/75	173.0(5)	15.0	
				2/15/75	175.0(5)	13.0	
				3/15/75	174.0(5)	14.0	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT HOLLYWOOD HYDRO SUBAREA						U-05 U-05.A U-05.A4	
01S/14W-17E02 S (CONTINUED)	19		188.0	4/12/75	174.0(5)	14.0	1101
				5/14/75	193.0(5)	-5.0	
				6/05/75	173.0(5)	15.0	
01S/14W-17E03 S	19		188.0	10/19/74	224.5(5)	-36.5	1101
				11/14/74	222.5(5)	-34.5	
				12/14/74	221.5(5)	-33.5	
				1/18/75	223.5(5)	-35.5	
				2/15/75	222.5(5)	-34.5	
				3/15/75	222.5(5)	-34.5	
				4/12/75	189.5(5)	-1.5	
				5/14/75	187.5(5)	0.5	
				6/14/75	186.5(5)	1.5	
				7/12/75	182.5(5)	5.5	
				8/14/75	181.5(5)	6.5	
				9/16/75	142.5(5)	45.5	
01S/14W-17R01 S	19		196.0	11/14/74	17.6	178.4	1101
01S/14W-18H02 S	19		189.5	10/19/74	177.5(5)	12.0	1101
				11/16/74	176.5(5)	13.0	
				12/14/74	174.5(5)	15.0	
				1/18/75	173.5(5)	16.0	
				2/15/75	174.5(5)	15.0	
				3/15/75	174.5(5)	15.0	
				4/12/75	174.5(5)	15.0	
				5/14/75	173.5(5)	16.0	
				6/05/75	171.5(5)	18.0	
				7/12/75	170.5(5)	19.0	
				8/14/75	168.5(5)	21.0	
01S/14W-18J01 S	19		175.5	10/02/74	96.8	78.7	1101
				11/04/74	92.8	82.7	
				12/03/74	94.3	81.2	
				1/06/75	93.6	81.9	
				2/05/75	94.1	81.4	
				3/12/75	93.6	81.9	
				4/18/75	93.7	81.8	
				5/06/75	93.4	82.1	
				6/09/75	92.9	82.6	
				7/08/75	81.6	93.9	
				8/08/75	81.2	94.3	
				9/04/75	80.2	95.3	
01S/14W-18J02 S	19		178.0	10/19/74	180.5(5)	-2.5	1101
				11/16/74	179.5(5)	-1.5	
				12/14/74	178.5(5)	-0.5	
				1/18/75	178.5(5)	-0.5	
				2/15/75	176.5(5)	1.5	
				3/15/75	176.5(5)	1.5	
				4/12/75	176.5(5)	1.5	
				5/14/75	177.5(5)	0.5	
				6/14/75	166.5(5)	11.5	
				7/12/75	163.5(5)	14.5	
				8/14/75	163.5(5)	14.5	
				9/16/75	164.5(5)	13.5	
01S/14W-18J04 S	19		182.5	10/19/74	181.5(5)	1.0	1101
				11/16/74	181.5(5)	1.0	
				12/14/74	180.5(5)	2.0	
				1/18/75	178.5(5)	4.0	
				2/15/75	177.5(5)	5.0	
				3/15/75	177.5(5)	5.0	
				4/12/75	176.5(5)	6.0	
				5/14/75	177.5(5)	5.0	
				6/14/75	172.5(5)	10.0	
				7/12/75	168.5(5)	14.0	
				8/14/75	169.5(5)	13.0	
				9/16/75	169.5(5)	13.0	
01S/14W-19D05 S	19		235.0	11/14/74	151.3	83.7	1101
				4/18/75	145.7	89.3	
CENTRAL HYDRO SUBAREA						U-05.A5	
01S/12W-06H01 S	19		569.2	10/03/74	23.9	545.3	1101
				11/01/74	23.0	546.2	
				3/31/75	22.5	546.7	
01S/12W-33P02 S	19		2555.4	10/01/74	345.4(1)	2210.0	1101
				11/01/74	324.4(5)	2231.0	
			255.5	12/31/74	288.0(5)	-32.5	
				1/31/75	308.0(1)	-52.5	
				2/28/75	287.0(5)	-31.5	
				3/31/75	306.0(1)	-50.5	
				4/30/75	287.0(5)	-31.5	
				5/31/75	306.0(1)	-50.5	
				6/30/75	286.0(5)	-30.5	
				7/31/75	308.0(1)	-52.5	
				8/31/75	287.0(5)	-31.5	
				9/30/75	301.0(1)	-45.5	
01S/12W-34C05 S	19		360.0	10/01/74	FLOW		1101
				11/01/74	FLOW		
				12/09/74	FLOW		
				2/01/75	FLOW		
				3/01/75	FLOW		
				4/01/75	FLOW		
				5/01/75	FLOW		
				6/01/75	FLOW		
				7/01/75	FLOW		
				8/01/75	FLOW		
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT CENTRAL HYDRO SUBAREA						U-05 U-05.A U-05.A5	
01S/12W-34C05 S	19		360.0	9/01/75	FLOW		1101
01S/13W-14E03 S	19		366.6	10/25/74	40.1	326.5	1200
				11/21/74	40.4	326.2	
				12/20/74	40.5	326.1	
				4/24/75	40.2	326.4	
				5/28/75	40.2	326.4	
				6/25/75	40.6	326.0	
				7/23/75	40.2	326.4	
				8/27/75	40.3	326.3	
				9/24/75	40.0	326.6	
01S/13W-15H01 S	19		352.3	10/24/74	51.8	300.5	1200
				11/21/74	51.9	300.4	
				12/20/74	52.2	300.1	
				4/24/75	52.1	300.2	
				6/25/75	52.0	300.3	
				7/23/75	52.0	300.3	
				8/27/75	52.1	300.2	
				9/24/75	52.4	299.9	
01S/13W-15R02 S	19		321.3	10/30/74	31.4	289.9	1200
				11/21/74	31.4	289.9	
				12/26/74	31.5	289.8	
				4/24/75	31.3	290.0	
				6/25/75	31.2	290.1	
				7/23/75	31.3	290.0	
				8/27/75	32.2	289.1	
				9/24/75	32.2	289.1	
01S/13W-15R03 S	19		322.1	10/30/74	28.5	293.6	1200
				11/21/74	28.5	293.6	
				12/15/74	NM-7		
				4/24/75	28.7	293.4	
				6/25/75	28.6	293.5	
				7/23/75	28.7	293.4	
				8/27/75	29.3	292.8	
				9/30/75	NM-7		
01S/13W-19C01 S	19		288.4	11/15/74	11.0	277.4	1101
01S/13W-22P01 S	19		296.4	10/02/74	35.1	261.3	1101
				12/03/74	35.1	261.3	
				1/06/75	35.1	261.3	
				2/05/75	34.9	261.5	
				4/11/75	34.7	261.7	
01S/13W-23N01 S	19		301.0	11/04/74	21.7(4)	279.3	1101
				5/06/75	21.9	279.1	
01S/13W-27D02 S	19		268.0	11/04/74	52.6	215.4	1101
				4/16/75	NM-9		
01S/13W-32F02 S	19		232.6	2/21/75	166.7	65.9	1101
				3/14/75	166.1	66.5	
				4/16/75	166.5	66.1	
				5/08/75	166.6	66.0	
				6/10/75	167.0	65.6	
				7/08/75	167.3	65.3	
				8/08/75	167.0	65.6	
				9/04/75	167.0(3)	65.6	
01S/13W-33A01 S	19		260.0	11/13/74	111.3	148.7	1101
				4/16/75	111.2	148.8	
01S/13W-35F01 S	19		523.8	10/24/74	5.8	518.0	1200
				11/22/74	5.6	518.2	
				12/27/74	5.0	518.8	
				4/24/75	3.6	520.2	
				5/28/75	4.1	519.7	
				6/30/75	2.7	521.1	
				7/30/75	3.5	520.3	
				8/29/75	7.4	516.4	
				9/30/75	5.6	518.2	
01S/14W-19J01 S	19		159.0	11/15/74	148.6	10.4	1101
				4/18/75	146.3	12.7	
01S/14W-20H02 S	19		145.0	11/14/74	134.3	10.7	1101
				4/18/75	132.1	12.9	
01S/14W-24C01 S	19		242.0	10/02/74	6.1	235.9	1101
				11/04/74	5.8	236.2	
01S/14W-24C02 S	19		242.0	4/17/75	5.4	236.6	1101
01S/14W-27D01 S	19		189.0	10/02/74	14.4	174.6	1101
				11/04/74	6.9	182.1	
				4/16/75	14.5	174.5	
01S/14W-27D02 S	19		183.0	10/02/74	12.0	171.0	1101
				11/04/74	11.6	171.4	
				4/16/75	12.2	170.8	
01S/14W-29D02 S	19		129.7	10/02/74	151.2	-21.5	1101
				11/04/74	150.9	-21.2	
				12/03/74	150.5	-20.8	
				1/06/75	150.3	-20.6	
				2/05/75	150.0	-20.3	
				3/12/75	147.9	-18.2	
				4/18/75	148.1	-18.4	
				5/06/75	147.4	-17.7	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT CENTRAL HYDRO SUBAREA						U-05 U-05.A U-05.A5	
01S/14W-29Q02 S (CONTINUED)	19		129.7	6/09/75	146.7	-17.0	1101
				7/08/75	146.2	-16.5	
				8/08/75	145.9	-16.2	
				9/04/75	145.3	-15.6	
01S/14W-29R03 S	19		127.0	11/14/74	98.1	28.9	1101
				4/18/75	95.5	31.5	
01S/14W-30G01 S	19		151.2	11/14/74	21.2	130.0	1101
				4/18/75	19.0	132.2	
01S/14W-32C01 S	19		105.5	11/14/74	13.9(8)	91.6	1101
01S/14W-32K01 S	19		91.0	10/20/74	194.7(5)	-103.7	1101
				11/17/74	195.7(5)	-104.7	
				12/15/74	190.7(5)	-99.7	
				1/12/75	184.7(5)	-93.7	
				2/06/75	NM-0		
01S/14W-32K02 S	19		91.0	11/15/74	40.4	50.6	1101
				4/18/75	39.9	51.1	
01S/14W-32L01 S	19			10/02/74	31.6	59.9	1101
				11/04/74	31.6	59.9	
			92.0	12/15/74	200.0(5)	-108.0	
				1/12/75	179.0(5)	-87.0	
				2/06/75	NM-0		
01S/14W-32M06 S	19		90.0	9/17/75	118.4	-28.4	1101
01S/15W-33C01 S	19		225.0	11/15/74	FLOW		1101
				4/21/75	FLOW		
02S/11W-06G02 S	19		207.0	10/28/74	15.4	191.6	1733
				11/25/74	15.7	191.3	
				12/23/74	15.3	191.7	
				1/27/75	15.3	191.7	
				2/24/75	15.2	191.8	
				3/24/75	15.0	192.0	
				4/28/75	15.7	191.3	
				5/26/75	16.0	191.0	
				6/23/75	15.2	191.8	
				7/28/75	16.2	190.8	
				8/25/75	16.7	190.3	
				9/22/75	17.8	189.2	
02S/11W-06Q01 S	19		195.1	10/29/74	19.9	175.2	1101
				11/25/74	20.0	175.1	
				12/30/74	18.6	176.5	
				1/27/75	19.0	176.1	
				2/25/75	18.1	177.0	
				3/24/75	17.4	177.7	
				4/29/75	19.6	175.5	
				5/27/75	19.8	175.3	
				6/25/75	18.1	177.0	
				7/28/75	19.4	175.7	
				8/26/75	21.8	173.3	
02S/11W-06Q04 S	19		196.5	11/07/74	19.2	177.3	1101
				12/30/74	18.0	178.5	
				1/27/75	18.2	178.3	
				2/25/75	17.5	179.0	
				3/24/75	17.1	179.4	
				5/27/75	18.7	177.8	
				6/25/75	16.7	179.8	
				7/28/75	18.4	178.1	
				8/26/75	20.5	176.0	
02S/11W-06R02 S	19		200.5	10/29/74	20.0	180.5	1101
				11/25/74	20.2	180.3	
				12/30/74	19.2	181.3	
				1/27/75	19.4	181.1	
				2/25/75	18.9	181.6	
				3/24/75	18.4	182.1	
				4/29/75	19.1	181.4	
				5/27/75	19.6	180.9	
				6/25/75	17.8	182.7	
				7/28/75	19.8	180.7	
				8/26/75	20.2	180.3	
02S/11W-07R01 S	19		195.0	10/28/74	23.1	172.9	1733
				11/25/74	23.4	172.6	
				12/23/74	22.3	173.7	
				1/27/75	22.6	173.4	
				2/24/75	21.8	174.2	
				3/24/75	21.1	174.9	
				4/28/75	21.8	174.2	
				5/26/75	22.6	173.4	
				6/23/75	21.6	174.4	
				7/28/75	22.7	173.3	
				8/25/75	25.6	170.4	
				9/22/75	27.4	168.6	
02S/11W-07R03 S	19		197.5	10/15/74	30.0	167.5	1101
				11/15/74	32.0	165.5	
				1/15/75	31.0	166.5	
				2/15/75	31.0	166.5	
				3/15/75	31.0	166.5	
				4/15/75	30.0	167.5	
				5/15/75	31.0	166.5	
02S/11W-07R05 S	19		198.0	10/15/74	28.0(5)	170.0	1101
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT CENTRAL HYDRO SUBAREA						U-05 U-05.A U-05.A5	
02S/11W-07R05 S (CONTINUED)	19		198.0	11/15/74	30.0(5)	168.0	1101
				1/15/75	29.0(5)	169.0	
				2/15/75	29.0(5)	169.0	
				3/15/75	29.0(5)	169.0	
				4/15/75	29.0(5)	169.0	
				5/15/75	29.0(5)	169.0	
				6/15/75	28.0(5)	170.0	
				7/15/75	28.0(5)	170.0	
				8/15/75	29.0(5)	169.0	
				9/15/75	30.0(5)	168.0	
02S/11W-07D04 S	19		187.6	10/29/74	21.2	166.4	1101
				11/25/74	21.0	166.6	
				12/31/74	19.6	168.0	
				1/27/75	20.2	167.4	
				2/25/75	5.4	182.2	
				3/24/75	17.7	169.9	
				4/29/75	19.6	168.0	
				5/27/75	21.4	166.2	
				6/25/75	21.6	166.0	
				7/28/75	20.9	166.7	
				8/26/75	23.6	164.0	
02S/11W-07D07 S	19		186.0	10/29/74	21.1	164.9	1101
				11/25/74	20.6	165.4	
				12/31/74	19.3	166.7	
				1/27/75	19.6	166.4	
				2/25/75	18.6	167.4	
				3/24/75	17.5	168.5	
				4/29/75	19.3	166.7	
				5/27/75	21.0	165.0	
				6/25/75	21.6	164.4	
				7/28/75	20.5	165.5	
				8/26/75	23.5	162.5	
02S/11W-07D08 S	19		191.1	10/29/74	23.0	168.1	1101
				11/25/74	22.9	168.2	
				12/31/74	22.5	168.6	
				1/27/75	22.0	169.1	
				2/25/75	21.3	169.8	
				3/24/75	19.6	171.5	
				4/29/75	21.5	169.6	
				5/27/75	23.3	167.8	
				6/25/75	23.3	167.8	
				7/28/75	22.9	168.2	
				8/26/75	25.5	165.6	
02S/11W-07H01 S	19		187.9	10/29/74	17.0(5)	170.9	1101
				11/06/74	DRY		
				12/30/74	18.0(5)	169.9	
				1/20/75	18.0(5)	169.9	
				2/24/75	18.0(5)	169.9	
				3/24/75	16.0(5)	171.9	
				4/28/75	16.0(5)	171.9	
				5/19/75	16.0(5)	171.9	
				6/23/75	16.0(5)	171.9	
				7/28/75	17.0(5)	170.9	
				8/18/75	17.0(5)	170.9	
02S/11W-07H02 S	19		190.2	11/07/74	17.1	173.1	1101
				4/09/75	16.6	173.6	
02S/11W-07H03 S	19		192.6	11/06/74	19.0	173.6	1101
02S/11W-07H04 S	19		191.0	11/06/74	16.5	174.5	1101
				4/01/75	16.2	174.8	
02S/11W-07J01 S	19		187.0	10/07/74	5.5	181.5	1101
				11/04/74	5.5	181.5	
				12/09/74	5.5	181.5	
				1/06/75	5.5	181.5	
				2/03/75	5.5	181.5	
				3/03/75	5.5	181.5	
				4/07/75	4.5	182.5	
				5/05/75	4.5	182.5	
				6/02/75	4.5	182.5	
				7/07/75	4.5	182.5	
				8/04/75	4.5	182.5	
				9/01/75	4.5	182.5	
02S/11W-07J03 S	19		189.4	11/06/74	14.5	174.9	1101
				4/01/75	14.8	174.6	
02S/11W-07J05 S	19		186.7	11/06/74	18.3	168.4	1101
02S/11W-07J06 S	19		189.8	11/06/74	19.4	170.4	1101
02S/11W-07K01 S	19		186.5	11/06/74	26.5	160.0	1101
				4/09/75	25.8	160.7	
02S/11W-07M04 S	19		186.0	11/06/74	47.4(4)	138.6	1101
				4/09/75	33.9(8)	152.1	
02S/11W-07P02 S	19		185.0	10/28/74	NM-1		1733
				11/25/74	40.0(4)	145.0	
				12/23/74	41.4(4)	143.6	
				1/27/75	39.1	145.9	
				2/24/75	NM-1		
				3/24/75	38.0(4)	147.0	
				4/28/75	NM-7		
				5/26/75	NM-2		
				6/23/75	39.1(4)	145.9	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT CENTRAL HYDRO SUBAREA					U-05 U-05.A U-05.A5		
02S/11W-07P02 S (CONTINUED)	19		185.0	7/28/75	39.8(4)	145.2	1733
				8/25/75	42.4(4)	142.6	
				9/22/75	45.7(4)	139.3	
02S/11W-07Q02 S	19		188.2	10/29/74	34.0	154.2	1101
				11/25/74	36.0	152.2	
				12/30/74	35.0	153.2	
				1/27/75	35.9	152.3	
				2/25/75	35.2	153.0	
				3/24/75	33.4	154.8	
				4/29/75	33.3	154.9	
				5/27/75	30.9	157.3	
				6/23/75	30.8	157.4	
				7/28/75	34.2	154.0	
				8/25/75	35.9	152.3	
02S/11W-07Q03 S	19		187.9	11/06/74	27.9	160.0	1101
02S/11W-07R01 S	19		185.5	10/29/74	21.0	164.5	1101
				11/25/74	23.5	162.0	
				12/30/74	22.5	163.0	
				1/27/75	24.4	161.1	
				2/25/75	24.0	161.5	
				3/24/75	21.5	164.0	
				4/29/75	24.7	160.8	
				5/27/75	18.5	167.0	
				6/23/75	19.5	166.0	
				7/28/75	22.5	163.0	
				8/25/75	23.3	162.2	
02S/11W-08D04 S	19		201.5	11/07/74	21.9	179.6	1101
02S/11W-08E01 S	19		198.8	11/06/74	18.4	180.4	1101
02S/11W-08F02 S	19		201.4	11/07/74	NM-9		1101
			199.0	4/01/75	17.3	181.7	
02S/11W-08H01 S	19		197.2	11/06/74	20.7	176.5	1101
				4/01/75	21.0	176.2	
02S/11W-08N01 S	19		202.0	10/28/74	33.3	168.7	1733
				11/25/74	34.9	167.1	
				12/23/74	34.4	167.6	
				1/27/75	35.7	166.3	
				2/24/75	36.2	165.8	
				3/24/75	33.2	168.8	
				4/28/75	32.3	169.7	
				5/26/75	31.6	170.4	
				6/23/75	32.0	170.0	
				7/28/75	32.2	169.8	
				8/25/75	34.9	167.1	
				9/22/75	36.8	165.2	
02S/11W-16D02 S	19		307.0	10/21/74	94.5(5)	212.5	1101
				11/14/74	93.5(5)	213.5	
				12/14/74	93.0(5)	214.0	
				1/14/75	94.0(5)	213.0	
				2/14/75	94.0(5)	213.0	
				3/14/75	94.0(5)	213.0	
				4/14/75	94.0(5)	213.0	
				5/14/75	97.0(5)	210.0	
				6/21/75	96.0(5)	211.0	
				7/14/75	98.0(5)	209.0	
				8/21/75	99.0(5)	208.0	
				9/14/75	99.0(5)	208.0	
02S/11W-18B02 S	19		185.0	10/29/74	NM-9		1733
				11/25/74	35.2(4)	149.8	
				12/23/74	34.6	150.4	
				1/27/75	35.7	149.3	
				2/24/75	34.2	150.8	
				3/24/75	32.4	152.6	
				4/28/75	31.8	153.2	
				5/26/75	30.3	154.7	
				6/23/75	30.0	155.0	
				7/28/75	29.4	155.6	
				8/25/75	35.5	149.5	
				9/22/75	38.8	146.2	
02S/11W-18B05 S	19		178.0	4/21/75	35.3	142.7	1101
02S/11W-18C03 S	19		180.5	11/06/74	39.0	141.5	1101
02S/11W-18H01 S	19		211.5	10/30/74	64.2	147.3	1101
				11/26/74	64.9	146.6	
				12/31/74	64.0	147.5	
				1/27/75	64.5	147.0	
				2/26/75	64.5	147.0	
				3/26/75	63.7	147.8	
				5/01/75	NM-9		
				6/25/75	62.1	149.4	
				7/29/75	64.0	147.5	
				8/25/75	66.1	145.4	
02S/11W-18K02 S	19		178.0	10/30/74	52.3	125.7	1101
				11/27/74	53.8	124.2	
				1/02/75	51.9	126.1	
				2/26/75	51.1	126.9	
				3/26/75	49.7	128.3	
				5/01/75	51.3	126.7	
				6/23/75	48.9	129.1	
				7/28/75	51.6	126.4	
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT CENTRAL HYDRO SUBAREA					U-05 U-05.A U-05.A5		
02S/11W-18K02 S	19		178.0	8/25/75	54.1	123.9	1101
02S/11W-18K03 S	19		173.0	10/07/74	49.3	123.7	1101
				11/04/74	49.3	123.7	
				12/09/74	44.3	128.7	
				1/06/75	43.3	129.7	
				2/03/75	44.3	128.7	
				3/03/75	45.3	127.7	
				4/07/75	47.3	125.7	
				5/05/75	42.3	130.7	
				6/02/75	42.3	130.7	
				7/07/75	45.3	127.7	
				8/04/75	49.3	123.7	
				9/01/75	50.3	122.7	
02S/11W-18L08 S	19		173.6	10/29/74	48.5	125.1	1101
				11/25/74	51.6	122.0	
				12/31/74	45.3	128.3	
				1/27/75	46.8	126.8	
				2/25/75	47.8	125.8	
				3/24/75	45.2	128.4	
				5/01/75	46.7	126.9	
				6/23/75	46.2	127.4	
				7/28/75	50.2	123.4	
				8/25/75	45.6	128.0	
02S/11W-18L09 S	19		172.5	10/29/74	15.5	157.0	1101
				11/25/74	24.2	148.3	
				12/31/74	27.0	145.5	
				1/27/75	30.1	142.4	
				2/25/75	28.5	144.0	
				3/24/75	27.8	144.7	
				5/01/75	25.5	147.0	
				6/23/75	18.4	154.1	
				7/28/75	20.3	152.2	
				8/25/75	21.1	151.4	
02S/11W-18M03 S	19		177.0	10/30/74	48.4	128.6	1101
				11/26/74	48.9	128.1	
				12/31/74	47.3	129.7	
				1/27/75	46.5	130.5	
				2/26/75	45.1	131.9	
				3/26/75	43.5	133.5	
				5/01/75	44.9	132.1	
				6/23/75	43.1	133.9	
				7/29/75	46.6	130.4	
				8/25/75	51.0	126.0	
02S/11W-18Q01 S	19		175.0	10/15/74	57.5(5)	117.5	1101
				11/15/74	57.5(5)	117.5	
				1/15/75	47.5(5)	127.5	
				2/15/75	50.5(5)	124.5	
				3/15/75	51.5(5)	123.5	
				4/15/75	50.5(5)	124.5	
				5/15/75	49.5(5)	125.5	
				6/15/75	50.5(5)	124.5	
				8/15/75	63.5(5)	111.5	
				9/15/75	67.5(5)	107.5	
02S/11W-18Q05 S	19		175.5	1/15/75	52.2(5)	123.3	1101
				5/15/75	50.2(5)	125.3	
				6/15/75	50.2(5)	125.3	
				7/15/75	50.2(5)	125.3	
				8/15/75	52.2(5)	123.3	
				9/15/75	56.2(5)	119.3	
02S/11W-18Q06 S	19		170.0	10/15/74	58.5(5)	111.5	1101
				11/15/74	60.5(5)	109.5	
				1/15/75	58.5(5)	111.5	
				5/15/75	49.5(5)	120.5	
				8/15/75	65.5(5)	104.5	
				9/15/75	64.5(5)	105.5	
02S/11W-19C01 S	19		170.3	10/29/74	12.3	158.0	1101
				11/25/74	33.9	136.4	
				12/31/74	28.4	141.9	
				1/27/75	38.4	131.9	
				2/25/75	36.1	134.2	
				3/24/75	29.8	140.5	
				5/01/75	13.5	156.8	
				6/23/75	25.2	145.1	
				7/28/75	29.9	140.4	
				8/25/75	31.2	139.1	
02S/11W-19E07 S	19		161.3	10/29/74	27.6	133.7	1101
				11/25/74	33.6	127.7	
				12/31/74	36.4	124.9	
				1/27/75	36.7	124.6	
				2/25/75	34.0	127.3	
				3/24/75	32.6	128.7	
				5/01/75	32.4	128.9	
				6/23/75	25.6	135.7	
				7/28/75	26.7	134.6	
				8/25/75	29.8	131.5	
02S/11W-19E08 S	19		160.2	10/29/74	0.4	159.8	1101
				11/25/74	11.4	148.8	
				12/31/74	2.7	157.5	
				1/27/75	11.3	148.9	
				2/25/75	8.8	151.4	
				3/24/75	4.9	155.3	
				5/01/75	-1.3	161.5	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT CENTRAL HYDRO SUBAREA						U-05 U-05.A U-05.A5	
02S/11W-19E08 S (CONTINUED)	19		160.2	6/23/75	10.0	150.2	1101
				7/28/75	9.9	150.3	
				8/25/75	7.2	153.0	
02S/11W-19E09 S	19		160.9	10/29/74	29.1	131.8	1101
				11/25/74	30.7	130.2	
				12/31/74	33.9	127.0	
				1/27/75	35.1	125.8	
				2/25/75	34.2	126.7	
				3/24/75	32.2	128.7	
				5/01/75	31.2	129.7	
				6/23/75	24.7	136.2	
				7/28/75	25.1	135.8	
				8/25/75	28.3	132.6	
02S/11W-19F14 S	19		164.4	10/29/74	28.5	135.9	1101
				11/25/74	39.0	125.4	
				12/31/74	38.7	125.7	
				1/27/75	41.4	123.0	
				2/25/75	39.5	124.9	
				3/24/75	36.6	127.8	
				5/01/75	31.5	132.9	
				6/23/75	32.0	132.4	
				7/28/75	34.7	129.7	
				8/25/75	36.4	128.0	
02S/11W-19F01 S	19		159.0	11/19/74	NM-1		1101
02S/11W-19F02 S	19		168.0	10/15/74	45.0(5)	123.0	1101
				11/15/74	46.0(5)	122.0	
				1/15/75	45.0(5)	123.0	
				2/15/75	45.0(5)	123.0	
				3/15/75	45.0(5)	123.0	
				4/15/75	43.0(5)	125.0	
				5/15/75	49.0(5)	119.0	
				6/15/75	47.0(5)	121.0	
				7/15/75	51.0(5)	117.0	
				8/15/75	62.0(5)	106.0	
				9/15/75	53.0(5)	115.0	
02S/11W-19H01 S	19		170.0	10/28/74	35.3	134.7	1733
				11/25/74	36.4	133.6	
				12/23/74	37.9	132.1	
				1/27/75	40.6	129.4	
				2/24/75	43.4	126.6	
				3/24/75	43.0	127.0	
				4/28/75	43.8	126.2	
				5/26/75	41.7	128.3	
				6/23/75	36.6	133.4	
				7/28/75	36.2	133.8	
				8/25/75	36.8	133.2	
				9/22/75	37.9	132.1	
02S/11W-19H01 S	19		160.0	11/19/74	55.8	104.2	1101
				4/21/75	52.1	107.9	
02S/11W-19H03 S	19		160.0	10/28/74	26.3	133.7	1733
				11/25/74	36.8	123.2	
				12/23/74	37.9	122.1	
				1/27/75	41.5	118.5	
				2/24/75	39.3	120.7	
				3/24/75	34.5	125.5	
				4/28/75	32.0	128.0	
				5/26/75	20.8	139.2	
				6/23/75	28.0	132.0	
				7/28/75	31.7	128.3	
				8/25/75	32.7	127.3	
				9/22/75	39.5	120.5	
02S/11W-29E01 S	19		150.5	10/27/74	71.5	79.0	1101
				11/17/74	63.5	87.0	
				12/28/74	59.5	91.0	
				1/26/75	59.5	91.0	
				2/02/75	58.5	92.0	
				3/16/75	56.5	94.0	
				4/26/75	59.5	91.0	
				6/29/75	75.5	75.0	
				7/27/75	66.5	84.0	
				8/17/75	60.5	90.0	
				9/27/75	68.5	82.0	
02S/11W-29F05 S	19		155.0	10/30/74	40.3	114.7	1101
				11/26/74	41.6	113.4	
				12/31/74	42.0	113.0	
				1/28/75	43.0	112.0	
				2/26/75	43.7	111.3	
				3/26/75	447.3	-292.3	
				5/01/75	42.9	112.1	
				6/23/75	40.5	114.5	
				7/29/75	40.9	114.1	
				8/25/75	42.0	113.0	
02S/11W-30D01 S	19		158.5	10/30/74	40.0	118.5	1101
				11/26/74	44.5	114.0	
				12/31/74	46.5	112.0	
				1/28/75	48.8	109.7	
				2/26/75	47.6	110.9	
				3/26/75	45.5	113.0	
				5/01/75	44.0	114.5	
				6/23/75	37.8	120.7	
				7/29/75	40.3	118.2	
				8/25/75	41.6	116.9	

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT CENTRAL HYDRO SUBAREA						U-05 U-05.A U-05.A5	
02S/11W-30G02 S	19		157.7	10/30/74	38.2	119.5	1101
				11/26/74	40.0	117.7	
				12/31/74	41.3	116.4	
				1/28/75	NM-9		
				2/26/75	42.6	115.1	
				3/26/75	40.5	117.2	
				5/01/75	42.6	115.1	
				6/23/75	38.0	119.7	
				7/29/75	38.1	119.6	
				8/25/75	39.4	118.3	
02S/11W-30H01 S	19		151.5	11/01/74	44.8	106.7	1101
				12/30/74	48.3	103.2	
				1/28/75	48.7	102.8	
				2/26/75	53.3	98.2	
				3/25/75	51.2	100.3	
				4/29/75	48.2	103.3	
				5/28/75	50.1	101.4	
				6/24/75	43.1	108.4	
				7/29/75	45.1	106.4	
				8/26/75	44.6	106.9	
02S/11W-31P04 S	19		155.0	11/01/74	54.4	100.6	1101
				12/30/74	56.0	99.0	
				1/27/75	57.1	97.9	
				2/27/75	57.8	97.2	
				3/25/75	57.6	97.4	
				4/29/75	58.1	96.9	
				5/28/75	57.4	97.6	
				6/24/75	56.0	99.0	
				7/29/75	55.4	99.6	
				8/26/75	55.7	99.3	
02S/11W-32J04 S	19		144.0	11/07/74	39.8	104.2	1101
				4/04/75	37.6	106.4	
02S/11W-32K05 S	19		150.0	11/01/74	39.3	110.7	1101
				12/30/74	41.5	108.5	
				1/28/75	39.6	110.4	
				2/26/75	43.7	106.3	
				3/25/75	43.5	106.5	
				4/29/75	39.2	110.8	
				5/28/75	44.0	106.0	
				6/24/75	42.8	107.2	
				7/29/75	44.5	105.5	
				8/26/75	40.0	110.0	
02S/11W-32Q03 S	19		153.0	11/07/74	NM-5		1101
				12/16/74	70.0	83.0	
				4/04/75	NM-5		
02S/11W-33E02 S	19		148.0	10/21/74	36.1	111.9	1733
				11/11/74	35.8	112.2	
				12/02/74	35.2	112.8	
				1/08/75	35.3	112.7	
				2/19/75	35.5	112.5	
				3/12/75	35.5	112.5	
				4/02/75	35.6	112.4	
				5/14/75	36.3	111.7	
				6/04/75	36.4	111.6	
				7/09/75	36.0	112.0	
				8/20/75	36.1	111.9	
				9/10/75	36.9	111.1	
02S/11W-33M01 S	19		140.3	11/04/74	72.5(5)	67.8	1101
				1/02/75	70.5(5)	69.8	
				3/05/75	69.5(5)	70.8	
				5/05/75	70.5(5)	69.8	
				7/07/75	53.5(5)	86.8	
				9/02/75	79.5(5)	60.8	
02S/11W-35R01 S	19		255.0	6/12/75	NM-0		1101
02S/12W-01J02 S	19		196.2	11/19/74	28.3	167.9	1101
				4/07/75	25.7(8)	170.5	
02S/12W-01P02 S	19		203.0	10/29/74	48.9	154.1	1101
				11/25/74	49.5	153.5	
				12/31/74	48.8	154.2	
				1/27/75	48.5	154.5	
				2/25/75	47.6	155.4	
				3/24/75	46.8	156.2	
				4/29/75	47.3	155.7	
				5/26/75	49.1	153.9	
				6/23/75	49.3	153.7	
				7/28/75	49.0	154.0	
				8/26/75	51.9	151.1	
02S/12W-01P03 S	19		218.0	11/19/74	56.0	162.0	1101
				4/07/75	NM-1		
				5/13/75	65.9(4)	152.1	
02S/12W-01R01 S	19		190.9	10/29/74	25.6	165.3	1101
				11/25/74	25.0	165.9	
				12/31/74	23.7	167.2	
				1/27/75	24.4	166.5	
				2/25/75	22.8	168.1	
			187.4	3/24/75	19.4	168.0	
				5/27/75	23.2	164.2	
				7/28/75	22.2	165.2	
02S/12W-01R02 S	19		187.6	10/15/74	25.0(5)	162.6	1101

See page 79 for key to terms a abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT CENTRAL HYDRO SUBAREA						U-05 U-05.A U-05.A5	
02S/12W-01P02 S (CONTINUED)	19		187.6	11/15/74	26.0(5)	161.6	1101
				1/15/75	25.0(5)	162.6	
				2/15/75	24.0(5)	163.6	
				3/15/75	23.0(5)	164.6	
				4/15/75	22.0(5)	165.6	
				5/15/75	25.0(5)	162.6	
				6/15/75	25.0(5)	162.6	
				7/15/75	23.0(5)	164.6	
				8/15/75	26.0(5)	161.6	
				9/15/75	29.0(5)	158.6	
02S/12W-01P04 S	19		189.0	10/15/74	25.0(5)	164.0	1101
				11/15/74	26.0(5)	163.0	
				1/15/75	25.0(5)	164.8	
				2/15/75	24.0(5)	165.0	
				3/15/75	23.0(5)	166.0	
				4/15/75	24.0(5)	165.0	
				5/15/75	26.0(5)	163.0	
				6/15/75	25.0(5)	164.0	
				7/15/75	25.0(5)	164.0	
				8/15/75	28.0(5)	161.0	
				9/15/75	31.0(5)	158.0	
02S/12W-01R07 S	19		186.3	10/29/74	DRY		1101
				11/25/74	DRY		
				12/31/74	13.8	172.5	
				1/27/75	16.9	169.4	
				2/25/75	13.0	173.3	
				3/24/75	9.7	176.6	
				4/29/75	14.6	171.7	
				5/27/75	DRY (6)		
				6/25/75	DRY (6)		
				7/28/75	DRY (6)		
				8/26/75	DRY		
02S/12W-01R09 S	19		188.4	10/29/74	23.9	164.5	1101
				11/25/74	23.6	164.8	
				12/31/74	22.3	166.1	
				1/27/75	22.9	165.5	
				2/25/75	21.5	166.9	
				3/24/75	20.1	168.3	
				4/29/75	21.9	166.5	
				5/27/75	24.0	164.4	
				6/25/75	25.0	163.4	
				7/28/75	23.1	165.3	
				8/26/75	26.2	162.2	
02S/12W-03C01 S	19		246.0	11/19/74	214.8	31.2	1101
				4/16/75	200.2	45.8	
02S/12W-04C01 S	19		247.8	11/01/74	280.0(5)	-32.2	1101
				12/31/74	279.0(5)	-31.2	
				2/28/75	276.0(5)	-28.2	
				4/30/75	277.0(5)	-29.2	
				6/30/75	276.0(5)	-28.2	
				8/31/75	276.0(5)	-28.2	
02S/12W-04F02 S	19		228.0	11/01/74	229.0(5)	-1.0	1101
				12/31/74	227.0(5)	1.0	
				2/28/75	224.0(5)	4.0	
				4/30/75	224.0(5)	4.0	
				6/30/75	224.0(5)	4.0	
				8/31/75	225.0(5)	3.0	
02S/12W-05A01 S	19		203.7	10/01/74	309.0(1)	-105.3	1101
				11/01/74	238.0(5)	-34.3	
				12/31/74	234.0(5)	-30.3	
				1/31/75	291.0(1)	-87.3	
				4/30/75	232.0(5)	-28.3	
				5/31/75	296.0(1)	-92.3	
				7/31/75	300.0(1)	-96.3	
02S/12W-05B01 S	19		261.5	11/01/74	221.0(5)	40.5	1101
02S/12W-05M01 S	19		196.5	10/01/74	359.0(1)	-162.5	1101
				11/01/74	199.0(5)	-2.5	
				12/31/74	190.0(5)	6.5	
				1/31/75	249.0(1)	-52.5	
				2/28/75	197.0(5)	-0.5	
				3/31/75	251.0(1)	-54.5	
				4/30/75	199.0(5)	-2.5	
				5/31/75	344.0(1)	-147.5	
				6/30/75	197.0(5)	-0.5	
				7/31/75	349.0(1)	-152.5	
				8/31/75	198.0(5)	-1.5	
				9/30/75	344.0(1)	-147.5	
02S/12W-05P02 S	19		196.8	10/01/74	252.0(1)	-55.2	1101
				11/01/74	228.0(5)	-31.2	
				12/31/74	219.0(5)	-22.2	
				1/31/75	249.0(1)	-52.2	
				2/28/75	223.0(5)	-26.2	
				3/31/75	251.0(1)	-54.2	
				4/30/75	223.0(5)	-26.2	
				5/31/75	252.0(1)	-55.2	
				6/30/75	223.0(5)	-26.2	
				7/31/75	253.0(1)	-56.2	
				8/31/75	221.0(5)	-24.2	
				9/30/75	253.0(1)	-56.2	
02S/12W-05Q01 S	19		190.0	11/01/74	211.5(5)	-21.5	1101
				12/31/74	202.5(5)	-12.5	
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT CENTRAL HYDRO SUBAREA						U-05 U-05.A U-05.A5	
02S/12W-05Q01 S (CONTINUED)	19		190.0	2/28/75	203.5(5)	-13.5	1101
				4/30/75	201.5(5)	-11.5	
				6/30/75	199.5(5)	-9.5	
				8/31/75	201.5(5)	-11.5	
02S/12W-06K01 S	19		210.8	11/12/74	208.1(8)	1.9	1101
				4/16/75	206.3	3.7	
02S/12W-06M01 S	19		224.9	11/01/74	234.0(5)	-9.1	1101
				12/31/74	231.0(5)	-6.1	
				2/28/75	227.0(5)	-2.1	
				4/30/75	227.0(5)	-2.1	
				6/30/75	227.0(5)	-2.1	
				8/31/75	231.0(5)	-6.1	
02S/12W-06P01 S	19		200.4	12/31/74	250.0(5)	-49.6	1101
				1/31/75	317.0(1)	-116.6	
				2/28/75	252.0(5)	-51.6	
				3/31/75	321.0(1)	-120.6	
				4/30/75	252.0(5)	-51.6	
				5/31/75	322.0(1)	-121.6	
				6/30/75	321.0(1)	-120.6	
				7/31/75	325.0(1)	-124.6	
				8/31/75	327.0(1)	-126.6	
02S/12W-06P03 S	19		196.0	11/01/74	250.0(5)	-54.0	1101
				12/31/74	230.0(5)	-34.0	
				2/28/75	247.0(5)	-51.0	
				4/30/75	245.0(5)	-49.0	
02S/12W-06P04 S	19		195.0	11/01/74	254.5(5)	-59.5	1101
				2/28/75	251.5(5)	-56.5	
				4/30/75	250.5(5)	-55.5	
				6/30/75	248.5(5)	-53.5	
				8/31/75	254.5(5)	-59.5	
02S/12W-07C01 S	19		188.6	10/01/74	285.0(1)	-96.4	1101
				11/01/74	210.0(5)	-21.4	
				12/31/74	204.0(5)	-15.4	
				1/31/75	278.0(1)	-89.4	
				2/28/75	206.0(5)	-17.4	
				3/31/75	279.0(1)	-90.4	
				4/30/75	206.0(5)	-17.4	
				5/31/75	283.0(1)	-94.4	
				6/30/75	204.0(5)	-15.4	
				7/31/75	286.0(1)	-97.4	
				8/31/75	205.0(5)	-16.4	
				9/30/75	281.0(1)	-92.4	
02S/12W-07C02 S	19		185.8	10/01/74	274.0(1)	-88.2	1101
				11/27/74	276.0(1)	-90.2	
				12/31/74	221.0(5)	-35.2	
				1/31/75	268.0(1)	-82.2	
				2/28/75	220.0(5)	-34.2	
				3/31/75	263.0(1)	-77.2	
				4/30/75	218.0(5)	-32.2	
				5/31/75	271.0(1)	-85.2	
				6/30/75	269.0(1)	-83.2	
				7/31/75	272.0(1)	-86.2	
				8/31/75	272.0(1)	-86.2	
				9/30/75	269.0(1)	-83.2	
02S/12W-07C03 S	19		193.1	10/01/74	328.0(1)	-134.9	1101
				11/27/74	329.0(1)	-135.9	
				12/31/74	230.0(5)	-36.9	
				1/31/75	324.0(1)	-130.9	
				2/28/75	233.0(5)	-39.9	
				3/31/75	325.0(1)	-131.9	
				4/30/75	232.0(5)	-38.9	
				5/31/75	271.0(1)	-77.9	
				6/30/75	315.0(1)	-121.9	
				7/31/75	325.0(1)	-131.9	
				8/31/75	324.0(1)	-130.9	
				9/30/75	323.0(1)	-129.9	
02S/12W-07D01 S	19		184.5	10/01/74	348.0(1)	-163.5	1101
				11/01/74	244.0(5)	-59.5	
				12/31/74	224.0(5)	-39.5	
				3/31/75	332.0(1)	-147.5	
				4/30/75	332.0(1)	-147.5	
				5/31/75	335.0(1)	-150.5	
				6/30/75	333.0(1)	-148.5	
				7/31/75	353.0(1)	-168.5	
				8/31/75	352.0(1)	-167.5	
				9/30/75	349.0(1)	-164.5	
02S/12W-07G01 S	19		168.8	10/01/74	237.0(1)	-68.2	1101
				11/01/74	210.0(5)	-41.2	
				12/31/74	199.0(5)	-30.2	
				1/31/75	234.0(1)	-65.2	
				2/28/75	206.0(5)	-37.2	
				3/31/75	235.0(1)	-66.2	
				4/30/75	206.0(5)	-37.2	
				5/31/75	235.0(1)	-66.2	
02S/12W-07H01 S	19		163.3	12/31/74	193.5(5)	-30.2	1101
				3/31/75	227.5(1)	-64.2	
				4/30/75	208.5(5)	-45.2	
				5/31/75	222.5(1)	-59.2	
				6/30/75	209.5(5)	-46.2	
				7/31/75	226.5(1)	-63.2	
				8/31/75	210.5(5)	-47.2	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT CENTRAL HYDRO SUBAREA						U-05 U-05.A U-05.A5	
02S/12W-07H01 S	19		163.3	9/30/75	224.5(1)	-61.2	1101
02S/12W-07Q01 S	19		160.0	10/01/74	227.5(1)	-67.5	1101
				11/01/74	180.5(5)	-20.5	
02S/12W-07Q05 S	19		160.0	12/31/74	168.5(5)	-8.5	1101
				1/31/75	205.5(1)	-45.5	
				2/28/75	174.5(5)	-14.5	
				3/31/75	204.5(1)	-44.5	
				4/30/75	173.5(5)	-13.5	
				5/31/75	208.5(1)	-48.5	
				6/30/75	171.5(5)	-11.5	
				7/31/75	211.5(1)	-51.5	
				8/31/75	174.5(5)	-14.5	
				9/30/75	213.5(1)	-53.5	
02S/12W-08R01 S	19		180.8	11/01/74	195.0(5)	-14.2	1101
				12/31/74	189.0(5)	-8.2	
				2/28/75	189.0(5)	-8.2	
				4/30/75	189.0(5)	-8.2	
				6/30/75	189.0(5)	-8.2	
				8/31/75	189.0(5)	-8.2	
02S/12W-08C01 S	19		174.2	10/01/74	254.0(1)	-79.8	1101
				11/01/74	208.0(5)	-33.8	
				12/31/74	196.0(5)	-21.8	
				1/31/75	253.0(1)	-78.8	
				2/28/75	203.0(5)	-28.8	
				3/31/75	260.0(1)	-85.8	
				4/30/75	202.0(5)	-27.8	
				5/31/75	261.0(1)	-86.8	
				6/30/75	203.0(5)	-28.8	
				7/31/75	261.0(1)	-86.8	
				8/31/75	206.0(5)	-31.8	
				9/30/75	256.0(1)	-81.8	
02S/12W-08F01 S	19		161.6	10/01/74	225.0(1)	-63.4	1101
				11/01/74	198.0(5)	-36.4	
				12/31/74	186.0(5)	-24.4	
				1/31/75	219.0(1)	-57.4	
				2/28/75	192.0(5)	-30.4	
				3/31/75	219.0(1)	-57.4	
				4/30/75	143.0(5)	18.6	
				5/31/75	219.0(1)	-57.4	
				6/30/75	193.0(5)	-31.4	
				7/31/75	220.0(1)	-58.4	
				8/31/75	194.0(5)	-32.4	
				9/30/75	221.0(1)	-59.4	
02S/12W-08K01 S	19		157.5	11/01/74	NM-0		1101
02S/12W-08P01 S	19		148.4	10/01/74	197.0(1)	-48.6	1101
				11/01/74	163.0(5)	-14.6	
				12/31/74	163.0	-14.6	
				6/30/75	158.0(5)	-9.6	
				7/31/75	196.0(1)	-47.6	
				8/31/75	162.0(5)	-13.6	
				9/30/75	197.0(1)	-48.6	
02S/12W-09H01 S	19		160.0	11/01/74	149.0(5)	11.0	1101
				12/31/74	145.0(5)	15.0	
				2/28/75	145.0(5)	15.0	
				4/30/75	142.0(5)	18.0	
				6/30/75	142.0(5)	18.0	
				8/31/75	144.0(5)	16.0	
02S/12W-09H02 S	19		160.4	10/01/74	166.0(1)	-5.6	1101
				11/01/74	140.0(5)	20.4	
				12/31/74	137.0(5)	23.4	
				1/31/75	163.0(1)	-2.6	
				2/28/75	139.0(5)	21.4	
				3/31/75	162.0(1)	-1.6	
				4/30/75	135.0(5)	25.4	
				5/31/75	161.0(1)	-0.6	
				6/30/75	140.0(5)	20.4	
				7/31/75	166.0(1)	-5.6	
				8/31/75	144.0(5)	16.4	
02S/12W-10J01 S	19		194.1	11/01/74	93.0(5)	101.1	1101
				12/31/74	90.0(5)	104.1	
				2/28/75	91.0(5)	103.1	
				4/30/75	89.0(5)	105.1	
				6/30/75	89.0(5)	105.1	
				8/31/75	92.0(5)	102.1	
02S/12W-10Q02 S	19		187.7	10/07/74	102.2	85.5	1733
				11/04/74	101.0	86.7	
				12/02/74	100.7	87.0	
				1/06/75	98.4	89.3	
				2/03/75	96.7	91.0	
				3/03/75	95.4	92.3	
				4/07/75	95.9	91.8	
				5/05/75	97.5	90.2	
				6/02/75	98.3	89.4	
				7/07/75	98.4	89.3	
				8/04/75	101.4	86.3	
				9/01/75	104.1	83.6	
02S/12W-11R03 S	19		181.7	11/01/74	49.5	132.2	1101
				12/30/74	54.5	127.2	
				1/28/75	53.5	128.2	
				2/26/75	51.5(4)	130.2	
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT CENTRAL HYDRO SUBAREA						U-05 U-05.A U-05.A5	
02S/12W-11R03 S (CONTINUED)	19		181.7	3/25/75	49.5(4)	132.2	1101
				4/29/75	53.5(4)	128.2	
				5/28/75	53.5	128.2	
				6/24/75	52.5(4)	129.2	
				7/29/75	55.5(4)	126.2	
				8/26/75	59.5(4)	122.2	
02S/12W-12A01 S	19		186.0	10/15/74	26.0(5)	160.0	1101
				11/15/74	27.0(5)	159.0	
				1/15/75	25.0(5)	161.0	
				2/15/75	26.0(5)	160.0	
				3/15/75	25.0(5)	161.0	
				4/15/75	24.0(5)	162.0	
				5/15/75	26.0(5)	160.0	
				6/15/75	25.0(5)	161.0	
				7/15/75	25.0(5)	161.0	
				8/15/75	27.0(5)	159.0	
				9/15/75	31.0(5)	155.0	
02S/12W-12A03 S	19		185.0	11/19/74	20.3	164.7	1101
				4/09/75	17.7	167.3	
02S/12W-12A05 S	19		185.0	10/15/74	24.0(5)	161.0	1101
				11/15/74	25.0(5)	160.0	
				1/15/75	24.0(5)	161.0	
				2/15/75	24.0(5)	161.0	
				3/15/75	24.0(5)	161.0	
				4/15/75	22.0(5)	163.0	
				5/15/75	25.0(5)	160.0	
				6/15/75	24.0(5)	161.0	
				7/15/75	24.0(5)	161.0	
				8/15/75	26.0(5)	159.0	
				9/15/75	30.0(5)	155.0	
02S/12W-12A06 S	19		181.0	10/29/74	20.3	160.7	1101
				11/25/74	20.1	160.9	
				12/31/74	19.2	161.8	
				1/27/75	NM-9		
				2/25/75	NM-9		
				3/24/75	17.0	164.0	
				4/29/75	18.0	163.0	
				5/27/75	19.8	161.2	
				6/25/75	20.8	160.2	
				7/28/75	18.7	162.3	
				8/26/75	22.2	158.8	
02S/12W-12E05 S	19		200.0	10/16/74	87.0(5)	113.0	1101
				11/16/74	89.0(5)	111.0	
				12/16/74	84.0(5)	116.0	
				1/16/75	91.0(5)	109.0	
				2/16/75	83.0(5)	117.0	
				3/16/75	84.0(5)	116.0	
				4/16/75	83.0(5)	117.0	
				5/16/75	88.0(5)	112.0	
				6/16/75	97.0(5)	103.0	
				7/16/75	92.0(5)	108.0	
				8/16/75	102.0(5)	98.0	
				9/16/75	97.0(5)	103.0	
02S/12W-12F06 S	19		205.0	10/16/74	93.0(5)	112.0	1101
				11/16/74	91.0(5)	114.0	
				12/16/74	89.0(5)	116.0	
				1/16/75	87.0(5)	118.0	
				2/16/75	86.0(5)	119.0	
				3/16/75	84.0(5)	121.0	
				4/16/75	84.0(5)	121.0	
				5/16/75	89.0(5)	116.0	
				6/16/75	96.0(5)	109.0	
				7/16/75	91.0(5)	114.0	
				8/16/75	98.0(5)	107.0	
				9/16/75	109.0(5)	96.0	
02S/12W-12F07 S	19		210.0	10/16/74	101.2(5)	108.8	1101
				11/16/74	101.2(5)	108.8	
				12/16/74	101.2(5)	108.8	
				1/16/75	96.2(5)	113.8	
				2/16/75	97.2(5)	112.8	
				3/16/75	93.2(5)	116.8	
				4/16/75	94.2(5)	115.8	
				5/16/75	96.2(5)	113.8	
				6/16/75	93.2(5)	116.8	
				7/16/75	102.2(5)	107.8	
				8/16/75	102.2(5)	107.8	
				9/16/75	109.2(5)	100.8	
02S/12W-12F04 S	19		178.0	10/29/74	35.4	142.6	1101
				11/25/74	33.4	144.6	
				12/30/74	32.9	145.1	
				1/27/75	32.1	145.9	
				2/25/75	30.4	147.6	
				3/24/75	29.9	148.1	
				4/29/75	29.7	148.3	
				5/26/75	32.2	145.8	
				6/23/75	31.8	146.2	
				7/28/75	31.2	146.8	
				8/25/75	34.7	143.3	
02S/12W-12H02 S	19		211.0	10/16/74	96.0(5)	115.0	1101
				11/16/74	95.0(5)	116.0	
				12/16/74	98.0(5)	113.0	
				1/16/75	90.0(5)	121.0	
				2/16/75	88.0(5)	123.0	

See page 79 for key to terms a abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT CENTRAL HYDRO SUBAREA						U-05 U-05.A U-05.A5	
02S/12W-12M02 S (CONTINUED)	19		211.0	3/16/75	86.0(5)	125.0	1101
				4/16/75	86.0(5)	125.0	
				5/16/75	90.0(5)	121.0	
				6/16/75	94.0(5)	117.0	
02S/12W-12N01 S	19		173.0	10/15/74	39.5(5)	133.5	1101
				11/15/74	40.5(5)	132.5	
				1/15/75	39.5(5)	133.5	
				2/15/75	36.5(5)	136.5	
				3/15/75	35.5(5)	137.5	
				4/15/75	34.5(5)	138.5	
				5/15/75	36.5(5)	136.5	
				6/15/75	36.5(5)	136.5	
				7/15/75	38.5(5)	134.5	
				8/15/75	46.5(5)	126.5	
				9/15/75	50.5(5)	122.5	
02S/12W-12R01 S	19		181.0	10/28/74	43.7	137.3	1733
				11/25/74	44.2	136.8	
				12/23/74	41.5	139.5	
				1/27/75	39.6	141.4	
				2/24/75	38.7	142.3	
				3/24/75	37.2	143.8	
				4/28/75	39.5	141.5	
				5/26/75	39.3	141.7	
				6/23/75	38.9	142.1	
				7/28/75	43.1	137.9	
				8/25/75	47.6	133.4	
				9/22/75	51.2	129.8	
02S/12W-13B02 S	19		175.0	10/29/74	40.4	134.6	1101
				11/25/74	41.1	133.9	
				12/30/74	38.1	136.9	
				1/27/75	34.3	140.7	
				2/25/75	33.3	141.7	
				3/24/75	32.1	142.9	
				4/29/75	35.7	139.3	
				5/27/75	34.7	140.3	
				6/23/75	34.1	140.9	
				7/28/75	39.8	135.2	
				8/25/75	45.7	129.3	
02S/12W-13C01 S	19		170.0	10/29/74	39.9	130.1	1101
				11/26/74	43.3	126.7	
				12/23/74	38.4	131.6	
				1/21/75	36.8	133.2	
				2/25/75	29.0	141.0	
				3/25/75	28.9	141.1	
				4/29/75	32.6	137.4	
				5/27/75	30.5	139.5	
				6/24/75	26.2	143.8	
				7/29/75	44.4	125.6	
				8/26/75	50.8	119.2	
				9/23/75	56.5	113.5	
02S/12W-13F01 S	19		173.7	10/07/74	29.5	144.2	1733
				11/04/74	40.6	133.1	
				12/07/74	41.7	132.0	
				1/06/75	26.1	147.6	
				2/03/75	35.7	138.0	
				3/03/75	29.8	143.9	
				4/07/75	27.7	146.0	
				5/05/75	34.6	139.1	
				6/02/75	35.9	137.8	
				7/07/75	35.5	138.2	
				8/04/75	46.9	126.8	
				9/01/75	53.5	120.2	
02S/12W-13F02 S	19		169.7	10/29/74	39.4	130.3	1101
				11/26/74	36.8	132.9	
				12/23/74	35.1(3)	134.6	
				1/21/75	29.7	140.0	
				2/25/75	17.1	152.6	
				3/25/75	18.3	151.4	
				4/29/75	21.4	148.3	
				5/27/75	20.7	149.0	
				6/24/75	14.9	154.8	
				7/29/75	40.0	129.7	
				8/26/75	53.1	116.6	
				9/23/75	DRY		
02S/12W-13F06 S	19		167.0	10/29/74	34.5	132.5	1101
				11/26/74	38.9	128.1	
				12/23/74	33.6	133.4	
				1/21/75	30.8	136.2	
				2/25/75	21.5	145.5	
				3/25/75	21.4	145.6	
				4/29/75	22.4	144.6	
				5/27/75	22.0	145.0	
				6/24/75	17.1	149.9	
				7/29/75	39.5	127.5	
				8/26/75	46.6	120.4	
				9/23/75	52.8	114.2	
02S/12W-13J02 S	19		174.0	10/30/74	47.7	126.3	1101
				11/26/74	49.0	125.0	
				12/31/74	48.1	125.9	
				1/27/75	47.5	126.5	
				2/26/75	45.6	128.4	
				3/26/75	43.7	130.3	
				5/01/75	44.9	129.1	
				6/23/75	42.0	132.0	
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT CENTRAL HYDRO SUBAREA						U-05 U-05.A U-05.A5	
02S/12W-13J02 S (CONTINUED)	19		174.0	7/29/75	45.0	129.0	1101
				8/25/75	49.0	125.0	
02S/12W-13L05 S	19		174.0	11/06/74	57.5	116.5	1101
				4/21/75	52.1	121.9	
02S/12W-13M01 S	19		166.1	10/29/74	61.5	104.6	1101
				11/26/74	61.6	104.5	
				12/23/74	58.8	107.3	
				1/21/75	58.0	108.1	
				2/25/75	55.1	111.0	
				3/25/75	53.3	112.8	
				4/29/75	56.7	109.4	
				5/27/75	56.7	109.4	
				6/24/75	55.7	110.4	
				7/29/75	61.8	104.3	
				8/26/75	62.7	103.4	
				9/23/75	69.7	96.4	
02S/12W-13M02 S	19		165.1	10/29/74	59.6	105.5	1101
				11/26/74	58.4	106.7	
				12/23/74	56.0(3)	109.1	
				1/21/75	55.4	109.7	
				2/25/75	51.4	113.7	
				3/25/75	50.0	115.1	
				4/29/75	54.3	110.8	
				5/27/75	54.1	111.0	
				6/24/75	52.7	112.4	
				7/29/75	60.4	104.7	
				8/26/75	65.2	99.9	
				9/23/75	69.7	95.4	
02S/12W-13M03 S	19		165.2	10/29/74	53.6	111.6	1101
				11/26/74	51.7	113.5	
				12/23/74	47.9	117.3	
				1/21/75	47.9	117.3	
				2/25/75	43.8	121.4	
				3/25/75	41.5	123.7	
				4/29/75	47.6	117.6	
				5/27/75	47.4	117.8	
				6/24/75	44.2	121.0	
				7/29/75	55.1	110.1	
				8/26/75	60.6	104.6	
				9/23/75	66.7	98.5	
02S/12W-13M04 S	19		165.4	10/29/74	43.0	122.4	1101
				11/26/74	40.3	125.1	
				12/23/74	35.8	129.6	
				1/21/75	36.8	128.6	
				2/25/75	28.5	136.9	
				3/25/75	28.2	137.2	
				4/29/75	39.4	126.0	
				5/27/75	36.6	128.8	
				6/24/75	30.3	135.1	
				7/29/75	43.4	122.0	
				8/26/75	52.4	113.0	
				9/23/75	59.4	106.0	
02S/12W-14B08 S	19		169.0	11/01/74	55.1	113.9	1101
				12/30/74	59.8(4)	109.2	
				1/28/75	64.3	104.7	
				2/26/75	50.6(4)	118.4	
				3/25/75	49.7(4)	119.3	
				4/29/75	49.6(4)	119.4	
				5/28/75	NM-1		
				6/24/75	NM-1		
				7/29/75	NM-1		
				8/26/75	NM-1		
02S/12W-14G05 S	19		163.1	10/29/74	46.9	116.2	1101
				11/26/74	41.0	122.1	
				12/23/74	31.9(3)	131.2	
				1/21/75	33.4	129.7	
				2/25/75	37.2	125.9	
				3/25/75	28.6	134.5	
				4/29/75	38.6	124.5	
				5/27/75	41.7	121.4	
				6/24/75	32.4	130.7	
				7/29/75	46.6	116.5	
				8/26/75	54.7	108.4	
				9/23/75	DRY		
02S/12W-14J01 S	19		166.3	10/29/74	40.8	125.5	1101
				11/26/74	31.8	134.5	
				12/23/74	27.1	139.2	
				1/21/75	28.3	138.0	
				2/25/75	19.2	147.1	
				3/25/75	23.0	143.3	
				4/29/75	DRY		
				5/27/75	DRY		
				6/24/75	27.4	138.9	
				7/29/75	DRY		
				8/26/75	DRY		
				9/23/75	DRY		
02S/12W-14J03 S	19		168.1	10/29/74	34.6	133.5	1101
				11/26/74	24.1	144.0	
				12/23/74	23.7	144.4	
				1/21/75	26.3	141.8	
				2/25/75	10.3	157.8	
				3/25/75	18.7	149.4	
				4/29/75	37.2	130.9	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GARRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT CENTRAL HYDRO SUBAREA						U-05 U-05.A U-05.A5	
02S/12W-14J03 S (CONTINUED)	19		168.1	5/27/75	32.0	136.1	1101
				6/24/75	23.3	144.8	
				7/29/75	41.2	126.9	
				8/26/75	DRY		
				9/23/75	DRY		
02S/12W-14K02 S	19		162.0	10/29/74	DRY		1101
				11/26/74	DRY		
				12/23/74	DRY		
				1/21/75	39.4	122.6	
				2/25/75	39.3	122.7	
				3/25/75	30.5	131.5	
				4/29/75	DRY		
				5/27/75	DRY		
				6/24/75	37.6	124.4	
				7/29/75	DRY		
				8/26/75	DRY		
				9/23/75	DRY		
02S/12W-14P01 S	19		157.1	10/29/74	54.8	102.3	1101
				11/26/74	49.4	107.7	
				12/23/74	43.6	113.5	
				1/21/75	46.2(1)	110.9	
				2/25/75	44.0	113.1	
				3/25/75	35.7(1)	121.4	
				4/29/75	42.4	114.7	
				5/27/75	46.6	110.5	
				6/24/75	44.1	113.0	
				7/29/75	49.5	107.6	
				8/26/75	56.8	100.3	
				9/23/75	62.1	95.0	
02S/12W-14Q04 S	19		151.7	10/29/74	51.4	100.3	1101
				11/26/74	43.2	108.5	
				12/23/74	42.5(3)	109.2	
				1/21/75	37.3	114.4	
				2/25/75	41.0	110.7	
				3/25/75	31.9	119.8	
				4/29/75	41.5	110.2	
				5/27/75	43.7	108.0	
				6/24/75	40.6	111.1	
				7/29/75	49.3	102.4	
				8/26/75	56.2	95.5	
				9/23/75	DRY		
02S/12W-14R06 S	19		162.2	10/29/74	48.1	114.1	1101
				11/26/74	38.2	124.0	
				12/23/74	34.5	127.7	
				1/21/75	27.0	135.2	
				2/25/75	29.4	132.8	
				3/25/75	23.4	138.8	
				4/29/75	37.4	124.8	
				5/27/75	38.0	124.2	
				6/24/75	27.9	134.3	
				7/29/75	43.2	119.0	
				8/26/75	50.4	111.8	
				9/23/75	57.7	104.5	
02S/12W-15J03 S	19		187.0	11/19/74	97.0	90.0	1101
				4/22/75	87.2	99.8	
02S/12W-15N01 S	19		157.9	11/14/74	99.2(8)	58.7	1101
				4/22/75	89.5(8)	68.4	
02S/12W-15Q01 S	19		176.0	10/31/74	93.9	82.1	1101
				11/25/74	95.4	80.6	
				12/27/74	95.7	80.3	
				1/27/75	87.9	88.1	
				2/25/75	93.0	83.0	
				3/24/75	90.2	85.8	
				4/28/75	89.2	86.8	
				5/27/75	90.1	85.9	
				6/23/75	91.2	84.8	
				7/28/75	93.6	82.4	
				8/25/75	93.9	82.1	
02S/12W-16B01 S	19		181.7	10/28/74	162.9	18.8	1733
				11/25/74	161.4	20.3	
				12/23/74	158.7	23.0	
				1/27/75	156.9	24.8	
				2/24/75	157.1	24.6	
				3/24/75	154.9	26.8	
				4/28/75	153.4	28.3	
				5/26/75	157.1	24.6	
				6/23/75	158.6	23.1	
				7/28/75	160.7	21.0	
				8/25/75	163.7	18.0	
				9/22/75	165.9	15.8	
02S/12W-16F02 S	19		143.4	10/14/74	116.2	27.2	1733
				11/04/74	113.2	30.2	
				12/16/74	117.8	25.6	
				1/06/75	106.6	36.8	
				2/24/75	108.9	34.5	
				3/10/75	109.9	33.5	
				4/21/75	106.0	37.4	
				5/12/75	108.5	34.9	
				6/02/75	112.5	30.9	
				7/14/75	112.0	31.4	
				8/04/75	113.9	29.5	
				9/15/75	116.5	26.9	
02S/12W-16H01 S	19		159.5	11/01/74	118.0(5)	41.5	1101
LA-SAN GARRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT CENTRAL HYDRO SUBAREA						U-05 U-05.A U-05.A5	
02S/12W-16H01 S (CONTINUED)	19		159.5	12/31/74	115.0(5)	44.5	1101
				2/28/75	114.0(5)	45.5	
				4/28/75	112.0(5)	47.5	
				6/30/75	113.0(5)	46.5	
				8/31/75	120.0(5)	39.5	
02S/12W-16L01 S	19		150.8	10/01/74	178.0(1)	-27.2	1101
				11/01/74	131.0(5)	19.8	
				12/31/74	129.0(5)	21.8	
				1/31/75	180.0(1)	-29.2	
				2/28/75	133.0(5)	17.8	
				3/31/75	182.0(1)	-31.2	
				4/30/75	125.0(5)	25.8	
				6/30/75	121.0(5)	29.8	
				7/31/75	164.0(1)	-13.2	
				8/31/75	125.0(5)	25.8	
02S/12W-16N01 S	19		141.0	10/31/74	114.9	26.1	1101
				11/25/74	114.3	26.7	
				12/27/74	115.4	25.6	
				1/27/75	117.9	23.1	
				2/25/75	111.1	29.9	
				3/24/75	110.5	30.5	
				4/28/75	108.7	32.3	
				5/27/75	110.9	30.1	
				6/23/75	111.7	29.3	
				7/28/75	114.1	26.9	
				8/25/75	115.7	25.3	
02S/12W-16Q01 S	19		150.5	10/01/74	243.0(1)	-92.5	1101
				11/01/74	126.0(5)	24.5	
				12/31/74	121.0(5)	29.5	
				1/31/75	219.0(1)	-68.5	
				2/28/75	127.0(5)	23.5	
				3/31/75	218.0(1)	-67.5	
				4/30/75	126.0(5)	24.5	
				5/31/75	216.0(1)	-65.5	
				6/30/75	127.0(5)	23.5	
				7/31/75	223.0(1)	-72.5	
				8/31/75	127.0(5)	23.5	
				9/30/75	221.0(1)	-70.5	
02S/12W-17C01 S	19		144.7	10/01/74	176.0(1)	-31.3	1101
				11/01/74	161.0(5)	-16.3	
				12/31/74	153.0(5)	-8.3	
				1/31/75	169.0(1)	-24.3	
				2/28/75	158.0(5)	-13.3	
				3/31/75	169.0(1)	-24.3	
				4/30/75	154.0(5)	-9.3	
				5/31/75	172.0(1)	-27.3	
				6/30/75	156.0(5)	-11.3	
				7/31/75	173.0(1)	-28.3	
				8/31/75	156.0(5)	-11.3	
				9/30/75	180.0(1)	-35.3	
02S/12W-17D02 S	19		146.1	10/01/74	188.0(1)	-41.9	1101
				11/01/74	161.0(5)	-14.9	
				12/31/74	152.0(5)	-5.9	
				1/31/75	184.0(1)	-37.9	
				2/28/75	156.0(5)	-9.9	
				3/31/75	183.0(1)	-36.9	
				4/30/75	152.0(5)	-5.9	
				5/31/75	184.0(1)	-37.9	
				6/30/75	157.0(5)	-10.9	
				7/31/75	186.0(1)	-39.9	
				8/31/75	159.0(5)	-12.9	
				9/30/75	189.0(1)	-42.9	
02S/12W-17M01 S	19		145.0	11/15/74	155.5(8)	-10.5	1101
				4/22/75	149.4	-4.4	
02S/12W-19C01 S	19		147.5	11/14/74	183.4	-35.9	1101
				4/16/75	163.7	-16.2	
02S/12W-19H01 S	19		147.8	11/14/74	85.7	62.1	1101
				4/16/75	85.7	62.1	
02S/12W-19M01 S	19		143.0	11/14/74	137.5	5.5	1101
				4/16/75	139.7	3.3	
02S/12W-20E02 S	19		139.0	11/14/74	140.7(4)	-1.7	1101
				5/07/75	NM-9		
02S/12W-20K03 S	19		137.0	11/14/74	136.1	-3.1	1101
				4/22/75	125.9	7.1	
02S/12W-20M03 S	19		139.0	11/14/74	151.2(4)	-12.2	1101
				5/07/75	144.7(4)	-5.7	
02S/12W-21H01 S	19		160.0	10/31/74	112.5	47.5	1101
				11/25/74	105.8	54.2	
				12/27/74	111.8	48.2	
				1/27/75	99.5	60.5	
				2/25/75	101.9	58.1	
				3/24/75	109.0	51.0	
				4/28/75	99.4	60.6	
				5/27/75	101.1	58.9	
				6/23/75	102.3	57.7	
				7/28/75	103.9	56.1	
				8/25/75	108.9	51.1	
02S/12W-21J01 S	19		155.0	12/10/74	119.5(5)	35.5	1101

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
COASTAL PL OF LA CO HYDRO SUBUNIT — U-05.A
CENTRAL HYDRO SUBAREA — U-05.A5

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
02S/12W-21N01 S	19		140.0	11/01/74	110.7	29.3	1101
				12/31/74	110.4	29.6	
02S/12W-21N02 S	19		137.0	10/31/74	109.1	27.9	1101
				11/25/74	107.8	29.2	
				12/09/74	NM-0		
				1/10/75	110.5	26.5	
				2/25/75	107.7	29.3	
				3/24/75	105.2	31.8	
				4/28/75	104.4	32.6	
				5/27/75	103.6	33.4	
				6/23/75	104.9	32.1	
				7/28/75	105.9	31.1	
				8/25/75	107.4	29.6	
				9/30/75	123.5	13.5	
02S/12W-21N03 S	19		139.0	11/01/74	123.5	15.5	1101
				12/31/74	115.5	23.5	
				1/31/75	117.5	21.5	
				2/28/75	118.5	20.5	
				3/31/75	113.5	25.5	
				4/30/75	129.5	9.5	
				5/30/75	121.5	17.5	
				6/30/75	145.5	-6.5	
				7/31/75	139.5	-0.5	
				8/31/75	141.5	-2.5	
				9/30/75	150.1	-11.1	
02S/12W-21Q01 S	19		147.0	10/31/74	106.2	40.8	1101
				11/25/74	106.1	40.9	
				12/27/74	104.0	43.0	
				1/27/75	103.9	43.1	
				2/25/75	107.6	39.4	
				3/24/75	101.5	45.5	
				4/28/75	101.2	45.8	
				5/27/75	103.1	43.9	
				6/23/75	104.2	42.8	
				7/28/75	106.1	40.9	
				8/25/75	108.2	38.8	
02S/12W-22D02 S	19		152.5	10/29/74	DRY		1101
				11/26/74	DRY		
				12/23/74	36.7(3)	115.8	
				1/21/75	DRY		
				2/25/75	36.0	116.5	
				3/25/75	38.3	114.2	
				4/29/75	37.2	115.3	
				5/27/75	39.0	113.5	
				6/24/75	37.8	114.7	
				7/29/75	DRY		
				8/26/75	DRY		
				9/23/75	DRY		
02S/12W-22G01 S	19		174.9	10/31/74	101.5	73.4	1101
				11/25/74	104.2	70.7	
				12/27/74	96.0	78.9	
				1/27/75	95.5	79.4	
				2/25/75	100.3	74.6	
				3/24/75	103.6	71.3	
				4/28/75	100.8	74.1	
				5/27/75	106.7	68.2	
				6/23/75	93.8	81.1	
				7/28/75	95.2	79.7	
				8/25/75	104.6	70.3	
02S/12W-22J01 S	19		175.0	11/19/74	94.0	81.0	1101
				4/22/75	86.2	88.8	
02S/12W-23B04 S	19		164.0	10/15/74	72.1(5)	91.9	1101
				11/15/74	73.1(5)	90.9	
				1/15/75	68.1(5)	95.9	
				2/15/75	67.1(5)	96.9	
				3/15/75	63.1(5)	100.9	
				4/15/75	67.1(5)	96.9	
				5/15/75	68.1(5)	95.9	
				6/15/75	64.1(5)	99.9	
				7/15/75	68.1(5)	95.9	
				8/15/75	77.1(5)	86.9	
				9/15/75	81.1(5)	82.9	
02S/12W-23B08 S	19		161.0	10/15/74	73.0(5)	88.0	1101
				11/15/74	72.0(5)	89.0	
				1/15/75	67.0(5)	94.0	
				2/15/75	67.0(5)	94.0	
				3/15/75	63.0(5)	98.0	
				4/15/75	66.0(5)	95.0	
				5/15/75	67.0(5)	94.0	
				6/15/75	69.0(5)	92.0	
				7/15/75	71.0(5)	90.0	
				8/15/75	77.0(5)	84.0	
				9/15/75	80.0(5)	81.0	
02S/12W-23F03 S	19		158.0	10/29/74	DRY		1101
				11/26/74	DRY		
				12/23/74	53.7	104.3	
				1/21/75	55.1	102.9	
				2/25/75	56.2	101.8	
				3/25/75	47.8	110.2	
				4/29/75	52.0	106.0	
				5/27/75	DRY		
				6/24/75	53.7	104.3	

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
COASTAL PL OF LA CO HYDRO SUBUNIT — U-05.A
CENTRAL HYDRO SUBAREA — U-05.A5

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
02S/12W-23F03 S (CONTINUED)	19		158.0	7/29/75	DRY		1101
				8/26/75	DRY		
				9/23/75	DRY		
02S/12W-23K01 S	19		161.0	10/31/74	67.3	93.7	1101
				11/26/74	NM-9		
				12/30/74	65.5	95.5	
				1/28/75	65.0	96.0	
				2/25/75	70.7	90.3	
				3/24/75	64.0	97.0	
				4/28/75	71.8	89.2	
				5/27/75	80.3	80.7	
				6/24/75	79.1	81.9	
				7/28/75	82.3	78.7	
				8/25/75	1.3	159.7	
02S/12W-23M03 S	19		142.0	10/29/74	52.2	89.8	1101
				11/26/74	48.7	93.3	
				12/23/74	36.7	105.3	
				1/21/75	36.1	105.9	
				2/25/75	45.4	96.6	
				3/25/75	36.5	105.5	
				4/29/75	39.8	102.2	
				5/27/75	46.8	95.2	
				6/24/75	40.1	101.9	
				7/29/75	49.9	92.1	
				8/26/75	56.4	85.6	
				9/23/75	61.8	80.2	
02S/12W-23M04 S	19		138.4	10/29/74	NM-9		1101
				11/25/74	NM-9		
				12/23/74	NM-9		
				1/21/75	NM-9		
				7/28/75	NM-9		
				8/26/75	NM-9		
02S/12W-23N02 S	19		146.7	10/29/74	69.5	77.2	1101
				11/26/74	68.0	78.7	
				12/23/74	63.5	83.2	
				1/21/75	64.0	82.7	
				2/25/75	65.6	81.1	
				3/25/75	60.9	85.8	
				4/29/75	63.7	83.0	
				5/27/75	66.1	80.6	
				6/24/75	64.5	82.2	
				7/29/75	63.6	83.1	
				8/26/75	72.9	73.8	
				9/23/75	76.2	70.5	
02S/12W-24A05 S	19		168.8	10/30/74	46.1	122.7	1101
				11/26/74	48.5	120.3	
				12/31/74	48.3	120.5	
				1/27/75	48.1	120.7	
				2/26/75	46.0	122.8	
				3/26/75	44.0	124.8	
				5/01/75	44.5	124.3	
				6/23/75	41.3	127.5	
				7/29/75	43.6	125.2	
				8/25/75	NM-9		
02S/12W-24K01 S	19		164.0	10/30/74	51.4	112.6	1101
				11/26/74	53.8	110.2	
				12/31/74	53.5	110.5	
				1/28/75	53.9(8)	110.1	
				2/26/75	52.1	111.9	
				3/26/75	49.7	114.3	
				5/01/75	50.5	113.5	
				6/23/75	47.4	116.6	
				7/29/75	48.9(8)	115.1	
				8/25/75	52.5	111.5	
02S/12W-24M03 S	19		160.1	10/21/74	59.8	100.3	1733
				11/12/74	60.2	99.9	
				12/02/74	59.5	100.6	
				1/13/75	58.3	101.8	
				2/05/75	58.4	101.7	
				3/17/75	54.3	105.8	
				4/07/75	54.3	105.8	
				5/19/75	55.4	104.7	
				6/09/75	55.3	104.8	
				7/21/75	55.7	104.4	
				8/11/75	59.3	100.8	
				9/01/75	62.0	98.1	
02S/12W-24M08 S	19		159.2	10/03/74	57.8	101.4	1101
				11/07/74	59.5	99.7	
				12/05/74	59.2	100.0	
				1/02/75	57.5	101.7	
				2/06/75	57.5	101.7	
				3/06/75	55.8	103.4	
				4/03/75	53.5	105.7	
				5/01/75	55.5	103.7	
				6/05/75	55.1	104.1	
				7/03/75	54.4	104.8	
				8/06/75	58.3	100.9	
				9/04/75	62.5	96.7	
02S/12W-24R08 S	19		159.7	10/29/74	46.3	113.4	1101
				11/25/74	50.2	109.5	
				12/31/74	49.8	109.9	
				1/27/75	51.1	108.6	
				2/25/75	49.7	110.0	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
COASTAL PL OF LA CO HYDRO SUBUNIT — U-05.A
CENTRAL HYDRO SUBAREA — U-05.A5

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
02S/12W-24P08 S (CONTINUED)	19		159.7	3/24/75	48.1	111.6	1101
				5/01/75	47.0	112.7	
				6/23/75	44.7	115.0	
				7/28/75	46.3	113.4	
				8/25/75	48.5	111.2	
02S/12W-25A01 S	19		155.4	11/01/74	40.5	114.9	1101
				12/30/74	46.5	108.9	
				1/28/75	55.3	100.1	
				2/26/75	47.3	108.1	
				3/25/75	45.2	110.2	
				4/29/75	45.2	110.2	
				5/28/75	36.4	119.0	
				6/24/75	38.4	117.0	
				7/29/75	39.6	115.8	
				8/26/75	40.9	114.5	
02S/12W-25C08 S	19		153.0	10/31/74	55.6	97.4	1101
				11/26/74	57.4	95.6	
				12/27/74	61.7	91.3	
				1/27/75	61.6	91.4	
				2/25/75	62.4	90.6	
				3/24/75	55.6	97.4	
				4/28/75	-3.8	156.8	
				5/27/75	53.6	99.4	
				6/24/75	52.4	100.6	
				7/28/75	54.7	98.3	
				8/25/75	DRY (6)		
02S/12W-25E06 S	19		154.0	10/27/74	63.5(5)	90.5	1101
				11/17/74	63.5(5)	90.5	
				12/29/74	63.5(5)	90.5	
				1/26/75	62.5(5)	91.5	
				2/16/75	62.5(5)	91.5	
				3/13/75	60.5(5)	93.5	
				4/27/75	60.5(5)	93.5	
				5/25/75	61.5(5)	92.5	
				6/29/75	60.5(5)	93.5	
				7/27/75	61.5(5)	92.5	
				8/24/75	62.5(5)	91.5	
				9/21/75	64.5(5)	89.5	
02S/12W-25G01 S	19		155.0	10/15/74	40.0(5)	115.0	1101
				11/15/74	43.0(5)	112.0	
				1/15/75	47.0(5)	108.0	
				2/15/75	45.0(5)	110.0	
				3/15/75	44.0(5)	111.0	
				4/15/75	44.0(5)	111.0	
				5/15/75	41.0(5)	114.0	
				6/15/75	39.0(5)	116.0	
				7/15/75	39.0(5)	116.0	
				8/15/75	43.0(5)	112.0	
				9/15/75	45.0(5)	110.0	
02S/12W-25G02 S	19		155.0	10/15/74	50.0(5)	105.0	1101
				11/15/74	51.0(5)	104.0	
				1/15/75	53.0(5)	102.0	
				2/15/75	52.0(5)	103.0	
				3/15/75	52.0(5)	103.0	
				4/15/75	51.0(5)	104.0	
				5/15/75	50.0(5)	105.0	
				6/15/75	46.0(5)	109.0	
				7/15/75	47.0(5)	108.0	
				8/15/75	50.0(5)	105.0	
				9/15/75	54.0(5)	101.0	
02S/12W-25M09 S	19		151.0	10/28/74	68.5	82.5	1733
				11/25/74	69.6	81.4	
				12/23/74	68.5	82.5	
				1/27/75	69.4	81.6	
				2/24/75	69.1	81.9	
				3/24/75	67.7	83.3	
				4/28/75	68.8	82.2	
				5/26/75	70.8(1)	80.2	
				6/23/75	66.7	84.3	
				7/28/75	70.4(1)	80.6	
				8/25/75	NM-2		
				9/22/75	74.5	76.5	
02S/12W-25P07 S	19		146.0	10/31/74	59.0	87.0	1101
				11/26/74	49.0	97.0	
				12/27/74	60.1	85.9	
				1/28/75	53.8	92.2	
				2/25/75	NM-1		
				3/24/75	50.8	95.2	
				4/29/75	NM-1		
				5/27/75	NM-1		
				6/24/75	57.5	88.5	
				7/28/75	56.8	89.2	
				8/25/75	60.6	85.4	
02S/12W-25Q05 S	19		146.0	11/17/74	75.2	70.8	1101
				12/22/74	69.2	76.8	
				1/26/75	71.2	74.8	
				2/16/75	68.2	77.8	
				3/30/75	69.2	76.8	
				4/27/75	70.2	75.8	
				5/25/75	71.2	74.8	
				6/29/75	71.2	74.8	
				7/29/75	74.2	71.8	
				8/24/75	77.2	68.8	
				9/28/75	80.2	65.8	

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
COASTAL PL OF LA CO HYDRO SUBUNIT — U-05.A
CENTRAL HYDRO SUBAREA — U-05.A5

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
02S/12W-26F01 S	19		148.0	10/31/74	77.1	70.9	1101
				11/26/74	75.3	72.7	
				12/30/74	70.9	77.1	
				1/28/75	72.6	75.4	
				2/25/75	76.6	71.4	
				3/24/75	68.3	79.7	
				4/28/75	69.6	78.4	
				5/27/75	72.2	75.8	
				6/24/75	NM-9		
				7/28/75	NM-9		
02S/12W-26L02 S	19		148.0	10/31/74	67.9	80.1	1101
				11/26/74	65.8	82.2	
				12/27/74	68.8	79.2	
				1/27/75	68.8	79.2	
				2/25/75	69.1	78.9	
				3/24/75	68.2	79.8	
				4/28/75	67.3	80.7	
				5/27/75	67.9	80.1	
				6/24/75	67.9	80.1	
				7/28/75	67.7	80.3	
				8/25/75	69.0	79.0	
02S/12W-26P06 S	19		142.0	11/14/74	81.0(5)	61.0	1101
				12/14/74	81.0(5)	61.0	
				3/14/75	77.0(5)	65.0	
				4/14/75	81.0(5)	61.0	
				5/07/75	79.0(5)	63.0	
				6/14/75	79.0(5)	63.0	
				7/14/75	80.0(5)	62.0	
				8/14/75	80.0(5)	62.0	
				9/14/75	79.0(5)	63.0	
02S/12W-27F01 S	19		141.4	10/29/74	DRY		1101
				11/26/74	DRY		
				12/23/74	DRY		
				1/21/75	DRY		
				2/25/75	DRY		
				3/25/75	74.5	66.9	
				4/29/75	DRY		
				5/27/75	DRY		
				6/24/75	DRY		
				7/29/75	DRY		
				8/26/75	DRY		
				9/23/75	DRY		
02S/12W-27H01 S	19		146.0	10/01/74	100.5	45.5	1101
				11/01/74	95.5	50.5	
				12/01/74	90.5	55.5	
				1/01/75	93.5	52.5	
				2/01/75	90.5	55.5	
				3/01/75	94.5	51.5	
				4/01/75	94.5	51.5	
				5/01/75	90.5	55.5	
				6/01/75	98.5	47.5	
				7/01/75	99.5	46.5	
				8/01/75	103.5	42.5	
				9/01/75	102.5	43.5	
02S/12W-27Q01 S	19		137.0	10/31/74	NM-7		1101
				11/07/74	83.8(8)	53.2	
				12/27/74	82.5(8)	54.5	
				1/27/75	82.2(8)	54.8	
				2/25/75	82.6(8)	54.4	
				3/24/75	81.1(8)	55.9	
				4/28/75	82.6(8)	54.4	
				5/27/75	83.0(8)	54.0	
				6/24/75	83.3(8)	53.7	
				7/28/75	86.0(8)	51.0	
				8/25/75	87.4(8)	49.6	
02S/12W-27Q07 S	19		136.6	10/31/74	77.0	59.6	1101
				11/25/74	72.0	64.6	
				12/27/74	79.9	56.7	
				1/27/75	80.5	56.1	
				2/25/75	NM-9		
				3/24/75	NM-9		
				4/28/75	70.9	65.7	
				5/27/75	NM-9		
				6/24/75	71.7	64.9	
				7/28/75	NM-9		
				8/25/75	DRY (6)		
02S/12W-28G01 S	19		134.5	10/31/74	98.2	36.3	1101
				11/25/74	95.1	39.4	
				12/27/74	94.1	40.4	
				1/27/75	93.4	41.1	
				2/25/75	93.2	41.3	
				3/24/75	92.5	42.0	
				4/28/75	92.8	41.7	
				5/27/75	93.4	41.1	
				6/23/75	93.9	40.6	
				7/28/75	95.8	38.7	
				8/25/75	96.8	37.7	
02S/12W-28J06 S	19		135.0	10/01/74	109.0(5)	26.0	1101
				11/01/74	103.0(5)	32.0	
				12/01/74	102.0(5)	33.0	
				1/01/75	106.0(5)	29.0	
				2/01/75	101.0(5)	34.0	
				3/01/75	100.0(5)	35.0	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
COASTAL PL OF LA CO HYDRO SUBUNIT — U-05.A
CENTRAL HYDRO SUBAREA — U-05.A5

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
02S/12W-28J06 S (CONTINUED)	19		135.0	4/01/75	101.0(5)	34.0	1101
				5/01/75	104.0(5)	31.0	
				6/01/75	98.0(5)	37.0	
				7/01/75	111.0(5)	24.0	
				8/01/75	119.0(5)	16.0	
				9/01/75	111.0(5)	24.0	
02S/12W-28J07 S	19		135.0	10/31/74	93.1	41.9	1101
				11/25/74	93.2	41.8	
				1/27/75	91.6	43.4	
				2/25/75	95.3	39.7	
				3/24/75	90.2	44.8	
				4/28/75	92.0	43.0	
				5/27/75	91.8	43.2	
				6/23/75	92.7	42.3	
				7/28/75	94.7	40.3	
				8/25/75	96.0	39.0	
02S/12W-28K01 S	19		127.5	10/14/74	91.3(5)	36.2	1101
				11/14/74	91.3(5)	36.2	
				12/14/74	91.3(5)	36.2	
				2/14/75	94.3(5)	33.2	
				3/14/75	96.3(5)	31.2	
				4/14/75	96.3(5)	31.2	
				5/21/75	92.3(5)	35.2	
				6/14/75	93.3(5)	34.2	
				7/14/75	93.3(5)	34.2	
				8/14/75	91.3(5)	36.2	
				9/14/75	104.3(5)	23.2	
02S/12W-28N03 S	19		120.0	10/14/74	100.0(5)	20.0	1101
				11/14/74	101.0(5)	19.0	
				12/14/74	104.0(5)	16.0	
				2/14/75	108.0(5)	12.0	
				3/21/75	104.0(1)	16.0	
				4/14/75	98.0(5)	22.0	
				5/21/75	101.0(5)	19.0	
				6/14/75	103.0(5)	17.0	
				7/14/75	102.0(5)	18.0	
				8/14/75	102.0(5)	18.0	
				9/07/75	102.0(5)	18.0	
02S/12W-28Q01 S	19		129.0	10/01/74	96.1(5)	32.9	1101
				11/01/74	94.1(5)	34.9	
				12/01/74	92.1(5)	36.9	
				1/01/75	93.1(5)	35.9	
				2/01/75	95.1(5)	33.9	
				3/01/75	93.1(5)	35.9	
				4/01/75	96.1(5)	32.9	
				5/01/75	95.1(5)	33.9	
				6/01/75	92.1(5)	36.9	
				7/01/75	99.1(5)	29.9	
				8/01/75	99.1(5)	29.9	
				9/01/75	99.1(5)	29.9	
02S/12W-29A02 S	19		128.3	11/14/74	117.2(8)	11.1	1101
				5/07/75	NM-4		
02S/12W-29D01 S	19		126.5	11/14/74	115.1	11.4	1101
				4/16/75	113.3	13.2	
02S/12W-29J01 S	19		122.0	11/14/74	105.0(5)	17.0	1101
				12/07/74	105.0(5)	17.0	
				3/14/75	100.0(1)	22.0	
				4/14/75	92.0(5)	30.0	
				5/21/75	91.0(5)	31.0	
				6/14/75	91.0(5)	31.0	
				7/14/75	99.0(5)	23.0	
				8/14/75	100.0(5)	22.0	
				9/14/75	100.0(5)	22.0	
02S/12W-29P05 S	19		118.0	11/14/74	119.0(5)	-1.0	1101
				12/07/74	171.0(1)	-53.0	
				2/14/75	170.0(1)	-52.0	
				3/21/75	166.0(1)	-48.0	
				4/14/75	122.0(5)	-4.0	
				7/07/75	196.0(1)	-78.0	
				8/07/75	126.0(5)	-8.0	
				9/07/75	126.0(5)	-8.0	
02S/12W-29P06 S	19		116.0	10/28/74	97.7	18.3	1733
				11/25/74	97.4	18.6	
				12/23/74	96.9	19.1	
				1/27/75	96.5	19.5	
				2/24/75	96.2	19.8	
				3/24/75	96.3	19.7	
				4/28/75	96.5	19.5	
				5/24/75	97.1	18.9	
				6/23/75	97.5	18.5	
				7/28/75	99.0	17.0	
				8/25/75	99.4	16.6	
				9/22/75	99.6	16.4	
02S/12W-30G03 S	19		124.0	10/14/74	133.1(5)	-9.1	1101
				11/14/74	135.1(5)	-11.1	
				12/14/74	129.1(5)	-5.1	
				2/14/75	277.1(1)	-153.1	
				3/14/75	139.1(5)	-15.1	
				4/14/75	142.1(5)	-18.1	
				5/07/75	113.1(5)	10.9	
				6/14/75	113.1(5)	10.9	
				7/07/75	113.1(5)	10.9	
02S/12W-30G03 S (CONTINUED)	19		124.0	8/14/75	113.1(5)	10.9	1101
				9/14/75	137.1(6)	-13.1	
02S/12W-30H02 S	19		127.0	11/14/74	135.4(4)	-8.4	1101
				4/16/75	134.1(4)	-7.1	
02S/12W-31H01 S	19		107.7	10/31/74	109.0	-1.3	5061
02S/12W-31H02 S	19		107.6	11/15/74	80.1	27.5	1101
				4/16/75	78.6	29.0	
02S/12W-31M02 S	19		112.9	10/01/74	135.3	-22.4	1101
				11/01/74	123.3	-10.4	
				12/01/74	119.3	-6.4	
				1/01/75	125.3	-12.4	
				2/01/75	125.3	-12.4	
				3/01/75	125.3	-12.4	
				4/01/75	128.3	-15.4	
				5/01/75	135.3	-22.4	
				6/01/75	130.3	-17.4	
				7/01/75	130.3	-17.4	
				8/01/75	137.3	-24.4	
				9/01/75	131.3	-18.4	
02S/12W-31N01 S	19		106.2	11/15/74	105.5	0.7	1101
				4/16/75	103.4	2.8	
02S/12W-33B04 S	19		126.2	10/14/74	88.1	38.1	1733
				11/04/74	88.3	37.9	
				12/16/74	88.5	37.7	
				1/06/75	88.3	37.9	
				2/17/75	87.9	38.3	
				3/10/75	88.1	38.1	
				4/21/75	88.3	37.9	
				5/12/75	88.6	37.6	
				6/02/75	87.8	38.4	
				7/14/75	90.0	36.2	
				8/04/75	88.7	37.5	
				9/15/75	92.7	33.5	
02S/12W-33D02 S	19		118.8	10/31/74	83.9	34.9	1101
				11/26/74	83.9	34.9	
				12/27/74	83.3	35.5	
				1/27/75	83.0	35.8	
				2/25/75	82.9	35.9	
				3/24/75	82.8	36.0	
				4/28/75	83.2	35.6	
				5/27/75	83.5	35.3	
				6/23/75	84.1	34.7	
				7/28/75	84.9	33.9	
				8/25/75	85.0	33.8	
02S/12W-33L01 S	19		118.0	11/15/74	96.8(8)	21.2	1101
				4/22/75	91.0(8)	27.0	
02S/12W-33L03 S	19		115.6	11/15/74	71.9	43.7	1101
				4/22/75	71.9	43.7	
02S/12W-33P02 S	19		114.0	10/31/74	75.8	38.2	1101
				11/25/74	69.6	44.4	
				12/27/74	75.5	38.5	
				1/27/75	71.0	43.0	
				2/25/75	71.0	43.0	
				3/24/75	74.6	39.4	
				4/28/75	71.0	43.0	
				5/27/75	71.0	43.0	
				6/23/75	71.1	42.9	
				7/28/75	71.8	42.2	
				8/25/75	71.6	42.4	
02S/12W-34A01 S	19		134.5	10/31/74	71.6	62.9	1101
				11/25/74	67.2	67.3	
				12/27/74	71.5	63.0	
				1/27/75	67.4	67.1	
				2/25/75	68.1	66.4	
				3/24/75	75.1	59.4	
				4/28/75	66.8	67.7	
				5/27/75	67.1	67.4	
				6/24/75	67.3	67.2	
				7/28/75	70.0	64.5	
				8/25/75	68.2	66.3	
02S/12W-34G01 S	19		129.0	10/01/74	91.0(5)	38.0	1101
				11/01/74	90.0(5)	39.0	
				12/01/74	87.0(5)	42.0	
				1/01/75	89.0(5)	40.0	
				2/01/75	89.0(5)	40.0	
				3/01/75	88.0(5)	41.0	
				4/01/75	87.0(5)	42.0	
				5/01/75	90.0(5)	39.0	
				6/01/75	89.0(5)	40.0	
				7/01/75	90.0(5)	39.0	
				8/01/75	95.0(5)	34.0	
				9/01/75	96.0(5)	33.0	
02S/12W-34P01 S	19		124.0	10/01/74	97.5	26.5	1101
				11/01/74	95.5	28.5	
				2/01/75	95.5	28.5	
				3/01/75	96.5	27.5	
				4/01/75	97.5	26.5	
				5/01/75	100.5	23.5	
				6/01/75	91.5	32.5	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
COASTAL PL OF LA CO HYDRO SUBUNIT — U-05.A
CENTRAL HYDRO SUBAREA — U-05.A5

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
02S/12W-34P01 S (CONTINUED)	19		124.0	7/01/75	93.5	30.5	1101
				8/01/75	94.5	29.5	
				9/01/75	93.5	30.5	
02S/12W-35C01 S	19		145.0	10/31/74	87.5	57.5	1101
				11/26/74	86.3	58.7	
				12/27/74	80.5	64.5	
				1/27/75	86.2	58.8	
				2/25/75	88.0	57.0	
				3/24/75	81.1	63.9	
				4/28/75	82.7	62.3	
				5/27/75	81.4	63.6	
				6/24/75	88.7	56.3	
				7/28/75	81.8	63.2	
				8/25/75	82.3	62.7	
02S/12W-35D02 S	19		142.5	11/14/74	82.6(5)	59.9	1101
				12/14/74	82.6(5)	59.9	
				1/14/75	90.6(5)	51.9	
				2/14/75	90.6(5)	51.9	
				3/14/75	91.6(5)	50.9	
				4/14/75	82.6(5)	59.9	
				5/21/75	89.6(5)	52.9	
				6/14/75	88.6(5)	53.9	
				7/14/75	93.6(1)	48.9	
				8/14/75	88.6(5)	53.9	
				9/14/75	88.6(5)	53.9	
02S/12W-35F01 S	19		136.5	10/31/74	76.9	59.6	1101
				11/25/74	76.9	59.6	
				12/27/74	71.1	65.4	
				1/27/75	75.8	60.7	
				2/25/75	80.1	56.4	
				3/24/75	78.9	57.6	
				4/28/75	73.4	63.1	
				5/27/75	74.1	62.4	
				6/24/75	71.7	64.8	
				7/28/75	74.0	62.5	
				8/25/75	DRY (6)		
02S/12W-35H12 S	19		142.5	10/31/74	73.8	68.7	1101
				11/26/74	74.2	68.3	
				12/30/74	70.8	71.7	
				1/28/75	73.1	69.4	
				2/25/75	74.3	68.2	
				3/24/75	71.6	70.9	
				4/29/75	72.3	70.2	
				5/27/75	NM-9		
				6/24/75	69.0	73.5	
				7/28/75	69.1	73.4	
				8/25/75	70.3	72.2	
02S/12W-35P01 S	19		129.0	10/31/74	96.5	32.5	1101
				11/07/74	NM-1		
				12/10/74	84.9	44.1	
				4/22/75	83.6(4)	45.4	
02S/12W-36R01 S	19		139.0	10/31/74	49.2	89.8	1101
				11/27/74	48.4	90.6	
				12/30/74	51.1	87.9	
				1/28/75	53.5	85.5	
				2/27/75	53.5	85.5	
				3/25/75	52.4	86.6	
				4/29/75	53.8	85.2	
				5/27/75	43.8	95.2	
				6/24/75	40.2	98.8	
				7/29/75	42.5	96.5	
				8/25/75	38.9	100.1	
02S/12W-36G02 S	19		134.0	10/31/74	46.4	87.6	1101
				11/26/74	51.4	82.6	
				12/27/74	51.3	82.7	
				1/28/75	53.3	80.7	
				2/25/75	53.4	80.6	
				3/24/75	52.1	81.9	
				4/29/75	53.8	80.2	
				5/27/75	48.9	85.1	
				6/24/75	42.9	91.1	
				7/28/75	44.6	89.4	
				8/25/75	41.4	92.6	
02S/12W-36L05 S	19		132.0	10/31/74	60.1	71.9	1101
				11/27/74	NM-3		
				12/30/74	60.8	71.2	
				1/28/75	65.0	67.0	
				2/27/75	64.8	67.2	
				3/25/75	62.1	69.9	
				4/29/75	72.0	60.0	
				5/27/75	59.9	72.1	
				6/24/75	58.3	73.7	
				7/29/75	58.3	73.7	
				8/25/75	57.4	74.6	
02S/12W-36R02 S	19		133.5	10/19/74	62.0	71.5	1101
				11/17/74	64.0	69.5	
				12/27/74	63.0	70.5	
				1/26/75	65.0	68.5	
				2/16/75	64.0	69.5	
				3/30/75	64.0	69.5	
				4/27/75	65.0	68.5	
				5/25/75	65.0	68.5	
				6/29/75	64.0	69.5	

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
COASTAL PL OF LA CO HYDRO SUBUNIT — U-05.A
CENTRAL HYDRO SUBAREA — U-05.A5

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
02S/12W-36R02 S (CONTINUED)	19		133.5	7/27/75	64.0	69.5	1101
				8/24/75	63.0	70.5	
				9/21/75	64.0	69.5	
02S/13W-01K01 S	19		197.5	11/12/74	220.1	-22.6	1101
				4/16/75	207.1	-9.6	
02S/13W-01N01 S	19		196.0	11/12/74	244.9	-48.9	1101
				4/16/75	240.1	-44.1	
02S/13W-04D01 S	19		230.8	11/13/74	262.3(6)	-31.5	1101
02S/13W-05A01 S	19		227.0	11/13/74	265.0	-38.0	1101
				4/16/75	263.5	-36.5	
02S/13W-10A01 S	19		214.2	10/02/74	283.2	-69.0	1101
				11/13/74	281.7	-67.5	
				12/03/74	278.8	-64.6	
				1/06/75	274.0	-59.8	
				2/05/75	278.3	-64.1	
				3/12/75	278.4	-64.2	
				4/11/75	277.3	-63.1	
				5/08/75	277.1	-62.9	
				6/09/75	NM-7		
				7/08/75	NM-7		
			216.9	8/05/75	281.2	-64.3	
				9/04/75	280.5	-63.6	
02S/13W-10A03 S	19		230.4	11/13/74	305.9	-75.3	1101
				4/11/75	293.5	-62.9	
02S/13W-10A04 S	19		226.8	11/13/74	284.4	-58.4	1101
				4/11/75	264.0	-38.0	
02S/13W-10A05 S	19		213.2	11/13/74	200.4	12.8	1101
				4/11/75	200.7	12.5	
02S/13W-10B01 S	19		224.5	11/13/74	293.4	-68.9	1101
				4/11/75	286.1	-61.6	
02S/13W-10M01 S	19		206.0	12/11/74	NM-0		1101
				6/17/75	NM-0		
02S/13W-10P05 S	19		200.6	10/31/74	276.2(5)	-75.6	1101
				11/30/74	277.2(5)	-76.6	
				1/03/75	269.2(5)	-68.6	
				3/03/75	266.2(5)	-65.6	
				4/04/75	271.2(5)	-70.6	
				5/05/75	263.2(5)	-62.6	
				6/01/75	380.2(1)	-179.6	
				7/03/75	268.2(5)	-67.6	
				8/03/75	271.2(5)	-70.6	
				9/01/75	267.2(5)	-66.6	
02S/13W-10P06 S	19		200.9	10/31/74	279.2(5)	-78.3	1101
				11/30/74	278.2(5)	-77.3	
				1/03/75	390.2(1)	-189.3	
				2/02/75	275.2(5)	-74.3	
				3/03/75	274.2(5)	-73.3	
				4/04/75	276.2(5)	-75.3	
				5/05/75	270.2(5)	-69.3	
				6/01/75	271.2(5)	-70.3	
				7/03/75	274.2(5)	-73.3	
				8/03/75	278.2(5)	-77.3	
				9/01/75	268.2(5)	-67.3	
02S/13W-10R05 S	19		199.8	10/02/74	207.4	-7.6	1101
				11/13/74	207.3	-7.5	
				12/03/74	207.3	-7.5	
				1/06/75	207.1	-7.3	
				2/05/75	NM-9		
				3/12/75	NM-9		
				4/11/75	NM-9		
				5/08/75	207.1	-7.3	
				6/09/75	207.2	-7.4	
				7/08/75	207.3	-7.5	
				8/11/75	207.6	-7.8	
				9/04/75	NM-9		
02S/13W-10R06 S	19		199.7	11/04/74	290.3(4)	-90.6	1101
				4/11/75	273.0	-73.3	
02S/13W-11F03 S	19		208.7	11/13/74	266.3	-57.6	1101
				4/11/75	263.8	-55.1	
02S/13W-11F04 S	19		206.0	10/31/74	264.0(5)	-58.0	1101
				11/30/74	283.0(5)	-77.0	
				1/03/75	332.0(1)	-126.0	
				2/02/75	280.0(5)	-74.0	
				3/03/75	334.0(1)	-128.0	
				4/04/75	339.0(1)	-133.0	
				5/05/75	329.0(1)	-123.0	
				6/01/75	277.0(5)	-71.0	
				7/06/75	277.0(5)	-71.0	
				8/03/75	283.0(5)	-77.0	
				9/01/75	277.0(5)	-71.0	
02S/13W-11R03 S	19		188.7	10/31/74	265.3(5)	-76.6	1101
				11/30/74	260.3(5)	-71.6	
				1/03/75	247.3(5)	-58.6	
				2/02/75	247.3(5)	-58.6	
				3/03/75	410.3(1)	-221.6	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
COASTAL PL OF LA CO HYDRO SUBUNIT — U-05.A
CENTRAL HYDRO SUBAREA — U-05.A5

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
02S/13W-11R03 S (CONTINUED)	19		188.7	4/04/75	261.3(5)	-72.6	1101
				5/05/75	412.3(1)	-223.6	
				6/01/75	244.3(5)	-55.6	
				7/07/75	246.3(5)	-57.6	
				8/03/75	255.3(5)	-66.6	
				9/01/75	247.3(5)	-58.6	
02S/13W-11R04 S	19		187.8	10/31/74	264.3(5)	-76.5	1101
				11/30/74	263.3(5)	-75.5	
				1/03/75	247.3(5)	-59.5	
				2/02/75	251.3(5)	-63.5	
				3/03/75	257.3(5)	-69.5	
				4/04/75	265.3(5)	-77.5	
				5/05/75	261.3(5)	-73.5	
				6/01/75	247.3(5)	-59.5	
				7/06/75	253.3(5)	-65.5	
				8/03/75	258.3(5)	-70.5	
				9/01/75	249.3(5)	-61.5	
02S/13W-12K01 S	19		180.0	11/12/74	225.5	-45.5	1101
				4/16/75	217.5	-37.5	
02S/13W-13A01 S	19		168.5	11/12/74	207.5(8)	-39.0	1101
				4/16/75	202.5	-34.0	
02S/13W-13F01 S	19		181.4	11/15/74	213.8(8)	-32.4	1101
02S/13W-13F06 S	19		181.3	11/15/74	241.8(8)	-60.5	1101
				4/16/75	240.3(8)	-59.0	
02S/13W-13F01 S	19		167.7	10/31/74	285.0(6)	-117.3	1101
				11/30/74	285.0(6)	-117.3	
				12/31/74	285.0(6)	-117.3	
				1/31/75	285.0(6)	-117.3	
				2/28/75	290.0(6)	-122.3	
				3/31/75	290.0(6)	-122.3	
				4/30/75	290.0(6)	-122.3	
				5/31/75	285.0(6)	-117.3	
				6/30/75	285.0(6)	-117.3	
				7/31/75	290.0(6)	-122.3	
				8/31/75	290.0(6)	-122.3	
				9/30/75	290.0(6)	-122.3	
02S/13W-13H01 S	19		162.2	10/31/74	199.0(5)	-36.8	1101
				11/30/74	199.0(5)	-36.8	
				12/31/74	199.0(5)	-36.8	
				1/31/75	199.0(5)	-36.8	
				2/28/75	199.0(5)	-36.8	
				3/31/75	204.0(5)	-41.8	
				4/30/75	204.0(5)	-41.8	
				5/31/75	209.0(5)	-46.8	
				6/30/75	209.0(5)	-46.8	
				7/31/75	209.0(5)	-46.8	
				8/31/75	209.0(5)	-46.8	
02S/13W-13P01 S	19		156.5	11/14/74	221.6(8)	-65.1	1101
				4/16/75	209.0	-52.5	
02S/13W-14A01 S	19		187.0	6/12/75	NM-0		1101
02S/13W-14H01 S	19		180.8	1/03/75	NM-0		1101
02S/13W-14H02 S	19		185.0	10/31/74	237.8(5)	-52.8	1101
				11/30/74	236.8(5)	-51.8	
				1/03/75	232.8(5)	-47.8	
				2/02/75	229.8(5)	-44.8	
				3/03/75	351.8(1)	-166.8	
				4/04/75	356.8(1)	-171.8	
				5/01/75	357.8(1)	-172.8	
				6/09/75	233.8(5)	-48.8	
				7/06/75	230.8(5)	-45.8	
				8/03/75	234.8(5)	-49.8	
				9/01/75	236.8(5)	-51.8	
02S/13W-14H03 S	19		187.0	10/31/74	254.9(5)	-67.9	1101
				11/30/74	250.9(5)	-63.9	
				1/03/75	238.9(5)	-51.9	
				2/02/75	242.9(5)	-55.9	
				3/03/75	335.9(1)	-148.9	
				4/04/75	345.9(1)	-158.9	
				5/05/75	339.9(1)	-152.9	
				6/01/75	241.9(5)	-54.9	
				7/06/75	242.9(5)	-55.9	
				8/03/75	252.9(5)	-65.9	
				9/01/75	245.9(5)	-58.9	
02S/13W-14H04 S	19		182.0	10/31/74	248.1(5)	-66.1	1101
				11/30/74	245.1(5)	-63.1	
				1/03/75	314.1(1)	-132.1	
				2/02/75	239.1(5)	-57.1	
				3/03/75	244.1(5)	-62.1	
				4/04/75	244.1(5)	-62.1	
				5/05/75	239.1(5)	-57.1	
				6/01/75	239.1(5)	-57.1	
				7/03/75	245.1(5)	-63.1	
				8/01/75	249.1(5)	-67.1	
				9/01/75	243.1(5)	-61.1	
02S/13W-15C01 S	19		195.0	11/04/74	185.7	9.3	1101
				4/11/75	185.3	9.7	
02S/13W-15L01 S	19		190.0	11/15/74	85.7	104.3	1101

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
COASTAL PL OF LA CO HYDRO SUBUNIT — U-05.A
CENTRAL HYDRO SUBAREA — U-05.A5

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
02S/13W-16Q06 S	19		175.0	10/23/74	174.3	0.7	1200
				11/20/74	174.1	0.9	
				12/20/74	174.3	0.7	
				4/25/75	174.0	1.0	
				5/30/75	174.1	0.9	
				6/25/75	174.1	0.9	
				7/25/75	173.8	1.2	
				8/27/75	174.4	0.6	
				9/24/75	174.5	0.5	
02S/13W-16Q07 S	19		176.0	10/23/74	210.9	-34.9	1200
				11/20/74	209.3	-33.3	
				12/20/74	209.9	-33.9	
				4/25/75	211.0	-35.0	
				5/30/75	211.7	-35.7	
				6/25/75	211.9	-35.9	
				7/25/75	211.6	-35.6	
				8/27/75	214.0	-38.0	
				9/24/75	214.2	-38.2	
02S/13W-20R02 S	19		153.0	10/01/74	115.9(5)	37.1	1101
				11/01/74	118.9(5)	34.1	
				12/01/74	114.9(5)	38.1	
				1/01/75	116.9(5)	36.1	
				2/01/75	122.9(5)	30.1	
				3/01/75	122.9(5)	30.1	
				4/01/75	123.9(5)	29.1	
				5/01/75	122.9(5)	30.1	
				6/01/75	121.9(5)	31.1	
				7/01/75	123.9(5)	29.1	
				8/01/75	124.9(5)	28.1	
				9/01/75	122.9(5)	30.1	
02S/13W-20R03 S	19		152.0	10/01/74	197.5(5)	-45.5	1101
				11/01/74	196.5(5)	-44.5	
				12/01/74	192.5(5)	-40.5	
				1/01/75	192.5(5)	-40.5	
				2/01/75	197.5(5)	-45.5	
				3/01/75	197.5(5)	-45.5	
				4/01/75	198.5(5)	-46.5	
				5/01/75	201.5(5)	-49.5	
				6/01/75	197.5(5)	-45.5	
				7/01/75	200.5(5)	-48.5	
				8/01/75	202.5(5)	-50.5	
				9/01/75	201.5(5)	-49.5	
02S/13W-20R04 S	19		156.0	10/01/74	186.0(5)	-30.0	1101
				11/01/74	185.0(5)	-29.0	
				12/01/74	185.0(5)	-29.0	
				1/01/75	185.0(5)	-29.0	
				2/01/75	185.0(5)	-29.0	
				3/01/75	185.0(5)	-29.0	
				4/01/75	187.0(5)	-31.0	
				5/01/75	188.0(5)	-32.0	
				6/01/75	188.0(5)	-32.0	
				7/01/75	187.0(5)	-31.0	
				8/01/75	188.0(5)	-32.0	
				9/01/75	183.0(5)	-27.0	
02S/13W-21F01 S	19		166.0	11/14/74	233.9(5)	-67.9	1101
				12/14/74	227.9(5)	-61.9	
				2/14/75	217.9(5)	-51.9	
				3/21/75	215.9(5)	-49.9	
				4/14/75	226.9(5)	-60.9	
				5/28/75	277.9(1)	-111.9	
				7/07/75	279.9(5)	-113.9	
				8/07/75	288.9(1)	-122.9	
				9/14/75	287.9(5)	-121.9	
02S/13W-21K04 S	19		164.7	11/13/74	198.9	-34.2	1101
02S/13W-21K07 S	19		165.0	11/13/74	244.4	-79.4	1101
				4/15/75	207.9(8)	-42.9	
02S/13W-22P02 S	19		162.0	12/11/74	236.0(5)	-74.0	1101
				1/15/75	229.0(5)	-67.0	
				7/16/75	230.0(5)	-68.0	
				8/09/75	225.0(5)	-63.0	
				9/22/75	228.0(5)	-66.0	
02S/13W-23D05 S	19		178.0	1/15/75	228.3(5)	-50.3	1101
				4/09/75	236.3(5)	-58.3	
				5/14/75	223.3(5)	-45.3	
				6/10/75	223.3(5)	-45.3	
				7/14/75	213.3(5)	-35.3	
				8/09/75	230.3(5)	-52.3	
				9/22/75	231.3(5)	-53.3	
02S/13W-23H01 S	19		154.0	6/12/75	NM-0		1101
				7/16/75	212.1(5)	-58.1	
				9/22/75	211.1(5)	-57.1	
02S/13W-23J02 S	19		145.7	1/15/75	183.1(5)	-37.4	1101
				2/12/75	186.1(5)	-40.4	
				3/12/75	184.1(5)	-38.4	
				4/09/75	191.1(5)	-45.4	
				5/14/75	187.1(5)	-41.4	
				6/10/75	180.1(5)	-34.4	
				7/16/75	199.1(5)	-53.4	
				8/09/75	194.1(5)	-48.4	
				9/22/75	194.1(5)	-48.4	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT CENTRAL HYDRO SUBAREA						U-05 U-05.A U-05.A5	
02S/13W-24Q02 S	19		146.0	10/07/74	191.0(5)	-45.0	1101
				11/14/74	191.0(5)	-45.0	
				12/21/74	181.0(5)	-35.0	
				2/21/75	181.0(5)	-35.0	
				3/07/75	181.0(5)	-35.0	
				7/14/75	184.0(5)	-38.0	
				8/07/75	183.0(5)	-37.0	
				9/14/75	183.0(5)	-37.0	
02S/13W-24Q03 S	19		145.0	10/14/74	145.1(5)	-0.1	1101
				11/14/74	176.1(5)	-31.1	
				12/21/74	161.1(5)	-16.1	
				2/21/75	166.1(5)	-21.1	
				3/14/75	168.1(5)	-23.1	
				4/07/75	168.1(5)	-23.1	
				5/14/75	149.1(5)	-4.1	
				6/14/75	150.1(5)	-5.1	
				7/14/75	165.1(5)	-20.1	
				8/14/75	160.1(5)	-15.1	
				9/14/75	165.1(5)	-20.1	
02S/13W-25Q03 S	19		140.0	12/11/74	177.6(5)	-37.6	1101
				1/15/75	178.6(5)	-38.6	
				2/12/75	186.6(5)	-46.6	
				3/12/75	175.6(5)	-35.6	
				4/09/75	188.6(5)	-48.6	
				5/14/75	178.6(5)	-38.6	
				6/10/75	181.6(5)	-41.6	
				7/16/75	230.6(5)	-90.6	
				8/09/75	184.6(5)	-44.6	
				9/22/75	184.6(5)	-44.6	
02S/13W-25Q04 S	19		142.7	12/11/74	203.0(5)	-60.3	1101
				1/15/75	202.0(5)	-59.3	
				2/12/75	208.0(5)	-65.3	
				3/12/75	203.0(5)	-60.3	
				4/09/75	214.0(5)	-71.3	
				5/14/75	207.0(5)	-64.3	
				6/10/75	205.0(5)	-62.3	
				7/16/75	216.0(5)	-73.3	
				8/09/75	215.0(5)	-72.3	
				9/22/75	211.0(5)	-68.3	
02S/13W-25H03 S	19		136.0	10/31/74	178.5(5)	-42.5	1101
				11/30/74	178.5(5)	-42.5	
				1/07/75	150.5(5)	-14.5	
				2/01/75	150.5(5)	-14.5	
				3/01/75	150.5(5)	-14.5	
				4/01/75	148.5(5)	-12.5	
				5/01/75	160.5(5)	-24.5	
				6/01/75	154.5(5)	-18.5	
				7/01/75	168.5(5)	-32.5	
				8/01/75	178.5(5)	-42.5	
				9/01/75	186.5(5)	-50.5	
02S/13W-25Q01 S	19		125.0	12/11/74	NM-7		1101
				1/15/75	138.7(5)	-13.7	
				2/12/75	144.7(5)	-19.7	
				3/12/75	139.7(5)	-14.7	
				4/09/75	136.7(5)	-11.7	
				5/14/75	141.7(5)	-16.7	
				6/10/75	139.7(5)	-14.7	
				7/16/75	147.7(5)	-22.7	
				8/09/75	144.7(5)	-19.7	
				9/22/75	145.7(5)	-20.7	
02S/13W-27R07 S	19		157.0	10/31/74	214.5(5)	-57.5	1101
				11/30/74	213.5(5)	-56.5	
				12/31/74	210.5(5)	-53.5	
				1/31/75	207.5(5)	-50.5	
				2/28/75	205.5(5)	-48.5	
				3/31/75	205.5(5)	-48.5	
				4/30/75	204.5(5)	-47.5	
				5/31/75	205.5(5)	-48.5	
				6/30/75	205.5(5)	-48.5	
				7/31/75	210.5(5)	-53.5	
				8/31/75	216.5(5)	-59.5	
				9/30/75	215.5(5)	-58.5	
02S/13W-27R19 S	19		157.0	10/31/74	225.5(5)	-68.5	1101
				11/30/74	212.5(5)	-55.5	
				12/31/74	214.5(5)	-57.5	
				1/31/75	206.5(5)	-49.5	
				2/28/75	207.5(5)	-50.5	
				3/31/75	209.5(5)	-52.5	
				4/30/75	205.5(5)	-48.5	
				5/31/75	206.5(5)	-49.5	
				6/30/75	205.5(5)	-48.5	
				7/31/75	208.5(5)	-51.5	
				8/31/75	218.5(5)	-61.5	
				9/30/75	218.5(5)	-61.5	
02S/13W-27P21 S	19		157.0	10/31/74	227.4(5)	-70.4	1101
				11/30/74	222.4(5)	-65.4	
				12/31/74	222.4(5)	-65.4	
				1/31/75	217.4(5)	-60.4	
				2/28/75	215.4(5)	-58.4	
				3/31/75	217.4(5)	-60.4	
				4/30/75	217.4(5)	-60.4	
				5/31/75	215.4(5)	-58.4	
				6/30/75	216.4(5)	-59.4	
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT CENTRAL HYDRO SUBAREA						U-05 U-05.A U-05.A5	
02S/13W-27R21 S (CONTINUED)	19		157.0	7/31/75	212.4(5)	-55.4	1101
				8/31/75	222.4(5)	-65.4	
				9/30/75	226.4(5)	-69.4	
02S/13W-27F04 S	19		142.5	11/14/74	181.0(5)	-38.5	1101
				12/21/74	169.0(5)	-26.5	
				2/14/75	169.0(5)	-26.5	
				3/14/75	109.0(6)	33.5	
				4/14/75	179.0(5)	-36.5	
				5/21/75	196.0(1)	-53.5	
				7/14/75	179.0(5)	-36.5	
				8/07/75	179.0(5)	-36.5	
				9/07/75	179.0(5)	-36.5	
02S/13W-28G01 S	19		142.0	11/14/74	180.3(5)	-38.3	1101
				12/07/74	180.3(5)	-38.3	
				2/14/75	180.3(5)	-38.3	
				3/14/75	183.3(5)	-41.3	
				4/14/75	182.3(5)	-40.3	
				5/14/75	180.3(5)	-38.3	
				6/14/75	182.3(5)	-40.3	
				7/14/75	178.3(5)	-36.3	
				8/14/75	179.3(5)	-37.3	
				9/14/75	179.3(5)	-37.3	
02S/13W-28G02 S	19		142.0	11/14/74	177.3(5)	-35.3	1101
				12/07/74	177.3(5)	-35.3	
				2/14/75	177.3(5)	-35.3	
				3/21/75	179.3(5)	-37.3	
				4/14/75	180.3(5)	-38.3	
				5/21/75	183.3(5)	-41.3	
				6/14/75	180.3(5)	-38.3	
				7/14/75	178.3(5)	-36.3	
				8/14/75	182.3(5)	-40.3	
				9/07/75	178.3(5)	-36.3	
02S/13W-28G03 S	19		142.0	11/14/74	186.4(5)	-44.4	1101
				12/07/74	184.4(5)	-42.4	
				2/14/75	184.4(5)	-42.4	
				3/14/75	188.4(5)	-46.4	
				4/14/75	188.4(5)	-46.4	
				5/28/75	183.4(5)	-41.4	
				6/14/75	179.4(5)	-37.4	
				7/14/75	184.4(5)	-42.4	
				8/14/75	183.4(5)	-41.4	
				9/14/75	183.4(5)	-41.4	
02S/13W-28H01 S	19		142.0	11/14/74	112.0(5)	30.0	1101
				12/14/74	109.0(5)	33.0	
				2/14/75	109.0(5)	33.0	
				3/14/75	109.0(5)	33.0	
				4/14/75	111.0(5)	31.0	
				5/28/75	108.0(5)	34.0	
				6/14/75	109.0(5)	33.0	
				7/14/75	116.5(1)	25.5	
				8/14/75	116.0(1)	26.0	
				9/14/75	116.0(1)	26.0	
02S/13W-31C02 S	19		132.9	11/07/74	NM-6		1101
02S/13W-32C04 S	19		130.0	10/23/74	195.7	-65.7	1200
				11/20/74	195.2	-65.2	
				12/20/74	194.0	-64.0	
				1/22/75	193.2	-63.2	
				2/25/75	188.0	-58.0	
				3/26/75	186.2	-56.2	
				4/25/75	186.2	-56.2	
				5/30/75	187.1	-57.1	
				6/25/75	193.9	-63.9	
				7/25/75	196.1	-66.1	
				8/27/75	197.7	-67.7	
				9/24/75	NM-7		
02S/13W-32R08 S	19		117.0	10/25/74	269.0(1)	-152.0	1200
				11/29/74	274.0(1)	-157.0	
				6/05/75	172.0(5)	-55.0	
				9/12/75	180.0(5)	-63.0	
02S/13W-32R09 S	19		117.0	10/23/74	184.7	-67.7	1200
				11/20/74	183.7	-66.7	
				12/20/74	182.3	-65.3	
				1/22/75	181.8	-64.8	
				2/25/75	173.3	-56.3	
				3/26/75	171.3	-54.3	
				4/25/75	180.7	-63.7	
				5/30/75	171.1	-54.1	
				6/25/75	188.9	-71.9	
				7/25/75	193.0	-76.0	
				8/24/75	193.2	-76.2	
				9/24/75	187.5	-70.5	
02S/13W-32R12 S	19		118.0	12/27/74	227.0(5)	-109.0	1200
				6/05/75	184.0(5)	-66.0	
02S/13W-35A01 S	19		121.0	10/01/74	152.7(5)	-31.7	1101
				11/01/74	143.7(5)	-22.7	
				12/01/74	140.7(5)	-19.7	
				1/01/75	139.7(5)	-18.7	
				2/01/75	144.7(5)	-23.7	
				3/01/75	142.7(5)	-21.7	
				4/01/75	144.7(5)	-23.7	
				5/01/75	140.7(5)	-19.7	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT CENTRAL HYDRO SUBAREA						U-05 U-05.A U-05.A5	
02S/13W-35A01 S (CONTINUED)	19		121.0	6/01/75	145.7(5)	-24.7	1101
				7/01/75	144.7(5)	-23.7	
				8/01/75	149.7(5)	-28.7	
				9/01/75	150.7(5)	-29.7	
02S/13W-36R01 S	19		122.4	10/01/74	146.3(5)	-23.9	1101
				11/01/74	143.3(5)	-20.9	
				12/01/74	153.3(5)	-30.9	
				1/01/75	150.3(5)	-27.9	
				2/01/75	154.3(5)	-31.9	
				3/01/75	148.3(5)	-25.9	
				4/01/75	151.3(5)	-28.9	
				5/01/75	154.3(5)	-31.9	
				6/01/75	155.3(5)	-32.9	
				7/01/75	156.3(5)	-33.9	
				8/01/75	159.3(5)	-36.9	
				9/01/75	159.3(5)	-36.9	
02S/13W-36F02 S	19		122.0	10/01/74	128.5	-6.5	1101
				11/01/74	143.5	-21.5	
				12/01/74	130.5	-8.5	
				1/01/75	128.5	-6.5	
				2/01/75	132.5	-10.5	
				3/01/75	132.5	-10.5	
02S/14W-03K01 S	19		111.4	10/02/74	162.9	-51.5	1101
				11/04/74	162.9	-51.5	
				12/03/74	163.4	-52.0	
				1/06/75	162.3	-50.9	
				2/05/75	162.5	-51.1	
				3/12/75	161.8	-50.4	
				4/16/75	161.1	-49.7	
				5/06/75	111.7	-0.3	
				6/09/75	162.0	-50.6	
				7/08/75	162.2	-50.8	
				8/08/75	161.9	-50.5	
				9/04/75	163.5	-52.1	
02S/14W-03K03 S	19		110.0	10/02/74	160.8	-50.8	1101
				11/04/74	160.8	-50.8	
				12/03/74	160.9	-50.9	
				1/06/75	160.7	-50.7	
				2/05/75	NM-9		
				3/12/75	160.0	-50.0	
				4/16/75	159.4	-49.4	
02S/14W-04N01 S	19		105.0	11/15/74	173.0	-68.0	1101
				4/21/75	149.4(4)	-44.4	
02S/14W-05C04 S	19		85.0	1/14/75	134.0(5)	-49.0	1101
				2/21/75	131.0(5)	-46.0	
				3/14/75	130.0(5)	-45.0	
				4/14/75	127.0(5)	-42.0	
				5/28/75	125.0(5)	-40.0	
				6/14/75	125.0(5)	-40.0	
				7/14/75	149.0(1)	-64.0	
				8/14/75	127.0(5)	-42.0	
				9/14/75	130.0(5)	-45.0	
02S/14W-05D08 S	19		88.0	1/14/75	133.0(5)	-45.0	1101
				2/14/75	130.0(5)	-42.0	
				3/21/75	128.0(5)	-40.0	
				4/21/75	126.0(5)	-38.0	
				5/21/75	125.0(5)	-37.0	
				6/14/75	126.0(5)	-38.0	
				7/14/75	154.0(1)	-66.0	
				8/14/75	129.0(5)	-41.0	
				9/14/75	132.0(5)	-44.0	
02S/14W-10D02 S	19		126.3	10/01/74	202.0	-75.7	1101
				12/01/74	190.0(5)	-63.7	
				1/01/75	198.0(5)	-71.7	
				2/01/75	197.0(5)	-70.7	
				3/01/75	200.0(5)	-73.7	
				4/01/75	196.0(5)	-69.7	
				5/01/75	197.0	-70.7	
				6/01/75	198.0	-71.7	
				7/01/75	200.0	-73.7	
				8/01/75	199.0	-72.7	
				9/01/75	198.0	-71.7	
02S/14W-14C01 S	19		129.9	10/01/74	202.1	-72.2	1101
				12/01/74	165.1(5)	-35.2	
				1/01/75	200.1(5)	-70.2	
				2/01/75	201.1(5)	-71.2	
				3/01/75	201.1(5)	-71.2	
				4/01/75	200.1(5)	-70.2	
				5/01/75	200.1	-70.2	
				6/01/75	201.1	-71.2	
				7/01/75	199.1	-69.2	
				8/01/75	201.1	-71.2	
02S/14W-14C02 S	19		130.7	12/01/74	199.0(5)	-68.3	1101
				6/01/75	199.0(5)	-68.3	
				7/01/75	198.0(5)	-67.3	
				8/01/75	197.0(5)	-66.3	
				9/01/75	197.0(5)	-66.3	
02S/14W-14C05 S	19		129.7	10/01/74	189.0	-59.3	1101
				12/01/74	183.0(5)	-53.3	
				1/01/75	186.0(5)	-56.3	
				2/01/75	187.0(5)	-57.3	
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT CENTRAL HYDRO SUBAREA						U-05 U-05.A U-05.A5	
02S/14W-14C05 S (CONTINUED)	19		129.7	3/01/75	190.0(5)	-60.3	1101
				4/01/75	189.0(5)	-59.3	
				5/01/75	187.0	-57.3	
				6/01/75	190.0	-60.3	
				7/01/75	190.0	-60.3	
				8/01/75	189.0	-59.3	
				9/01/75	189.0	-59.3	
02S/14W-14F02 S	19		133.6	10/01/74	203.1(5)	-69.5	1101
				11/08/74	209.0	-75.4	
				12/01/74	206.1(5)	-72.5	
				1/01/75	206.1(5)	-72.5	
				2/01/75	205.1(5)	-71.5	
				3/01/75	209.1(5)	-75.5	
				4/01/75	203.1(5)	-69.5	
				5/01/75	204.1(5)	-70.5	
				6/01/75	209.1(5)	-75.5	
				7/01/75	207.1(5)	-73.5	
				8/01/75	209.1(5)	-75.5	
				9/01/75	206.1(5)	-72.5	
02S/14W-22P03 S	19		167.0	10/30/74	205.3	-38.3	5050
02S/14W-22P04 S	19		170.0	10/30/74	208.8	-38.8	5050
02S/14W-23C02 S	19		159.0	10/29/74	DRY		1101
				11/26/74	DRY		
				12/23/74	DRY		
				1/21/75	DRY		
				2/25/75	DRY		
				3/25/75	DRY		
				4/29/75	DRY		
				5/27/75	DRY		
				6/24/75	DRY		
				7/29/75	DRY		
				8/26/75	DRY		
				9/23/75	DRY		
02S/14W-23H02 S	19		136.7	6/05/75	205.5(5)	-68.8	1200
02S/14W-23H03 S	19		136.0	10/25/74	226.2(1)	-90.2	1200
				12/27/74	221.2(1)	-85.2	
				1/22/75	NM-1		
				2/25/75	NM-1		
				3/28/75	NM-1		
				4/25/75	NM-1		
				5/30/75	NM-1		
				6/05/75	193.2(5)	-57.2	
				7/23/75	NM-1		
				8/23/75	NM-1		
				9/12/75	199.2(5)	-63.2	
02S/14W-23H06 S	19		135.7	10/25/74	289.0(1)	-153.3	1200
				11/29/74	299.0(1)	-163.3	
				6/05/75	216.0(5)	-80.3	
02S/14W-23H12 S	19		135.7	6/05/75	195.5(5)	-59.8	1200
				9/12/75	202.5(5)	-66.8	
02S/14W-24G01 S	19		138.6	11/08/74	107.9	30.7	1101
				4/15/75	107.5	31.1	
02S/14W-27C09 S	19		158.0	10/30/74	204.6	-46.6	5050
03S/11W-01C01 S	19		284.0	11/07/74	50.1	233.9	1101
				4/04/75	52.4	231.6	
03S/11W-01P01 S	19		264.0	11/01/74	190.5(5)	73.5	1101
				1/02/75	185.5(5)	78.5	
				3/05/75	185.5(5)	78.5	
				5/05/75	213.5(1)	50.5	
				7/07/75	214.5(1)	49.5	
				9/02/75	218.5(1)	45.5	
03S/11W-01P02 S	19		264.0	11/01/74	30.5	235.5	1101
				1/02/75	30.5	235.5	
				6/12/75	NM-0		
03S/11W-02G01 S	19		214.0	1/02/75	139.0(5)	75.0	1101
				3/05/75	140.0(5)	74.0	
				5/05/75	206.0(1)	8.0	
				7/07/75	140.0(5)	74.0	
				9/02/75	201.0(1)	13.0	
03S/11W-02K01 S	19		216.0	11/04/74	151.0(5)	65.0	1101
				1/02/75	147.0(5)	69.0	
				6/12/75	NM-0		
03S/11W-02Q01 S	19		214.0	11/04/74	143.0	71.0	1101
03S/11W-04J03 S	19		152.2	11/06/74	DRY (6)		1101
				4/04/75	DRY (6)		
03S/11W-04M02 S	19		154.0	11/21/74	55.1	98.9	1101
				4/04/75	53.1	100.9	
03S/11W-05H03 S	19		161.0	11/04/74	55.0(5)	106.0	1101
				1/02/75	54.0(5)	107.0	
				3/05/75	52.0(5)	109.0	
				5/05/75	53.0(5)	108.0	
				7/07/75	73.0(5)	88.0	
				9/02/75	61.0(5)	100.0	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT CENTRAL HYDRO SUBAREA						U-05 U-05.A U-05.A5	
03S/11W-05N04 S	19		151.0	11/07/74	123.5	27.5	1101
				4/04/75	112.1(8)	38.9	
03S/11W-05P02 S	19		171.0	11/01/74	79.9	91.1	1101
				12/30/74	79.0	92.0	
				1/28/75	79.2	91.8	
				2/26/75	79.0	92.0	
				3/25/75	77.6	93.4	
				4/29/75	78.2	92.8	
				5/28/75	78.7	92.3	
				6/24/75	78.7	92.3	
				7/29/75	79.9	91.1	
				8/26/75	78.5	92.5	
03S/11W-06R02 S	19		129.0	10/09/74	102.2	26.8	1733
				11/20/74	102.2	26.8	
				12/11/74	101.1	27.9	
				1/06/75	99.6	29.4	
				2/12/75	98.1	30.9	
				3/05/75	97.2	31.8	
				4/16/75	96.5	32.5	
				5/07/75	97.4	31.6	
				6/18/75	94.4	34.6	
				7/09/75	97.6	31.4	
				8/20/75	99.4	29.6	
				9/10/75	101.7	27.3	
03S/11W-07R02 S	19		123.0	11/01/74	91.3	31.7	1101
				1/28/75	92.0	31.0	
				2/26/75	99.3	23.7	
				3/25/75	91.9	31.1	
				4/29/75	95.2	27.8	
				5/28/75	97.4	25.6	
				6/24/75	92.0	31.0	
				7/29/75	95.2	27.8	
				8/26/75	98.5	24.5	
03S/11W-07E01 S	19		116.0	10/14/74	91.1(5)	24.9	1101
				11/14/74	96.1(5)	19.9	
				12/21/74	89.6(5)	26.4	
				1/14/75	90.1(5)	25.9	
				2/21/75	89.1(5)	26.9	
				3/21/75	88.1(5)	27.9	
				4/14/75	88.1(5)	27.9	
				5/14/75	93.1(5)	22.9	
				6/14/75	97.1(5)	18.9	
				7/14/75	101.1(5)	14.9	
				8/21/75	99.1(5)	16.9	
				9/14/75	96.1(5)	19.9	
03S/11W-07F02 S	19		117.0	10/14/74	86.0(5)	31.0	1101
				11/21/74	91.0(5)	26.0	
				12/21/74	86.0(5)	31.0	
				1/14/75	85.0(5)	32.0	
				2/14/75	85.0(5)	32.0	
				3/14/75	84.0(5)	33.0	
				4/14/75	84.0(5)	33.0	
				5/14/75	87.0(5)	30.0	
				6/21/75	92.0(5)	25.0	
				7/14/75	95.0(5)	22.0	
				8/07/75	92.0(5)	25.0	
				9/14/75	99.0(5)	18.0	
03S/11W-07J01 S	19		125.0	10/28/74	110.1	14.9	1733
				11/25/74	110.1	14.9	
				12/23/74	110.0	15.0	
				1/27/75	109.6	15.4	
				2/24/75	109.3	15.7	
				3/24/75	109.0	16.0	
				4/28/75	108.7	16.3	
				5/26/75	108.5	16.5	
				6/23/75	108.7	16.3	
				7/28/75	109.0	16.0	
				8/25/75	109.5	15.5	
				9/22/75	109.9	15.1	
03S/11W-07P03 S	19		107.5	10/09/74	90.9	16.6	1733
				11/20/74	90.9	16.6	
				12/11/74	89.6	17.9	
				1/01/75	88.7	18.8	
				2/12/75	88.0	19.5	
				3/05/75	88.7	18.8	
				4/16/75	88.0	19.5	
				5/07/75	88.7	18.8	
				6/18/75	91.0	16.5	
				7/09/75	93.2	14.3	
				8/20/75	94.9	12.6	
				9/10/75	94.1	13.4	
03S/11W-08H01 S	19		160.0	10/14/74	143.5(5)	16.5	1101
				11/14/74	143.5(5)	16.5	
				12/14/74	142.5(5)	17.5	
				1/14/75	140.5(5)	19.5	
				2/21/75	138.5(5)	21.5	
				3/14/75	139.5(5)	20.5	
				4/14/75	139.5(5)	20.5	
				5/14/75	138.5(5)	21.5	
				6/14/75	139.5(5)	20.5	
				7/14/75	139.5(5)	20.5	
				8/14/75	140.5(5)	19.5	
				9/14/75	142.0(5)	18.0	
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT CENTRAL HYDRO SUBAREA						U-05 U-05.A U-05.A5	
03S/11W-09R01 S	19		142.0	11/06/74	75.9	66.1	1101
03S/11W-09G01 S	19		154.0	11/06/74	98.9	55.1	1101
				4/04/75	103.0	51.0	
03S/11W-09J01 S	19		114.0	11/06/74	83.8	30.2	1101
03S/11W-09N01 S	19		99.0	10/28/74	NM-9		1733
				11/25/74	88.5	10.5	
				12/23/74	NM-9		
				1/27/75	88.5	10.5	
				2/24/75	88.5	10.5	
				3/24/75	88.6	10.4	
				4/28/75	88.6	10.4	
				5/26/75	88.6	10.4	
				6/23/75	88.6	10.4	
				7/28/75	88.8	10.2	
				8/25/75	88.9	10.1	
				9/22/75	89.2	9.8	
03S/11W-10N01 S	19		143.5	10/21/74	93.7	49.8	1733
				11/11/74	90.6	52.9	
				12/02/74	90.6	52.9	
				1/08/75	88.1	55.4	
				2/19/75	NM-6		
03S/11W-10N02 S	19		145.0	11/06/74	NM-9		1101
				4/04/75	71.5	73.5	
03S/11W-14R01 S	19		237.0	11/06/74	179.5	57.5	1101
03S/11W-14H04 S	19		268.5	11/06/74	NM-1		1101
03S/11W-14N02 S	19		161.5	11/07/74	117.5	44.0	1101
				4/04/75	116.3	45.2	
03S/11W-14R02 S	19		220.0	11/06/74	154.5	65.5	1101
				4/04/75	153.7(8)	66.3	
03S/11W-15G01 S	19		160.4	11/04/74	106.0(5)	54.4	1101
				1/02/75	103.0(5)	57.4	
				3/05/75	108.0(5)	52.4	
				5/01/75	107.0(5)	53.4	
				7/07/75	117.0(5)	43.4	
				9/02/75	117.0(5)	43.4	
03S/11W-15P01 S	19		125.0	11/01/74	166.5(1)	-41.5	1101
				1/02/75	86.5	38.5	
				3/05/75	170.5(1)	-45.5	
				5/01/75	167.5(1)	-42.5	
				7/07/75	181.5(1)	-56.5	
				9/02/75	181.5(1)	-56.5	
03S/11W-16F03 S	19		110.0	11/06/74	145.1(4)	-35.1	1101
				4/04/75	NM-8		
03S/11W-18G04 S	19		102.0	10/14/74	94.0(5)	8.0	1101
				11/21/74	93.0(5)	9.0	
				12/14/74	92.0(5)	10.0	
				1/21/75	91.0(5)	11.0	
				2/14/75	90.0(5)	12.0	
				3/14/75	90.0(5)	12.0	
				4/14/75	90.0(5)	12.0	
				5/14/75	93.0(5)	9.0	
				6/14/75	95.0(5)	7.0	
				7/14/75	95.5(5)	6.5	
				8/21/75	98.0(5)	4.0	
				9/14/75	97.0(5)	5.0	
03S/11W-18G05 S	19		100.5	10/14/74	94.5(5)	6.0	1101
				11/21/74	93.5(5)	7.0	
				12/14/74	91.5(5)	9.0	
				1/14/75	89.5(5)	11.0	
				2/21/75	90.5(5)	10.0	
				3/14/75	91.5(5)	9.0	
				4/14/75	90.0(5)	10.5	
				5/21/75	93.5(5)	7.0	
				6/14/75	95.5(5)	5.0	
				7/14/75	96.5(5)	4.0	
				8/14/75	110.5(5)	-10.0	
				9/14/75	97.5(5)	3.0	
03S/11W-18L01 S	19		96.0	10/31/74	99.4(5)	-3.4	1101
				11/15/74	103.4(5)	-7.4	
				12/02/74	103.4(5)	-7.4	
				1/27/75	100.4(5)	-4.4	
				2/27/75	100.4(5)	-4.4	
				4/16/75	100.4(5)	-4.4	
				5/19/75	109.4(5)	-13.4	
				6/15/75	109.4(5)	-13.4	
				7/15/75	106.4(5)	-10.4	
				8/15/75	107.4(5)	-11.4	
				9/15/75	107.4(5)	-11.4	
03S/11W-18L02 S	19		95.5	10/31/74	95.8(5)	-0.3	1101
				11/15/74	111.8(5)	-16.3	
				12/02/74	111.8(5)	-16.3	
				1/27/75	104.8(5)	-9.3	
				2/27/75	101.8(5)	-6.3	
				4/16/75	102.8(5)	-7.3	
				6/15/75	121.8(5)	-26.3	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
COASTAL PL OF LA CO HYDRO SUBUNIT — U-05.A
CENTRAL HYDRO SUBAREA — U-05.A5

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
03S/11W-18L02 S (CONTINUED)	19		95.5	7/15/75	122.8(5)	-27.3	1101
				8/15/75	124.8(5)	-29.3	
				9/15/75	124.8(5)	-29.3	
03S/11W-18N04 S	19		93.5	10/21/74	81.4	12.1	1733
				11/11/74	82.4	11.1	
				12/02/74	82.3	11.2	
				1/08/75	81.3	12.2	
				2/19/75	81.1	12.4	
				3/12/75	81.8	11.7	
				4/02/75	80.9	12.6	
				5/14/75	80.6	12.9	
				6/04/75	80.8	12.7	
				7/09/75	81.3	12.2	
				8/20/75	82.0	11.5	
				9/10/75	82.2	11.3	
03S/11W-18N05 S	19		175.5	10/15/74	54.2(5)	121.3	1101
				11/15/74	54.2(5)	121.3	
03S/11W-20F01 S	19		79.0	11/06/74	67.8	11.2	1101
				4/07/75	66.3	12.7	
03S/11W-20P07 S	19		73.2	10/27/74	81.5	-8.3	1101
				11/17/74	79.5	-6.3	
			73.8	6/29/75	83.5	-9.7	
				7/27/75	88.5	-14.7	
				8/24/75	86.5	-12.7	
				9/28/75	90.5	-16.7	
03S/11W-21D03 S	19		81.5	11/06/74	82.7	-1.2	1101
				4/04/75	81.0	0.5	
03S/11W-22L01 S	19		85.0	11/04/74	48.5	36.5	1101
				4/07/75	86.2	-1.2	
				7/07/75	49.5(5)	35.5	
				9/02/75	51.5(5)	33.5	
03S/11W-27G03 S	19		64.0	10/21/74	73.9	-9.9	5102
				11/06/74	68.8	-4.8	1101
				12/31/74	63.6	0.4	5102
				2/27/75	73.2	-9.2	
				4/07/75	64.1	-0.1	1101
03S/11W-27L01 S	19		62.0	4/07/75	NM-I		1101
03S/11W-28B02 S	19		63.0	11/06/74	59.5	3.5	1101
				4/07/75	59.4	3.6	
03S/11W-28N01 S	19		62.5	10/09/74	60.1	2.4	1733
				11/20/74	56.9	5.6	
				12/11/74	55.9	6.6	
				1/06/75	54.6	7.9	
				2/12/75	53.5	9.0	
				3/12/75	NM-8		
				4/16/75	NM-8		
				5/07/75	53.0	9.5	
				6/18/75	51.6	10.9	
				7/09/75	53.9	8.6	
				8/20/75	53.9	8.6	
				9/10/75	51.0	11.5	
03S/11W-29F03 S	19		67.6	11/06/74	83.8	-16.2	1101
				4/07/75	NM-9		
03S/11W-29F08 S	19		58.5	11/06/74	NM-1		1101
03S/11W-30D01 S	19		71.0	11/06/74	63.5	7.5	1101
				4/07/75	59.7	11.3	
03S/11W-30N02 S	19		60.0	10/09/74	NM-9		1733
				11/20/74	57.7(4)	2.3	
				12/11/74	57.1	2.9	
				1/01/75	56.1	3.9	
				2/12/75	55.2	4.8	
				3/12/75	55.3	4.7	
				4/16/75	55.0	5.0	
				5/07/75	58.4	1.6	
				6/18/75	NM-8		
				7/09/75	NM-8		
				8/20/75	NM-8		
				9/10/75	NM-8		
03S/11W-30P02 S	19		56.5	10/14/74	73.8(5)	-17.3	1101
				11/14/74	70.8(5)	-14.3	
				12/14/74	67.8(5)	-11.3	
				1/14/75	64.8(5)	-8.3	
				2/14/75	63.8(5)	-7.3	
				3/21/75	63.8(5)	-7.3	
				4/07/75	64.8(5)	-8.3	
				5/14/75	70.8(5)	-14.3	
				6/14/75	71.8(5)	-15.3	
				7/14/75	75.8(5)	-19.3	
				8/14/75	76.8(5)	-20.3	
				9/14/75	75.8(5)	-19.3	
03S/11W-31H03 S	19		51.5	10/14/74	79.0(5)	-27.5	1101
				11/14/74	72.0(5)	-20.5	
				12/14/74	66.0(5)	-14.5	
				1/21/75	65.0(5)	-13.5	
				2/14/75	63.0(5)	-11.5	
				3/14/75	61.0(5)	-9.5	

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
COASTAL PL OF LA CO HYDRO SUBUNIT — U-05.A
CENTRAL HYDRO SUBAREA — U-05.A5

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
03S/11W-31H03 S (CONTINUED)	19		51.5	4/14/75	60.0(5)	-8.5	1101
				5/14/75	69.0(5)	-17.5	
				6/14/75	75.0(5)	-23.5	
				7/14/75	75.0(5)	-23.5	
				8/14/75	77.0(5)	-25.5	
				9/21/75	75.0(5)	-23.5	
03S/11W-32R03 S	19		46.2	2/12/75	43.0	3.2	1733
				3/05/75	43.7	2.5	
				4/16/75	41.7	4.5	
				5/07/75	45.1	1.1	
				6/18/75	50.0	-3.8	
				7/09/75	52.1	-5.9	
				8/20/75	NM-9		
				9/10/75	NM-9		
03S/11W-32R04 S	19		47.0	11/15/74	NM-6		1101
03S/11W-32R06 S	19		47.0	10/30/74	NM-7		5102
				1/03/75	46.8	0.2	
				3/18/75	43.3	3.7	
				4/29/75	44.0	3.0	
				6/26/75	56.2	-9.2	
				8/29/75	NM-7		
03S/11W-33P03 S	30		47.9	10/04/74	75.8	-27.9	1101
				11/13/74	73.4	-25.5	
				4/07/75	64.5	-16.6	
03S/12W-01A04 S	19		130.0	11/01/74	63.4	66.6	1101
				12/30/74	63.3	66.7	
				1/28/75	63.6	66.4	
				2/27/75	63.7	66.3	
				3/25/75	63.5	66.5	
				4/29/75	63.7	66.3	
				5/28/75	64.5	65.5	
				6/24/75	64.0	66.0	
				7/29/75	64.2	65.8	
				8/26/75	64.4	65.6	
03S/12W-01A06 S	19		134.0	10/09/74	67.1	68.9	1733
				11/20/74	68.1	67.9	
				12/11/74	68.1	67.9	
				1/01/75	68.3	67.7	
				2/12/75	68.9	67.1	
				3/05/75	69.0	67.0	
				4/16/75	69.0	67.0	
				5/07/75	69.4	66.6	
				6/18/75	68.8	67.2	
				7/09/75	68.6	67.4	
				8/20/75	69.3	66.7	
				9/10/75	69.6	66.4	
03S/12W-01B01 S	19		128.5	11/07/74	76.8(8)	51.7	1101
				4/04/75	76.2(8)	52.3	
03S/12W-01D02 S	19		128.6	10/31/74	71.8	56.8	1101
				11/27/74	74.0	54.6	
				12/30/74	72.8	55.8	
				1/28/75	72.9	55.7	
				2/27/75	73.5	55.1	
				3/25/75	72.5	56.1	
				4/29/75	73.9	54.7	
				5/27/75	72.6	56.0	
				6/24/75	73.0	55.6	
				7/29/75	74.1	54.5	
				8/25/75	74.9	53.7	
03S/12W-01E03 S	19		126.0	12/29/74	107.0	19.0	1101
				1/26/75	105.0	21.0	
				2/16/75	104.0	22.0	
				3/30/75	102.0	24.0	
				4/27/75	102.0	24.0	
				5/18/75	101.0	25.0	
				6/29/75	103.0	23.0	
				7/26/75	103.0	23.0	
				8/24/75	106.0	20.0	
				9/28/75	109.0	17.0	
03S/12W-01F06 S	19		127.6	11/07/74	77.1	50.5	1101
				12/30/74	75.9	51.7	
				1/28/75	77.3	50.3	
				2/26/75	82.6	45.0	
				3/25/75	80.4	47.2	
				4/29/75	77.4	50.2	
				5/27/75	84.8	42.8	
				6/24/75	77.5	50.1	
				7/29/75	78.6	49.0	
				8/26/75	78.8	48.8	
03S/12W-01K01 S	19		125.0	10/27/74	78.5	46.5	1101
				11/17/74	78.5	46.5	
				12/22/74	78.5	46.5	
				1/25/75	77.5	47.5	
				2/16/75	77.5	47.5	
				3/30/75	78.5	46.5	
				4/27/75	79.5	45.5	
				5/25/75	86.5	38.5	
				6/29/75	79.0	46.0	
				7/27/75	78.0	47.0	
				8/24/75	76.0	49.0	
				9/30/75	80.0	45.0	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT CENTRAL HYDRO SUBAREA						U-05 U-05.A U-05.A5	
03S/12W-01K02 S	19		122.0	11/01/74	80.4	41.6	1101
				1/28/75	85.1	36.9	
				2/26/75	NM-9		
				3/25/75	79.8	42.2	
				4/28/75	79.6	42.4	
				5/28/75	81.3	40.7	
				7/29/75	81.3	40.7	
				8/26/75	81.9	40.1	
03S/12W-01L03 S	19		120.0	11/01/74	79.8	40.2	1101
				12/30/74	78.9	41.1	
				1/28/75	79.6	40.4	
				2/26/75	79.0	41.0	
				3/25/75	78.3	41.7	
				4/29/75	80.2	39.8	
				5/27/75	82.2	37.8	
				6/24/75	82.1	37.9	
				7/29/75	83.4	36.6	
				8/26/75	83.0	37.0	
03S/12W-01M04 S	19		119.0	11/01/74	81.8	37.2	1101
				1/28/75	81.5	37.5	
				2/26/75	81.1	37.9	
				3/25/75	80.4	38.6	
				4/29/75	82.2	36.8	
				5/28/75	84.8	34.2	
				6/24/75	84.3	34.7	
				7/29/75	86.3	32.7	
				8/26/75	85.5	33.5	
03S/12W-01N05 S	19		118.0	10/19/74	80.5	37.5	1101
				11/17/74	78.5	39.5	
				12/29/74	78.5	39.5	
				1/26/75	78.5	39.5	
				2/14/75	77.5	40.5	
				3/30/75	77.5	40.5	
				4/27/75	77.5	40.5	
				5/25/75	80.5	37.5	
				6/29/75	80.5	37.5	
				7/27/75	81.5	36.5	
				8/24/75	81.5	36.5	
				9/28/75	82.5	35.5	
03S/12W-02C02 S	19		130.0	10/31/74	74.0	56.0	1101
				11/26/74	NM-9		
				12/30/74	74.7	55.3	
				1/27/75	79.3	50.7	
				2/25/75	79.0	51.0	
				3/24/75	75.0	55.0	
				4/28/75	74.8	55.2	
				5/27/75	76.1	53.9	
				6/24/75	75.0	55.0	
				7/28/75	75.5	54.5	
				8/25/75	76.6	53.4	
03S/12W-02F01 S	19		127.5	11/07/74	84.3	43.2	1101
				4/22/75	NM-9		
03S/12W-02H04 S	19		119.5	11/07/74	85.8(8)	33.7	1101
				4/22/75	83.1(8)	36.4	
03S/12W-02L01 S	19		116.5	10/01/74	79.0(5)	37.5	1101
				11/01/74	79.0(5)	37.5	
				12/01/74	77.0(5)	39.5	
				2/01/75	99.0(5)	17.5	
				3/01/75	84.0(5)	32.5	
				4/01/75	79.0(5)	37.5	
				5/01/75	80.0(5)	36.5	
				6/01/75	80.0(5)	36.5	
				7/01/75	82.0(5)	34.5	
				8/01/75	81.0(5)	35.5	
				9/01/75	84.0(5)	32.5	
03S/12W-02P01 S	19		115.5	10/14/74	85.0(5)	30.5	1101
				11/14/74	85.0(5)	30.5	
				12/14/74	83.0(5)	32.5	
				1/14/75	83.0(5)	32.5	
				2/14/75	81.0(5)	34.5	
				3/14/75	83.0(5)	32.5	
				4/21/75	81.0(5)	34.5	
				5/14/75	85.0(5)	30.5	
				6/14/75	88.0(5)	27.5	
				7/14/75	87.0(5)	28.5	
				8/14/75	88.0(5)	27.5	
				9/14/75	88.0(5)	27.5	
03S/12W-03J01 S	19		118.0	10/01/74	94.0	24.0	1101
				11/01/74	94.0	24.0	
				12/01/74	92.0	26.0	
				1/01/75	83.0	35.0	
				2/01/75	87.0	31.0	
				3/01/75	89.0	29.0	
				4/01/75	93.0	25.0	
				5/01/75	94.0	24.0	
				6/01/75	94.0	24.0	
				7/01/75	96.0	22.0	
				8/01/75	97.0	21.0	
				9/01/75	91.0	27.0	
03S/12W-03M01 S	19		113.0	10/01/74	91.0(5)	22.0	1101
				11/01/74	89.0(5)	24.0	
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT CENTRAL HYDRO SUBAREA						U-05 U-05.A U-05.A5	
03S/12W-03M01 S (CONTINUED)	19		113.0	12/01/74	89.0(5)	24.0	1101
				1/01/75	87.0(5)	26.0	
				2/01/75	88.0(5)	25.0	
				3/01/75	89.0(5)	24.0	
				4/01/75	92.0(5)	21.0	
				5/01/75	92.0(5)	21.0	
				6/01/75	94.0(5)	19.0	
				7/01/75	89.0(5)	24.0	
				8/01/75	96.0(5)	17.0	
				9/01/75	95.0(5)	18.0	
03S/12W-04A02 S	19		113.0	10/01/74	91.5(5)	21.5	1101
				11/01/74	91.5(5)	21.5	
				12/01/74	89.5(5)	23.5	
				1/01/75	92.5(5)	20.5	
				2/01/75	89.5(5)	23.5	
				3/01/75	90.5(5)	22.5	
				4/01/75	94.5(5)	18.5	
				5/01/75	93.5(5)	19.5	
				6/01/75	99.5(5)	13.5	
				7/01/75	101.5(5)	11.5	
				8/01/75	97.5(5)	15.5	
				9/01/75	98.5(5)	14.5	
03S/12W-04P01 S	19		110.0	11/07/74	74.2	35.8	1101
03S/12W-04Q02 S	19		112.0	10/01/74	94.0	18.0	1101
				11/01/74	104.0	8.0	
				12/01/74	90.0	22.0	
				1/01/75	94.0	18.0	
				2/01/75	92.0	20.0	
				3/01/75	93.0	19.0	
				4/01/75	95.0	17.0	
				5/01/75	95.0	17.0	
				6/01/75	99.0	13.0	
				7/01/75	101.0	11.0	
				8/01/75	100.0	12.0	
				9/01/75	102.0	10.0	
03S/12W-05D02 S	19		105.0	10/31/74	79.4	25.6	1101
				11/25/74	77.8	27.2	
				12/27/74	72.5	32.5	
				1/27/75	79.7	25.3	
				2/25/75	72.0	33.0	
				3/24/75	75.0	30.0	
				4/28/75	74.6	30.4	
				5/27/75	NM-9		
				6/23/75	NM-9		
				7/28/75	NM-9		
			105.2	8/13/75	76.2	29.0	
03S/12W-05H06 S	19		105.5	10/31/74	NM-9		1101
				11/25/74	69.0(8)	36.5	
				12/27/74	69.0(8)	36.5	
				1/27/75	70.5(8)	35.0	
				2/25/75	68.5(8)	37.0	
				3/24/75	68.7(8)	36.8	
				4/28/75	71.0(8)	34.5	
				5/27/75	68.7(8)	36.8	
				6/23/75	69.0(8)	36.5	
				7/28/75	69.3(8)	36.2	
				8/25/75	DRY (6)		
03S/12W-05M01 S	19		99.0	11/15/74	101.2(4)	-2.2	1101
03S/12W-05R01 S	19		102.0	10/14/74	131.0(1)	-29.0	1101
				11/14/74	92.0(5)	10.0	
				12/21/74	93.0(5)	9.0	
				2/14/75	101.0(5)	1.0	
				3/14/75	101.0(5)	1.0	
				4/14/75	92.0(5)	10.0	
				5/07/75	95.0(5)	7.0	
				6/14/75	95.0(5)	7.0	
				7/14/75	95.0(5)	7.0	
				8/14/75	95.0(5)	7.0	
				9/07/75	94.0(5)	8.0	
03S/12W-06A03 S	19		102.1	10/01/74	125.0	-22.9	1101
				11/01/74	115.0	-12.9	
				12/01/74	114.0	-11.9	
				1/01/75	113.0	-10.9	
				2/01/75	109.0	-6.9	
				3/01/75	110.0	-7.9	
				4/01/75	110.0	-7.9	
				5/01/75	110.0	-7.9	
				6/01/75	111.0	-8.9	
				7/01/75	115.0	-12.9	
				8/01/75	119.0	-16.9	
				9/01/75	117.0	-14.9	
03S/12W-06A01 S	19		106.5	10/01/74	119.8	-13.3	1101
				11/01/74	116.8	-10.3	
				12/01/74	111.8	-5.3	
				1/01/75	111.8	-5.3	
				2/01/75	108.8	-2.3	
				3/01/75	114.8	-8.3	
				4/01/75	114.8	-8.3	
				5/01/75	114.8	-8.3	
				6/01/75	122.8	-16.3	
				7/01/75	121.8	-15.3	
				8/01/75	130.8	-24.3	
				9/01/75	126.8	-20.3	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
COASTAL PL OF LA CO HYDRO SUBUNIT — U-05.A
CENTRAL HYDRO SUBAREA — U-05.A5

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
03S/12W-06D02 S	19		105.4	10/01/74	126.9	-21.5	1101
				11/01/74	117.9	-12.5	
				12/01/74	110.9	-5.5	
				1/01/75	113.9	-8.5	
				2/01/75	119.9	-14.5	
				3/01/75	123.9	-18.5	
				4/01/75	123.9	-18.5	
				5/01/75	119.9	-14.5	
				6/01/75	120.9	-15.5	
				7/01/75	120.9	-15.5	
				8/01/75	122.9	-17.5	
				9/01/75	126.9	-21.5	
03S/12W-06D03 S	19		104.7	10/01/74	121.8	-17.1	1101
				11/01/74	119.8	-15.1	
				12/01/74	118.8	-14.1	
				1/01/75	107.8	-3.1	
				2/01/75	112.8	-8.1	
				3/01/75	115.8	-11.1	
				4/01/75	116.8	-12.1	
				5/01/75	115.8	-11.1	
				6/01/75	119.8	-15.1	
				7/01/75	123.8	-19.1	
				8/01/75	125.8	-21.1	
				9/01/75	123.8	-19.1	
03S/12W-06D04 S	19		106.6	10/01/74	141.0	-34.4	1101
				11/01/74	135.0	-28.4	
				12/01/74	134.0	-27.4	
				1/01/75	129.0	-22.4	
				2/01/75	130.0	-23.4	
				3/01/75	136.0	-29.4	
				4/01/75	133.0	-26.4	
				5/01/75	134.0	-27.4	
				6/01/75	137.0	-30.4	
				7/01/75	143.0	-36.4	
				8/01/75	135.0	-28.4	
				9/01/75	129.0	-22.4	
03S/12W-06F01 S	19		105.4	10/01/74	122.0	-16.6	1101
				11/01/74	120.0	-14.6	
				12/01/74	117.0	-11.6	
				1/01/75	117.0	-11.6	
				2/01/75	118.0	-12.6	
				3/01/75	116.0	-10.6	
				4/01/75	118.0	-12.6	
				5/01/75	118.0	-12.6	
				6/01/75	119.0	-13.6	
				7/01/75	123.0	-17.6	
				8/01/75	129.0	-23.6	
				9/01/75	126.0	-20.6	
03S/12W-07C04 S	19		92.0	10/01/74	110.5(5)	-18.5	1101
				11/06/74	110.5(5)	-18.5	
				12/26/74	98.5(5)	-6.5	
				3/05/75	100.5(5)	-8.5	
				6/11/75	107.5(5)	-15.5	
				7/02/75	110.5(5)	-18.5	
				8/06/75	112.5(5)	-20.5	
				9/03/75	110.5(5)	-18.5	
03S/12W-07D05 S	19		83.0	10/21/74	64.2(5)	18.8	1101
				11/14/74	59.2(5)	23.8	
				12/14/74	64.2(5)	18.8	
				2/14/75	62.2(5)	20.8	
				3/14/75	63.2(5)	19.8	
				4/14/75	61.2(5)	21.8	
				5/14/75	61.2(5)	21.8	
				6/14/75	63.2(5)	19.8	
				7/14/75	64.2(5)	18.8	
				8/07/75	82.2(1)	0.8	
				9/14/75	66.2(5)	16.8	
03S/12W-08C01 S	19		97.3	10/28/74	64.6	32.7	1733
				11/25/74	64.9	32.4	
				12/23/74	64.7	32.6	
				1/27/75	64.0	33.3	
				2/24/75	64.1	33.2	
				3/24/75	63.8	33.5	
				4/28/75	63.9	33.4	
				5/26/75	64.7	32.6	
				6/23/75	65.0	32.3	
				7/28/75	66.0	31.3	
				8/25/75	65.9	31.4	
				9/22/75	66.2	31.1	
03S/12W-08D03 S	19		95.6	10/28/74	65.7	29.9	1733
				11/25/74	65.4	30.2	
				12/23/74	65.0	30.6	
				1/27/75	64.6	31.0	
				2/24/75	64.5	31.1	
				3/24/75	64.2	31.4	
				4/28/75	64.4	31.2	
				5/26/75	65.2	30.4	
				6/23/75	65.7	29.9	
				7/28/75	67.1	28.5	
				8/25/75	66.7	28.9	
				9/22/75	66.8	28.8	
03S/12W-08F01 S	19		93.0	11/15/74	96.5(8)	-3.5	1101
				4/22/75	NM-1		

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
COASTAL PL OF LA CO HYDRO SUBUNIT — U-05.A
CENTRAL HYDRO SUBAREA — U-05.A5

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
03S/12W-08F01 S	19		93.0	5/07/75	90.3(8)	2.7	1101
03S/12W-08L03 S	19		92.0	10/07/74	65.5	26.5	1733
				11/04/74	64.6	27.4	
				12/02/74	64.3	27.7	
				1/06/75	63.6	28.4	
				2/03/75	63.3	28.7	
				3/03/75	63.1	28.9	
				4/07/75	63.1	28.9	
				5/05/75	63.4	28.6	
				6/02/75	64.8	27.2	
				7/07/75	65.9	26.1	
				8/04/75	66.2	25.8	
				9/01/75	66.3	25.7	
03S/12W-08M02 S	19		88.0	10/14/74	62.2(5)	25.8	1101
				11/14/74	66.2(5)	21.8	
				2/14/75	69.2(5)	18.8	
				3/14/75	66.2(5)	21.8	
				4/14/75	69.2(5)	18.8	
				5/28/75	96.2(1)	-8.2	
				6/14/75	66.2(5)	21.8	
				7/14/75	66.2(5)	21.8	
				8/14/75	66.2(5)	21.8	
				9/14/75	69.2(5)	18.8	
03S/12W-09R01 S	19		107.0	10/01/74	107.0(5)	0.0	1101
				11/01/74	105.0(5)	2.0	
				12/01/74	104.0(5)	3.0	
				1/01/75	104.0(5)	3.0	
				2/01/75	104.0(5)	3.0	
				3/01/75	105.0(5)	2.0	
				4/01/75	108.0(5)	-1.0	
				5/01/75	107.0(5)	0.0	
				6/01/75	98.0(5)	9.0	
				7/01/75	100.0(5)	7.0	
				8/01/75	98.0(5)	9.0	
				9/01/75	100.0(5)	7.0	
03S/12W-09R02 S	19		106.0	10/21/74	94.0	12.0	1733
				11/11/74	92.6	13.4	
				12/02/74	90.9	15.1	
				1/13/75	88.5	17.5	
				2/03/75	88.2	17.8	
				3/17/75	88.8	17.2	
				4/07/75	89.1	16.9	
				5/19/75	92.3	13.7	
				6/09/75	92.5	13.5	
				7/21/75	96.7	9.3	
				8/11/75	98.2	7.8	
				9/01/75	96.8	9.2	
03S/12W-09D05 S	19		105.0	10/14/74	99.0(1)	6.0	1101
				11/14/74	92.0(5)	13.0	
				12/21/74	90.0(5)	15.0	
				2/14/75	90.0(5)	15.0	
				3/21/75	92.0(5)	13.0	
				4/14/75	90.0(5)	15.0	
				5/07/75	93.0(5)	12.0	
				6/14/75	94.0(5)	11.0	
				7/14/75	94.0(5)	11.0	
				8/21/75	93.0(5)	12.0	
				9/14/75	93.0(5)	12.0	
03S/12W-09G02 S	19		103.0	10/31/74	74.2	28.8	1101
				11/25/74	87.2	15.8	
				12/27/74	74.3	28.7	
				1/27/75	74.0(8)	29.0	
				2/25/75	83.6(8)	19.4	
				3/24/75	79.8(8)	23.2	
				4/28/75	78.8(8)	24.2	
				5/27/75	80.1(8)	22.9	
				6/23/75	73.9(8)	29.1	
				7/28/75	74.5(8)	28.5	
				8/25/75	DRY (6)		
03S/12W-10C02 S	19		107.0	11/07/74	73.5	33.5	1101
				4/22/75	72.9	34.1	
03S/12W-10K02 S	19		100.0	10/28/74	70.4	29.6	1733
				11/25/74	70.5	29.5	
				12/23/74	70.6	29.4	
				1/27/75	70.0	30.0	
				2/24/75	69.8	30.2	
				3/24/75	69.9	30.1	
				4/28/75	69.6	30.4	
				5/26/75	NM-2		
				6/23/75	70.0	30.0	
				7/28/75	70.3	29.7	
				8/25/75	70.6	29.4	
				9/22/75	70.9	29.1	
03S/12W-11R04 S	19		109.0	11/21/74	87.4(8)	21.6	1101
				4/22/75	83.0(8)	26.0	
03S/12W-11R06 S	19		115.0	10/31/74	79.8	35.2	1101
				11/26/74	79.9	35.1	
				12/27/74	79.7	35.3	
				1/27/75	79.6	35.4	
				2/25/75	79.7	35.3	
				3/24/75	NM-9		
				4/28/75	78.8	36.2	

See page 791 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
COASTAL PL OF LA CO HYDRO SUBUNIT — U-05.A
CENTRAL HYDRO SUBAREA — U-05.A5

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
03S/12W-11R06 S (CONTINUED)	19		115.0	5/27/75	79.5	35.5	1101
				6/24/75	79.9	35.1	
				7/28/75	80.2	34.8	
				8/25/75	80.2	34.8	
03S/12W-11F10 S	19		110.0	10/31/74	87.5	22.5	1101
				11/26/74	87.8	22.2	
				12/27/74	86.0	24.0	
				1/27/75	85.5	24.5	
				2/25/75	85.0	25.0	
				3/24/75	85.1	24.9	
				4/28/75	85.0	25.0	
				5/27/75	88.0	22.0	
				6/24/75	88.8	21.2	
				7/28/75	91.0	19.0	
				8/25/75	91.6	18.4	
03S/12W-11M11 S	19		103.0	11/21/74	NM-8		1101
				4/22/75	NM-8		
03S/12W-11P01 S	19		98.3	10/31/74	72.9	25.4	1101
				11/26/74	73.0	25.3	
				12/27/74	72.7	25.6	
				1/27/75	72.4	25.9	
				2/25/75	72.6	25.7	
				3/24/75	72.0	26.3	
				4/28/75	71.7	26.6	
				5/27/75	71.8	26.5	
				6/24/75	71.8	26.5	
				7/28/75	72.6	25.7	
				8/25/75	72.4	25.9	
03S/12W-12A02 S	19		116.0	10/14/74	93.3(5)	22.7	1101
				11/21/74	93.3(5)	22.7	
				12/21/74	92.3(5)	23.7	
				1/14/75	91.3(5)	24.7	
				2/14/75	90.3(5)	25.7	
				3/14/75	90.3(5)	25.7	
				4/21/75	89.3(5)	26.7	
				5/14/75	93.3(5)	22.7	
				6/21/75	94.3(5)	21.7	
				7/14/75	97.3(5)	18.7	
				8/14/75	98.3(5)	17.7	
				9/14/75	95.3(5)	20.7	
03S/12W-12C10 S	19		116.0	10/31/74	104.0(5)	12.0	1101
				11/15/74	103.0(5)	13.0	
				12/02/74	103.0(5)	13.0	
				1/27/75	104.0(5)	12.0	
				2/27/75	101.0(5)	15.0	
				4/16/75	103.0(5)	13.0	
				6/15/75	105.5(5)	10.5	
				7/15/75	106.0(5)	10.0	
				8/15/75	104.0(5)	12.0	
				9/15/75	105.0(5)	11.0	
03S/12W-12E03 S	19		113.0	11/21/74	85.5	27.5	1101
				4/04/75	84.7	28.3	
03S/12W-13A02 S	19		104.0	10/14/74	97.5(5)	6.5	1101
				11/21/74	92.5(5)	11.5	
				12/21/74	87.5(5)	16.5	
				1/14/75	90.5(5)	13.5	
				2/14/75	88.5(5)	15.5	
				3/14/75	88.5(5)	15.5	
				4/14/75	89.5(5)	14.5	
				5/21/75	89.5(5)	14.5	
				6/14/75	90.5(5)	13.5	
				7/14/75	93.5(5)	10.5	
				8/14/75	98.5(5)	5.5	
				9/14/75	96.5(5)	7.5	
03S/12W-13R04 S	19		104.0	10/14/74	178.9(1)	-74.9	1101
				11/07/74	90.9(5)	13.1	
				12/14/74	85.9(5)	18.1	
				2/14/75	146.9(1)	-42.9	
				3/21/75	82.9(5)	21.1	
				4/28/75	81.9(5)	22.1	
				5/14/75	86.9(5)	17.1	
				6/14/75	88.9(5)	15.1	
				7/14/75	93.9(5)	10.1	
				8/21/75	93.9(5)	10.1	
				9/14/75	90.9(5)	13.1	
03S/12W-13R06 S	19		104.0	10/14/74	98.5(5)	5.5	1101
				11/21/74	94.5(5)	9.5	
				12/14/74	87.5(5)	16.5	
				1/14/75	91.5(5)	12.5	
				2/14/75	90.5(5)	13.5	
				3/14/75	90.5(5)	13.5	
				4/21/75	88.5(5)	15.5	
				5/14/75	89.5(5)	14.5	
				6/14/75	94.5(5)	9.5	
				7/14/75	95.5(5)	8.5	
				8/14/75	99.5(5)	4.5	
				9/14/75	94.5(5)	9.5	
03S/12W-13F01 S	19		98.0	10/31/74	92.8	5.2	1101
				11/07/74	NM-1		
				4/04/75	NM-1		
03S/12W-13L01 S	19		92.0	10/31/74	82.0	10.0	1101

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
COASTAL PL OF LA CO HYDRO SUBUNIT — U-05.A
CENTRAL HYDRO SUBAREA — U-05.A5

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
03S/12W-13L01 S (CONTINUED)	19		92.0	11/15/74	82.0	10.0	1101
				12/02/74	82.0	10.0	
				1/27/75	82.0	10.0	
				2/27/75	80.0	12.0	
				4/16/75	80.0	12.0	
				5/19/75	89.0	3.0	
				6/15/75	88.0	4.0	
				7/15/75	89.0	3.0	
				8/15/75	89.0	3.0	
				9/15/75	91.0	1.0	
03S/12W-13M01 S	19		89.0	10/31/74	82.5(5)	6.5	1101
				11/15/74	83.5(5)	5.5	
				12/02/74	83.5(5)	5.5	
				1/27/75	81.5(5)	7.5	
				2/27/75	81.5(5)	7.5	
				4/16/75	79.5(5)	9.5	
				6/15/75	86.5(5)	2.5	
				7/15/75	87.5(5)	1.5	
				8/15/75	90.5(5)	-1.5	
				9/15/75	91.5(5)	-2.5	
03S/12W-14F01 S	19		93.0	11/07/74	85.6	7.4	1101
				4/22/75	80.8	12.2	
03S/12W-14F03 S	19		89.9	10/04/74	69.5	20.4	1101
				11/08/74	69.8	20.1	
				12/13/74	69.9	20.0	
				1/13/75	69.5	20.4	
				2/06/75	69.2	20.7	
				3/04/75	68.3	21.6	
				4/15/75	68.3	21.6	
				5/06/75	66.5	23.4	
				6/03/75	65.7	24.2	
				7/02/75	69.0	20.9	
				9/03/75	69.9	20.0	
03S/12W-14J01 S	19		89.0	10/31/74	91.0	-2.0	1101
				11/07/74	NM-1		
				4/04/75	NM-1		
03S/12W-15M01 S	19		86.5	10/14/74	66.3	20.2	1733
				11/04/74	65.5	21.0	
				12/16/74	65.1	21.4	
				1/06/75	64.5	22.0	
				2/17/75	64.0	22.5	
				3/10/75	63.6	22.9	
				4/21/75	63.6	22.9	
				5/12/75	64.5	22.0	
				6/16/75	64.7	21.8	
				7/07/75	66.0	20.5	
				8/18/75	66.3	20.2	
				9/08/75	66.5	20.0	
03S/12W-17A01 S	19		87.0	10/14/74	61.2(5)	25.8	1101
				11/14/74	60.2(5)	26.8	
				12/14/74	61.2(1)	25.8	
				2/14/75	60.2(5)	26.8	
				3/07/75	57.2(5)	29.8	
				4/14/75	59.2(5)	27.8	
				5/21/75	59.2(5)	27.8	
				6/14/75	61.2(5)	25.8	
				7/14/75	61.2(5)	25.8	
				8/21/75	61.2(5)	25.8	
				9/14/75	61.2(5)	25.8	
03S/12W-17A02 S	19		87.0	11/14/74	128.0(1)	-41.0	1101
				12/21/74	126.0(1)	-39.0	
				2/21/75	131.0(1)	-44.0	
				3/14/75	131.0(1)	-44.0	
				4/21/75	121.0(5)	-34.0	
				6/21/75	89.0(5)	-2.0	
				7/14/75	124.0(1)	-37.0	
				8/14/75	124.0(1)	-37.0	
				9/14/75	134.0(1)	-47.0	
03S/12W-18D05 S	19		82.0	11/15/74	77.8	4.2	1101
				4/16/75	74.3	7.7	
03S/12W-18J02 S	19		77.0	11/13/74	54.6	22.4	1101
				4/16/75	52.7	24.3	
03S/12W-18Q03 S	19		74.0	11/13/74	19.8(8)	54.2	1101
03S/12W-18Q08 S	19		74.0	4/16/75	DRY (6)		1101
03S/12W-19G01 S	19		71.1	10/21/74	51.7(2)	19.4	1733
				11/11/74	51.6	19.5	
				12/02/74	51.5	19.6	
				1/13/75	51.2	19.9	
				2/03/75	50.4	20.7	
				3/17/75	50.8	20.3	
				4/07/75	50.7	20.4	
				5/19/75	50.4	20.7	
				6/09/75	50.5	20.6	
				7/21/75	50.8	20.3	
				8/11/75	50.9	20.2	
				9/01/75	51.1	20.0	
03S/12W-19P05 S	19		66.0	10/01/74	98.2(5)	-32.2	1101
				11/15/74	NM-1		
				12/30/74	77.2(5)	-11.2	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
COASTAL PL OF LA CO HYDRO SUBUNIT — U-05.A
CENTRAL HYDRO SUBAREA — U-05.A5

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
03S/12W-19P05 S (CONTINUED)	19		66.0	1/31/75	89.2(5)	-23.2	1101
				2/28/75	101.2(5)	-35.2	
				4/08/75	69.3(8)	-3.3	
				6/27/75	79.2(5)	-13.2	
				7/31/75	95.2(5)	-29.2	
				8/29/75	146.2(1)	-80.2	
				9/29/75	98.2(5)	-32.2	
03S/12W-21G04 S	19		79.0	11/21/74	59.1	19.9	1101
				4/18/75	60.2	18.8	
03S/12W-21001 S	19		70.0	10/14/74	81.3	-11.3	1733
				11/04/74	76.9	-6.9	
				12/16/74	75.2	-5.2	
				1/04/75	70.5	-0.5	
				2/17/75	69.9	0.1	
				3/10/75	70.9	-0.9	
				4/21/75	70.6	-0.6	
				5/12/75	76.8	-6.8	
				6/02/75	78.0	-8.0	
				7/14/75	83.9	-13.9	
				8/04/75	86.5	-16.5	
				9/15/75	83.1	-13.1	
03S/12W-21003 S	19		71.0	10/31/74	55.0(5)	16.0	1101
				11/30/74	55.0(5)	16.0	
				12/31/74	54.0(5)	17.0	
				1/31/75	53.0(5)	18.0	
				2/28/75	52.0(5)	19.0	
				3/31/75	54.0(5)	17.0	
				4/30/75	54.0(5)	17.0	
				5/31/75	55.0(5)	16.0	
				6/30/75	58.0(5)	13.0	
				7/31/75	58.0(5)	13.0	
				8/31/75	58.0(5)	13.0	
				9/30/75	57.0(5)	14.0	
03S/12W-22F01 S	19		75.0	10/15/74	73.0(6)	2.0	1101
				11/15/74	63.0(6)	12.0	
				12/15/74	73.0(6)	2.0	
				1/15/75	73.0(6)	2.0	
				2/14/75	63.0(6)	12.0	
				3/15/75	63.0(6)	12.0	
				4/11/75	73.0(6)	2.0	
				5/15/75	63.0(6)	12.0	
				6/15/75	63.0(5)	12.0	
				7/26/75	63.0(5)	12.0	
				8/16/75	63.0(5)	12.0	
				9/15/75	63.0(5)	12.0	
03S/12W-22G02 S	19		81.0	10/15/74	130.0(1)	-49.0	1101
				11/16/74	87.0(5)	-6.0	
				12/15/74	87.0(5)	-6.0	
				1/15/75	87.0	-6.0	
				2/15/75	130.0	-49.0	
				3/15/75	130.0	-49.0	
				4/15/75	130.0	-49.0	
				5/15/75	130.0	-49.0	
				6/15/75	130.0(1)	-49.0	
				7/15/75	130.0(1)	-49.0	
				8/15/75	130.0(1)	-49.0	
				9/15/75	145.0(1)	-64.0	
03S/12W-22H01 S	19		80.3	10/07/74	62.8	17.5	1733
				11/18/74	62.0	18.3	
				12/09/74	61.6	18.7	
				1/20/75	61.1	19.2	
				2/10/75	60.6	19.7	
				3/03/75	60.4	19.9	
				4/14/75	60.1	20.2	
				5/07/75	60.4	19.9	
				6/16/75	61.2	19.1	
				7/07/75	60.8	19.5	
				8/18/75	62.8	17.5	
			82.0	9/08/75	63.5	18.5	
03S/12W-22P02 S	19		75.0	10/31/74	57.0(5)	18.0	1101
				11/30/74	60.0(5)	15.0	
				12/01/74	55.0(5)	20.0	
				1/31/75	56.0(5)	19.0	
				2/28/75	55.0(5)	20.0	
				3/31/75	55.0(5)	20.0	
				4/30/75	55.0(5)	20.0	
				5/31/75	57.0(5)	18.0	
				6/30/75	59.0(5)	16.0	
				7/31/75	60.0(5)	15.0	
				8/31/75	59.0(5)	16.0	
				9/30/75	59.0(5)	16.0	
03S/12W-23C03 S	19		82.9	10/07/74	66.6	16.3	1733
				11/18/74	65.9	17.0	
				12/09/74	65.6	17.3	
				1/20/75	65.0	17.9	
				2/10/75	64.6	18.3	
				3/03/75	64.3	18.6	
				4/14/75	64.0	18.9	
				5/05/75	64.0	18.9	
				6/16/75	64.8	18.1	
				7/07/75	65.3	17.6	
				8/18/75	66.2	16.7	
				9/08/75	66.4	16.5	
03S/12W-23E05 S	19		82.5	10/15/74	188.0(1)	-105.5	1101

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
COASTAL PL OF LA CO HYDRO SUBUNIT — U-05.A
CENTRAL HYDRO SUBAREA — U-05.A5

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
03S/12W-23E05 S (CONTINUED)	19		82.5	11/15/74	188.0(1)	-105.5	1101
				12/16/74	84.0(5)	-1.5	
				1/15/75	188.0	-105.5	
				2/24/75	84.0	-1.5	
				3/15/75	84.0	-1.5	
				4/14/75	84.0	-1.5	
				5/15/75	188.0	-105.5	
				6/13/75	84.0(5)	-1.5	
				7/15/75	188.0(1)	-105.5	
				8/15/75	188.0(1)	-105.5	
				9/18/75	188.0(1)	-105.5	
03S/12W-25C01 S	19		70.5	11/07/74	83.4	-12.9	1101
				4/10/75	91.1	-20.6	
03S/12W-25H01 S	19		68.0	11/06/74	60.7	7.3	1101
				4/07/75	59.9	8.1	
03S/12W-25J01 S	19		62.0	11/07/74	82.6	-20.6	1101
				4/07/75	84.4	-22.4	
03S/12W-25P05 S	19		58.0	10/14/74	57.0(5)	1.0	1101
				11/21/74	52.0(5)	6.0	
				12/21/74	50.5(5)	7.5	
				1/21/75	49.0(5)	9.0	
				2/14/75	49.0(5)	9.0	
				3/14/75	49.0(5)	9.0	
				4/14/75	49.0(5)	9.0	
				5/14/75	52.0(5)	6.0	
				6/21/75	54.0(5)	4.0	
				7/14/75	55.0(5)	3.0	
				8/21/75	55.0(5)	3.0	
				9/21/75	55.0(5)	3.0	
03S/12W-26C02 S	19		74.0	10/15/74	94.0(6)	-20.0	1101
				11/01/74	94.0(6)	-20.0	
				12/01/74	94.0	-20.0	
				1/15/75	119.0	-45.0	
				2/15/75	86.0	-12.0	
				3/15/75	86.0	-12.0	
				4/15/75	119.0	-45.0	
				5/15/75	86.0	-12.0	
				6/09/75	86.0(5)	-12.0	
				7/26/75	86.0(5)	-12.0	
				8/19/75	86.0(5)	-12.0	
				9/11/75	84.0(5)	-10.0	
03S/12W-26J01 S	19		71.4	11/07/74	NM-1		1101
				12/16/74	NM-1		
				4/08/75	NM-1		
03S/12W-26L03 S	19		67.0	10/15/74	57.0(6)	10.0	1101
				11/15/74	130.0(1)	-63.0	
				12/15/74	130.0(1)	-63.0	
				1/15/75	130.0(6)	-63.0	
				2/15/75	130.0(6)	-63.0	
				3/15/75	130.0(6)	-63.0	
				4/15/75	130.0(6)	-63.0	
				5/15/75	57.0(6)	10.0	
				6/15/75	57.0(1)	10.0	
				7/15/75	57.0(1)	10.0	
				8/15/75	57.0(1)	10.0	
				9/15/75	57.0(1)	10.0	
03S/12W-26N02 S	19		63.0	10/09/74	59.0(5)	4.0	1101
				11/17/74	59.0(5)	4.0	
				12/18/74	68.0(6)	-5.0	
				1/15/75	68.0(5)	-5.0	
				2/15/75	68.0(5)	-5.0	
				3/15/75	59.0(5)	4.0	
				4/14/75	59.0(5)	4.0	
				5/15/75	68.0(5)	-5.0	
				6/12/75	59.0(5)	4.0	
				7/16/75	59.0(5)	4.0	
				8/13/75	58.0(5)	5.0	
				9/11/75	58.0(5)	5.0	
03S/12W-26N03 S	19		63.0	10/01/74	58.0(5)	5.0	1101
				11/01/74	58.0(6)	5.0	
				12/01/74	58.0(6)	5.0	
				1/01/75	58.0(6)	5.0	
				2/02/75	58.0(6)	5.0	
				3/01/75	58.0(6)	5.0	
				4/01/75	58.0(6)	5.0	
				5/01/75	58.0(6)	5.0	
03S/12W-27C02 S	19		71.0	10/31/74	82.0(5)	-11.0	1101
				11/30/74	80.0(5)	-9.0	
				12/31/74	77.0(5)	-6.0	
				1/31/75	74.0(5)	-3.0	
				2/28/75	76.0(5)	-5.0	
				3/31/75	79.0(5)	-8.0	
				4/30/75	81.0(5)	-10.0	
				5/31/75	84.0(5)	-13.0	
				6/30/75	89.0(5)	-18.0	
				7/31/75	93.0(5)	-22.0	
				8/31/75	93.0(5)	-22.0	
				9/30/75	91.0(5)	-20.0	
03S/12W-27G01 S	19		71.0	10/31/74	62.0(5)	9.0	1101
				11/30/74	61.0(5)	10.0	
				12/31/74	61.0(5)	10.0	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
COASTAL PL OF LA CO HYDRO SUBUNIT — U-05.A
CENTRAL HYDRO SUBAREA — U-05.A5

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
03S/12W-27G01 S (CONTINUED)	19		71.0	1/31/75	60.0(S)	11.0	1101
				2/28/75	60.0(S)	11.0	
				3/31/75	60.0(S)	11.0	
				4/30/75	59.0(S)	12.0	
				5/31/75	65.0(S)	6.0	
				6/30/75	64.0(S)	7.0	
				7/31/75	64.0(S)	7.0	
				8/31/75	64.0(S)	7.0	
				9/30/75	64.0(S)	7.0	
03S/12W-27H01 S	19		66.0	10/31/74	53.0(S)	13.0	1101
				11/30/74	53.0(S)	13.0	
				12/31/74	51.0(S)	15.0	
				1/31/75	51.0(S)	15.0	
				2/28/75	51.0(S)	15.0	
				3/31/75	51.0(S)	15.0	
				4/30/75	52.0(S)	14.0	
				5/31/75	54.0(S)	12.0	
				6/30/75	57.0(S)	9.0	
				7/31/75	56.0(S)	10.0	
				8/31/75	57.0(S)	9.0	
				9/30/75	55.0(S)	11.0	
03S/12W-27N01 S	19		66.0	10/31/74	76.0(S)	-10.0	1101
				11/30/74	76.0(S)	-10.0	
				12/31/74	70.0(S)	-4.0	
				1/31/75	69.0(S)	-3.0	
				2/28/75	72.0(S)	-6.0	
				3/31/75	75.0(S)	-9.0	
				4/30/75	72.0(S)	-6.0	
				5/31/75	80.0(S)	-14.0	
				6/30/75	86.0(S)	-20.0	
				7/31/75	88.0(S)	-22.0	
				8/31/75	86.0(S)	-20.0	
				9/30/75	90.0(S)	-24.0	
03S/12W-27R01 S	19		62.0	10/15/74	95.5(S)	-33.5	1101
				11/16/74	95.5(S)	-33.5	
				12/15/74	95.5(6)	-33.5	
				1/15/75	119.5(S)	-57.5	
				2/01/75	95.5(S)	-33.5	
				4/04/75	89.5(S)	-27.5	
				5/15/75	79.5(S)	-17.5	
				6/10/75	79.5(S)	-17.5	
				7/15/75	79.5(S)	-17.5	
				8/18/75	79.5(S)	-17.5	
				9/15/75	79.5(S)	-17.5	
03S/12W-28H02 S	19		67.0	10/31/74	55.0(S)	12.0	1101
				11/30/74	55.0(S)	12.0	
				12/31/74	54.0(S)	13.0	
				1/31/75	60.0(S)	7.0	
				2/28/75	54.0(S)	13.0	
				3/31/75	54.0(S)	13.0	
				4/30/75	54.0(S)	13.0	
				5/31/75	57.0(S)	10.0	
				6/30/75	59.0(S)	8.0	
				7/31/75	58.0(S)	9.0	
				8/31/75	59.0(S)	8.0	
				9/30/75	58.0(S)	9.0	
03S/12W-28H03 S	19		67.0	10/31/74	54.0(S)	13.0	1101
				11/30/74	54.0(S)	13.0	
				12/31/74	53.0(S)	14.0	
				1/31/75	52.0(S)	15.0	
				2/28/75	53.0(S)	14.0	
				3/31/75	53.0(S)	14.0	
				4/30/75	53.0(S)	14.0	
				5/31/75	56.0(S)	11.0	
				6/30/75	58.0(S)	9.0	
				7/31/75	57.0(S)	10.0	
				8/31/75	58.0(S)	9.0	
				9/30/75	57.0(S)	10.0	
03S/12W-28J02 S	19		64.0	10/31/74	42.0(S)	22.0	1101
				11/30/74	42.0(S)	22.0	
				12/31/74	40.0(S)	24.0	
				1/31/75	40.0(S)	24.0	
				2/28/75	42.0(S)	22.0	
				3/31/75	41.0(S)	23.0	
				4/30/75	42.0(S)	22.0	
				5/31/75	44.0(S)	20.0	
				6/30/75	44.0(S)	20.0	
				7/31/75	44.0(S)	20.0	
				8/31/75	53.0(S)	11.0	
				9/30/75	44.0(S)	20.0	
03S/12W-28Q01 S	19		63.0	10/31/74	52.0(S)	11.0	1101
				11/30/74	52.0(S)	11.0	
				12/31/74	51.0(S)	12.0	
				1/31/75	49.0(S)	14.0	
				2/28/75	51.0(S)	12.0	
				3/31/75	49.0(S)	14.0	
				4/30/75	51.0(S)	12.0	
				5/31/75	54.0(S)	9.0	
				6/30/75	56.0(S)	7.0	
				7/31/75	57.0(S)	6.0	
				8/31/75	57.0(S)	6.0	
				9/30/75	55.0(S)	8.0	
03S/12W-29J01 S	19		63.0	10/14/74	48.8	14.2	1733
				11/04/74	46.8	16.2	
03S/12W-29J01 S (CONTINUED)	19		63.0	12/16/74	46.2	16.8	1733
				1/06/75	45.2	17.8	
				2/17/75	44.5	18.5	
				3/10/75	44.6	18.4	
				4/21/75	44.9	18.1	
				5/12/75	46.7	16.3	
				6/02/75	48.0	15.0	
				7/14/75	49.4	13.6	
				8/04/75	50.5	12.5	
				9/15/75	50.0	13.0	
03S/12W-29H01 S	19		62.5	11/15/74	52.1	10.4	1101
				4/08/75	45.2	17.3	
03S/12W-29H02 S	19		63.0	11/15/74	47.0	16.0	1101
				4/08/75	49.4	13.6	
03S/12W-29R01 S	19		56.0	11/18/74	44.2	11.8	1101
				4/03/75	42.5	13.5	
03S/12W-30B02 S	19		63.0	10/01/74	121.7(1)	-58.7	1101
				11/29/74	104.7(S)	-41.7	
				12/30/74	81.7(S)	-18.7	
				1/31/75	102.7(S)	-39.7	
				2/25/75	119.7(S)	-56.7	
				4/28/75	103.7(S)	-40.7	
				5/29/75	121.7(S)	-58.7	
				6/27/75	116.7(S)	-53.7	
				7/31/75	121.7(1)	-58.7	
				8/29/75	114.7(S)	-51.7	
				9/29/75	125.7(1)	-62.7	
03S/12W-30C03 S	19		65.0	10/01/74	151.2(1)	-86.2	1101
				11/29/74	137.2(1)	-72.2	
				12/30/74	92.2(S)	-27.2	
				1/31/75	107.2(S)	-42.2	
				2/25/75	97.2(S)	-32.2	
				4/28/75	88.2(S)	-23.2	
				5/29/75	112.2(S)	-47.2	
				6/27/75	97.2(S)	-32.2	
				8/29/75	109.2(S)	-44.2	
03S/12W-30E01 S	19		60.0	11/14/74	49.5	10.5	1101
				4/08/75	48.1	11.9	
03S/12W-30G01 S	19		60.0	11/15/74	48.0	12.0	1101
				4/08/75	45.8	14.2	
03S/12W-30K02 S	19		59.0	11/15/74	74.9	-15.9	1101
				4/08/75	70.9	-11.9	
03S/12W-31E03 S	19		51.7	10/02/74	119.7	-68.0	4206
			52.2	11/06/74	117.0	-65.3	
				12/04/74	115.6	-63.9	
			51.7	1/08/75	108.9	-57.2	
				2/05/75	107.5	-55.8	
				3/05/75	102.6	-50.9	
				4/02/75	99.1	-47.4	
				5/07/75	100.4	-48.7	
			52.2	6/04/75	117.3	-65.1	
				7/02/75	125.2	-73.0	
				8/06/75	130.2	-78.0	
				9/03/75	130.0	-77.8	
03S/12W-32L01 S	19		52.6	10/31/74	41.4	11.2	5061
03S/12W-32Q01 S	19		51.6	11/15/74	40.5	11.1	1101
				4/09/75	38.9	12.7	
03S/12W-33A06 S	19		63.0	10/20/74	90.6(S)	-27.6	1101
				11/20/74	87.6(S)	-24.6	
				12/15/74	173.6(1)	-110.6	
				1/15/75	171.6(1)	-108.6	
				2/12/75	73.6(S)	-10.6	
				3/15/75	84.6(S)	-21.6	
				4/15/75	90.6(S)	-27.6	
				5/17/75	79.6(S)	-16.6	
				6/19/75	82.6(S)	-19.6	
				7/13/75	87.6(S)	-24.6	
				8/15/75	171.6(1)	-108.6	
				9/15/75	173.6(1)	-110.6	
03S/12W-33A07 S	19		59.0	10/18/74	95.5(S)	-36.5	1101
				11/18/74	91.5(S)	-32.5	
				12/15/74	113.5(1)	-54.5	
				1/15/75	110.5(1)	-51.5	
				2/15/75	109.5(1)	-50.5	
				3/05/75	77.5(S)	-18.5	
				4/15/75	107.5(1)	-48.5	
				5/08/75	82.5(S)	-23.5	
				6/12/75	80.5(S)	-21.5	
				7/26/75	94.5(S)	-35.5	
				8/10/75	94.5(S)	-35.5	
				9/15/75	80.5(S)	-21.5	
03S/12W-33F07 S	19		56.0	11/21/74	41.9	14.1	1101
				4/10/75	45.1	10.9	
03S/12W-33G02 S	19		60.0	10/31/74	84.4(S)	-24.4	1101
				11/30/74	83.4(3)	-23.4	
				12/31/74	73.4(S)	-13.4	
				1/31/75	72.4(S)	-12.4	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT CENTRAL HYDRO SUBAREA					U-05 U-05.A U-05.A5		
03S/12W-33G02 S (CONTINUED)	19		60.0	2/28/75	74.4(5)	-14.4	1101
				3/31/75	76.4(5)	-16.4	
				4/30/75	76.4(5)	-16.4	
				5/31/75	82.4(5)	-22.4	
				6/30/75	82.4(5)	-22.4	
				7/31/75	91.4(5)	-31.4	
				8/31/75	88.4(5)	-28.4	
				9/30/75	86.4(5)	-26.4	
03S/12W-33P01 S	19		48.0	10/15/74	54.5(5)	-6.5	1101
				11/16/74	53.5(5)	-5.5	
				12/15/74	63.5(5)	-15.5	
				1/15/75	64.5(5)	-16.5	
				2/15/75	59.5(5)	-11.5	
				3/15/75	57.5(5)	-9.5	
				4/15/75	57.5(5)	-9.5	
				5/15/75	53.5(5)	-5.5	
				6/15/75	56.5(5)	-8.5	
				7/15/75	60.5(5)	-12.5	
				8/15/75	58.5(5)	-10.5	
				9/15/75	62.5(5)	-14.5	
03S/12W-33R04 S	19		56.0	10/15/74	148.0(1)	-92.0	1101
				11/15/74	144.0(1)	-88.0	
				12/15/74	106.0(5)	-50.0	
				1/15/75	100.0(5)	-44.0	
				2/13/75	100.0(5)	-44.0	
				3/10/75	91.0(5)	-35.0	
				4/16/75	88.0(5)	-32.0	
				5/15/75	68.0(5)	-12.0	
				6/13/75	80.0(5)	-24.0	
				7/17/75	151.0(1)	-95.0	
				8/15/75	148.0(1)	-92.0	
				9/15/75	88.0(5)	-32.0	
03S/12W-34C01 S	19		63.0	10/31/74	84.0(5)	-21.0	1101
				11/30/74	83.0(5)	-20.0	
				12/31/74	74.0(5)	-11.0	
				1/31/75	73.0	-10.0	
				2/28/75	81.0	-18.0	
				3/31/75	81.0	-18.0	
				4/30/75	81.0	-18.0	
				5/31/75	90.0(5)	-27.0	
				6/30/75	97.0(5)	-34.0	
				7/31/75	99.0(5)	-35.0	
				8/31/75	97.0(5)	-34.0	
				9/30/75	97.0(5)	-34.0	
03S/12W-34N01 S	19		62.0	11/30/74	48.0(5)	14.0	1101
				12/31/74	48.0(5)	14.0	
				1/31/75	58.0(5)	4.0	
				2/28/75	58.0(5)	4.0	
				3/31/75	59.0(5)	3.0	
				4/30/75	57.0(5)	5.0	
				5/31/75	64.0(5)	-2.0	
				6/30/75	63.0(5)	-1.0	
				7/31/75	63.0(5)	-1.0	
				8/31/75	64.0(5)	-2.0	
				9/30/75	61.0(5)	1.0	
03S/12W-34F01 S	19		61.5	10/11/74	80.5(5)	-19.0	1101
				11/23/74	72.5(5)	-11.0	
				12/15/74	72.5(5)	-11.0	
				1/15/75	113.5(1)	-52.0	
				2/15/75	73.5(5)	-12.0	
				3/15/75	72.5(5)	-11.0	
				4/17/75	73.5(5)	-12.0	
				5/15/75	110.5(1)	-49.0	
				6/15/75	114.5(1)	-53.0	
				7/15/75	120.5(1)	-59.0	
				8/15/75	120.5(1)	-59.0	
				9/15/75	122.5(1)	-61.0	
03S/12W-34G01 S	19		62.0	10/07/74	88.0	-26.0	1733
				11/18/74	83.3	-21.3	
				12/09/74	77.2	-15.2	
				1/20/75	75.6	-13.6	
				2/18/75	69.1	-7.1	
				3/03/75	73.2	-11.2	
				4/14/75	71.6	-9.6	
				5/05/75	74.9	-12.9	
				6/16/75	82.1	-20.1	
				7/07/75	86.6	-24.6	
				8/18/75	93.3	-31.3	
				9/08/75	90.7	-28.7	
03S/12W-35C01 S	19		64.0	11/15/74	51.2	12.8	1101
				4/08/75	48.6(8)	15.4	
03S/12W-35D02 S	19		61.0	10/07/74	41.9	19.1	1733
				11/18/74	41.0	20.0	
				12/09/74	NM-9		
				1/20/75	NM-9		
				2/05/75	NM-6		
03S/12W-35L02 S	19		56.0	11/07/74	NM-8		1101
				4/08/75	48.1	7.9	
03S/12W-36A01 S	19		57.0	10/14/74	87.5(5)	-30.5	1101
				11/07/74	80.5(5)	-23.5	
				12/21/74	76.0(5)	-19.0	
				1/21/75	73.5(5)	-16.5	
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT CENTRAL HYDRO SUBAREA					U-05 U-05.A U-05.A5		
03S/12W-36A01 S (CONTINUED)	19		57.0	2/14/75	76.5(5)	-19.5	1101
				3/14/75	75.5(5)	-18.5	
				4/14/75	76.5(5)	-19.5	
				5/14/75	82.5(5)	-25.5	
				6/14/75	82.5(5)	-25.5	
				7/21/75	90.5(5)	-33.5	
				8/14/75	94.5(5)	-37.5	
				9/21/75	89.5(5)	-32.5	
03S/12W-36C01 S	19		61.0	11/07/74	41.1	19.9	1101
				4/08/75	40.1	20.9	
03S/13W-01G01 S	19		104.5	10/01/74	128.0	-23.5	1101
				11/01/74	128.0	-23.5	
				12/01/74	130.0	-25.5	
				1/01/75	125.0	-20.5	
				2/01/75	119.0	-14.5	
				3/01/75	116.0	-11.5	
				4/01/75	119.0	-14.5	
				5/01/75	119.0	-14.5	
				6/01/75	130.0	-25.5	
				7/01/75	132.0	-27.5	
				8/01/75	135.0	-30.5	
				9/01/75	132.0	-27.5	
03S/13W-02A02 S	19		106.2	10/02/74	63.0	43.2	1101
				11/04/74	62.8	43.4	
				12/03/74	62.6	43.6	
				1/06/75	62.6	43.6	
				2/05/75	62.4	43.8	
				3/12/75	62.0	44.2	
				4/11/75	62.0	44.2	
				5/08/75	62.2	44.0	
				6/09/75	62.7	43.5	
				7/08/75	62.4	43.8	
				8/11/75	62.4	43.8	
				9/04/75	DRY (6)		
03S/13W-02M01 S	19		98.4	10/02/74	67.2	31.2	1101
				11/04/74	67.1	31.3	
				12/03/74	66.7	31.7	
				1/06/75	66.7	31.7	
				2/05/75	66.7	31.7	
				3/12/75	65.9	32.5	
				4/11/75	65.7	32.7	
				5/08/75	65.9	32.5	
				6/09/75	66.6	31.8	
				7/08/75	65.9	32.5	
				8/11/75	65.8	32.6	
				9/04/75	65.6	32.8	
03S/13W-02Q01 S	19		97.0	10/01/74	70.0(5)	27.0	1101
				11/06/74	68.0(5)	29.0	
				12/04/74	70.0(5)	27.0	
				1/08/75	68.0(5)	29.0	
				2/05/75	69.0(5)	28.0	
				3/05/75	69.0(5)	28.0	
				4/09/75	65.0(5)	32.0	
				5/07/75	65.0(5)	32.0	
				6/04/75	66.0(5)	31.0	
				7/02/75	67.0(5)	30.0	
				8/06/75	66.0(5)	31.0	
				9/03/75	68.0(5)	29.0	
03S/13W-03R01 S	19		98.5	10/01/74	145.0(6)	-46.5	1101
				11/06/74	145.0(6)	-46.5	
				12/04/74	145.0(5)	-46.5	
				1/08/75	145.0(5)	-46.5	
				2/05/75	145.0(5)	-46.5	
				3/05/75	145.0(5)	-46.5	
				4/09/75	145.0(5)	-46.5	
				5/07/75	145.0(5)	-46.5	
				6/04/75	145.0(5)	-46.5	
				7/02/75	145.0(5)	-46.5	
				8/06/75	145.0(5)	-46.5	
				9/03/75	162.0(5)	-63.5	
03S/13W-04D01 S	19		115.0	12/27/74	259.0(1)	-144.0	1200
				6/05/75	175.0(5)	-60.0	
03S/13W-04N01 S	19		98.0	10/14/74	219.6(1)	-121.6	1101
				11/14/74	169.6(5)	-71.6	
				12/21/74	218.6(1)	-120.6	
				1/14/75	167.6(5)	-69.6	
				2/14/75	165.6(5)	-67.6	
				3/28/75	160.6(5)	-62.6	
				4/14/75	160.6(5)	-62.6	
				5/21/75	161.6(5)	-63.6	
				6/21/75	158.6(5)	-60.6	
				7/14/75	219.6(1)	-121.6	
				8/14/75	164.6(5)	-66.6	
				9/14/75	167.6(5)	-69.6	
03S/13W-04N03 S	19		98.0	10/21/74	254.4(1)	-156.4	1101
				11/14/74	255.4(1)	-157.4	
				12/14/74	253.4(1)	-155.4	
				1/14/75	255.4(1)	-157.4	
				2/14/75	255.4(1)	-157.4	
				3/21/75	251.4(1)	-153.4	
				4/07/75	251.4(1)	-153.4	
				5/14/75	255.4(1)	-157.4	
				6/07/75	164.4(5)	-66.4	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
COASTAL PL OF LA CO HYDRO SUBUNIT — U-05.A
CENTRAL HYDRO SUBAREA — U-05.A5

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
03S/13W-04N03 S (CONTINUED)	19		98.0	7/14/75	251.4(1)	-153.4	1101
				8/14/75	253.4(1)	-155.4	
				9/21/75	248.4(1)	-150.4	
03S/13W-05F01 S	19		114.0	10/25/74	293.0(1)	-179.0	1200
				12/27/74	286.0(1)	-172.0	
				6/05/75	166.0(5)	-52.0	
03S/13W-05F02 S	19		114.0	10/23/74	174.1	-60.1	5050
				11/29/74	334.0(1)	-220.0	1200
				6/05/75	164.0(5)	-50.0	
03S/13W-06R01 S	19		131.0	10/23/74	193.8	-62.8	1200
				11/20/74	193.7	-62.7	
				12/20/74	194.8	-63.8	
				1/22/75	193.4	-62.4	
				2/25/75	192.3	-61.3	
				3/28/75	191.5	-60.5	
				4/25/75	191.3	-60.3	
				5/30/75	190.9	-59.9	
				6/25/75	191.0	-60.0	
				7/23/75	191.3	-60.3	
				8/27/75	191.6	-60.6	
				9/24/75	191.6	-60.6	
03S/13W-10G01 S	19		85.0	10/25/74	143.0(1)	-58.0	1200
				11/29/74	139.0(1)	-54.0	
				12/27/74	135.0(1)	-50.0	
				6/05/75	124.0(5)	-39.0	
03S/13W-10G02 S	19		85.0	10/25/74	120.5(5)	-35.5	1200
				11/29/74	119.5(5)	-34.5	
				12/27/74	133.5(1)	-48.5	
				6/05/75	125.5(5)	-40.5	
03S/13W-10L01 S	19		85.0	11/13/74	129.5	-44.5	1101
				4/15/75	118.4	-33.4	
03S/13W-10L02 S	19		86.0	11/13/74	128.3	-42.3	1101
				4/15/75	116.9(8)	-30.9	
03S/13W-11R02 S	19		89.0	11/15/74	112.9	-23.9	1101
				4/16/75	109.2	-20.2	
03S/13W-11C01 S	19		88.5	10/01/74	111.5(5)	-23.0	1101
				11/06/74	115.5(5)	-27.0	
				12/04/74	104.5(5)	-16.0	
				1/08/75	103.5(5)	-15.0	
				2/05/75	104.5(5)	-16.0	
				3/05/75	104.5(5)	-16.0	
				4/09/75	105.5(5)	-17.0	
				5/07/75	109.5(5)	-21.0	
				6/04/75	107.5(5)	-19.0	
				7/02/75	109.5(5)	-21.0	
				8/06/75	115.5(5)	-27.0	
				9/03/75	111.5(5)	-23.0	
03S/13W-11E01 S	19		85.0	10/01/74	110.0(5)	-25.0	1101
				11/06/74	115.0(5)	-30.0	
				12/04/74	113.0(5)	-28.0	
				1/08/75	115.0(5)	-30.0	
				2/05/75	115.0(5)	-30.0	
				3/05/75	110.0(5)	-25.0	
				4/09/75	100.0(5)	-15.0	
				5/07/75	115.0(5)	-30.0	
				6/04/75	115.0(5)	-30.0	
				7/02/75	118.0(5)	-33.0	
				8/06/75	120.0(5)	-35.0	
03S/13W-11K01 S	19		84.4	10/02/74	112.3	-27.9	1101
				11/04/74	108.0	-23.6	
				4/11/75	108.3	-23.9	
03S/13W-11K02 S	19		84.4	10/02/74	57.2	27.2	1101
				11/04/74	56.8	27.6	
				4/11/75	55.4	29.0	
03S/13W-12E04 S	19		89.0	10/01/74	95.0(5)	-6.0	1101
				11/06/74	90.0(5)	-1.0	
				12/04/74	88.0(5)	1.0	
				1/08/75	88.0(5)	1.0	
				2/05/75	88.0(5)	1.0	
				3/05/75	89.0(5)	0.0	
				4/09/75	91.0(5)	-2.0	
				5/07/75	91.0(5)	-2.0	
				6/04/75	98.0(5)	-9.0	
				7/02/75	97.0(5)	-8.0	
				8/06/75	102.0(5)	-13.0	
				9/03/75	98.0(5)	-9.0	
03S/13W-12J01 S	19		85.0	12/12/74	NM-0		1101
03S/13W-12Q01 S	19		82.5	10/01/74	105.0(5)	-22.5	1101
				11/06/74	105.0(5)	-22.5	
				12/04/74	97.0(5)	-14.5	
				1/08/75	97.0(5)	-14.5	
				2/05/75	97.0(5)	-14.5	
				3/05/75	97.0(5)	-14.5	
				4/09/75	97.0(5)	-14.5	
				5/07/75	104.0(5)	-21.5	
				6/04/75	102.0(5)	-19.5	
				7/09/75	105.0(5)	-22.5	

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
COASTAL PL OF LA CO HYDRO SUBUNIT — U-05.A
CENTRAL HYDRO SUBAREA — U-05.A5

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
03S/13W-12Q01 S (CONTINUED)	19		82.5	8/06/75	111.0(5)	-28.5	1101
				9/03/75	108.0(5)	-25.5	
03S/13W-13D01 S	19		79.0	10/01/74	103.0(5)	-24.0	1101
				11/06/74	100.0(5)	-21.0	
				12/04/74	98.0(5)	-19.0	
				1/08/75	97.0(5)	-18.0	
				2/05/75	98.0(5)	-19.0	
				3/05/75	98.0(5)	-19.0	
				4/09/75	98.0(5)	-19.0	
				5/07/75	103.0(5)	-24.0	
				6/04/75	101.0(5)	-22.0	
				7/02/75	103.0(5)	-24.0	
				8/06/75	103.0(5)	-24.0	
				9/03/75	106.0(5)	-27.0	
03S/13W-13F01 S	19		77.5	11/13/74	56.2	21.3	1101
				4/16/75	55.0	22.5	
03S/13W-13H01 S	19		76.0	10/15/74	104.0(5)	-28.0	1101
				11/15/74	103.0(5)	-27.0	
				12/15/74	104.0(5)	-28.0	
				1/15/75	102.0(5)	-26.0	
				2/15/75	98.0(5)	-22.0	
				3/15/75	98.0(5)	-22.0	
				4/15/75	97.0(5)	-21.0	
				5/15/75	99.0(5)	-23.0	
				6/15/75	99.0(5)	-23.0	
				7/15/75	99.0(5)	-23.0	
				8/15/75	108.0(5)	-32.0	
				9/15/75	106.0(5)	-30.0	
03S/13W-13H02 S	19		75.6	10/15/74	104.6(5)	-29.0	1101
				11/15/74	105.6(5)	-30.0	
				12/15/74	105.6(5)	-30.0	
				1/15/75	105.6(5)	-30.0	
				2/15/75	104.6(5)	-29.0	
				3/15/75	98.6(5)	-23.0	
				4/15/75	102.4(5)	-26.8	
				5/15/75	101.6(5)	-26.0	
				6/15/75	101.6(5)	-26.0	
				7/15/75	101.6	-26.0	
				8/15/75	110.6	-35.0	
				9/15/75	106.5	-30.9	
03S/13W-13R02 S	19		76.0	11/21/74	NM-1		1101
				4/16/75	NM-1		
03S/13W-14H01 S	19		73.0	11/13/74	104.5	-31.5	1101
				4/15/75	101.8	-28.8	
03S/13W-15C02 S	19		79.0	10/31/74	97.5(5)	-18.5	1101
				3/31/75	108.5(5)	-29.5	
				9/30/75	118.5(5)	-39.5	
03S/13W-15G01 S	19		75.0	10/31/74	117.0(5)	-42.0	1101
				3/25/75	114.0(5)	-39.0	
				9/30/75	126.0(5)	-51.0	
03S/13W-15H03 S	19		80.0	11/13/74	110.1	-30.1	1101
				4/15/75	106.9	-26.9	
03S/13W-15H05 S	19		77.0	10/31/74	139.5(1)	-62.5	1101
				3/25/75	124.5(5)	-47.5	
				9/30/75	129.5(5)	-52.5	
03S/13W-15R01 S	19		71.5	10/15/74	131.1(1)	-59.6	1101
				11/15/74	132.5(1)	-61.0	
				12/13/74	NM-0		
				1/15/75	127.0(1)	-55.5	
				2/15/75	127.0(1)	-55.5	
				3/15/75	126.0(1)	-54.5	
				4/15/75	127.4(1)	-55.9	
				5/15/75	125.0(1)	-53.5	
				6/15/75	54.0(5)	17.5	
				7/15/75	132.2(1)	-60.7	
				8/15/75	106.5	-35.0	
				9/15/75	124.0(1)	-52.5	
03S/13W-16D01 S	19		95.0	11/12/74	147.5	-52.5	1101
				4/15/75	147.2	-52.2	
03S/13W-16E01 S	19		93.5	10/15/74	141.0(5)	-47.5	1101
				11/15/74	141.0(5)	-47.5	
				12/15/74	143.0(5)	-49.5	
				1/15/75	140.0(5)	-46.5	
				2/15/75	142.0(5)	-48.5	
				3/15/75	139.0(5)	-45.5	
				4/15/75	138.5(5)	-45.0	
				5/15/75	137.0(5)	-43.5	
				6/15/75	139.0(5)	-45.5	
				7/15/75	139.0(5)	-45.5	
				8/15/75	184.0(1)	-90.5	
				9/15/75	182.0(1)	-88.5	
03S/13W-16H02 S	19		82.0	10/14/74	124.4(5)	-42.4	1101
				11/14/74	123.4(5)	-41.4	
				12/21/74	125.4(1)	-43.4	
				1/14/75	121.4(5)	-39.4	
				2/14/75	123.4(1)	-41.4	
				3/21/75	120.4(5)	-38.4	
				4/07/75	120.4(5)	-38.4	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT CENTRAL HYDRO SUBAREA						U-05 U-05.A U-05.A5	
03S/13W-16H02 S (CONTINUED)	19		82.0	5/21/75	122.4(S)	-40.4	1101
				6/14/75	121.4(S)	-39.4	
				7/21/75	123.4(S)	-41.4	
				8/14/75	124.4(S)	-42.4	
				9/14/75	124.4(S)	-42.4	
03S/13W-16H06 S	19		107.0	11/12/74	157.0	-50.0	1101
				4/15/75	155.2	-48.2	
03S/13W-20H06 S	19		106.0	11/12/74	164.5(6)	-58.5	1101
				4/04/75	163.7(6)	-57.7	
03S/13W-20H07 S	19		108.0	11/12/74	155.7	-47.7	1101
				4/04/75	154.1	-46.1	
03S/13W-21P01 S	19		91.8	10/21/74	157.2	-65.4	1733
				11/11/74	155.8	-64.0	
				12/02/74	151.1	-59.3	
				1/13/75	152.7	-60.9	
				2/03/75	153.1	-61.3	
				3/17/75	154.5	-62.7	
				4/07/75	153.7	-61.9	
				5/19/75	155.0	-63.2	
				6/09/75	156.7	-64.9	
				7/21/75	159.1	-67.3	
				8/11/75	165.2	-73.4	
				9/01/75	155.7	-63.9	
03S/13W-22H02 S	19		69.2	12/15/74	137.5(1)	-68.3	1101
				1/15/75	136.5(1)	-67.3	
				2/15/75	134.5(1)	-65.3	
				3/15/75	103.2(S)	-34.0	
				4/15/75	102.3(S)	-33.1	
				5/15/75	103.5(S)	-34.3	
				6/15/75	149.5(1)	-80.3	
				7/15/75	153.5(1)	-84.3	
				8/15/75	102.7	-33.5	
				9/15/75	152.5(1)	-83.3	
03S/13W-22H07 S	19		68.5	10/15/74	131.8(1)	-63.3	1101
				11/15/74	133.8(1)	-65.3	
				12/15/74	135.8(S)	-67.3	
				1/15/75	134.8(S)	-66.3	
				2/15/75	139.3(S)	-70.8	
				3/15/75	138.8(S)	-70.3	
				4/15/75	112.7(S)	-44.2	
				5/15/75	120.0(S)	-51.5	
				6/15/75	124.6	-56.1	
				7/15/75	127.8(S)	-59.3	
				8/15/75	123.5	-55.0	
				9/15/75	123.0	-54.5	
03S/13W-22P04 S	19		70.1	12/15/74	126.0(S)	-55.9	1101
				1/15/75	125.5(S)	-55.4	
				2/15/75	125.0(S)	-54.9	
				3/15/75	220.5(1)	-150.4	
				4/15/75	218.9(1)	-148.8	
				5/15/75	219.0(1)	-148.9	
				6/15/75	224.0(1)	-153.9	
				7/15/75	223.0(1)	-152.9	
				8/15/75	218.0(1)	-147.9	
				9/15/75	214.0(1)	-143.9	
03S/13W-23P02 S	19		66.3	10/21/74	58.2	8.1	1733
				11/11/74	58.3	8.0	
				12/02/74	58.0	8.3	
				1/13/75	57.9	8.4	
				2/03/75	57.7	8.6	
				3/17/75	57.7	8.6	
				4/07/75	57.3	9.0	
				5/19/75	57.6	8.7	
				6/09/75	57.2	9.1	
				7/21/75	57.4	8.9	
				8/11/75	57.5	8.8	
				9/01/75	57.5	8.8	
03S/13W-24A01 S	19		70.7	10/15/74	55.4(S)	15.3	1101
				11/15/74	57.4(S)	13.3	
				12/15/74	55.4(S)	15.3	
				1/15/75	55.4(S)	15.3	
				2/15/75	57.4(S)	13.3	
				3/15/75	54.4(S)	16.3	
				4/15/75	53.4(S)	17.3	
				5/15/75	54.4(S)	16.3	
				6/15/75	54.4(S)	16.3	
				7/15/75	54.4(S)	16.3	
				8/15/75	57.4(S)	13.3	
				9/15/75	55.4(S)	15.3	
03S/13W-24A06 S	19		65.8	11/14/74	57.5	7.5	1101
				4/08/75	56.5	8.5	
03S/13W-24A07 S	19		65.0	11/14/74	57.8	7.2	1101
				4/08/75	56.4	8.6	
03S/13W-25A02 S	19		57.0	11/14/74	47.0	10.0	1101
				4/08/75	NW-6		
03S/13W-25G02 S	19		63.0	11/14/74	118.0(4)	-55.0	1101
				4/08/75	103.8(4)	-40.8	
03S/13W-25H02 S	19		57.1	11/14/74	89.3	-32.2	1101

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT CENTRAL HYDRO SUBAREA						U-05 U-05.A U-05.A5	
03S/13W-26C01 S	19		62.6	10/15/74	184.0(1)	-121.4	1101
				11/15/74	184.0(1)	-121.4	
				12/31/74	137.0(S)	-74.4	
				2/15/75	217.0(1)	-154.4	
				8/15/75	120.3	-57.7	
03S/13W-26F01 S	19		61.0	10/29/74	133.0	-72.0	5050
03S/13W-26J03 S	19		59.3	10/18/74	59.0	0.3	4206
				11/29/74	59.5	-0.2	
				12/20/74	64.2	-4.9	
				1/31/75	59.2	0.1	
				2/21/75	58.8	0.5	
				3/14/75	58.8	0.5	
				4/25/75	59.4	-0.1	
				5/16/75	58.3	1.0	
			59.3	6/27/75	61.0	-2.0	
				7/18/75	61.4	-2.4	
				8/22/75	60.9	-1.9	
				9/19/75	61.0	-2.0	
03S/13W-26M01 S	19		61.0	10/15/74	148.3(S)	-87.3	1101
				11/15/74	148.3(S)	-87.3	
				12/15/74	143.3(S)	-82.3	
				1/15/75	142.3(S)	-81.3	
				2/15/75	148.3(S)	-87.3	
				3/15/75	144.3(S)	-83.3	
				4/15/75	144.3(S)	-83.3	
				5/15/75	140.3(S)	-79.3	
				6/15/75	145.3(S)	-84.3	
				7/15/75	148.3(S)	-87.3	
				8/15/75	145.3(S)	-84.3	
				9/15/75	147.3(S)	-86.3	
03S/13W-27F02 S	19		89.3	10/15/74	152.7(S)	-63.4	1101
				11/15/74	165.0(S)	-75.7	
				12/15/74	286.0(1)	-196.7	
				2/28/75	279.0(1)	-189.7	
				3/15/75	284.0(1)	-194.7	
				4/30/75	282.0(1)	-192.7	
				5/15/75	280.0(1)	-190.7	
				6/30/75	286.0(1)	-196.7	
				7/31/75	170.0(S)	-80.7	
				8/31/75	174.0(S)	-84.7	
				9/30/75	165.0(S)	-75.7	
03S/13W-27G01 S	19		68.2	10/15/74	147.0(S)	-78.8	1101
				11/15/74	148.0(S)	-79.8	
				12/15/74	146.5(S)	-78.3	
				1/15/75	146.0(S)	-77.8	
				2/15/75	142.0(S)	-73.8	
				3/15/75	145.0(S)	-76.8	
				4/15/75	142.5(S)	-74.3	
				5/15/75	142.5(S)	-74.3	
				6/15/75	146.5(S)	-78.3	
				7/15/75	149.0(S)	-80.8	
				8/15/75	151.5(S)	-83.3	
				9/15/75	149.5(S)	-81.3	
03S/13W-28G01 S	19		91.9	10/29/74	150.3	-58.4	5050
03S/13W-28G04 S	19		96.0	11/12/74	158.7	-62.7	1101
				4/07/75	157.1	-61.1	
03S/13W-33B01 S	19		156.8	10/30/74	226.4	-69.6	5050
03S/13W-34H01 S	19		132.0	11/12/74	214.2	-82.2	1101
				4/07/75	213.6	-81.6	
03S/13W-34H02 S	19		130.0	10/30/74	237.2	-107.2	5050
03S/13W-35A05 S	19		27.3	11/18/74	57.2	-29.9	1101
				4/04/75	56.3	-29.0	
03S/13W-35K03 S	19		44.8	10/02/74	177.5(2)	-132.7	1101
				11/01/74	176.7(2)	-131.9	
				12/01/74	176.3(2)	-131.5	
				1/08/75	171.7(2)	-126.9	
				2/05/75	174.1(2)	-129.3	
				3/05/75	171.0(2)	-126.2	
				4/02/75	172.9(2)	-128.1	
				5/07/75	149.2(6)	-104.4	
				6/04/75	171.3(2)	-126.5	
				7/15/75	150.0(6)	-105.2	
				8/15/75	150.0(6)	-105.2	
				9/15/75	172.5(2)	-127.7	
03S/13W-35K04 S	19		46.5	11/15/74	66.6	-20.1	1101
				4/08/75	65.0	-18.5	
03S/13W-35P01 S	19		50.0	10/24/74	227.0(1)	-177.0	5050
03S/13W-35Q01 S	19		47.0	10/24/74	184.2(2)	-137.2	5050
03S/13W-35Q03 S	19		47.0	10/24/74	181.8	-134.8	5050
03S/13W-36N01 S	19		46.5	11/15/74	153.4	-106.9	1101
03S/14W-01F03 S	19		227.8	11/07/74	278.2	-51.2	1101
				4/14/75	278.3	-51.3	
04S/11W-04D01 S	19		41.5	11/15/74	53.2	-11.7	1101

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
COASTAL PL OF LA CO HYDRO SUBUNIT — U-05.A
CENTRAL HYDRO SUBAREA — U-05.A5

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
04S/11W-07A01 S	19		44.5	11/15/74	53.7	-9.2	1101
04S/11W-07H01 S	19		38.0	11/15/74	47.1	-9.1	1101
				4/07/75	39.4	-1.4	
04S/11W-07H02 S	19		38.5	10/14/74	88.7(5)	-50.2	1101
				11/14/74	81.7(5)	-43.2	
				12/14/74	50.7(5)	-12.2	
				1/14/75	58.7(5)	-20.2	
				2/14/75	59.7(5)	-21.2	
				3/21/75	48.7(5)	-10.2	
				4/14/75	48.7(5)	-10.2	
				5/14/75	48.7(5)	-10.2	
				6/14/75	66.7(5)	-28.2	
				7/07/75	64.7(5)	-26.2	
				8/21/75	77.7(5)	-39.2	
				9/21/75	71.7(5)	-33.2	
04S/11W-07H03 S	19		35.0	11/15/74	8.9	26.1	1101
				4/07/75	NM-9		
04S/11W-07L01 S	19		33.5	10/14/74	52.5(5)	-19.0	1101
				11/14/74	46.5(5)	-13.0	
				12/14/74	41.5(5)	-8.0	
				1/14/75	38.5(5)	-5.0	
				2/14/75	40.5(5)	-7.0	
				3/14/75	37.5(5)	-4.0	
				4/14/75	36.5(5)	-3.0	
				5/14/75	47.5(5)	-14.0	
				6/14/75	45.5(5)	-12.0	
				7/14/75	49.5(5)	-16.0	
				8/14/75	53.5(5)	-20.0	
				9/21/75	57.5(5)	-24.0	
04S/11W-07L02 S	19		33.5	11/15/74	52.2(2)	-18.7	1101
04S/11W-18A01 S	19		33.0	11/15/74	37.5	-4.5	1101
				4/07/75	33.7	-0.7	
04S/11W-18F01 S	19		28.8	11/15/74	NM-5		1101
04S/11W-18F01 S	19		28.0	10/14/74	44.0(5)	-16.0	1101
				11/14/74	40.0(5)	-12.0	
				12/07/74	34.0(5)	-6.0	
				1/14/75	35.0(5)	-7.0	
				2/14/75	35.0(5)	-7.0	
				3/21/75	33.0(5)	-5.0	
				4/14/75	34.0(5)	-6.0	
				5/14/75	33.0(5)	-5.0	
				6/14/75	41.0(5)	-13.0	
				7/14/75	43.0(5)	-15.0	
				8/14/75	44.0(5)	-16.0	
				9/14/75	43.0(5)	-15.0	
04S/11W-18J01 S	19		31.0	11/14/74	38.0(5)	-7.0	1101
				12/21/74	36.5(5)	-5.5	
				1/14/75	34.5(5)	-3.5	
				2/21/75	31.5(5)	-0.5	
				3/14/75	31.5(5)	-0.5	
				4/14/75	30.5(5)	0.5	
				5/14/75	35.5(5)	-4.5	
				6/14/75	43.5(5)	-12.5	
				7/14/75	46.5(5)	-15.5	
				8/14/75	44.5(5)	-13.5	
				9/14/75	44.5(5)	-13.5	
04S/11W-18J05 S	19		28.1	10/04/74	66.6	-38.5	1101
				11/13/74	59.6	-31.5	
				4/07/75	53.8	-25.7	
04S/11W-18P01 S	19		26.4	10/18/74	59.7	-33.3	4206
				11/29/74	51.3	-24.9	
				12/28/74	45.2	-18.8	
				1/31/75	43.7	-17.3	
				2/21/75	41.0	-14.6	
				3/14/75	41.8	-15.4	
				4/25/75	46.3	-19.9	
				5/16/75	56.0	-29.6	
			25.0	6/27/75	57.1	-32.1	
				7/18/75	57.5	-32.5	
				8/22/75	70.0	-45.0	
				9/19/75	66.9	-41.9	
04S/12W-02Q01 S	19		47.0	10/06/74	117.9(5)	-70.9	1101
				11/06/74	184.9(1)	-137.9	
				12/15/74	181.9(1)	-134.9	
				1/21/75	81.9(5)	-34.9	
				2/19/75	74.9(5)	-27.9	
				3/15/75	71.9(5)	-24.9	
				4/11/75	52.9(5)	-5.9	
				5/15/75	61.9(5)	-14.9	
				6/17/75	61.9(5)	-14.9	
				7/13/75	66.9(5)	-19.9	
				8/15/75	193.9(1)	-146.9	
				9/15/75	189.9(1)	-142.9	
04S/12W-03F01 S	19		53.0	10/18/74	87.5(5)	-34.5	1101
				11/04/74	79.5(5)	-26.5	
				12/15/74	87.5(5)	-34.5	
				1/15/75	82.5(5)	-29.5	
				2/15/75	82.5(5)	-29.5	

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
COASTAL PL OF LA CO HYDRO SUBUNIT — U-05.A
CENTRAL HYDRO SUBAREA — U-05.A5

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
04S/12W-03F01 S (CONTINUED)	19		53.0	3/16/75	82.5(5)	-29.5	1101
				4/08/75	78.5	-25.5	
				5/15/75	81.5(5)	-28.5	
				6/16/75	88.5(5)	-35.5	
				7/14/75	95.5(5)	-42.5	
				8/15/75	87.5(5)	-34.5	
				9/12/75	94.5(5)	-41.5	
04S/12W-03H01 S	19		55.0	10/24/74	78.0(5)	-23.0	1101
				11/21/74	76.0(5)	-21.0	
				12/15/74	126.0(1)	-71.0	
				1/15/75	123.0(1)	-68.0	
				2/15/75	71.0(5)	-16.0	
				3/15/75	71.0(5)	-16.0	
				4/26/75	71.0(5)	-16.0	
				5/12/75	71.0(5)	-16.0	
				6/12/75	71.0(5)	-16.0	
				7/15/75	141.0(1)	-86.0	
				8/15/75	122.0(1)	-67.0	
				9/15/75	122.0(1)	-67.0	
04S/12W-04J03 S	19		53.0	10/17/74	82.0(5)	-29.0	1101
				11/20/74	81.0(5)	-28.0	
				12/15/74	80.0(5)	-27.0	
				1/15/75	67.0(5)	-14.0	
				2/15/75	75.0(5)	-22.0	
				3/16/75	78.0(5)	-25.0	
				4/15/75	65.0(5)	-12.0	
				5/15/75	55.0(5)	-2.0	
				6/13/75	75.0(5)	-22.0	
				7/18/75	73.0(5)	-20.0	
				8/15/75	75.0(5)	-22.0	
				9/15/75	83.0(5)	-30.0	
04S/12W-05H01 S	19		50.0	11/21/74	41.4	8.6	1101
04S/12W-05H02 S	19		50.8	11/18/74	41.2	8.8	4206
				4/09/75	40.0	10.0	
04S/12W-06J01 S	19		47.0	10/15/74	105.0	-58.0	1101
				11/05/74	99.8	-52.8	
				12/10/74	93.7	-46.7	
				1/08/75	88.6	-41.6	
				2/05/75	96.4	-49.4	
				3/05/75	85.0	-38.0	
				4/02/75	85.3	-38.3	
				5/14/75	82.9	-35.9	
			48.3	6/04/75	87.0	-38.7	
				7/02/75	95.4	-47.1	
				8/06/75	111.9	-63.6	
				9/03/75	117.3	-69.0	
04S/12W-06J02 S	19		45.9	10/08/74	119.1	-73.2	1101
				11/05/74	112.7	-66.8	
				12/10/74	106.4	-60.5	
				1/08/75	102.0	-56.1	
				2/05/75	102.6	-56.7	
				3/05/75	96.8	-50.9	
				4/09/75	65.5	-19.6	
				5/07/75	168.0(1)	-122.1	
04S/12W-06K01 S	19		47.7	10/08/74	107.9	-60.2	1101
				11/05/74	101.3	-53.6	
				12/10/74	95.2	-47.5	
				1/08/75	90.3	-42.6	
				2/05/75	88.2	-40.5	
				3/05/75	81.2	-33.5	
				4/02/75	85.8	-38.1	
				5/07/75	82.4	-34.7	
				6/04/75	86.0	-38.3	
				7/02/75	94.3	-46.6	
				8/06/75	141.6(1)	-93.9	
				9/03/75	143.3(1)	-95.6	
04S/12W-06K02 S	19		47.1	10/08/74	123.6	-76.5	1101
				11/05/74	120.7	-73.6	
				12/10/74	116.0	-68.9	
				1/08/75	194.6(1)	-147.5	
				2/05/75	110.3	-63.2	
				3/05/75	102.8	-55.7	
				4/02/75	101.7	-54.6	
				5/07/75	194.3(1)	-147.2	
				6/11/75	110.3	-63.2	
				7/09/75	121.5	-74.4	
				8/06/75	128.1	-81.0	
				9/03/75	123.2	-76.1	
04S/12W-06K04 S	19		44.6	10/02/74	138.9(1)	-92.3	1101
				11/05/74	136.7(1)	-90.1	
				12/10/74	132.2(1)	-85.6	
				1/08/75	129.7(1)	-83.1	
				2/05/75	127.6(1)	-81.0	
				3/05/75	102.2	-55.6	
				4/02/75	120.1(1)	-73.5	
				5/07/75	123.3(1)	-76.7	
			46.0	6/04/75	128.8(1)	-82.8	
				7/02/75	137.0(1)	-91.0	
				8/06/75	139.8(1)	-93.8	
				9/03/75	139.4(1)	-93.4	
04S/12W-08B02 S	19		62.0	11/21/74	NM-4		1101
04S/12W-08N02 S	19		70.0	10/07/74	132.6(4)	-62.6	1733

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
COASTAL PL OF LA CO HYDRO SUBUNIT — U-05.A
CENTRAL HYDRO SUBAREA — U-05.A5

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
04S/12W-08N02 S (CONTINUED)	19		70.0	11/18/74	121.0(4)	-51.0	1733
				12/09/74	117.4(4)	-47.4	
				1/20/75	111.1	-41.1	
				2/10/75	106.3(4)	-36.3	
				3/03/75	106.3	-36.3	
				4/14/75	101.0	-31.0	
				5/05/75	108.8	-38.8	
				6/02/75	113.2	-43.2	
				7/07/75	116.5	-46.5	
				8/18/75	131.9(4)	-61.9	
				9/08/75	134.6(4)	-64.6	
04S/12W-08R01 S	19		58.0	10/11/74	87.0(5)	-29.0	1101
				11/15/74	110.0(5)	-52.0	
				12/13/74	102.0(5)	-44.0	
				1/17/75	96.0(5)	-38.0	
				2/14/75	108.0(5)	-50.0	
				3/14/75	95.0(5)	-37.0	
				4/18/75	89.0(5)	-31.0	
				5/16/75	93.0(5)	-35.0	
				6/20/75	96.0(5)	-38.0	
				7/18/75	102.0(5)	-44.0	
				8/15/75	101.0(5)	-43.0	
				9/12/75	120.0(5)	-62.0	
04S/12W-10G01 S	19		47.0	10/17/74	106.0(5)	-59.0	1101
				11/16/74	61.0(5)	-14.0	
				12/15/74	68.0(5)	-21.0	
				1/15/75	95.0(5)	-48.0	
				2/15/75	106.0(5)	-59.0	
				3/15/75	96.0(5)	-49.0	
				4/15/75	101.0(5)	-54.0	
				5/17/75	100.0(5)	-53.0	
				6/21/75	96.0(5)	-49.0	
				7/15/75	114.0(5)	-67.0	
				8/15/75	106.0(5)	-59.0	
				9/16/75	116.0(5)	-69.0	
04S/12W-10H01 S	19		46.0	11/17/74	108.0(5)	-62.0	1101
				12/15/74	139.0(1)	-93.0	
				1/15/75	139.0(1)	-93.0	
				2/15/75	140.0(1)	-94.0	
				3/27/75	98.0(5)	-52.0	
				4/15/75	140.0(1)	-94.0	
				5/15/75	142.0(1)	-96.0	
				6/16/75	149.0(1)	-103.0	
				7/19/75	73.0(5)	-27.0	
				8/15/75	148.0(1)	-102.0	
				9/15/75	150.0(1)	-104.0	
04S/12W-10H03 S	19		46.5	10/13/74	93.0(5)	-46.5	1101
				11/13/74	92.0(5)	-45.5	
				12/15/74	85.0(5)	-38.5	
				1/15/75	130.0(1)	-83.5	
				2/15/75	83.0(5)	-36.5	
				3/15/75	90.0(5)	-43.5	
				4/15/75	92.0(5)	-45.5	
				5/15/75	102.0(5)	-55.5	
				6/12/75	88.0(5)	-41.5	
				7/23/75	81.0(5)	-34.5	
				8/16/75	105.0(5)	-58.5	
				9/15/75	108.0(5)	-61.5	
04S/12W-10J02 S	19		45.5	10/19/74	98.0(5)	-52.5	1101
				11/16/74	97.0(5)	-51.5	
				12/15/74	91.0(5)	-45.5	
				1/15/75	95.0(5)	-49.5	
				2/13/75	97.0(5)	-51.5	
				3/21/75	89.0(5)	-43.5	
				4/15/75	83.0(5)	-37.5	
				5/15/75	95.0(5)	-49.5	
				6/12/75	95.0(5)	-49.5	
				7/19/75	95.0(5)	-49.5	
				8/17/75	94.0(5)	-48.5	
				9/15/75	96.0(5)	-50.5	
04S/12W-11R03 S	19		42.0	10/15/74	93.0(5)	-51.0	1101
				11/15/74	91.0(5)	-49.0	
				12/15/74	83.0(5)	-41.0	
				1/15/75	82.0(5)	-40.0	
				2/15/75	82.0(5)	-40.0	
				5/15/75	84.0(5)	-42.0	
				6/17/75	89.0(5)	-47.0	
				7/07/75	97.0(5)	-55.0	
				8/12/75	100.0(5)	-58.0	
				9/15/75	82.0(5)	-40.0	
04S/12W-12D03 S	19		46.3	10/04/74	61.1	-14.8	1101
				11/13/74	62.1	-15.8	
				4/08/75	62.8	-16.5	
04S/12W-12J01 S	19		40.0	10/14/74	79.8(5)	-39.8	1101
				11/14/74	73.8(5)	-33.8	
				12/21/74	66.8(5)	-26.8	
				1/21/75	56.8(5)	-16.8	
				2/14/75	54.8(5)	-14.8	
				3/21/75	58.8(5)	-18.8	
				4/21/75	61.8(5)	-21.8	
				5/07/75	63.8(5)	-23.8	
				6/14/75	74.8(5)	-34.8	
				7/14/75	81.8(5)	-41.8	
				8/14/75	85.8(5)	-45.8	

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
COASTAL PL OF LA CO HYDRO SUBUNIT — U-05.A
CENTRAL HYDRO SUBAREA — U-05.A5

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
04S/12W-12J01 S	19		40.0	9/14/75	79.8(5)	-39.8	1101
04S/12W-13C01 S	19		33.5	10/01/74	139.3(1)	-105.8	1101
				11/05/74	80.1(1)	-46.6	
				12/10/74	73.8	-40.3	
				1/08/75	71.2	-37.7	
				2/05/75	73.2	-39.7	
				3/05/75	76.3	-42.8	
				4/02/75	71.6	-38.1	
				5/07/75	76.7	-43.2	
			33.0	6/04/75	137.0(1)	-104.0	
				7/02/75	140.0(1)	-107.0	
				8/06/75	137.8(1)	-104.8	
				9/17/75	91.7	-58.7	
04S/12W-13C02 S	19		36.5	11/15/74	77.4	-40.9	1101
				4/09/75	60.1	-23.6	
04S/12W-13C03 S	19		33.0	10/08/74	75.2	-42.2	1101
				11/05/74	70.1	-37.1	
				12/10/74	62.4	-29.4	
				1/08/75	58.9	-25.9	
				2/05/75	56.5	-23.5	
				3/05/75	58.1	-25.1	
				4/02/75	57.0	-24.0	
				5/07/75	76.4	-43.4	
				6/04/75	73.7	-40.7	
				7/09/75	95.9	-62.9	
				8/06/75	179.6(1)	-146.6	
				9/17/75	81.7	-48.7	
04S/12W-13D01 S	19		36.1	11/15/74	80.7	-44.6	1101
				4/09/75	57.6	-21.5	
04S/12W-13D03 S	19		36.0	10/08/74	85.1	-49.1	1101
				11/05/74	209.0(1)	-173.0	
				12/10/74	69.2	-33.2	
				1/08/75	65.7	-29.7	
				2/05/75	66.4	-30.4	
				3/05/75	65.7	-29.7	
				4/02/75	64.4	-28.4	
				5/07/75	188.7(1)	-152.7	
				6/04/75	202.7(1)	-166.7	
			35.5	7/02/75	202.1(1)	-166.6	
				8/06/75	218.6(1)	-183.1	
				9/03/75	207.9(1)	-172.4	
04S/12W-13G01 S	19		35.0	10/18/74	92.0	-57.0	4206
				11/29/74	69.4	-34.4	
				12/20/74	63.0	-28.0	
				1/31/75	59.8	-24.8	
				2/21/75	58.0	-23.0	
				3/14/75	58.1	-23.1	
				4/04/75	58.1	-23.1	
				5/16/75	109.2(1)	-74.2	
04S/12W-13J02 S	19		28.0	10/18/74	67.4	-39.4	4206
				11/29/74	56.8	-28.8	
				12/20/74	49.6	-21.6	
				1/31/75	44.8	-16.8	
				2/21/75	42.9	-14.9	
				3/14/75	42.9	-14.9	
				4/25/75	53.3	-25.3	
				5/16/75	62.0	-34.0	
				6/27/75	72.6	-44.6	
				7/18/75	65.1	-37.1	
				8/22/75	86.5	-58.5	
				9/19/75	76.1	-48.1	
04S/12W-13N01 S	19		28.5	11/19/74	76.3	-47.8	1101
04S/12W-13N02 S	19		29.0	10/02/74	183.5(1)	-154.5	1101
				11/06/74	185.6(1)	-156.6	
				12/11/74	182.5(1)	-153.5	
				1/08/75	182.2(1)	-153.2	
				2/05/75	183.4(1)	-154.4	
				3/05/75	182.6(1)	-153.6	
				4/02/75	180.7(1)	-151.7	
				5/07/75	182.9(1)	-153.9	
			26.5	6/04/75	182.0(1)	-155.5	
				7/02/75	183.4(1)	-156.9	
				8/06/75	182.6(1)	-156.1	
				9/03/75	188.9(1)	-162.4	
04S/12W-14A02 S	19		36.0	10/01/74	169.8(1)	-133.8	1101
				11/05/74	165.0(1)	-129.0	
				12/10/74	162.2(1)	-126.2	
				1/08/75	159.9(1)	-123.9	
				2/05/75	161.4(1)	-125.4	
				3/05/75	160.9(1)	-124.9	
				4/02/75	161.1(1)	-125.1	
				5/07/75	163.3(1)	-127.3	
			35.4	6/09/75	169.1(1)	-133.7	
				7/02/75	169.0(1)	-133.6	
				8/06/75	173.3(1)	-137.9	
				9/03/75	165.8(1)	-130.4	
04S/12W-14A03 S	19		34.4	10/15/74	167.0	-167.0	4206
				11/29/74	40.3	-5.9	
				12/19/74	166.0(1)	-166.0	
				1/28/75	32.0	-32.0	
			34.5	2/25/75	30.7	-30.7	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
COASTAL PL OF LA CO HYDRO SUBUNIT — U-05.A
CENTRAL HYDRO. SUBAREA — U-05.A5

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
04S/12W-14A03 S (CONTINUED)	19		34.5	3/14/75	2.6	-2.6	4206
				4/25/75	2.5	-2.5	
			34.4	5/16/75	39.4	-5.0	
				6/06/75	40.6	-6.2	
				7/18/75	43.0	-8.5	
				8/22/75	44.9	-10.4	
				9/19/75	44.0	-9.6	
04S/12W-14A01 S	19		39.0	10/08/74	94.8	-55.8	1101
				11/05/74	88.9	-49.9	
				12/10/74	85.6	-46.6	
				1/08/75	83.7	-44.7	
				2/05/75	85.0	-46.0	
				3/05/75	84.8	-45.8	
				4/02/75	88.9	-49.9	
				5/07/75	92.5	-53.5	
			38.0	7/02/75	108.9	-70.9	
				8/06/75	122.5	-84.5	
				9/03/75	108.4	-70.4	
04S/12W-14C01 S	19		44.5	11/15/74	100.2	-55.7	1101
				4/09/75	88.2	-43.7	
04S/12W-14C02 S	19		44.5	10/23/74	87.0	-42.5	1101
				11/05/74	80.9	-36.4	
				12/10/74	75.8	-31.3	
				1/08/75	71.2	-26.7	
				2/05/75	70.1	-25.6	
				3/05/75	97.8(1)	-53.3	
				4/02/75	64.7	-20.2	
				5/07/75	62.3	-17.8	
				6/04/75	93.9(1)	-49.4	
				7/16/75	105.3	-60.8	
				8/06/75	111.6(1)	-67.1	
				9/03/75	114.4(1)	-69.9	
04S/12W-14C06 S	19		36.2	10/08/74	91.7	-55.5	1101
				11/05/74	85.8	-49.6	
				12/10/74	80.9	-44.7	
				1/08/75	78.6	-42.4	
				2/05/75	91.0	-54.8	
				3/05/75	78.9	-42.7	
				4/02/75	179.0(1)	-142.8	
				5/07/75	178.0(1)	-141.8	
			35.8	7/02/75	175.6(1)	-139.8	
				8/06/75	179.3(1)	-143.5	
				9/03/75	172.8(1)	-137.0	
04S/12W-14D01 S	19		46.0	10/09/74	96.9	-50.9	1101
				11/05/74	84.8	-38.8	
				12/10/74	75.5	-29.5	
				1/08/75	71.0	-25.0	
				2/05/75	69.9	-23.9	
				3/05/75	77.6	-31.6	
				4/02/75	66.0	-20.0	
				5/07/75	62.3	-16.3	
				6/04/75	72.1	-26.1	
				7/02/75	81.1	-35.1	
				8/06/75	90.5	-44.5	
				9/03/75	93.6	-47.6	
04S/12W-14D02 S	19		45.6	10/09/74	92.0	-46.4	1733
				11/20/74	90.4	-44.8	
				12/11/74	91.5	-45.9	
				1/01/75	84.9	-39.3	
				2/12/75	86.0	-40.4	
				3/05/75	83.7	-38.1	
				4/16/75	80.0	-34.4	
				5/07/75	88.2	-42.6	
				6/18/75	92.1	-46.5	
				7/09/75	102.9	-57.3	
				8/20/75	103.4	-57.8	
				9/10/75	98.6	-53.0	
04S/12W-14K01 S	19		29.7	10/02/74	86.1	-56.4	1101
				11/20/74	80.9	-51.2	
				1/29/75	74.5	-44.8	
				2/05/75	74.4	-44.7	
				3/19/75	68.3	-38.6	
				4/16/75	73.6	-43.9	
				5/21/75	79.3	-49.6	
				6/18/75	85.5	-55.8	
04S/12W-14P01 S	19		28.0	10/08/74	70.5	-42.5	1101
				11/05/74	62.0	-34.0	
				12/10/74	55.7	-27.7	
				1/08/75	52.0	-24.0	
				2/10/75	48.2	-20.2	
				3/05/75	51.7	-23.7	
				4/02/75	46.2	-18.2	
				5/07/75	42.9	-14.9	
			28.6	6/04/75	47.5	-18.9	
				7/02/75	49.1	-20.5	
				8/06/75	65.0	-36.4	
				9/03/75	67.8	-39.2	
04S/12W-14R01 S	19		20.0	10/02/74	72.9	-52.9	1101
				11/06/74	163.8(1)	-143.8	
				12/11/74	161.7(1)	-141.7	
				1/08/75	163.6(1)	-143.6	
				2/05/75	171.9(1)	-151.9	
				3/19/75	54.9	-34.9	

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
COASTAL PL OF LA CO HYDRO SUBUNIT — U-05.A
CENTRAL HYDRO SUBAREA — U-05.A5

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
04S/12W-14R01 S (CONTINUED)	19		20.0	4/02/75	151.9(1)	-131.9	1101
				5/07/75	157.3(1)	-137.3	
				6/04/75	159.4(1)	-139.4	
				7/02/75	171.6(1)	-151.6	
				8/06/75	189.8(1)	-169.8	
				9/03/75	174.3(1)	-154.3	
04S/12W-15B01 S	19		40.0	10/08/74	91.8	-51.8	1101
				11/05/74	82.5	-42.5	
				12/10/74	76.7	-36.7	
				1/08/75	72.1	-32.1	
				2/05/75	70.2	-30.2	
				3/05/75	70.3	-30.3	
				4/02/75	66.0	-26.0	
				5/07/75	62.3	-22.3	
				6/04/75	67.0	-27.0	
				7/02/75	75.9	-35.9	
				8/06/75	86.6	-46.6	
				9/03/75	90.2	-50.2	
04S/12W-15B02 S	19		40.0	10/18/74	54.2	-14.2	4206
				11/29/74	53.3	-13.3	
				12/20/74	52.3	-12.3	
				1/31/75	51.8	-11.8	
				2/21/75	51.3	-11.3	
				3/14/75	51.1	-11.1	
				4/25/75	50.7	-10.7	
				5/16/75	52.2	-12.2	
				6/27/75	54.6	-14.6	
				7/18/75	56.4	-16.4	
				8/22/75	56.7	-16.7	
				9/19/75	56.0	-16.0	
04S/12W-15C01 S	19		40.0	11/15/74	19.2	20.8	1101
				4/08/75	19.6	20.4	
04S/12W-15K03 S	19		37.0	11/15/74	83.7	-46.7	1101
				4/09/75	70.4	-33.4	
04S/12W-16J01 S	19		34.0	10/09/74	107.9	-73.9	1101
				11/20/74	122.6	-88.6	
				12/11/74	157.1(1)	-123.1	
				1/08/75	103.5	-69.5	
				2/05/75	102.2	-68.2	
				3/05/75	142.8(1)	-108.8	
				4/02/75	132.5(1)	-98.5	
				5/07/75	134.2(1)	-100.2	
				6/04/75	96.4	-62.4	
				7/02/75	151.4(1)	-119.4	
				8/13/75	93.1	-59.1	
				9/10/75	102.7	-68.7	
04S/12W-16J02 S	19		35.0	11/15/74	35.7	-0.7	1101
				4/08/75	36.3	-1.3	
04S/12W-16P01 S	19		31.9	10/30/74	96.0	-64.1	1101
				12/04/74	93.6	-61.7	
				1/08/75	151.2(1)	-119.3	
				2/05/75	149.8(1)	-117.9	
				3/05/75	75.7	-43.8	
				4/02/75	145.5(1)	-113.6	
				5/07/75	146.1(1)	-114.2	
			30.3	6/04/75	150.6(1)	-120.3	
				7/02/75	157.7(1)	-127.4	
				8/06/75	97.4	-67.1	
				9/03/75	95.2	-64.9	
04S/12W-17F01 S	19		65.1	10/08/74	130.9	-65.8	1101
				11/05/74	124.2	-59.1	
				12/10/74	117.7	-52.6	
				1/08/75	112.0	-46.9	
				2/05/75	109.0	-43.9	
				3/05/75	105.0	-39.9	
				4/02/75	102.9	-37.8	
				5/07/75	100.7	-35.6	
			64.0	6/04/75	104.8	-40.8	
				7/02/75	116.3	-52.3	
				8/06/75	129.2	-65.2	
				9/03/75	131.2	-67.2	
04S/12W-17N01 S	19		57.0	10/08/74	140.8	-83.8	1101
				11/05/74	136.4	-79.4	
				12/10/74	111.9	-54.9	
				1/08/75	121.5	-64.5	
				2/05/75	116.4	-59.4	
				3/05/75	108.9	-51.9	
				4/02/75	104.8	-47.8	
				5/07/75	107.5	-50.5	
			56.0	6/04/75	117.7	-61.7	
				7/02/75	133.4	-77.4	
				8/06/75	139.0	-83.0	
				9/03/75	139.5	-83.5	
04S/12W-17N02 S	19		54.0	10/08/74	138.2	-82.2	1101
				11/05/74	133.9	-77.9	
				12/10/74	127.0	-71.0	
				1/08/75	120.4	-64.4	
				2/05/75	113.8	-57.8	
				3/05/75	106.9	-50.9	
				4/02/75	106.1	-52.1	
				5/07/75	104.4	-48.4	
			54.0	6/04/75	115.8	-61.8	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
COASTAL PL OF LA CO HYDRO SUBUNIT — U-05.A
CENTRAL HYDRO SUBAREA — U-05.A5

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
04S/12W-17N02 S (CONTINUED)	19		54.0	7/02/75	131.6	-77.6	1101
				8/06/75	137.2	-83.2	
				9/03/75	135.1	-81.1	
04S/12W-17P04 S	19		46.0	10/01/74	204.1(1)	-158.1	1101
				11/05/74	212.1(1)	-166.1	
				12/10/74	211.4(1)	-165.4	
				1/29/75	107.5	-61.5	
				2/05/75	98.4	-52.4	
				3/05/75	91.7	-45.7	
				4/02/75	89.2	-43.2	
				5/07/75	88.8	-42.8	
			46.4	6/04/75	99.4	-53.0	
				7/02/75	212.6(1)	-166.2	
				8/06/75	113.4(1)	-67.0	
				9/03/75	112.2(1)	-65.8	
04S/12W-17Q01 S	19		47.2	10/08/74	128.7	-81.5	1101
				11/05/74	124.4	-77.2	
				12/10/74	116.5	-69.3	
				1/08/75	110.9	-63.7	
				2/05/75	104.7	-57.5	
				3/05/75	98.6	-51.4	
				4/02/75	94.7	-47.5	
				5/07/75	95.4	-48.2	
			45.2	6/04/75	105.0	-59.8	
				7/09/75	123.3	-78.1	
				8/06/75	191.1(1)	-145.9	
				9/10/75	125.4	-80.2	
04S/12W-18R01 S	19		63.0	10/08/74	144.8	-81.8	1101
				11/05/74	139.8	-76.8	
				12/04/74	137.7	-74.7	
				1/08/75	127.8	-64.8	
				2/05/75	121.9	-58.9	
				3/05/75	115.6	-52.6	
				4/02/75	113.0	-50.0	
				5/07/75	113.1	-50.1	
				6/04/75	124.0	-61.0	
				7/02/75	138.2	-75.2	
				8/06/75	143.7	-80.7	
				9/03/75	141.2	-78.2	
04S/12W-19A01 S	19		72.0	11/15/74	NM-2		1101
				4/07/75	120.7	-48.7	
04S/12W-20R01 S	19		34.1	10/08/74	126.5	-92.4	1101
				11/05/74	127.0	-92.9	
				12/10/74	114.2	-80.1	
				1/08/75	108.0	-73.9	
				2/05/75	101.9	-67.8	
				3/05/75	93.8	-59.7	
				4/02/75	93.0	-58.9	
				5/07/75	93.3	-59.2	
04S/12W-21F01 S	19		29.0	10/02/74	86.6	-57.6	4206
				11/06/74	81.0	-52.0	
				12/04/74	77.0	-48.0	
				1/08/75	69.1	-40.1	
				2/05/75	66.8	-37.8	
				3/05/75	63.3	-34.3	
				4/02/75	60.5	-31.5	
				5/07/75	58.1	-29.1	
			31.0	6/04/75	63.8	-32.8	
				7/02/75	74.5	-43.5	
				8/04/75	84.3	-53.3	
				9/03/75	86.9	-55.9	
04S/12W-21J01 S	19		25.2	11/15/74	30.7	-5.5	1101
				4/08/75	30.5	-5.3	
04S/12W-21J04 S	19		36.7	10/08/74	102.0	-65.3	1101
				11/05/74	96.0	-59.3	
				12/10/74	88.3	-51.6	
				1/08/75	82.7	-46.0	
				2/05/75	79.7	-43.0	
				3/05/75	74.5	-37.8	
				4/02/75	72.1	-35.4	
				5/07/75	70.3	-33.6	
			36.0	6/04/75	77.0	-41.0	
				7/02/75	88.3	-52.3	
				8/06/75	97.1	-61.1	
				9/03/75	98.1	-62.1	
04S/12W-21M02 S	19		35.6	10/15/74	118.4	-82.8	1101
				11/05/74	114.7	-79.1	
				12/10/74	104.6	-69.0	
				1/08/75	98.6	-63.0	
				2/05/75	94.3	-58.7	
				3/05/75	86.5	-50.9	
				4/02/75	84.5	-48.9	
				5/07/75	85.5	-49.9	
			35.5	6/04/75	100.0	-64.5	
				7/02/75	113.3	-77.8	
				8/06/75	118.4	-82.9	
				9/03/75	116.0	-80.5	
04S/12W-21M04 S	19		30.0	10/08/74	116.4	-86.4	1101
				11/05/74	106.8	-76.8	
				12/10/74	95.7	-65.7	
				1/08/75	90.3	-60.3	
				2/05/75	86.3	-56.3	
04S/12W-21M04 S (CONTINUED)	19		30.0	3/05/75	78.2	-48.2	1101
				4/02/75	76.1	-46.1	
				5/07/75	77.2	-47.2	
				6/04/75	95.1	-65.1	
				7/02/75	107.8	-77.8	
				8/06/75	112.7	-82.7	
				9/03/75	109.4	-79.4	
04S/12W-21M05 S	19		36.7	10/01/74	167.3(1)	-130.6	1101
				11/05/74	166.6(1)	-129.9	
				12/10/74	104.5	-67.8	
				1/08/75	94.0	-57.3	
				2/05/75	95.1	-58.4	
				3/05/75	87.3	-50.6	
				4/02/75	86.2	-49.5	
				5/07/75	86.7	-50.0	
			36.5	6/25/75	136.7(1)	-100.2	
				7/02/75	137.8(1)	-101.3	
				8/06/75	137.3(1)	-100.8	
				9/03/75	136.7(1)	-100.2	
04S/12W-22J03 S	19		24.0	11/15/74	29.8	-5.8	1101
				4/08/75	29.7	-5.7	
04S/12W-22L01 S	19		22.8	11/15/74	58.2	-35.4	4206
				4/03/75	53.5	-30.7	
04S/12W-22M01 S	19		25.0	10/09/74	69.9	-44.9	1733
				11/20/74	69.6	-44.6	
				12/11/74	70.2	-45.2	
				1/01/75	63.7	-38.7	
				2/12/75	64.3	-39.3	
				3/05/75	61.5	-36.5	
				4/16/75	62.0	-37.0	
				5/07/75	63.0	-38.0	
				6/18/75	67.4	-42.4	
				7/09/75	70.1	-45.1	
				8/20/75	69.2	-44.2	
				9/10/75	68.2	-43.2	
04S/12W-23C01 S	19		30.7	10/01/74	182.1(1)	-151.4	1101
				11/05/74	183.2(1)	-152.5	
				12/10/74	183.8(1)	-153.1	
				1/08/75	184.3(1)	-153.6	
				2/05/75	187.5(1)	-156.8	
				3/05/75	182.7(1)	-152.0	
				4/02/75	183.9(1)	-153.2	
				5/07/75	185.5(1)	-154.8	
			30.4	6/14/75	187.2(1)	-156.8	
				7/02/75	188.9(1)	-158.5	
				8/06/75	193.9(1)	-163.5	
				9/03/75	185.0(1)	-154.6	
04S/12W-23K02 S	19		17.9	11/15/74	50.6	-32.7	1101
				4/09/75	42.2	-24.3	
04S/12W-23K03 S	19		19.6	10/09/74	81.3	-61.7	1101
				11/27/74	78.3	-58.7	
				12/04/74	76.7	-57.1	
				1/08/75	89.8(1)	-70.2	
				2/05/75	89.2(1)	-69.6	
				3/05/75	64.2	-44.6	
				4/02/75	82.6(1)	-63.0	
				5/07/75	84.3(1)	-64.7	
			19.3	6/04/75	70.1	-50.8	
				7/16/75	80.7	-61.4	
				8/20/75	77.4	-58.1	
				9/03/75	98.3(1)	-79.0	
04S/12W-24J01 S	19		24.0	11/15/74	62.5(2)	-38.5	1101
				4/07/75	NM-3		
			22.7	6/11/75	63.6(4)	-40.9	
04S/12W-24J02 S	19		22.5	10/25/74	69.8	-47.3	5102
				1/07/75	58.9	-36.4	
				3/13/75	57.6	-35.1	
				5/02/75	61.6	-39.1	
				8/26/75	NM-1		
04S/12W-24M02 S	19		22.0	10/04/74	91.1	-69.1	1101
				11/06/74	85.1	-63.1	
				12/10/74	83.5	-61.5	
				1/08/75	77.8	-55.8	
				2/05/75	76.0	-54.0	
				3/05/75	72.8	-50.8	
				4/02/75	68.9	-46.9	
				5/07/75	67.9	-45.9	
				6/04/75	72.8	-50.8	
				7/02/75	82.1	-60.1	
				8/06/75	90.0	-68.0	
				9/03/75	84.9	-62.9	
04S/12W-24M04 S	19		22.7	10/09/74	85.9	-63.2	1101
				11/06/74	82.8	-60.1	
				12/10/74	77.7	-55.0	
				1/09/75	75.0	-52.3	
				2/05/75	73.6	-50.9	
				3/05/75	67.0	-44.3	
				4/02/75	66.8	-44.1	
				5/07/75	68.6	-45.9	
			19.7	6/04/75	71.2	-51.5	
				7/02/75	80.0	-60.3	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT CENTRAL HYDRO SUBAREA						U-05 U-05.A U-05.A5	
04S/12W-24H04 S (CONTINUED)	19		19.7	8/06/75	83.5	-63.8	1101
				9/03/75	79.2	-59.5	
04S/12W-24H08 S	19		21.6	10/02/74	153.9(1)	-132.3	1101
				11/06/74	151.8(1)	-130.2	
				12/04/74	152.4(1)	-130.8	
				1/08/75	149.8(1)	-128.2	
				2/05/75	148.0(1)	-126.4	
				3/05/75	146.5(1)	-124.9	
				4/02/75	143.5(1)	-121.9	
				5/07/75	149.0(1)	-127.4	
				6/04/75	155.8(1)	-134.2	
				7/02/75	159.9(1)	-138.3	
				8/20/75	77.5	-55.9	
				9/03/75	155.2(1)	-133.6	
04S/12W-25E01 S	19		15.7	10/02/74	53.2	-37.5	1101
				11/27/74	42.8	-27.1	
			15.5	6/04/75	30.6	-15.1	
				7/02/75	62.8(1)	-47.3	
				8/27/75	45.4	-29.9	
				9/03/75	49.8	-34.3	
04S/12W-26F02 S	19		16.0	10/18/74	61.2	-45.2	4206
				11/29/74	58.2	-42.2	
				12/20/74	56.2	-40.2	
				3/14/75	51.0	-35.0	
				4/04/75	37.8	-21.8	
				5/16/75	43.6	-27.6	
				6/27/75	59.1	-43.1	
				7/18/75	NM-2		
				8/08/75	63.4	-47.4	
				9/24/75	NM-2		
04S/12W-26G01 S	19		15.0	11/15/74	52.9	-37.9	4206
04S/12W-26H01 S	19		16.6	11/15/74	69.0	-52.4	4206
04S/12W-28H01 S	19		23.4	10/15/74	76.3	-52.9	1101
				11/05/74	70.0	-46.6	
				12/10/74	63.6	-40.2	
				6/04/75	53.3	-29.9	
				7/02/75	62.6	-39.2	
				8/06/75	71.5	-48.1	
				9/03/75	73.6	-50.2	
04S/12W-28H06 S	19		22.7	10/15/74	75.0	-52.3	1101
				11/05/74	69.1	-46.4	
				12/10/74	62.8	-40.1	
				6/04/75	52.2	-29.5	
				7/02/75	61.5	-38.8	
				8/06/75	69.3	-46.6	
				9/03/75	72.3	-49.6	
04S/12W-28H08 S	19		22.8	11/20/74	55.4	-32.6	4206
04S/12W-28H09 S	19		21.4	10/02/74	97.7	-76.3	4206
				11/06/74	93.1	-71.7	
				12/04/74	90.2	-68.8	
				2/05/75	76.9	-55.5	
				3/05/75	69.5	-48.1	
				4/02/75	67.3	-45.9	
				5/07/75	68.5	-47.1	
			26.6	6/04/75	85.5	-58.9	
				7/02/75	96.6	-70.0	
				8/06/75	101.3	-74.7	
				9/03/75	97.7	-71.1	
04S/12W-28H12 S	19		21.9	10/15/74	91.9	-70.0	1101
				11/05/74	87.9	-66.0	
				12/10/74	80.2	-58.3	
			21.3	6/04/75	73.7	-52.4	
				7/02/75	84.7	-63.4	
				8/06/75	90.6	-69.3	
				9/03/75	89.9	-68.6	
04S/12W-34R02 S	19		12.5	11/15/74	52.5	-40.0	1101
04S/12W-34R03 S	19		12.5	11/15/74	51.0	-38.5	1101
04S/12W-35A01 S	19		11.0	10/30/74	27.3	-16.3	1101
				11/26/74	26.7	-15.7	
				1/02/75	24.6	-13.6	
				6/26/75	30.2	-19.2	
				7/30/75	33.6	-22.6	
				8/26/75	32.4	-21.4	
04S/12W-35C02 S	19		11.8	11/15/74	29.6	-17.8	4206
04S/12W-35H04 S	19		10.7	10/30/74	22.4	-11.7	1101
				11/26/74	21.6	-10.9	
				1/02/75	20.2	-9.5	
				6/26/75	26.2	-15.5	
				7/30/75	29.5	-18.8	
				8/26/75	28.1	-17.4	
04S/12W-35H05 S	19		11.9	10/30/74	43.9	-32.0	1101
				11/26/74	43.7	-31.8	
				1/02/75	39.5	-27.6	
				6/26/75	44.6	-32.7	
				7/30/75	48.8	-36.9	
				8/26/75	46.1	-34.2	

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT CENTRAL HYDRO SUBAREA						U-05 U-05.A U-05.A5	
04S/12W-35J01 S	19		9.0	11/26/74	16.3	-7.3	1101
				1/02/75	15.2	-6.2	
				6/26/75	21.7	-12.7	
				7/30/75	24.9	-15.9	
				8/26/75	23.2	-14.2	
04S/12W-35J06 S	19		9.0	10/30/74	32.8	-23.8	1101
				11/26/74	32.1	-23.1	
				1/02/75	30.0	-21.0	
				2/07/75	29.9	-20.9	
				4/02/75	28.3	-19.3	
				5/01/75	30.3	-21.3	
				6/26/75	38.4	-29.4	
				7/30/75	42.7	-33.7	
				8/26/75	39.8	-30.8	
04S/12W-35J07 S	19		10.0	10/30/74	30.8	-20.8	1101
				11/26/74	30.2	-20.2	
				1/02/75	28.4	-18.4	
				2/07/75	28.3	-18.3	
				4/02/75	27.0	-17.0	
				5/01/75	29.0	-19.0	
				6/26/75	37.2	-27.2	
				7/30/75	41.5	-31.5	
				8/26/75	38.6	-28.6	
04S/12W-35N01 S	19		60.0	11/15/74	76.8	-16.8	1101
04S/12W-35P04 S	19		9.3	10/30/74	11.1	-1.8	1101
				11/26/74	10.6	-1.3	
				1/02/75	10.1	-0.8	
				6/26/75	18.1	-8.8	
				7/30/75	20.4	-11.1	
				8/26/75	18.0	-8.7	
04S/12W-35P09 S	19		8.0	10/30/74	25.6	-17.6	1101
				11/26/74	24.1	-16.1	
				1/02/75	24.9	-16.9	
				6/26/75	33.4	-25.4	
				7/30/75	37.6	-29.6	
				8/26/75	34.2	-26.2	
04S/12W-35R11 S	19		9.0	10/30/74	13.8	-4.8	1101
				11/26/74	13.4	-4.4	
				1/02/75	12.7	-3.7	
				6/26/75	20.0	-11.0	
				7/30/75	23.0	-14.0	
				8/26/75	20.5	-11.5	
04S/12W-36C01 S	19		15.9	10/18/74	37.8	-21.9	4206
				11/29/74	34.6	-18.7	
				12/20/74	32.4	-16.5	
				3/14/75	29.7	-13.8	
				4/25/75	30.0	-14.1	
				5/16/75	33.4	-17.5	
			14.0	6/27/75	38.8	-24.8	
				7/18/75	42.8	-28.8	
				8/22/75	41.0	-27.0	
				9/19/75	40.1	-26.1	
04S/12W-36H01 S	19		22.3	10/30/74	50.9	-28.6	1101
				11/26/74	50.0	-27.7	
				1/02/75	47.4	-25.1	
				6/26/75	55.5	-33.2	
				7/31/75	59.8	-37.5	
				8/26/75	56.9	-34.6	
04S/12W-36H02 S	19		22.1	10/30/74	32.0	-9.9	1101
				11/26/74	31.5	-9.4	
				1/02/75	29.7	-7.6	
				6/26/75	37.9	-15.8	
				7/30/75	40.4	-18.3	
				8/26/75	37.8	-15.7	
04S/13W-01F01 S	19		44.5	11/18/74	99.3	-54.8	1101
				4/07/75	92.0	-47.5	
04S/13W-12F01 S	19		33.0	10/18/74	125.0	-92.0	4206
				11/29/74	132.4	-99.4	
				12/20/74	132.5	-99.5	
				1/31/75	132.3	-99.3	
				2/21/75	131.7	-98.7	
				3/14/75	126.0	-93.0	
				4/25/75	130.9	-97.9	
				5/16/75	129.5	-96.5	
			34.0	6/27/75	134.7	-100.7	
				7/31/75	134.8	-100.8	
				8/22/75	128.6	-94.6	
				9/19/75	132.4	-98.4	
04S/13W-12F04 S	19		28.2	11/15/74	55.4	-27.2	1101
				4/07/75	54.6	-26.4	
04S/13W-12F06 S	19		38.0	10/24/74	136.8	-98.8	5050
04S/13W-12F01 S	19		85.2	11/15/74	125.7	-40.5	1101
				4/07/75	129.5	-44.3	
04S/13W-12K01 S	19		89.0	10/02/74	148.7	-59.7	4206
				11/06/74	148.3	-59.3	
				12/04/74	144.1	-55.1	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT CENTRAL HYDRO SUBAREA						U-05 U-05.A U-05.A5	
04S/13W-12K01 S (CONTINUED)	19		89.0	1/08/75	137.1	-48.1	4206
				2/05/75	135.0	-46.0	
				3/05/75	130.9	-41.9	
				4/02/75	128.7	-39.7	
				5/07/75	125.4	-36.4	
				6/04/75	127.4	-38.4	
				7/02/75	133.4	-44.4	
				8/06/75	146.9	-57.9	
				9/03/75	152.5	-63.5	
04S/13W-12M01 S	19		28.0	11/15/74	54.6	-26.6	1101
				4/07/75	50.1	-22.1	
04S/13W-12M04 S	19		38.0	11/15/74	132.2	-94.2	1101
				4/07/75	124.1	-86.1	
04S/13W-13D01 S	19		25.0	10/24/74	128.1	-103.1	5050
05S/12W-01F02 S	19		9.0	11/27/74	10.2	-1.2	1101
				1/02/75	9.1	-0.1	
				2/07/75	8.0	1.0	
				4/03/75	9.3	-0.3	
				5/01/75	9.1	-0.1	
				6/26/75	14.1	-5.1	
				7/31/75	17.3	-8.3	
				8/26/75	16.4	-7.4	
05S/12W-01F08 S	19		6.7	10/31/74	14.6	-7.9	1101
				11/27/74	16.3	-9.6	
				1/02/75	15.8	-9.1	
				2/07/75	17.7	-11.0	
				4/03/75	15.6	-8.9	
				5/01/75	17.3	-10.6	
				6/26/75	24.5	-17.8	
				7/31/75	28.5	-21.8	
				8/26/75	26.0	-19.3	
05S/12W-02A05 S	19		20.9	10/31/74	18.8	2.1	1101
				11/27/74	18.9	2.0	
				1/02/75	17.0	3.9	
				2/07/75	19.1	1.8	
				4/02/75	20.3	0.6	
				5/01/75	21.1	-0.2	
				6/26/75	27.6	-6.7	
				7/31/75	32.4	-11.5	
				8/26/75	25.1	-4.2	
05S/12W-02A09 S	19		8.0	10/31/74	4.0	4.0	1101
				11/27/74	4.3	3.7	
				1/02/75	4.2	3.8	
				6/26/75	9.0	-1.0	
				7/31/75	14.0	-6.0	
				8/26/75	11.5	-3.5	
05S/12W-02A10 S	19		8.0	10/31/74	4.2	3.8	1101
				11/27/74	4.5	3.5	
				1/02/75	4.4	3.6	
				6/26/75	9.1	-1.1	
				7/31/75	14.0	-6.0	
				8/26/75	11.4	-3.4	
05S/12W-02A11 S	19		8.0	10/31/74	8.6	-0.6	1101
				11/27/74	8.8	-0.8	
				1/02/75	8.3	-0.3	
				6/26/75	15.5	-7.5	
				7/31/75	14.5	-6.5	
				8/26/75	15.2	-7.2	
05S/12W-02A12 S	19		8.0	10/31/74	24.4	-16.4	1101
				11/27/74	24.6	-16.6	
				1/02/75	23.1	-15.1	
				6/26/75	32.0	-24.0	
				7/31/75	36.4	-28.4	
				8/26/75	32.9	-24.9	
05S/12W-02A13 S	19		11.1	6/26/75	6.7	4.4	1101
				7/31/75	16.4	-5.3	
				8/26/75	8.8	2.3	
05S/12W-02A14 S	19		11.1	6/26/75	9.2	1.9	1101
				7/31/75	16.5	-5.4	
				8/26/75	10.2	0.9	
05S/12W-02A15 S	19		11.1	11/27/74	20.5	-9.4	1101
				6/26/75	16.2	-5.1	
				7/31/75	19.5	-8.4	
				8/26/75	14.0	-2.9	
05S/12W-02A16 S	19		11.1	10/31/74	27.2	-16.1	1101
				11/27/74	27.2	-16.1	
				1/02/75	26.1	-15.0	
				6/26/75	35.4	-24.3	
				7/31/75	39.5	-28.4	
				8/26/75	35.4	-24.3	
05S/12W-02B01 S	19		11.4	11/18/74	7.5	3.9	4206
05S/12W-02B14 S	19		10.4	10/30/74	6.5	3.9	1101
				11/27/74	5.9	4.5	
				1/02/75	6.3	4.1	
				6/26/75	15.7	-5.3	
				7/31/75	17.8	-7.4	
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT CENTRAL HYDRO SUBAREA						U-05 U-05.A U-05.A5	
05S/12W-02B14 S	19		10.4	8/26/75	13.3	-2.9	1101
05S/12W-02B15 S	19		10.4	10/30/74	22.0	-11.6	1101
				11/27/74	21.4	-11.0	
				1/02/75	21.0	-10.6	
				7/31/75	34.6	-24.2	
				8/26/75	30.7	-20.3	
05S/12W-02B16 S	19		10.8	10/30/74	6.4	4.4	1101
				11/26/74	5.9	4.9	
				1/02/75	6.2	4.6	
				2/07/75	6.6	4.2	
				4/02/75	8.2	2.6	
				5/01/75	9.2	1.6	
				6/26/75	15.7	-4.9	
				7/30/75	18.3	-7.5	
				8/26/75	14.7	-3.9	
05S/12W-02B17 S	19		10.8	10/30/74	12.2	-1.4	1101
				11/26/74	12.0	-1.2	
				1/02/75	12.1	-1.3	
				2/07/75	12.9	-2.1	
				4/02/75	13.2	-2.4	
				5/01/75	14.7	-3.9	
				6/26/75	23.0	-12.2	
				7/30/75	26.2	-15.4	
				8/26/75	22.4	-11.6	
05S/12W-02B21 S	19		10.0	10/31/74	8.1	1.9	1101
				11/26/74	9.2	0.8	
				1/02/75	7.6	2.4	
				6/26/75	8.9	1.1	
				7/30/75	11.1	-1.1	
				8/26/75	8.7	1.3	
05S/12W-02C01 S	19		25.0	10/29/74	18.5	6.5	5102
				1/07/75	19.5	5.5	
				3/13/75	18.1	6.9	
				5/02/75	21.6	3.4	
				8/26/75	28.6	-3.6	
05S/12W-02C06 S	19		18.0	10/30/74	15.9	2.1	1101
				11/26/74	15.6	2.4	
				1/02/75	15.9	2.1	
				2/07/75	15.9	2.1	
				4/02/75	16.3	1.7	
				5/01/75	16.5	1.5	
				6/26/75	17.7	0.3	
				7/30/75	18.7	-0.7	
				8/26/75	19.1	-1.1	
05S/12W-02C07 S	19		18.0	10/30/74	9.9	8.1	1101
				11/26/74	9.6	8.4	
				1/02/75	10.3	7.7	
				2/07/75	10.9	7.1	
				4/02/75	12.9	5.1	
				5/01/75	13.9	4.1	
				6/26/75	19.7	-1.7	
				7/30/75	22.6	-4.6	
				8/26/75	20.4	-2.4	
05S/12W-02C08 S	19		16.0	10/30/74	13.4	2.6	1101
				11/26/74	13.3	2.7	
				1/02/75	13.6	2.4	
				2/07/75	13.9	2.1	
				4/02/75	14.1	1.9	
				5/01/75	14.3	1.7	
				6/26/75	16.2	-0.2	
				7/30/75	17.7	-1.7	
				8/26/75	18.0	-2.0	
05S/12W-02C09 S	19		16.0	10/30/74	9.6	6.4	1101
				11/26/74	8.8	7.2	
				1/02/75	10.4	5.6	
				2/07/75	11.2	4.8	
				4/02/75	11.8	4.2	
				5/01/75	11.9	4.1	
				6/26/75	17.8	-1.8	
				7/30/75	19.3	-3.3	
				8/26/75	18.0	-2.0	
05S/12W-02D04 S	19		15.0	10/30/74	14.0	1.0	1101
				11/26/74	14.4	0.6	
				1/02/75	13.7	1.3	
				2/07/75	14.2	0.8	
				4/02/75	15.2	-0.2	
				5/01/75	14.0	1.0	
				6/26/75	15.1	-0.1	
				7/30/75	15.3	-0.3	
				8/26/75	14.9	0.1	
05S/12W-02D05 S	19		15.0	10/30/74	9.1	5.9	1101
				11/26/74	8.8	6.2	
				1/02/75	9.1	5.9	
				2/07/75	8.8	6.2	
				4/02/75	10.9	4.1	
				5/01/75	12.0	3.0	
				6/26/75	18.8	-3.8	
				7/30/75	21.6	-6.6	
				8/26/75	18.5	-3.5	
05S/12W-02D06 S	19		15.0	10/30/74	14.1	0.9	1101

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT CENTRAL HYDRO SUBAREA						U-05 U-05.A U-05.A5	
05S/12W-02D06 S (CONTINUED)	19		15.0	11/26/74	14.1	0.9	1101
				1/02/75	14.6	0.4	
				2/07/75	15.6	-0.6	
				4/02/75	16.0	-1.0	
				5/01/75	17.6	-2.6	
				6/26/75	26.4	-11.4	
				7/30/75	29.7	-14.7	
				8/26/75	27.2	-12.2	
05S/12W-02F01 S	19		8.1	11/15/74	5.6	2.5	1101
05S/12W-02F16 S	19		8.1	10/31/74	10.3	-2.2	1101
				11/26/74	10.3	-2.2	
				1/02/75	9.2	-1.1	
				6/26/75	10.8	-2.7	
				7/30/75	12.6	-4.5	
				8/26/75	12.9	-4.8	
05S/12W-02G05 S	19		9.0	10/31/74	10.4	-1.4	1101
				11/26/74	10.6	-1.6	
				1/02/75	10.2	-1.2	
				6/26/75	13.1	-4.1	
				7/30/75	13.6	-4.6	
				8/26/75	13.7	-4.7	
05S/12W-02G07 S	19		9.7	11/15/74	7.1	2.6	1101
05S/12W-02G19 S	19		9.9	10/31/74	10.8	-0.9	1101
				11/27/74	11.3	-1.4	
				1/02/75	11.0	-1.1	
				6/26/75	12.5	-2.6	
				7/31/75	14.9	-5.0	
				8/26/75	15.1	-5.2	
05S/12W-02G20 S	19		11.6	10/31/74	11.4	0.2	1101
				11/27/74	12.1	-0.5	
				6/26/75	14.7	-3.1	
				7/31/75	17.1	-5.5	
				8/26/75	16.3	-4.7	
05S/12W-02H08 S	19		19.9	10/31/74	19.0	0.9	1101
				11/27/74	19.7	0.2	
				1/02/75	19.0	0.9	
05S/12W-02H11 S	19		19.2	10/31/74	22.1	-2.9	1101
				11/27/74	22.4	-3.2	
				1/02/75	21.5	-2.3	
				6/26/75	22.2	-3.0	
				7/31/75	25.9	-6.7	
				8/26/75	26.1	-6.9	
05S/12W-02H16 S	19		21.0	10/31/74	34.4	-13.4	1101
				11/27/74	34.8	-13.8	
				1/02/75	33.6	-12.6	
				2/07/75	36.5	-15.5	
				4/03/75	32.9	-11.9	
				5/01/75	34.6	-13.6	
				6/26/75	42.4	-21.4	
				7/31/75	46.2	-25.2	
				8/26/75	43.0	-22.0	
05S/12W-02J02 S	19		8.0	10/18/74	49.3	-41.3	4206
				11/29/74	45.9	-37.9	
				12/20/74	45.6	-37.6	
				1/31/75	41.2	-33.2	
				2/21/75	37.8	-29.8	
				3/14/75	36.2	-28.2	
				4/25/75	36.1	-28.1	
				5/16/75	38.4	-30.4	
			10.0	6/27/75	46.0	-36.0	
				7/18/75	53.1	-43.1	
				8/22/75	56.1	-46.1	
				9/19/75	52.6	-42.6	
05S/12W-02J04 S	19		7.4	11/18/74	44.9	-37.5	4206
05S/12W-02P05 S	19		5.0	11/15/74	5.6	-0.6	1101
05S/12W-02P11 S	19		3.0	11/26/74	3.2	-0.2	1101
				1/02/75	2.9	0.1	
				6/26/75	3.8	-0.8	
				7/31/75	4.6	-1.6	
				8/26/75	4.0	-1.0	
05S/12W-02Q01 S	19		5.2	10/31/74	6.9	-1.7	1101
				11/27/74	7.3	-2.1	
				1/02/75	6.9	-1.7	
				6/26/75	7.5	-2.3	
				7/31/75	8.8	-3.6	
				8/26/75	8.7	-3.5	
05S/12W-02R01 S	19		17.9	10/31/74	22.3	-4.4	1101
				11/27/74	24.4	-6.5	
				1/02/75	23.4	-5.5	
				6/26/75	22.0	-4.1	
				7/31/75	30.3	-12.4	
				8/26/75	24.8	-6.9	
05S/12W-11G04 S	19		5.0	10/31/74	6.2	-1.2	1101
				11/26/74	7.1	-2.1	
				1/02/75	6.9	-1.9	
				2/07/75	7.4	-2.4	
LA-SAN GABRIEL RIVER HYDRO UNIT COASTAL PL OF LA CO HYDRO SUBUNIT CENTRAL HYDRO SUBAREA						U-05 U-05.A U-05.A5	
05S/12W-11G04 S (CONTINUED)	19		5.0	4/02/75	7.0	-2.0	1101
				5/01/75	6.8	-1.8	
				6/26/75	7.0	-2.0	
				7/31/75	8.3	-3.3	
				8/26/75	7.9	-2.9	
SAN FERNANDO HYDRO SUBUNIT SAN FERNANDO HYDRO SUBAREA						U-05.B U-05.B1	
01N/13W-15D03 S	19		764.0	10/03/74	24.1	739.9	1101
				11/18/74	23.8	740.2	
				4/23/75	23.5	740.5	
01N/13W-18N01 S	19		477.6	10/01/74	268.6(1)	209.0	1101
				11/05/74	264.6(1)	213.0	
				1/21/75	251.1(5)	226.5	
				3/11/75	245.1(5)	232.5	
				4/01/75	234.1(1)	243.5	
				5/06/75	239.1(1)	238.5	
				6/03/75	249.1(1)	228.5	
				7/08/75	234.1(1)	243.5	
				8/05/75	234.1(1)	243.5	
				9/02/75	267.1(1)	210.5	
01N/13W-19R01 S	19		470.0	10/01/74	240.7(1)	229.3	1101
				11/05/74	236.7(1)	233.3	
				1/21/75	222.7(5)	247.3	
				3/11/75	213.7(5)	256.3	
				4/01/75	211.7(1)	258.3	
				5/06/75	212.7(1)	257.3	
				6/03/75	214.7(1)	255.3	
				7/08/75	223.7(1)	246.3	
				8/05/75	222.7(1)	247.3	
				9/02/75	237.7(1)	232.3	
01N/13W-19R06 S	19		465.0	10/01/74	236.6(1)	228.4	1101
				11/05/74	238.2(1)	226.8	
				1/21/75	225.5(5)	239.5	
				3/11/75	233.6(5)	231.4	
				4/01/75	212.8(1)	252.2	
				5/06/75	212.8(1)	252.2	
				6/03/75	213.0(1)	252.0	
				7/01/75	223.0(1)	242.0	
				8/05/75	222.0(1)	243.0	
				9/02/75	223.0(1)	242.0	
01N/13W-19R07 S	19		470.8	10/01/74	233.7(1)	236.9	1101
				11/05/74	248.7(1)	221.9	
				1/21/75	248.7(5)	221.9	
				3/11/75	241.7(5)	228.9	
				4/01/75	240.7(1)	229.9	
				5/06/75	238.7(1)	231.9	
				6/03/75	238.7(1)	231.9	
				7/08/75	243.7(1)	226.9	
				8/05/75	243.7(1)	226.9	
				9/02/75	259.7(1)	210.9	
01N/13W-19C01 S	19		471.0	10/01/74	240.2(1)	230.8	1101
				11/05/74	244.2(1)	226.8	
				1/20/75	231.2(5)	239.8	
				3/12/75	224.2(5)	246.8	
				4/01/75	224.2(1)	246.8	
				5/06/75	221.2(1)	249.8	
				6/03/75	224.2(1)	246.8	
				7/08/75	229.2(1)	241.8	
				8/05/75	229.2(1)	241.8	
				9/02/75	247.2(1)	223.8	
01N/13W-19D03 S	19		472.6	10/01/74	256.0(1)	216.6	1101
				11/05/74	251.0(1)	221.6	
				1/21/75	238.2(5)	234.4	
				3/11/75	240.2(5)	232.4	
				5/28/75	235.2(1)	237.4	
				6/03/75	220.2(1)	252.4	
				7/08/75	225.2(1)	247.4	
				8/05/75	255.2(1)	217.4	
				9/02/75	245.2(1)	227.4	
01N/13W-19F01 S	19		468.2	10/01/74	232.0(1)	236.2	1101
				11/05/74	237.0(1)	231.2	
				1/20/75	NM-7		
				3/12/75	NM-7		
				5/28/75	218.0(1)	250.2	
				6/03/75	219.0(1)	249.2	
				7/08/75	222.0(1)	246.2	
				8/05/75	224.0(1)	244.2	
				9/02/75	241.0(1)	227.2	
01N/13W-19G01 S	19		438.0	10/15/74	192.2	245.8	1200
				11/12/74	188.5	249.5	
				12/17/74	171.5	266.5	
				4/01/75	159.4	278.6	
				5/20/75	162.4	275.6	
				6/17/75	167.3	270.7	
				7/15/75	174.1	263.9	
				8/19/75	183.2	254.8	
				9/09/75	184.6	253.4	
01N/13W-19J01 S	19		458.9	12/05/74	195.4	263.5	1101
				1/14/75	188.4	270.5	
				2/06/75	184.1	274.8	
				6/10/75	181.0	277.9	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT SAN FERNANDO HYDRO SUBUNIT SAN FERNANDO HYDRO SUBAREA						U-05 U-05.8 U-05.81	
01N/13W-19J01 S (CONTINUED)	19		458.9	7/11/75	186.0	272.9	1101
				8/07/75	193.2	265.7	
				9/09/75	196.3	262.6	
01N/13W-19J04 S	19		466.3	12/05/74	206.0	260.3	1101
				1/14/75	198.0	268.3	
				2/06/75	198.8	267.5	
				5/09/75	178.9	287.4	
				6/10/75	190.0	276.3	
				7/11/75	196.3	270.0	
				8/07/75	204.0	262.3	
				9/09/75	207.4	258.9	
01N/13W-19K03 S	19		450.0	10/01/74	221.0	229.0	1200
				11/29/74	212.4	237.6	
				12/31/74	204.9	245.1	
				4/30/75	170.0	280.0	
				5/30/75	177.0	273.0	
				6/30/75	183.0	267.0	
				7/31/75	201.5	248.5	
				8/29/75	196.0	254.0	
				9/30/75	187.9	262.1	
01N/13W-19L02 S	19		461.0	10/01/74	215.0	246.0	1200
				11/29/74	208.0	253.0	
				12/31/74	200.7	260.3	
				1/31/75	193.8	267.2	
				2/28/75	190.0	271.0	
				3/31/75	183.3	277.7	
				4/30/75	181.5	279.5	
				5/30/75	187.0	274.0	
				6/30/75	191.7	269.3	
				7/31/75	201.5	259.5	
				8/29/75	207.8	253.2	
				9/30/75	196.4	264.6	
01N/13W-19M02 S	19		439.1	10/30/74	160.7	278.4	1200
				11/21/74	160.8	278.3	
				12/31/74	161.1	278.0	
				1/24/75	157.9	281.2	
				2/27/75	154.8	284.3	
				3/27/75	151.9	287.2	
				4/24/75	149.9	289.2	
				5/22/75	146.5	292.6	
				6/26/75	147.2	291.9	
				7/24/75	149.3	289.8	
				8/28/75	153.7	285.4	
				9/30/75	142.8	296.3	
01N/13W-20D01 S	19		483.8	11/18/74	161.3	322.5	1101
				5/06/75	NM-9		
01N/13W-20F02 S	19		517.0	11/18/74	196.8	320.2	1101
				5/06/75	NM-9		
01N/13W-20H01 S	19		542.0	11/18/74	208.6	333.4	1101
				5/06/75	206.2	335.8	
01N/13W-20R01 S	19		540.0	11/06/74	NM-0		1101
				1/09/75	NM-7		
01N/13W-21D01 S	19		605.0	10/30/74	253.6	351.4	1200
				11/21/74	253.4	351.6	
				12/31/74	253.6	351.4	
				4/25/75	253.2	351.8	
				5/28/75	253.5	351.5	
				6/26/75	253.5	351.5	
				7/25/75	253.7	351.3	
				8/27/75	254.4	350.6	
				9/26/75	254.5	350.5	
01N/13W-28A01 S	19		589.0	11/18/74	DRY		1101
				4/23/75	DRY		
01N/13W-29L01 S	19		461.0	5/06/75	NM-3		1101
01N/13W-32D01 S	19		415.2	10/24/74	67.2	348.0	1200
				11/20/74	67.3	347.9	
				12/26/74	67.5	347.7	
				4/24/75	67.3	347.9	
				5/21/75	67.2	348.0	
				6/25/75	67.1	348.1	
				7/25/75	67.2	348.0	
				8/27/75	67.2	348.0	
				9/24/75	67.2	348.0	
01N/13W-33N02 S	19		440.5	11/18/74	96.6	343.9	1101
				4/23/75	93.7	346.8	
01N/13W-33N03 S	19		435.2	11/18/74	95.3	339.9	1101
				4/23/75	89.3	345.9	
01N/14W-03F03 S	19		681.0	10/03/74	209.4	471.6	1101
				11/14/74	208.7	472.3	
				12/10/74	207.7	473.3	
				1/02/75	207.2	473.8	
				2/04/75	207.3	473.7	
01N/14W-03F06 S	19		681.0	3/05/75	207.3	473.7	1101
				4/02/75	207.6	473.4	
01N/14W-04N03 S	19		693.0	11/14/74	214.8	478.2	1101

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT SAN FERNANDO HYDRO SUBUNIT SAN FERNANDO HYDRO SUBAREA						U-05 U-05.8 U-05.81	
01N/14W-04N03 S	19		693.0	4/02/75	209.8	483.2	1101
01N/14W-05N01 S	19		707.2	10/31/74	209.5	497.7	1200
				4/28/75	203.4	503.8	
01N/14W-05P01 S	19		707.0	10/31/74	213.5	493.5	1200
				4/28/75	211.3	495.7	
01N/14W-05P02 S	19		708.2	10/31/74	212.7	495.5	1200
				4/28/75	207.4	500.8	
01N/14W-06A02 S	19		730.0	10/17/74	226.0	504.0	1200
				11/14/74	223.6	506.4	
				12/17/74	222.2	507.8	
				4/24/75	219.2	510.8	
				5/20/75	220.7	509.3	
				6/12/75	220.0	510.0	
				7/25/75	232.8	497.2	
				8/21/75	238.8	491.2	
				9/16/75	238.4	491.6	
01N/14W-06F01 S	19		738.0	10/17/74	225.4	512.6	1200
				11/14/74	222.8	515.2	
				12/17/74	220.3	517.7	
				1/16/75	219.6	518.4	
				2/21/75	218.4	519.6	
				3/28/75	219.7	518.3	
				4/24/75	217.7	520.3	
				5/20/75	217.9	520.1	
				6/12/75	218.2	519.8	
				7/25/75	227.7	510.3	
				8/21/75	229.7	508.3	
				9/16/75	235.1	502.9	
01N/14W-06F02 S	19		721.0	11/01/74	208.4	512.6	1200
				4/29/75	204.7	516.3	
01N/14W-06H02 S	19		746.0	10/17/74	237.1	508.9	1200
				11/14/74	235.6	510.4	
				12/17/74	235.2	510.8	
				4/24/75	232.0	514.0	
				5/20/75	232.5	513.5	
				6/12/75	233.1	512.9	
				7/25/75	241.9	504.1	
				8/21/75	246.6	499.4	
				9/16/75	246.4	499.6	
01N/14W-06J02 S	19		713.7	10/31/74	209.6	504.1	1200
				4/28/75	206.2	507.5	
01N/14W-06K07 S	19		714.4	10/31/74	208.6	505.8	1200
01N/14W-06L01 S	19		732.0	11/01/74	216.4	515.6	1200
				4/29/75	212.6	519.4	
01N/14W-06M01 S	19		718.6	11/01/74	208.0	510.6	1200
				4/29/75	199.5	519.1	
01N/14W-06N01 S	19		717.9	10/01/74	203.2	514.7	1200
				4/29/75	199.2	518.7	
01N/14W-06P01 S	19		721.1	11/01/74	208.6	512.5	1200
				4/29/75	204.7	516.4	
01N/14W-06Q01 S	19		714.0	10/31/74	208.5	505.5	1200
01N/14W-06Q02 S	19		712.0	10/31/74	204.5	507.5	1200
				4/28/75	200.9	511.1	
01N/14W-06Q03 S	19		713.3	10/31/74	205.5	507.8	1200
				4/28/75	201.9	511.4	
01N/14W-06R01 S	19		713.3	10/31/74	209.8	503.5	1200
				4/28/75	205.5	507.8	
01N/14W-06R05 S	19		710.0	10/31/74	205.1	504.9	1200
				4/28/75	202.6	507.4	
01N/14W-07A01 S	19		699.0	10/31/74	200.2	498.8	1200
				4/28/75	195.3	503.7	
01N/14W-07G02 S	19		691.6	10/15/74	192.3	499.3	1200
				11/19/74	189.8	501.8	
				12/17/74	189.2	502.4	
				1/07/75	188.1	503.5	
				2/18/75	188.3	503.3	
				3/18/75	187.1	504.5	
				4/22/75	185.3	506.3	
				5/20/75	184.4	507.2	
				6/10/75	184.5	507.1	
				7/01/75	184.2	507.4	
				8/19/75	193.9	497.7	
				9/16/75	197.9	493.7	
01N/14W-07H01 S	19		681.0	11/01/74	182.6	498.4	1200
				4/28/75	177.4	503.6	
01N/14W-07J01 S	19		677.5	11/01/74	181.0	496.5	1200
				4/28/75	176.3	501.2	
01N/14W-07J03 S	19		667.5	11/01/74	175.0	492.5	1200
				4/28/75	169.9	497.6	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT SAN FERNANDO HYDRO SUBUNIT SAN FERNANDO HYDRO SUBAREA						U-05 U-05.B U-05.B1	
01N/14W-08A02 S	19		687.2	10/31/74	206.6	480.6	1200
				4/28/75	200.7	486.5	
01N/14W-08B01 S	19		687.0	10/31/74	205.4	481.6	1200
			690.0	4/28/75	200.2	489.8	
01N/14W-08J01 S	19		665.5	10/31/74	195.0	470.5	1200
				4/28/75	186.7	478.8	
01N/14W-08J03 S	19		656.0	10/31/74	NM-1		1200
				4/28/75	176.5	479.5	
01N/14W-08J04 S	19		665.0	10/31/74	NM-1		1200
				4/28/75	175.2	489.8	
01N/14W-08L01 S	19		669.0	11/01/74	184.9	484.1	1200
				4/28/75	NM-4		
01N/14W-08L02 S	19		668.0	11/01/74	180.9	484.1	1200
				4/28/75	173.7	491.3	
01N/14W-09A03 S	19		661.0	10/07/74	196.6(5)	464.4	1101
				11/04/74	229.5(1)	431.5	
				12/02/74	193.2(5)	467.8	
				1/02/75	189.7(5)	471.3	
				2/01/75	227.7(1)	433.3	
				3/06/75	226.4(1)	434.6	
				4/03/75	193.7(5)	467.3	
				5/01/75	225.7(1)	435.3	
				6/05/75	191.7(5)	469.3	
				7/01/75	192.2(5)	468.8	
				9/01/75	213.2(5)	447.8	
01N/14W-09B04 S	19		662.5	10/07/74	187.4(5)	475.1	1101
				11/04/74	187.7(5)	474.8	
				12/02/74	183.7(5)	478.8	
				1/02/75	180.3(5)	482.2	
				2/01/75	187.6(5)	474.9	
				3/07/75	185.8(5)	476.7	
				5/16/75	180.7(5)	481.8	
				6/05/75	182.7(5)	479.8	
				7/01/75	187.9(5)	474.6	
01N/14W-09E03 S	19		665.0	10/15/74	193.7	471.3	1200
				11/12/74	193.0	472.0	
				12/17/74	191.0	474.0	
				1/07/75	190.9	474.1	
				2/18/75	189.3	475.7	
				3/25/75	188.8	476.2	
				4/22/75	187.1	477.9	
				5/27/75	188.3	476.7	
				6/24/75	187.6	477.4	
				7/29/75	193.3	471.7	
				9/16/75	201.6	463.4	
01N/14W-09G02 S	19		643.0	10/07/74	200.9(1)	442.1	1101
				11/04/74	179.3(5)	463.7	
				12/02/74	175.6(5)	467.4	
				1/02/75	173.7(5)	469.3	
				2/01/75	177.4(5)	465.6	
				3/06/75	177.9(5)	465.1	
				4/03/75	178.0(5)	465.0	
				5/01/75	192.3(1)	450.7	
				6/05/75	177.0(5)	466.0	
				7/01/75	194.3(1)	448.7	
				8/01/75	205.7(1)	437.3	
				9/01/75	218.2(1)	424.8	
01N/14W-09G03 S	19		654.9	12/02/74	NM-0		1101
				4/02/75	185.0(5)	469.9	
				5/01/75	265.8(1)	389.1	
				6/05/75	182.5(5)	472.4	
				7/01/75	184.5(5)	470.4	
				9/15/75	197.4(5)	457.5	
01N/14W-09H01 S	19		646.3	10/07/74	184.5(5)	461.8	1101
				11/04/74	183.9(5)	462.4	
				12/02/74	181.2(5)	465.1	
				1/02/75	178.8(5)	467.5	
				2/01/75	182.5(5)	463.8	
				3/06/75	182.4(5)	463.9	
				4/03/75	196.2(1)	450.1	
				5/15/75	180.5(5)	465.8	
				6/05/75	180.2(5)	466.1	
				9/08/75	192.9(5)	453.4	
01N/14W-09H04 S	19		637.9	10/07/74	251.1(1)	386.8	1101
				11/04/74	179.3(5)	458.6	
				12/02/74	173.8(5)	464.1	
				1/02/75	170.8(5)	467.1	
				2/01/75	248.8(1)	389.1	
				3/13/75	173.8(5)	464.1	
				4/03/75	175.0(5)	462.9	
				5/03/75	253.4(5)	384.5	
				6/05/75	251.5(1)	386.4	
				7/01/75	261.4(1)	376.5	
				8/01/75	275.6(1)	362.3	
				9/08/75	192.3(5)	445.6	
01N/14W-09J01 S	19		628.0	11/13/74	DRY		1101
				5/06/75	DRY		
LA-SAN GABRIEL RIVER HYDRO UNIT SAN FERNANDO HYDRO SUBUNIT SAN FERNANDO HYDRO SUBAREA						U-05 U-05.B U-05.B1	
01N/14W-09K02 S	19		631.0	10/07/74	171.1(5)	459.9	1101
				11/04/74	173.0(5)	458.0	
				12/02/74	167.8(5)	463.2	
				1/02/75	163.1(5)	467.9	
				2/01/75	169.9(5)	461.1	
				3/06/75	168.0(5)	463.0	
				4/09/75	165.1(5)	465.9	
				5/01/75	167.2(5)	463.8	
				6/05/75	169.7(5)	461.3	
				7/01/75	170.5(5)	460.5	
				8/01/75	184.5(5)	446.5	
				9/01/75	188.3(5)	442.7	
01N/14W-09L04 S	19		650.5	10/07/74	184.5(5)	466.0	1101
				11/04/74	184.9(5)	465.6	
				12/02/74	177.2(5)	473.3	
				1/02/75	175.8(5)	474.7	
				2/01/75	185.8(5)	464.7	
				3/06/75	178.8(5)	471.7	
				4/02/75	180.4(5)	470.1	
				6/05/75	180.4(5)	470.1	
				9/08/75	180.3(5)	470.2	
01N/14W-09Q01 S	19		637.1	10/07/74	186.1(5)	451.0	1101
				11/04/74	165.1(5)	472.0	
				12/02/74	165.3(5)	471.8	
				1/02/75	161.3(5)	475.8	
				2/13/75	162.8(5)	474.3	
				3/06/75	169.6(5)	467.5	
				4/03/75	207.0(1)	430.1	
				5/01/75	164.9(5)	472.2	
				6/05/75	166.1(5)	471.0	
				7/01/75	173.2(5)	463.9	
				8/11/75	189.6(5)	447.5	
				9/01/75	195.1(5)	442.0	
01N/14W-11Q01 S	19		555.3	10/07/74	117.2(5)	438.1	1101
				11/04/74	116.1(5)	439.2	
				12/02/74	115.4(5)	439.9	
				1/02/75	116.2(5)	439.1	
				2/06/75	107.4(5)	447.9	
				3/06/75	107.2(5)	448.1	
				4/03/75	107.2(5)	448.1	
				5/01/75	106.8(5)	448.5	
				6/05/75	105.1(5)	450.2	
				7/01/75	145.8(1)	409.5	
				8/01/75	152.2(1)	403.1	
				9/01/75	156.1(1)	399.2	
01N/14W-12M02 S	19		620.2	11/18/74	189.6	430.6	1101
				5/12/75	NM-9		
01N/14W-13B02 S	19		483.8	1/21/75	246.7(5)	237.1	1101
				3/11/75	238.7(5)	245.1	
				4/01/75	236.7(1)	247.1	
				5/06/75	234.7(1)	249.1	
				6/03/75	244.7(1)	239.1	
				7/08/75	246.7(1)	237.1	
				8/05/75	244.7(1)	239.1	
				9/02/75	260.7(1)	223.1	
01N/14W-13P01 S	19		488.6	10/01/74	264.6(1)	224.0	1101
				11/05/74	260.6(1)	228.0	
				1/21/75	245.5(5)	243.1	
				3/11/75	240.5(5)	248.1	
				4/08/75	239.5(1)	249.1	
				5/06/75	238.5(1)	250.1	
				6/03/75	244.5(1)	244.1	
				7/08/75	245.5(1)	243.1	
				8/05/75	245.5(1)	243.1	
				9/02/75	258.5(1)	230.1	
01N/14W-14R08 S	19		557.7	10/07/74	110.1(5)	447.6	1101
				11/04/74	110.4(5)	447.3	
				12/02/74	108.9(5)	448.8	
				1/02/75	107.9(5)	449.8	
				2/06/75	108.8(5)	448.9	
				3/06/75	107.8(5)	449.9	
				4/03/75	107.6(5)	450.1	
				5/01/75	107.4(5)	450.3	
				6/05/75	106.7(5)	451.0	
				7/01/75	161.8(1)	395.9	
				8/01/75	169.7(1)	388.0	
				9/08/75	114.9(5)	442.8	
01N/14W-14F05 S	19		546.5	10/03/74	108.4	438.1	1101
				11/14/74	107.7	438.8	
				12/10/74	107.8	438.7	
				1/02/75	106.0	440.5	
				2/04/75	106.5	440.0	
				3/05/75	106.7	439.8	
				4/02/75	106.1	440.4	
				5/12/75	106.3	440.2	
				6/05/75	105.0	441.5	
				7/02/75	109.0	437.5	
				9/04/75	115.6	430.9	
01N/14W-15P02 S	19		551.9	10/01/74	176.5	377.4	1200
				11/19/74	172.0	381.9	
				12/17/74	173.6	380.3	
				1/07/75	172.7	381.2	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT SAN FERNANDO HYDRO SUBUNIT SAN FERNANDO HYDRO SUBAREA						U-05 U-05.8 U-05.81	
01N/14W-15P02 S (CONTINUED)	19		553.9	2/04/75	171.4	382.5	1200
				3/25/75	170.1	383.8	
				4/01/75	171.2	382.7	
				5/27/75	169.0	384.9	
				6/10/75	167.2	386.7	
				7/15/75	171.5	382.4	
				8/19/75	174.4	379.5	
				9/16/75	177.0	376.9	
01N/14W-16D01 S	19		625.0	11/01/74	DRY		1200
				4/30/75	DRY		
01N/14W-16E01 S	19		616.0	10/31/74	182.8	433.2	1200
				4/28/75	176.1	439.9	
01N/14W-16P04 S	19		593.0	11/01/74	DRY		1200
				4/30/75	DRY		
01N/14W-18L02 S	19		641.9	10/17/74	143.1	498.8	1200
				11/14/74	142.7	499.2	
				12/17/74	142.5	499.4	
				4/24/75	140.8	501.1	
				5/20/75	140.6	501.3	
				6/12/75	140.8	501.1	
				7/22/75	142.2	499.7	
				8/19/75	144.1	497.8	
				9/16/75	145.6	496.3	
01N/14W-19A05 S	19		611.1	10/17/74	105.9	505.2	1200
				4/25/75	104.5	506.6	
01N/14W-19R03 S	19		627.8	10/17/74	128.7	499.1	1200
				11/14/74	127.5	500.3	
				12/17/74	127.5	500.3	
				4/24/75	126.5	501.3	
				5/20/75	126.2	501.6	
				6/12/75	126.3	501.5	
				7/22/75	126.8	501.0	
				8/19/75	128.0	499.8	
				9/16/75	129.0	498.8	
01N/14W-19D01 S	19		639.1	10/17/74	126.0	513.1	1200
				4/25/75	123.3	515.8	
01N/14W-20F02 S	19		594.1	10/15/74	156.9	437.2	1200
				11/12/74	155.9	438.2	
				12/17/74	156.2	437.9	
				1/14/75	156.0	438.1	
				2/18/75	156.6	437.5	
				3/18/75	156.0	438.1	
				4/29/75	153.9	440.2	
				5/27/75	153.5	440.6	
				6/17/75	153.6	440.5	
				7/15/75	154.7	439.4	
				8/19/75	157.1	437.0	
				9/16/75	158.1	436.0	
01N/14W-22H03 S	19		535.6	11/14/74	178.8	356.8	1101
				5/06/75	177.9	357.7	
01N/14W-23J05 S	19		503.0	10/30/74	67.4	435.6	1200
				11/21/74	66.5	436.5	
				12/31/74	65.3	437.7	
				1/24/75	64.6	438.4	
				2/21/75	65.0	438.0	
				3/26/75	66.1	436.9	
				4/24/75	66.1	436.9	
				5/22/75	65.4	437.6	
				6/25/75	65.8	437.2	
				7/24/75	66.5	436.5	
				8/28/75	67.9	435.1	
				9/30/75	67.1	435.9	
01N/14W-23L01 S	19		487.6	10/08/74	101.0	386.6	1200
				11/12/74	103.9	383.7	
				12/17/74	DRY		
				4/15/75	DRY		
				5/27/75	DRY		
				6/03/75	DRY		
				7/24/75	100.2	387.4	
				8/19/75	DRY		
				9/30/75	DRY		
01N/14W-23M02 S	19		512.0	10/30/74	163.3	348.7	1200
				11/21/74	162.9	349.1	
				12/31/74	161.0	351.0	
				1/29/75	167.6	344.4	
				2/21/75	169.0	343.0	
				3/26/75	169.0	343.0	
				5/22/75	184.6	327.4	
				6/25/75	157.7	354.3	
				7/24/75	159.1	352.9	
				8/28/75	152.8	359.2	
				9/30/75	168.2	343.8	
01N/14W-24D05 S	19		480.0	10/30/74	NM-1		1200
				11/21/74	NM-1		
				12/31/74	NM-3		
				1/24/75	NM-1		
				2/21/75	NM-1		
				3/26/75	NM-1		
				4/24/75	NM-1		

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT SAN FERNANDO HYDRO SUBUNIT SAN FERNANDO HYDRO SUBAREA						U-05 U-05.8 U-05.81	
01N/14W-24D05 S (CONTINUED)	19		480.0	5/22/75	NM-1		1200
				6/25/75	NM-1		
				7/24/75	NM-1		
				8/29/75	NM-1		
				9/30/75	NM-1		
01N/14W-24E07 S	19		476.7	10/15/74	209.7	267.0	1200
				11/12/74	208.0	268.7	
				12/17/74	201.0	275.7	
				1/07/75	195.2	281.5	
				2/04/75	191.9	284.8	
				3/11/75	194.2	282.5	
				4/01/75	194.4	282.3	
				5/20/75	193.2	283.5	
				6/17/75	193.9	282.8	
				7/15/75	196.8	279.9	
				8/19/75	202.0	274.7	
				9/16/75	203.2	273.5	
01N/14W-24H01 S	19		461.0	10/15/74	214.6	246.4	1200
				11/12/74	211.1	249.9	
				12/17/74	199.5	261.5	
				1/28/75	190.6	270.4	
				2/18/75	187.0	274.0	
				3/18/75	185.1	275.9	
				4/01/75	183.4	277.6	
				5/20/75	186.9	274.1	
				6/17/75	192.6	268.4	
				7/15/75	199.0	262.0	
				8/19/75	207.5	253.5	
				9/16/75	200.8	260.2	
01N/14W-24H02 S	19		464.0	10/01/74	216.5	247.5	1200
				11/29/74	205.5	258.5	
				12/31/74	201.4	262.6	
				1/31/75	190.3	273.7	
				2/28/75	188.5	275.5	
				3/31/75	185.0	279.0	
				4/30/75	183.7	280.3	
				5/30/75	190.8	273.2	
				6/30/75	198.6	265.4	
				7/31/75	203.1	260.9	
				8/29/75	208.4	255.6	
				9/30/75	197.8	266.2	
01N/14W-24H03 S	19		462.0	10/01/74	209.9	252.1	1200
				11/29/74	204.3	257.7	
				12/31/74	199.3	262.7	
				4/30/75	NM-1		
				5/30/75	NM-1		
				6/30/75	192.2	269.8	
				7/31/75	201.8	260.2	
				8/29/75	207.0	255.0	
				9/30/75	198.4	263.6	
01N/14W-27F02 S	19		525.8	11/01/74	36.4	489.4	1200
				4/30/75	NM-6		
01N/14W-28R01 S	19		544.3	10/30/74	NM-7		1200
				11/21/74	NM-4		
				12/31/74	NM-9		
				1/30/75	NM-1		
				2/27/75	NM-1		
				3/26/75	NM-1		
				4/24/75	NM-1		
				5/22/75	NM-1		
				6/25/75	NM-1		
				7/25/75	NM-1		
				8/28/75	NM-1		
				9/30/75	NM-1		
01N/14W-28R01 S	19		768.0	11/08/74	101.3	666.7	1101
01N/15W-01K01 S	19		725.6	11/01/74	199.3	526.3	1200
				4/29/75	199.2	526.4	
01N/15W-01K02 S	19		730.0	11/01/74	203.6	526.4	1200
				4/29/75	204.4	525.6	
01N/15W-01P04 S	19		719.8	1/30/75	NM-0		1200
				4/02/75	NM-7		
01N/15W-01Q02 S	19		721.2	10/01/74	197.1	524.1	1200
				4/29/75	195.5	525.7	
01N/15W-01Q03 S	19		720.0	11/01/74	199.5	520.5	1200
				4/29/75	196.7	523.3	
01N/15W-01Q04 S	19		719.9	10/01/74	198.1	521.8	1200
				4/29/75	196.5	523.4	
01N/15W-02J01 S	19		724.8	4/28/75	187.9	536.9	1200
01N/15W-02K01 S	19		715.3	10/31/74	174.7	540.6	1200
				4/28/75	174.3	541.0	
01N/15W-02R01 S	19		723.9	10/31/74	188.6	535.3	1200
				4/28/75	187.8	536.1	
01N/15W-04P01 S	19		729.4	10/17/74	163.7	565.9	1200
				11/14/74	163.6	566.0	
				12/20/74	163.2	566.4	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT						U-05	
SAN FERNANDO HYDRO SUBUNIT						U-05.8	
SAN FERNANDO HYDRO SUBAREA						U-05.81	
01N/15W-04P01 S (CONTINUED)	19		729.6	4/23/75	163.8	565.8	1200
				5/23/75	163.7	565.9	
				6/12/75	164.3	565.3	
				7/18/75	163.8	565.8	
				8/29/75	164.7	564.9	
				9/25/75	165.9	563.7	
01N/15W-06N01 S	19		743.0	10/16/74	139.3	603.7	1200
				11/20/74	139.7	603.3	
				12/18/74	139.8	603.2	
				4/16/75	140.6	602.4	
				5/15/75	140.8	602.2	
				6/12/75	140.9	602.1	
				7/17/75	140.9	602.1	
				8/21/75	140.9	602.1	
				9/17/75	141.0	602.0	
01N/15W-07E01 S	19		724.8	10/16/74	97.4	627.4	1200
				11/20/74	97.7	627.1	
				12/18/74	97.8	627.0	
				4/16/75	98.3	626.5	
				6/12/75	98.3	626.5	
				7/17/75	98.3	626.5	
				8/21/75	98.6	626.2	
				9/17/75	99.1	625.7	
01N/15W-07F02 S	19		718.0	10/24/74	106.3	611.7	1200
				4/16/75	106.9	611.1	
01N/15W-08R01 S	19		700.4	10/17/74	119.4	581.0	1200
				11/14/74	119.5	580.9	
				12/20/74	119.5	580.9	
				1/16/75	119.4	581.0	
				2/20/75	119.8	580.6	
				3/28/75	119.9	580.5	
				4/23/75	119.9	580.5	
				5/23/75	119.9	580.5	
				6/12/75	119.8	580.6	
				7/18/75	121.0	579.4	
				8/29/75	120.5	579.9	
				9/25/75	120.8	579.6	
01N/15W-09R02 S	19		689.8	10/17/74	17.0(6)	672.8	1200
				4/25/75	41.0(6)	648.8	
01N/15W-10H02 S	19		707.2	10/17/74	165.6	541.6	1200
				11/24/74	165.5	541.7	
				12/20/74	164.2	543.0	
				1/16/75	164.0	543.2	
				2/20/75	163.9	543.3	
				3/28/75	163.9	543.3	
				4/23/75	163.8	543.4	
				5/23/75	163.6	543.6	
				6/12/75	163.4	543.8	
				7/25/75	166.8	540.4	
				8/27/75	166.2	541.0	
				9/25/75	168.3	538.9	
01N/15W-11P04 S	19		673.7	10/03/74	145.1	528.6	1101
				11/13/74	144.7	529.0	
				4/02/75	144.5	529.2	
01N/15W-14F01 S	19		687.6	10/17/74	142.2	545.4	1200
				4/25/75	141.3	546.3	
01N/15W-14J01 S	19		668.1	10/15/74	134.1	534.0	1200
				11/19/74	134.0	534.1	
				12/17/74	133.6	534.5	
				4/01/75	132.6	535.5	
				5/13/75	132.7	535.4	
				6/17/75	131.7	536.4	
				7/15/75	134.3	533.8	
				8/19/75	136.1	532.0	
				9/16/75	137.6	530.5	
01N/15W-15A02 S	19		679.3	10/17/74	134.8	544.5	1200
				11/14/74	134.8	544.5	
				12/20/74	134.4	544.9	
				4/23/75	133.8	545.5	
				5/23/75	133.6	545.7	
				6/12/75	133.2	546.1	
				7/25/75	135.3	544.0	
				8/27/75	136.9	542.4	
				9/25/75	138.9	540.4	
01N/15W-15J02 S	19		667.1	10/17/74	118.0	549.1	1200
				4/25/75	117.3	549.8	
01N/15W-16H04 S	19		678.2	10/17/74	114.7	563.5	1200
				4/25/75	114.7	563.5	
01N/15W-17N02 S	19		688.0	11/14/74	9.7	678.3	1101
				4/11/75	8.9	679.1	
01N/15W-18N01 S	19		717.1	10/16/74	10.8	706.3	1200
				11/20/74	11.0	706.1	
				12/18/74	11.3	705.8	
				4/16/75	10.3	706.8	
				5/15/75	10.5	706.6	
				6/12/75	10.4	706.7	
				7/17/75	10.7	706.4	
				8/21/75	10.8	706.3	
LA-SAN GABRIEL RIVER HYDRO UNIT						U-05	
SAN FERNANDO HYDRO SUBUNIT						U-05.8	
SAN FERNANDO HYDRO SUBAREA						U-05.81	
01N/15W-18N01 S	19		717.1	9/19/75	10.8	706.3	1200
01N/15W-21A02 S	19		659.3	10/17/74	86.3	573.0	1200
				11/14/74	86.6	572.7	
				12/20/74	86.5	572.8	
				4/23/75	86.5	572.8	
				6/12/75	86.4	572.9	
				7/25/75	86.6	572.7	
				8/29/75	87.3	572.0	
				9/25/75	87.9	571.4	
01N/15W-23A01 S	19		652.4	10/17/74	118.9	533.5	1200
				4/25/75	116.0	536.4	
01N/15W-23D01 S	19		651.9	10/03/74	100.2	551.7	1101
				11/13/74	99.5	552.4	
				4/02/75	99.3	552.6	
01N/15W-23J01 S	19		631.8	10/17/74	DRY (6)		1200
				4/25/75	14.7	617.1	
01N/15W-23J02 S	19		632.0	10/17/74	46.0	586.0	1200
				4/25/75	45.7	586.3	
01N/15W-23P01 S	19		629.0	11/13/74	NM-4		1101
01N/15W-28R02 S	19		700.0	11/13/74	NM-4		1101
				4/02/75	12.2	687.8	
01N/15W-28C03 S	19		705.0	11/14/74	6.9	698.1	1101
				4/02/75	7.3	697.7	
01N/16W-02D01 S	19		728.4	10/02/74	26.8	701.6	1101
				11/14/74	26.9	701.5	
				12/03/74	26.9	701.5	
				1/07/75	26.8	701.6	
				2/11/75	26.7	701.7	
				3/11/75	26.4	702.0	
				4/11/75	26.3	702.1	
				5/13/75	26.3	702.1	
				6/10/75	26.2	702.2	
				7/09/75	26.3	702.1	
				8/07/75	26.9	701.5	
				9/08/75	26.9	701.5	
01N/16W-03R01 S	19		739.1	10/02/74	13.4	725.7	1101
				11/14/74	13.5	725.6	
				4/11/75	11.5	727.6	
01N/16W-03D01 S	19		753.0	10/18/74	8.1	744.9	1200
				11/20/74	8.0	745.0	
				12/18/74	7.4	745.6	
				4/23/75	5.6	747.4	
				5/15/75	5.9	747.1	
				6/19/75	6.4	746.6	
				7/22/75	7.1	745.9	
				8/26/75	7.2	745.8	
				9/17/75	7.9	745.1	
01N/16W-03E01 S	19		746.0	10/16/74	12.0	734.0	1200
				12/18/74	11.5	734.5	
				4/23/75	9.8	736.2	
				5/15/75	9.8	736.2	
				6/19/75	10.0	736.0	
				7/17/75	10.5	735.5	
				8/27/75	11.1	734.9	
				9/18/75	11.5	734.5	
01N/16W-03G02 S	19		735.8	11/14/74	20.2	715.6	1101
				4/11/75	19.2	716.6	
01N/16W-03G03 S	19		738.7	11/14/74	14.0	724.7	1101
01N/16W-03G04 S	19		742.9	10/16/74	17.3	725.6	1200
				11/20/74	17.2	725.7	
				12/18/74	16.9	726.0	
				4/16/75	15.7	727.2	
				5/15/75	15.2	727.7	
				6/19/75	15.8	727.1	
				7/17/75	16.2	726.7	
				8/26/75	16.7	726.2	
				9/17/75	16.7	726.2	
01N/16W-03H03 S	19		737.5	10/16/74	26.4	711.1	1200
				11/20/74	26.6	710.9	
				12/18/74	26.4	711.1	
				4/16/75	25.5	712.0	
				5/15/75	25.4	712.1	
				6/19/75	25.4	712.1	
				7/17/75	25.6	711.9	
				8/26/75	25.9	711.6	
				9/17/75	26.1	711.4	
01N/16W-03P01 S	19		732.1	10/16/74	29.9	702.2	1200
				11/20/74	29.8	702.3	
				12/18/74	29.7	702.4	
				1/15/75	29.5	702.6	
				2/20/75	29.3	702.8	
				3/19/75	29.1	703.0	
				4/16/75	28.7	703.4	
				5/15/75	28.5	703.6	
				6/16/75	28.5	703.6	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT						U-05	
SAN FERNANDO HYDRO SUBUNIT						U-05.8	
SAN FERNANDO HYDRO SUBAREA						U-05.81	
01N/16W-03R01 S (CONTINUED)	19		732.1	7/17/75	28.9	703.2	1200
				8/26/75	29.3	702.8	
				9/17/75	29.5	702.6	
01N/16W-04D01 S	19		771.0	10/18/74	DRY		1200
				11/20/74	DRY		
				12/18/74	DRY		
				4/23/75	DRY		
				5/16/75	DRY		
				6/19/75	DRY		
				7/24/75	DRY		
				8/27/75	DRY		
				9/18/75	DRY		
01N/16W-04E01 S	19		778.0	10/18/74	DRY		1200
				11/20/74	DRY		
				12/19/74	DRY		
				5/16/75	DRY		
				7/22/75	DRY		
				9/18/75	DRY		
01N/16W-04F02 S	19		766.0	10/18/74	DRY		1200
				11/20/74	DRY		
				12/18/74	10.7	755.3	
				4/23/75	DRY		
				5/16/75	DRY		
				6/19/75	DRY		
				7/24/75	DRY		
				8/27/75	DRY		
				9/18/75	DRY		
01N/16W-04F01 S	19		757.2	10/12/74	DRY		1200
				11/18/74	DRY		
				12/20/74	DRY		
				4/23/75	8.1	749.1	
				5/15/75	7.2	750.0	
				6/19/75	8.4	748.8	
				7/24/75	DRY		
				8/27/75	DRY		
				9/18/75	DRY		
01N/16W-04G01 S	19		757.0	11/14/74	14.8	742.2	1101
				4/14/75	14.0	743.0	
01N/16W-04K01 S	19		752.0	10/16/74	13.0	739.0	1200
				11/20/74	12.7	739.3	
				12/18/74	12.7	739.3	
				4/23/75	11.9	740.1	
				5/15/75	11.8	740.2	
				6/19/75	11.6	740.4	
				7/17/75	11.6	740.4	
				8/27/75	11.6	740.4	
				9/18/75	12.9	739.1	
01N/16W-04M01 S	19		761.5	10/16/74	15.5	746.0	1200
				11/20/74	15.4	746.1	
				12/18/74	15.1	746.4	
				4/23/75	13.1	748.4	
				5/15/75	13.1	748.4	
				6/19/75	13.5	748.0	
				7/17/75	14.1	747.4	
				8/27/75	15.0	746.5	
				9/18/75	15.6	745.9	
01N/16W-04Q01 S	19		747.0	11/14/74	16.7	730.3	1101
				4/14/75	16.2	730.8	
01N/16W-04R01 S	19		741.0	10/16/74	16.5	724.5	1200
				11/20/74	16.5	724.5	
				12/18/74	16.3	724.7	
				1/15/75	16.1	724.9	
				2/20/75	15.7	725.3	
				3/19/75	14.9	726.1	
				4/23/75	14.7	726.3	
				5/15/75	14.7	726.3	
				6/19/75	15.0	726.0	
				7/17/75	15.3	725.7	
				8/27/75	15.9	725.1	
				9/18/75	16.4	724.6	
01N/16W-05D01 S	19		790.0	10/16/74	DRY		1200
				11/20/74	DRY		
				12/19/74	DRY		
				5/16/75	DRY		
				7/21/75	DRY		
				9/18/75	DRY		
01N/16W-05F02 S	19		777.2	10/16/74	DRY		1200
				11/20/74	DRY		
				12/18/74	DRY		
				5/16/75	DRY		
				7/21/75	DRY		
				9/18/75	DRY		
01N/16W-05F05 S	19		779.8	10/16/74	15.0	764.8	1200
				11/20/74	14.7	765.1	
				12/18/74	14.5	765.3	
				4/23/75	13.4	766.4	
				5/16/75	13.4	766.4	
				6/19/75	13.6	766.2	
				7/22/75	15.9	763.9	
				8/27/75	14.6	765.2	

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT						U-05	
SAN FERNANDO HYDRO SUBUNIT						U-05.8	
SAN FERNANDO HYDRO SUBAREA						U-05.81	
01N/16W-05F05 S	19		779.8	9/18/75	14.7	765.1	1200
01N/16W-05F07 S	19		775.0	11/14/74	15.7	759.3	1101
				4/14/75	15.6	759.4	
01N/16W-05K01 S	19		772.0	10/16/74	20.3	751.7	1200
				11/20/74	20.2	751.8	
				12/18/74	20.2	751.8	
				4/23/75	18.5	753.5	
				5/16/75	18.5	753.5	
				6/19/75	18.8	753.2	
				7/17/75	19.0	753.0	
				8/27/75	20.1	751.9	
				9/18/75	20.2	751.8	
01N/16W-05M01 S	19		780.0	10/16/74	17.4	762.6	1200
				11/20/74	17.1	762.9	
				12/19/74	16.6	763.4	
				4/23/75	15.5	764.5	
				5/16/75	15.7	764.3	
				6/19/75	15.9	764.1	
				7/17/75	16.4	763.6	
				8/27/75	17.3	762.7	
				9/18/75	17.5	762.5	
01N/16W-05Q02 S	19		768.0	10/23/74	18.1	749.9	1200
				4/23/75	16.8	751.2	
01N/16W-06G02 S	19		791.6	10/16/74	22.9	768.7	1200
				11/20/74	22.9	768.7	
				12/19/74	22.9	768.7	
				1/15/75	22.8	768.8	
				2/19/75	22.7	768.9	
				3/19/75	22.5	769.1	
				4/23/75	22.4	769.2	
				5/16/75	22.3	769.3	
				6/19/75	22.5	769.1	
				7/17/75	22.3	769.3	
				8/27/75	23.0	768.6	
				9/18/75	23.2	768.4	
01N/16W-08R02 S	19		768.0	11/14/74	12.7	755.3	1101
				4/14/75	12.4	755.6	
01N/16W-09Q01 S	19		757.0	10/16/74	18.0	739.0	1200
				11/20/74	18.0	739.0	
				12/18/74	17.8	739.2	
				4/23/75	16.9	740.1	
				5/15/75	17.0	740.0	
				6/19/75	17.2	739.8	
				7/17/75	17.6	739.4	
				8/27/75	18.0	739.0	
				9/18/75	18.2	738.8	
01N/16W-12L02 S	19		717.1	10/02/74	29.9	687.2	1101
				11/14/74	30.1	687.0	
				4/11/75	29.6	687.5	
01N/16W-14F02 S	19		778.4	12/10/74	79.9	698.5	1101
				1/09/75	82.6	695.8	
				2/11/75	82.8	695.6	
				3/11/75	82.7	695.7	
				4/11/75	82.9	695.5	
				5/13/75	83.0	695.4	
				6/10/75	82.8	695.6	
				7/09/75	82.6	695.8	
				8/07/75	83.2	695.2	
				9/08/75	82.7	695.7	
01N/16W-15K01 S	19		813.0	10/16/74	26.4	786.6	1200
				11/20/74	26.6	786.4	
				12/18/74	26.7	786.3	
				4/23/75	26.4	786.6	
				5/15/75	26.6	786.4	
				6/16/75	26.4	786.6	
				7/17/75	26.5	786.5	
				8/19/75	26.7	786.3	
				9/19/75	26.9	786.1	
01N/16W-15N02 S	19		860.0	11/14/74	19.1	840.9	1101
				4/11/75	18.0	842.0	
01N/16W-16G05 S	19		788.5	10/16/74	14.1	774.4	1200
				11/20/74	14.1	774.4	
				12/19/74	14.1	774.4	
				4/23/75	13.4	775.1	
				6/19/75	13.6	774.9	
				7/17/75	14.1	774.4	
				8/27/75	14.7	773.8	
				9/18/75	14.9	773.6	
01N/16W-18F01 S	19		867.0	10/16/74	13.4	853.6	1200
				11/20/74	NM-9		
				12/19/74	13.5	853.5	
				4/23/75	14.4	852.6	
				5/16/75	13.5	853.5	
				6/19/75	13.7	853.3	
				7/17/75	NM-9		
				8/19/75	14.0	853.0	
				9/19/75	14.2	852.8	
01N/17W-01G02 S	19		801.9	11/14/74	15.3	786.6	1101

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT SAN FERNANDO HYDRO SUBUNIT SAN FERNANDO HYDRO SUBAREA						U-05 U-05.8 U-05.81	
01N/17W-01G02 S	19		801.9	4/14/75	14.8	787.1	1101
01N/17W-01J02 S	19		798.0	10/02/74	NM-9		1101
				11/14/74	NM-6		
01N/17W-03N03 S	19		898.0	11/14/74	47.5	850.5	1101
				4/14/75	42.8	855.2	
01N/17W-03P01 S	19		870.0	11/14/74	26.8	843.2	1101
				4/14/75	26.4	843.6	
01N/17W-11F06 S	19		842.0	11/14/74	27.1	814.9	1101
				4/14/75	27.0	815.0	
01N/17W-11G04 S	19		833.0	11/14/74	25.7	807.3	1101
				4/14/75	27.3	805.7	
01N/17W-12N01 S	19		844.6	10/16/74	31.1	813.5	1200
				11/20/74	30.6	814.0	
				12/19/74	30.6	814.0	
				4/23/75	30.3	814.3	
				5/16/75	30.2	814.4	
				6/19/75	30.3	814.3	
				7/17/75	30.6	814.0	
				8/19/75	NM-9		
				9/19/75	NM-5		
02N/14W-18J02 S	19		930.2	11/06/74	59.3	870.9	1101
				2/06/75	57.6(6)	872.6	
				4/03/75	59.6(6)	870.6	
02N/14W-18N01 S	19		940.0	10/02/74	DRY		1101
				11/06/74	184.3	755.7	
				12/03/74	193.2	746.8	
				1/02/75	211.8	728.2	
				2/04/75	DRY		
				3/03/75	DRY		
				4/01/75	184.3	755.7	
				5/01/75	155.7	784.3	
				6/03/75	189.8	750.2	
				7/01/75	205.9	734.1	
				8/01/75	216.0	724.0	
				9/04/75	DRY		
02N/14W-18N06 S	19		940.0	10/02/74	DRY		1101
				11/06/74	63.1	876.9	
				12/03/74	100.0	840.0	
				1/02/75	116.2	823.8	
				2/04/75	DRY		
				3/03/75	DRY		
				4/01/75	77.0	863.0	
				5/01/75	60.7	879.3	
				6/03/75	109.5	830.5	
				7/01/75	DRY		
				8/01/75	DRY		
				9/04/75	DRY		
02N/14W-19H01 S	19		768.0	10/22/74	79.2	688.8	1200
				11/15/74	77.3	690.7	
				12/10/74	77.8	690.2	
				1/14/75	79.5	688.5	
				2/21/75	84.0	684.0	
				3/28/75	87.6	680.4	
				4/08/75	86.6	681.4	
				5/06/75	80.3	687.7	
				6/03/75	75.1	692.9	
				7/01/75	75.9	692.1	
				8/05/75	79.9	688.1	
				9/02/75	83.8	684.2	
02N/14W-19H02 S	19		906.0	10/22/74	244.7	661.3	1200
				11/15/74	237.9	668.1	
				12/20/74	235.6	670.4	
				1/17/75	234.2	671.8	
				2/21/75	243.4	662.6	
				3/28/75	245.3	660.7	
				4/24/75	240.2	665.8	
				5/23/75	225.8	680.2	
				6/13/75	228.5	677.5	
				7/25/75	235.8	670.2	
				8/27/75	243.6	662.4	
				9/16/75	243.2	662.8	
02N/14W-22P01 S	19		1062.2	1/30/75	NM-0		1200
02N/14W-29H01 S	19		854.8	10/02/74	240.1	614.7	1101
				11/06/74	239.9	614.9	
				12/03/74	239.9	614.9	
				1/02/75	240.3	614.5	
02N/14W-29H02 S	19		854.8	11/06/74	DRY		1101
				12/03/74	DRY		
				1/02/75	DRY		
				2/04/75	238.8	616.0	
				3/03/75	241.4	613.4	
				4/03/75	245.8	609.0	
02N/14W-30A01 S	19		890.0	11/12/74	240.2	649.8	1101
				4/03/75	247.7	642.3	
02N/14W-30A03 S	19		871.5	11/12/74	235.9	635.6	1101
				4/03/75	238.0	633.5	
LA-SAN GABRIEL RIVER HYDRO UNIT SAN FERNANDO HYDRO SUBUNIT SAN FERNANDO HYDRO SUBAREA						U-05 U-05.8 U-05.81	
02N/15W-02J01 S	19		1105.0	11/07/74	DRY		1101
				4/10/75	DRY		
02N/15W-03D01 S	19		1111.2	10/02/74	68.3	1042.9	1101
				11/07/74	68.0	1043.2	
				4/10/75	68.5	1042.7	
02N/15W-04A01 S	19		1046.8	10/02/74	17.6	1029.2	1101
				11/07/74	17.7	1029.1	
02N/15W-04J01 S	19		1046.8	4/10/75	17.7	1029.1	1101
02N/15W-07A02 S	19			7/09/75	134.4	837.6	1101
				8/07/75	135.8	836.2	
				9/08/75	136.7	835.3	
02N/15W-08H01 S	19		957.0	10/18/74	253.6	703.4	1200
				11/14/74	253.5	703.5	
				12/20/74	253.5	703.5	
				4/24/75	253.4	703.6	
				5/22/75	253.4	703.6	
				6/12/75	253.3	703.7	
				7/18/75	253.3	703.7	
				8/27/75	253.6	703.4	
				9/25/75	253.8	703.2	
02N/15W-09G02 S	19		1001.0	10/02/74	318.3	682.7	1101
				11/07/74	318.5	682.5	
				4/10/75	319.1	681.9	
02N/15W-10A01 S	19		1051.1	10/02/74	76.0	975.1	1101
				11/07/74	75.7	975.4	
				4/10/75	75.1	976.0	
02N/15W-12R01 S	19		1103.0	10/18/74	120.0	983.0	1200
				11/15/74	119.9	983.1	
				12/19/74	119.9	983.1	
02N/15W-12R02 S	19		1103.0	4/23/75	120.0	983.0	1200
				5/22/75	120.1	982.9	
				6/13/75	130.2	972.8	
				7/24/75	120.3	982.7	
				8/27/75	120.3	982.7	
				9/17/75	120.4	982.6	
02N/15W-15L02 S	19		937.1	11/07/74	366.9	570.2	1101
				2/06/75	367.5	569.6	
				4/10/75	280.2	656.9	
02N/15W-16J05 S	19		918.2	10/02/74	239.2	679.0	1101
				11/07/74	239.5	678.7	
				12/03/74	239.5	678.7	
				1/02/75	240.0	678.2	
				2/04/75	239.5	678.7	
				3/03/75	240.1	678.1	
				4/10/75	238.6	679.6	
				5/01/75	234.7	683.5	
				6/03/75	238.5	679.7	
				7/02/75	235.6	682.6	
				8/01/75	237.0	681.2	
				9/04/75	238.6	679.6	
02N/15W-16R01 S	19		902.0	10/02/74	269.9	632.1	1101
				11/07/74	271.9	630.1	
				12/03/74	273.7	628.3	
				1/02/75	274.1	627.9	
				2/04/75	279.2	622.8	
				3/03/75	280.7	621.3	
				4/10/75	141.4	760.6	
				5/01/75	141.5	760.5	
				6/03/75	141.8	760.2	
				7/02/75	197.1	704.9	
				8/01/75	243.7	658.3	
				9/04/75	251.7	650.3	
02N/15W-18D01 S	19		943.8	10/15/74	233.4	709.6	1200
				11/21/74	233.6	709.4	
				12/19/74	233.1	709.9	
				1/14/75	233.6	709.4	
				2/19/75	233.8	709.2	
				3/20/75	234.0	709.0	
				4/16/75	234.2	708.8	
				5/16/75	NM-7		
				6/12/75	234.3	708.7	
				7/18/75	235.0	708.0	
				8/19/75	235.4	707.6	
				9/17/75	235.7	707.3	
02N/15W-19K01 S	19		892.0	10/22/74	339.2	552.8	1200
				11/15/74	338.0	554.0	
				12/20/74	337.7	554.3	
				4/24/75	340.0	552.0	
				5/23/75	337.5	554.5	
				6/13/75	334.9	557.1	
				7/25/75	334.8	557.2	
				8/27/75	336.4	555.6	
				9/16/75	338.2	553.8	
02N/15W-21D01 S	19		878.9	10/18/74	308.5	570.4	1200
				11/14/74	308.8	570.1	
				12/20/74	309.2	569.7	

See page 79 for key to terms a abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT SAN FERNANDO HYDRO SUBUNIT SAN FERNANDO HYDRO SUBAREA						U-05 U-05.8 U-05.81	
02N/15W-21D01 S (CONTINUED)	19		878.9	4/24/75	310.6	568.3	1200
				5/22/75	310.8	568.1	
				6/12/75	310.2	568.7	
				7/18/75	309.8	569.1	
				8/27/75	309.9	569.0	
				9/25/75	310.1	568.8	
02N/15W-22A01 S	19		908.5	10/02/74	351.4	557.1	1101
				11/07/74	351.7	556.8	
				12/03/74	351.6	556.9	
				1/02/75	352.4	556.1	
				2/04/75	352.4	556.1	
				3/03/75	352.8	555.7	
				4/10/75	353.0	555.5	
				5/01/75	352.6	555.9	
				6/03/75	351.9	556.6	
				7/02/75	351.2	557.3	
				8/01/75	350.8	557.7	
				9/04/75	351.8	556.7	
02N/15W-24H01 S	19		918.9	10/22/74	236.6	682.3	1200
				11/15/74	224.3	694.6	
				12/20/74	225.6	693.3	
				1/17/75	231.5	687.4	
				2/21/75	236.9	682.1	
				3/28/75	237.8	681.1	
				4/24/75	233.3	685.6	
				5/23/75	211.8	707.1	
				6/13/75	217.1	701.8	
				7/25/75	228.1	690.8	
				8/27/75	234.5	684.4	
				9/16/75	237.6	681.3	
02N/15W-24J01 S	19		901.0	11/06/74	345.4	555.6	1101
				2/06/75	347.4	553.6	
				4/03/75	349.2	551.8	
02N/15W-25G01 S	19		862.0	10/22/74	313.8	548.2	1200
				11/15/74	313.5	548.5	
				12/20/74	313.6	548.4	
				4/24/75	312.4	549.6	
				5/23/75	310.7	551.3	
				6/13/75	309.5	552.5	
				7/25/75	308.0	554.0	
				8/27/75	309.7	552.3	
				9/16/75	310.9	551.1	
02N/15W-25L01 S	19		831.5	10/22/74	282.0(S)	549.5	1200
				11/20/74	282.0(S)	549.5	
				12/20/74	283.0(S)	548.5	
				4/21/75	282.0(S)	549.5	
				5/20/75	280.0(S)	551.5	
				6/13/75	278.0	553.5	
				7/28/75	277.0	554.5	
				8/29/75	279.0	552.5	
				9/26/75	280.0	551.5	
02N/15W-25P01 S	19		817.0	10/15/74	277.6	539.4	1200
				11/12/74	277.7	539.3	
				12/17/74	277.5	539.5	
				1/21/75	276.3	540.7	
				2/25/75	276.1	540.9	
				3/18/75	276.2	540.8	
				4/15/75	275.5	541.5	
				5/27/75	273.6	543.4	
				6/10/75	272.6	544.4	
				7/15/75	271.6	545.4	
				8/19/75	273.1	543.9	
				9/16/75	275.1	541.9	
02N/15W-26H01 S	19		831.9	11/06/74	284.8	547.1	1101
				2/06/75	285.1	546.8	
				4/03/75	219.1	612.8	
02N/15W-26P02 S	19		797.2	10/02/74	250.0	547.2	1101
				11/07/74	245.7	551.5	
				4/03/75	250.1	547.1	
02N/15W-27J01 S	19		818.2	10/18/74	265.5	552.7	1200
				11/14/74	265.9	552.3	
				12/20/74	266.2	552.0	
				4/24/75	265.4	552.8	
				5/22/75	265.1	553.1	
				6/12/75	264.1	554.1	
				7/24/75	264.0	554.2	
				8/27/75	265.0	553.2	
				9/25/75	266.1	552.1	
02N/15W-28C01 S	19		837.2	11/07/74	DRY		1101
				4/10/75	DRY		
02N/15W-28P01 S	19		805.0	10/02/74	225.5	579.5	1101
				11/07/74	226.0	579.0	
				12/03/74	225.7	579.3	
				1/02/75	226.2	578.8	
				2/04/75	226.2	578.8	
				3/03/75	226.4	578.6	
				4/03/75	225.7	579.3	
				5/01/75	226.3	578.7	
				6/03/75	230.2	574.8	
				7/02/75	226.4	578.6	
				8/01/75	226.9	578.1	
LA-SAN GABRIEL RIVER HYDRO UNIT SAN FERNANDO HYDRO SUBUNIT SAN FERNANDO HYDRO SUBAREA						U-05 U-05.8 U-05.81	
02N/15W-28P01 S	19		805.0	9/04/75	225.9	579.1	1101
02N/15W-29E01 S	19		817.0	10/16/74	217.3	599.7	1200
				11/21/74	217.7	599.3	
				12/19/74	217.7	599.3	
				4/16/75	218.5	598.5	
				5/15/75	218.7	598.3	
				6/12/75	218.9	598.1	
				7/18/75	219.0	598.0	
				8/21/75	219.1	597.9	
				9/17/75	219.2	597.8	
02N/15W-31N01 S	19		773.6	10/02/74	140.3	633.3	1101
				11/14/74	140.5	633.1	
				12/03/74	140.5	633.1	
				1/07/75	139.4	634.2	
02N/15W-31N02 S	19		773.6	10/02/74	113.4	660.2	1101
				11/14/74	113.9	659.7	
				12/03/74	113.5	660.1	
				1/07/75	113.5	660.1	
02N/16W-07Q01 S	19		1017.0	11/15/74	49.0	968.0	1101
				4/15/75	50.0	967.0	
02N/16W-14C02 S	19		1020.6	11/15/74	79.8	940.8	1101
				12/17/74	77.8	942.8	
				1/29/75	78.5	942.1	
				2/11/75	78.6	942.0	
				3/11/75	78.4	942.2	
				4/15/75	78.5	942.1	
				5/13/75	79.1	941.5	
				6/10/75	79.7	940.9	
				7/09/75	79.4	941.2	
				8/07/75	79.4	941.2	
				9/08/75	79.8	940.8	
02N/16W-18M02 S	19		968.0	11/15/74	14.7	953.3	1101
				4/14/75	14.8	953.2	
02N/16W-19C01 S	19		941.6	11/22/74	57.4	884.2	1101
				12/17/74	65.3	876.3	
				1/29/75	65.3	876.3	
				2/11/75	65.7	875.9	
				3/11/75	66.1	875.5	
				4/14/75	65.9	875.7	
				5/13/75	66.3	875.3	
				6/10/75	66.4	875.2	
				7/09/75	66.9	874.7	
				8/07/75	67.1	874.5	
				9/08/75	66.9	874.7	
02N/16W-19K01 S	19		910.2	10/02/74	87.1	823.1	1101
				11/15/74	87.4	822.8	
				12/03/74	87.5	822.7	
				1/07/75	87.7	822.5	
				2/11/75	87.8	822.4	
				3/11/75	88.1	822.1	
				4/14/75	88.2	822.0	
				5/13/75	88.4	821.8	
				6/10/75	88.4	821.8	
				7/09/75	88.6	821.6	
				8/07/75	88.7	821.5	
				9/08/75	88.8	821.4	
02N/16W-20R02 S	19		867.2	12/02/74	73.2	794.0	1101
				1/29/75	74.2	793.0	
				2/11/75	73.0	794.2	
				3/11/75	72.7	794.5	
				4/15/75	71.9	795.3	
				5/13/75	72.2	795.0	
				6/10/75	72.3	794.9	
				7/09/75	72.4	794.8	
				8/07/75	73.0	794.2	
				9/08/75	73.3	793.9	
02N/16W-21B01 S	19		913.2	10/18/74	112.4	800.8	1200
				11/20/74	112.6	800.6	
				12/19/74	112.6	800.6	
				4/23/75	113.2	800.0	
				5/15/75	113.2	800.0	
				6/12/75	113.3	799.9	
				7/24/75	DRY		
				8/19/75	117.4	795.8	
				9/18/75	113.7	799.5	
02N/16W-21L01 S	19		873.3	10/23/74	77.6	795.7	1200
				4/25/75	77.9	795.4	
02N/16W-22K01 S	19		850.4	10/18/74	58.8	791.6	1200
				12/19/74	59.0	791.4	
				4/23/75	59.5	790.9	
				5/15/75	59.6	790.8	
				6/12/75	59.7	790.7	
				7/22/75	59.8	790.6	
				8/19/75	59.9	790.5	
				9/18/75	60.0	790.4	
02N/16W-25P01 S	19		782.7	10/18/74	75.2	707.5	1200
				11/21/74	75.3	707.4	
				12/18/74	75.4	707.3	
				1/14/75	75.4	707.3	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
SAN FERNANDO HYDRO SUBUNIT — U-05.8
SAN FERNANDO HYDRO SUBAREA — U-05.81

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
02N/16W-25P01 S (CONTINUED)	19		782.7	2/19/75	75.6	707.1	1200
				3/20/75	75.5	707.2	
				4/16/75	75.5	707.2	
				5/15/75	75.6	707.1	
				6/19/75	75.6	707.1	
				7/17/75	75.8	706.9	
				8/21/75	75.8	706.9	
				9/17/75	75.9	706.8	
02N/16W-27F01 S	19		793.5	10/02/74	15.7	777.8	1101
				11/14/74	15.8	777.7	
				4/11/75	14.6	778.9	
02N/16W-27F02 S	19		801.9	10/16/74	21.9	780.0	1200
				12/18/74	22.0	779.9	
				4/16/75	21.2	780.7	
				5/15/75	21.4	780.5	
				6/19/75	21.4	780.5	
				7/22/75	21.9	780.0	
				8/21/75	21.8	780.1	
				9/17/75	22.4	779.5	
02N/16W-27F03 S	19		792.7	11/14/74	DRY (6)		1101
02N/16W-27H01 S	19		795.9	11/14/74	14.4	781.5	1101
				4/01/75	14.2	781.7	
02N/16W-27L01 S	19		783.3	10/18/74	8.7	774.6	1200
				11/20/74	8.5	774.8	
				12/18/74	8.1	775.2	
				4/23/75	6.4	776.9	
				5/15/75	7.4	775.9	
				6/19/75	7.5	775.8	
				7/22/75	8.2	775.1	
				8/21/75	8.5	774.8	
				9/17/75	8.8	774.5	
02N/16W-27P02 S	19		773.7	10/16/74	FLOW		1200
				12/18/74	FLOW		
				4/16/75	FLOW		
				5/15/75	FLOW		
				6/19/75	FLOW		
				7/22/75	FLOW		
				8/26/75	FLOW		
				9/17/75	FLOW		
02N/16W-27P03 S	19		773.5	10/02/74	12.3	761.2	1101
				11/14/74	12.2	761.3	
				4/11/75	11.2	762.3	
02N/16W-27P04 S	19		769.9	11/14/74	10.7	759.2	1101
				4/11/75	9.7	760.2	
02N/16W-27P05 S	19		771.5	11/14/74	11.8	759.7	1101
02N/16W-28A02 S	19		830.3	10/23/74	38.7	791.6	1200
				4/23/75	39.1	791.2	
02N/16W-28J02 S	19		797.1	10/18/74	17.9	779.2	1200
				11/20/74	18.1	779.0	
				12/18/74	17.7	779.4	
				4/23/75	16.0	781.1	
				5/15/75	16.0	781.1	
				6/19/75	16.4	780.7	
				7/22/75	17.0	780.1	
				8/21/75	17.6	779.5	
				9/17/75	18.0	779.1	
02N/16W-28J03 S	19		799.5	10/18/74	15.3	784.2	1200
				11/20/74	15.5	784.0	
				12/18/74	15.5	784.0	
				4/23/75	14.7	784.8	
				5/15/75	14.7	784.8	
				6/19/75	14.7	784.8	
				7/22/75	14.9	784.6	
				8/21/75	15.1	784.4	
				9/17/75	15.4	784.1	
02N/16W-29H01 S	19		846.0	10/18/74	54.1	791.9	1200
				11/20/74	54.3	791.7	
				12/19/74	54.3	791.7	
				4/23/75	54.7	791.3	
				5/16/75	54.7	791.3	
				6/19/75	54.8	791.2	
				7/22/75	54.9	791.1	
				8/22/75	55.2	790.8	
				9/18/75	55.1	790.9	
02N/16W-30H02 S	19		858.8	10/18/74	64.0	794.8	1200
				11/20/74	64.2	794.6	
				12/19/74	64.3	794.5	
				1/15/75	64.5	794.3	
				2/20/75	64.7	794.1	
				3/20/75	64.7	794.1	
				4/23/75	64.7	794.1	
				5/16/75	65.2	793.6	
				6/19/75	65.0	793.8	
				7/22/75	65.1	793.7	
				8/22/75	65.3	793.5	
				9/18/75	65.4	793.4	
02N/16W-32F01 S	19		805.0	10/18/74	DRY		1200
02N/16W-32F01 S (CONTINUED)	19		805.0	11/20/74	DRY		1200
				12/19/74	DRY		
				5/16/75	DRY		
				7/22/75	DRY		
				9/18/75	DRY		
02N/16W-32H01 S	19		800.0	10/18/74	DRY		1200
				11/20/74	DRY		
				12/18/74	19.8	780.2	
				5/15/75	DRY (6)		
				6/19/75	DRY		
				7/24/75	DRY		
				8/27/75	DRY		
				9/18/75	DRY (6)		
02N/16W-32N01 S	19		799.8	10/16/74	DRY		1200
				11/20/74	DRY		
				12/19/74	DRY		
				1/15/75	DRY		
				2/20/75	DRY		
				3/20/75	DRY		
				5/16/75	DRY		
				6/19/75	DRY		
				7/21/75	DRY		
				9/18/75	DRY		
02N/16W-32P06 S	19		793.4	10/18/74	17.1	776.3	1200
				11/20/74	17.1	776.3	
				12/19/74	17.1	776.3	
				4/23/75	16.5	776.9	
				5/16/75	16.5	776.9	
				6/19/75	16.6	776.8	
				7/22/75	16.9	776.5	
				8/27/75	17.3	776.1	
				9/18/75	17.4	776.0	
02N/16W-33G06 S	19		774.9	10/18/74	DRY		1200
				11/20/74	DRY		
				12/18/74	DRY		
				5/15/75	DRY		
				7/24/75	DRY		
				9/18/75	DRY		
02N/16W-33G07 S	19		785.0	10/18/74	17.5	767.5	1200
				11/20/74	17.5	767.5	
				12/18/74	17.1	767.9	
				4/23/75	15.9	769.1	
				5/15/75	15.7	769.3	
				6/19/75	15.5	769.5	
				7/24/75	15.8	769.2	
				8/27/75	17.1	767.9	
				9/18/75	17.5	767.5	
02N/16W-33G08 S	19		779.0	11/14/74	14.0	765.0	1101
				4/14/75	13.3	765.7	
02N/16W-33H01 S	19		772.5	10/18/74	DRY		1200
				11/20/74	DRY		
				12/18/74	DRY		
				5/15/75	DRY		
				7/24/75	DRY		
				9/18/75	DRY		
02N/16W-33Q01 S	19		770.0	10/18/74	12.1	757.9	1200
				11/20/74	12.4	757.6	
				12/18/74	12.6	757.4	
				4/18/75	10.8	759.2	
				5/15/75	10.5	759.5	
				6/19/75	10.5	759.5	
				7/24/75	10.7	759.3	
				8/27/75	11.1	758.9	
				9/18/75	11.4	758.6	
02N/16W-34D01 S	19		772.2	10/18/74	8.5	763.7	1200
				11/20/74	8.6	763.6	
				12/18/74	8.5	763.7	
				4/23/75	6.3	765.9	
				5/15/75	6.7	765.5	
				6/19/75	7.3	764.9	
				7/22/75	8.0	764.2	
				8/26/75	8.6	763.6	
				9/17/75	8.9	763.3	
02N/16W-34G01 S	19		758.0	10/23/74	0.6	757.4	1200
02N/16W-34G02 S	19		756.9	10/16/74	FLOW		1200
				11/20/74	FLOW		
				12/18/74	FLOW		
				4/16/75	FLOW		
				5/15/75	FLOW		
				6/19/75	FLOW		
				7/22/75	FLOW		
				8/26/75	FLOW		
				9/17/75	FLOW		
02N/16W-34K01 S	19		747.0	10/02/74	11.2	735.8	1101
				11/14/74	11.1	735.9	
				4/11/75	9.4	737.6	
02N/16W-34K02 S	19		750.3	10/16/74	FLOW		1200
				11/20/74	FLOW		
				12/18/74	FLOW		

See page 79 for key to terms a abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
SAN FERNANDO HYDRO SUBUNIT — U-05.8
SAN FERNANDO HYDRO SUBAREA — U-05.81

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
02N/16W-34K02 S (CONTINUED)	19		750.3	4/16/75	FLOW		1200
				5/15/75	FLOW		
				6/19/75	FLOW		
				7/22/75	FLOW		
				8/26/75	FLOW		
				9/17/75	FLOW		
02N/16W-34N01 S	19		755.0	10/18/74	11.6	743.4	1200
				11/20/74	11.8	743.2	
				12/18/74	11.8	743.2	
				4/23/75	10.9	744.1	
				5/15/75	10.8	744.2	
				6/19/75	10.7	744.3	
				7/17/75	10.8	744.2	
				8/27/75	11.1	743.9	
				9/18/75	11.2	743.8	
02N/17W-12R05 S	19		984.0	11/15/74	17.4	966.6	1101
				4/15/75	17.4	966.6	
02N/17W-12R06 S	19		979.0	11/25/74	16.6	962.4	1101
				4/15/75	16.1	962.9	
02N/17W-12R07 S	19		977.0	4/15/75	15.6	961.4	1101
02N/17W-13A01 S	19		970.5	10/02/74	13.5	957.0	1101
				11/15/74	13.7	956.8	
				12/03/74	13.8	956.7	
				1/07/75	13.1	957.4	
				2/11/75	12.5	958.0	
				3/11/75	11.5	959.0	
				4/14/75	12.4	958.1	
				5/13/75	12.2	958.3	
				6/10/75	12.5	958.0	
				7/09/75	12.8	957.7	
				8/07/75	13.4	957.1	
				9/08/75	13.5	957.0	
02N/17W-13G03 S	19		954.0	11/15/74	11.1	942.9	1101
02N/17W-13L01 S	19		946.0	11/15/74	7.9	938.1	1101
				4/14/75	5.2	940.8	
02N/17W-14J01 S	19		1066.0	11/15/74	50.4	1015.6	1101
				4/14/75	47.2	1018.8	
02N/17W-34P01 S	19		959.2	11/14/74	38.7	920.5	1101
				4/14/75	NM-1		
02N/17W-35J01 S	19		825.6	10/02/74	21.1	804.5	1101
				11/14/74	DRY (6)		
				4/14/75	21.2	804.4	
				6/10/75	DRY (6)		
02N/17W-36P02 S	19		807.0	10/02/74	19.3	787.7	1101
				11/14/74	19.5	787.5	
03N/15W-34P01 S	19		1130.3	11/06/74	66.2	1064.1	1101
03N/15W-35P02 S	19		1156.9	10/02/74	105.9	1051.0	1101
				11/07/74	NM-3		
03N/15W-36F01 S	19		1230.8	10/03/74	26.2	1204.6	1101
				11/07/74	24.7	1206.1	
				12/03/74	25.1	1205.7	
				1/02/75	24.8	1206.0	
				2/04/75	25.4	1205.4	
				3/04/75	24.4	1206.4	
				4/23/75	17.0	1213.8	1200
				5/22/75	17.0	1213.8	
				6/13/75	16.4	1214.4	
				7/18/75	18.7	1212.1	
				8/21/75	20.9	1209.9	
				9/17/75	18.0	1212.8	
01S/12W-25G05 S	19		257.2	7/09/75	96.2(5)	161.0	1101
				8/14/75	95.2(5)	162.0	
				9/08/75	93.2(5)	164.0	
01S/13W-04R01 S	19		409.4	11/18/74	64.5	344.9	1101
				4/23/75	66.9	342.5	
01S/13W-04C17 S	19		405.9	10/03/74	61.2	344.7	1200
				11/07/74	61.1	344.8	
				12/05/74	60.8	345.1	
				1/02/75	60.6	345.3	
				2/20/75	60.4	345.5	
				3/20/75	60.3	345.6	
				4/17/75	60.2	345.7	
				5/15/75	60.3	345.6	
				6/19/75	60.3	345.6	
				7/17/75	60.2	345.7	
				8/21/75	60.1	345.8	
				9/18/75	60.1	345.8	
01S/13W-04F01 S	19		394.8	10/24/74	50.0	344.8	1200
				11/20/74	49.9	344.9	
				12/20/74	49.7	345.1	
				1/24/75	49.5	345.3	
				2/26/75	49.4	345.4	
				3/20/75	49.2	345.6	
				4/24/75	49.1	345.7	

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
SAN FERNANDO HYDRO SUBUNIT — U-05.8
SAN FERNANDO HYDRO SUBAREA — U-05.81

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
01S/13W-04E01 S (CONTINUED)	19		394.8	5/21/75	50.5	344.3	1200
				6/25/75	49.0	345.8	
				7/25/75	49.0	345.8	
				8/27/75	49.0	345.8	
				9/24/75	49.0	345.8	
01S/13W-04J01 S	19		373.7	10/24/74	95.3	278.4	1200
				11/21/74	100.4	273.3	
				12/20/74	105.3	268.4	
				1/24/75	109.2	264.5	
				2/20/75	111.4	262.3	
				3/26/75	112.5	261.2	
				4/24/75	113.3	260.4	
				5/28/75	114.5	259.2	
				6/25/75	115.9	257.8	
				7/30/75	118.5	255.2	
				8/27/75	119.7	254.0	
				9/30/75	121.7	252.0	
01S/13W-04K01 S	19		381.1	10/24/74	NM-1		1200
				11/20/74	120.5	260.6	
				12/23/74	123.6	257.5	
				4/24/75	127.5	253.6	
				5/21/75	128.9	252.2	
				6/25/75	134.2	246.9	
				7/30/75	141.1	240.0	
				8/27/75	145.4	235.7	
				9/24/75	148.2	232.9	
01S/13W-04L03 S	19		381.2	10/24/74	NM-1		1200
				11/20/74	NM-1		
				12/23/74	NM-1		
				4/24/75	130.5	250.7	
				5/21/75	131.8	249.4	
				6/25/75	NM-1		
				7/30/75	NM-1		
				8/27/75	NM-1		
				9/24/75	NM-1		
01S/13W-04L04 S	19		367.0	10/24/74	NM-1		1200
				11/20/74	NM-1		
				12/23/74	NM-1		
				4/24/75	NM-1		
				5/21/75	NM-1		
				6/25/75	122.3	244.7	
				7/30/75	NM-1		
				8/27/75	NM-1		
				9/24/75	NM-1		
01S/13W-04L08 S	19		366.4	10/24/74	NM-1		1200
				11/20/74	NM-1		
				12/23/74	NM-1		
				4/24/75	NM-1		
				5/21/75	NM-1		
				6/25/75	NM-1		
				7/30/75	NM-1		
				8/27/75	NM-1		
				9/24/75	NM-1		
01S/13W-04P01 S	19		367.4	10/24/74	99.6	267.8	1200
				12/15/74	NM-6		
01S/13W-04P02 S	19		364.2	10/15/74	95.6	268.6	1200
				11/12/74	100.9	263.3	
				4/29/75	NM-9		
				5/27/75	NM-9		
				6/25/75	NM-9		
				7/01/75	NM-9		
				8/19/75	NM-9		
				9/24/75	NM-9		
01S/13W-04P03 S	19		366.8	10/24/74	100.7	266.1	1200
				11/20/74	105.3	261.5	
				12/26/74	110.2	256.6	
				1/31/75	115.6	251.2	
				2/20/75	114.5	252.3	
				3/20/75	114.9	251.9	
				4/24/75	116.4	250.4	
				5/21/75	118.1	248.7	
				6/25/75	117.9	248.9	
				7/30/75	126.3	240.5	
				8/29/75	130.0	236.8	
				9/24/75	132.4	234.4	
01S/13W-05J01 S	19		370.5	10/24/74	76.8	293.7	1200
				11/20/74	79.8	290.7	
				12/20/74	82.3	288.2	
01S/13W-09R01 S	19		346.4	10/24/74	49.2	297.2	1200
				11/21/74	53.1	293.3	
				12/26/74	57.6	288.8	
				4/24/75	68.6	277.8	
				5/21/75	70.3	276.1	
				6/25/75	72.7	273.7	
				7/30/75	74.5	271.9	
				8/29/75	23.0	323.4	
				9/24/75	76.4	270.0	
01S/13W-09R07 S	19		346.0	10/24/74	45.5	300.5	1200
				11/21/74	48.6	297.4	
				12/26/74	52.7	293.3	
				4/24/75	64.1	281.9	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT						U-05	
SAN FERNANDO HYDRO SUBUNIT						U-05.8	
SAN FERNANDO HYDRO SUBAREA						U-05.81	
01S/13W-09P02 S (CONTINUED)	19		346.0	5/21/75	66.3	279.7	1200
				6/25/75	DRY		
				7/30/75	DRY		
				8/29/75	DRY		
				9/24/75	DRY		
01S/13W-10N01 S	19		335.2	10/24/74	25.5	309.7	1200
				11/21/74	25.3	309.9	
				12/26/74	27.1	308.1	
				4/24/75	28.4	306.8	
				6/25/75	29.0	306.2	
				7/30/75	28.8	306.4	
				8/29/75	28.5	306.7	
				9/24/75	28.0	307.2	
01S/13W-10P01 S	19		328.0	10/24/74	19.4	308.6	1200
				11/21/74	19.7	308.3	
				12/26/74	19.9	308.1	
				4/24/75	21.2	306.8	
				5/21/75	21.2	306.8	
				6/25/75	21.6	306.4	
				7/30/75	21.6	306.4	
				8/29/75	21.4	306.6	
				9/24/75	20.8	307.2	
SYLMAR HYDRO SUBAREA						U-05.82	
02N/15W-04R02 S	19		1130.0	10/18/74	63.9	1066.1	1200
				11/15/74	59.6	1070.4	
				12/19/74	57.1	1072.9	
				4/23/75	73.3	1056.7	
				5/22/75	74.1	1055.9	
				6/12/75	74.5	1055.5	
				7/18/75	75.2	1054.8	
				8/27/75	76.0	1054.0	
				9/25/75	76.2	1053.8	
02N/15W-04R03 S	19		1143.2	10/18/74	72.0	1071.2	1200
				11/15/74	70.4	1072.8	
				12/19/74	68.2	1075.0	
				4/23/75	69.8	1073.4	
				5/22/75	70.4	1072.8	
				6/12/75	71.0	1072.2	
				7/18/75	72.5	1070.7	
				8/27/75	73.9	1069.3	
				9/25/75	76.4	1066.8	
02N/15W-04R05 S	19		1115.3	10/18/74	49.0	1066.3	1200
				11/15/74	47.3	1068.0	
				12/19/74	44.9	1070.4	
				4/23/75	43.9	1071.4	
				5/22/75	44.9	1070.4	
				6/12/75	46.2	1069.1	
				7/18/75	48.8	1066.5	
				8/27/75	51.2	1064.1	
				9/25/75	52.2	1063.1	
02N/15W-04R09 S	19		1130.5	10/18/74	64.2	1066.3	1200
				11/15/74	64.5	1066.0	
				12/19/74	60.0	1070.5	
				4/23/75	NM-1		
				5/22/75	NM-1		
				6/12/75	NM-1		
03N/15W-15H01 S	19		1525.0	11/27/74	12.9	1512.1	1101
				4/16/75	3.8	1521.2	
03N/15W-25R01 S	19		1390.8	11/06/74	208.7	1182.1	1101
03N/15W-27L01 S	19		1300.4	10/18/74	166.8	1133.6	1200
				11/15/74	166.6	1133.8	
				12/19/74	166.5	1133.9	
				4/23/75	166.9	1133.5	
				5/22/75	167.0	1133.4	
				6/12/75	167.1	1133.3	
				7/18/75	167.0	1133.4	
				8/27/75	167.3	1133.1	
				9/25/75	167.5	1132.9	
03N/15W-27Q01 S	19		1285.0	11/06/74	224.0	1061.0	1101
03N/15W-33F01 S	19		1188.9	10/18/74	106.1	1082.8	1200
				11/15/74	106.7	1082.2	
				12/19/74	105.4	1083.5	
				1/16/75	105.2	1083.7	
				2/20/75	103.9	1085.0	
				3/28/75	104.3	1084.6	
				4/23/75	104.9	1084.0	
				5/22/75	105.9	1083.0	
				6/12/75	106.6	1082.3	
				7/18/75	107.5	1081.4	
				8/27/75	108.6	1080.3	
				9/25/75	109.3	1079.6	
03N/15W-33M01 S	19		1158.4	11/07/74	85.9	1072.5	1101
				4/10/75	84.0	1074.4	
03N/15W-33Q01 S	19		1137.2	10/18/74	84.0	1053.2	1200
				11/15/74	75.8	1061.4	
				12/19/74	70.4	1066.8	
				4/23/75	NM-1		
				5/22/75	NM-1		

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT						U-05	
SAN FERNANDO HYDRO SUBUNIT						U-05.8	
SYLMAR HYDRO SUBAREA						U-05.82	
03N/15W-33Q01 S (CONTINUED)	19		1137.2	6/12/75	NM-1		1200
				7/18/75	NM-1		
				8/27/75	NM-1		
				9/25/75	NM-1		
03N/15W-34A01 S	19		1244.0	11/06/74	177.6	1066.4	1101
03N/15W-34R02 S	19		1222.2	11/06/74	NM-1		1101
03N/15W-34C01 S	19		1237.0	11/06/74	173.5	1063.5	1101
				4/01/75	168.5	1068.5	
03N/15W-34K02 S	19		1149.0	10/18/74	82.5	1066.5	1200
				11/15/74	82.2	1066.8	
				12/19/74	82.0	1067.0	
				1/16/75	81.7	1067.3	
				2/20/75	80.4	1068.6	
				3/28/75	77.6	1071.4	
				4/23/75	77.8	1071.2	
				5/22/75	78.0	1071.0	
				6/12/75	78.3	1070.7	
				7/24/75	81.9	1067.1	
				8/21/75	83.2	1065.8	
				9/25/75	84.8	1064.2	
03N/15W-34K03 S	19		1154.5	10/18/74	NM-1		1200
				4/29/75	NM-0		
03N/15W-34P06 S	19		1130.3	11/07/74	65.6	1064.7	1101
03N/15W-34P07 S	19		1125.4	11/06/74	58.5	1066.9	1101
03N/15W-34P10 S	19		1133.0	10/02/74	71.7	1061.3	1101
				11/07/74	70.1	1062.9	
				12/03/74	68.0	1065.0	
				1/02/75	66.4	1066.6	
				2/04/75	NM-3		
				3/03/75	64.9	1068.1	
				4/10/75	66.2	1066.8	
03N/15W-36C01 S	19		1280.5	1/30/75	NM-0		1200
03N/15W-36D03 S	19		1298.5	10/03/74	78.8	1219.7	1101
				11/07/74	79.0	1219.5	
				4/10/75	68.7	1229.8	
TUJUNGA HYDRO SUBAREA						U-05.83	
02N/13W-18N01 S	19		1796.2	10/22/74	339.0	1457.2	1200
				11/18/74	338.0	1458.2	
				12/17/74	338.1	1458.1	
				1/17/75	338.3	1457.9	
				2/27/75	338.6	1457.6	
				3/21/75	338.8	1457.4	
				5/22/75	339.1	1457.1	
				6/17/75	339.1	1457.1	
				7/22/75	339.8	1456.4	
				8/19/75	340.0	1456.2	
				9/17/75	340.2	1456.0	
02N/14W-05L01 S	19		1141.0	11/04/74	6.5	1134.5	1101
				4/10/75	3.5	1137.5	
02N/14W-06J01 S	19		1204.2	1/30/75	NM-0		1200
02N/14W-08G02 S	19		1063.9	10/18/74	12.2	1051.7	1200
				11/15/74	12.5	1051.4	
				12/19/74	12.7	1051.2	
				1/17/75	13.0	1050.9	
				2/27/75	14.0	1049.9	
				3/21/75	13.6	1050.3	
				4/24/75	13.0	1050.9	
				5/22/75	12.4	1051.5	
				6/13/75	12.1	1051.8	
				7/24/75	12.9	1051.0	
				8/21/75	13.6	1050.3	
				9/17/75	13.7	1050.2	
02N/14W-09F01 S	19		1098.6	10/18/74	39.0	1059.6	1200
				4/29/75	35.1	1063.5	
02N/14W-09F01 S	19		1130.1	10/18/74	42.9	1087.3	1200
				11/15/74	43.6	1086.5	
				12/19/74	44.2	1085.9	
				1/17/75	47.1	1083.0	
				2/27/75	44.4	1085.7	
				3/21/75	45.1	1085.0	
				4/24/75	42.2	1087.9	
				5/22/75	42.6	1087.5	
				6/13/75	43.0	1087.1	
				7/24/75	42.9	1087.2	
				8/21/75	44.5	1085.6	
				9/17/75	44.7	1085.4	
02N/14W-09H01 S	19		1164.0	10/18/74	47.3	1116.7	1200
				11/15/74	48.2	1115.8	
				12/19/74	49.0	1115.0	
				1/17/75	51.9	1112.1	
				2/27/75	49.8	1114.2	
				3/21/75	48.8	1115.2	
				4/24/75	46.5	1117.5	
				5/22/75	46.7	1117.3	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT SAN FERNANDO HYDRO SUBUNIT TUJUNGA HYDRO SUBAREA						U-05 U-05.B U-05.B3	
02N/14W-09H01 S (CONTINUED)	19		1164.0	6/13/75	47.0	1117.0	1200
				7/24/75	47.9	1116.1	
				8/21/75	48.7	1115.3	
				9/17/75	48.8	1115.2	
02N/14W-10F01 S	19		1192.6	10/08/74	42.5	1150.1	1200
				4/29/75	40.9	1151.7	
02N/14W-10R02 S	19		1215.0	10/22/74	28.5	1186.5	1200
				11/15/74	29.3	1185.7	
				12/19/74	28.8	1186.2	
				1/17/75	29.0	1186.0	
				2/27/75	29.5	1185.5	
				3/21/75	27.3	1187.7	
				4/24/75	26.6	1188.4	
				5/22/75	27.7	1187.3	
				6/13/75	28.1	1186.9	
				7/24/75	28.0	1187.0	
				8/21/75	29.6	1185.4	
				9/17/75	30.0	1185.0	
02N/14W-11J01 S	19		1343.5	10/22/74	DRY		1200
				4/29/75	DRY		
02N/14W-11K01 S	19		1285.5	10/22/74	34.4	1251.1	1200
				4/29/75	34.0	1251.5	
02N/14W-11K04 S	19		1283.5	10/22/74	35.0	1248.5	1200
				11/15/74	35.9	1247.6	
				12/17/74	36.2	1247.3	
				4/24/75	35.1	1248.4	
				5/22/75	35.8	1247.7	
				6/17/75	36.2	1247.3	
				7/22/75	37.7	1245.8	
				8/21/75	37.0	1246.5	
				9/16/75	37.2	1246.3	
02N/14W-11N03 S	19		1242.5	11/04/74	12.6	1229.9	1101
				4/02/75	11.8	1230.7	
02N/14W-11P01 S	19		1267.2	10/22/74	27.7	1239.5	1200
				11/15/74	27.0	1240.2	
				12/17/74	27.0	1240.2	
				4/24/75	25.7	1241.5	
				5/22/75	26.6	1240.6	
				6/17/75	27.3	1239.9	
				7/22/75	28.0	1239.2	
				8/21/75	28.5	1238.7	
				9/16/75	28.8	1238.4	
02N/14W-11P02 S	19		1316.7	10/22/74	18.7	1298.0	1200
				11/15/74	18.6	1298.1	
				12/17/74	18.5	1298.2	
				4/24/75	18.0	1298.7	
				5/22/75	18.1	1298.6	
				6/17/75	18.2	1298.5	
				7/22/75	18.4	1298.3	
				8/21/75	18.5	1298.2	
				9/16/75	12.6	1304.1	
02N/14W-11Q01 S	19		1326.9	10/15/74	69.7	1257.2	1200
				11/15/74	67.0	1259.9	
				12/15/74	67.2	1259.7	
				4/24/75	67.1	1259.8	
				5/22/75	67.3	1259.6	
				6/17/75	67.6	1259.3	
				7/22/75	68.1	1258.8	
				8/21/75	68.4	1258.5	
				9/16/75	68.7	1258.2	
02N/14W-12C02 S	19		1356.1	10/22/74	13.1	1343.0	1200
				11/15/74	11.5	1344.6	
				12/17/74	10.7	1345.4	
				1/17/75	11.7	1344.4	
				2/27/75	10.5	1345.6	
				3/21/75	9.1	1347.0	
				4/24/75	9.6	1346.5	
				5/22/75	10.3	1345.8	
				6/17/75	8.8	1347.3	
				7/24/75	9.0	1347.1	
				8/19/75	9.8	1346.3	
				9/17/75	NM-9		
02N/14W-13D02 S	19		1453.4	10/22/74	63.5	1389.9	1200
				4/29/75	63.7	1389.7	
02N/14W-13D04 S	19		1467.0	11/13/74	81.9	1385.1	1101
				4/16/75	69.8	1397.2	
02N/14W-13F02 S	19		1439.9	10/22/74	51.2	1388.7	1200
				4/29/75	51.4	1388.5	
02N/14W-13F03 S	19		1454.0	10/22/74	62.3	1391.7	1200
				11/15/74	62.3	1391.7	
				12/17/74	62.4	1391.6	
				4/24/75	62.7	1391.3	
				5/22/75	62.9	1391.1	
				6/17/75	62.9	1391.1	
				7/22/75	63.1	1390.9	
				8/19/75	63.2	1390.8	
				9/16/75	63.4	1390.6	
02N/14W-13F04 S	19		1456.4	4/29/75	66.0	1390.4	1200
02N/14W-14A01 S	19		1402.0	10/22/74	22.2	1379.8	1200
				4/29/75	22.1	1379.9	
02N/14W-14B01 S	19		1334.4	11/04/74	FLOW		1101
				4/02/75	FLOW		
02N/14W-14C04 S	19		1325.3	10/22/74	5.9	1319.4	1200
				4/29/75	5.2	1320.1	
02N/14W-14G01 S	19		1372.0	10/22/74	23.8	1348.2	1200
				4/29/75	23.3	1348.7	
02N/14W-14H02 S	19		1415.7	10/22/74	34.2	1381.5	1200
				11/15/74	34.1	1381.6	
				12/17/74	34.1	1381.6	
				4/24/75	34.3	1381.4	
				5/22/75	34.5	1381.2	
				6/17/75	34.5	1381.2	
				7/22/75	34.7	1381.0	
				8/19/75	34.8	1380.9	
				9/16/75	35.0	1380.7	
02N/14W-14K03 S	19		1400.5	11/13/74	37.1	1363.4	1101
				4/02/75	36.3	1364.2	
02N/14W-14L02 S	19		1413.0	10/22/74	19.5	1393.5	1200
				11/15/74	20.3	1392.7	
				12/17/74	21.1	1391.9	
				4/24/75	29.1	1383.9	
				5/22/75	29.3	1383.7	
				6/17/75	29.9	1383.1	
				7/22/75	30.3	1382.7	
				8/19/75	30.3	1382.7	
				9/16/75	30.7	1382.3	
02N/14W-14Q01 S	19		1480.0	10/22/74	24.7	1455.3	1200
				11/15/74	25.3	1454.7	
				12/17/74	25.8	1454.2	
				4/24/75	26.3	1453.7	
				5/22/75	25.2	1454.8	
				6/17/75	25.3	1454.7	
				7/22/75	25.8	1454.2	
				8/19/75	26.3	1453.7	
				9/16/75	25.9	1454.1	
VERDUGO HYDRO SUBAREA						U-05.B4	
01N/13W-03D05 S	19		1160.0	10/31/74	102.7(1)	1057.3	1101
				11/30/74	96.1(1)	1063.9	
				12/31/74	76.1	1083.9	
				1/31/75	75.8	1084.2	
				2/28/75	101.1(1)	1058.9	
				3/31/75	92.0	1068.0	
				4/30/75	89.5	1070.5	
				5/31/75	89.0(1)	1071.0	
				6/30/75	93.7(1)	1066.3	
				7/31/75	96.2(1)	1063.8	
				8/31/75	107.5(1)	1052.5	
				9/30/75	100.0(1)	1060.0	
01N/13W-03G01 S	19		1170.0	11/04/74	NM-4		1101
				4/16/75	DRY		
01N/13W-05Q01 S	19		399.7	10/25/74	25.0	374.7	1200
				11/21/74	25.0	374.7	
				12/31/74	25.2	374.5	
				4/29/75	24.9	374.8	
				5/21/75	24.8	374.9	
				6/27/75	24.8	374.9	
				7/31/75	25.1	374.6	
				8/27/75	24.7	375.0	
				9/30/75	24.9	374.8	
01N/13W-10P01 S	19		1006.2	10/02/74	32.8	973.4	1101
				11/06/74	34.0	972.2	
				12/04/74	34.9	971.3	
				1/01/75	34.9	971.3	
				2/05/75	35.3	970.9	
				3/05/75	35.1	971.1	
				4/02/75	34.6	971.6	
				5/07/75	34.6	971.6	
				6/04/75	34.0	972.2	
				7/02/75	34.0	972.2	
				8/06/75	35.0	971.2	
				9/03/75	34.0	972.2	
01N/13W-10F01 S	19		964.4	10/02/74	34.7	929.7	1101
				11/06/74	30.9	933.5	
				12/04/74	31.5(5)	932.9	
				6/04/75	36.2(5)	928.2	
				7/09/75	36.2(5)	928.2	
				8/06/75	36.2(5)	928.2	
				9/03/75	37.2(5)	927.2	
01N/13W-10F02 S	19		964.5	10/02/74	29.7	934.8	1101
				11/06/74	29.6	934.9	
				12/04/74	31.8	932.7	
				1/01/75	34.2	930.3	
				2/05/75	27.8	936.7	
				3/05/75	29.3	935.2	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT SAN FERNANDO HYDRO SUBUNIT VERDUGO HYDRO SUBAREA						U-05 U-05.8 U-05.84	
01N/13W-10F02 S (CONTINUED)	19		964.5	4/02/75	30.3	934.2	1101
				5/07/75	29.7	934.8	
				6/04/75	32.0	932.5	
				7/02/75	31.0	933.5	
				8/06/75	32.0	932.5	
				9/03/75	32.0	932.5	
01N/13W-10F03 S	19		966.0	10/02/74	46.9(1)	919.1	1101
				11/06/74	55.9(1)	910.1	
				1/01/75	32.4(5)	933.6	
				2/05/75	89.7(1)	876.3	
				3/05/75	99.6(1)	866.4	
				4/02/75	91.7(1)	874.3	
				5/07/75	99.6(1)	866.4	
				6/04/75	100.4(1)	865.6	
				7/02/75	124.4(1)	841.6	
				8/06/75	95.4(1)	870.6	
				9/03/75	90.4(1)	875.6	
01N/13W-10G01 S	19		884.9	10/02/74	15.9	869.0	1101
				11/06/74	16.1	868.8	
				12/04/74	16.1	868.8	
				1/01/75	15.8	869.1	
				2/05/75	16.1	868.8	
				3/05/75	15.2	869.7	
				4/02/75	14.8	870.1	
				5/07/75	15.0	869.9	
				6/04/75	15.4	869.5	
				7/02/75	16.0	868.9	
				8/06/75	16.6	868.3	
				9/03/75	17.0	867.9	
01N/13W-15B01 S	19		851.5	10/02/74	13.9	837.6	1101
				11/06/74	14.1	837.4	
				12/04/74	14.2	837.3	
				1/01/75	14.1	837.4	
				2/05/75	14.3	837.2	
				3/05/75	14.0	837.5	
				4/02/75	13.6	837.9	
				5/07/75	13.8	837.7	
				6/04/75	14.0	837.5	
				7/02/75	14.2	837.3	
				8/06/75	14.5	837.0	
				9/03/75	14.7	836.8	
01N/13W-15B02 S	19		846.7	10/02/74	6.6	840.1	1101
				11/06/74	4.2	842.5	
				12/04/74	5.2	841.5	
				1/01/75	5.8	840.9	
				2/05/75	6.4	840.3	
				3/05/75	6.7	840.0	
				4/02/75	6.8	839.9	
				5/07/75	6.0	840.7	
				6/04/75	6.0	840.7	
				7/02/75	6.1	840.6	
				8/06/75	7.2	839.5	
				9/03/75	7.3	839.4	
01N/13W-15B03 S	19		831.5	10/02/74	9.9	821.6	1101
				11/06/74	7.2	824.3	
				12/04/74	7.2	824.3	
				1/01/75	7.1	824.4	
				2/05/75	7.1	824.4	
				3/05/75	7.0	824.5	
				4/02/75	6.8	824.7	
				5/07/75	7.0	824.5	
				6/04/75	7.1	824.4	
				7/07/75	7.3	824.2	
				8/06/75	7.5	824.0	
				9/03/75	7.5	824.0	
01N/13W-15B04 S	19		815.2	10/02/74	5.2	810.0	1101
				11/06/74	5.2	810.0	
				12/04/74	5.1	810.1	
				1/01/75	5.1	810.1	
				2/05/75	5.1	810.1	
				3/05/75	5.1	810.1	
				4/02/75	5.0	810.2	
				5/07/75	5.1	810.1	
				6/04/75	5.1	810.1	
				7/07/75	5.3	809.9	
				8/06/75	5.4	809.8	
				9/03/75	5.5	809.7	
01N/13W-15B05 S	19		826.1	10/02/74	10.9	815.2	1101
				11/06/74	11.1	815.0	
				12/04/74	11.0	815.1	
				1/01/75	10.9	815.2	
				2/05/75	9.3	816.8	
				3/05/75	10.6	815.5	
				4/02/75	10.6	815.5	
				5/07/75	10.8	815.3	
				6/04/75	10.9	815.2	
				7/02/75	11.0	815.1	
				8/06/75	11.1	815.0	
				9/03/75	10.6	815.5	
02N/13W-27N01 S	19		1695.0	10/23/74	162.9	1532.1	1101
				11/04/74	164.3	1530.7	
				12/09/74	163.0	1532.0	
				1/06/75	163.4	1531.6	
				2/05/75	163.7	1531.3	
LA-SAN GABRIEL RIVER HYDRO UNIT SAN FERNANDO HYDRO SUBUNIT VERDUGO HYDRO SUBAREA						U-05 U-05.8 U-05.84	
02N/13W-27N01 S (CONTINUED)	19		1695.0	3/03/75	164.0	1531.0	1101
				4/02/75	164.7	1530.3	
				5/06/75	164.5	1530.5	
				6/09/75	169.9	1525.1	
				7/24/75	165.5	1529.5	
				8/04/75	165.7	1529.3	
02N/13W-28N01 S	19		1413.0	10/31/74	74.6(1)	1338.4	1101
				11/30/74	66.2	1346.8	
				12/31/74	65.8	1347.2	
				1/31/75	59.4	1353.6	
				2/28/75	66.6	1346.4	
				3/31/75	75.3(1)	1337.7	
				4/30/75	76.2(1)	1336.8	
				5/31/75	71.0(1)	1342.0	
				6/30/75	74.5(1)	1338.5	
				7/31/75	64.5(1)	1348.5	
				8/31/75	58.3(1)	1354.7	
				9/30/75	68.2	1344.8	
02N/13W-29A01 S	19		1737.5	10/02/74	111.0	1626.5	1101
				11/06/74	102.0	1635.5	
				12/04/74	110.0	1627.5	
				1/01/75	98.0	1639.5	
				2/05/75	89.0	1648.5	
				3/05/75	101.0	1636.5	
				4/02/75	112.0	1625.5	
				5/07/75	98.0	1639.5	
				6/04/75	115.0	1622.5	
				7/02/75	116.0	1621.5	
				8/04/75	113.0	1624.5	
				9/03/75	119.0	1618.5	
02N/13W-29F01 S	19		1590.0	10/31/74	53.5(1)	1536.5	1101
				11/30/74	47.2(1)	1542.8	
				12/31/74	41.3	1548.7	
				1/31/75	44.0	1546.0	
				2/28/75	41.4(1)	1548.6	
				3/31/75	39.3(1)	1550.7	
				4/30/75	73.5(1)	1516.5	
				5/31/75	40.4(1)	1549.6	
				6/30/75	45.1(1)	1544.9	
				7/31/75	57.8(1)	1532.2	
				8/31/75	61.1(1)	1528.9	
				9/30/75	66.2(1)	1523.8	
02N/13W-29R01 S	19		1435.0	10/31/74	33.1	1401.9	1101
				4/16/75	NM-6		
02N/13W-29R02 S	19		1435.0	11/04/74	35.1	1399.9	1101
				4/16/75	NM-7		
				5/15/75	35.9	1399.1	
02N/13W-33C01 S	19		1374.0	10/31/74	68.5	1305.5	1101
				12/31/74	62.7	1311.3	
				1/31/75	58.8	1315.2	
				2/28/75	70.2	1303.8	
				3/31/75	65.2	1308.8	
				4/30/75	50.5	1323.5	
				5/31/75	58.9	1315.1	
				6/30/75	63.2	1310.8	
				7/31/75	64.9(1)	1309.1	
				8/31/75	62.2	1311.8	
				9/30/75	69.3	1304.7	
02N/13W-33C03 S	19		1350.0	10/30/74	64.5(1)	1285.5	1101
				12/31/74	64.8	1285.2	
				2/28/75	60.0	1290.0	
				3/31/75	58.5(1)	1291.5	
				4/30/75	72.5(1)	1277.5	
				5/31/75	55.7(1)	1294.3	
				6/30/75	79.7(1)	1270.3	
				7/31/75	58.4(1)	1291.6	
				8/31/75	59.9(5)	1290.1	
				9/30/75	62.5(5)	1287.5	
02N/13W-33C05 S	19		1341.0	11/04/74	38.4	1302.6	1101
				4/16/75	33.7	1307.3	
02N/13W-33C06 S	19		1350.0	10/30/74	71.3(1)	1278.7	1101
				12/31/74	94.1(5)	1255.9	
				1/31/75	80.2(5)	1269.8	
				2/28/75	94.5(1)	1255.5	
				3/31/75	92.3(1)	1257.7	
				4/30/75	106.5(1)	1243.5	
				6/30/75	81.7(1)	1268.3	
				7/31/75	75.4(1)	1274.6	
				8/31/75	65.3(5)	1284.7	
				9/30/75	80.6(1)	1269.4	
02N/13W-33G01 S	19		1300.0	10/31/74	65.7(1)	1234.3	1101
				11/30/74	67.7(1)	1232.3	
				12/31/74	59.4	1240.6	
				1/31/75	56.9	1243.1	
				2/28/75	58.4	1241.6	
				3/31/75	54.7	1245.3	
				4/30/75	48.5	1251.5	
				5/31/75	47.8	1252.2	
				6/30/75	50.2	1249.8	
				7/31/75	56.7	1243.3	
				8/31/75	51.0	1249.0	
				9/30/75	57.8	1242.2	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT SAN FERNANDO HYDRO SUBUNIT VERDUGO HYDRO SUBAREA						U-05 U-05.B U-05.B4	
02N/13W-33R01 S	19		1237.0	10/31/74	87.9(1)	1149.1	1101
				11/30/74	84.3	1152.7	
				12/31/74	76.9	1160.1	
				1/31/75	77.7	1159.3	
				2/28/75	88.8(1)	1148.2	
				3/31/75	76.5	1160.5	
				4/30/75	112.4(1)	1124.6	
				5/31/75	79.8(1)	1157.2	
				6/30/75	83.3(1)	1153.7	
				7/31/75	88.9(1)	1148.1	
				8/31/75	99.4(1)	1137.6	
				9/30/75	87.8	1149.2	
02N/13W-33R03 S	19		1224.5	10/30/74	68.0(1)	1156.5	1101
				12/09/74	67.2(5)	1157.3	
				1/31/75	57.5(5)	1167.0	
				2/28/75	56.8(5)	1167.7	
				3/31/75	45.2(5)	1179.3	
				4/30/75	45.9(5)	1178.6	
				5/30/75	47.4(5)	1177.1	
				6/30/75	56.7	1167.8	
				7/31/75	58.0(1)	1166.5	
				8/31/75	64.1(1)	1160.4	
				9/30/75	70.4(1)	1154.1	
02N/13W-33R05 S	19		1233.0	10/30/74	80.6(5)	1152.4	1101
				12/09/74	71.7(5)	1161.3	
				1/31/75	60.0(5)	1173.0	
				2/28/75	56.5(5)	1176.5	
				3/31/75	52.2(5)	1180.8	
				4/30/75	50.6(5)	1182.4	
				5/30/75	52.9(1)	1180.1	
				6/30/75	63.8(5)	1169.2	
				7/31/75	63.5(1)	1169.5	
				8/31/75	62.0(5)	1171.0	
				9/30/75	78.1(1)	1154.9	
02N/13W-33R07 S	19		1232.0	10/31/74	77.2(1)	1154.8	1101
				11/30/74	78.6	1153.4	
				12/31/74	67.4	1164.6	
				1/31/75	66.6	1165.4	
				2/28/75	72.7	1159.3	
				3/31/75	53.3	1178.7	
				4/30/75	57.8	1174.2	
				5/31/75	57.5	1174.5	
				6/30/75	72.2	1159.8	
				7/31/75	68.8	1163.2	
				8/31/75	75.1	1156.9	
				9/30/75	87.2(1)	1144.8	
EAGLE ROCK HYDRO SUBAREA						U-05.B5	
01N/13W-34R01 S	19		519.9	10/30/74	188.3	331.6	1200
				11/21/74	188.3	331.6	
				12/26/74	187.7	332.2	
				1/24/75	187.2	332.7	
				2/21/75	184.5	335.4	
				3/26/75	185.9	334.0	
				4/25/75	185.3	334.6	
				5/28/75	185.2	334.7	
				6/26/75	185.5	334.4	
				7/25/75	186.1	333.8	
				8/27/75	187.2	332.7	
				9/26/75	187.5	332.4	
RAYMOND HYDRO SUBUNIT PASADENA HYDRO SUBAREA						U-05.C U-05.C1	
01N/11W-07H01 S	19		1442.7	10/25/74	17.2	1425.5	5050
01N/11W-07N01 S	19		1340.0	10/25/74	109.3	1230.7	5050
01N/11W-07N02 S	19		1330.0	10/25/74	172.2	1157.8	5050
01N/11W-18C01 S	19		1187.5	10/25/74	58.4	1129.1	5050
01N/11W-29G01 S	19		521.0	10/25/74	27.6	493.4	5050
01N/11W-29L03 S	19		523.0	10/25/74	NM-5		5050
01N/11W-29N01 S	19		569.0	10/01/74	116.0(5)	453.0	5062
01N/11W-29N02 S	19		571.7	10/25/74	NM-7		5050
01N/11W-30D04 S	19		701.0	10/25/74	NM-1		5062
01N/11W-30H01 S	19		629.0	10/25/74	147.0	482.0	5050
01N/11W-30J01 S	19		600.6	10/01/74	157.4(5)	443.2	5062
				11/01/74	145.4(5)	455.2	
01N/11W-30K01 S	19		634.0	10/01/74	190.2(1)	443.8	5062
				11/01/74	164.2(5)	469.8	
01N/11W-30Q01 S	19		603.6	10/01/74	89.0	514.6	5062
				11/01/74	90.0	513.6	
01N/11W-30Q03 S	19		580.0	10/01/74	94.0(5)	486.0	5062
				11/01/74	93.0(5)	487.0	
01N/11W-30R01 S	19		581.0	10/01/74	119.5(5)	461.5	5062

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT RAYMOND HYDRO SUBUNIT PASADENA HYDRO SUBAREA						U-05 U-05.C U-05.C1	
01N/11W-30R03 S	19		585.0	10/01/74	152.0(5)	433.0	5062
01N/11W-31Q01 S	19		596.0	10/25/74	110.3	485.7	5050
				12/12/74	NM-5		1101
				5/12/75	NM-5		
01N/11W-31Q02 S	19		590.0	10/25/74	112.9	477.1	5050
01N/12W-07D01 S	19		1173.0	10/25/74	NM-7		5050
01N/12W-09R01 S	19		1109.3	10/25/74	184.5	924.8	5050
01N/12W-10A01 S	19		1354.0	10/25/74	NM-4		5050
01N/12W-10G01 S	19		1335.0	10/25/74	NM-7		5050
01N/12W-10H01 S	19		1272.0	12/02/74	194.7	1077.3	1101
				4/23/75	194.9	1077.1	
01N/12W-11F01 S	19		1277.0	10/25/74	NM-9		5050
01N/12W-11G01 S	19		1297.0	10/25/74	NM-7		5050
01N/12W-11J01 S	19		1115.0	10/25/74	25.6	1089.4	5050
01N/12W-11N03 S	19		1173.2	10/25/74	NM-7		5050
				12/02/74	DRY		1101
				4/23/75	DRY		
01N/12W-11N04 S	19		1173.2	10/25/74	356.6	816.6	5050
				12/02/74	358.2	815.0	1101
				4/23/75	355.8	817.4	
01N/12W-13C01 S	19		958.0	10/25/74	36.3	921.7	5050
01N/12W-13F03 S	19		964.6	10/25/74	218.0	746.6	5050
01N/12W-13H01 S	19		1155.8	10/25/74	118.7	1036.3	5050
01N/12W-13K01 S	19		865.0	10/25/74	351.5	513.5	5050
			862.4	11/13/74	361.2	501.2	1101
				12/11/74	363.9	498.5	
				1/09/75	366.8	495.6	
				2/06/75	355.3	507.1	
				3/20/75	344.6	517.8	
				4/01/75	347.7	514.7	
				5/06/75	344.5	517.9	
				6/09/75	343.4	519.0	
				7/25/75	NM-2		
				8/04/75	NM-1		
				9/03/75	NM-1		
01N/12W-13L01 S	19		903.3	10/25/74	135.2	768.1	5050
01N/12W-20A01 S	19		934.5	10/25/74	326.0(5)	608.5	5062
01N/12W-20R01 S	19		916.5	10/25/74	305.8(5)	610.7	5062
01N/12W-21K01 S	19		898.0	10/25/74	289.9(5)	608.1	5062
01N/12W-21K02 S	19		889.4	10/26/74	291.8(5)	597.6	5062
01N/12W-23G01 S	19		878.8	10/25/74	369.0(5)	509.0	5062
01N/12W-23L01 S	19		843.0	10/25/74	336.9	506.1	5062
				12/05/74	335.5	507.5	1101
				4/04/75	332.1	510.9	
				6/03/75	331.6	511.4	
01N/12W-24B02 S	19		775.6	11/20/74	21.1	754.5	1101
				4/15/75	NM-9		
01N/12W-24R04 S	19		775.7	10/25/74	NM-7		5050
				11/20/74	236.9	538.8	1101
				4/15/75	NM-9		
01N/12W-25R01 S	19		710.2	10/25/74	190.3(5)	519.9	5062
01N/12W-25R01 S	19		719.8	10/16/74	NM-9		5062
				8/01/75	199.0(5)	520.8	1101
				9/01/75	202.0(5)	517.8	
01N/12W-25G01 S	19		698.8	10/25/74	201.1	497.7	5050
01N/12W-25K01 S	19		679.6	10/25/74	NM-1		5050
01N/12W-25L01 S	19		683.0	10/24/74	201.2	481.8	5050
01N/12W-25L02 S	19		674.5	10/24/74	NM-3		5050
01N/12W-25R02 S	19		634.0	10/24/74	144.7	489.3	5050
01N/12W-26A01 S	19		754.2	10/01/74	260.6(5)	493.6	1101
				11/01/74	255.6(5)	498.6	
				2/01/75	250.6(5)	503.6	
				3/01/75	248.6(5)	505.6	
				4/01/75	250.6(5)	503.6	
				7/01/75	274.6(5)	479.6	
				9/01/75	265.6(5)	488.6	
01N/12W-26C01 S	19		791.0	10/25/74	289.5(5)	501.5	5062

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT RAYMOND HYDRO SUBUNIT PASADENA HYDRO SUBAREA						U-05 U-05.C U-05.C1	
01N/12W-26P01 S	19		681.6	10/01/74	189.5	492.1	1101
				11/01/74	189.5	492.1	
				12/01/74	189.5	492.1	
				1/01/75	181.5	500.1	
				2/01/75	174.5	507.1	
				6/01/75	175.5(5)	506.1	
				9/01/75	191.5(5)	490.1	
01N/12W-28N01 S	19		793.9	10/25/74	187.8	606.1	5050
01N/12W-28P01 S	19		776.0	10/25/74	299.3	476.7	5050
01N/12W-33E01 S	19		757.8	10/25/74	164.3	593.5	5050
01N/12W-33F02 S	19		756.5	10/25/74	142.0	614.5	5050
01N/12W-33G01 S	19		750.0	10/03/74	145.1	604.9	1101
				11/01/74	145.2	604.8	
				12/10/74	145.5	604.5	
				1/06/75	145.8	604.2	
				2/06/75	146.0	604.0	
				3/05/75	145.3	604.7	
				5/09/75	146.0	604.0	
				6/05/75	146.4	603.6	
				7/02/75	144.9	605.1	
				9/04/75	146.8	603.2	
01N/12W-33H01 S	19		748.5	10/25/74	NM-6		5062
01N/12W-33P01 S	19		689.0	10/25/74	NM-9		5050
01N/12W-34A01 S	19		736.0	10/25/74	231.2	504.8	5050
01N/12W-34C01 S	19		726.8	10/01/74	222.4(5)	504.4	1101
				11/01/74	200.4(5)	526.4	
				12/01/74	217.4(5)	509.4	
				1/01/75	192.4(5)	534.4	
				2/01/75	195.4(5)	531.4	
				3/01/75	220.4(5)	506.4	
				4/01/75	193.4(5)	533.4	
				6/01/75	237.4(5)	489.4	
				7/01/75	208.4(5)	518.4	
				8/01/75	224.4(5)	502.4	
				9/01/75	243.4(5)	483.4	
01N/12W-34F01 S	19		695.0	10/05/74	165.2(5)	529.8	5062
01N/12W-34E02 S	19		751.9	10/01/74	206.8	545.1	1101
				11/01/74	196.8	555.1	
				12/01/74	192.8	559.1	
				1/01/75	191.8	560.1	
				2/01/75	194.8	557.1	
				3/01/75	194.8	557.1	
				4/01/75	192.8	559.1	
				6/01/75	195.8	556.1	
				7/01/75	202.8	549.1	
				9/01/75	202.8	549.1	
01N/12W-34F04 S	19		667.3	10/09/74	212.3(5)	455.0	5062
01N/12W-34E11 S	19		711.0	10/25/74	167.6	543.4	5050
01N/12W-34H01 S	19		659.0	10/01/74	160.0	499.0	5062
				11/01/74	155.0	504.0	
01N/12W-34L01 S	19		703.0	10/25/74	218.1	484.9	5050
01N/12W-34N01 S	19		707.2	10/25/74	128.5	578.7	5050
01N/12W-35P01 S	19		671.0	10/01/74	179.0(5)	492.0	1101
				11/01/74	169.0(5)	502.0	
				12/01/74	166.0(5)	505.0	
				1/01/75	162.0(5)	509.0	
				2/01/75	166.0(5)	505.0	
				7/01/75	174.0(5)	497.0	
				8/01/75	171.0(5)	500.0	
				9/01/75	174.0(5)	497.0	
01N/12W-35Q01 S	19		693.0	10/01/74	199.6	493.4	5062
				11/01/74	195.6	497.4	
01N/12W-36A01 S	19		611.6	10/18/74	239.8(1)	371.8	5062
01N/12W-36C01 S	19		664.0	10/25/74	172.7	491.3	5050
01N/12W-36F01 S	19		623.1	10/25/74	200.5	422.6	5050
01N/12W-36F02 S	19		625.3	10/25/74	206.0	419.3	5050
01N/12W-36H01 S	19		606.0	10/25/74	149.9(5)	456.1	5050
01N/12W-36N02 S	19		550.0	10/16/74	460.0(1)	90.0	5062
01N/13W-02B01 S	19		1349.6	10/25/74	NM-7		5050
HONK HILL HYDRO SUBAREA						U-05.C2	
01N/12W-03D01 S	19		1800.0	10/25/74	64.9(1)	1735.1	5050
01N/12W-04D01 S	19		1510.0	10/25/74	264.7	1245.3	5050

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT RAYMOND HYDRO SUBUNIT HONK HILL HYDRO SUBAREA						U-05 U-05.C U-05.C2	
01N/12W-05G01 S	19		1302.0	10/25/74	285.9	1016.1	5050
01N/12W-05K01 S	19		1258.0	10/25/74	NM-7		5050
01N/12W-05H01 S	19		1090.0	10/25/74	145.8	944.2	5062
01N/12W-05N01 S	19		1070.0	10/26/74	121.4	948.6	5062
01N/12W-05P01 S	19		1201.7	10/24/74	NM-1		1101
				11/04/74	NM-1		
				12/02/74	NM-1		
				1/06/75	NM-1		
				2/05/75	261.6	940.1	
				3/03/75	259.1	942.6	
				4/01/75	249.6	952.1	
				5/06/75	248.6	953.1	
				6/09/75	247.6	954.1	
				7/25/75	293.5(6)	908.2	
				8/04/75	NM-1		
				9/08/75	NM-1		
01N/12W-05P02 S	19		1203.0	10/25/74	276.8	926.2	5050
01N/12W-05Q02 S	19		1202.9	10/25/74	265.4	937.4	5050
01N/12W-06M01 S	19		1179.0	10/25/74	184.3	994.7	5050
01N/12W-06M04 S	19		1172.0	10/01/74	NM-9		5062
01N/12W-06M05 S	19		1192.9	10/24/74	192.1	1000.8	1101
				11/04/74	191.7	1001.2	
				12/11/74	192.5	1000.4	
				1/06/75	192.6	1000.3	
				2/05/75	193.9	999.0	
				3/03/75	194.2	998.7	
				4/02/75	192.7	1000.2	
				5/06/75	189.9	1003.0	
				6/09/75	195.1	997.8	
				7/24/75	190.1	1002.8	
				8/04/75	193.4	999.5	
				9/15/75	198.7	994.2	
01N/12W-06M06 S	19		1161.0	10/25/74	166.5	994.5	5050
01N/12W-06M09 S	19		1153.0	10/01/74	156.8	996.2	5062
01N/12W-06Q01 S	19		1062.6	10/25/74	42.7	1019.9	5050
01N/12W-08D02 S	19		1090.0	10/25/74	229.0(5)	923.3	5062
01N/12W-08E01 S	19		1109.0	10/25/74	148.8	960.2	5062
01N/12W-08H01 S	19		1140.0	10/25/74	203.7	936.3	5050
01N/12W-08H02 S	19		1155.0	10/01/74	222.0	933.0	5062
				11/01/74	222.0	933.0	
01N/12W-08H03 S	19		1152.0	10/25/74	226.7	925.3	5050
01N/12W-08L02 S	19		1085.0	10/25/74	134.9	950.1	5062
01N/12W-09A01 S	19		1354.8	10/25/74	166.5	1188.3	5050
			1358.0	12/02/74	DRY		1101
				4/23/75	DRY		
01N/12W-09F01 S	19		1187.7	10/25/74	269.3	918.4	5050
01N/12W-09K01 S	19		1130.0	10/25/74	203.7	926.3	5050
01N/12W-09Q01 S	19		1129.2	10/25/74	198.0	931.2	5050
01N/12W-17Q01 S	19		1045.7	10/25/74	89.5	956.2	5062
01N/13W-01R01 S	19		1294.0	10/25/74	NM-7		5050
				11/13/74	192.2	1101.8	1101
01N/13W-01E01 S	19		1240.0	10/25/74	132.8	1107.2	5050
01N/13W-01F01 S	19		1185.0	10/25/74	93.5	1091.5	5050
01N/13W-01L01 S	19		1178.0	10/25/74	71.1	1106.9	5050
01N/13W-01N01 S	19		1330.0	10/25/74	58.5	1271.5	5050
01N/13W-02B01 S	19		1355.0	11/13/74	DRY		1101
				4/02/75	DRY		
02N/12W-33Q01 S	19		1685.0	10/25/74	NM-7		5050
02N/13W-34A03 S	19		1629.2	10/25/74	145.1	1484.1	5050
				11/14/74	145.0	1484.2	1101
02N/13W-34A04 S	19		1629.2	10/25/74	NM-7		5050
				11/14/74	DRY		1101
02N/13W-34A02 S	19		1632.0	10/25/74	132.2	1499.8	5050
				11/13/74	132.8	1499.2	1101

See page 79 for key to terms a abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT RAYMOND HYDRO SUBUNIT SANTA ANITA HYDRO SUBAREA						U-05 U-05.C U-05.C3	
01N/11W-15P01 S	19		740.3	11/06/74	DRY		1101
				4/02/75	DRY		
01N/11W-20Q01 S	19		659.3	10/25/74	184.2	475.1	5050
01N/11W-20Q02 S	19		697.5	10/25/74	85.9	611.6	5050
01N/11W-21C02 S	19		702.0	10/25/74	206.4	495.6	5050
01N/11W-21C03 S	19		703.8	10/25/74	208.2	495.6	5050
01N/11W-21C06 S	19		705.0	10/25/74	209.9	495.1	5050
01N/11W-21C07 S	19		680.0	10/25/74	184.7	495.3	5050
01N/11W-21G02 S	19		602.1	10/01/74	109.6(5)	492.4	5062
01N/11W-21G03 S	19		611.5	10/01/74	117.9(5)	493.6	5062
01N/11W-21G05 S	19		608.4	10/01/74	122.5(5)	485.9	5062
01N/11W-21H02 S	19		602.4	10/01/74	112.2(5)	490.2	5062
01N/11W-21H03 S	19		609.5	10/01/74	121.5(5)	488.0	5062
01N/11W-22F01 S	19		611.5	10/22/74	36.6	574.9	1101
				11/04/74	36.6	574.9	
				4/02/75	36.4	575.1	
01N/11W-22N03 S	19		522.0	11/04/74	NM-7		1101
				4/02/75	NM-9		
01N/11W-22N04 S	19		522.0	11/04/74	DRY (6)		1101
				4/02/75	DRY (6)		
01N/11W-22N05 S	19		522.9	11/04/74	DRY (6)		1101
				4/02/75	DRY (6)		
01N/11W-28C01 S	19		546.3	10/02/74	61.9	484.4	1101
				12/03/74	68.1	478.2	
				1/09/75	64.9	481.4	
				2/05/75	49.2	497.1	
				3/14/75	40.8	505.5	
				5/12/75	47.4	498.9	
				6/05/75	50.5	495.8	
				7/01/75	47.8	498.5	
				9/05/75	73.4	472.9	
SAN GABRIEL VALLEY HYDRO SUBUNIT MAIN SAN GABRIEL HYDRO SUBAREA						U-05.D U-05.D1	
01N/09W-19K01 S	19		1237.0	10/31/74	36.6	1200.4	1101
01N/09W-20J01 S	19		1122.0	10/04/74	30.3	1091.7	1101
				12/10/74	37.9	1084.1	
				1/09/75	21.7	1100.3	
				2/06/75	19.6	1102.4	
				4/15/75	15.0	1107.0	
01N/09W-29C01 S	19		968.0	11/12/74	410.8(4)	557.2	1101
				4/08/75	404.1	563.9	
01N/09W-29C02 S	19		950.0	11/12/74	380.5	569.5	1101
				4/08/75	388.0	562.0	
01N/09W-29F01 S	19		910.0	11/12/74	370.2	539.8	1101
				4/08/75	380.0	530.0	
01N/09W-29K01 S	19		935.0	10/04/74	349.1	585.9	1101
				12/13/74	351.5	583.5	
				1/09/75	348.4	586.6	
				2/07/75	353.2	581.8	
				3/05/75	353.6	581.4	
				4/04/75	352.1	582.9	
01N/09W-29N02 S	19		868.0	10/31/74	344.7	523.3	1101
				4/08/75	NM-5		
				5/15/75	335.4	532.6	
01N/09W-30R01 S	19		820.0	10/04/74	294.5	525.5	1101
				11/08/74	291.5	528.5	
				12/13/74	304.7	515.3	
				1/09/75	290.1	529.9	
				2/07/75	374.6(6)	445.4	
				3/05/75	291.8	528.2	
				4/01/75	289.4	530.6	
				5/07/75	290.3	529.7	
				6/26/75	292.7	527.3	
				7/09/75	295.1	524.9	
				8/12/75	300.1	519.9	
				9/10/75	300.5	519.5	
01N/09W-31P03 S	19		703.0	2/07/75	127.1	575.9	1101
				3/05/75	105.3	597.7	
01N/09W-32A02 S	19		868.8	11/08/74	133.5	735.3	1101
				4/04/75	134.7	734.1	
01N/09W-32H08 S	19		829.6	3/11/75	97.1	732.5	1101
				4/01/75	96.6	733.0	
				5/07/75	97.4	732.2	
				6/11/75	97.1	732.5	
LA-SAN GABRIEL RIVER HYDRO UNIT SAN GABRIEL VALLEY HYDRO SUBUNIT MAIN SAN GABRIEL HYDRO SUBAREA						U-05 U-05.D U-05.D1	
01N/09W-32H08 S (CONTINUED)	19		829.6	7/09/75	99.0	730.6	1101
				8/12/75	98.8	730.8	
				9/10/75	97.8	731.8	
01N/09W-35L02 S	19		1079.0	11/03/74	44.5	1034.5	1101
01N/09W-35L03 S	19		1090.0	11/13/74	62.0	1028.0	1101
				4/17/75	38.4	1051.6	
01N/09W-35P01 S	19		1047.0	11/13/74	122.8	924.2	1101
				4/07/75	123.5	923.5	
01N/09W-35P02 S	19		1054.0	10/08/74	125.7	928.3	1101
				12/11/74	128.6	925.4	
				1/09/75	129.3	924.7	
				2/07/75	130.9	923.1	
				3/07/75	134.6	919.4	
				4/01/75	130.4	923.6	
				5/07/75	122.5	931.5	
				6/10/75	138.5	915.5	
				7/09/75	140.9	913.1	
				8/12/75	NM-2		
				9/11/75	143.7	910.3	
01N/09W-35Q01 S	19		1073.0	11/13/74	147.3	925.7	1101
01N/09W-35Q03 S	19		1061.0	10/08/74	133.5	927.5	1101
				11/13/74	140.1	920.9	
01N/09W-35Q04 S	19		1060.0	11/13/74	137.0	923.0	1101
01N/09W-35Q05 S	19		1069.0	11/14/74	138.5	930.5	1101
				5/22/75	144.3	924.7	
01N/09W-36P01 S	19		1170.0	11/14/74	204.6	965.4	1101
				4/21/75	198.1	971.9	
01N/10W-25G01 S	19		882.0	10/31/74	137.8	744.2	1101
				4/02/75	134.6	747.4	
01N/10W-25G03 S	19		810.0	10/31/74	DRY		1101
01N/10W-25K01 S	19		717.0	10/31/74	FLOW		1101
01N/10W-25R01 S	19		703.2	10/17/74	262.4	440.8	1733
				11/07/74	262.2	441.0	
				12/19/74	272.6	430.6	
				1/09/75	262.1	441.1	
				2/20/75	262.0	441.2	
				3/13/75	263.7	439.5	
				4/03/75	260.2	443.0	
				5/15/75	262.5	440.7	
				6/05/75	261.6	441.6	
				7/17/75	267.3	435.9	
				8/07/75	NM-1		
				9/18/75	NM-1		
01N/10W-29R02 S	19		575.0	10/01/74	314.3	260.7	1101
				11/01/74	316.3	258.7	
				12/01/74	318.3	256.7	
				1/01/75	322.3	252.7	
				2/01/75	316.3	258.7	
				5/01/75	322.3	252.7	
				6/01/75	278.3	296.7	
01N/10W-31A01 S	19		510.3	10/17/74	272.9(4)	237.4	1733
				11/07/74	274.6(4)	235.7	
				12/19/74	276.0(4)	234.3	
				1/09/75	276.8(4)	233.5	
				2/20/75	279.1(4)	231.2	
				3/13/75	278.6	231.7	
				4/03/75	277.2(4)	233.1	
				5/15/75	243.7	266.6	
				6/05/75	240.8	269.5	
				7/17/75	264.6	245.7	
				8/07/75	272.8	237.5	
				9/18/75	279.9	230.4	
01N/10W-31M01 S	19		447.0	10/17/74	213.9	233.1	1733
				11/07/74	215.0	232.0	
				12/19/74	221.2	225.8	
				1/09/75	226.7	220.3	
				2/20/75	NM-9		
				3/13/75	NM-3		
				4/03/75	NM-3		
				5/15/75	226.2	220.8	
				6/05/75	199.2(4)	247.8	
				7/17/75	213.5(4)	233.5	
				8/07/75	221.1(4)	225.9	
				9/18/75	236.2	210.8	
01N/10W-32J01 S	19		547.7	11/01/74	308.7(2)	239.0	1101
				4/01/75	313.7(2)	234.0	
01N/10W-32J02 S	19		548.7	11/01/74	NM-1		1101
				4/01/75	NM-1		
01N/10W-33C01 S	19		550.0	11/01/74	301.5	248.5	1101
				4/15/75	314.8	235.2	
01N/10W-33M01 S	19		549.0	10/17/74	312.9	236.1	1733
				11/07/74	309.5	239.5	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT						U-05	
SAN GABRIEL VALLEY HYDRO SUBUNIT						U-05.0	
MAIN SAN GABRIEL HYDRO SUBAREA						U-05.01	
01N/10W-33M01 S (CONTINUED)	19		549.0	12/19/74	311.8	237.2	1733
				1/09/75	312.8	236.2	
				2/20/75	315.3	233.7	
				3/13/75	315.4	233.6	
				4/03/75	313.8	235.2	
				5/15/75	304.6	244.4	
				6/05/75	297.3	251.7	
				7/17/75	301.0	248.0	
				8/07/75	307.7	241.3	
				9/17/75	315.4	233.6	
01N/10W-34L01 S	19		556.0	11/01/74	271.0(5)	285.0	1101
				4/01/75	241.0	315.0	
01N/10W-34N01 S	19		428.3	10/31/74	187.4	240.9	1101
				4/01/75	198.4	229.9	
01N/10W-34N02 S	19		438.9	10/31/74	198.2	240.7	1101
				4/01/75	203.0	235.9	
01N/11W-13D01 S	19		334.5	10/01/74	105.6	228.9	1101
				12/03/74	108.7	225.8	
				17/15/74	102.0	232.5	
				1/08/75	108.6	225.9	
				2/05/75	109.1	225.4	
				3/05/75	111.9	222.6	
				4/14/75	109.7	224.8	
01N/11W-13L02 S	19		337.0	11/02/74	108.3	228.7	1101
				4/14/75	106.7	230.3	
01N/11W-14P01 S	19		309.8	10/01/74	83.4	226.4	1101
				12/03/74	87.2	222.6	
				1/08/75	85.7	224.1	
				2/05/75	86.2	223.6	
				3/05/75	87.2	222.6	
				4/14/75	86.6	223.2	
01N/11W-24F03 S	19		759.0	11/06/74	51.6	707.4	1101
				4/15/75	58.1	700.9	
01N/11W-24F01 S	19		748.9	11/06/74	DRY		1101
				4/15/75	DRY		
01N/11W-24L01 S	19		697.1	10/17/74	74.2	622.9	1733
				11/06/74	66.8	630.3	1101
				12/19/74	66.5	630.6	1733
				1/09/75	70.4	626.7	
				2/20/75	67.9	629.2	
				3/13/75	70.5	626.6	
				4/03/75	65.7	631.4	
				5/15/75	70.1	627.0	
				6/05/75	65.1	632.0	
				7/17/75	74.6	622.5	
				8/07/75	72.1	625.0	
				9/18/75	79.7	617.4	
01N/11W-26L08 S	19		284.2	10/01/74	59.2	225.0	1101
				12/03/74	60.7	223.5	
				1/08/75	61.5	222.7	
				2/06/75	62.3	221.9	
				3/05/75	62.8	221.4	
				4/14/75	61.8	222.4	
01N/11W-26L09 S	19		283.7	11/12/74	59.3	224.4	1101
				4/14/75	61.3	222.4	
01N/11W-26P04 S	19		287.0	11/12/74	64.4	222.6	1101
				4/02/75	68.2	218.8	
01N/11W-27F01 S	19		495.8	10/01/74	256.8(5)	239.0	5062
01N/11W-31R01 S	19		503.0	10/01/74	311.0(5)	192.0	5062
				11/01/74	308.0(5)	195.0	
01N/11W-32Q02 S	19		468.0	10/01/74	262.1(5)	205.9	5062
01N/11W-33Q01 S	19		407.8	10/02/74	171.7	236.1	1101
				12/03/74	172.2	235.6	
				1/09/75	172.5	235.3	
				2/05/75	173.2	234.6	
				3/14/75	173.7	234.1	
				5/12/75	174.5	233.3	
				6/05/75	174.8	233.0	
				7/01/75	175.1	232.7	
				9/05/75	176.6	231.2	
01N/11W-34N03 S	19		402.0	10/01/74	170.4(5)	231.6	5062
01N/11W-34N05 S	19		402.0	10/01/74	170.0(5)	232.0	5062
01N/11W-35L01 S	19		403.0	10/21/74	171.0(5)	232.0	1101
				11/14/74	173.0(5)	230.0	
				12/07/74	173.0(5)	230.0	
				1/21/75	173.0(5)	230.0	
				3/14/75	186.0(1)	217.0	
				4/14/75	174.0(5)	229.0	
				5/28/75	172.5(5)	230.5	
				6/14/75	172.0(5)	231.0	
				7/14/75	176.0(5)	227.0	
				8/14/75	176.0(5)	227.0	
				9/14/75	177.0(5)	226.0	
LA-SAN GABRIEL RIVER HYDRO UNIT						U-05	
SAN GABRIEL VALLEY HYDRO SUBUNIT						U-05.0	
MAIN SAN GABRIEL HYDRO SUBAREA						U-05.01	
01N/11W-36L01 S	19		413.5	10/17/74	NM-9		1733
				11/07/74	NM-9		
				12/19/74	NM-9		
				1/09/75	NM-9		
				2/20/75	NM-9		
				3/13/75	NM-9		
				4/03/75	184.3	229.2	
				5/15/75	NM-3		
				6/05/75	188.5	225.0	
				7/17/75	NM-3		
				8/07/75	196.1	217.4	
				9/18/75	199.3	214.2	
01N/11W-36R01 S	19		424.0	11/01/74	206.7	217.3	1101
				4/01/75	196.4	227.6	
01S/08W-06C01 S	19		1153.5	11/14/74	200.5	953.0	1101
				4/21/75	194.3	959.2	
01S/09W-01C02 S	19		1131.0	11/14/74	171.5	959.5	1101
				4/07/75	164.3	966.7	
01S/09W-01F01 S	19		1119.3	10/03/74	181.8	937.5	1101
				12/11/74	165.6	953.7	
				1/09/75	163.8	955.5	
				2/07/75	166.5	952.8	
				3/05/75	163.4	955.9	
				4/01/75	162.2	957.1	
				5/07/75	159.9	959.4	
				6/10/75	160.5	958.8	
				7/09/75	173.9	945.4	
				8/12/75	171.5	947.8	
				9/11/75	175.4	943.9	
01S/09W-01G01 S	19		1107.5	11/14/74	157.6	949.9	1101
				4/07/75	NM-5		
01S/09W-02C01 S	19		1046.1	11/14/74	NM-9		1101
01S/09W-02C03 S	19		1051.0	11/14/74	125.8	925.2	1101
01S/09W-02D01 S	19		1029.0	10/08/74	87.9	941.1	1101
				11/08/74	NM-2		
				12/17/74	103.3	925.7	
				5/22/75	113.1	915.9	
01S/09W-02H01 S	19		1080.0	10/03/74	135.4	944.6	1101
				12/11/74	130.9	949.1	
				1/09/75	129.8	950.2	
				2/07/75	128.3	951.7	
				3/05/75	129.4	950.6	
				4/01/75	128.1	951.9	
				5/07/75	126.9	953.1	
				6/10/75	144.8	935.2	
				7/09/75	131.7	948.3	
				8/12/75	143.2	936.8	
				9/11/75	131.8	948.2	
01S/09W-02Q01 S	19		1020.0	11/14/74	263.2	756.8	1101
				4/07/75	NM-1		
01S/09W-02Q02 S	19		1023.0	11/14/74	86.5	936.5	1101
				4/07/75	93.6	929.4	
01S/09W-03P01 S	19		975.0	10/03/74	152.7	822.3	1101
				11/08/74	135.5	839.5	
				12/11/74	129.7	845.3	
				1/09/75	130.4	844.6	
				2/07/75	137.2	837.8	
				3/05/75	153.4	821.6	
				4/01/75	160.4	814.6	
				5/07/75	161.3	813.7	
				6/11/75	161.6	813.4	
				7/09/75	162.2	812.8	
				8/12/75	165.4	809.6	
				9/11/75	161.5	813.5	
01S/09W-03C01 S	19		957.0	11/08/74	132.9(2)	824.1	1101
				4/02/75	NM-1		
01S/09W-03F01 S	19		930.0	11/08/74	NM-1		1101
				12/17/74	69.1(4)	860.9	
				4/17/75	79.6	850.4	
01S/09W-03G01 S	19		983.0	11/08/74	71.9	911.1	1101
				3/31/75	73.1	909.9	
01S/09W-03H01 S	19		1018.0	11/08/74	103.0	915.0	1101
				4/07/75	108.2	909.8	
01S/09W-04G01 S	19		883.7	10/03/74	98.0	785.7	1101
				11/08/74	98.7	785.0	
				12/11/74	99.2	784.5	
				1/09/75	98.0	785.7	
				2/06/75	99.9	783.8	
				3/05/75	101.1	782.6	
				4/01/75	99.9	783.8	
				5/07/75	99.5	784.2	
				6/11/75	98.3	785.4	
				7/09/75	99.5	784.2	
				8/12/75	99.4	784.3	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT						U-05	
SAN GABRIEL VALLEY HYDRO SUBUNIT						U-05.0	
MAIN SAN GABRIEL HYDRO SUBAREA						U-05.01	
01S/09W-04G01 S	19		883.7	9/11/75	99.2	784.5	1101
01S/09W-04J01 S	19		906.6	10/07/74	96.9	809.7	1101
				11/04/74	95.3	811.3	
				12/03/74	100.8	805.8	
				1/06/75	96.5	810.1	
				2/06/75	100.2	806.4	
				3/03/75	95.3	811.3	
				4/17/75	95.0	811.6	
				7/07/75	111.7	794.9	
01S/09W-05G01 S	19		797.0	10/31/74	151.4	645.6	1101
				3/31/75	133.3	663.7	
01S/09W-05G02 S	19		795.0	11/27/74	164.9	630.1	1101
				4/02/75	153.7	641.3	
01S/09W-05J01 S	19		821.6	10/08/74	150.5(4)	671.1	1101
				11/08/74	NM-1		
				12/11/74	143.9	677.7	
				1/09/75	138.2	683.4	
				2/07/75	165.5	656.1	
				3/05/75	NM-1		
				4/01/75	137.7	683.9	
				5/07/75	139.6	682.0	
				6/11/75	NM-1		
				7/09/75	NM-2		
01S/09W-06J01 S	19		741.0	10/04/74	DRY (6)		1101
				12/13/74	DRY (6)		
				1/09/75	DRY (6)		
				2/07/75	DRY (6)		
				3/05/75	DRY (6)		
01S/09W-08F01 S	19		728.4	10/31/74	221.5	506.9	1101
				4/02/75	222.3	506.1	
01S/09W-09R01 S	19		840.0	10/03/74	209.0	631.0	1101
				11/08/74	208.5	631.5	
				12/13/74	208.3	631.7	
				1/09/75	209.1	630.9	
				2/07/75	208.8	631.2	
				3/05/75	210.3	629.7	
01S/09W-09R02 S	19		870.0	10/03/74	209.0	661.0	1101
				11/08/74	209.2	660.8	
				12/13/74	209.1	660.9	
				1/09/75	209.3	660.7	
				2/07/75	209.8	660.2	
				3/05/75	210.1	659.9	
				4/01/75	210.3	659.7	
				5/07/75	210.7	659.3	
				6/10/75	210.9	659.1	
				7/09/75	210.5	659.5	
				8/12/75	211.1	658.9	
				9/11/75	210.1	659.9	
01S/09W-09F01 S	19		795.0	10/03/74	246.0	549.0	1101
				3/31/75	NM-9		
01S/09W-18A04 S	19		673.0	11/12/74	170.6	502.4	1101
				4/03/75	172.6	500.4	
01S/09W-19C03 S	19		526.0	11/12/74	101.3	424.7	1101
				4/03/75	NM-4		
01S/09W-32G02 S	19		700.0	11/19/74	6.5	693.5	1101
				4/03/75	NM-9		
01S/10W-01R01 S	19		657.0	10/17/74	DRY		1733
				11/07/74	DRY		
				12/19/74	DRY		
				1/09/75	DRY		
01S/10W-03A01 S	19		525.0	12/13/74	274.8	250.2	1101
01S/10W-03H01 S	19		517.0	11/01/74	NM-1		1101
				4/01/75	275.8	241.2	
01S/10W-03K02 S	19		496.0	10/16/74	257.2	238.8	1733
				11/06/74	255.8	240.2	
				12/18/74	257.0	239.0	
				1/08/75	257.0	239.0	
				2/19/75	256.0	240.0	
				3/12/75	261.0	235.0	
				4/02/75	260.7	235.3	
				5/14/75	259.9	236.1	
				6/04/75	257.3	238.7	
				7/16/75	257.8	238.2	
				8/06/75	261.3	234.7	
				9/17/75	263.4	232.6	
01S/10W-04G01 S	19		504.8	10/31/74	264.9	239.9	1101
				4/01/75	269.8	235.0	
01S/10W-05J01 S	19		473.0	10/17/74	DRY		1733
				11/07/74	DRY		
				12/19/74	DRY		
				1/09/75	DRY		
				2/20/75	DRY		
				3/13/75	DRY		
				4/03/75	NM-0		
LA-SAN GABRIEL RIVER HYDRO UNIT						U-05	
SAN GABRIEL VALLEY HYDRO SUBUNIT						U-05.0	
MAIN SAN GABRIEL HYDRO SUBAREA						U-05.01	
01S/10W-05J01 S (CONTINUED)	19		473.0	5/15/75	DRY		1733
				6/05/75	DRY		
				7/17/75	DRY		
				8/07/75	DRY		
				9/17/75	DRY		
01S/10W-05N01 S	19		443.0	10/17/74	208.1	234.9	1733
				11/07/74	209.3	233.7	
				12/19/74	210.8	232.2	
				1/09/75	211.3	231.7	
				2/20/75	212.7	230.3	
				3/13/75	212.8	230.2	
				4/03/75	212.2	230.8	
				5/15/75	206.6	236.4	
				6/05/75	202.4	240.6	
01S/10W-06J01 S	19		444.0	10/17/74	209.7	234.3	1733
				11/07/74	211.0	233.0	
				12/19/74	212.6	231.4	
				1/09/75	213.0	231.0	
				2/20/75	214.5	229.5	
				3/13/75	214.5	229.5	
				4/03/75	213.7	230.3	
				5/15/75	206.7	237.3	
				6/05/75	201.9	242.1	
				7/17/75	205.7	238.3	
				8/07/75	210.7	233.3	
				9/17/75	216.3	227.7	
01S/10W-06N02 S	19		404.0	11/02/74	NM-3		1101
01S/10W-07A02 S	19		425.0	11/12/74	220.5	204.5	1101
				4/23/75	NM-3		
01S/10W-07R02 S	19		386.7	10/02/74	153.2	233.5	1733
				11/01/74	154.9	231.8	1101
				12/02/74	156.1	230.6	
				1/01/75	156.5	230.2	1733
				2/03/75	157.4	229.3	1101
				3/03/75	158.1	228.6	
				4/02/75	157.9	228.8	1733
				5/02/75	156.5	230.2	1101
				6/02/75	154.1	232.6	
				7/02/75	151.9	234.8	1733
				8/01/75	155.2	231.5	1101
				9/02/75	159.2	227.5	
01S/10W-08A02 S	19		454.5	4/03/75	NM-1		1101
01S/10W-08R01 S	19		410.3	10/01/74	176.0	234.3	1101
				12/03/74	178.7	231.6	
				1/07/75	179.0	231.3	
				2/06/75	179.7	230.6	
				3/05/75	181.0	229.3	
				4/14/75	179.7	230.6	
01S/10W-09F01 S	19		440.0	10/31/74	207.6	232.4	1101
				4/14/75	211.0	229.0	
01S/10W-09F02 S	19		440.0	10/31/74	204.3	235.7	1101
01S/10W-09N01 S	19		452.0	10/31/74	216.6(2)	235.4	1101
				4/03/75	NM-1		
01S/10W-09J01 S	19		449.0	10/01/74	212.8	236.2	1101
				4/14/75	216.2	232.8	
01S/10W-10C01 S	19		471.0	10/16/74	234.2	236.8	1733
				11/06/74	235.0	236.0	
				12/18/74	234.8	236.2	
				1/08/75	234.7	236.3	
				2/19/75	237.0	234.0	
				3/12/75	237.1	233.9	
				4/02/75	238.5	232.5	
				5/14/75	237.7	233.3	
				6/04/75	234.7	236.3	
				7/16/75	236.2	234.8	
				8/06/75	238.6	232.4	
				9/17/75	240.6	230.4	
01S/10W-10P01 S	19		461.9	10/16/74	NM-9		1733
				11/06/74	222.5	239.4	
				12/18/74	223.4	238.5	
				1/08/75	223.6	238.3	
				2/19/75	224.6	237.3	
				3/12/75	225.3	236.6	
				4/02/75	225.4	236.5	
				5/14/75	225.1	236.8	
				6/04/75	224.5	237.4	
				7/16/75	223.6	238.3	
				8/06/75	224.7	237.2	
				9/17/75	NM-2		
01S/10W-11H01 S	19		562.2	10/31/74	DRY		1101
				4/02/75	NM-3		
01S/10W-12A01 S	19		647.1	10/17/74	239.4	407.7	1733
				11/07/74	239.7	407.4	
				12/19/74	240.2	406.9	
				1/09/75	240.7	406.4	
				2/20/75	241.3	405.8	
				3/13/75	241.4	405.7	

See page 79 for key to terms a abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT						U-05	
SAN GABRIEL VALLEY HYDRO SUBUNIT						U-05.0	
MAIN SAN GABRIEL HYDRO SUBAREA						U-05.01	
01S/10W-12A01 S (CONTINUED)	19		647.1	4/03/75	242.2	404.9	1733
				5/15/75	243.6	403.5	
				6/05/75	244.5	402.6	
				7/17/75	245.5	401.6	
				8/07/75	246.0	401.1	
				9/18/75	247.0	400.1	
01S/10W-12C18 S	19		599.0	10/31/74	195.0	404.0	1101
				4/02/75	201.9	397.1	
01S/10W-12R01 S	19		624.1	11/21/74	356.8	267.3	1101
				4/02/75	348.4	275.7	
01S/10W-13E01 S	19		550.0	12/17/74	387.2(1)	162.8	1101
				4/08/75	388.2	161.8	
01S/10W-13H01 S	19		587.0	10/04/74	316.0	271.0	1101
				11/08/74	316.5	270.5	
				12/13/74	314.3	272.7	
				1/09/75	317.2	269.8	
				2/07/75	319.7	267.3	
				3/06/75	319.8	267.2	
				4/01/75	320.1	266.9	
				5/07/75	319.9	267.1	
				6/11/75	318.0	269.0	
				7/09/75	321.0	266.0	
				8/12/75	321.0	266.0	
				9/11/75	NM-4		
01S/10W-13P01 S	19		527.8	10/04/74	257.4	270.4	1101
				11/12/74	258.1	269.7	
				4/02/75	259.1	268.7	
01S/10W-14A01 S	19		333.3	10/16/74	NM-1		1733
				11/06/74	84.9(4)	248.4	
				12/18/74	NM-1		
				1/08/75	NM-1		
				2/19/75	NM-1		
				3/12/75	NM-1		
				4/02/75	NM-1		
				5/14/75	NM-1		
				6/04/75	79.4	253.9	
				7/16/75	81.9	251.4	
				8/06/75	79.7	253.6	
				9/17/75	81.3	252.0	
01S/10W-14H01 S	19		493.0	10/16/74	243.5	249.5	1733
				11/06/74	244.2	248.8	
				12/18/74	244.7	248.3	
				1/08/75	244.8	248.2	
				2/19/75	245.3	247.7	
				3/12/75	245.8	247.2	
				4/02/75	246.0	247.0	
				5/14/75	245.1	247.9	
				6/04/75	244.9	248.1	
				7/16/75	245.2	247.8	
				8/06/75	246.0	247.0	
				9/17/75	247.8	245.2	
01S/10W-16B01 S	19		422.7	2/19/75	189.5	233.2	1733
				3/12/75	190.1	232.6	
				4/02/75	190.0	232.7	
				5/14/75	NM-1		
				6/04/75	NM-1		
				7/16/75	188.3	234.4	
				8/06/75	189.6	233.1	
				9/17/75	192.7	230.0	
01S/10W-17A01 S	19		401.5	10/16/74	168.5	233.0	1733
				11/06/74	169.2	232.3	
				12/18/74	170.3	231.2	
				1/08/75	170.5	231.0	
				2/19/75	171.4	230.1	
				3/12/75	172.0	229.5	
				4/02/75	172.8	228.7	
				5/14/75	171.9	229.6	
				6/04/75	169.3	232.2	
				7/16/75	173.4	228.1	
				8/06/75	NM-1		
				9/17/75	175.6	225.9	
01S/10W-17A02 S	19		401.3	10/16/74	168.4	232.9	1733
				11/06/74	169.1	232.2	
				12/18/74	170.1	231.2	
				1/08/75	170.4	230.9	
				2/19/75	171.2	230.1	
				3/12/75	171.8	229.5	
				4/02/75	172.7	228.6	
				5/14/75	172.3	229.0	
				6/04/75	169.2	232.1	
				7/16/75	169.8(2)	231.5	
				8/06/75	NM-1		
				9/17/75	175.7	225.6	
01S/10W-17N01 S	19		364.3	11/12/74	138.0	226.3	1101
				4/25/75	139.2	225.1	
01S/10W-18B01 S	19		422.7	10/16/74	187.2	235.5	1733
				11/06/74	187.6	235.1	
				12/18/74	188.5	234.2	
				1/08/75	188.7	234.0	
01S/10W-19C03 S	19		343.0	11/12/74	119.0	224.0	1101
01S/10W-19C03 S	19		343.0	4/03/75	120.0	223.0	1101
01S/10W-19K01 S	19		335.0	11/12/74	108.5	226.5	1101
				4/29/75	111.4	223.6	
01S/10W-19L02 S	19		332.0	10/15/74	112.5(5)	219.5	1101
				11/15/74	111.5(5)	220.5	
				1/15/75	113.5(5)	218.5	
				2/15/75	111.5(5)	220.5	
				3/15/75	113.5(5)	218.5	
				4/15/75	113.5(5)	218.5	
				5/15/75	113.5(5)	218.5	
				6/15/75	112.5(5)	219.5	
				7/15/75	113.5(5)	218.5	
				8/15/75	115.5(5)	216.5	
				9/15/75	117.5(5)	214.5	
01S/10W-22C01 S	19		430.0	10/04/74	191.2	238.8	1101
				11/08/74	191.7	238.3	
				4/29/75	193.7	236.3	
01S/10W-22N01 S	19		409.0	11/04/74	168.5(5)	240.5	1101
				1/06/75	166.5(5)	242.5	
01S/10W-22R01 S	19		427.2	10/16/74	186.7	240.5	1733
				11/06/74	186.5	240.7	
				12/18/74	185.9	241.3	
				1/08/75	185.2	242.0	
				2/19/75	184.5	242.7	
				3/12/75	184.5	242.7	
				4/02/75	184.6	242.6	
				5/14/75	186.0	241.2	
				6/04/75	186.9	240.3	
				7/16/75	189.2	238.0	
				8/06/75	190.3	236.9	
				9/17/75	191.7	235.5	
01S/10W-23F01 S	19		476.6	10/16/74	231.2	245.4	1733
				11/06/74	225.0	251.6	
				12/18/74	226.1	250.5	
				1/08/75	NM-8		
				2/19/75	226.3	250.3	
				3/12/75	226.3	250.3	
				4/02/75	228.9	247.7	
				5/14/75	228.3	248.3	
				6/04/75	227.7	248.9	
				7/16/75	240.7	235.9	
				8/06/75	247.0	229.6	
				9/17/75	231.5	245.1	
01S/10W-23J03 S	19		470.0	11/04/74	198.0(5)	272.0	1101
				1/06/75	193.0(5)	277.0	
				3/04/75	193.0(5)	277.0	
				5/05/75	195.0(5)	275.0	
				7/02/75	200.0(5)	270.0	
				9/02/75	230.0(1)	240.0	
01S/10W-23K01 S	19		458.0	11/04/74	202.5(5)	255.5	1101
				1/06/75	198.5(5)	259.5	
				3/03/75	201.5(5)	256.5	
				5/02/75	197.5(5)	260.5	
				7/02/75	254.5(1)	203.5	
				9/02/75	262.5(1)	195.5	
01S/10W-23K02 S	19		459.2	11/04/74	203.0(5)	256.2	1101
				1/06/75	201.0(5)	258.2	
				3/03/75	203.0(5)	256.2	
				5/02/75	201.0(5)	258.2	
				6/03/75	278.0(1)	181.2	
				7/02/75	282.0(1)	177.2	
				9/02/75	279.0(1)	180.2	
01S/10W-23L01 S	19		448.0	11/04/74	188.0(5)	260.0	1101
				1/05/75	179.0(5)	269.0	
				3/03/75	190.0(5)	258.0	
				5/01/75	186.0(5)	262.0	
				6/03/75	207.0(1)	241.0	
				7/02/75	212.0(1)	236.0	
				9/02/75	218.0(1)	230.0	
01S/10W-23M04 S	19		444.0	1/06/75	187.5(5)	256.5	1101
				3/03/75	221.5(1)	222.5	
				5/02/75	188.5(5)	255.5	
				7/02/75	235.5(1)	208.5	
				9/02/75	239.5(1)	204.5	
01S/10W-23R01 S	19		378.0	1/06/75	193.9(1)	184.1	1101
				3/04/75	190.9(1)	187.1	
				5/02/75	192.9(1)	185.1	
				6/03/75	185.9(1)	192.1	
				7/02/75	195.9(1)	182.1	
				9/02/75	202.9(1)	175.1	
01S/10W-24001 S	19		503.1	10/04/74	238.2	264.9	1101
				11/12/74	235.3	267.8	
				4/02/75	235.4	267.7	
01S/10W-24F01 S	19		484.4	10/04/74	194.2(8)	290.2	1101
				11/12/74	194.5(8)	289.9	
				4/03/75	187.4(8)	297.0	
01S/10W-24H01 S	19		471.7	11/12/74	220.3	251.4	1101

See page 79 for key to terms a abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT SAN GABRIEL VALLEY HYDRO SUBUNIT MAIN SAN GABRIEL HYDRO SUBAREA						U-05 U-05.D U-05.D1	
01S/10W-24H01 S	19		471.7	4/02/75	NM-3		1101
01S/10W-24H02 S	19		472.0	11/12/74	220.7	251.3	1101
				4/02/75	224.3	247.7	
01S/10W-27C02 S	19		412.0	11/04/74	184.0(1)	228.0	1101
				1/06/75	176.0(5)	236.0	
				3/03/75	178.0(5)	234.0	
				5/05/75	177.0(5)	235.0	
				6/02/75	189.0(1)	223.0	
				7/02/75	185.0(1)	227.0	
				9/02/75	187.0(1)	225.0	
01S/10W-28H02 S	19		397.0	11/04/74	165.0(5)	232.0	1101
				1/06/75	164.0(5)	233.0	
				3/04/75	165.0(5)	232.0	
				5/02/75	164.0(5)	233.0	
				7/02/75	204.0(1)	193.0	
				9/02/75	202.0(1)	195.0	
01S/10W-28K01 S	19		379.0	11/04/74	180.2(1)	198.8	1101
				1/06/75	179.7(1)	199.3	
				3/04/75	176.7(1)	202.3	
				5/02/75	169.7(1)	209.3	
				6/03/75	181.7(1)	197.3	
				7/02/75	178.7(1)	200.3	
				9/02/75	182.7(1)	196.3	
01S/10W-28K05 S	19		378.0	11/04/74	151.9(5)	226.1	1101
01S/10W-29A05 S	19		367.0	10/04/74	137.6	229.4	1101
				11/08/74	135.4	231.6	
				4/03/75	138.5	228.5	
01S/10W-29E07 S	19		338.0	10/16/74	113.1	224.9	1733
				11/06/74	112.1	225.9	
				12/18/74	111.9	226.1	
				1/08/75	111.5	226.5	
				2/19/75	112.3	225.7	
				3/12/75	112.4	225.6	
				4/02/75	112.7	225.3	
				5/14/75	112.3	225.7	
				6/04/75	115.2	222.8	
				7/16/75	116.0	222.0	
				8/06/75	116.6	221.4	
				9/17/75	117.6	220.4	
01S/10W-29G02 S	19		354.0	10/16/74	126.6	227.4	1733
				11/06/74	NM-1		
				12/18/74	126.1	227.9	
				1/08/75	125.7	228.3	
				2/19/75	127.8	226.2	
				3/12/75	128.8	225.2	
				4/02/75	129.9	224.1	
				5/14/75	NM-1		
				6/04/75	NM-1		
				7/16/75	130.2	223.8	
				8/06/75	129.4	224.6	
				9/17/75	133.3	220.7	
01S/10W-30K01 S	19		327.1	11/07/74	DRY		1101
01S/10W-30L05 S	19		321.0	11/07/74	100.3	220.7	1101
				4/02/75	101.4	219.6	
01S/10W-31A02 S	19		320.0	10/14/74	103.7	216.3	1733
				11/06/74	96.6	223.4	
				12/18/74	96.0	224.0	
				1/08/75	95.8	224.2	
				2/19/75	97.7	222.3	
				3/12/75	97.3	222.7	
				4/02/75	96.7	223.3	
				5/14/75	103.0	217.0	
				6/04/75	104.0	216.0	
				7/16/75	105.0	215.0	
				8/06/75	NM-2		
				9/17/75	107.8	212.2	
01S/10W-31A03 S	19		320.5	11/01/74	97.5(5)	223.0	1101
				1/05/75	167.5(1)	153.0	
				3/03/75	92.5(5)	228.0	
				5/02/75	163.5(1)	157.0	
				6/03/75	166.5(1)	154.0	
				7/01/75	181.5(1)	139.0	
				9/03/75	192.5(1)	128.0	
01S/10W-31B01 S	19		314.0	10/15/74	93.5(5)	220.5	1101
				11/15/74	93.5(5)	220.5	
				1/15/75	96.5(5)	217.5	
				2/15/75	91.5(5)	222.5	
				3/15/75	89.5(5)	224.5	
				4/15/75	89.5(5)	224.5	
				5/15/75	97.5(5)	216.5	
				6/15/75	94.5(5)	219.5	
				7/15/75	101.5(5)	212.5	
				8/15/75	100.5(5)	213.5	
				9/15/75	103.5(5)	210.5	
01S/10W-31F01 S	19		306.4	10/15/74	89.0(5)	217.4	1101
				11/15/74	88.0(5)	218.4	
				1/15/75	91.0(5)	215.4	
				2/15/75	82.0(5)	224.4	
LA-SAN GABRIEL RIVER HYDRO UNIT SAN GABRIEL VALLEY HYDRO SUBUNIT MAIN SAN GABRIEL HYDRO SUBAREA						U-05 U-05.D U-05.D1	
01S/10W-31E01 S (CONTINUED)	19		306.4	3/15/75	81.0(5)	225.4	1101
				4/15/75	81.0(5)	225.4	
				5/15/75	93.0(5)	213.4	
				6/15/75	91.0(5)	215.4	
				7/15/75	96.0(5)	210.4	
				9/15/75	97.0(5)	209.4	
01S/10W-31F03 S	19		309.0	10/15/74	95.5	213.5	1101
				11/15/74	92.5	216.5	
				1/15/75	98.5	210.5	
				2/15/75	93.5	215.5	
				3/15/75	88.5	220.5	
				4/15/75	88.5	220.5	
				5/15/75	97.5	211.5	
				6/15/75	95.5	213.5	
				7/15/75	95.5	213.5	
				9/15/75	104.5	204.5	
01S/10W-31G04 S	19		312.0	11/01/74	81.0(5)	231.0	1101
				1/02/75	80.0(5)	232.0	
				3/05/75	79.5(5)	232.5	
				5/01/75	116.5(1)	195.5	
				6/03/75	116.5(1)	195.5	
				7/01/75	116.5(1)	195.5	
				9/03/75	118.5(1)	193.5	
01S/10W-31G04 S	19		312.0	11/01/74	202.4(1)	109.6	1101
				1/06/75	93.4(5)	218.6	
				3/03/75	89.4(5)	222.6	
				5/01/75	92.4(5)	219.6	
				7/01/75	193.4(1)	118.6	
				9/03/75	183.4(1)	128.6	
01S/10W-31L01 S	19		306.6	10/15/74	94.0(5)	212.6	1101
				11/15/74	93.0(5)	213.6	
				1/15/75	93.0(5)	213.6	
				2/15/75	93.0(5)	213.6	
				3/15/75	92.0(5)	214.6	
				4/15/75	91.0(5)	215.6	
				5/15/75	96.0(5)	210.6	
				6/15/75	94.0(5)	212.6	
				7/15/75	100.0(5)	206.6	
				9/15/75	101.0(5)	205.6	
01S/10W-31P01 S	19		304.6	10/15/74	99.5(5)	205.1	1101
				11/15/74	116.5(5)	188.1	
				1/15/75	91.5(5)	213.1	
				2/15/75	96.5(5)	208.1	
				3/15/75	94.5(5)	210.1	
				4/15/75	92.5(5)	212.1	
				5/15/75	94.5(5)	210.1	
				6/15/75	93.5(5)	211.1	
				7/15/75	94.5(5)	210.1	
				9/15/75	101.5(5)	203.1	
01S/10W-31P05 S	19		303.0	10/15/74	104.5(5)	198.5	1101
				11/15/74	111.5(5)	191.5	
				1/15/75	104.5(5)	198.5	
				2/15/75	99.5(5)	203.5	
				3/15/75	94.5(5)	208.5	
				4/15/75	99.5(5)	203.5	
				5/15/75	100.5(5)	202.5	
				6/15/75	96.5(5)	206.5	
				7/15/75	98.5(5)	204.5	
				9/15/75	119.5(5)	183.5	
01S/10W-32B01 S	19		341.0	11/04/74	145.2(1)	195.8	1101
				1/06/75	110.2(5)	230.8	
				3/04/75	112.2(5)	228.8	
				5/02/75	144.2(1)	196.8	
				6/03/75	145.2(1)	195.8	
				7/02/75	147.2(1)	193.8	
				9/03/75	149.2(1)	191.8	
01S/10W-32N02 S	19		314.4	10/04/74	90.0	224.4	1101
				11/12/74	90.7	223.7	
				4/02/75	87.5	226.9	
01S/10W-33P01 S	19		343.0	11/12/74	91.8	251.2	1101
				4/03/75	92.8	250.2	
01S/11W-01B05 S	19		404.4	3/03/75	174.6	229.8	1101
				4/01/75	174.1	230.3	
				5/12/75	169.5	234.9	
				6/03/75	164.8	239.6	
				7/01/75	164.1	240.3	
				9/05/75	176.0	228.4	
01S/11W-02A01 S	19		375.0	10/01/74	139.9	235.1	1101
				12/03/74	NM-2		
				1/02/75	NM-2		
				2/06/75	NM-2		
				3/03/75	NM-2		
				4/03/75	NM-2		
				5/12/75	NM-2		
01S/11W-02B01 S	19		368.0	11/01/74	134.5(5)	233.5	1101
				12/01/74	133.5(5)	234.5	
				1/28/75	137.5(5)	230.5	
				2/25/75	144.5(5)	223.5	
				3/23/75	135.5(5)	232.5	
				4/28/75	136.5(5)	231.5	

See page 79 for key to terms & abbreviations'

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT SAN GABRIEL VALLEY HYDRO SUBUNIT MAIN SAN GABRIEL HYDRO SUBAREA						U-05 U-05.0 U-05.01	
01S/11W-02B01 S (CONTINUED)	19		368.0	6/01/75	144.5(5)	223.5	1101
				7/20/75	137.5(5)	230.5	
				8/31/75	142.5(5)	225.5	
				9/30/75	145.5(5)	222.5	
01S/11W-02C01 S	19		367.5	10/21/74	134.0(1)	233.5	1101
				11/14/74	135.0(1)	232.5	
				12/21/74	131.0(5)	236.5	
				1/14/75	134.0(1)	233.5	
				2/14/75	132.0(5)	235.5	
				3/21/75	145.0(1)	222.5	
				4/14/75	146.0(5)	221.5	
				5/21/75	141.0(5)	226.5	
				6/21/75	138.0(5)	229.5	
				7/28/75	143.0(5)	224.5	
				8/14/75	147.5(5)	220.0	
				9/14/75	152.5(1)	215.0	
01S/11W-02F01 S	19		360.0	10/01/74	131.3(5)	228.7	5062
01S/11W-02F02 S	19		360.0	10/01/74	129.7(5)	230.3	5062
01S/11W-02G01 S	19		368.0	11/01/74	136.9(5)	231.1	1101
				12/01/74	134.9(5)	233.1	
				1/28/75	125.9(5)	242.1	
				2/25/75	134.9(5)	233.1	
				3/23/75	136.9(5)	231.1	
				4/28/75	136.9(5)	231.1	
				6/01/75	136.9(5)	231.1	
				7/31/75	131.9(5)	236.1	
				8/31/75	144.9(5)	223.1	
				9/30/75	149.9(5)	218.1	
01S/11W-02H01 S	19		376.0	11/01/74	143.5(5)	232.5	1101
				12/01/74	146.5(5)	229.5	
				1/28/75	144.5(5)	231.5	
				2/25/75	148.5(5)	227.5	
				3/23/75	147.5(5)	228.5	
				4/28/75	143.5(5)	232.5	
				6/01/75	145.5(5)	230.5	
				7/31/75	137.5(5)	238.5	
				8/31/75	151.5(5)	224.5	
				9/30/75	153.5(5)	222.5	
01S/11W-02K04 S	19		357.0	10/02/74	127.0	230.0	1733
				11/13/74	130.7	226.3	
				12/04/74	130.7	226.3	
				1/15/75	132.7	224.3	
				2/05/75	134.6	222.4	
				3/19/75	DRY		
				4/09/75	132.1	224.9	
				5/21/75	132.5	224.5	
				6/11/75	130.8	226.2	
				7/02/75	131.6	225.4	
				8/13/75	DRY		
				9/03/75	DRY		
01S/11W-02L02 S	19		354.0	11/06/74	DRY		1101
01S/11W-02L03 S	19		346.5	10/01/74	118.2	228.3	1101
				12/03/74	119.8	226.7	
				1/02/75	120.3	226.2	
				2/05/75	121.2	225.3	
				3/03/75	122.4	224.1	
				4/01/75	122.0	224.5	
01S/11W-02N01 S	19		348.0	4/01/75	NM-3		1101
01S/11W-02N02 S	19		345.0	11/06/74	DRY		1101
01S/11W-03P02 S	19		342.5	10/02/74	108.8	233.7	1733
				11/13/74	110.3	232.2	
				12/04/74	110.1	232.4	
				1/15/75	110.9	231.6	
				2/05/75	111.7	230.8	
				3/19/75	112.6	229.9	
				4/09/75	112.5	230.0	
				5/21/75	112.1	230.4	
				6/11/75	111.7	230.8	
				7/02/75	113.0	229.5	
				8/13/75	114.7	227.8	
				9/03/75	115.5	227.0	
01S/11W-03Q05 S	19		345.7	10/01/74	110.5	235.2	1101
				4/01/75	114.4	231.3	
01S/11W-04L02 S	19		369.5	10/01/74	130.9(5)	238.6	5062
01S/11W-06D01 S	19		506.0	10/15/74	337.0(5)	169.0	1101
				11/22/74	330.0(5)	176.0	
				12/13/74	332.0(5)	174.0	
				1/08/75	328.0(5)	178.0	
				2/16/75	327.0(5)	179.0	
				3/16/75	327.0(5)	179.0	
				4/15/75	325.0(5)	181.0	
				5/15/75	332.0(5)	174.0	
				6/21/75	329.0(5)	177.0	
				7/15/75	356.0(1)	150.0	
				8/15/75	334.0(5)	172.0	
01S/11W-06D02 S	19		501.3	10/09/74	338.0(5)	163.3	1101
				11/15/74	325.0(5)	176.3	

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT SAN GABRIEL VALLEY HYDRO SUBUNIT MAIN SAN GABRIEL HYDRO SUBAREA						U-05 U-05.0 U-05.01	
01S/11W-06D02 S (CONTINUED)	19		501.3	12/13/74	340.0(5)	161.3	1101
				1/15/75	341.0(5)	160.3	
				2/14/75	342.0(5)	159.3	
				3/15/75	340.0(5)	161.3	
				4/15/75	335.0(5)	166.3	
				5/15/75	342.0(5)	159.3	
				6/21/75	336.0(5)	165.3	
				7/12/75	343.0(5)	158.3	
				8/15/75	349.0(5)	152.3	
				9/15/75	343.0(5)	158.3	
01S/11W-06J01 S	19		455.0	10/15/74	NM-7		1101
				11/27/74	273.7(5)	181.3	
				12/15/74	273.7(5)	181.3	
				1/15/75	273.7(5)	181.3	
				2/15/75	273.7(5)	181.3	
				3/15/75	273.7(5)	181.3	
				6/17/75	273.7(5)	181.3	
				7/15/75	308.7(1)	146.3	
				8/15/75	310.7(1)	144.3	
				9/15/75	308.7(1)	146.3	
01S/11W-06M02 S	19		468.8	10/02/74	237.3	231.5	1101
				11/01/74	237.3	231.5	
				12/03/74	237.3	231.5	
				1/06/75	237.3	231.5	
				2/04/75	237.4	231.4	
				3/07/75	237.6	231.2	
01S/11W-07C01 S	19		423.4	10/02/74	215.7	207.7	1101
				11/01/74	215.2	208.2	
				3/31/75	214.8	208.6	
01S/11W-07N01 S	19		370.0	10/01/74	204.4(5)	165.6	1101
				11/01/74	201.4(5)	168.6	
				12/01/74	198.4(5)	171.6	
				1/01/75	198.4(5)	171.6	
				2/01/75	197.4(5)	172.6	
				3/01/75	197.4(5)	172.6	
				4/01/75	196.4(5)	173.6	
				5/01/75	199.4(5)	170.6	
				6/01/75	204.4(5)	165.6	
				7/01/75	210.4(5)	159.6	
				8/01/75	209.4(5)	160.6	
				9/01/75	207.4(5)	162.6	
01S/11W-07N02 S	19		365.0	10/01/74	189.0	176.0	1101
				11/01/74	185.0	180.0	
				12/01/74	184.0	181.0	
				1/01/75	184.0	181.0	
				2/01/75	184.0	181.0	
				3/01/75	182.0	183.0	
				4/01/75	182.0	183.0	
				5/01/75	187.0	178.0	
				6/01/75	190.0	175.0	
				7/01/75	192.0	173.0	
				8/01/75	197.0	168.0	
				9/01/75	196.0	169.0	
01S/11W-08A03 S	19		378.0	10/01/74	178.0(5)	200.0	5062
01S/11W-08F02 S	19		381.0	10/01/74	206.5(5)	174.5	1101
				11/01/74	205.5(5)	175.5	
				12/01/74	204.5(5)	176.5	
				1/01/75	203.5(5)	177.5	
				2/01/75	204.5(5)	176.5	
				3/01/75	203.5(5)	177.5	
				4/01/75	194.5(5)	186.5	
				5/01/75	202.5(5)	178.5	
				6/01/75	205.5(5)	175.5	
				7/01/75	227.5(5)	153.5	
				9/01/75	215.5(5)	165.5	
01S/11W-08J01 S	19		349.0	10/02/74	110.3	238.7	1733
				11/13/74	109.6	239.4	
				12/04/74	110.6	238.4	
				1/15/75	111.1	237.9	
				2/05/75	111.5	237.5	
				3/19/75	111.5	237.5	
				4/09/75	111.7	237.3	
				5/21/75	112.5	236.5	
				6/11/75	112.6	236.4	
				7/02/75	112.8	236.2	
				8/13/75	113.4	235.6	
				9/03/75	113.7	235.3	
01S/11W-08J07 S	19		350.0	10/01/74	156.9	193.1	1101
				11/01/74	158.9	191.1	
				12/01/74	144.9	205.1	
				1/01/75	158.9	191.1	
				2/01/75	156.9	193.1	
				3/01/75	182.9(1)	167.1	
				4/01/75	160.9	189.1	
				5/01/75	160.9	189.1	
				6/01/75	164.9	185.1	
				7/01/75	169.9	180.1	
				9/01/75	184.9	165.1	
01S/11W-08K01 S	19		350.0	10/01/74	114.0(6)	236.0	1101
				11/01/74	114.0(6)	236.0	
				1/01/75	115.0(5)	235.0	
				2/01/75	116.0(5)	234.0	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT						U-05	
SAN GABRIEL VALLEY HYDRO SUBUNIT						U-05.0	
MAIN SAN GABRIEL HYDRO SUBAREA						U-05.01	
01S/11W-08K01 S (CONTINUED)	19		350.0	3/01/75	116.0(5)	234.0	1101
				4/01/75	116.0(5)	234.0	
				6/01/75	114.0(5)	236.0	
				7/01/75	115.0(5)	235.0	
				9/01/75	117.0(5)	233.0	
01S/11W-08K02 S	19		350.0	10/01/74	108.0	242.0	1101
				11/01/74	108.0	242.0	
01S/11W-09G03 S	19		331.2	10/02/74	94.9	236.3	1101
				3/31/75	97.4	233.8	
01S/11W-09Q01 S	19		306.4	10/02/74	71.5	234.9	1733
				11/13/74	72.1	234.3	
				12/04/74	72.4	234.0	
				1/15/75	73.2	233.2	
				2/05/75	73.6	232.8	
				3/19/75	74.2	232.2	
				4/09/75	74.6	231.8	
				5/21/75	NM-6		
				6/11/75	NM-6		
01S/11W-09Q04 S	19		311.0	10/21/74	97.0(5)	214.0	1101
				11/21/74	95.0(5)	216.0	
				12/14/74	95.0(5)	216.0	
				1/21/75	95.0(5)	216.0	
				2/14/75	96.5(5)	214.5	
				3/14/75	97.0(5)	214.0	
				4/14/75	96.0(5)	215.0	
				5/21/75	98.0(5)	213.0	
				6/21/75	97.0(5)	214.0	
				7/14/75	99.0(5)	212.0	
				8/14/75	102.0(5)	209.0	
				9/14/75	101.0(5)	210.0	
01S/11W-10F01 S	19		325.0	10/21/74	98.5(1)	226.5	1101
				11/14/74	89.5(5)	235.5	
01S/11W-10F02 S	19		330.0	10/21/74	102.0(5)	228.0	1101
				11/14/74	101.0(5)	229.0	
			325.0	12/14/74	91.5(5)	233.5	
				1/14/75	90.5(5)	234.5	
				2/14/75	93.5(5)	231.5	
				3/14/75	103.5(1)	221.5	
				4/07/75	93.5(5)	231.5	
				28/75	92.5(5)	232.5	
				14/75	106.0(5)	224.0	
				8/21/75	95.5(5)	229.5	
				9/07/75	97.5(5)	227.5	
01S/11W-10H01 S	19		325.0	11/06/74	95.9	229.1	1101
				4/01/75	98.6(8)	226.4	
01S/11W-10N06 S	19		310.0	10/15/74	90.0(5)	220.0	1101
				11/15/74	90.0(5)	220.0	
				1/15/75	106.0(5)	204.0	
				2/15/75	90.0(5)	220.0	
				3/15/75	89.0(5)	221.0	
				4/15/75	89.0(5)	221.0	
				5/15/75	89.0(5)	221.0	
				6/15/75	91.0(5)	219.0	
				7/15/75	93.0(5)	217.0	
				8/15/75	95.0(5)	215.0	
				9/15/75	97.0(5)	213.0	
01S/11W-10N08 S	19		310.0	10/15/74	85.0(5)	225.0	1101
				11/15/74	86.0(5)	224.0	
				1/15/75	87.0(5)	223.0	
				2/15/75	87.0(5)	223.0	
				3/15/75	86.0(5)	224.0	
				4/15/75	86.0(5)	224.0	
				5/15/75	86.0(5)	224.0	
				6/15/75	86.0(5)	224.0	
				7/15/75	89.0(5)	221.0	
				8/15/75	94.0(5)	216.0	
				9/15/75	96.0(5)	214.0	
01S/11W-10P02 S	19		321.0	11/06/74	NM-2		1101
01S/11W-10R02 S	19		326.0	11/06/74	114.5	211.5	1101
01S/11W-10R03 S	19		326.5	4/01/75	98.2	228.3	1101
01S/11W-11A01 S	19		300.0	10/24/74	69.8	230.2	1101
				3/12/75	72.4	227.6	
				8/27/75	73.5	226.5	
01S/11W-11C04 S	19		355.0	10/01/74	129.9(5)	225.1	5062
01S/11W-11F04 S	19		3370.0	10/02/74	105.4	231.6	1733
				11/13/74	3139.9	230.1	
				12/04/74	3140.5	229.5	
				1/15/75	3140.8	229.2	
				2/05/75	3141.5	228.5	
				3/19/75	3141.7	228.3	
				4/09/75	3141.5	228.5	
				5/21/75	3140.3	229.7	
				6/11/75	3139.8	230.2	
				7/02/75	3139.4	230.6	
				8/13/75	3141.9	228.1	
				9/03/75	3143.7	226.3	
01S/11W-11L03 S	19		339.0	10/01/74	109.5	229.5	1101

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT						U-05	
SAN GABRIEL VALLEY HYDRO SUBUNIT						U-05.0	
MAIN SAN GABRIEL HYDRO SUBAREA						U-05.01	
01S/11W-11L03 S (CONTINUED)	19		339.0	11/15/74	107.5	231.5	1101
				12/03/74	111.6	227.4	
				1/07/75	112.5	226.5	
				2/06/75	113.6	225.4	
				3/05/75	114.3	224.7	
				4/14/75	108.5	230.5	
				5/15/75	109.5	229.5	
				6/15/75	109.5	229.5	
				7/15/75	104.5	234.5	
				8/15/75	110.5	228.5	
				9/15/75	110.5	228.5	
01S/11W-12A01 S	19		377.7	10/01/74	147.7	230.0	1101
				12/03/74	151.7	226.0	
				4/14/75	152.3	225.4	
01S/11W-12B01 S	19		334.4	10/24/74	103.7	230.7	1101
				1/29/75	105.5	228.9	
01S/11W-12C08 S	19		366.8	11/08/74	132.7	234.1	1101
01S/11W-12G01 S	19		359.2	10/01/74	NM-9		1101
				12/03/74	130.9	228.3	
				1/07/75	NM-9		
				2/06/75	133.8	225.4	
				3/05/75	135.0	224.2	
				4/14/75	134.4	224.8	
01S/11W-12J01 S	19		370.7	10/09/74	138.7	232.0	1733
				11/20/74	140.8	229.9	
				12/11/74	141.2	229.5	
				1/01/75	141.6	229.1	
				2/12/75	146.1	224.6	
				3/05/75	142.6	228.1	
				4/16/75	142.7	228.0	
				5/07/75	139.7	231.0	
				6/18/75	139.1	231.6	
				7/09/75	143.3	227.4	
				8/20/75	142.9	227.8	
				9/10/75	147.4	223.3	
01S/11W-12J06 S	19		367.5	10/11/74	144.2	223.3	1101
				11/08/74	145.2	222.3	
				12/06/74	146.2	221.3	
				1/10/75	146.2	221.3	
				2/07/75	147.2	220.3	
				3/07/75	147.2	220.3	
				4/11/75	147.2	220.3	
				5/09/75	146.2	221.3	
				6/06/75	141.2	226.3	
				7/11/75	141.2	226.3	
				8/08/75	146.2	221.3	
				9/05/75	149.2	218.3	
01S/11W-14E02 S	19		324.0	10/15/74	95.0(5)	229.0	1101
				11/15/74	100.0(5)	224.0	
				1/15/75	99.0(5)	225.0	
				2/15/75	98.0(5)	226.0	
				3/15/75	99.0(5)	225.0	
				4/15/75	97.0(5)	227.0	
				5/15/75	98.0(5)	226.0	
				6/15/75	97.0(5)	227.0	
				7/15/75	95.0(5)	229.0	
				8/15/75	98.0(5)	226.0	
				9/15/75	99.0(5)	225.0	
01S/11W-14E04 S	19		325.0	10/15/74	104.5(5)	220.5	1101
				11/15/74	105.5(5)	219.5	
				2/15/75	107.5(5)	217.5	
				3/15/75	107.5(5)	217.5	
				4/15/75	106.5(5)	218.5	
				5/15/75	108.5(5)	216.5	
				6/15/75	105.5(5)	219.5	
				8/15/75	110.5(5)	214.5	
				9/15/75	111.5(5)	213.5	
01S/11W-14K01 S	19		315.0	10/01/74	88.6	226.4	1101
				4/14/75	92.0	223.0	
01S/11W-14H04 S	19		324.5	10/15/74	95.0	229.5	1101
				11/15/74	97.0	227.5	
				1/15/75	98.0	226.5	
				2/15/75	97.0	227.5	
				3/15/75	97.0	227.5	
				4/15/75	98.0	226.5	
				5/15/75	98.0	226.5	
				6/15/75	97.0	227.5	
				7/15/75	98.0	226.5	
				8/15/75	98.0	226.5	
				9/15/75	101.0	223.5	
01S/11W-15C02 S	19		318.0	11/06/74	NM-4		1101
				4/01/75	92.3	225.7	
01S/11W-16A01 S	19		292.4	11/06/74	64.3	228.1	1101
01S/11W-16F01 S	19		296.0	11/06/74	87.0	209.0	1101
				4/02/75	81.7	214.3	
01S/11W-16G08 S	19		282.7	11/06/74	60.4	222.3	1101
01S/11W-16N01 S	19		285.0	10/31/74	74.0(5)	211.0	1101

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
SAN GABRIEL VALLEY HYDRO SUBUNIT — U-05.D
MAIN SAN GABRIEL HYDRO SUBAREA — U-05.D1

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
01S/11W-16N01 S (CONTINUED)	19		285.0	12/03/74	68.0(5)	217.0	1101
				1/31/75	73.0(5)	212.0	
				2/28/75	71.0(5)	214.0	
				3/31/75	72.0(5)	213.0	
				4/30/75	71.0(5)	214.0	
				5/30/75	71.0(5)	214.0	
				6/30/75	74.0(5)	211.0	
				7/31/75	77.0(5)	208.0	
				8/29/75	74.0(5)	211.0	
				9/30/75	74.0(5)	211.0	
01S/11W-17B02 S	19		314.6	4/02/75	NM-7		1101
01S/11W-17B05 S	19		313.0	10/01/74	132.0(5)	181.0	1101
				11/01/74	137.0(5)	176.0	
				12/01/74	137.0(5)	176.0	
				1/01/75	137.0(5)	176.0	
				2/01/75	127.0(5)	186.0	
				3/01/75	160.0(1)	153.0	
				4/01/75	127.0(5)	186.0	
				5/01/75	125.0(5)	188.0	
				6/01/75	127.0(5)	186.0	
				7/01/75	136.0(5)	177.0	
				9/01/75	132.0(5)	181.0	
01S/11W-18A04 S	19		325.0	10/21/74	149.5(5)	175.5	1101
				11/14/74	149.5(5)	175.5	
				12/14/74	147.5(5)	177.5	
				1/14/75	147.5(5)	177.5	
				2/07/75	147.5(5)	177.5	
				3/14/75	147.5(1)	177.5	
				4/07/75	142.5(5)	182.5	
				5/07/75	146.5(5)	178.5	
				6/21/75	146.5(5)	178.5	
				7/14/75	148.5(5)	176.5	
				8/21/75	157.5(5)	167.5	
				9/14/75	155.5(5)	169.5	
01S/11W-18A05 S	19		323.0	10/21/74	158.0(1)	165.0	1101
				11/14/74	159.5(1)	163.5	
				12/14/74	154.5(1)	168.5	
				1/28/75	147.5(5)	175.5	
				4/14/75	142.5(5)	180.5	
				5/14/75	158.5(5)	164.5	
				6/21/75	159.5(5)	163.5	
				7/21/75	162.0(5)	161.0	
				8/28/75	166.5(5)	156.5	
				9/14/75	176.5(1)	146.5	
01S/11W-18H01 S	19		321.0	10/02/74	110.7(4)	210.3	1733
				11/13/74	108.3(2)	212.7	
				12/04/74	107.1(2)	213.9	
				1/15/75	107.8	213.2	
				2/05/75	107.3	213.7	
				3/19/75	107.2	213.8	
				4/09/75	107.1(4)	213.9	
				5/21/75	108.1	212.9	
				6/11/75	112.3(4)	208.7	
				7/02/75	116.5(4)	204.5	
				8/13/75	111.8(4)	209.2	
				9/03/75	112.8(4)	208.2	
01S/11W-18K01 S	19		330.0	10/01/74	146.7	183.3	1101
				11/01/74	145.7	184.3	
				12/01/74	145.7	184.3	
				1/01/75	144.7	185.3	
				2/01/75	143.7	186.3	
				3/01/75	143.7	186.3	
				4/01/75	143.7	186.3	
				6/01/75	147.7	182.3	
				7/01/75	154.7	175.3	
				9/01/75	152.7	177.3	
01S/11W-19F01 S	19		272.0	10/01/74	103.0(5)	169.0	1101
				11/01/74	99.0(5)	173.0	
				12/01/74	98.0(5)	174.0	
				1/01/75	100.0(5)	172.0	
				2/01/75	98.0(5)	174.0	
				3/01/75	95.0(5)	177.0	
				4/01/75	98.0(5)	174.0	
				6/01/75	101.0(5)	171.0	
				7/01/75	110.0(5)	162.0	
				9/01/75	108.0(5)	164.0	
01S/11W-19H01 S	19		279.5	10/15/74	102.5(5)	177.0	1101
				11/15/74	104.5(5)	175.0	
				1/15/75	101.5(5)	178.0	
				2/15/75	96.5(5)	183.0	
				3/15/75	95.5(5)	184.0	
				4/15/75	93.5(5)	186.0	
				5/15/75	102.5(5)	177.0	
				6/15/75	99.5(5)	180.0	
				7/15/75	103.5(5)	176.0	
				8/15/75	108.5(5)	171.0	
				9/15/75	110.5(5)	169.0	
01S/11W-19001 S	19		247.0	1/15/75	61.0(5)	186.0	1101
				2/15/75	55.0(5)	192.0	
				3/15/75	54.0(5)	193.0	
				4/15/75	53.0(5)	194.0	
				5/15/75	61.0(5)	186.0	
01S/11W-19P01 S	19		243.6	11/06/74	27.2	216.4	1101

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
SAN GABRIEL VALLEY HYDRO SUBUNIT — U-05.D
MAIN SAN GABRIEL HYDRO SUBAREA — U-05.D1

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
01S/11W-19P01 S	19		243.6	4/08/75	27.8	215.8	1101
01S/11W-20G02 S	19		254.5	10/04/74	33.8	222.7	1101
				11/01/74	34.0	222.5	
				4/02/75	35.3	221.2	
01S/11W-20L01 S	19		267.0	10/31/74	54.5(5)	202.5	1101
				12/03/74	55.5(5)	201.5	
				1/31/75	55.5(5)	201.5	
				2/28/75	56.5(5)	200.5	
				3/31/75	54.5(5)	202.5	
				4/30/75	55.5(5)	201.5	
				5/30/75	58.5(5)	198.5	
				6/30/75	59.5(5)	197.5	
				7/31/75	64.5(5)	192.5	
				8/29/75	64.5(5)	192.5	
				9/30/75	64.5(5)	192.5	
01S/11W-20N01 S	19		244.8	10/02/74	29.4	215.4	1733
				11/13/74	29.5	215.3	
				12/04/74	29.0	215.8	
				1/15/75	29.2	215.6	
				2/05/75	30.2	214.6	
				3/19/75	DRY		
				4/09/75	29.4	215.4	
				5/21/75	NM-4		
				6/11/75	30.1	214.7	
				7/02/75	30.3	214.5	
				8/13/75	30.8	214.0	
				9/03/75	31.2	213.6	
01S/11W-21D02 S	19		272.4	10/02/74	55.8	216.6	1733
				11/13/74	56.4	216.0	
				12/04/74	56.6	215.8	
				1/15/75	57.2	215.2	
				2/05/75	57.5	214.9	
				3/19/75	57.9	214.5	
				4/09/75	58.2	214.2	
				5/21/75	58.4	214.0	
				6/11/75	NM-3		
				7/02/75	59.3	213.1	
				8/13/75	59.8	212.6	
				9/03/75	60.2	212.2	
01S/11W-21G01 S	19		286.0	10/31/74	64.5(5)	221.5	1101
				12/03/74	64.5(5)	221.5	
				1/31/75	65.5(5)	220.5	
				2/28/75	66.5(5)	219.5	
				3/31/75	66.5(5)	219.5	
				4/30/75	66.5(5)	219.5	
				5/30/75	66.5(5)	219.5	
				6/30/75	67.5(5)	218.5	
				7/31/75	68.5(5)	217.5	
				8/29/75	68.5(5)	217.5	
				9/30/75	70.5(5)	215.5	
01S/11W-21G07 S	19		284.0	10/31/74	73.0(5)	211.0	1101
				12/03/74	72.0(5)	212.0	
				3/31/75	72.0(5)	212.0	
				4/30/75	73.0(5)	211.0	
				5/30/75	73.0(5)	211.0	
				6/30/75	74.0(5)	210.0	
				7/31/75	76.0(5)	208.0	
				8/29/75	77.0(5)	207.0	
				9/30/75	77.0(5)	207.0	
01S/11W-21H01 S	19		283.0	10/31/74	62.5(5)	220.5	1101
				12/03/74	64.5(5)	218.5	
				1/31/75	63.5(5)	219.5	
				2/28/75	66.5(5)	216.5	
				3/31/75	64.5(5)	218.5	
				4/30/75	65.5(5)	217.5	
				5/30/75	67.5(5)	215.5	
				6/30/75	67.5(5)	215.5	
				7/31/75	71.5(5)	211.5	
				8/29/75	73.5(5)	209.5	
				9/30/75	73.5(5)	209.5	
01S/11W-21K01 S	19		390.0	10/04/74	156.8	233.2	1101
				11/12/74	157.6	232.4	
				4/29/75	162.0	228.0	
				7/29/75	160.6	229.4	
01S/11W-21O01 S	19		271.0	10/31/74	52.5(5)	218.5	1101
				12/03/74	52.5(5)	218.5	
				1/31/75	54.5(5)	216.5	
				2/28/75	52.5(5)	218.5	
				3/31/75	54.5(5)	216.5	
				4/30/75	54.5(5)	216.5	
				5/30/75	54.5(5)	216.5	
				6/30/75	54.5(5)	216.5	
				7/31/75	56.5(5)	214.5	
				8/29/75	56.5(5)	214.5	
				9/30/75	57.5(5)	213.5	
01S/11W-22F02 S	19		292.6	10/02/74	70.4	222.2	1733
				11/13/74	71.1	221.5	
				12/04/74	71.2	221.4	
			291.8	1/07/75	77.2	214.6	
				2/05/75	72.7	219.9	
				6/11/75	73.4	218.4	
				7/02/75	73.6	218.2	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT						U-05	
SAN GABRIEL VALLEY HYDRO SUBUNIT						U-05.0	
MAIN SAN GABRIEL HYDRO SUBAREA						U-05.01	
01S/11W-22F02 S (CONTINUED)	19		291.8	8/13/75	74.1	217.7	1733
				9/03/75	74.8	217.0	
01S/11W-23K03 S	19		297.0	10/01/74	73.1	223.9	1101
				4/14/75	NM-4		
01S/11W-23P14 S	19		293.1	10/02/74	71.3	221.8	1733
				11/06/74	71.5	221.6	
				12/04/74	73.3	219.8	
				1/01/75	73.2	219.9	
				2/05/75	74.0	219.1	
				3/05/75	73.3	219.8	
				4/02/75	72.9	220.2	
				5/07/75	73.3	219.8	
				6/04/75	73.5	219.6	
				7/02/75	74.7	218.4	
				8/06/75	75.8	217.3	
				9/03/75	75.6	217.5	
01S/11W-24F01 S	19		314.0	10/01/74	89.0	225.0	1101
				12/03/74	90.4	223.6	
				1/08/75	91.1	222.9	
				2/06/75	91.6	222.4	
				3/05/75	92.5	221.5	
				4/15/75	92.1	221.9	
01S/11W-24G04 S	19		317.5	10/01/74	90.3	227.2	1101
				12/03/74	91.3	226.2	
				1/08/75	91.9	225.6	
				2/06/75	93.0	224.5	
				3/05/75	93.6	223.9	
				4/15/75	93.2	224.3	
01S/11W-24G08 S	19		315.0	10/15/74	96.5(S)	218.5	1101
				11/15/74	94.5(S)	220.5	
				1/15/75	96.5(S)	218.5	
				2/15/75	96.5(S)	218.5	
				3/15/75	94.5(S)	220.5	
				4/15/75	92.5(S)	222.5	
				5/15/75	98.5(S)	216.5	
				6/15/75	96.5(S)	218.5	
				7/15/75	98.5(S)	216.5	
				8/15/75	97.5(S)	217.5	
				9/15/75	103.5(S)	211.5	
01S/11W-25D01 S	19		297.0	10/01/74	67.2	229.8	1101
				4/15/75	70.2	226.8	
01S/11W-25G01 S	19		305.0	10/16/74	77.0	228.0	1733
				11/06/74	77.3	227.7	
				12/18/74	77.9	227.1	
				1/08/75	78.1	226.9	
				2/19/75	78.7	226.3	
				3/12/75	79.2	225.8	
				4/02/75	79.3	225.7	
				5/14/75	79.6	225.4	
				6/04/75	79.8	225.2	
				7/16/75	81.1	223.9	
				8/06/75	80.6	224.4	
				9/17/75	82.3	222.7	
01S/11W-26B01 S	19		290.0	10/01/74	64.1	225.9	1101
				4/15/75	66.6	223.4	
01S/11W-26D02 S	19		295.0	11/05/74	66.5	228.5	1101
				1/02/75	81.5(1)	213.5	
				3/05/75	67.5	227.5	
				5/05/75	68.5	226.5	
				7/01/75	79.5(1)	215.5	
				9/03/75	74.5	220.5	
01S/11W-26G01 S	19		284.0	10/15/74	63.5(S)	220.5	1101
				11/15/74	65.5(S)	218.5	
				1/15/75	64.5(S)	219.5	
				2/15/75	62.5(S)	221.5	
				3/15/75	63.5(S)	220.5	
				4/15/75	66.5(S)	217.5	
				5/15/75	70.5(S)	213.5	
				6/15/75	72.5(S)	211.5	
				7/15/75	69.5(S)	214.5	
				8/15/75	75.5(S)	208.5	
				9/15/75	65.5(S)	218.5	
01S/11W-26K01 S	19		283.5	10/15/74	65.0(S)	218.5	1101
				11/15/74	67.0(S)	216.5	
				1/15/75	66.0(S)	217.5	
				2/15/75	64.0(S)	219.5	
				3/15/75	65.0(S)	218.5	
				4/15/75	60.0(S)	223.5	
				5/15/75	72.0(S)	211.5	
				6/15/75	62.0(S)	221.5	
				7/15/75	71.0(S)	212.5	
				8/15/75	67.0(S)	216.5	
				9/15/75	67.0(S)	216.5	
01S/11W-26M03 S	19		280.4	11/11/74	57.0	223.4	1101
				4/14/75	58.5	221.9	
01S/11W-26P05 S	19		291.0	10/16/74	65.3	225.7	1733
				11/06/74	65.8	225.2	
				12/18/74	67.1	223.9	
				1/08/75	67.6	223.4	
LA-SAN GABRIEL RIVER HYDRO UNIT						U-05	
SAN GABRIEL VALLEY HYDRO SUBUNIT						U-05.0	
MAIN SAN GABRIEL HYDRO SUBAREA						U-05.01	
01S/11W-26P05 S (CONTINUED)	19		291.0	2/19/75	68.2	222.8	1733
				3/12/75	68.7	222.3	
				4/02/75	68.6	222.4	
				5/14/75	68.5	222.5	
				6/04/75	68.3	222.7	
				7/16/75	68.4	222.6	
				8/06/75	69.0	222.0	
				9/17/75	70.1	220.9	
01S/11W-27H05 S	19		291.0	10/01/74	69.6	222.4	1101
				12/03/74	69.9	221.1	
				1/08/75	71.5	219.5	
				2/06/75	72.1	218.9	
				3/05/75	71.5	219.5	
				4/15/75	69.9	221.1	
01S/11W-27M05 S	19		281.0	4/21/75	60.4	220.6	1101
01S/11W-27Q03 S	19		280.0	8/15/75	60.5	219.5	1101
				9/15/75	60.5	219.5	
01S/11W-28R01 S	19		266.0	10/15/74	49.0	217.0	1101
				11/15/74	49.0	217.0	
				1/15/75	48.0	218.0	
				2/15/75	47.0	219.0	
				3/15/75	47.0	219.0	
				4/15/75	47.0	219.0	
				5/15/75	47.0	219.0	
				6/15/75	48.0	218.0	
				7/15/75	48.0	218.0	
				8/15/75	51.0	215.0	
				9/15/75	51.0	215.0	
01S/11W-28D02 S	19		272.0	10/02/74	56.9	215.1	1733
				11/13/74	57.0	215.0	
				12/04/74	57.0	215.0	
				1/15/75	57.2	214.8	
				2/05/75	57.5	214.5	
				3/19/75	57.6	214.4	
				4/09/75	57.6	214.4	
				5/21/75	58.6	213.4	
				6/11/75	58.8	213.2	
				7/02/75	59.2	212.8	
				8/13/75	60.3	211.7	
				9/03/75	60.7	211.3	
01S/11W-28M03 S	19		255.0	10/15/74	43.0(S)	212.0	1101
				11/15/74	43.0(S)	212.0	
				1/15/75	43.0(S)	212.0	
				2/15/75	44.0(S)	211.0	
				3/15/75	44.0(S)	211.0	
				4/15/75	44.0(S)	211.0	
				5/15/75	44.0(S)	211.0	
				6/15/75	44.0(S)	211.0	
				7/15/75	45.0(S)	210.0	
				8/15/75	46.0(S)	209.0	
				9/15/75	55.0(S)	200.0	
01S/11W-28R01 S	19		257.6	10/02/74	40.8	216.8	1733
				11/13/74	41.4	216.2	
				12/04/74	41.8	215.8	
				1/15/75	42.5	215.1	
				2/05/75	42.8	214.8	
				3/19/75	43.0	214.6	
				4/09/75	42.9	214.7	
				5/21/75	43.1	214.5	
				6/11/75	43.3	214.3	
				7/02/75	42.9	214.7	
				8/13/75	44.3	213.3	
				9/03/75	44.8	212.8	
01S/11W-29R03 S	19		253.5	10/15/74	44.5	209.0	1101
				11/15/74	44.5	209.0	
				1/15/75	43.5	210.0	
				2/15/75	43.5	210.0	
				3/15/75	42.5	211.0	
				4/15/75	42.5	211.0	
				5/15/75	44.5	209.0	
				6/15/75	45.5	208.0	
				7/15/75	47.5	206.0	
				8/15/75	47.5	206.0	
				9/15/75	49.5	204.0	
01S/11W-29Q02 S	19		241.0	11/06/74	DRY		1101
				4/09/75	DRY		
01S/11W-29R01 S	19		237.0	10/29/74	28.0	209.0	1101
				11/25/74	28.0	209.0	
				12/30/74	27.8	209.2	
				1/27/75	28.0	209.0	
				2/25/75	27.9	209.2	
				3/24/75	27.8	209.2	
				4/29/75	28.2	208.8	
				5/26/75	28.6	208.4	
				6/23/75	28.9	208.1	
				7/28/75	29.9	207.1	
				8/25/75	30.8	206.2	
01S/11W-30R01 S	19		236.0	10/15/74	43.0(S)	193.0	1101
				11/15/74	58.0(S)	178.0	
				1/15/75	51.0(S)	185.0	
				2/15/75	51.0(S)	185.0	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
SAN GABRIEL VALLEY HYDRO SUBUNIT — U-05.D
MAIN SAN GABRIEL HYDRO SUBAREA — U-05.D1

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
01S/11W-30R01 S (CONTINUED)	19		236.0	3/15/75	41.0(5)	195.0	1101
				4/15/75	42.0(5)	194.0	
				5/15/75	56.0(5)	180.0	
				6/15/75	56.0(5)	180.0	
				7/15/75	57.0(5)	179.0	
				8/15/75	66.0(5)	170.0	
				9/15/75	60.0(5)	176.0	
01S/11W-30R02 S	19		230.0	10/15/74	45.0(5)	185.0	1101
				11/15/74	56.0(5)	174.0	
				1/15/75	50.0(5)	180.0	
				2/15/75	49.0(5)	181.0	
				3/15/75	42.0(5)	188.0	
				4/15/75	41.0(5)	189.0	
				5/15/75	54.0(5)	176.0	
				6/15/75	57.0(5)	173.0	
				7/15/75	58.0(5)	172.0	
				8/15/75	63.0(5)	167.0	
				9/15/75	60.0(5)	170.0	
01S/11W-30R03 S	19		233.0	10/15/74	46.5(5)	186.5	1101
				11/15/74	55.5(5)	177.5	
				1/15/75	49.5(5)	183.5	
				2/15/75	48.5(5)	184.5	
				3/15/75	43.5(5)	189.5	
				4/15/75	45.5(5)	187.5	
				5/15/75	56.5(5)	176.5	
				6/15/75	58.5(5)	174.5	
				7/15/75	59.5(5)	173.5	
				8/15/75	64.5(5)	168.5	
				9/15/75	62.5(5)	170.5	
01S/11W-30F03 S	19		230.0	10/07/74	57.0(5)	173.0	1101
				11/07/74	57.0(5)	173.0	
				12/09/74	52.0(5)	178.0	
				1/06/75	54.0(5)	176.0	
				2/10/75	52.0(5)	178.0	
				3/03/75	55.0(5)	175.0	
				4/07/75	57.0(5)	173.0	
				5/05/75	59.0(5)	171.0	
				6/02/75	64.0(5)	166.0	
				7/08/75	67.0(5)	163.0	
				8/11/75	67.0(5)	163.0	
				9/08/75	67.0(5)	163.0	
01S/11W-30F01 S	19		234.5	10/07/74	62.0(5)	172.5	1101
				11/11/74	59.0(5)	175.5	
				12/09/74	59.0(5)	175.5	
				1/09/75	57.0(5)	177.5	
				2/10/75	54.0(5)	180.5	
				3/03/75	60.0(5)	174.5	
				4/07/75	57.0(5)	177.5	
				5/05/75	59.0(5)	175.5	
				6/02/75	62.0(5)	172.5	
				7/07/75	72.0(5)	162.5	
				8/11/75	71.0(5)	163.5	
				9/08/75	67.0(5)	167.5	
01S/11W-30F03 S	19		230.0	10/07/74	52.5(5)	177.5	1101
				11/11/74	47.5(5)	182.5	
				12/09/74	50.5(5)	179.5	
				1/06/75	52.5(5)	177.5	
				2/10/75	45.5(5)	184.5	
				3/03/75	49.5(5)	180.5	
				4/07/75	45.5(5)	184.5	
				5/01/75	45.5(5)	184.5	
				6/02/75	55.5(5)	174.5	
				7/08/75	58.5(5)	171.5	
				8/11/75	59.5(5)	170.5	
				9/08/75	59.5(5)	170.5	
01S/11W-30M02 S	19		229.0	10/07/74	47.0(5)	182.0	1101
				11/11/74	45.0(5)	184.0	
				12/10/74	42.0(5)	187.0	
				1/06/75	43.0(5)	186.0	
				2/10/75	39.0(5)	190.0	
				3/03/75	44.0(5)	185.0	
				4/07/75	43.0(5)	186.0	
				5/01/75	43.0(5)	186.0	
				6/02/75	49.0(5)	180.0	
				7/07/75	54.0(5)	175.0	
				8/11/75	55.0(5)	174.0	
				9/08/75	53.0(5)	176.0	
01S/11W-30N02 S	19		225.0	11/19/74	40.3	184.7	1101
				4/09/75	34.6	190.4	
01S/11W-30Q01 S	19		223.7	11/06/74	DRY		1101
				4/07/75	DRY		
01S/11W-30R02 S	19		230.0	10/29/74	NM-3		1101
				11/25/74	NM-3		
				12/30/74	NM-3		
				1/27/75	NM-3		
				2/25/75	NM-3		
				3/24/75	NM-3		
				4/29/75	NM-3		
01S/11W-31C01 S	19		214.0	11/19/74	NM-1		1101
				1/09/75	NM-2		
				4/09/75	16.6	197.4	
01S/11W-31D02 S	19		230.4	10/29/74	44.6	185.8	1101

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
SAN GABRIEL VALLEY HYDRO SUBUNIT — U-05.D
MAIN SAN GABRIEL HYDRO SUBAREA — U-05.D1

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
01S/11W-31D02 S (CONTINUED)	19		230.4	11/25/74	45.8	184.6	1101
				12/30/74	43.7	186.7	
				1/27/75	44.3	186.1	
				2/25/75	43.1	187.3	
				3/24/75	42.7	187.7	
				4/29/75	43.8	186.6	
				5/26/75	45.3	185.1	
				6/23/75	47.5	182.9	
				7/28/75	49.3	181.1	
				8/25/75	50.2	180.2	
01S/11W-31P01 S	19		206.0	11/06/74	13.6	192.4	1101
				4/07/75	12.3	193.7	
01S/11W-31Q02 S	19		200.0	11/06/74	7.2	192.8	1101
				4/07/75	7.2	192.8	
01S/11W-32D01 S	19		230.5	11/08/74	23.0	207.5	1101
				4/01/75	24.6	205.9	
01S/11W-32H05 S	19		231.9	10/02/74	26.7(4)	205.2	1733
				11/13/74	26.7(4)	205.2	
				12/04/74	26.9	205.0	
				1/15/75	26.7	205.2	
				2/05/75	26.9	205.0	
				3/19/75	26.6	205.3	
				4/09/75	26.9	205.0	
				5/21/75	27.7(4)	204.2	
				6/11/75	27.4(4)	204.5	
				7/02/75	27.7(4)	204.2	
				8/13/75	29.2(4)	202.7	
				9/03/75	30.1(4)	201.8	
01S/11W-32L01 S	19		222.6	10/29/74	18.8	203.8	1101
				11/25/74	19.7	202.9	
				12/30/74	17.0	205.6	
				1/27/75	18.4	204.2	
01S/11W-32H04 S	19		219.6	10/29/74	18.7	200.9	1101
				11/25/74	19.2	200.4	
				12/30/74	17.5	202.1	
				1/27/75	17.9	201.7	
01S/11W-32P01 S	19		219.6	10/29/74	18.4	201.2	1101
				11/25/74	18.8	200.8	
				12/30/74	17.8	201.8	
				1/27/75	17.5	202.1	
				2/25/75	18.0	201.6	
				3/24/75	18.0	201.6	
				4/29/75	18.5	201.1	
				5/27/75	18.8	200.8	
				6/23/75	18.3	201.3	
				7/28/75	21.4	198.2	
				8/25/75	DRY (6)		
01S/11W-32Q02 S	19		223.4	11/08/74	18.5	204.9	1101
				4/01/75	20.5	202.9	
01S/11W-32Q05 S	19		226.0	10/29/74	22.9	203.1	1101
				11/25/74	23.2	202.8	
				12/30/74	22.5	203.5	
				1/27/75	23.2	202.8	
				2/25/75	22.8	203.2	
				3/24/75	22.8	203.2	
				4/29/75	23.1	202.9	
				5/27/75	23.7	202.3	
				6/23/75	23.1	202.9	
				7/28/75	25.1	200.9	
				8/25/75	26.4	199.6	
01S/11W-32R03 S	19		226.0	11/12/74	26.8	199.2	1101
				4/01/75	36.4(6)	189.6	
01S/11W-33G01 S	19		245.0	10/02/74	29.5	215.5	1733
				11/13/74	30.0	215.0	
				12/04/74	30.4	214.6	
				1/15/75	30.4	214.6	
				2/05/75	30.7	214.3	
				3/19/75	30.6	214.4	
				4/09/75	30.9	214.1	
				5/21/75	31.1	213.9	
				6/11/75	31.1	213.9	
				7/02/75	31.1	213.9	
				8/13/75	NM-2		
				9/03/75	33.0	212.0	
01S/11W-33G04 S	19		246.0	10/15/74	34.5	211.5	1101
				11/15/74	35.5	210.5	
				1/15/75	33.5	212.5	
				2/15/75	32.5	213.5	
				3/15/75	32.5	213.5	
				4/15/75	33.5	212.5	
				5/15/75	35.5	210.5	
				6/15/75	35.5	210.5	
				7/15/75	38.5	207.5	
				8/15/75	40.5	205.5	
				9/15/75	41.5	204.5	
01S/11W-33K01 S	19		237.0	11/12/74	29.9	207.1	1101
				4/02/75	29.1	207.9	
01S/11W-33L01 S	19		235.0	10/02/74	23.9	211.1	1733

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT SAN GABRIEL VALLEY HYDRO SUBUNIT MAIN SAN GABRIEL HYDRO SUBAREA						U-05 U-05.0 U-05.01	
01S/11W-33L01 S (CONTINUED)	19		235.0	11/13/74	24.3	210.7	1733
				12/04/74	24.6	210.4	
				1/15/75	24.6	210.4	
				2/05/75	24.7	210.3	
				3/19/75	24.5	210.5	
				4/09/75	25.0	210.0	
				5/21/75	25.1	209.9	
				6/11/75	25.0	210.0	
				7/02/75	25.1	209.9	
				8/13/75	26.6	208.4	
				9/03/75	27.4	207.6	
01S/11W-33P01 S	19		246.0	10/28/74	27.3	218.7	1733
				11/25/74	28.3	217.7	
				12/23/74	27.9	218.1	
				1/27/75	28.8	217.2	
				2/24/75	28.5	217.5	
				3/24/75	28.3	217.7	
				4/28/75	29.2	216.8	
				5/26/75	28.5	217.5	
				6/23/75	28.2	217.8	
				7/28/75	29.3	216.7	
				8/25/75	30.2	215.8	
				9/22/75	31.0	215.0	
01S/11W-34E01 S	19		260.5	11/12/74	43.5	217.0	1101
				4/02/75	45.0	215.5	
01S/11W-34F01 S	19		248.0	10/15/74	48.5(S)	199.5	1101
				11/15/74	39.5(S)	208.5	
				1/15/75	37.5(S)	210.5	
				2/15/75	37.5(S)	210.5	
				3/15/75	37.5(S)	210.5	
				4/15/75	35.5(S)	212.5	
				5/15/75	45.5(S)	202.5	
				6/15/75	43.5(S)	204.5	
				7/15/75	50.5(S)	197.5	
				8/15/75	52.5(S)	195.5	
				9/15/75	55.5(S)	192.5	
01S/11W-34F02 S	19		248.0	10/15/74	48.0(S)	200.0	1101
				11/15/74	42.0(S)	206.0	
				1/15/75	40.0(S)	208.0	
				2/15/75	40.0(S)	208.0	
				3/15/75	40.0(S)	208.0	
				4/15/75	38.0(S)	210.0	
				5/15/75	50.0(S)	198.0	
				6/15/75	49.0(S)	199.0	
				7/15/75	54.0(S)	194.0	
				8/15/75	55.0(S)	193.0	
				9/15/75	59.0(S)	189.0	
01S/11W-34F03 S	19		247.5	10/15/74	55.5(S)	192.0	1101
				11/15/74	46.5(S)	201.0	
				1/15/75	45.5(S)	202.0	
				2/15/75	44.5(S)	203.0	
				3/15/75	38.5(S)	209.0	
				4/15/75	40.5(S)	207.0	
				5/15/75	48.5(S)	199.0	
				6/15/75	50.5(S)	197.0	
				7/15/75	52.5(S)	195.0	
				8/15/75	55.5(S)	192.0	
				9/15/75	52.5(S)	195.0	
01S/11W-34H01 S	19		264.0	10/01/74	25.8	238.2	1101
				4/14/75	29.7	234.3	
01S/11W-34J01 S	19		257.2	11/12/74	NM-1		1101
				12/16/74	40.3(4)	216.9	
				4/15/75	NM-1		
01S/11W-34K02 S	19		266.0	11/12/74	47.1	218.9	1101
				4/02/75	45.9	220.1	
01S/11W-34P01 S	19		275.7	4/01/75	61.0	214.7	1101
01S/11W-36G04 S	19		289.2	10/01/74	61.3	227.9	1101
				12/03/74	62.2	227.0	
				1/08/75	62.7	226.5	
				2/06/75	63.4	225.8	
				3/05/75	63.5	225.7	
				4/15/75	63.8	225.4	
01S/11W-36Q01 S	19		296.5	10/16/74	57.5	239.0	1733
				11/06/74	57.7	238.8	
				12/18/74	58.2	238.3	
				1/08/75	58.4	238.1	
				2/19/75	59.0	237.5	
				3/12/75	59.4	237.1	
				4/02/75	59.7	236.8	
				5/14/75	60.1	236.4	
				6/04/75	60.4	236.1	
				7/14/75	61.1	235.4	
				8/06/75	61.5	235.0	
				9/17/75	62.1	234.4	
01S/12W-01F01 S	19		498.6	10/05/74	NM-9		5062
01S/12W-01F02 S	19		500.0	10/05/74	NM-9		5062
01S/12W-02H01 S	19		506.7	10/01/74	349.6	157.1	1101
				11/01/74	347.6	159.1	
LA-SAN GABRIEL RIVER HYDRO UNIT SAN GABRIEL VALLEY HYDRO SUBUNIT MAIN SAN GABRIEL HYDRO SUBAREA						U-05 U-05.0 U-05.01	
01S/12W-02H01 S (CONTINUED)	19		506.7	12/01/74	343.6	163.1	1101
				1/01/75	344.6	162.1	
				2/01/75	338.6	168.1	
				3/01/75	341.6	165.1	
				4/01/75	341.6	165.1	
				6/01/75	345.6	161.1	
				7/01/75	342.6	164.1	
				9/01/75	349.6	157.1	
01S/12W-02H02 S	19		518.0	10/31/74	396.0	122.0	5062
01S/12W-02Q01 S	19		478.9	10/31/74	304.0(S)	174.9	1101
				11/30/74	304.0(S)	174.9	
				12/31/74	306.0(S)	172.9	
				1/31/75	305.0(S)	173.9	
				2/28/75	305.0(S)	173.9	
				3/31/75	306.0(S)	172.9	
				4/30/75	305.0(S)	173.9	
				5/31/75	304.0(S)	174.9	
				6/30/75	306.0(S)	172.9	
				7/31/75	306.0(S)	172.9	
				8/31/75	304.0(S)	174.9	
				9/30/75	304.0(S)	174.9	
01S/12W-03K01 S	19		518.9	10/01/74	372.0	146.3	1101
				11/01/74	369.0	149.3	
				12/01/74	366.0	152.3	
				1/01/75	360.0	158.3	
				2/01/75	369.0	149.3	
				3/01/75	359.0	159.3	
				4/01/75	357.0	161.3	
				6/01/75	365.0	153.3	
				9/01/75	371.0	147.3	
01S/12W-03M01 S	19		560.9	10/31/74	402.5(S)	158.4	1101
				11/30/74	403.5(S)	157.4	
				12/31/74	401.5(S)	159.4	
				1/31/75	403.5(S)	157.4	
				2/28/75	403.5(S)	157.4	
				3/31/75	402.5(S)	158.4	
				4/30/75	403.5(S)	157.4	
				5/31/75	402.5(S)	158.4	
				6/30/75	402.5(S)	158.4	
				7/31/75	401.5(S)	159.4	
				8/31/75	401.5(S)	159.4	
				9/30/75	399.5(S)	161.4	
01S/12W-10A01 S	19		491.0	10/05/74	335.0(S)	156.0	5062
01S/12W-10F01 S	19			10/17/74	377.0(S)	157.6	1733
				11/07/74	382.6	152.0	
			534.6	12/19/74	377.0	157.6	
				1/09/75	370.1	164.5	
				2/20/75	375.4	159.2	
				3/13/75	372.0(S)	162.6	
				4/03/75	373.0(S)	161.6	
				6/05/75	374.0(S)	160.6	
				7/17/75	386.0(S)	148.6	
				8/07/75	377.0(S)	157.6	
01S/12W-10R01 S	19		440.0	10/05/74	280.1(S)	159.9	5062
01S/12W-11D01 S	19		440.0	10/31/74	270.0	170.0	5062
01S/12W-11K01 S	19		416.3	10/05/74	254.5(S)	161.8	5062
01S/12W-11N02 S	19		402.0	10/08/74	248.4(S)	153.6	5062
01S/12W-12C01 S	19		435.7	10/31/74	264.0	171.7	5062
01S/12W-13B01 S	19		368.5	10/31/74	194.4	174.1	5062
01S/12W-13B02 S	19		353.0	10/31/74	190.5	162.5	5062
01S/12W-13H01 S	19		355.8	10/02/74	179.9	175.9	1733
				11/13/74	178.2	177.6	
				12/04/74	176.5	179.3	
				1/15/75	176.4	179.4	
				2/05/75	174.3	181.5	
				3/19/75	173.7	182.1	
				4/09/75	173.1	182.7	
				5/21/75	176.8	179.0	
				6/11/75	178.9	176.9	
				7/02/75	182.3	173.5	
				8/13/75	184.5	171.3	
				9/03/75	184.5	171.3	
01S/12W-14D01 S	19		425.0	10/04/74	260.0(S)	165.0	5062
01S/12W-14F01 S	19		366.0	10/05/74	209.5(S)	156.5	5062
01S/12W-14G01 S	19		380.0	10/08/74	217.5(S)	162.5	5062
01S/12W-14H01 S	19		358.0	11/19/74	166.5	191.5	1101
01S/12W-22P02 S	19		394.0	10/24/74	163.0	231.0	1101
				11/06/74	161.3	232.7	
				12/12/74	158.4	235.6	
01S/12W-24D01 S	19		325.0	10/09/74	163.5(S)	161.5	5062
01S/12W-24F02 S	19		308.0	10/07/74	147.5(S)	160.5	1101

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
SAN GABRIEL VALLEY HYDRO SUBUNIT — U-05.D
MAIN SAN GABRIEL HYDRO SUBAREA — U-05.D1

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
01S/12W-24F02 S (CONTINUED)	19		308.0	11/14/74	160.0(1)	148.0	1101
				12/14/74	155.5(1)	152.5	
				1/14/75	155.0(1)	153.0	
				2/14/75	152.5(1)	155.5	
				3/21/75	151.5(1)	156.5	
				4/07/75	154.0(1)	154.0	
				5/21/75	147.0(5)	161.0	
				6/21/75	152.5(5)	155.5	
				7/21/75	158.0(5)	150.0	
				8/14/75	148.5(5)	159.5	
				9/07/75	148.0(5)	160.0	
01S/12W-24E04 S	19		308.5	10/07/74	147.0(5)	161.5	1101
				11/14/74	179.0(1)	129.5	
				12/14/74	174.0(1)	134.5	
				1/14/75	172.5(1)	136.0	
				2/14/75	169.0(1)	139.5	
				3/14/75	168.0(1)	140.5	
				4/07/75	144.0(5)	164.5	
				5/21/75	144.0(5)	164.5	
				6/07/75	143.0(5)	165.5	
				7/14/75	155.5(5)	153.0	
				8/14/75	149.0(5)	159.5	
				9/14/75	153.0(5)	155.5	
01S/12W-25A01 S	19		262.2	10/07/74	103.0(5)	159.2	1101
				11/11/74	97.0(5)	165.2	
				12/09/74	99.0(5)	163.2	
				1/06/75	95.0(5)	167.2	
				2/10/75	101.0(5)	161.2	
				3/10/75	101.0(5)	161.2	
				4/07/75	93.0(5)	169.2	
				5/05/75	97.0(5)	165.2	
				6/02/75	102.0(5)	160.2	
				7/07/75	109.0(5)	153.2	
				8/11/75	110.0(5)	152.2	
				9/08/75	109.0(5)	153.2	
01S/12W-25A02 S	19		262.0	10/07/74	98.5(5)	163.5	1101
				11/11/74	91.5(5)	170.5	
				12/10/74	94.5(5)	167.5	
				1/06/75	91.5(5)	170.5	
				2/11/75	95.5(5)	166.5	
				3/03/75	92.5(5)	169.5	
				4/07/75	91.5(5)	170.5	
				5/01/75	91.5(5)	170.5	
				6/02/75	98.5(5)	163.5	
				7/08/75	106.5(5)	155.5	
				8/11/75	107.5(5)	154.5	
				9/08/75	107.5(5)	154.5	
01S/12W-25A03 S	19		266.0	10/21/74	107.5(5)	158.5	1101
				11/14/74	108.0(5)	158.0	
				12/14/74	98.0(5)	168.0	
				1/21/75	104.0(5)	162.0	
				2/21/75	96.0(5)	170.0	
				3/28/75	96.0(5)	170.0	
				4/07/75	97.5(5)	168.5	
				5/21/75	105.0(5)	161.0	
				6/28/75	111.0(5)	155.0	
				7/14/75	118.0(5)	148.0	
				8/14/75	114.5(5)	151.5	
				9/14/75	114.0(5)	152.0	
01S/12W-25A05 S	19		265.0	10/21/74	109.0(1)	156.0	1101
				11/14/74	109.0(1)	156.0	
				12/14/74	99.0(1)	166.0	
				1/21/75	105.0(1)	160.0	
				2/21/75	95.0(5)	170.0	
				3/21/75	101.0(1)	164.0	
				4/07/75	96.5(5)	168.5	
				5/21/75	106.5(5)	158.5	
				6/21/75	108.0(5)	157.0	
				7/14/75	115.5(5)	149.5	
				8/14/75	110.0(5)	155.0	
				9/14/75	112.5(5)	152.5	
01S/12W-25A07 S	19		259.0	10/07/74	86.5(5)	172.5	1101
				11/11/74	79.5(5)	179.5	
				12/09/74	78.5(5)	180.5	
				1/06/75	78.5(5)	180.5	
				2/10/75	80.5(5)	178.5	
				3/03/75	80.5(5)	178.5	
				4/07/75	78.5(5)	180.5	
				5/05/75	80.5(5)	178.5	
				6/02/75	92.5(5)	166.5	
				7/08/75	90.5(5)	168.5	
				8/11/75	96.5(5)	162.5	
				9/08/75	94.5(5)	164.5	
01S/12W-25A08 S	19		258.0	10/21/74	87.5(5)	170.5	1101
				11/11/74	78.5(5)	179.5	
				12/09/74	76.5(5)	181.5	
				1/06/75	76.5(5)	181.5	
				2/09/75	82.5(5)	175.5	
				3/03/75	78.5(5)	179.5	
				4/07/75	73.5(5)	184.5	
				5/05/75	82.5(5)	175.5	
				6/03/75	84.5(5)	173.5	
				7/09/75	90.5(5)	167.5	
				8/11/75	94.5(5)	163.5	
				9/08/75	92.5(5)	165.5	

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
SAN GABRIEL VALLEY HYDRO SUBUNIT — U-05.D
MAIN SAN GABRIEL HYDRO SUBAREA — U-05.D1

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
01S/12W-25A10 S	19		262.5	10/21/74	109.0(5)	153.5	1101
				11/14/74	100.0(5)	162.5	
				12/07/74	95.5(5)	167.0	
				1/14/75	91.5(5)	171.0	
				2/21/75	93.5(5)	169.0	
				3/21/75	101.5(5)	161.0	
				4/07/75	96.5(5)	166.0	
				5/21/75	112.5(5)	150.0	
				6/14/75	108.5(5)	154.0	
				7/14/75	117.5(5)	145.0	
				8/14/75	118.0(5)	144.5	
				9/28/75	116.5(5)	146.0	
01S/12W-25A12 S	19		267.0	10/07/74	102.5(5)	164.5	1101
				11/11/74	95.5(5)	171.5	
				12/09/74	98.5(5)	168.5	
				1/06/75	96.5(5)	170.5	
				2/11/75	97.5(5)	169.5	
				3/03/75	96.5(5)	170.5	
				4/07/75	94.5(5)	172.5	
				5/05/75	103.5(5)	163.5	
				6/03/75	103.5(5)	163.5	
				7/09/75	109.5(5)	157.5	
				8/11/75	112.5(5)	154.5	
				9/08/75	112.5(5)	154.5	
01S/12W-25G03 S	19		254.0	10/07/74	82.5(5)	171.5	1101
				11/11/74	81.5(5)	172.5	
				12/09/74	78.5(5)	175.5	
				1/06/75	75.5(5)	178.5	
				2/10/75	81.5(5)	172.5	
				3/03/75	78.5(5)	175.5	
				4/07/75	77.5(5)	176.5	
				5/05/75	88.5(5)	165.5	
				6/02/75	83.5(5)	170.5	
				7/09/75	89.5(5)	164.5	
				8/11/75	98.5(5)	155.5	
				9/08/75	98.5(5)	155.5	
01S/12W-25G05 S	19		257.2	1/06/75	81.2(5)	176.0	1101
				2/10/75	86.2(5)	171.0	
				3/03/75	82.2(5)	175.0	
				4/07/75	82.2(5)	175.0	
				5/06/75	95.2(5)	162.0	
				6/03/75	91.2(5)	166.0	
01S/12W-36A06 S	19		228.0	10/15/74	41.0	187.0	1101
				11/15/74	40.0	188.0	
				1/15/75	39.0	189.0	
				2/15/75	37.0	191.0	
				3/15/75	36.0	192.0	
				4/15/75	36.0	192.0	
				5/15/75	36.0	192.0	
01S/12W-36A08 S	19		231.0	10/15/74	42.0	189.0	1101
				11/15/74	41.0	190.0	
				1/15/75	40.0	191.0	
				2/15/75	38.0	193.0	
				3/15/75	37.0	194.0	
				4/15/75	37.0	194.0	
				5/15/75	37.0	194.0	
				6/15/75	36.0	195.0	
				7/15/75	43.0	188.0	
				8/15/75	43.0	188.0	
				9/15/75	45.0	186.0	
01S/13W-10H02 S	19		350.0	10/24/74	38.6	311.4	1200
				11/20/74	39.5	310.5	
				12/31/74	39.8	310.2	
				4/24/75	43.0	307.0	
				5/21/75	43.6	306.4	
				6/26/75	43.9	306.1	
				7/24/75	43.9	306.1	
				8/29/75	42.9	307.1	
				9/30/75	43.2	306.8	
01S/13W-10H03 S	19		349.0	10/24/74	40.0	309.0	1200
				11/20/74	41.0	308.0	
				12/31/74	41.4	307.6	
				4/24/75	44.2	304.8	
				5/21/75	44.9	304.1	
				6/26/75	45.0	304.0	
				7/24/75	45.0	304.0	
				8/29/75	44.5	304.5	
				9/30/75	40.3	308.7	
02S/09W-04E01 S	19		608.5	11/04/74	30.9	577.6	1101
				5/07/75	NM-4		
02S/09W-04F02 S	19		609.0	11/04/74	30.6	578.4	1101
				4/03/75	NM-5		
				5/07/75	NM-5		
02S/09W-04G01 S	19		620.0	11/04/74	67.0	553.0	1101
				4/10/75	52.2	567.8	
02S/09W-04L01 S	19		604.0	11/04/74	45.6	558.4	1101
				4/02/75	46.3	557.7	
02S/09W-07R03 S	19		521.5	2/06/75	33.2	488.3	1101
				3/06/75	33.0	488.5	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT SAN GABRIEL VALLEY HYDRO SUBUNIT MAIN SAN GABRIEL HYDRO SUBAREA						U-05 U-05.D U-05.D1	
02S/09W-07P03 S (CONTINUED)	19		521.5	4/02/75	29.8	491.7	1101
				5/07/75	29.0	492.5	
				6/11/75	31.6	489.9	
				7/09/75	33.4	488.1	
				8/12/75	35.4	486.1	
				9/11/75	42.6	478.9	
02S/09W-09B01 S	19		563.0	11/04/74	19.0	544.0	1101
				4/02/75	20.6	542.4	
02S/09W-08E02 S	19		532.0	11/07/74	15.2	516.8	1101
				4/02/75	NM-5		
02S/09W-17H02 S	19		583.0	11/04/74	18.7	564.3	1101
02S/09W-18D05 S	19		475.0	11/07/74	20.6	454.4	1101
				4/03/75	18.4	456.6	
02S/09W-18E06 S	19		480.0	11/07/74	19.3	460.7	1101
				4/03/75	17.5	462.5	
02S/10W-06R05 S	19		307.0	10/16/74	71.4	235.6	1733
				11/06/74	70.3	236.7	
				12/18/74	70.8	236.2	
				1/08/75	70.6	236.4	
				2/19/75	70.9	236.1	
				3/12/75	70.9	236.1	
				4/02/75	71.5	235.5	
				5/14/75	73.5	233.5	
				6/04/75	73.7	233.3	
				7/16/75	74.8	232.2	
				8/06/75	75.3	231.7	
				9/17/75	75.8	231.2	
02S/10W-06P02 S	19		308.0	10/16/74	26.7	281.3	1733
				11/06/74	25.3	282.7	
				12/18/74	25.9	282.1	
				1/08/75	26.4	281.6	
				2/19/75	26.4	281.6	
				3/12/75	25.5	282.5	
				4/02/75	26.6	281.4	
				5/14/75	27.7	280.3	
				6/04/75	28.0	280.0	
				7/16/75	28.9	279.1	
				8/06/75	29.1	278.9	
				9/17/75	29.7	278.3	
02S/10W-07C02 S	19		314.2	11/07/74	51.8	262.4	1101
				4/03/75	70.5	243.7	
02S/10W-07P01 S	19		352.0	11/07/74	DRY (6)		1101
				4/03/75	NM-7		
02S/10W-08G02 S	19		331.0	10/04/74	26.3	304.7	1101
				11/07/74	NM-5		
				4/03/75	26.7	304.3	
				6/03/75	26.7	304.3	
				8/12/75	27.3	303.7	
				9/11/75	27.2	303.8	
02S/10W-09K01 S	19		342.0	11/01/74	68.5(1)	273.5	1101
				1/06/75	79.5(1)	262.5	
				3/04/75	74.5(1)	267.5	
				5/01/75	74.5(1)	267.5	
				6/02/75	77.5(1)	264.5	
				7/01/75	80.5(1)	261.5	
				9/03/75	82.5(1)	259.5	
02S/10W-09L01 S	19		342.0	11/04/74	42.3(5)	299.7	1101
				1/06/75	59.3(5)	282.7	
				3/04/75	64.3(5)	277.7	
				5/01/75	64.3(5)	277.7	
				7/01/75	95.3(1)	246.7	
				9/03/75	121.3(1)	220.7	
02S/10W-09P01 S	19		360.0	4/03/75	47.5	312.5	1101
02S/10W-09Q07 S	19		375.0	11/07/74	46.6	328.4	1101
				4/03/75	NM-3		
				6/03/75	NM-2		
02S/10W-10P04 S	19		397.7	11/07/74	38.4	359.3	1101
				4/03/75	NM-5		
02S/10W-11K01 S	19		444.0	11/07/74	34.6	489.4	1101
				4/10/75	35.1	408.9	
02S/10W-13A02 S	19		480.0	11/07/74	25.0	455.0	1101
				4/03/75	23.4	456.6	
02S/10W-13F01 S	19		441.8	11/21/74	17.5	424.3	1101
				4/03/75	NM-7		
				6/10/75	15.2	426.6	
02S/10W-14G01 S	19		482.0	11/07/74	24.0	458.0	1101
				4/03/75	NM-5		
02S/10W-14G02 S	19		420.0	11/07/74	NM-6		1101
02S/10W-14H01 S	19		431.0	11/07/74	19.6	411.4	1101
				4/03/75	17.9	413.1	
02S/10W-15D02 S	19		375.0	11/07/74	32.0	343.0	1101

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT SAN GABRIEL VALLEY HYDRO SUBUNIT MAIN SAN GABRIEL HYDRO SUBAREA						U-05 U-05.D U-05.D1	
02S/10W-15D02 S	19		375.0	4/03/75	31.9	343.1	1101
02S/10W-15H01 S	19		419.0	11/07/74	NM-6		1101
02S/10W-15H02 S	19		420.0	11/07/74	NM-6		1101
02S/10W-15K01 S	19		424.0	11/07/74	18.8	405.2	1101
				4/03/75	NM-7		
02S/10W-23N01 S	19		516.0	11/07/74	14.6	501.4	1101
				4/03/75	NM-5		
02S/11W-01B01 S	19		291.0	11/07/74	52.0	239.0	1101
				4/02/75	53.3	237.7	
02S/11W-01J02 S	19		295.5	10/01/74	51.2	244.3	1101
				12/03/74	51.3	244.2	
				1/08/75	51.5	244.0	
02S/11W-03D07 S	19		252.5	11/12/74	24.0	228.5	1101
				4/01/75	22.2	230.3	
02S/11W-04D03 S	19		221.0	10/29/74	15.7	205.3	1101
				11/25/74	16.3	204.7	
				12/30/74	16.3	204.7	
				1/27/75	17.0	204.0	
				2/25/75	16.9	204.1	
				3/24/75	16.7	204.3	
				4/29/75	16.8	204.2	
				5/26/75	16.7	204.3	
				6/23/75	16.0	205.0	
				7/28/75	17.7	203.3	
				8/25/75	18.5	202.5	
02S/11W-04M03 S	19		218.0	11/05/74	126.0(1)	92.0	1101
				1/02/75	122.0(1)	96.0	
				3/05/75	122.0(1)	96.0	
				5/05/75	123.0(1)	95.0	
				7/02/75	134.0(1)	84.0	
				9/03/75	127.0(1)	91.0	
02S/11W-04N01 S	19		225.0	10/29/74	29.6(8)	195.4	1101
				11/25/74	29.8(8)	195.2	
				12/30/74	28.0(8)	197.0	
				1/27/75	29.3(8)	195.7	
				2/25/75	28.3(8)	196.7	
				3/24/75	28.1(8)	196.9	
				4/29/75	29.1(8)	195.9	
				5/26/75	27.9	197.1	
				6/23/75	29.0(8)	196.0	
				7/28/75	32.3(8)	192.7	
				8/25/75	33.0(8)	192.0	
02S/11W-05B11 S	19		222.5	11/08/74	20.0	202.5	1101
				4/14/75	22.0	200.5	
02S/11W-05E02 S	19		209.8	10/07/74	15.4	194.4	1733
				11/18/74	15.0	194.8	
				12/09/74	14.1	195.7	
				1/20/75	14.7	195.1	
				2/10/75	13.8	196.0	
				3/03/75	14.3	195.5	
				4/14/75	14.5	195.3	
				5/05/75	14.8	195.0	
				6/16/75	13.6	196.2	
				7/07/75	15.4	194.4	
				8/18/75	17.5	192.3	
				9/08/75	18.2	191.6	
02S/11W-05F03 S	19		217.0	10/29/74	17.4	199.6	1101
				11/25/74	17.8	199.2	
				12/30/74	17.9	199.1	
				1/27/75	18.1	198.9	
				2/25/75	18.1	198.9	
				3/24/75	18.1	198.9	
02S/11W-05G01 S	19		210.0	10/07/74	NM-9		1101
				11/04/74	NM-9		
				12/09/74	NM-9		
				2/03/75	19.0	191.0	
				3/03/75	19.0	191.0	
				4/07/75	18.0	192.0	
				5/05/75	61.0(1)	149.0	
				6/02/75	61.0(1)	149.0	
				7/07/75	62.0(1)	148.0	
				8/04/75	18.0	192.0	
				9/01/75	65.0(1)	145.0	
02S/11W-05G02 S	19		214.0	10/07/74	35.0(1)	179.0	1101
				11/04/74	21.0(5)	193.0	
				12/09/74	20.0(5)	194.0	
				1/06/75	35.0(1)	179.0	
				2/03/75	23.0(5)	191.0	
				3/03/75	35.0(1)	179.0	
				4/07/75	35.0(1)	179.0	
				5/05/75	34.0(1)	180.0	
				6/02/75	20.0(5)	194.0	
				7/07/75	37.0(1)	177.0	
				8/04/75	37.0(1)	177.0	
				9/01/75	26.0(5)	188.0	
02S/11W-05G04 S	19		211.0	10/07/74	55.5(1)	155.5	1101

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
SAN GABRIEL VALLEY HYDRO SUBUNIT — U-05.D
MAIN SAN GABRIEL HYDRO SUBAREA — U-05.D1

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
02S/11W-05G04 S (CONTINUED)	19		211.0	11/04/74	56.5(1)	154.5	1101
				12/09/74	56.5(1)	154.5	
				1/06/75	57.5(1)	153.5	
				2/03/75	57.6(1)	153.4	
				3/03/75	55.5(1)	155.5	
				4/07/75	56.5(1)	154.5	
				5/05/75	19.5(1)	191.5	
				6/02/75	56.5(1)	154.5	
				7/07/75	60.5(1)	150.5	
				8/04/75	60.5(1)	150.5	
				9/01/75	64.5(1)	146.5	
02S/11W-05G05 S	19		210.0	10/07/74	15.4(6)	194.6	1101
				11/04/74	15.4(6)	194.6	
				12/09/74	15.4(6)	194.6	
				1/06/75	15.4(6)	194.6	
				2/03/75	15.4(6)	194.6	
				3/03/75	15.4(6)	194.6	
				4/07/75	16.4(6)	193.6	
				5/05/75	16.4(6)	193.6	
				6/02/75	16.4(6)	193.6	
				7/07/75	16.4	193.6	
				8/04/75	16.4	193.6	
				9/01/75	16.4	193.6	
02S/11W-05J02 S	19		215.0	11/05/74	26.5	188.5	1101
				1/02/75	20.5	194.5	
				4/14/75	24.9	190.1	
02S/11W-05J03 S	19		213.0	11/05/74	68.5(1)	144.5	1101
				1/02/75	25.5(5)	187.5	
				3/05/75	71.5(1)	141.5	
				5/05/75	25.5(5)	187.5	
				7/02/75	64.5(1)	148.5	
				9/03/75	36.5(5)	176.5	
02S/11W-05J09 S	19		214.0	11/05/74	54.0(1)	160.0	1101
				1/02/75	54.0(1)	160.0	
				3/05/75	51.0(1)	163.0	
				5/05/75	53.0(1)	161.0	
				7/02/75	53.0(1)	161.0	
				9/03/75	61.0(1)	153.0	
02S/11W-05K01 S	19		209.5	10/07/74	27.0	182.5	1101
				11/04/74	26.0	183.5	
				12/09/74	25.0	184.5	
				1/06/75	26.0	183.5	
				2/03/75	22.0	187.5	
				3/03/75	25.0	184.5	
				4/07/75	15.0	194.5	
				5/05/75	18.0	191.5	
				6/02/75	23.0	186.5	
				7/07/75	31.0	178.5	
				8/04/75	29.0	180.5	
				9/01/75	33.0	176.5	
02S/11W-05K02 S	19		215.0	11/05/74	31.0	184.0	1101
				1/02/75	25.0	190.0	
02S/11W-05L01 S	19		212.5	10/07/74	17.5	195.0	1733
				11/04/74	16.2	196.3	
				12/02/74	16.4	196.1	
				1/06/75	16.1	196.4	
				2/03/75	15.7	196.8	
				3/03/75	16.4	196.1	
				4/07/75	16.5	196.0	
				5/05/75	16.2	196.3	
				6/02/75	13.8	198.7	
				7/07/75	17.0	195.5	
				8/04/75	17.7	194.8	
				9/01/75	19.6	192.9	
02S/11W-05N04 S	19		203.2	10/28/74	15.1	188.1	1733
				11/25/74	15.5	187.7	
				12/23/74	16.2	187.0	
				1/27/75	15.6	187.6	
				2/24/75	15.0	188.2	
				3/24/75	14.9	188.3	
				4/28/75	15.1	188.1	
				5/26/75	15.4	187.8	
				6/23/75	14.3	188.9	
				7/28/75	16.3	186.9	
				8/25/75	17.0	186.2	
				9/22/75	17.6	185.6	
02S/11W-05N05 S	19		199.7	11/07/74	20.9	178.8	1101
				4/09/75	19.7	180.0	
02S/11W-05N06 S	19		206.5	11/07/74	16.6	189.9	1101
				12/30/74	15.9	190.6	
				1/27/75	16.6	189.9	
				2/25/75	16.1	190.4	
				3/24/75	15.9	190.6	
				4/29/75	14.7	191.8	
				5/27/75	16.4	190.1	
				6/25/75	15.3	191.2	
				7/28/75	17.6	188.9	
				8/26/75	18.7	187.8	
02S/11W-05P05 S	19		204.0	10/27/74	13.5	190.5	1101
				11/25/74	12.9	191.1	
				12/30/74	12.0	192.0	

LA-SAN GABRIEL RIVER HYDRO UNIT — U-05
SAN GABRIEL VALLEY HYDRO SUBUNIT — U-05.D
MAIN SAN GABRIEL HYDRO SUBAREA — U-05.D1

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
02S/11W-05P05 S (CONTINUED)	19		204.0	1/27/75	12.7	191.3	1101
				2/25/75	12.3	191.7	
				3/24/75	12.1	191.9	
				4/29/75	12.7	191.3	
				5/27/75	12.3	191.7	
				6/25/75	11.6	192.4	
				7/28/75	14.1	189.9	
				8/26/75	15.0	189.0	
02S/11W-05Q04 S	19		213.0	11/05/74	43.0(5)	170.0	1101
				1/02/75	36.0(5)	177.0	
				3/05/75	40.0(5)	173.0	
				5/05/75	108.0(1)	105.0	
				7/02/75	40.0(5)	173.0	
				9/03/75	113.0(1)	100.0	
02S/11W-05Q09 S	19		210.1	10/29/74	15.0	195.1	1101
				11/25/74	15.5	194.6	
				12/30/74	14.8	195.3	
				1/27/75	15.6	194.5	
				2/25/75	15.2	194.9	
				3/24/75	14.9	195.2	
				4/29/75	15.1	195.0	
				5/27/75	14.9	195.2	
				6/25/75	13.8	196.3	
				7/28/75	16.8	193.3	
				8/26/75	17.4	192.7	
02S/11W-05Q06 S	19		209.3	10/29/74	14.1	195.2	1101
				11/25/74	14.4	194.9	
				12/30/74	13.5	195.8	
				1/27/75	14.5	194.8	
				2/25/75	14.2	195.1	
				3/24/75	13.8	195.5	
				4/29/75	14.6	194.7	
				5/27/75	14.0	195.3	
				6/25/75	13.1	196.2	
				7/28/75	16.0	193.3	
				8/26/75	16.7	192.6	
02S/11W-05R03 S	19		207.0	11/12/74	19.5	187.5	1101
				4/01/75	19.6(8)	187.4	
02S/11W-05R04 S	19		214.0	10/29/74	18.6	195.4	1101
				11/25/74	18.9	195.1	
				12/30/74	17.7	196.3	
				1/27/75	18.8	195.2	
				2/25/75	18.3	195.7	
				3/24/75	18.1	195.9	
				4/29/75	18.8	195.2	
				5/27/75	18.6	195.4	
				6/25/75	17.9	196.1	
				7/28/75	20.7	193.3	
				8/26/75	21.5	192.5	
02S/11W-06A01 S	19		209.6	10/29/74	11.7	197.9	1101
				11/25/74	11.6	198.0	
				12/30/74	10.9	198.7	
				1/27/75	11.2	198.4	
				2/25/75	10.8	198.8	
				3/24/75	10.8	198.8	
				4/29/75	11.3	198.3	
				5/26/75	11.7	197.9	
				6/23/75	DRY. (6)		
				7/28/75	14.3	195.3	
				8/25/75	13.9	195.7	
02S/11W-06A02 S	19		210.0	10/29/74	13.9	196.1	1101
				11/25/74	13.8	196.2	
				12/30/74	13.0	197.0	
				1/27/75	13.5	196.5	
				2/25/75	13.0	197.0	
				3/24/75	13.0	197.0	
				4/29/75	13.6	196.4	
				5/26/75	14.0	196.0	
				6/23/75	13.2	196.8	
				7/28/75	15.7	194.3	
				8/25/75	16.4	193.6	
02S/11W-06A01 S	19		203.0	11/06/74	12.9	190.1	1101
				4/07/75	11.2	191.8	
02S/11W-06G08 S	19		197.0	10/30/74	7.7	189.3	1101
				4/07/75	7.8	189.2	
02S/11W-06H02 S	19		207.7	10/29/74	13.9	193.8	1101
				11/25/74	14.6	193.1	
				12/30/74	13.2	194.5	
				1/27/75	13.7	194.0	
				2/25/75	13.2	194.5	
				3/24/75	13.5	194.2	
02S/11W-06J04 S	19		202.0	10/01/74	8.8	193.2	1101
				4/07/75	NM-5		
02S/11W-08A02 S	19		218.0	11/12/74	22.6	195.4	1101
				4/01/75	21.1(8)	196.9	
02S/11W-08A01 S	19		217.0	10/28/74	23.0	194.0	1733
				11/25/74	22.4	194.6	
				12/23/74	21.7	195.3	
				1/27/75	22.2	194.8	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT						U-05	
SAN GABRIEL VALLEY HYDRO SUBUNIT						U-05.D	
MAIN SAN GABRIEL HYDRO SUBAREA						U-05.01	
02S/11W-08R01 S (CONTINUED)	19		217.0	2/24/75	21.3	195.7	1733
				3/24/75	21.2	195.8	
				4/28/75	21.8	195.2	
				5/26/75	22.1	194.9	
				6/23/75	21.3	195.7	
				7/28/75	24.0	193.0	
				8/25/75	24.9	192.1	
				9/22/75	25.5	191.5	
02S/11W-08R02 S	19		205.0	10/29/74	16.1	188.9	1101
				11/25/74	16.3	188.7	
				12/30/74	16.3	188.7	
				1/27/75	16.4	188.6	
				2/25/75	16.5	188.5	
				3/24/75	16.3	188.7	
				4/29/75	16.4	188.6	
				5/26/75	16.5	188.5	
				6/23/75	16.3	188.7	
				7/28/75	16.3	188.7	
				8/26/75	16.4	188.6	
02S/11W-08B03 S	19		207.9	11/06/74	15.0	192.9	1101
02S/11W-08C03 S	19		214.6	11/07/74	25.5	189.1	1101
				4/01/75	25.5	189.1	
02S/11W-08G01 S	19		211.0	11/08/74	18.0	193.0	1101
				4/01/75	18.0	193.0	
LOWER CANYON HYDRO SUBAREA						U-05.02	
01N/10W-25F02 S	19		809.0	10/31/74	60.5	748.5	1101
				4/02/75	57.3	751.7	
01N/10W-27J01 S	19		654.4	10/17/74	121.6	532.8	1733
				11/07/74	120.4	534.0	
				12/19/74	139.7	514.7	
				1/09/75	142.2	512.2	
				2/20/75	137.9	516.5	
				3/13/75	144.4	510.0	
				4/03/75	149.8	504.6	
				5/15/75	148.1	506.3	
				6/05/75	144.4	510.0	
				7/17/75	143.0	511.4	
				8/07/75	145.3	509.1	
				9/18/75	148.1	506.3	
01N/10W-27K02 S	19		647.8	10/17/74	118.6	529.2	1733
				11/07/74	118.1	529.7	
				12/19/74	NM-1		
				1/09/75	142.0	505.8	
				2/20/75	133.7	514.1	
				3/13/75	145.5	502.3	
				4/03/75	149.6	498.2	
				5/15/75	149.1	498.7	
				6/05/75	NM-1		
				7/17/75	146.4	501.4	
				8/07/75	NM-1		
				9/18/75	148.9	498.9	
01N/10W-27K03 S	19		660.0	10/01/74	60.9	599.1	1101
				12/10/74	65.4	594.6	
				1/06/75	72.3	587.7	
				2/06/75	84.2	575.8	
				3/14/75	91.2	568.8	
				4/18/75	76.4	583.6	
				5/02/75	54.0	606.0	
				6/06/75	42.4	617.6	
				7/31/75	59.7	600.3	
				9/08/75	73.6	586.4	
01N/10W-27K04 S	19		655.0	11/01/74	NM-1		1101
				12/19/74	122.0	533.0	
				4/01/75	NM-1		
01N/10W-27M01 S	19		631.1	10/31/74	DRY		1101
				3/31/75	DRY		
01N/10W-27P01 S	19		625.0	11/01/74	111.1	513.9	1101
				3/31/75	131.1	493.9	
01N/10W-28M01 S	19		603.4	10/01/74	121.4	482.0	1101
				12/03/74	122.9	480.5	
				1/02/75	124.4	479.0	
				2/05/75	125.8	477.6	
				3/13/75	126.6	476.8	
				4/18/75	122.8	480.6	
				5/02/75	118.7	484.7	
				6/06/75	111.2	492.2	
				7/01/75	111.5	491.9	
				9/04/75	118.0	485.4	
01N/10W-29A03 S	19		631.9	10/01/74	33.5	598.4	1101
				11/01/74	32.5	599.4	
				12/01/74	35.5	596.4	
				1/01/75	37.5	594.4	
				2/01/75	37.5	594.4	
				4/01/75	33.5	598.4	
				5/01/75	36.5	595.4	
				6/01/75	27.5	604.4	
				9/01/75	33.5	598.4	
01N/10W-29K01 S	19		591.2	10/17/74	47.0	544.2	1733
LA-SAN GABRIEL RIVER HYDRO UNIT						U-05	
SAN GABRIEL VALLEY HYDRO SUBUNIT						U-05.D	
LOWER CANYON HYDRO SUBAREA						U-05.02	
01N/10W-29K01 S (CONTINUED)	19		591.2	11/07/74	47.1	544.1	1733
				12/19/74	49.5	541.7	
				1/09/75	51.5	539.7	
				2/20/75	54.9	536.3	
				3/13/75	53.2	538.0	
				4/03/75	47.9	543.3	
				6/05/75	43.1	548.1	
				7/17/75	46.2	545.0	
				8/07/75	47.5	543.7	
				9/18/75	49.5	541.7	
UPPER CANYON HYDRO SUBAREA						U-05.03	
01N/10W-03R11 S	19		603.0	10/17/74	11.8	591.2	1733
				11/07/74	12.6	590.4	
				12/19/74	12.4	590.6	
				1/09/75	13.1	589.9	
				2/20/75	13.2	589.8	
				3/13/75	12.1	590.9	
				4/03/75	12.4	590.6	
				5/15/75	13.0	590.0	
				6/05/75	13.2	589.8	
				7/17/75	11.9	591.1	
				8/07/75	2.4(6)	600.6	
				9/18/75	12.7	590.3	
01N/10W-03C03 S	19		527.0	11/12/74	289.7	237.3	1101
				4/15/75	NM-2		
01N/10W-22M01 S	19		704.2	10/17/74	72.3(4)	631.9	1733
				11/07/74	71.4(4)	632.8	
				12/19/74	82.4	621.8	
				1/09/75	87.1	617.1	
				2/20/75	87.8	616.4	
				3/13/75	82.5	621.7	
				4/03/75	76.8	627.4	
				5/15/75	56.3	647.9	
				6/05/75	57.0	647.2	
				7/17/75	70.2	634.0	
				8/07/75	74.4	629.8	
				9/18/75	78.4	625.8	
01N/10W-22P02 S	19		694.6	10/17/74	57.9	636.7	1733
				11/07/74	NM-1		
				12/19/74	NM-1		
				1/09/75	80.4	614.2	
				2/20/75	82.7	611.9	
				3/13/75	72.4	622.2	
				4/03/75	64.9	629.7	
				5/15/75	34.4	660.2	
				6/05/75	35.7	658.9	
				7/17/75	54.7	639.9	
				8/07/75	NM-1		
				9/18/75	65.4	629.2	
01N/10W-22R02 S	19		716.8	10/31/74	51.9(4)	664.1	1101
				3/31/75	47.5	668.5	
01N/10W-23A05 S	19		815.0	10/01/74	20.1	794.9	1101
				12/10/74	14.1	800.9	
				1/06/75	19.7	795.3	
				2/06/75	20.9	794.1	
				3/04/75	21.0	794.0	
				4/18/75	9.2	805.8	
				5/12/75	9.6	805.4	
				7/31/75	NM-2		
01N/10W-23C01 S	19		784.9	10/31/74	23.1	761.8	1101
				12/10/74	17.1	767.8	
				1/06/75	20.2	764.7	
				2/06/75	22.8	762.1	
				3/04/75	23.5	761.4	
				4/18/75	14.3	770.6	
				5/12/75	14.7	770.2	
				6/03/75	14.8	770.1	
				7/01/75	19.1	765.8	
				9/08/75	19.1	765.8	
01N/10W-23E01 S	19		755.3	10/01/74	23.6	731.7	1101
				12/10/74	16.0	739.3	
				1/06/75	20.4	734.9	
				2/06/75	22.6	732.7	
				3/04/75	23.9	731.4	
				4/18/75	2.1	753.2	
				5/12/75	2.9	752.4	
				6/03/75	3.2	752.1	
				7/01/75	11.3	744.0	
				9/08/75	21.9	733.4	
01N/10W-27H01 S	19		690.7	10/03/74	61.2	629.5	1101
				11/07/74	58.5	632.2	
				12/06/74	76.3	614.4	
				1/06/75	86.1	604.6	
				2/06/75	88.1	602.6	
				3/07/75	88.4	602.3	
				4/04/75	71.6	619.1	
				5/02/75	42.0	648.7	
				6/13/75	44.2	646.5	
				7/03/75	49.9	640.8	
				8/14/75	68.7	622.0	
				9/08/75	74.6	616.1	
01N/10W-27H02 S	19		695.9	10/31/74	DRY		1101

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT SAN GABRIEL VALLEY HYDRO SUBUNIT UPPER CANYON HYDRO SUBAREA						U-05 U-05.D U-05.D3	
01N/10W-27R02 S	19		695.9	3/31/75	DRY		1101
01N/10W-27C02 S	19		681.1	10/10/74	58.3	622.8	1101
				11/01/74	55.1	626.0	
				12/19/74	72.6(1)	608.5	
				1/03/75	79.7(1)	601.4	
				2/01/75	84.1(1)	597.0	
				3/28/75	66.4	614.7	
				4/22/75	43.5	637.6	
				5/02/75	44.7(1)	636.4	
				6/10/75	48.5(1)	632.6	
				7/10/75	53.4(1)	627.7	
				8/01/75	64.1(1)	617.0	
				9/01/75	75.2(1)	605.9	
01N/10W-27C03 S	19		675.8	10/01/74	42.6	633.2	1101
				12/10/74	47.8	628.0	
				1/06/75	50.9	624.9	
				2/06/75	53.4	622.4	
				3/14/75	DRY		
				4/04/75	DRY		
				5/02/75	50.9	624.9	
				6/06/75	42.6	633.2	
				7/31/75	40.1	635.7	
				9/10/75	46.7	629.1	
01N/10W-27E01 S	19		658.3	10/01/74	32.5	625.8	1101
				12/10/74	42.5	615.8	
				1/06/75	47.1	611.2	
				2/06/75	51.7	606.6	
				3/14/75	46.8	611.5	
				4/18/75	28.1	630.2	
				5/02/75	19.7	638.6	
				6/06/75	15.5	642.8	
				7/31/75	32.5	625.8	
				9/08/75	40.8	617.5	
01N/10W-27F01 S	19		663.2	10/01/74	57.9	605.3	1101
				12/10/74	55.6	607.6	
				1/06/75	56.9	606.3	
				2/06/75	59.6	603.6	
				3/14/75	63.2	600.0	
				4/18/75	65.6	597.6	
				5/02/75	65.0	598.2	
				6/06/75	55.0	608.2	
				7/31/75	50.3	612.9	
01N/10W-27G03 S	19		662.2	10/01/74	67.2	595.0	1101
				12/10/74	72.4	589.8	
				1/06/75	79.4	582.8	
				2/06/75	DRY		
				3/14/75	DRY		
				4/18/75	71.8	590.4	
				5/02/75	59.2	603.0	
				6/06/75	51.7	610.5	
				7/31/75	68.0	594.2	
				9/08/75	82.7	579.5	
01N/10W-27H01 S	19		669.7	10/17/74	75.1	594.6	1733
				11/07/74	74.1	595.6	
				12/19/74	87.2	582.5	
				1/09/75	93.0	576.7	
				2/20/75	93.6	576.1	
				3/13/75	94.6	575.1	
				4/03/75	90.6	579.1	
				5/15/75	63.2	606.5	
				6/05/75	62.7	607.0	
				7/17/75	72.1	597.6	
				8/07/75	81.4	588.3	
				9/18/75	92.5	577.2	
01N/10W-27H02 S	19		667.4	11/01/74	67.5	599.9	1101
				4/02/75	91.5	575.9	
01N/10W-27H03 S	19		673.2	10/31/74	DRY		1101
				3/31/75	DRY		
				5/30/75	41.2	632.0	
				6/06/75	42.3	630.9	
				7/01/75	45.6	627.6	
01N/10W-28H01 S	19		653.2	10/01/74	30.2	623.0	1101
				12/03/74	36.6	616.6	
				1/06/75	41.0	612.2	
				2/06/75	44.5	608.7	
				3/14/75	39.4	613.8	
				4/18/75	25.8	627.4	
				5/02/75	22.8	630.4	
				6/06/75	21.5	631.7	
				7/31/75	30.9	622.3	
				8/29/75	34.3	618.9	
FOOTHILL HYDRO SUBAREA						U-05.D4	
01N/09W-25G01 S	19		1235.0	11/13/74	40.8	1194.2	1101
				4/14/75	35.1	1199.9	
01N/09W-25K01 S	19		1315.7	10/01/74	128.1	1187.6	1101
				12/11/74	130.3	1185.4	
				1/09/75	131.0	1184.7	
				2/07/75	130.9	1184.8	
				3/05/75	128.8	1186.9	
				4/01/75	126.6	1189.1	
LA-SAN GABRIEL RIVER HYDRO UNIT SAN GABRIEL VALLEY HYDRO SUBUNIT FOOTHILL HYDRO SUBAREA						U-05 U-05.D U-05.D4	
01N/09W-25K01 S (CONTINUED)	19		1315.7	5/07/75	130.2	1185.5	1101
				6/10/75	127.0	1188.7	
				7/09/75	129.8	1185.9	
				8/12/75	131.2	1184.5	
				9/11/75	128.9	1186.8	
01N/09W-35H01 S	19		1155.0	10/03/74	58.1	1096.9	1101
				11/13/74	NM-1		
				4/14/75	46.0	1109.0	
01N/09W-36D03 S	19		1165.0	10/03/74	53.5	1111.5	1101
				12/11/74	50.1	1114.9	
				1/09/75	48.5	1116.5	
				2/07/75	49.3	1115.7	
				3/05/75	49.1	1115.9	
				4/01/75	44.0	1121.0	
				5/07/75	45.1	1119.9	
				6/10/75	47.6	1117.4	
				7/09/75	50.4	1114.6	
				8/12/75	51.5	1113.5	
				9/11/75	54.4	1110.6	
01N/09W-36E02 S	19		1235.0	11/13/74	161.9	1073.1	1101
				4/21/75	141.2	1093.8	
01N/09W-36F01 S	19		1277.0	11/15/74	138.3	1138.7	1101
				4/07/75	136.7	1140.3	
SPADRA HYDRO SUBUNIT SPADRA HYDRO SUBAREA						U-05.E U-05.E1	
01S/08W-19N01 S	19		851.0	11/12/74	301.3	549.7	1101
				4/10/75	262.0	589.0	
01S/09W-23N02 S	19		761.8	10/04/74	143.7	618.1	1101
				11/08/74	146.0	615.8	
				12/13/74	144.3	617.5	
				1/10/75	139.8	622.0	
				2/06/75	137.8	624.0	
				3/06/75	136.5	625.3	
				4/02/75	142.7	619.1	
				5/07/75	145.1	616.7	
				6/11/75	145.6	616.2	
				7/09/75	146.6	615.2	
				8/12/75	146.7	615.1	
				9/11/75	147.9	613.9	
01S/09W-23R01 S	19		800.3	11/04/74	NM-3		1101
				4/10/75	NM-3		
				5/08/75	137.0	663.3	
01S/09W-24Q02 S	19		836.0	11/04/74	235.8	600.2	1101
				4/10/75	198.4	637.6	
01S/09W-25B01 S	19		824.0	11/12/74	178.4	645.6	1101
				4/10/75	163.8	660.2	
01S/09W-25E01 S	19		798.0	11/04/74	NM-3		1101
01S/09W-25E02 S	19		803.0	11/04/74	NM-3		1101
01S/09W-25F01 S	19		804.7	11/04/74	172.8	631.9	1101
				4/10/75	176.9	627.8	
01S/09W-25G01 S	19		823.0	11/12/74	184.3	638.7	1101
				4/10/75	160.9	662.1	
01S/09W-26H01 S	19		792.5	10/01/74	190.2(1)	602.3	1101
				11/01/74	189.1(1)	603.4	
				12/01/74	167.1(5)	625.4	
				1/01/75	163.7(5)	628.8	
				2/01/75	198.3(1)	594.2	
				3/01/75	205.2(1)	587.3	
				4/01/75	207.5(1)	585.0	
				5/15/75	219.1(1)	573.4	
				6/15/75	223.5(1)	569.0	
				7/01/75	217.9(1)	574.6	
				8/01/75	190.2(1)	602.3	
				9/01/75	199.5(1)	593.0	
01S/09W-27J01 S	19		730.0	11/04/74	132.8(6)	597.2	1101
				4/10/75	133.8	596.2	
01S/09W-27N04 S	19		702.0	10/04/74	64.1	637.9	1101
				11/08/74	64.3	637.7	
				12/13/74	65.4	636.6	
01S/09W-33J02 S	19		664.2	11/04/74	37.3	626.9	1101
				4/10/75	35.6	628.6	
01S/09W-34F01 S	19		688.0	11/04/74	96.1	591.9	1101
				4/10/75	94.6	593.4	
POMONA HYDRO SUBAREA						U-05.E2	
01S/08W-07G01 S	19		1094.0	11/14/74	NM-2		1101
				4/07/75	389.0	705.0	
01S/08W-07G02 S	19		1092.8	11/14/74	NM-1		1101
				4/07/75	NM-1		
01S/08W-08B03 S	19		1044.0	11/08/74	200.0	844.0	1101

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT SPADRA HYDRO SUBUNIT POMONA HYDRO SUBAREA					U-05 U-05.E U-05.E2		
01S/08W-0AR03 S	19		1044.0	4/07/75	171.8	872.2	1101
01S/08W-16J02 S	19		991.3	10/01/74	638.8(1)	352.5	1101
				11/01/74	504.8(5)	486.5	
				12/01/74	500.2(5)	491.1	
				1/01/75	496.7(5)	494.6	
				2/01/75	495.5(5)	495.8	
				3/01/75	492.1(1)	499.2	
				4/01/75	486.3(5)	505.0	
				5/15/75	493.2(5)	498.1	
				6/01/75	486.3(5)	505.0	
				7/01/75	487.4(5)	503.9	
				8/01/75	611.0(1)	380.3	
				9/01/75	624.9(1)	366.4	
01S/08W-19A01 S	19		922.5	6/27/75	205.2	717.3	1101
				7/25/75	204.6	717.9	
				8/12/75	206.1	716.4	
				9/11/75	NM-4		
01S/09W-11R01 S	19		980.0	11/12/74	67.5	912.5	1101
				4/21/75	33.4	946.6	
01S/09W-11R02 S	19		972.0	10/04/74	24.8	947.2	1101
				11/08/74	25.0	947.0	
				4/07/75	23.8	948.2	
01S/09W-12F01 S	19		1029.0	10/03/74	170.5	858.5	1101
				12/11/74	156.9	872.1	
				1/09/75	156.4	872.6	
				2/07/75	154.0	875.0	
				3/05/75	154.8	874.2	
				4/01/75	149.7	879.3	
				5/07/75	149.0	880.0	
				6/10/75	166.1	862.9	
				7/09/75	157.2	871.8	
				8/12/75	151.5	877.5	
				9/11/75	150.6	878.4	
01S/09W-12H01 S	19		1055.0	4/07/75	NM-1		1101
01S/09W-12J01 S	19		1048.0	11/08/74	DRY		1101
				4/07/75	DRY		
01S/09W-12L01 S	19		1030.4	10/03/74	193.0	837.4	1101
				12/11/74	174.2	856.2	
				1/09/75	174.6	855.8	
				2/07/75	169.5	860.9	
				3/05/75	171.3	859.1	
				4/01/75	157.4	873.0	
				5/07/75	158.6	871.8	
				6/10/75	171.9	858.5	
				7/09/75	172.4	858.0	
				8/12/75	161.3	869.1	
				9/11/75	159.5	870.9	
01S/09W-12M01 S	19		984.0	11/12/74	44.7	939.3	1101
				4/21/75	NM-2		
01S/09W-12N03 S	19		998.0	10/04/74	68.2	929.8	1101
				11/08/74	68.2	929.8	
				4/07/75	68.0	930.0	
01S/09W-13A01 S	19		1018.0	10/08/74	285.4	732.6	1101
				11/08/74	NM-5		
				12/11/74	284.6	733.4	
				1/10/75	284.9	733.1	
				2/07/75	285.0	733.0	
				3/05/75	285.3	732.7	
				4/01/75	285.7	732.3	
				5/07/75	285.4	732.6	
				6/10/75	285.4	732.6	
				7/09/75	285.6	732.4	
				8/12/75	285.2	732.8	
				9/11/75	286.2	731.8	
LIVE OAK HYDRO SUBAREA					U-05.E3		
01N/08W-26N01 S	19		1830.0	11/14/74	25.5	1804.5	1101
				4/11/75	20.0	1810.0	
01N/08W-27H01 S	19		1779.0	11/14/74	54.8	1724.2	1101
				4/11/75	52.5	1726.5	
01N/08W-33A01 S	19		1530.9	10/03/74	43.0	1487.9	1101
				12/11/74	43.4	1487.5	
				1/09/75	42.6	1488.3	
				2/07/75	42.8	1488.1	
				3/06/75	48.2	1482.7	
				4/01/75	32.1	1498.8	
				5/07/75	33.7	1497.2	
				6/10/75	35.2	1495.7	
				7/09/75	39.9	1491.0	
				8/12/75	41.2	1489.7	
				9/11/75	42.0	1488.9	
01N/08W-33L01 S	19		1396.0	11/14/74	38.1	1357.9	1101
				4/17/75	27.7	1368.3	
01N/08W-33N02 S	19		1348.0	11/14/74	111.3	1236.7	1101
01N/08W-33P01 S	19		1374.0	11/14/74	NM-1		1101
LA-SAN GABRIEL RIVER HYDRO UNIT SPADRA HYDRO SUBUNIT LIVE OAK HYDRO SUBAREA					U-05 U-05.E U-05.E3		
01N/08W-33P01 S	19		1374.0	4/17/75	139.2	1234.8	1101
01N/08W-33Q03 S	19		1402.4	10/28/74	354.2(1)	1048.2	1101
				11/21/74	208.2(5)	1194.2	
				12/07/74	204.2(5)	1198.2	
				1/28/75	364.2(1)	1038.2	
				2/21/75	175.2(5)	1227.2	
				3/07/75	175.2(5)	1227.2	
				4/14/75	177.2(5)	1225.2	
				8/07/75	294.2(6)	1108.2	
01S/08W-04D01 S	19		1319.0	10/04/74	105.2	1213.8	1101
				12/11/74	100.6	1218.4	
				1/09/75	100.6	1218.4	
				2/07/75	99.8	1219.2	
				3/05/75	98.7	1220.3	
				4/01/75	94.6	1224.4	
				5/07/75	106.4	1212.6	
				6/10/75	110.4	1208.6	
				7/09/75	107.5	1211.5	
				8/12/75	118.5	1200.5	
				9/11/75	128.1	1190.9	
01S/08W-04L01 S	19		1305.1	10/01/74	221.9(1)	1083.2	1101
				11/01/74	189.5(5)	1115.6	
				12/01/74	171.1(5)	1134.0	
				1/01/75	148.0(5)	1157.1	
				2/01/75	166.4(5)	1138.7	
				3/01/75	195.3(1)	1109.8	
				4/01/75	163.0(5)	1142.1	
				5/15/75	166.4(5)	1138.7	
				6/01/75	166.4(5)	1138.7	
				7/01/75	195.3(1)	1109.8	
				8/01/75	201.1(1)	1104.0	
				9/01/75	208.0(1)	1097.1	
01S/08W-04M01 S	19		1267.0	12/11/74	NM-0		1101
				2/14/75	248.0(6)	1019.0	
				4/14/75	202.0(6)	1065.0	
01S/08W-05A02 S	19		1284.5	10/03/74	NM-2		1101
				12/11/74	65.1	1219.4	
				1/09/75	58.9	1225.6	
				2/07/75	59.0	1225.5	
				3/05/75	58.0	1226.5	
				4/17/75	53.7	1230.8	
01S/08W-05R01 S	19		1298.0	11/14/74	60.7(4)	1227.3	1101
				4/14/75	60.2(5)	1227.8	
				6/21/75	61.2(1)	1226.8	
				7/21/75	90.2(1)	1197.8	
				8/21/75	73.2(5)	1214.8	
				9/21/75	64.2(5)	1223.8	
01S/08W-05D01 S	19		1290.2	11/14/74	204.9	1085.3	1101
				4/21/75	231.7(2)	1058.5	
01S/08W-05D02 S	19		1289.8	11/14/74	201.5	1088.3	1101
				4/07/75	215.7(8)	1074.1	
01S/08W-05D04 S	19		1267.6	11/14/74	NM-7		1101
01S/08W-05E02 S	19		1277.4	10/03/74	174.2	1103.2	1101
				12/11/74	172.5	1104.9	
				1/09/75	175.8	1102.4	
				2/07/75	173.2	1104.2	
				3/05/75	180.0	1097.4	
				4/05/75	179.4	1098.0	
				5/07/75	178.8	1098.6	
				6/10/75	181.8	1095.6	
				7/09/75	181.9	1095.5	
				8/12/75	181.4	1096.0	
				9/11/75	181.1	1096.3	
01S/08W-06A01 S	19		1257.0	4/07/75	NM-1		1101
01S/08W-06A03 S	19		1242.1	10/03/74	148.5	1093.6	1101
				12/11/74	148.2	1093.9	
				1/09/75	148.0	1094.1	
				2/07/75	144.6	1097.5	
				3/05/75	159.8	1082.3	
				4/07/75	148.9	1093.2	
01S/08W-06H01 S	19		1230.0	11/21/74	145.9	1084.1	1101
01S/08W-06J02 S	19		1224.8	10/03/74	140.2	1083.8	1101
				12/11/74	129.8	1094.2	
				1/09/75	132.3	1091.7	
				2/07/75	131.7	1092.3	
				3/05/75	137.1	1086.9	
				4/01/75	133.5	1090.5	
				5/07/75	133.2	1090.8	
				6/10/75	137.7	1086.3	
				7/09/75	142.8	1081.2	
				8/12/75	148.5	1075.5	
				9/11/75	141.6	1082.4	
01S/08W-06L01 S	19		1133.8	11/14/74	NM-1		1101
				4/07/75	156.5	977.3	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

LA-SAN GABRIEL RIVER HYDRO UNIT
ANAHEIM HYDRO SUBUNIT
ANAHEIM HYDRO SUBAREA

U-05
U-05.F
U-05.F1

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
03S/09W-31J01 S	30		225.0	10/24/74	97.6	127.4	5102
				1/06/75	96.9	128.1	
				3/05/75	94.0	131.0	
				4/28/75	101.3	123.7	
				6/23/75	106.0	119.0	
				8/28/75	123.7	101.3	
03S/09W-31J02 S	30		220.0	10/24/74	113.8	106.2	5102
				1/06/75	104.1	115.9	
				3/05/75	115.1	104.9	
				4/28/75	108.0	112.0	
				6/23/75	117.9	102.1	
				8/28/75	125.2	94.8	
03S/09W-31J03 S	30		220.0	10/24/74	NM-7		5102
				1/06/75	NM-7		
				3/05/75	NM-2		
				4/28/75	NM-2		
				8/10/75	117.2	102.8	
03S/09W-31M01 S	30		211.5	10/24/74	122.8	88.7	5102
				1/06/75	NM-9		
				3/05/75	NM-9		
				4/28/75	NM-9		
				6/23/75	124.0	87.5	
				8/28/75	132.7	78.8	
03S/09W-32K06 S	30		235.0	10/01/74	103.5	131.5	5102
				11/01/74	84.9	150.1	
				12/01/74	83.3	151.7	
				1/01/75	88.5	146.5	
				2/01/75	92.5	142.5	
				3/01/75	91.6	143.4	
				4/01/75	89.7	145.3	
				5/01/75	90.0	145.0	
				6/01/75	92.0	143.0	
				7/01/75	100.4	134.6	
				8/01/75	113.7	121.3	
				9/01/75	120.5	114.5	
03S/09W-32K07 S	30		235.0	10/01/74	98.0	137.0	5102
				11/01/74	81.2	153.8	
				12/01/74	79.2	155.8	
				1/01/75	82.8	152.2	
				2/01/75	87.3	147.7	
				3/01/75	87.3	147.7	
				4/01/75	88.5	146.5	
				5/01/75	87.0	148.0	
				6/01/75	87.8	147.2	
				7/01/75	93.5	141.5	
				8/01/75	105.7	129.3	
				9/01/75	115.0	120.0	
03S/09W-32P02 S	30		231.1	10/24/74	102.3	128.8	5102
				1/06/75	95.7	135.4	
				3/05/75	102.1	129.0	
				4/28/75	95.6	135.5	
				6/23/75	96.3	134.8	
				8/28/75	NM-1		
03S/09W-32P03 S	30		231.0	10/01/74	103.9	127.1	5102
				11/01/74	82.2	148.8	
				12/01/74	81.1	149.9	
				1/01/75	82.0	149.0	
				2/01/75	90.2	140.8	
				3/01/75	92.0	139.0	
				4/01/75	89.6	141.4	
				5/01/75	92.3	138.7	
				6/01/75	90.8	140.2	
				7/01/75	98.0	133.0	
				8/01/75	111.5	119.5	
				9/01/75	118.3	112.7	
03S/09W-32P04 S	30		231.0	10/01/74	109.3	121.7	5102
				11/01/74	100.3	130.7	
				12/01/74	106.8	124.2	
				1/01/75	107.3	123.7	
				2/01/75	110.2	120.8	
				3/01/75	101.2	129.8	
				4/01/75	92.8	138.2	
				5/01/75	89.2	141.8	
				6/01/75	92.5	138.5	
				7/01/75	103.5	127.5	
				8/01/75	106.4	124.6	
				9/01/75	120.5	110.5	
03S/09W-33H01 S	30		254.7	10/24/74	53.6	201.1	5102
				1/06/75	50.1	204.6	
				3/05/75	53.5	201.2	
				4/28/75	55.6	199.1	
				6/23/75	58.0	196.7	
				8/28/75	63.5	191.2	
03S/09W-33K01 S	30		250.0	10/04/74	55.7	194.3	4742
				11/01/74	68.5(1)	181.5	
				12/06/74	51.5	198.5	
				1/01/75	66.4(1)	183.6	
				2/07/75	55.9	194.1	
				3/07/75	56.6	193.4	
				4/04/75	57.7	192.3	
				5/02/75	71.2(1)	178.8	
				6/06/75	75.3(1)	174.7	
03S/09W-33K01 S (CONTINUED)	30		250.0	7/01/75	78.5(1)	171.5	4742
				8/01/75	76.8(1)	173.2	
				9/05/75	80.8(1)	169.2	
03S/09W-33K03 S	30		250.0	10/04/74	61.4	188.6	4742
				11/01/74	60.8	189.2	
				12/06/74	51.8	198.2	
				1/01/75	56.4	193.6	
				2/07/75	55.6	194.4	
				3/07/75	57.7	192.3	
				4/04/75	57.6	192.4	
				5/02/75	56.8	193.2	
				6/06/75	59.4	190.6	
				7/01/75	63.8	186.2	
				8/01/75	62.6	187.4	
				9/05/75	66.0	184.0	
03S/09W-33K04 S	30		250.0	10/04/74	61.2	188.8	4742
				11/01/74	61.7	188.3	
				12/06/74	55.2	194.8	
				1/01/75	54.9	195.1	
				2/07/75	58.0	192.0	
				3/07/75	59.6	190.4	
				4/04/75	60.0	190.0	
				5/02/75	70.2(1)	179.8	
				6/06/75	78.0(1)	172.0	
				7/01/75	66.0	184.0	
				8/01/75	84.0(1)	166.0	
				9/05/75	72.0	178.0	
03S/09W-33K05 S	30		252.0	10/04/74	64.8	187.2	4742
				11/01/74	63.9	188.1	
				12/06/74	59.7	192.3	
				1/01/75	59.8	192.2	
				2/07/75	63.7	188.3	
				3/07/75	65.1	186.9	
				4/04/75	64.3	187.7	
				5/02/75	63.5	188.5	
				6/06/75	66.4	185.6	
				7/01/75	68.8	183.2	
				8/01/75	85.5(1)	166.5	
				9/05/75	73.3	178.7	
03S/09W-33K06 S	30		252.0	10/04/74	65.2	186.8	4742
				11/01/74	64.6	187.4	
				12/06/74	60.2	191.8	
				1/01/75	61.4	190.6	
				2/07/75	65.2	186.8	
				3/07/75	66.2	185.8	
				4/04/75	65.5	186.5	
				5/02/75	64.8	187.2	
				6/06/75	68.3	183.7	
				7/01/75	69.9	182.1	
				8/01/75	68.5	183.5	
				9/05/75	70.5	181.5	
03S/09W-33K07 S	30		252.0	10/04/74	60.0	192.0	4742
				11/01/74	70.0(1)	182.0	
				12/06/74	52.0	200.0	
				1/01/75	58.0	194.0	
				2/07/75	70.0(1)	182.0	
				3/07/75	52.0	200.0	
				4/04/75	52.0	200.0	
				5/02/75	67.0(1)	185.0	
				6/06/75	72.0(1)	180.0	
				7/01/75	75.0(1)	177.0	
				8/01/75	65.0	187.0	
				9/05/75	68.0	184.0	
03S/09W-33L01 S	30		248.0	10/24/74	NM-1		5102
				1/06/75	53.2	194.8	
				3/05/75	64.5	183.5	
				4/28/75	65.2	182.8	
				6/23/75	NM-7		
				8/28/75	73.0	175.0	
03S/09W-33N03 S	30		244.5	10/24/74	NM-1		5102
				1/06/75	64.7	179.8	
				3/05/75	68.3	176.2	
				4/28/75	66.9	177.6	
				6/23/75	70.7	173.8	
				8/28/75	73.5	171.0	
03S/09W-33Q02 S	30		251.9	10/24/74	49.9	202.0	5102
				1/06/75	48.8	203.1	
				3/05/75	54.3	197.6	
				4/28/75	53.3	198.6	
				6/23/75	58.1	193.8	
				8/28/75	57.3	194.6	
03S/09W-33Q03 S	30		251.4	10/24/74	45.3	206.1	5102
				1/06/75	45.2	206.2	
				3/05/75	54.7	196.7	
				4/28/75	55.5	195.9	
				6/23/75	NM-1		
				8/28/75	57.6	193.8	
03S/09W-34L02 S	30		260.8	10/24/74	29.5	230.5	5102
				1/06/75	29.9	230.1	
				3/05/75	43.5	216.5	
				4/28/75	38.8	221.2	
				8/28/75	NM-2		

See page 79 for key to terms a abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT ANAHEIM HYDRO SUBUNIT ANAHEIM HYDRO SUBAREA						U-05 U-05.F U-05.F1	
03S/09W-35N02 S	30		276.0	10/24/74	29.0	247.0	5102
				1/06/75	27.6	248.4	
				3/06/75	29.8	246.2	
				4/28/75	30.8	245.2	
				6/23/75	32.2	243.8	
				8/28/75	NM-1		
03S/10W-32P01 S	30		121.0	10/21/74	101.5	19.5	5102
				12/31/74	95.8	25.2	
				2/27/75	94.3	26.7	
				4/28/75	95.2	25.8	
				6/26/75	100.8	20.2	
				9/03/75	98.6	22.4	
03S/11W-26R01 S	30		80.0	11/06/74	62.0(8)	18.0	1101
				4/07/75	57.1(8)	22.9	
03S/11W-26R03 S	30		115.0	10/21/74	82.2	32.8	5102
				12/31/74	79.4	35.6	
				2/27/75	104.6	10.4	
				4/28/75	85.5	29.5	
				6/26/75	84.4	30.6	
				9/03/75	NM-7		
03S/11W-36H01 S	30		90.0	10/21/74	NM-1		5102
04S/09W-04D01 S	30		245.4	10/24/74	94.6	150.8	5102
				1/06/75	82.8	162.6	
				3/05/75	90.4	155.0	
				4/28/75	82.3	163.1	
				6/23/75	NM-1		
				8/28/75	93.8	151.6	
04S/10W-01F01 S	30		195.2	10/01/74	128.5	66.7	4210
				11/01/74	128.3	66.9	
				12/01/74	127.1	68.1	
				1/01/75	136.3	56.9	
				2/01/75	127.6	67.6	
				3/01/75	128.7	66.5	
				4/01/75	105.0	90.2	
				5/01/75	129.9	65.3	
				6/01/75	107.9	87.3	
				7/01/75	109.7	85.5	
				8/01/75	132.0	63.2	
				9/01/75	135.2	60.0	
04S/10W-01P01 S	30		196.3	10/24/74	135.1	61.2	5102
				1/06/75	125.5	70.8	
				3/05/75	145.3	51.0	
				4/28/75	126.3	70.0	
				6/23/75	132.4	63.9	
				8/28/75	156.5	39.8	
04S/10W-02R01 S	30		186.5	10/24/74	141.6	44.9	5102
				1/06/75	134.0	52.5	
				3/05/75	NM-9		
				4/28/75	138.6	47.9	
				6/23/75	135.4	51.1	
				8/28/75	140.9	45.6	
04S/10W-03P01 S	30		160.4	10/01/74	128.0	32.4	4210
				11/01/74	124.7	35.7	
				12/01/74	125.8	34.6	
				1/01/75	126.7	33.7	
				2/01/75	118.8	41.6	
				3/01/75	120.6	39.8	
				4/01/75	120.3	40.1	
				5/01/75	121.0	39.4	
				6/01/75	125.3	35.1	
				7/01/75	128.7	31.7	
				8/01/75	131.1	29.3	
				9/01/75	129.7	30.7	
04S/10W-03P02 S	30		160.1	10/01/74	128.3	31.8	4210
				11/01/74	122.7	37.4	
				12/01/74	125.5	34.6	
				1/01/75	125.8	34.3	
				2/01/75	120.9	39.2	
				3/01/75	120.5	39.6	
				4/01/75	119.3	40.8	
				5/01/75	121.6	38.5	
				6/01/75	122.5	37.6	
				7/01/75	126.7	33.4	
				8/01/75	128.7	31.4	
				9/01/75	129.0	31.1	
04S/10W-04A01 S	30		147.0	10/21/74	137.7	9.3	5102
				12/31/74	129.4	17.6	
				2/27/75	140.3	6.7	
				4/28/75	161.7	-14.7	
				6/26/75	157.7	-10.7	
				9/03/75	135.0	12.0	
04S/10W-04A02 S	30		150.0	10/01/74	139.8	10.2	4210
				11/01/74	128.0	22.0	
				12/01/74	131.6	18.4	
				1/01/75	131.1	18.9	
				2/01/75	126.4	23.6	
				3/01/75	126.6	23.4	
				4/01/75	125.3	24.7	
				5/01/75	125.3	24.7	
LA-SAN GABRIEL RIVER HYDRO UNIT ANAHEIM HYDRO SUBUNIT ANAHEIM HYDRO SUBAREA						U-05 U-05.F U-05.F1	
04S/10W-04A02 S (CONTINUED)	30		150.0	6/01/75	131.1	18.9	4210
				7/01/75	133.8	16.2	
				8/01/75	134.4	15.6	
				9/01/75	133.5	16.5	
04S/10W-07F01 S	30		101.0	10/01/74	114.9	-13.9	4210
				11/01/74	108.9	-7.9	
				12/01/74	106.1	-5.1	
				1/01/75	107.2	-6.2	
				2/01/75	101.6	-0.6	
				3/01/75	101.6	-0.6	
				4/01/75	100.8	0.2	
				5/01/75	86.4	14.6	
				6/01/75	109.2	-8.2	
				7/01/75	112.6	-11.6	
				8/01/75	116.9	-15.9	
				9/01/75	116.5	-15.5	
04S/10W-07J01 S	30		111.0	10/30/74	NM-1		5102
				1/03/75	NM-1		
				3/18/75	NM-1		
				4/29/75	NM-1		
				6/27/75	111.7	-0.7	
04S/10W-07J03 S	30		94.8	10/30/74	66.4	28.4	5102
				1/03/75	52.4	42.4	
				3/18/75	52.8	42.0	
				4/29/75	48.3	46.5	
				6/27/75	71.2	23.6	
				8/29/75	65.9	28.9	
04S/10W-07K03 S	30		104.8	10/30/74	69.1	34.9	5102
				1/03/75	52.8	51.2	
				3/18/75	16.5	87.5	
				4/29/75	47.4	56.6	
				6/26/75	68.9	35.1	
				8/29/75	62.1	41.9	
04S/10W-07K04 S	30		98.2	10/30/74	51.8	46.4	5102
				1/03/75	52.2	46.0	
				3/18/75	52.4	45.8	
				4/29/75	52.4	45.8	
				6/26/75	53.0	45.2	
				8/29/75	57.2	41.0	
04S/10W-08C02 S	30		125.8	10/01/74	137.3	-11.5	4210
				11/01/74	133.2	-7.4	
				12/01/74	113.3	12.5	
				1/01/75	123.0	2.8	
				2/01/75	107.0	18.8	
				3/01/75	106.7	19.1	
				4/01/75	105.0	20.8	
				5/01/75	113.2	12.6	
				6/01/75	113.4	12.4	
				7/01/75	117.8	8.0	
				8/01/75	122.4	3.4	
				9/01/75	126.1	-0.3	
04S/10W-08K01 S	30		126.1	10/30/74	NM-3		5102
				1/03/75	117.8	8.3	
				3/18/75	116.7	9.4	
				4/29/75	115.9	10.2	
				6/27/75	NM-3		
				8/29/75	NM-3		
04S/10W-08N05 S	30		115.5	10/01/74	115.8	-0.3	4210
				11/01/74	110.0	5.5	
				12/01/74	109.8	5.7	
				1/01/75	110.3	5.2	
				2/01/75	104.0	11.5	
				3/01/75	104.7	10.8	
				4/01/75	102.7	12.8	
				5/01/75	104.6	10.9	
				6/01/75	100.7	14.8	
				7/01/75	115.2	0.3	
				8/01/75	117.8	-2.3	
				9/01/75	118.7	-3.2	
04S/10W-09R02 S	30		145.3	10/01/74	134.6	10.7	4210
				11/01/74	128.8	16.5	
				12/01/74	134.1	11.2	
				1/01/75	133.3	12.0	
				2/01/75	122.8	22.5	
				3/01/75	126.5	18.8	
				4/01/75	124.5	20.8	
				5/01/75	127.5	17.8	
				6/01/75	134.8	10.5	
				7/01/75	134.7	10.6	
				8/01/75	137.0	8.3	
				9/01/75	138.7	6.6	
04S/10W-09R03 S	30		144.2	10/01/74	134.2	10.0	4210
				11/01/74	127.0	17.2	
				12/01/74	131.3	12.9	
				1/01/75	131.9	12.3	
				2/01/75	125.9	18.3	
				3/01/75	125.7	18.5	
				4/01/75	123.0	21.2	
				5/01/75	125.5	18.7	
				6/01/75	138.5	5.7	
				7/01/75	130.0	14.2	
				8/01/75	132.7	11.5	

See page 79 for key to terms a abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT ANAHEIM HYDRO SUBUNIT ANAHEIM HYDRO SUBAREA						U-05 U-05.F U-05.F1	
04S/10W-09R03 S	30		144.2	9/01/75	136.5	7.7	4210
04S/10W-18A01 S	30		107.0	10/30/74	91.7	15.3	5102
				1/03/75	87.9	19.1	
				3/18/75	86.3	20.7	
				4/29/75	87.0	20.0	
				6/26/75	90.1	16.9	
				8/29/75	86.0	21.0	
04S/10W-18R02 S	30		103.9	10/30/74	NM-1		5102
04S/11W-05C02 S	19		44.0	11/15/74	45.3	-1.3	1101
				4/07/75	41.3	2.7	
04S/11W-08P01 S	30		38.6	10/09/74	64.9	-26.3	1733
				11/20/74	60.4	-21.8	
				12/11/74	54.8	-16.2	
				1/01/75	53.3	-14.7	
				2/12/75	51.3	-12.7	
				3/05/75	54.0	-15.4	
				4/16/75	51.3	-12.7	
				5/07/75	58.7	-20.1	
				6/18/75	67.0	-28.4	
				7/09/75	71.6	-33.0	
				8/20/75	76.1	-37.5	
				9/10/75	74.8	-36.2	
04S/11W-10H03 S	30		67.0	10/30/74	80.3	-13.3	5102
				3/18/75	70.9	-3.9	
				4/29/75	71.5	-4.5	
				6/26/75	89.8	-22.8	
				8/29/75	83.2	-16.2	
04S/11W-12F01 S	30		90.0	10/30/74	95.8	-5.8	5102
				1/02/75	88.1	1.9	
				3/19/75	85.1	4.9	
				4/29/75	85.0	5.0	
				6/26/75	NM-1		
				8/29/75	99.8	-9.8	
04S/11W-12R07 S	30		91.0	10/30/74	81.3	9.7	5102
				1/03/75	81.0	10.0	
04S/11W-13D03 S	30		81.0	10/01/74	92.3	-11.3	5102
				11/01/74	85.2	-4.2	
				12/01/74	83.6	-2.6	
				1/01/75	76.7	4.3	
				2/01/75	83.3	-2.3	
				3/01/75	80.6	0.4	
				4/01/75	85.3	-4.3	
				5/01/75	82.0	-1.0	
				6/01/75	87.5	-6.5	
				7/01/75	94.6	-13.6	
				8/01/75	85.6	-4.6	
				9/01/75	86.7	-5.7	
04S/11W-14H01 S	30		70.0	10/01/74	92.7	-22.7	5102
				11/01/74	87.1	-17.1	
				12/01/74	86.0	-16.0	
				1/01/75	78.0	-8.0	
				2/01/75	78.5	-8.5	
				3/01/75	78.9	-8.9	
				4/01/75	79.7	-9.7	
				5/01/75	80.8	-10.8	
				6/01/75	87.5	-17.5	
				7/01/75	90.7	-20.7	
				8/01/75	94.6	-24.6	
				9/01/75	95.0	-25.0	
04S/11W-14H04 S	30		65.0	10/01/74	70.0	-5.0	4210
				11/01/74	67.2	-2.2	
				12/01/74	69.3	-4.3	
				1/01/75	55.8	9.2	
				2/01/75	63.5	1.5	
				3/01/75	57.3	7.7	
				4/01/75	63.4	1.6	
				5/01/75	64.1	0.9	
				6/01/75	60.7	4.3	
				7/01/75	72.2	-7.2	
				8/01/75	60.0	5.0	
				9/01/75	65.4	-0.4	
04S/11W-15L06 S	30		58.0	10/30/74	22.3	35.7	5102
				3/18/75	20.2	37.8	
04S/11W-19K01 S	30		25.8	10/23/74	47.7	-21.9	4206
				11/20/74	45.1	-19.3	
				12/23/74	42.7	-16.9	
				1/22/75	39.9	-14.1	
				2/19/75	37.5	-11.7	
				3/27/75	36.7	-10.9	
				4/23/75	39.1	-13.3	
			26.0	5/21/75	48.4	-22.4	
				6/18/75	49.2	-23.2	
				7/29/75	54.8	-28.8	
				8/20/75	58.1	-32.1	
				9/17/75	54.1	-28.1	
04S/11W-19D02 S	30		24.0	10/14/74	86.0(1)	-62.0	1101
				11/28/74	56.0(5)	-32.0	
				12/21/74	55.0(5)	-31.0	
				1/07/75	53.0(5)	-29.0	
LA-SAN GABRIEL RIVER HYDRO UNIT ANAHEIM HYDRO SUBUNIT ANAHEIM HYDRO SUBAREA						U-05 U-05.F U-05.F1	
04S/11W-19D02 S (CONTINUED)	30		24.0	2/14/75	52.0(5)	-28.0	1101
				3/21/75	53.0(5)	-29.0	
				4/14/75	54.0(5)	-30.0	
				5/21/75	56.0(5)	-32.0	
				6/14/75	57.0(5)	-33.0	
				7/14/75	65.0(5)	-41.0	
				8/14/75	69.0(5)	-45.0	
				9/14/75	68.0(5)	-44.0	
04S/11W-19G03 S	30		26.0	10/25/74	49.3	-23.3	5102
04S/11W-23D02 S	30		58.0	10/30/74	53.1	4.9	5102
				1/03/75	NM-8		
				3/18/75	46.8	11.2	
				4/29/75	NM-8		
				6/26/75	NM-8		
				8/29/75	36.9	21.1	
04S/11W-27A03 S	30		52.0	10/30/74	NM-1		5102
04S/11W-27D01 S	30		38.5	10/30/74	57.4	-18.9	5102
				1/03/75	50.7	-12.2	
				3/18/75	46.8	-8.3	
				4/29/75	53.0	-14.5	
				6/26/75	65.5	-27.0	
				8/29/75	65.3	-26.8	
04S/11W-28A01 S	30		33.0	10/30/74	61.1	-28.1	5102
				1/02/75	45.2	-12.2	
				3/18/75	49.6	-16.6	
				6/26/75	70.1	-37.1	
				8/29/75	NM-7		
04S/11W-30M04 S	30		18.1	10/14/74	139.9(1)	-121.8	1101
				11/14/74	62.9(5)	-44.8	
				12/14/74	60.9(5)	-42.8	
				1/14/75	59.9(5)	-41.8	
				2/14/75	59.9(5)	-41.8	
				3/14/75	59.9(5)	-41.8	
				4/14/75	60.9(5)	-42.8	
				5/21/75	62.9(5)	-44.8	
				6/14/75	63.9(5)	-45.8	
				7/14/75	65.9(5)	-47.8	
				8/14/75	65.9(5)	-47.8	
				9/14/75	64.9(5)	-46.8	
04S/11W-30M05 S	30		17.5	10/14/74	105.6(1)	-88.1	1101
				11/14/74	50.6(5)	-33.1	
				12/21/74	48.6(5)	-31.1	
				1/14/75	44.6(5)	-27.1	
				2/14/75	42.6(5)	-25.1	
				3/14/75	41.6(5)	-24.1	
				4/14/75	39.6(5)	-22.1	
				5/21/75	42.6(5)	-25.1	
				6/14/75	45.6(5)	-28.1	
				7/14/75	53.6(5)	-36.1	
				8/14/75	57.6(5)	-40.1	
				9/14/75	54.6(5)	-37.1	
04S/11W-31D01 S	30		13.8	12/07/74	NM-7		1101
				3/07/75	NM-7		
				4/28/75	NM-7		
				5/07/75	NM-7		
				6/17/75	NM-0		
04S/11W-31F03 S	30		16.0	10/29/74	NM-8		5102
				1/07/75	19.8	-3.8	
				3/13/75	18.6	-2.6	
				5/02/75	NM-7		
				8/26/75	28.0	-12.0	
04S/11W-31F05 S	30		12.3	10/14/74	104.4(1)	-92.1	1101
				11/14/74	32.4(5)	-20.1	
				12/21/74	26.4(5)	-14.1	
				1/14/75	25.4(5)	-13.1	
				2/14/75	24.4(5)	-12.1	
				3/21/75	24.4(5)	-12.1	
				4/21/75	23.4(5)	-11.1	
				5/28/75	27.4(5)	-15.1	
				6/14/75	29.4(5)	-17.1	
				7/14/75	33.4(5)	-21.1	
				8/14/75	37.4(5)	-25.1	
				9/14/75	39.4(5)	-27.1	
04S/11W-31P01 S	30		12.4	10/14/74	76.4(1)	-64.0	1101
				11/14/74	54.4(5)	-42.0	
				12/14/74	50.4(5)	-38.0	
				1/14/75	47.4(5)	-35.0	
				2/14/75	45.4(5)	-33.0	
				3/21/75	38.4(5)	-26.0	
				4/14/75	43.4(5)	-31.0	
				5/28/75	44.4(5)	-32.0	
				6/14/75	46.4(5)	-34.0	
				7/14/75	50.4(5)	-38.0	
				8/14/75	58.4(5)	-46.0	
				9/14/75	58.4(5)	-46.0	
04S/12W-36J02 S	30		12.0	6/17/75	NM-0		1101
04S/12W-36N05 S	30		8.0	10/29/74	17.2	-9.2	5102
				1/07/75	15.3	-7.3	
				3/13/75	13.4	-5.4	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LA-SAN GABRIEL RIVER HYDRO UNIT						U-05	
ANAHEIM HYDRO SUBUNIT						U-05.F	
ANAHEIM HYDRO SUBAREA						U-05.F1	
04S/12W-36N05 S (CONTINUED)	30		8.0	5/02/75	15.4	-7.4	5102
				8/26/75	DRY		
04S/12W-36P05 S	30		8.8	10/31/74	11.0	-2.2	1101
				11/27/74	11.7	-2.9	
				1/02/75	10.3	-1.5	
				6/26/75	14.8	-6.0	
				7/31/75	20.3	-11.5	
				8/26/75	19.0	-10.2	
04S/14W-16L05 S	19		73.6	7/02/75	90.6	-17.0	1101
04S/14W-16L06 S	19		73.6	7/24/75	88.8	-15.2	1101
05S/12W-01F09 S	19		6.7	10/31/74	5.9	0.8	1101
				11/27/74	6.8	-0.1	
				1/02/75	5.9	0.8	
				2/07/75	5.0	1.7	
				4/03/75	5.6	1.1	
				5/01/75	6.2	0.5	
				6/26/75	12.4	-5.7	
				7/31/75	15.9	-9.2	
				8/26/75	15.1	-8.4	
05S/12W-01F10 S	19		6.7	10/31/74	8.6	-1.9	1101
				11/27/74	9.3	-2.6	
				1/02/75	8.0	-1.3	
				2/07/75	6.9	-0.2	
				4/03/75	7.5	-0.8	
				5/01/75	7.9	-1.2	
				6/26/75	12.3	-5.6	
				7/31/75	16.3	-9.6	
				8/26/75	13.1	-6.4	
05S/12W-01M04 S	30		6.1	10/31/74	20.0	-13.9	1101
				11/27/74	20.3	-14.2	
				1/02/75	18.4	-12.3	
				2/07/75	18.5	-12.4	
				4/03/75	16.9	-10.8	
				5/01/75	18.5	-12.4	
				6/26/75	25.7	-19.6	
				7/31/75	30.0	-23.9	
				8/26/75	28.3	-22.2	
05S/12W-01M05 S	30		6.1	10/31/74	6.4	-0.3	1101
				11/27/74	7.2	-1.1	
				1/02/75	6.2	-0.1	
				2/07/75	5.4	0.7	
				4/03/75	5.8	0.3	
				5/01/75	6.3	-0.2	
				6/26/75	11.4	-5.3	
				7/31/75	15.0	-8.9	
				8/26/75	13.4	-7.3	
05S/12W-01M06 S	30		6.1	10/31/74	11.8	-5.7	1101
				11/27/74	11.8	-5.7	
				1/02/75	10.3	-4.2	
				2/07/75	9.9	-3.8	
				4/03/75	9.7	-3.6	
				5/01/75	9.8	-3.7	
				6/26/75	13.0	-6.9	
				7/31/75	16.2	-10.1	
				8/26/75	15.8	-9.7	
05S/12W-12C01 S	30		17.0	10/29/74	57.0	-40.0	5102
				1/07/75	49.7	-32.7	1101
				3/15/75	44.4	-27.4	
				5/02/75	44.7	-27.7	
				8/26/75	53.5	-36.5	5102
LA HABRA HYDRO SUBAREA						U-05.F2	
03S/10W-02N02 S	30		423.0	10/21/74	191.0	232.0	5102
				12/31/74	169.0	254.0	
				2/27/75	175.1	247.9	
				4/28/75	159.1	263.9	
				6/26/75	NM-1		
				9/03/75	168.1	254.9	
03S/10W-02Q01 S	30		373.5	12/31/74	20.4	353.1	5102
				2/27/75	20.8	352.7	
				4/28/75	23.8	349.7	
				6/26/75	21.3	352.2	
				9/03/75	21.5	352.0	
03S/10W-09H02 S	30		327.0	10/21/74	44.9	282.1	5102
				2/27/75	NM-3		
				4/28/75	43.8	283.2	
				6/26/75	41.6	285.4	
				9/03/75	40.8	286.2	
03S/10W-09Q02 S	30		305.0	12/31/74	33.8	271.2	5102
				2/27/75	39.0	266.0	
				4/28/75	35.1	269.9	
				6/26/75	NM-1		
				9/03/75	NM-1		
03S/10W-10C01 S	30		345.0	10/21/74	96.1	248.9	5102
				12/31/74	92.6	252.4	
				2/27/75	96.3	248.7	
				4/28/75	NM-1		
				6/26/75	NM-1		
LA-SAN GABRIEL RIVER HYDRO UNIT						U-05	
ANAHEIM HYDRO SUBUNIT						U-05.F	
LA HABRA HYDRO SUBAREA						U-05.F2	
03S/10W-10C01 S	30		345.0	9/03/75	NM-1		5102
03S/10W-10N02 S	30		315.0	12/31/74	22.7	292.3	5102
				2/27/75	27.2	287.8	
				4/28/75	23.4	291.6	
				6/26/75	NM-1		
				9/03/75	NM-1		
03S/10W-11H02 S	30		350.7	10/21/74	41.1	309.6	5102
				12/31/74	42.1	308.6	
				2/27/75	10.9	339.8	
				4/28/75	34.2	316.5	
				6/26/75	37.9	312.8	
				9/03/75	NM-1		
03S/10W-15B01 S	30		327.0	12/31/74	76.9	250.1	5102
				2/27/75	72.1	254.9	
				4/28/75	70.2	256.8	
				6/26/75	NM-1		
				9/03/75	NM-1		
03S/10W-15C01 S	30		322.0	10/21/74	102.6	219.4	5102
				12/31/74	84.0	238.0	
				2/27/75	99.1	222.9	
				4/28/75	90.2	231.8	
				6/26/75	98.4	223.6	
				9/03/75	101.6	220.4	
03S/10W-18C01 S	30		211.0	10/21/74	99.2	111.8	5102
				12/31/74	98.8	112.2	
				2/27/75	98.2	112.8	
				4/28/75	98.1	112.9	
				6/26/75	7.7	203.3	
03S/10W-22C02 S	30		280.0	10/21/74	162.6	117.4	5102
				12/31/74	148.6	131.4	
				2/27/75	158.0	122.0	
				4/28/75	159.6	120.4	
				6/26/75	160.2	119.8	
				9/03/75	160.0	120.0	
YORBA LINDA HYDRO SUBAREA						U-05.F3	
03S/09W-19N01 S	30		292.0	10/24/74	188.9	103.1	5102
03S/09W-20H01 S	30		335.2	10/24/74	169.2	166.0	5102
				1/06/75	169.2	166.0	
				3/05/75	170.2	165.0	
				4/28/75	170.5	164.7	
				6/23/75	169.7	165.5	
				8/28/75	171.1	164.1	
03S/09W-21H01 S	30		365.0	10/24/74	71.2	293.8	5102
				1/06/75	71.0	294.0	
				3/05/75	73.2	291.8	
				4/29/75	78.1	286.9	
				6/23/75	71.4	293.6	
				8/28/75	74.1	290.9	
03S/09W-21H05 S	30		356.0	10/24/74	72.7	283.3	5102
				1/06/75	70.8	285.2	
				2/05/75	73.8	282.2	
				4/28/75	72.3	283.7	
				8/28/75	NM-1		
03S/09W-30R01 S	30		262.0	10/24/74	75.4	186.6	5102
				1/06/75	74.4	187.6	
				3/05/75	74.8	187.2	
				4/28/75	74.0	188.0	
				6/23/75	74.8	187.2	
				8/28/75	75.2	186.8	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
LAHONTAN DRAINAGE PROVINCE INDIAN WELLS HYDRO UNIT INDIAN WELLS HYDRO SUBUNIT						W W-24 W-24.B	
24S/39E-33N01 M			2254.5	10/23/74	61.1	2193.4	5000
24S/40E-32H01 M		14	2178.8	10/24/74	4.6	2174.2	5000
24S/40E-33N01 M		14	2175.8	10/24/74	3.6	2172.2	5000
24S/40E-34E01 M		14	2176.7	10/24/74	4.7	2172.0	5000
24S/40E-36H01 M		14	2174.4	10/24/74	2.6	2171.8	5000
25S/38E-11K01 M		15	2400.0	10/24/74	197.0	2203.0	5000
25S/38E-13D01 M		15	2351.2	10/24/74	150.0	2201.2	5000
25S/38E-13K01 M		15	2316.2	10/24/74	115.7	2200.5	5000
25S/38E-23G01 M		15	2412.0	10/24/74	209.4	2202.6	5000
25S/38E-24C01 M		15	2329.2	10/24/74	128.3	2200.9	5000
25S/38E-25L01 M		15	2329.2	10/24/74	128.3	2200.9	5000
25S/38E-35B01 M		15	2402.8	10/24/74	193.4	2209.4	5000
25S/39E-02E01 M		15	2227.4	10/23/74	38.6	2188.8	5000
25S/39E-04R01 M		15	2252.6	10/23/74	NM-1		5000
25S/39E-11N01 M		15	2228.1	10/23/74	36.8	2191.3	5000
25S/39E-12P01 M		15	2200.9	10/22/74	18.5	2182.4	5000
25S/39E-13F01 M		15	2209.9	10/22/74	NM-0		5000
25S/39E-21D01 M		15	2235.2	10/24/74	39.5	2195.7	5000
25S/39E-22J01 M		15	2215.4	10/23/74	25.5	2189.9	5000
25S/39E-26H01 M		15	2202.8	10/24/74	16.5	2186.3	5000
25S/39E-26N01 M		15	2220.6	10/23/74	30.3	2190.3	5000
25S/39E-28P01 M		15	2228.9	10/23/74	34.0	2194.9	5000
25S/39E-28P01 M		15	2221.7	10/23/74	34.5	2187.2	5000
25S/39E-29H01 M		15	2232.1	10/24/74	34.1	2198.0	5000
25S/39E-31E01 M		15	2283.7	10/24/74	82.3	2201.4	5000
25S/39E-35N01 M		15	2253.2	10/23/74	61.2	2192.0	5000
25S/40E-08A01 M		15	2183.2	10/24/74 3/24/75	7.6 7.4	2175.6 2175.8	5000
25S/40E-11K01 M		15	2166.3	10/24/74	-2.0	2168.3	5000
25S/40E-12D01 M		36	2160.6	10/24/74	3.7	2156.9	5000
25S/40E-18P01 M		15	2183.0	10/22/74 3/24/75	3.6 2.9	2179.4 2180.1	5000
25S/40E-19L01 M		15	2188.2	10/22/74	9.7	2178.5	5000
25S/40E-20F01 M		15	2179.5	10/22/74 3/24/75	1.0 0.6	2178.5 2178.9	5000
25S/40E-27E01 M		15	2168.7	10/22/74	4.6	2164.1	5000
25S/40E-33L01 M		15	2171.1	10/23/74 3/25/75	2.5 2.3	2168.6 2168.8	5000
25S/40E-33L02 M		36	2171.0	10/23/74 3/25/75	2.3 2.1	2168.7 2168.9	5000
25S/40E-35P01 M		15	2158.8	10/22/74	8.3	2150.5	5000
25S/41E-19L01 M		36	2157.8	10/24/74	4.6	2153.2	5000
25S/41E-28B01 M		36	2238.6	10/23/74	68.0	2170.6	5000
25S/41E-31C01 M		36	2153.1	10/24/74	4.3	2148.8	5000
26S/39E-02C01 M		15	2248.3	10/23/74	57.1	2191.2	5000
26S/39E-02N01 M		15	2285.7	10/23/74	91.6	2194.1	5000
26S/39E-05F01 M		15	2276.7	10/23/74	75.7	2201.0	5000
26S/39E-07N01 M		15	2394.3	10/24/74	197.4	2196.9	5000
26S/39E-08K01 M		15	2321.0	10/23/74	123.5	2197.5	5000
26S/39E-11E01 M		15	2305.0	10/24/74	110.8	2194.2	5000
26S/39E-12G01 M		15	2277.0	10/22/74	85.0	2192.0	5000
26S/39E-14F01 M		15	2334.2	10/24/74	143.2	2191.0	5000
26S/39E-19D02 M		15	2418.0	10/24/74	221.2	2196.8	5000
26S/39E-23E01 M		15	2372.3	10/24/74	196.9	2175.4	5000
INDIAN WELLS HYDRO UNIT INDIAN WELLS HYDRO SUBUNIT						W-24 W-24.B	
26S/39E-24K01 M		15	2347.4	10/22/74	182.0	2165.4	5000
26S/39E-24M01 M		15	2364.5	10/23/74	NM-1		5000
26S/39E-24Q01 M		15	2350.4	10/24/74	195.5	2154.9	5000
26S/39E-24R01 M		15	2344.9	10/24/74	190.7	2154.2	5000
26S/39E-25D01 M		15	2372.0	10/24/74	217.8	2154.2	5000
26S/39E-25D02 M		15	2368.0	10/24/74	NM-0		5000
26S/39E-25E01 M		15	2372.2	10/24/74	218.5	2153.7	5000
26S/39E-26C01 M		15	2394.9	10/24/74	231.4	2163.5	5000
26S/39E-26E01 M		15	2402.3	10/24/74	NM-1		5000
26S/39E-30C01 M		15	2427.1	10/24/74	232.3	2194.8	5000
26S/39E-30F01 M		15	2433.5	10/24/74	238.8	2194.7	5000
26S/40E-01A01 M		36	2153.5	10/24/74	5.1	2148.4	5000
26S/40E-01A02 M		36	2157.6	10/24/74	FLOW		5000
26S/40E-01J01 M		15	2161.8	10/23/74	3.1	2158.7	5000
26S/40E-01D01 M		15	2161.6	10/22/74	3.1	2158.5	5000
26S/40E-01Q02 M		15	2159.7	10/22/74	3.5	2156.2	5000
26S/40E-06F01 M		15	2231.8	10/22/74	DRY		5000
26S/40E-10F01 M		15	2188.8	10/22/74 3/25/75	17.1 17.0	2171.7 2171.8	5000
26S/40E-11J01 M		15	2174.0 2173.9	10/22/74 3/25/75	3.9 3.3	2170.1 2170.6	5000
26S/40E-12A01 M		36	2167.8	10/22/74	3.6	2164.2	5000
26S/40E-12G01 M		36	2170.4	10/22/74	6.1	2164.3	5000
26S/40E-12Q01 M		36	2175.7	10/22/74	1.7	2174.0	5000
26S/40E-12R01 M		36	2181.5	10/22/74	0.7	2180.8	5000
26S/40E-13C01 M		36	2189.1	10/22/74	6.5	2182.6	5000
26S/40E-13M01 M		36	2196.2	10/22/74	10.8	2185.4	5000
26S/40E-14H01 M		15	2195.4	10/22/74	9.6	2185.8	5000
26S/40E-15F01 M		15	2223.1	10/22/74 3/26/75	45.1 44.9	2178.0 2178.2	5000
26S/40E-15F02 M		15	2226.1	10/22/74 3/26/75	45.1 44.7	2181.0 2181.4	5000
26S/40E-15N01 M		15	2241.1	10/22/74	57.1	2184.0	5000
26S/40E-17N01 M		15	2293.0	10/22/74	122.1	2170.9	5000
26S/40E-18E01 M		15	2297.0	10/22/74	102.6	2194.4	5000
26S/40E-18N01 M		15	2316.1	10/22/74	156.7	2159.4	5000
26S/40E-19N01 M		15	2337.7	10/22/74	182.1	2155.6	5000
26S/40E-19P01 M		15	2336.0	10/24/74	175.6	2160.4	5000
26S/40E-20N01 M		15	2311.9	10/22/74	145.0	2166.9	5000
26S/40E-22N01 M		15	2261.4	10/22/74 3/26/75	78.0 77.9	2183.4 2183.5	5000
26S/40E-22P01 M		15	2258.7	10/22/74	83.6	2175.1	5000
26S/40E-23C01 M		15	2213.8	10/22/74	21.5	2192.3	5000
26S/40E-24C01 M		36	2212.0	10/22/74	27.4	2184.6	5000
26S/40E-28J01 M		15	2288.8	10/24/74	115.7	2173.1	5000
26S/40E-30E02 M		15	2342.9	10/24/74	NM-1		5000
26S/40E-30Q01 M		15	2353.1	10/24/74	NM-0		5000
26S/40E-32D01 M		15	2348.9	10/24/74	183.8	2157.1	5000
26S/40E-32N01 M		15	2368.0	10/24/74	218.6	2149.4	5000
26S/40E-34N01 M		15	2290.4	10/25/74	115.6	2174.8	5000
26S/40E-36A01 M		36	2247.2	10/22/74 3/25/75	57.5 57.3	2189.7 2189.9	5000
26S/41E-07D01 M		36	2160.2	10/23/74	1.2	2159.0	5000
26S/41E-07E01 M		36	2166.5	10/22/74	5.3	2161.2	5000
26S/41E-07G01 M		36	2177.0	10/22/74	23.5	2153.5	5000

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
INDIAN WELLS HYDRO UNIT INDIAN WELLS HYDRO SUBUNIT						W-24 W-24.8	
27S/38E-01H01 M	15		2639.0	10/25/74	294.4	2344.6	5000
27S/39E-02A01 M	15		2440.0	10/24/74	254.3	2185.7	5000
27S/39E-07P01 M	15		2562.7	10/25/74	NM-6		5000
27S/40E-01K01 M	36		2318.1	10/25/74	130.2	2187.9	5000
27S/40E-02J01 M	15		2300.0	10/25/74 3/25/75	NM-1 NM-1		5000
27S/40E-03P01 M	15		2287.3	10/25/74 3/25/75	97.1 96.7	2190.2 2190.6	5000
27S/40E-04A01 M	15		2305.0	10/24/74	130.1	2174.9	5000
27S/40E-07M01 M	15		2515.0	10/24/74	314.4	2200.6	5000
27S/40E-09P01 M	15		2360.0	10/24/74	NM-0		5000
27S/40E-10R01 M	15		2380.0	10/25/74 3/25/75	197.3 197.0	2182.7 2183.0	5000
27S/40E-15Q01 M	15		2385.0	10/25/74	201.9	2183.1	5000
27S/40E-15L01 M	15		2470.0	10/25/74 3/25/75	252.0 251.0	2218.0 2219.0	5000

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
FREMONT HYDRO UNIT KOEHN HYDRO SUBUNIT						W-25 W-25.0	
30S/37E-24J02 M	15		1960.0	2/06/75	99.3	1860.7	5000
30S/37E-27H02 M	15		2040.0	2/06/75	195.3	1844.7	5000
30S/37E-34R01 M	15		2010.0	2/06/75	173.4	1836.6	5000
30S/37E-36G01 M	15		1991.0	2/06/75	99.7	1881.3	5000
30S/38E-03J01 M	15		1900.0	2/06/75	1.2	1898.8	5000
30S/38E-24F01 M	15		1940.0	2/06/75	26.9	1913.1	5000
30S/38E-30E01 M	15		1964.0	2/06/75	90.3	1873.7	5000
30S/38E-30P01 M	15		1957.0	2/06/75	126.5(2)	1830.5	5000
30S/38E-08A01 M	15		2050.0	2/06/75	140.5	1909.5	5000
31S/37E-04J01 M	15		2050.0	2/06/75	NM-1		5000
31S/37E-04Q01 M	15		2100.0	2/06/75	197.0	1903.0	5000
31S/37E-08C01 M	15		2190.0	2/06/75	245.5	1944.5	5000
31S/37E-10A01 M	15		2105.0	2/05/75	258.3	1846.7	5000
31S/37E-12H01 M	15		2085.0	2/05/75	327.2	1757.8	5000
31S/37E-30F01 M	15		2371.7	2/06/75	321.4	2050.3	5000
31S/37E-33H01 M	15		2340.0	2/05/75	273.7	2066.3	5000
31S/37E-35N01 M	15		2320.0	2/05/75	251.4	2068.6	5000
31S/38E-18P01 M	15		2225.0	2/05/75	147.3	2077.7	5000
32S/36E-22C01 M	15		2720.0	2/05/75	623.8	2096.2	5000
32S/36E-35D01 M	15		2692.0	2/04/75	269.9	2422.1	5000
32S/37E-09Q01 M	15		2410.0	2/05/75	333.2	2076.8	5000
32S/37E-11N01 M	15		2375.0	2/05/75	283.1	2091.9	5000
32S/37E-12H01 M	15		2350.0	2/05/75	242.8	2107.2	5000
32S/37E-22N01 M	15		2460.0	2/04/75	365.5	2094.5	5000
32S/37E-26N01 M	15		2420.0	2/04/75	330.7	2089.3	5000
11N/11W-07A01 S	15		2627.9	2/04/75	205.8	2422.1	5000
11N/11W-09A01 S	15		2549.6	2/04/75	128.1	2421.5	5000
12N/12W-35R01 S	15		2743.3	2/04/75	321.0	2422.3	5000

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
ANTELOPE HYDRO UNIT ANTELOPE HYDRO SUBUNIT CHAFEE HYDRO SUBAREA						W-26 W-26.A W-26.A1	
11N/12W-12M01 S	15		2695.0	2/04/75	272.0	2423.0	5000
11N/12W-26J01 S	15		2594.6	2/04/75	179.8	2414.8	5000
11N/13W-19C01 S	15		3610.0	2/05/75	307.1	3302.9	5000
11N/13W-24A01 S	15		2840.0	2/05/75	248.4	2591.6	5000
GLOSTER HYDRO SUBAREA						W-26.A2	
10N/11W-08P01 S	15		2504.0	2/04/75	53.9	2450.1	5000
10N/12W-09A01 S	15		2594.0	2/05/75	154.7	2439.3	5000
10N/12W-13H01 S	15		2505.0	2/04/75	63.2	2441.8	5000
10N/12W-20C06 S	15		2655.0	2/05/75	103.0	2552.0	5000
10N/12W-22J01 S	15		2530.0	2/04/75	40.2	2489.8	5000
10N/13W-22C01 S	15		2878.0	2/05/75	318.0	2560.0	5000
WILLOW SPRINGS HYDRO SUBAREA						W-26.A3	
09N/13W-04A01 S	15		2636.8	2/20/75	154.8	2482.0	5000
09N/13W-07D03 S	15		2605.0	2/19/75	72.8	2532.2	5000
09N/14W-01H01 S	15		2700.0	2/19/75	155.5	2544.5	5000
09N/15W-11A01 S	15		2953.4	2/20/75	85.5	2867.9	5000
09N/15W-12M01 S	15		2899.1	2/20/75	503.6	2395.5	5000
10N/13W-19W01 S	15		2905.0	2/05/75	316.3	2588.7	5000
10N/15W-32A01 S	15		3395.0	2/20/75	188.1	3206.9	5000
11N/13W-29W01 S	15		3391.0	10/00/74	327.0	3064.0	4785
				12/09/74	327.0	3064.0	
			3350.0	2/05/75	330.5	3019.5	5000
			3391.0	3/01/75	303.0	3088.0	4785
				5/06/75	324.0	3067.0	
				6/09/75	323.0	3068.0	
				7/23/75	323.0	3068.0	
				8/10/75	323.0	3068.0	
				9/01/75	324.0	3067.0	
NEENACH HYDRO SUBAREA						W-26.A4	
08N/14W-17M01 S	19		2592.0	2/19/75	175.1	2416.9	5000
08N/14W-18N01 S	19		2642.0	2/19/75	121.0	2521.0	5000
08N/15W-07N01 S	19		2763.0	2/15/75	NM-4		5000
08N/15W-09F01 S	19		2698.0	2/20/75	139.3	2558.7	5000
08N/15W-10P01 S	19		2712.0	2/20/75	NM-1		5000
08N/15W-18H01 S	19		2790.0	2/20/75	210.3	2579.7	5000
08N/15W-22A03 S	19		2745.0	2/20/75	133.2	2611.8	5000
08N/15W-33G01 S	19		2930.0	2/20/75	224.2	2705.8	5000
08N/16W-02P01 S	19		2795.0	2/20/75	178.8	2616.2	5000
08N/16W-03F01 S	19		2860.0	2/21/75	208.9	2651.1	5000
08N/16W-05C01 S	19		2900.0	2/21/75	255.0	2645.0	5000
08N/16W-09A02 S	19		2890.0	2/21/75	258.3	2631.7	5000
08N/16W-18E01 S	19		3029.0	2/21/75	280.8	2748.2	5000
08N/16W-23G01 S	19		2913.0	2/21/75	82.9	2830.1	5000
08N/17W-01N01 S	19		2955.5	2/21/75	296.4	2659.1	5000
08N/17W-04N01 S	19		3036.0	2/21/75	125.8	2910.2	5000
09N/14W-15M01 S	19		2954.2	2/20/75	365.1	2589.1	5000
09N/14W-20R01 S	19		2656.4	2/20/75	328.9	2327.5	5000
09N/15W-30Q01 S	15		2880.0	2/20/75	371.4	2508.6	5000
09N/16W-36C01 S	19		2925.0	2/20/75	288.7	2636.3	5000
09N/20W-33L01 S	15		5160.0	4/01/75	124.7	5035.3	5121
				6/17/75	112.6	5047.4	
LANCASTER HYDRO SUBAREA						W-26.A5	
05N/12W-03H01 S	19		2824.0	11/12/74	20.5	2803.5	1101
05N/12W-03J01 S	19		2824.0	11/12/74	15.4	2808.6	1101
05N/12W-04H01 S	19		3250.0	11/12/74	NM-5		1101

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
ANTELOPE HYDRO UNIT ANTELOPE HYDRO SUBUNIT LANCASTER HYDRO SUBAREA						W-26 W-26.A W-26.A5	
05N/12W-04H01 S	19		3250.0	12/19/74	NM-6		1101
06N/09W-10M01 S	19		2639.0	7/15/75	201.5(S)	2437.5	1101
				8/05/75	231.5(1)	2407.5	
				9/02/75	199.5(S)	2439.5	
06N/09W-10Q01 S	19		2652.5	7/15/75	205.5(1)	2447.0	1101
				8/05/75	206.5(1)	2446.0	
				9/02/75	210.5(1)	2442.0	
06N/11W-19E06 S	19		2584.0	12/15/74	432.0(S)	2152.0	1101
				1/15/75	430.0(S)	2154.0	
				6/15/75	465.2(S)	2118.8	
				7/15/75	481.0(1)	2103.0	
				8/20/75	474.0(S)	2110.0	
				9/15/75	467.0(S)	2117.0	
06N/11W-19G01 S	19		2584.0	6/15/75	459.0	2125.0	1101
06N/12W-04A01 S	19		2540.0	2/20/75	364.2	2175.8	5000
06N/12W-07A01 S	19		2597.0	2/19/75	346.4	2250.6	5000
06N/12W-24A03 S	19		2579.0	10/15/74	456.0(S)	2123.0	1101
				1/15/75	435.0(S)	2144.0	
				2/15/75	432.0(S)	2147.0	
				3/15/75	444.0(S)	2135.0	
				4/15/75	442.0(S)	2137.0	
				6/15/75	466.0(S)	2113.0	
				9/15/75	472.0(S)	2107.0	
06N/12W-34N04 S	19		2850.0	10/15/74	63.5	2786.5	1101
				12/15/74	51.5	2798.5	
				1/15/75	62.5	2787.5	
				2/15/75	63.5	2786.5	
				3/15/75	62.5	2787.5	
				4/15/75	63.5	2786.5	
				7/15/75	72.5	2777.5	
				8/20/75	62.5	2787.5	
				9/15/75	67.5	2782.5	
07N/09W-17N02 S	19		2492.0	2/11/75	231.4	2260.6	5000
07N/10W-01P03 S	19		2435.0	2/11/75	346.7	2088.3	5000
07N/10W-03A01 S	19		2402.0	7/15/75	394.0(1)	2008.0	1101
				8/04/75	396.0(1)	2006.0	
				9/02/75	400.0(1)	2002.0	
07N/10W-05E01 S	19		2391.0	2/10/75	203.8	2187.2	5000
07N/10W-05N05 S	19		2398.0	2/10/75	NM-1		5000
07N/10W-10N01 S	19		2437.0	2/11/75	347.5	2089.5	5000
07N/10W-14P03 S	19		2466.0	2/11/75	381.8	2084.2	5000
07N/10W-15J01 S	19		2460.0	2/11/75	377.0	2083.0	5000
07N/10W-19D01 S	19		2446.0	10/10/74	288.1	2157.9	1101
				11/06/74	298.2(6)	2147.8	
				12/13/74	282.8	2163.2	
				1/09/75	282.2	2163.8	
				2/11/75	282.4	2163.6	
				3/12/75	282.3	2163.7	
				4/13/75	281.5	2164.5	
				5/08/75	285.5(1)	2160.5	
				6/11/75	283.4	2162.6	
				7/03/75	283.7	2162.3	
				8/06/75	283.7	2162.3	
				9/11/75	283.6	2162.4	
07N/10W-22P01 S	19		2481.0	2/11/75	343.5	2137.5	5000
07N/10W-31M01 S	19		2505.3	2/11/75	379.1	2126.2	5000
07N/10W-33J01 S	19		2538.0	2/11/75	338.6	2199.4	5000
07N/11W-01Q01 S	19		2385.0	2/10/75	208.5	2176.5	5000
07N/11W-05L01 S	19		2363.0	2/10/75	119.3	2243.7	5000
07N/11W-09P02 S	19		2386.0	2/10/75	215.4	2170.6	5000
07N/11W-10F02 S	19		2396.0	2/10/75	191.4	2204.6	5000
07N/11W-11A03 S	19		2391.0	2/10/75	208.4	2182.6	5000
07N/11W-14P02 S	19		2425.0	2/11/75	293.4	2131.6	5000
07N/11W-19Q01 S	19		2418.0	2/11/75	231.8	2186.2	5000
07N/11W-21F01 S	19		2422.0	2/11/75	117.2	2304.8	5000
07N/11W-26G01 S	19		2459.0	2/11/75	336.9	2122.1	5000
07N/11W-27Q01 S	19		2467.0	2/11/75	340.3	2126.7	5000
07N/11W-28P01 S	19		2453.0	2/11/75	105.7	2347.3	5000
07N/11W-29H01 S	19		2440.0	2/11/75	298.7	2141.3	5000
07N/11W-31H01 S	19		2468.0	2/13/75	289.8	2178.2	5000

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
ANTELOPE HYDRO UNIT ANTELOPE HYDRO SUBUNIT LANCASTER HYDRO SUBAREA						W-26 W-26.A W-26.A5	
07N/11W-33N01 S	19		2473.0	2/11/75	326.9	2146.1	5000
07N/12W-02F08 S	19		2326.0	2/12/75	53.3	2272.7	5000
07N/12W-09F01 S	19		2318.0	2/13/75	136.1	2181.9	5000
07N/12W-13F01 S	19		2382.0	2/11/75	180.4	2201.6	5000
07N/12W-13H02 S	19		2385.0	2/11/75	133.3	2251.7	5000
07N/12W-15F01 S	19		2348.0	2/13/75	160.9	2187.1	5000
07N/12W-15R01 S	19		2383.4	7/16/75	239.7	2143.7	1101
				8/04/75	231.7	2151.7	
				9/03/75	233.7	2149.7	
07N/12W-15R02 S	19		2384.9	7/16/75	322.8(1)	2062.1	1101
				8/04/75	328.8(1)	2056.1	
				9/03/75	305.8(1)	2079.1	
07N/12W-15R03 S	19		2371.0	7/15/75	318.5(1)	2052.5	1101
				8/04/75	324.5(1)	2046.5	
				9/03/75	306.5(1)	2064.5	
07N/12W-19R01 S	19		2386.0	2/12/75	195.5	2190.5	5000
07N/12W-21A04 S	19		2365.0	2/13/75	166.4	2198.6	5000
07N/12W-21C01 S	19		2359.3	7/14/75	181.1	2178.2	1101
				8/06/75	181.1	2178.2	
				9/05/75	181.1	2178.2	
07N/12W-22K01 S	19		2407.0	2/13/75	228.8	2178.2	5000
07N/12W-22R02 S	19		2411.0	10/10/74	NM-3		1101
				11/26/74	243.0(6)	2168.0	
07N/12W-22P04 S	19		2411.5	11/26/74	234.6	2176.9	1101
				12/13/74	234.4	2177.1	
				1/09/75	233.9	2177.6	
				2/11/75	233.8	2177.7	
				3/12/75	233.9	2177.6	
				4/13/75	235.5	2176.0	
				5/08/75	235.2	2176.3	
				6/11/75	236.6	2174.9	
				7/03/75	237.1	2174.4	
				8/06/75	238.5	2173.0	
				9/08/75	239.1	2172.4	
07N/12W-23P01 S	19		2425.0	2/11/75	244.4	2180.6	5000
07N/12W-24R01 S	19		2437.0	2/11/75	249.4	2187.6	5000
07N/12W-26D01 S	19		2459.0	7/15/75	358.5(1)	2100.5	1101
				8/04/75	361.5(1)	2097.5	
				9/03/75	360.5(1)	2098.5	
07N/12W-27H01 S	19		2449.0	2/13/75	281.7	2167.3	5000
07N/12W-29F01 S	19		2415.0	7/17/75	242.5(5)	2172.5	1101
				8/06/75	242.5(5)	2172.5	
				9/05/75	242.5(1)	2172.5	
07N/12W-29F02 S	19		2415.0	2/12/75	NM-4		5000
07N/12W-32H01 S	19		2512.0	9/17/75	339.7	2172.3	1101
07N/12W-35H01 S	19		2512.0	2/12/75	331.8	2180.2	5000
				4/16/75	332.0	2180.0	5050
				5/07/75	333.0	2179.0	
				8/04/75	340.5	2171.5	
07N/13W-03F01 S	19		2381.0	2/12/75	175.1	2205.9	5000
07N/13W-06A02 S	19		2440.0	2/12/75	209.5	2230.5	5000
07N/13W-09K01 S	19		2382.0	2/12/75	175.4	2206.6	5000
07N/13W-13Q01 S	19		2349.0	2/12/75	89.4	2259.6	5000
07N/13W-21A01 S	19		2360.0	2/12/75	46.6	2313.4	5000
07N/13W-26J02 S	19		2417.0	2/12/75	272.7(2)	2144.3	5000
07N/13W-34R01 S	19		2433.0	2/12/75	318.3	2114.7	5000
07N/14W-13A01 S	19		2467.0	2/12/75	277.5	2189.5	5000
08N/09W-06D01 S	19		2293.0	2/06/75	43.2	2249.8	5000
08N/10W-02N01 S	19		2308.0	2/05/75	47.2	2260.8	5000
08N/10W-04E01 S	19		2300.0	2/05/75	110.1	2189.9	5000
08N/10W-08R03 S	19		2318.0	2/05/75	76.2	2241.8	5000
08N/10W-23F02 S	19		2350.0	2/05/75	121.5	2228.5	5000
08N/10W-28R01 S	19		2358.0	2/05/75	144.1	2213.9	5000
08N/10W-30H01 S	19		2361.0	2/07/75	155.0	2206.0	5000
ANTELOPE HYDRO UNIT ANTELOPE HYDRO SUBUNIT LANCASTER HYDRO SUBAREA						W-26 W-26.A W-26.A5	
08N/11W-14R01 S	19		2317.0	2/07/75	90.5	2226.5	5000
08N/11W-15Q01 S	19		2307.0	2/07/75	86.1	2220.9	5000
08N/11W-18L01 S	19		2297.0	2/07/75	14.3	2282.7	5000
08N/11W-18Q01 S	19		2298.0	2/27/75	21.9	2276.1	5000
08N/11W-24R02 S	19		2337.0	2/07/75	107.8	2229.2	5000
08N/11W-24R03 S	19		2337.0	2/07/75	113.3	2223.7	5000
08N/11W-32E01 S	19		2340.0	2/07/75	101.9	2238.1	5000
08N/11W-34Q02 S	19		2340.0	2/07/75	138.9	2201.1	5000
08N/11W-34R02 S	19		2358.0	2/07/75	137.6	2220.4	5000
08N/11W-35J01 S	19		2361.0	2/07/75	251.9	2109.1	5000
08N/12W-02Q01 S	19		2283.0	2/12/75	48.1	2234.9	5000
08N/12W-05Q01 S	19		2329.0	2/12/75	149.8	2179.2	5000
08N/12W-10J01 S	19		2285.0	2/12/75	32.8	2252.2	5000
08N/12W-14R01 S	19		2291.0	2/12/75	70.2	2220.8	5000
08N/12W-20R02 S	19		2317.5	2/12/75	78.2	2239.3	5000
08N/12W-22Q01 S	19		2302.0	2/12/75	55.4	2246.6	5000
08N/12W-26F01 S	19		2303.0	2/12/75	18.7	2284.3	5000
08N/12W-28Q01 S	19		2308.0	2/12/75	54.5	2253.5	5000
08N/12W-30K01 S	19		2324.0	2/12/75	101.3	2222.7	5000
08N/12W-31Q02 S	19		2322.0	2/12/75	60.2	2261.8	5000
08N/12W-32L01 S	19		2317.0	2/12/75	58.0	2259.0	5000
08N/12W-34P01 S	19		2318.0	2/12/75	47.0	2271.0	5000
08N/13W-02Q01 S	19		2373.0	2/19/75	204.8	2168.2	5000
08N/13W-03M01 S	19		2400.0	2/19/75	255.9	2144.1	5000
08N/13W-05F01 S	19		2440.0	2/19/75	306.2	2133.8	5000
08N/13W-06F01 S	19		2462.0	2/19/75	342.0	2120.0	5000
08N/13W-08D04 S	19		2442.0	2/19/75	308.1	2133.9	5000
08N/13W-09K01 S	19		2412.0	2/19/75	222.6	2189.4	5000
08N/13W-11Q01 S	19		2374.0	2/19/75	206.1	2167.9	5000
08N/13W-15M01 S	19		2402.0	2/19/75	242.3	2159.7	5000
08N/13W-18Q02 S	19		2453.0	2/18/75	290.6	2162.4	5000
08N/13W-20B01 S	19		2438.0	2/18/75	279.2	2150.8	5000
08N/13W-23F01 S	19		2382.0	2/19/75	205.4	2176.6	5000
08N/13W-23M02 S	19		2376.0	2/19/75	78.0	2298.0	5000
08N/13W-25Q01 S	19		2333.0	2/18/75	55.9	2277.1	5000
08N/13W-27R02 S	19		2354.0	2/18/75	DRY		5000
08N/13W-31Q01 S	19		2440.0	2/18/75	221.8	2218.2	5000
08N/13W-32N01 S	19		2426.0	2/18/75	210.7	2215.3	5000
08N/13W-34P03 S	19		2365.0	2/18/75	80.2	2284.8	5000
08N/13W-35M01 S	19		2354.0	2/18/75	134.0	2220.0	5000
08N/13W-36L01 S	19		2349.0	2/18/75	129.7	2219.3	5000
08N/14W-09Q01 S	19		2554.0	2/19/75	342.9	2211.1	5000
08N/14W-15G01 S	19		2525.0	2/19/75	289.2	2235.8	5000
08N/14W-23G01 S	19		2500.0	2/19/75	290.1	2209.9	5000
08N/14W-36E01 S	19		2488.0	2/19/75	282.4	2205.6	5000
09N/09W-06H01 S	19		2387.0	2/07/75	164.1(4)	2222.9	5000
09N/09W-02Q01 S	19		2274.0	2/07/75	57.5	2217.3	5000
09N/09W-06F01 S	19		2290.0	2/06/75	49.1	2241.1	5000
09N/09W-10R01 S	19		2280.0	2/07/75	67.8	2212.2	5000
09N/09W-18C01 S	19		2281.3	2/06/75	79.0	2201.3	5000
09N/09W-27H02 S	19		2280.0	2/07/75	65.4	2214.6	5000

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
ANTELOPE HYDRO UNIT ANTELOPE HYDRO SUBUNIT LANCASTER HYDRO SUBAREA						W-26 W-26.A W-26.A5	
09N/10W-08P01 S	15		2372.0	2/06/75	84.2	2287.8	5000
09N/10W-12R01 S	15		2280.0	2/06/75	77.6	2202.4	5000
09N/10W-22J02 S	15		2285.0	2/06/75	NM-4		5000
09N/10W-24C01 S	15		2285.0	2/06/75	95.5	2189.5	5000
09N/10W-28F02 S	15		2290.0	2/06/75	73.7	2216.3	5000
09N/10W-34H01 S	15		2285.0	2/06/75	80.0	2205.0	5000
09N/11W-21N01 S	15		2274.4	2/06/75	NM-4		5000
09N/11W-36L01 S	15		2290.0	2/06/75	100.5	2189.5	5000
09N/12W-16E04 S	15		2380.0	2/05/75	29.0	2351.0	5000
09N/12W-23N01 S	15		2294.0	2/05/75	58.7	2235.3	5000
09N/12W-33Q01 S	15		2310.0	2/05/75	NM-6		5000
09N/12W-35N01 S	15		2295.0	2/05/75	43.5	2251.5	5000
09N/13W-14Q01 S	15		2442.0	2/20/75	201.2	2240.8	5000
09N/13W-27K01 S	15		2390.0	2/20/75	NM-1		5000
09N/14W-24D03 S	15		2500.0	2/20/75	330.1	2169.9	5000
09N/14W-27P01 S	15		2522.9	2/20/75	363.4	2159.5	5000
NORTH MUROC HYDRO SUBAREA						W-26.A6	
31S/39E-24P01 M	15		2925.0	2/04/75	422.0	2503.0	5000
32S/39E-33H01 M	15		2474.0	2/07/75	467.8	2006.2	5000
10N/09W-04D01 S	15		2304.0	2/07/75	114.5	2189.5	5000
10N/09W-24A02 S	15		2287.0	2/07/75	80.1	2206.9	5000
11N/08W-29K01 S	15		2351.8	2/07/75	164.9	2186.9	5000
11N/09W-13D01 S	15		2375.0	2/07/75	186.9	2188.1	5000
11N/09W-17N01 S	15		2319.9	2/07/75	142.7	2177.2	5000
11N/09W-24A01 S	15		2348.8	2/07/75	157.4	2191.4	5000
11N/09W-30H01 S	15		2298.3	2/07/75	106.9	2191.4	5000
11N/09W-36R01 S	15		2312.5	2/07/75	108.8	2203.7	5000
11N/10W-12F01 S	15		2350.0	2/07/75	175.3	2174.7	5000
RUTTES HYDRO SUBAREA						W-26.A7	
05N/11W-01M01 S	19		2738.5	2/19/75	96.9	2641.6	5000
05N/11W-04F01 S	19		2694.6	11/12/74	157.6	2537.0	1101
05N/11W-04P01 S	19		2740.0	10/15/74	157.0	2583.0	1101
				12/15/74	155.0	2585.0	
				1/15/75	156.0	2584.0	
				2/15/75	155.0	2585.0	
				3/15/75	154.0	2586.0	
				4/15/75	155.0	2585.0	
				5/15/75	161.0(5)	2579.0	
				7/15/75	157.0	2583.0	
05N/11W-04P02 S	19		2755.0	2/19/75	163.2	2591.8	5000
05N/11W-07F02 S	19		2905.0	11/12/74	NM-5		1101
05N/11W-09Q01 S	19		2857.0	11/12/74	67.0	2790.0	1101
05N/11W-16R01 S	19		2950.0	11/12/74	31.7	2918.3	1101
05N/11W-17H01 S	19		3060.0	6/15/75	56.0	3004.0	1101
05N/11W-17H02 S	19		3060.0	12/15/74	52.0	3008.0	1101
				1/15/75	53.0	3007.0	
				2/15/75	53.0	3007.0	
				3/15/75	52.0	3008.0	
				4/15/75	52.0	3008.0	
				5/15/75	49.0	3011.0	
				6/15/75	57.4	3002.6	
				7/15/75	53.0	3007.0	
				8/20/75	54.0	3006.0	
				9/15/75	63.0	2997.0	
05N/12W-02A02 S	19		2808.0	11/12/74	12.5	2795.5	1101
05N/12W-02P04 S	19		2840.0	10/15/74	26.0	2814.0	1101
				12/15/74	27.0	2813.0	
				1/15/75	28.0	2812.0	
				2/15/75	28.0	2812.0	
				3/15/75	28.0	2812.0	

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
ANTELOPE HYDRO UNIT ANTELOPE HYDRO SUBUNIT RUTTES HYDRO SUBAREA						W-26 W-26.A W-26.A7	
05N/12W-02P04 S (CONTINUED)	19		2840.0	4/15/75	27.0	2813.0	1101
				5/15/75	25.0	2815.0	
				7/15/75	28.0	2812.0	
				8/20/75	31.0	2809.0	
				9/15/75	29.0	2811.0	
05N/12W-12A02 S	19		2892.0	11/12/74	9.5	2882.5	1101
05N/12W-14L01 S	19		3140.0	11/26/74	205.9	2934.1	1101
				4/23/75	206.2	2933.8	
06N/10W-30E01 S	19		2666.0	11/12/74	NM-5		1101
				12/19/74	90.8	2575.2	
06N/10W-34D01 S	19		2706.0	7/16/75	130.0(5)	2576.0	1101
				8/05/75	130.0(5)	2576.0	
				9/02/75	131.0(5)	2575.0	
06N/11W-34Q01 S	19		2700.0	10/15/74	123.0	2577.0	1101
				5/15/75	165.0	2535.0	
				6/15/75	141.8(5)	2558.2	
				9/15/75	185.0(1)	2515.0	
ROCK CREEK HYDRO SUBAREA						W-26.A8	
04N/08W-07R01 S	19		4307.0	2/13/75	125.7	4181.3	5000
04N/09W-06R02 S	19		3464.0	10/10/74	12.6(2)	3451.4	1101
				11/26/74	7.5(2)	3456.5	
04N/09W-06G01 S	19		3493.0	10/10/74	NM-9		1101
				11/26/74	NM-9		
				8/21/75	100.0	3393.0	
				9/04/75	8.2	3484.8	
04N/09W-07R01 S	19		3596.0	10/10/74	12.6	3583.4	1101
				11/06/74	12.5	3583.5	
				12/06/74	10.5	3585.5	
				1/07/75	11.2	3584.8	
				2/11/75	NM-9		
				3/12/75	NM-9		
				4/11/75	9.1	3586.9	
				5/08/75	15.2(4)	3580.8	
				6/11/75	10.5	3585.5	
				7/03/75	NM-9		
				8/06/75	NM-1		
				9/04/75	NM-1		
04N/09W-08L01 S	19		3735.0	10/10/74	46.3	3688.7	1101
				11/06/74	49.0	3686.0	
				12/05/74	43.0	3692.0	
				1/07/75	NM-1		
				2/11/75	NM-1		
				3/12/75	41.7	3693.3	
				4/11/75	39.4	3695.6	
				5/08/75	NM-1		
				6/11/75	38.9	3696.1	
				7/03/75	NM-1		
				8/06/75	NM-1		
				9/04/75	NM-1		
04N/09W-09M01 S	19		3800.0	10/10/74	84.2	3715.8	1101
				11/26/74	81.3	3718.7	
				8/06/75	86.4	3713.6	
				9/04/75	86.5	3713.5	
04N/09W-09N04 S	19		3831.0	10/10/74	56.7	3774.3	1101
				11/26/74	53.7	3777.3	
04N/09W-09P01 S	19		3845.0	10/10/74	75.9	3769.1	1101
				11/06/74	72.8	3772.2	
				12/05/74	70.0	3775.0	
				1/07/75	70.1	3774.9	
				2/11/75	70.6	3774.4	
				3/12/75	71.7	3773.3	
				4/11/75	66.1	3778.9	
				5/08/75	71.5(2)	3773.5	
				6/11/75	77.9(2)	3767.1	
				7/03/75	76.0	3769.0	
04N/09W-17H01 S	19		3920.0	10/10/74	16.5	3903.5	1101
				11/26/74	16.0	3904.0	
04N/10W-02N01 S	19		3840.0	12/13/74	NM-5		1101
04N/10W-02Q01 S	19		3820.0	12/13/74	48.0	3772.0	1101
04N/10W-11A01 S	19		3810.0	12/13/74	21.0	3789.0	1101
04N/10W-11R01 S	19		3835.0	12/13/74	55.0	3780.0	1101
04N/10W-23F01 S	19		4537.0	11/26/74	97.8	4439.2	1101
05N/09W-02D01 S	19		2865.0	2/13/75	160.0	2705.0	5000
05N/09W-04F01 S	19		2882.0	2/13/75	129.6	2752.4	5000
05N/09W-17A01 S	19		3022.0	2/13/75	DRY		5000
05N/09W-20K01 S	19		3177.5	10/10/74	246.1	2931.4	1101
				11/26/74	246.3	2931.2	
			3178.0	2/13/75	246.2	2931.8	5000

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
ANTELOPE HYDRO UNIT						W-26	
ANTELOPE HYDRO SUBUNIT						W-26.A	
ROCK CREEK HYDRO SUBAREA						W-26.AR	
05N/09W-24P01	S	19	3373.0	11/26/74	331.0	3042.0	1101
05N/09W-26D01	S	19	3354.0	11/26/74	NM-5		1101
				12/19/74	NM-1		
05N/09W-30N01	S	19	3310.0	11/26/74	NM-3		1101
05N/09W-31P01	S	19	3432.5	7/15/75	15.5(1)	3417.0	1101
				8/05/75	14.5(5)	3418.0	
				9/02/75	16.5(5)	3416.0	
05N/10W-03L01	S	19	2802.0	2/19/75	104.0	2698.0	5000
05N/10W-06N01	S	19	2777.0	10/10/74	120.5	2656.5	1101
				11/06/74	119.8	2657.2	
				12/13/74	119.9	2657.1	
				1/09/75	118.4	2658.6	
				2/11/75	117.9	2659.1	
				4/13/75	117.7	2659.3	
				5/08/75	119.8	2657.2	
				6/11/75	121.2	2655.8	
				7/03/75	121.4	2655.6	
				8/06/75	NM-9		
				9/08/75	121.7	2655.3	
05N/10W-07P01	S	19	2892.0	7/15/75	244.5(5)	2647.5	1101
				8/05/75	251.5(1)	2640.5	
				9/02/75	250.5(1)	2641.5	
05N/10W-16P01	S	19	3023.0	2/13/75	257.5	2765.5	5000
05N/10W-26G03	S	19	3249.0	12/13/74	40.2(1)	3208.8	1101
05N/10W-29C01	S	19	3200.0	12/13/74	228.0(1)	2972.0	1101
05N/10W-34N02	S	19	3549.7	12/13/74	30.2	3519.5	1101
05N/10W-34P01	S	19	3552.0	12/13/74	NM-1		1101
05N/11W-16K01	S	19	2812.0	11/12/74	127.0	2685.0	1101
05N/11W-12D01	S	19	2832.0	11/12/74	178.7	2653.3	1101
05N/11W-12R01	S	19	2841.0	2/19/75	184.2	2656.8	5000
05N/11W-13R01	S	19	2845.0	5/30/75	189.2	2655.8	1101
05N/11W-13J01	S	19	2912.0	11/12/74	NM-5		1101
			2913.0	12/19/74	276.7(3)	2636.3	
05N/11W-21J01	S	19	3040.0	11/12/74	28.9	3011.1	1101
06N/07W-19E02	S	36	2931.0	11/15/74	87.7	2843.3	5101
				4/24/75	90.0	2841.0	

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
MOJAVE HYDRO UNIT						W-28	
EL MIRAGE HYDRO SUBUNIT						W-28.A	
04N/07W-27D01	S	19	890.0	12/17/74	8.0	882.0	1101
				4/02/75	8.0	882.0	
06N/07W-07A01	S	36	2866.0	11/18/74	32.0	2834.0	5101
				4/24/75	33.8	2832.2	
06N/07W-10R01	S	36	2865.0	11/15/74	NM-1		5101
06N/07W-26P01	S	36	3005.0	11/15/74	127.5	2877.5	5101
				4/24/75	127.5(2)	2877.5	
06N/07W-27N01	S	36	3020.0	11/15/74	147.5	2872.5	5101
				4/24/75	139.5	2880.5	
UPPER MOJAVE HYDRO SUBUNIT						W-28.B	
03N/04W-13R02	S	36	3005.3	11/13/74	98.8	2906.5	5101
				4/23/75	88.0	2917.3	
03N/04W-32C01	S	36	3187.0	11/12/74	10.2	3176.8	5101
				4/23/75	7.0	3180.0	
04N/03W-01N01	S	36	3037.0	11/13/74	230.8	2806.2	5101
				4/23/75	228.6	2808.4	
04N/03W-06D02	S	36	2870.0	10/04/74	70.2	2799.8	5101
				11/01/74	68.3	2801.7	
				12/13/74	72.7	2797.3	
				1/02/75	72.8	2797.2	
				2/14/75	75.2	2794.8	
				3/13/75	74.0	2796.0	
				4/02/75	68.4	2801.6	
				5/09/75	74.1	2795.9	
				7/01/75	68.9	2801.1	
				8/12/75	80.6	2789.4	
				9/10/75	77.4	2792.6	
04N/03W-07P02	S	36	2868.5	10/04/74	62.9	2805.6	5101
				11/01/74	NM-1		
				12/13/74	NM-1		
04N/04W-08G01	S	36	3165.0	10/04/74	NM-3		5101
				11/01/74	NM-9		
				12/13/74	NM-1		
				1/02/75	NM-1		
05N/02W-33N01	S	36	3030.0	11/07/74	165.4	2864.6	5713
				2/27/75	167.8	2862.2	
05N/03W-03D02	S	36	2920.0	11/13/74	139.8	2780.2	5101
				4/23/75	137.7	2782.3	
05N/03W-24N01	S	36	2927.7	11/13/74	119.5	2808.2	5101
				4/23/75	118.0	2809.7	
05N/03W-35N01	S	36	2984.0	11/13/74	171.8	2812.2	5101
				4/23/75	178.8	2805.2	
06N/03W-09F04	S	36	3085.0	11/13/74	32.5	3052.5	5101
				4/23/75	32.7	3052.3	
06N/05W-28F01	S	36	2875.6	11/14/74	119.3	2756.3	5101
				4/24/75	119.8	2755.8	
06N/05W-32P02	S	36	2945.0	11/14/74	145.0	2800.0	5101
				4/24/75	131.9	2813.1	
06N/06W-21A01	S	36	2860.0	11/14/74	62.4	2797.6	5101
				4/24/75	59.4	2800.6	
06N/06W-24C01	S	36	2895.0	11/15/74	49.5	2845.5	5101
				4/24/75	49.5(1)	2845.5	
07N/04W-30C01	S	36	2961.5	10/04/74	67.4	2494.1	5101
				11/01/74	71.9	2489.6	
				12/13/74	61.6	2499.9	
				1/02/75	61.8	2499.7	
				2/14/75	60.9	2500.6	
				3/13/75	68.9	2492.6	
				4/02/75	60.7	2500.8	
				5/09/75	72.8	2488.7	
				6/06/75	61.4	2500.1	
				7/01/75	64.7	2496.8	
				8/12/75	63.2	2498.3	
				9/10/75	63.2	2498.3	
MIDDLE MOJAVE HYDRO SUBUNIT						W-28.C	
08N/01W-29F01	S	36	2869.2	11/13/74	102.9	2766.3	5101
				4/23/75	93.2	2776.0	
08N/03W-07N01	S	36	2348.0	10/04/74	32.2	2307.8	5101
				11/01/74	32.7	2307.3	
				12/13/74	NM-1		
				1/02/75	NM-1		
				2/14/75	38.7	2301.3	
				3/13/75	35.5	2304.5	
				4/02/75	35.5	2304.5	
				5/09/75	40.4	2299.6	
				6/06/75	39.3(2)	2300.7	
				7/01/75	39.2	2300.8	
				8/12/75	40.8	2299.2	
				9/10/75	50.4	2289.6	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
MOJAVE HYDRO UNIT							
MIDDLE MOJAVE HYDRO SUBUNIT						W-28 W-28.C	
08N/04W-20N01 S	36		2407.7	11/19/74	18.2(1)	2389.5	5101
				4/28/75	18.2(1)	2389.5	
08N/04W-30F01 S	36		2480.0	11/19/74	76.7	2403.3	5101
				4/28/75	NM-6		
09N/02W-04B02 S	36		2160.0	11/21/74	61.9	2098.1	5101
				4/29/75	62.0	2098.0	
09N/02W-20B01 S	36		2293.0	10/04/74	131.3	2161.7	5101
				11/01/74	149.4	2143.6	
				12/13/74	141.0	2152.0	
				1/02/75	131.5	2161.5	
09N/02W-34D01 S	36		2450.0	11/21/74	DRY		5101
				4/29/75	DRY		
09N/03W-11N01 S	36		2209.0	11/19/74	60.8	2148.2	5101
				4/28/75	DRY		
09N/03W-28A03 S	36		2245.0	11/19/74	45.5	2199.5	5101
				4/28/75	44.7	2200.3	
10N/02W-19P01 S	36		2216.0	10/04/74	119.4	2096.6	5101
				11/01/74	112.7	2103.3	
				12/13/74	118.7	2097.3	
				1/02/75	NM-1		
				2/14/75	111.5	2104.5	
				3/13/75	120.0	2096.0	
				4/02/75	122.4	2093.6	
				5/09/75	127.5	2088.5	
				6/06/75	120.5	2095.5	
				7/01/75	129.9	2086.1	
				8/12/75	115.6	2100.4	
				9/10/75	115.0	2101.0	
10N/02W-32K01 S	36		2170.0	11/21/74	61.8(1)	2108.2	5101
				4/29/75	60.7(1)	2109.3	
10N/03W-10R01 S	36		2535.0	11/20/74	NM-5		5101
				4/29/75	NM-5		
10N/03W-27D01 S	36		2164.6	10/04/74	69.8	2094.8	5101
				11/01/74	72.0	2092.6	
				12/13/74	74.0	2090.6	
				1/02/75	71.0	2093.6	
				2/14/75	119.4	2045.2	
				3/13/75	95.0	2069.6	
				4/02/75	90.0	2074.6	
				5/09/75	92.5	2072.1	
				6/06/75	74.0	2090.6	
				7/01/75	71.4	2093.2	
				8/12/75	72.1	2092.5	
				9/10/75	74.7	2089.9	
10N/03W-29H01 S	36		2206.0	11/19/74	59.0	2147.0	5101
				4/28/75	57.8	2148.2	
10N/03W-35Q03 S	36		2197.0	11/19/74	116.0	2081.0	5101
				4/28/75	120.7	2076.3	
HARPER HYDRO SUBUNIT						W-28.D	
HARPER HYDRO SUBAREA						W-28.D2	
32S/43E-28Q01 M	36		2277.0	11/19/74	DRY		5101
				4/28/75	DRY		
10N/03W-10Q01 S	36		2040.0	11/19/74	64.8(4)	1975.2	5101
				4/29/75	64.0	1976.0	
10N/03W-36J02 S	36		2180.0	10/04/74	83.0	2097.0	5101
				11/01/74	87.1	2092.9	
				12/13/74	80.3	2099.7	
				1/02/75	NM-1		
				2/14/75	69.3	2110.7	
				3/13/75	NM-1		
				4/02/75	77.1	2102.9	
				5/09/75	79.3	2100.7	
				6/06/75	NM-1		
				7/04/75	NM-1		
				8/12/75	NM-1		
				9/10/75	NM-1		
11N/03W-07D01 S	36		2065.0	11/20/74	69.3	1995.7	5101
				4/29/75	69.3	1995.7	
11N/03W-28R02 S	36		2073.0	11/20/74	47.3	2025.7	5101
				4/29/75	47.6	2025.4	
11N/03W-30J01 S	36		2033.0	11/20/74	3.9	2029.1	5101
				4/28/75	4.5	2028.5	
11N/03W-30J02 S	36		2030.8	11/20/74	9.6	2021.2	5101
				4/28/75	8.6	2022.2	
11N/04W-19H01 S	36		2039.1	11/19/74	143.4(3)	1895.7	5101
				4/28/75	139.9(3)	1899.2	
11N/04W-32A01 S	36		2058.0	11/19/74	NM-1		5101
11N/04W-32D01 S	36		2075.0	11/19/74	169.6	1905.4	5101
				4/28/75	173.6	1901.4	
MOJAVE HYDRO UNIT							
HARPER HYDRO SUBUNIT						W-28	
HARPER HYDRO SUBAREA						W-28.D W-28.D2	
11N/04W-32Q02 S	36		2065.0	11/20/74	176.0	1889.0	5101
				4/28/75	173.0	1892.0	
11N/05W-13H01 S	36		2036.2	11/20/74	28.5(6)	2007.7	5101
				4/28/75	34.5(6)	2001.7	
LOWER MOJAVE HYDRO SUBUNIT						W-28.E	
09N/01E-03H01 S	36		1948.0	11/21/74	104.1(3)	1843.9	5101
				4/25/75	105.1(3)	1842.9	
09N/01E-13E02 S	36		1949.6	10/04/74	118.8(6)	1830.8	5101
				11/01/74	107.9	1841.7	
				12/13/74	112.8	1836.8	
				1/02/75	105.7	1843.9	
				2/14/75	135.8	1813.8	
				3/13/75	122.3	1827.3	
				4/02/75	124.3	1825.3	
				5/09/75	132.8	1816.8	
				6/06/75	122.3	1827.3	
				7/01/75	122.3	1827.3	
				8/12/75	125.1	1824.5	
				9/10/75	107.9	1841.7	
09N/02E-14N02 S	36		1886.0	10/04/74	48.5	1837.5	5101
				11/01/74	48.5	1837.5	
				12/13/74	47.8	1838.2	
				1/02/75	47.1	1838.9	
				2/14/75	51.2(6)	1834.8	
				3/13/75	48.4	1837.6	
				4/02/75	48.0	1838.0	
				5/09/75	48.0	1838.0	
				6/06/75	52.2	1833.8	
				7/01/75	48.7	1837.3	
				8/12/75	48.5	1837.5	
				9/10/75	49.0	1837.0	
09N/02E-20Q01 S	36		1921.4	10/04/74	82.4	1839.0	5101
				11/01/74	97.6	1823.8	
				12/13/74	88.1	1833.3	
				1/02/75	93.3	1828.1	
				2/14/75	107.4	1814.0	
				3/13/75	89.9	1831.5	
				4/02/75	87.9	1833.5	
				5/09/75	107.4	1814.0	
				6/06/75	93.3	1828.1	
				7/01/75	93.2	1828.2	
				8/12/75	94.1	1827.3	
				9/10/75	95.7	1825.7	
09N/03E-15M01 S	36		1830.0	11/22/74	63.9	1766.1	5101
				4/25/75	62.0	1768.0	
09N/04E-07M02 S	36		1803.0	10/04/74	NM-1		5101
				11/01/74	NM-1		
				12/13/74	48.6	1754.4	
				1/02/75	48.1	1754.9	
				2/14/75	48.2	1754.8	
				3/13/75	NM-1		
				4/02/75	NM-1		
				5/09/75	NM-1		
				6/06/75	NM-1		
				7/01/75	NM-1		
				8/12/75	NM-1		
				9/10/75	NM-1		
10N/02E-32P01 S	36		1906.5	11/22/74	61.0	1844.5	5101
				4/25/75	62.8	1842.7	
10N/03E-21A01 S	36		1817.0	11/22/74	119.5	1697.5	5101
				4/25/75	120.9	1696.1	
09N/01W-10D02 S	36		2045.0	11/21/74	21.0	2024.0	5101
				4/25/75	21.6	2023.4	
09N/01W-10P01 S	36		2081.0	11/22/74	62.0	2019.0	5101
				4/25/75	61.8	2019.2	
TROY HYDRO SUBUNIT						W-28.F	
TROY HYDRO SUBAREA						W-28.F2	
08N/03E-04R03 S	36		1819.6	11/22/74	15.4	1804.2	5101
				4/25/75	14.3	1805.3	
09N/03E-19F01 S	36		1860.1	11/22/74	24.0	1836.1	5101
				4/25/75	22.5	1837.6	
09N/03E-29G02 S	36		1850.0	11/22/74	19.1	1830.9	5101
				4/25/75	19.8	1830.2	
09N/03E-34D03 S	36		1828.8	11/22/74	55.5	1773.3	5101
				4/25/75	54.9	1773.9	
09N/03E-34N01 S	36		1820.0	10/09/74	35.5	1784.5	5101
				11/01/74	NM-1		
				12/13/74	36.1	1783.9	
				1/02/75	36.0	1784.0	
				2/14/75	38.0	1782.0	
				3/13/75	35.0	1785.0	
				4/02/75	35.8	1784.2	
				5/09/75	37.9	1782.1	

See page 79 for key to terms a abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
MOJAVE HYDRO UNIT						W-24	
TROY HYDRO SUBUNIT						W-28.F	
TROY HYDRO SUBAREA						W-28.F2	
09N/03E-34N01 S (CONTINUED)	36		1820.0	6/06/75	36.3	1783.7	5101
				7/01/75	41.0	1779.0	
				8/12/75	41.5	1778.5	
				9/10/75	43.7	1776.3	
AFTON HYDRO SUBUNIT						W-28.G	
CAVES HYDRO SUBAREA						W-28.G1	
10N/04E-04E01 S	36		1740.0	11/22/74	88.8	1651.2	5101
				4/25/75	88.8	1651.2	

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA

See page 79 for key to terms a abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
COLORADO R. BASIN DRAINAGE PROV						X	
LUCERNE HYDRO UNIT						X-01	
04N/01E-02L01 S	36		2927.0	11/07/74	97.8	2829.2	5713
				2/27/75	104.2	2822.8	
04N/01E-02M01 S	36		2922.0	11/07/74	NM-7		5713
				2/27/75	NM-7		
04N/01E-05H01 S	36		2905.0	11/07/74	145.2	2759.8	5713
				2/27/75	142.6	2762.4	
04N/01E-06R01 S	36		2895.0	11/14/74	123.7	2771.3	5101
				4/23/75	132.6	2762.4	
04N/01E-07P02 S	36		2950.0	11/07/74	134.1	2815.9	5713
				2/27/75	DRY		
04N/01E-07R02 S	36		2940.0	11/07/74	110.4	2829.6	5713
				2/27/75	123.0	2817.0	
04N/01E-11D02 S	36		2940.0	11/07/74	115.8	2824.2	5713
				2/27/75	116.1	2823.9	
04N/01E-12P01 S	36		2971.0	11/13/74	135.6	2835.4	5101
				4/23/75	141.6	2829.4	
04N/01E-20A01 S	36		3035.0	11/07/74	132.3	2902.7	5713
				2/27/75	132.3	2902.7	
05N/01E-16C01 S	36		2932.0	11/07/74	118.4	2813.6	5713
				2/27/75	119.0	2813.0	
05N/01E-17D01 S	36		2880.0	11/07/74	121.0	2759.0	5713
				2/27/75	120.1	2759.9	
05N/01E-27D01 S	36		2908.0	11/07/74	106.4	2801.6	5713
				2/27/75	107.5	2800.5	
05N/01E-27H01 S	36		2930.0	11/07/74	113.8	2816.2	5713
				2/27/75	118.9	2811.1	
04N/01W-02P01 S	36		2880.0	11/07/74	89.3	2790.7	5713
				2/27/75	101.8	2778.2	
04N/01W-08N01 S	36		2940.0	11/07/74	15.5	2924.5	5713
				2/27/75	15.4	2924.6	
04N/01W-09Q01 S	36		2975.0	11/13/74	46.7	2928.3	5101
				4/23/75	44.2	2930.8	
04N/01W-10A01 S	36		2907.0	11/07/74	9.6	2897.4	5713
				2/27/75	9.0	2898.0	
04N/01W-14A02 S	36		2965.0	11/07/74	85.3	2879.7	5713
				2/27/75	94.0	2871.0	
04N/01W-14R02 S	36		2940.0	11/07/74	17.6	2922.4	5713
				2/27/75	15.6	2924.4	
04N/02W-13A01 S	36		2980.0	11/13/74	68.5	2911.5	5101
				4/23/75	82.5	2897.5	
05N/01W-01C02 S	36		2920.7	11/14/74	156.0	2764.7	5101
				4/23/75	175.8	2744.9	
05N/01W-01L01 S	36		2905.0	11/14/74	133.5	2771.5	5101
				4/23/75	135.5	2769.5	
05N/01W-25G01 S	36		2850.0	11/07/74	NM-9		5713
				2/27/75	85.7	2764.3	
06N/01W-05J01 S	36		3229.0	11/13/74	132.0	3097.0	5101
				4/23/75	154.0(6)	3075.0	
06N/01W-22P01 S	36		3059.0	11/13/74	172.0	2887.0	5101
				4/23/75	179.7	2879.3	
06N/01W-36K01 S	36		2933.0	11/14/74	210.5	2722.5	5101
				4/23/75	205.5	2727.5	
06N/01W-36K02 S	36		2940.0	11/14/74	192.5	2747.5	5101
				4/23/75	220.0	2720.0	

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
JOSHUA TREE HYDRO UNIT						X-08	
WARREN HYDRO SUBUNIT						X-08.A	
01N/04E-28L01 S	36		2970.0	12/06/74	166.1	2803.9	5101
				4/30/75	169.8	2800.2	
01N/04E-31P01 S	36		3280.0	12/05/74	NM-7		5101
				4/30/75	NM-7		
01S/05E-04P02 S	36		3520.0	12/06/74	79.1	3440.9	5101
				4/30/75	76.0	3444.0	
COPPER MOUNTAIN HYDRO SUBUNIT						X-08.B	
01N/06E-09Q01 S	36		3220.0	12/05/74	DRY		5101
				4/30/75	DRY		
01N/06E-13P01 S	36		2650.0	12/12/74	431.9	2218.1	5101
				5/01/75	436.2	2213.8	
01N/07E-14N01 S	36		2359.0	12/06/74	187.3	2171.7	5101
				4/30/75	185.6	2173.4	
01N/07E-21J01 S	36		2440.0	12/06/74	269.5(1)	2170.5	5101
				4/30/75	268.5(1)	2171.5	
01N/07E-23A01 S	36		2865.0	12/06/74	217.0	2648.0	5101
				4/30/75	217.0	2648.0	
01N/07E-30P01 S	36		2670.0	12/05/74	375.8	2294.2	5101
				4/30/75	373.8	2296.2	
01S/07E-27R01 S	36		3770.0	10/18/74	170.2	3599.8	5000
				4/07/75	170.8	3599.2	
02S/08E-03C01 S	36		4300.0	10/18/74	94.3	4205.7	5000
				4/08/75	94.4	4205.6	
02S/08E-07K01 S	36		4100.0	10/18/74	224.0	3876.0	5000
				4/07/75	224.6	3875.4	
02S/08E-21G01 S	36		4400.0	10/18/74	63.9	4336.1	5000
				4/08/75	63.4	4336.6	
02S/08E-21G02 S	36		4480.0	10/18/74	38.3	4441.7	5000
				4/08/75	38.6	4441.4	

See page 79 for key to terms & abbreviations

TABLE G-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
DALE HYDRO UNIT						X-09	
TWENTYNINE PALMS HYDRO SUBUNIT						X-09.A	
01N/08E-01H01 S	36		1856.0	12/06/74	DRY		5101
				5/01/75	DRY		
01N/08E-12G01 S	36		1972.7	12/06/74	214.8	1757.9	5101
				5/01/75	201.0	1771.7	
01N/08E-33A02 S	36		2520.0	12/06/74	NM-1		5101
				4/30/75	305.4(4)	2214.6	
01N/08E-36A01 S	36		2129.7	12/06/74	167.9	1961.8	5101
				4/30/75	172.4	1957.3	
01N/09E-04N03 S	36		1787.0	12/06/74	15.8	1771.2	5101
				5/01/75	16.2	1770.8	
01N/09E-06E01 S	36		1840.0	12/06/74	72.7	1767.3	5101
				5/01/75	57.5(1)	1782.5	
01N/09E-09N02 S	36		1810.0	12/06/74	42.6	1767.4	5101
				5/01/75	36.8	1773.2	
01N/09E-15G02 S	36		1800.0	12/06/74	14.5	1785.5	5101
				5/01/75	15.5	1784.5	
01N/09E-17E01 S	36		1870.0	12/06/74	110.9	1759.1	5101
				5/01/75	111.0	1759.0	
01N/09E-22E01 S	36		1827.0	12/06/74	56.1	1770.9	5101
				5/01/75	60.4	1766.6	
01N/09E-24A01 S	36		1936.0	12/06/74	158.0	1778.0	5101
				5/01/75	153.5	1782.5	
01N/09E-27C04 S	36		1870.0	12/06/74	84.5	1785.5	5101
				5/01/75	89.8	1780.2	
01N/09E-31A01 S	36		2095.0	12/06/74	120.5	1974.5	5101
				4/30/75	122.0	1973.0	
01N/09E-31C01 S	36		2102.3	12/06/74	156.4	1945.9	5101
				4/30/75	141.5	1960.8	
01N/09E-33F03 S	36		1979.0	12/06/74	9.9	1969.1	5101
01N/09E-33F04 S	36		1981.0	4/08/75	8.7	1972.3	5000
01N/09E-33F05 S	36		1981.0	4/08/75	9.0	1972.0	5000
01N/09E-33G01 S	36		1961.9	4/08/75	32.0	1929.9	5000
01N/09E-33H01 S	36		1960.7	4/08/75	52.3	1908.4	5000
01N/09E-33H02 S	36		1960.7	4/08/75	51.1	1909.6	5000
01N/09E-33J02 S	36		1973.2	4/08/75	15.6	1957.6	5000
01N/09E-33J03 S	36		1972.0	4/08/75	15.5	1956.5	5000
01N/09E-33J04 S	36		1972.0	4/08/75	15.3	1956.7	5000
01N/09E-33J05 S	36		1960.4	4/08/75	5.0	1955.4	5000
01N/09E-33K01 S	36		1970.5	4/08/75	20.3	1950.2	5000
01N/09E-33K02 S	36		1972.0	4/08/75	21.5	1950.5	5000
01N/09E-33K03 S	36		1972.0	4/08/75	21.5	1950.5	5000
01N/09E-33K04 S	36		1973.1	4/08/75	22.5	1950.6	5000
01N/09E-33K05 S	36		1973.1	4/08/75	22.4	1950.7	5000
01N/09E-34A01 S	36		1950.0	12/06/74	157.0	1793.0	5101
01N/09E-35F01 S	36		1971.0	12/06/74	112.4	1858.6	5101
				5/01/75	112.0	1859.0	
01N/09E-35N01 S	36		2079.5	12/06/74	123.0	1956.5	5101
				5/01/75	NM-2		
02N/09E-19N01 S	36		1834.0	12/06/74	75.5	1758.5	5101
				5/01/75	71.7	1762.3	
01S/09E-03D01 S	36		2076.4	12/06/74	114.4	1962.0	5101
				5/01/75	112.6	1963.8	
DALE HYDRO SUBUNIT						X-09.B	
01N/09E-12G03 S	36		1750.0	12/12/74	229.7	1520.3	5101
				5/01/75	222.7	1527.3	
01N/10E-22J01 S	36		1640.0	12/12/74	312.0	1328.0	5101
				5/01/75	308.0	1332.0	
01N/10E-24P02 S	36		1520.0	12/12/74	230.3	1289.7	5101
				5/01/75	212.8	1307.2	
01N/11E-04M01 S	36		1360.0	12/12/74	140.2	1219.8	5101
				5/01/75	145.9	1214.1	
01N/11E-14A01 S	36		1285.0	12/12/74	80.3	1204.7	5101
				5/01/75	80.5	1204.5	
01N/11E-35P01 S	36		1265.0	12/12/74	66.5	1198.5	5101
DALE HYDRO UNIT						X-09	
DALE HYDRO SUBUNIT						X-09.B	
01N/11E-35P01 S	36		1265.0	5/01/75	65.0	1200.0	5101

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
CHUCKWALLA HYDRO UNIT						X-17	
PINTO HYDRO SUBUNIT						X-17.C	
02S/12E-36F01 S	33		1347.0	10/17/74	NM-0		5000
03S/15E-04J01 S	33		1080.6	10/17/74	167.4	913.2	5000
				4/07/75	167.8(2)	912.8	
04S/11E-27Q01 S	33		2975.0	10/17/74	188.4	2786.6	5000
				4/07/75	NM-1		

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
WHITEWATER HYDRO UNIT						X-19	
MORONGO HYDRO SUBUNIT						X-19.A	
01S/04E-14N01 S	36		2750.0	12/03/74	199.5	2550.5	5101
				4/30/75	187.6	2562.4	
01S/04E-22J01 S	36		2750.0	12/03/74	NM-8		5101
				4/30/75	179.6(3)	2570.4	
01S/04E-23C01 S	36		2700.0	12/03/74	150.0	2550.0	5101
				4/30/75	149.8	2550.2	
SAN GORGONIO HYDRO SUBUNIT						X-19.C	
SAN GORGONIO HYDRO SUBAREA						X-19.C2	
02S/01E-17F01 S	33		3730.0	10/04/74	55.0	3675.0	4829
				11/01/74	75.0	3655.0	
				12/05/74	48.0	3682.0	
				1/03/75	46.0	3684.0	
				2/07/75	77.0	3653.0	
				3/14/75	69.0	3661.0	
				4/04/75	33.0	3697.0	
				5/01/75	28.0	3702.0	
				6/13/75	45.0	3685.0	
				7/07/75	24.0	3706.0	
				8/22/75	62.0	3668.0	
				9/05/75	67.0	3663.0	
02S/01E-17L01 S	33		3696.0	10/04/74	3.0	3693.0	4829
				11/01/74	8.0	3688.0	
				12/05/74	14.0	3682.0	
				1/03/75	18.0	3678.0	
				2/07/75	10.0	3686.0	
				3/14/75	13.0	3683.0	
				4/04/75	7.0	3689.0	
				5/01/75	5.0	3691.0	
				6/13/75	5.0	3691.0	
				7/07/75	8.0	3688.0	
				8/22/75	6.0	3690.0	
				9/05/75	4.0	3692.0	
02S/01E-20M01 S	33		3395.0	10/04/74	62.0	3333.0	4829
				11/01/74	62.0	3333.0	
				12/05/74	64.0	3331.0	
				1/03/75	64.0	3331.0	
				2/07/75	61.0	3334.0	
				3/14/75	61.0	3334.0	
				4/04/75	61.0	3334.0	
				5/01/75	61.0	3334.0	
				6/13/75	61.0	3334.0	
				7/07/75	72.0	3323.0	
				8/22/75	72.0	3323.0	
				9/05/75	72.0	3323.0	
02S/01E-29F01 S	33		3210.0	10/04/74	107.0	3103.0	4829
				11/01/74	108.0	3102.0	
				12/05/74	87.0	3123.0	
				1/03/75	82.0	3128.0	
				2/07/75	81.0	3129.0	
				3/14/75	84.0	3126.0	
				4/04/75	85.0	3125.0	
				5/01/75	74.0	3136.0	
				6/13/75	77.0	3133.0	
				7/07/75	77.0	3133.0	
				8/22/75	85.0	3125.0	
				9/05/75	88.0	3122.0	
02S/01E-29H01 S	33		3158.0	10/04/74	64.0	3094.0	4829
				11/01/74	62.0	3096.0	
				12/05/74	47.0	3111.0	
				1/03/75	45.0	3113.0	
				2/07/75	47.0	3111.0	
				3/14/75	49.0	3109.0	
				4/04/75	51.0	3107.0	
				5/01/75	42.0	3116.0	
				6/13/75	39.0	3119.0	
				7/07/75	39.0	3119.0	
				8/22/75	46.0	3112.0	
				9/05/75	44.0	3114.0	
02S/01E-33J01 S	33		2750.0	10/04/74	33.0	2717.0	4829
				11/01/74	32.0	2718.0	
				12/05/74	58.0	2692.0	
				1/03/75	36.0	2714.0	
				2/07/75	31.0	2719.0	
				3/14/75	29.0	2721.0	
				4/04/75	40.0	2710.0	
				5/01/75	43.0	2707.0	
				6/13/75	35.0	2715.0	
				7/07/75	45.0	2705.0	
				8/22/75	41.0	2709.0	
				9/05/75	38.0	2712.0	
02S/01E-33J02 S	33		2768.0	10/04/74	43.0	2725.0	4829
				11/01/74	42.0	2726.0	
				12/05/74	79.0	2689.0	
				1/03/75	46.0	2722.0	
				2/07/75	45.0	2723.0	
				3/14/75	37.0	2731.0	
				4/04/75	52.0	2716.0	
				5/01/75	55.0	2713.0	
				6/13/75	43.0	2725.0	
				7/07/75	55.0	2713.0	
				8/22/75	46.0	2722.0	
				9/05/75	44.0	2724.0	
02S/01E-33J03 S	33		2770.0	10/04/74	38.0	2732.0	4829

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
WHITEWATER HYDRO UNIT						X-19	
SAN GORGONIO HYDRO SUBUNIT						X-19.C	
SAN GORGONIO HYDRO SUBAREA						X-19.C2	
02S/01E-33J03 S (CONTINUED)	33		2770.0	11/01/74	36.0	2734.0	4829
				12/05/74	55.0	2715.0	
				1/03/75	41.0	2729.0	
				2/07/75	35.0	2735.0	
				3/14/75	31.0	2739.0	
				4/04/75	36.0	2734.0	
				5/01/75	41.0	2729.0	
				6/13/75	38.0	2732.0	
				7/07/75	40.0	2730.0	
				8/22/75	32.0	2738.0	
				9/05/75	32.0	2738.0	
03S/01E-07E01 S	33		2521.0	10/04/74	330.0	2191.0	4829
				11/01/74	300.0	2221.0	
				12/05/74	304.0	2217.0	
				1/03/75	305.0	2216.0	
				2/07/75	301.0	2220.0	
				3/14/75	301.0	2220.0	
				4/04/75	301.0	2220.0	
				5/01/75	301.0	2220.0	
				6/13/75	341.0	2180.0	
				7/07/75	305.0	2216.0	
				8/22/75	351.0	2170.0	
				9/05/75	357.0	2164.0	
03S/02E-23P01 S	33		1524.0	1/10/75	312.7	1211.3	5135
				5/23/75	313.2	1210.8	
				9/12/75	313.7	1210.3	
03S/03E-07M01 S	33		1472.0	1/10/75	320.2	1151.8	5135
				5/23/75	320.4	1151.6	
				9/12/75	320.8	1151.2	
03S/03E-08M01 S	33		1350.0	10/17/74	227.3(4)	1122.7	5103
				11/19/74	226.4	1123.6	
				12/10/74	NM-1		
				1/10/75	221.9	1128.1	5135
				4/15/75	221.9	1128.1	5103
				5/23/75	222.3	1127.7	5135
				6/04/75	NM-1		5103
				9/12/75	222.7	1127.3	5135
COACHELLA HYDRO SUBUNIT						X-19.D	
GARNET HILL HYDRO SUBAREA						X-19.D1	
02S/03E-09H01 S	33		2603.0	10/17/74	NM-9		5103
				4/09/75	69.3	2533.7	
02S/03E-09H02 S	33		2613.0	10/17/74	NM-9		5103
				4/09/75	174.0	2439.0	
02S/03E-09J01 S	33		2582.5	10/17/74	NM-9		5103
				4/09/75	73.0	2509.5	
03S/04E-13N01 S	33		713.0	1/09/75	230.1	482.9	5135
				5/13/75	228.2	484.8	
				9/12/75	228.4	484.6	
03S/04E-17K01 S	33		901.0	1/09/75	336.0	565.0	5135
				5/13/75	342.4	558.6	
				9/11/75	336.2	564.8	
03S/04E-22A01 S	33		711.0	1/09/75	164.2	546.8	5135
				5/13/75	164.0	547.0	
				9/11/75	163.8	547.2	
03S/04E-23D01 S	33		714.0	10/16/74	167.4(1)	546.6	5103
				11/19/74	NM-1		
				12/10/74	167.3(1)	546.7	
				4/15/75	167.3(1)	546.7	
				6/04/75	NM-8		
03S/05E-30G01 S	33		590.0	1/23/75	201.4	388.6	5135
				5/15/75	201.6	388.4	
				9/16/75	201.8	388.2	
MISSION CREEK HYDRO SUBAREA						X-19.D2	
02S/03E-25K01 S	33		2140.0	1/10/75	149.0	1991.0	5135
				5/23/75	160.3	1979.7	
				9/12/75	159.4	1980.6	
02S/04E-25N01 S	33		1099.0	10/17/74	347.2	751.8	5103
				1/09/75	348.3	750.7	5135
				4/15/75	346.3	752.7	5103
				5/13/75	349.6	749.4	5135
				9/11/75	350.8	748.2	
02S/04E-34A01 S	33		1180.0	1/09/75	417.1	762.9	5135
				5/23/75	416.0	764.0	
				9/11/75	416.5	763.5	
02S/04E-35D01 S	33		1044.0	1/09/75	293.7	750.3	5135
				5/13/75	293.8	750.2	
				9/11/75	294.5	749.5	
02S/05E-31L01 S	33		984.0	1/09/75	233.2	750.8	5135
				5/13/75	233.2	750.8	
				9/11/75	233.8	750.2	
03S/04E-02F01 S	33		1010.0	10/16/74	263.9	746.1	5103
				11/19/74	262.1	747.9	
WHITEWATER HYDRO UNIT						X-19	
COACHELLA HYDRO SUBUNIT						X-19.D	
MISSION CREEK HYDRO SUBAREA						X-19.D2	
03S/04E-02F01 S (CONTINUED)	33		1010.0	12/10/74	NM-8		5103
				4/15/75	262.8	747.2	
				6/04/75	263.0	747.0	
				7/08/75	263.1	746.9	
				8/13/75	NM-3		
				9/15/75	NM-8		
03S/04E-10J01 S	33		869.0	10/16/74	124.6	744.4	5103
				4/15/75	124.0	745.0	
03S/04E-11B02 S	33		912.0	10/16/74	NM-1		5103
				4/15/75	160.6	751.4	
03S/04E-12B01 S	33		885.0	10/15/74	133.9	751.1	5135
				3/06/75	134.2	750.8	
				5/29/75	138.4	746.6	
				6/30/75	134.6	750.4	
03S/04E-12C01 S	33		890.0	10/15/74	140.3	749.7	5135
				3/06/75	140.7	749.3	
				5/29/75	142.0	748.0	
				6/30/75	141.0	749.0	
03S/04E-12E02 S	33		857.0	10/15/74	112.1	744.9	5103
				11/19/74	114.0	743.0	
				12/10/74	114.3	742.7	
				4/15/75	114.3	742.7	
				6/04/75	114.6	742.4	
03S/04E-12H01 S	33		842.6	10/15/74	96.1	746.5	5135
				3/06/75	96.5	746.1	
03S/04E-13H01 S	33		769.0	10/16/74	42.7	726.3	5103
				4/14/75	43.0	726.0	
03S/05E-06P01 S	33		867.0	10/16/74	121.0	746.0	5103
				11/19/74	121.1	745.9	
				12/10/74	121.3	745.7	
				4/15/75	121.3	745.7	
				6/04/75	121.6	745.4	
03S/05E-08M02 S	33		820.0	10/17/74	75.6	744.4	5103
				11/19/74	75.8	744.2	
				12/10/74	75.6	744.4	
				4/14/75	78.8	741.2	
				6/04/75	77.5	742.5	
03S/05E-10L02 S	33		925.0	1/23/75	172.0	753.0	5135
				5/15/75	172.2	752.8	
				9/16/75	NM-2		
03S/05E-17G01 S	33		789.0	10/17/74	43.6	745.4	5103
				4/15/75	43.6	745.4	
03S/05E-17J01 S	33		787.0	10/15/74	43.3	743.7	5135
				3/06/75	43.5	743.5	
				6/30/75	43.8	743.2	
03S/05E-22G01 S	33		845.0	10/17/74	NM-9		5103
				4/15/75	103.9	741.1	
MIRACLE HILL HYDRO SUBAREA						X-19.D3	
02S/05E-30Q01 S	33		1095.8	10/16/74	107.8	988.0	5103
				4/15/75	112.8	983.0	
02S/05E-32E06 S	33		1167.0	1/09/75	56.1	1110.9	5135
				5/12/75	57.2	1109.8	
				9/11/75	57.2	1109.8	
02S/05E-33E05 S	33		1240.0	1/09/75	151.8	1088.2	5135
				5/12/75	142.2	1097.8	
				9/12/75	143.1	1096.9	
03S/05E-03L01 S	33		1165.0	1/23/75	221.0	944.0	5135
				5/14/75	220.9	944.1	
				9/16/75	220.8	944.2	
03S/05E-03R01 S	33		1055.0	1/23/75	50.5	1004.5	5135
				5/14/75	50.3	1004.7	
				9/16/75	50.4	1004.6	
03S/05E-04H01 S	33		1160.0	1/23/75	247.3	912.7	5135
				5/14/75	247.3	912.7	
				9/16/75	247.3	912.7	
03S/05E-04K01 S	33		1074.0	10/17/74	92.9	981.1	5103
				4/14/75	95.7	978.3	
03S/05E-09C01 S	33		1020.0	10/17/74	264.0(3)	756.0	5103
				4/14/75	NM-2		
03S/05E-10R01 S	33		960.0	1/23/75	69.2	890.8	5135
				5/14/75	69.0	891.0	
				9/16/75	73.0	887.0	
03S/05E-11J01 S	33		1101.0	10/17/74	NM-1		5103
				11/19/74	237.7	863.3	
				12/10/74	237.7	863.3	
				4/14/75	234.7	866.3	
				6/04/75	NM-1		
				7/08/75	NM-1		

See page 79 for key to terms & abbreviations

TABLE C-1
GROUND WATER LEVELS AT WELLS
SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
WHITEWATER HYDRO UNIT						X-19	
COACHELLA HYDRO SUBUNIT						X-19.D	
MIPACLE HILL HYDRO SUBAREA						X-19.D3	
03S/05E-11J01 S (CONTINUED)	33		1101.0	8/13/75	NM-1		5103
				9/16/75	NM-1		
03S/05E-11Q01 S	33		1075.0	1/22/75	193.1	881.9	5135
				5/14/75	193.2	881.8	
				9/16/75	193.8	881.2	
03S/05E-12P01 S	33		1165.0	1/22/75	306.7	858.3	5135
				5/14/75	306.8	858.2	
				9/16/75	306.8	858.2	
SKY VALLEY HYDRO SUBAREA						X-19.D4	
03S/06E-17E01 S	33		1265.0	1/22/75	474.4	790.6	5135
				5/15/75	488.6	776.4	
				9/17/75	474.6	790.4	
03S/06E-21F02 S	33		1070.0	1/22/75	297.9	772.1	5135
				5/15/75	297.5	772.5	
				9/17/75	297.4	772.6	
03S/06E-25Q01 S	33		955.0	1/22/75	232.8	722.2	5135
				5/15/75	232.8	722.2	
				9/18/75	232.8	722.2	
03S/06E-26P01 S	33		960.0	1/22/75	248.7	711.3	5135
				5/15/75	248.4	711.6	
				9/18/75	248.6	711.4	
03S/06E-28A01 S	33		996.0	10/16/74	NM-8		5103
			1000.0	1/22/75	248.3	751.7	5135
			996.0	4/14/75	248.3	747.7	5103
			1000.0	5/15/75	248.1	751.9	5135
				9/18/75	248.3	751.7	
03S/06E-36P01 S	33		772.0	1/22/75	82.0	690.0	5135
				5/15/75	81.2	690.8	
				9/18/75	82.1	689.9	
04S/06E-12C01 S	33		610.0	1/29/75	5.2	604.8	5135
				5/28/75	5.6	604.4	
				9/16/75	6.7	603.3	
04S/06E-12K01 S	33		525.0	1/24/75	3.0	522.0	5135
				5/28/75	5.5	519.5	
				9/16/75	5.5	519.5	
FARGO CANYON HYDRO SUBAREA						X-19.D5	
04S/07E-14E01 S	33		1100.0	1/22/75	372.9	727.1	5135
				5/29/75	373.7	726.3	
				9/18/75	373.2	726.8	
04S/08E-31P01 S	33		280.0	1/21/75	174.5	105.5	5135
				5/29/75	176.0	104.0	
				9/18/75	172.1	107.9	
THOUSAND PALMS HYDRO SUBAREA						X-19.D6	
04S/06E-08L01 S	33		365.0	1/24/75	NM-7		5135
				9/16/75	286.7	78.3	
04S/06E-17R01 S	33		215.0	10/11/74	132.6	82.4	5135
				3/04/75	132.6	82.4	
				6/27/75	136.1	78.9	
				8/09/75	137.2	77.8	
04S/06E-20A01 S	33		203.0	1/24/75	118.7	84.3	5135
				5/28/75	123.1	79.9	
				9/16/75	126.3	76.7	
04S/06E-22C01 S	33		217.0	10/11/74	151.4	65.6	5135
				3/04/75	151.1	65.9	
				6/27/75	155.3	61.7	
04S/06E-22C02 S	33		217.0	10/11/74	146.4	70.6	5135
				3/04/75	145.8	71.2	
				6/27/75	148.6	68.4	
04S/06E-22J01 S	33		230.0	1/24/75	154.4	75.6	5135
				5/28/75	154.6	75.4	
				9/16/75	155.1	74.9	
04S/06E-22K01 S	33		215.0	1/24/75	134.9	80.1	5135
				5/28/75	134.8	80.2	
				9/16/75	135.7	79.3	
04S/07E-30M01 S	33		150.0	1/21/75	115.6	34.4	5135
				6/02/75	118.2	31.8	
				9/18/75	120.9	29.1	
04S/07E-33N01 S	33		55.0	1/21/75	43.0	12.0	5135
				5/29/75	45.9	9.1	
				9/18/75	48.9	6.1	
05S/07E-04A01 S	33		47.0	2/14/75	39.9	7.1	5135
				6/04/75	43.7	3.3	
				9/23/75	46.0	1.0	
05S/07E-04D01 S	33		58.0	10/04/74	55.3	2.7	5135
				2/27/75	49.2	8.8	
				6/13/75	55.1	2.9	
WHITEWATER HYDRO UNIT						X-19	
COACHELLA HYDRO SUBUNIT						X-19.D	
INDIO HYDRO SUBAREA						X-19.D7	
03S/03E-10P01 S	33		1170.0	10/07/74	525.0	645.0	5135
				11/08/74	525.0	645.0	
				12/06/74	525.5	644.5	
				1/03/75	525.5	644.5	
				2/06/75	524.0	646.0	
				3/07/75	523.0	647.0	
				4/11/75	525.0	645.0	
				5/09/75	522.0	648.0	
				6/06/75	524.5	645.5	
				7/18/75	525.0	645.0	
				8/15/75	523.0	647.0	
				9/05/75	524.0	646.0	
03S/04E-20N01 S	33		910.0	10/07/74	535.9	374.1	5135
				11/08/74	536.3	373.7	
				12/06/74	537.5	372.5	
				1/03/75	538.3	371.7	
				2/06/75	537.7	372.3	
				3/07/75	534.9	375.1	
				4/11/75	530.2	379.8	
				5/09/75	528.3	381.7	
				6/06/75	526.2	383.8	
				7/18/75	526.4	383.6	
				8/15/75	526.7	383.3	
				9/05/75	527.4	382.6	
03S/04E-23H01 S	33		649.0	1/09/75	240.3	408.7	5135
				5/13/75	240.7	408.3	
				9/12/75	240.7	408.3	
03S/04E-29F01 S	33		863.0	10/07/74	503.4	359.6	5135
				11/08/74	503.8	359.2	
				12/06/74	504.0	359.0	
				1/03/75	505.2	357.8	
				2/06/75	505.2	357.8	
				3/07/75	503.4	359.6	
				4/11/75	499.8	363.2	
				5/09/75	497.9	365.1	
				6/06/75	NM-9		
				7/23/75	496.3	366.7	
				8/15/75	496.3	366.7	
				9/05/75	496.3	366.7	
03S/04E-29R01 S	33		780.0	10/07/74	497.6	282.4	5135
				11/08/74	497.5	282.5	
				12/06/74	498.2	281.8	
				1/03/75	499.4	280.6	
				2/06/75	498.9	281.1	
				3/07/75	499.0	281.0	
				4/11/75	498.2	281.8	
				5/09/75	498.5	281.5	
				6/06/75	NM-9		
				7/23/75	498.5	281.5	
				8/15/75	498.9	281.1	
				9/05/75	498.2	281.8	
03S/04E-30C01 S	33		944.0	1/06/75	559.0	385.0	5135
				6/13/75	560.0	384.0	
				8/08/75	558.0	386.0	
03S/04E-36H01 S	33		545.8	1/06/75	352.0	193.8	5135
				4/09/75	353.0	192.8	
				8/07/75	354.0	191.8	
04S/04E-01B03 S	33		510.0	10/21/74	322.2	187.8	5135
				1/24/75	322.8	187.2	
				5/22/75	324.5	185.5	
				9/19/75	324.8	185.2	
04S/04E-01N02 S	33		500.0	1/06/75	317.8	182.2	5135
				5/08/75	317.0	183.0	
				8/08/75	318.0	182.0	
04S/04E-11K01 S	33		492.9	1/14/75	306.0	186.9	5135
				5/08/75	307.0	185.9	
				8/08/75	308.0	184.9	
04S/04E-11Q01 S	33		470.0	1/14/75	280.0	190.0	5135
				5/09/75	302.0	168.0	
				8/07/75	302.0	168.0	
04S/04E-11R01 S	33		458.0	1/13/75	280.8	177.2	5135
				5/08/75	283.0	175.0	
				8/06/75	283.0	175.0	
04S/04E-13H01 S	33		418.0	1/23/75	249.2	168.8	5135
				5/22/75	248.6	169.4	
				9/19/75	250.7	167.3	
04S/04E-13P01 S	33		141.0	1/24/75	241.8	-100.8	5135
				5/23/75	242.2	-101.2	
				9/19/75	244.8	-103.8	
04S/04E-14R01 S	33		410.0	2/10/75	244.0	166.0	5135
				5/07/75	245.0	165.0	
				8/06/75	245.0	165.0	
04S/04E-15J01 S	33		453.0	1/24/75	270.8	182.2	5135
				5/22/75	280.8	172.2	
				6/06/75	273.7	179.3	
				9/19/75	276.5	176.5	
04S/04E-23E01 S	33		438.0	1/14/75	266.0	172.0	5135

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
WHITEWATER HYDRO UNIT, COACHELLA HYDRO SUBUNIT, INDIO HYDRO SUBAREA						X-19, X-19.D, X-19.D7	
04S/04E-23E01 S (CONTINUED)	33		438.0	5/07/75	265.0	173.0	5135
				8/06/75	285.0	153.0	
04S/04E-26A01 S	33		428.0	1/09/75	292.0	136.0	5135
				4/14/75	263.0	165.0	
				8/11/75	289.0	139.0	
04S/04E-35K01 S	33		528.0	1/24/75	357.7	170.3	5135
				5/23/75	357.9	170.1	
				9/19/75	363.0	165.0	
04S/05E-03P01 S	33		380.0	2/03/75	221.0	159.0	5135
				5/27/75	222.2	157.8	
				9/29/75	223.8	156.2	
04S/05E-04F01 S	33		430.0	1/30/75	265.0	165.0	5135
				5/22/75	263.5	166.5	
				9/17/75	264.5	165.5	
04S/05E-05K01 S	33		446.0	10/11/74	272.9	173.1	5135
				3/04/75	273.4	172.6	
				4/29/75	274.1	171.9	
				6/26/75	274.9	171.1	
04S/05E-09B01 S	33		405.0	10/11/74	235.7	169.3	5135
				3/06/75	236.3	168.7	
				4/29/75	235.9	169.1	
				6/26/75	237.8	167.2	
04S/05E-09F01 S	33		397.0	10/11/74	238.6	158.4	5135
				3/04/75	239.4	157.6	
				6/26/75	240.7	156.3	
04S/05E-11F01 S	33		327.0	2/03/75	181.4	145.6	5135
				6/02/75	182.3	144.7	
				9/29/75	183.8	143.2	
04S/05E-15P02 S	33		346.0	5/22/75	213.4	132.6	5135
04S/05E-16N01 S	33		360.0	10/11/74	217.1	142.9	5135
				3/04/75	217.6	142.4	
				6/26/75	219.1	140.9	
04S/05E-16N02 S	33		360.0	10/11/74	217.1	142.9	5135
04S/05E-17L01 S	33		375.0	10/07/74	216.3	158.7	5135
				11/08/74	216.6	158.4	
				12/06/74	217.2	157.8	
				1/03/75	217.5	157.5	
				2/06/75	217.7	157.3	
				3/07/75	218.0	157.0	
				4/11/75	218.0	157.0	
				5/08/75	218.3	156.7	5050
				6/06/75	218.6	156.4	5135
				7/18/75	218.8	156.2	
				8/04/75	218.5	156.5	5050
				9/05/75	219.5	155.5	5135
04S/05E-19D01 S	33		393.0	1/13/75	225.0	168.0	5135
				5/09/75	226.0	167.0	
				8/07/75	227.0	166.0	
04S/05E-21A01 S	33		357.0	10/10/74	220.0	137.0	5135
				3/04/75	220.7	136.3	
				6/26/75	222.0	135.0	
04S/05E-21H01 S	33		356.0	10/10/74	219.2	136.8	5135
				3/04/75	220.7	135.3	
				6/26/75	221.2	134.8	
04S/05E-21J02 S	33		348.0	10/11/74	209.6	138.4	5135
				3/04/75	209.9	138.1	
				6/10/75	209.9	138.1	
04S/05E-22A01 S	33		347.0	1/29/75	214.7	132.3	5135
				5/22/75	215.7	131.3	
				9/17/75	217.0	130.0	
04S/05E-27E01 S	33		313.0	10/10/74	184.1	128.9	5135
				3/04/75	184.5	128.5	
				6/11/75	185.5	127.5	
04S/05E-27H01 S	33		296.0	1/29/75	175.1	120.9	5135
				5/20/75	175.7	120.3	
				9/16/75	177.2	118.8	
04S/05E-28F02 S	33		310.0	10/11/74	183.7	126.3	5135
				3/04/75	183.2	126.8	
				6/26/75	185.6	124.4	
				7/14/75	186.7	123.3	
04S/05E-29A01 S	33		332.0	1/29/75	189.4	142.6	5135
				5/20/75	NM-6		
04S/05E-29F01 S	33		329.0	1/29/75	184.3	144.7	5135
				5/20/75	184.8	144.2	
				9/17/75	186.3	142.7	
04S/05E-29K01 S	33		325.0	5/20/75	183.4	141.6	5135
04S/05E-29P01 S	33		312.0	1/29/75	174.9	137.1	5135
				5/20/75	NM-6		
WHITEWATER HYDRO UNIT, COACHELLA HYDRO SUBUNIT, INDIO HYDRO SUBAREA						X-19, X-19.D, X-19.D7	
04S/05E-30G01 S	33		357.0	1/29/75	202.5	154.5	5135
				5/20/75	203.0	154.0	
				9/17/75	205.3	151.7	
04S/05E-33P01 S	33		302.0	1/13/75	168.8	133.2	5135
				5/08/75	171.0	131.0	
				8/13/75	179.0	123.0	
04S/05E-35G02 S	33		268.0	1/29/75	161.9	106.2	5135
				5/23/75	162.5	105.5	
				9/17/75	164.3	103.7	
04S/05E-35G03 S	33		262.0	10/10/74	167.9	94.1	5135
				3/04/75	167.4	94.6	
				6/24/75	169.4	92.6	
04S/05E-35G04 S	33		262.0	10/10/74	168.4	93.6	5135
				3/04/75	168.1	93.9	
				6/18/75	172.7	89.3	
04S/05E-36D01 S	33		320.0	1/29/75	221.0	99.0	5135
				5/20/75	221.7	98.3	
				9/17/75	222.3	97.7	
04S/05E-36H01 S	33		257.0	10/10/74	158.9	98.1	5135
				3/04/75	157.7	99.3	
				6/11/75	167.9	89.1	
04S/06E-18P01 S	33		232.0	10/11/74	131.4	100.6	5135
				11/26/74	130.4	101.6	
				3/04/75	131.8	100.2	
				6/27/75	134.0	98.0	
04S/06E-18Q02 S	33		242.0	10/11/74	144.2	97.8	5135
				3/04/75	144.5	97.5	
				6/27/75	145.7	96.3	
				8/04/75	146.8	95.2	
04S/06E-18R01 S	33		240.0	10/11/74	148.6	91.4	5135
				3/04/75	148.6	91.4	
				6/27/75	151.1	88.9	
				8/09/75	152.6	87.4	
04S/06E-19J02 S	33		218.0	1/24/75	115.3	102.7	5135
				5/28/75	119.8	98.2	
				9/16/75	121.3	96.7	
04S/06E-20H01 S	33		205.0	10/11/74	119.2	85.8	5135
				3/04/75	118.9	86.1	
				6/30/75	122.8	82.2	
04S/06E-27N01 S	33		165.0	1/24/75	109.0	56.0	5135
				6/02/75	NM-8		
				9/16/75	120.9	44.1	
04S/06E-28A02 S	33		175.0	1/29/75	108.3	66.7	5135
				6/02/75	113.3	61.7	
				9/24/75	NM-3		
04S/06E-28J02 S	33		166.0	1/24/75	102.2	63.8	5135
				6/02/75	108.0	58.0	
				9/16/75	111.0	55.0	
04S/06E-29A01 S	33		179.0	1/24/75	100.0	79.0	5135
				6/02/75	105.0	74.0	
				9/16/75	108.4	70.6	
04S/06E-34D01 S	33		160.0	6/02/75	108.1	51.9	5135
04S/06E-34F01 S	33		161.0	6/02/75	75.5	85.5	5135
04S/06E-34G01 S	33		168.0	1/24/75	75.9	92.1	5135
				6/02/75	77.4	90.6	
				9/16/75	77.4	90.6	
04S/07E-31D03 S	33		69.4	1/21/75	78.6	-9.2	5135
				5/29/75	81.4	-12.0	
				9/18/75	84.9	-15.5	
04S/07E-32N01 S	33		73.3	10/15/74	62.5	10.8	5135
				3/05/75	61.8	11.5	
				6/11/75	66.5	6.8	
				8/04/75	68.9	4.4	
04S/07E-32N02 S	33		73.3	10/15/74	62.5	10.9	5135
05S/04E-02G01 S	33		581.0	1/31/75	339.6	241.4	5135
				5/23/75	351.5	229.5	
				9/19/75	352.0	229.0	
05S/05E-01C01 S	33		244.0	1/30/75	156.2	87.8	5135
				5/21/75	157.7	86.3	
				9/19/75	161.2	82.8	
05S/05E-01D02 S	33		250.8	1/30/75	157.3	93.5	5135
				5/21/75	NM-8		
				9/22/75	160.0	90.8	
05S/05E-01F02 S	33		248.0	1/30/75	157.6	90.4	5135
				5/21/75	NM-3		
				9/18/75	159.8	88.2	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

WHITEWATER HYDRO UNIT
COACHELLA HYDRO SUBUNIT
INDIO HYDRO SUBAREA

X-19
X-19.0
X-19.07

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
05S/05E-01L05 S	33		242.0	3/05/75	154.7	87.3	5135
				6/20/75	159.5	82.5	
05S/05E-01M03 S	33		246.2	1/30/75	158.0	88.2	5135
				5/21/75	159.9	86.3	
				9/18/75	161.5	84.7	
05S/05E-01P01 S	33		240.0	10/10/74	155.5	84.5	5135
				3/05/75	155.6	84.4	
				6/20/75	156.5	83.5	
05S/05E-01D01 S	33		239.0	1/30/75	152.9	86.1	5135
				5/21/75	153.4	85.6	
				9/18/75	154.9	84.1	
05S/05E-02F02 S	33		252.0	10/10/74	159.1	92.9	5135
				3/05/75	158.2	93.8	
				6/10/75	161.3	90.7	
05S/05E-02L01 S	33		252.0	1/31/75	159.3	92.7	5135
				5/22/75	160.9	91.1	
				9/19/75	162.7	89.3	
05S/05E-02Q01 S	33		239.0	1/30/75	156.5	82.5	5135
				5/21/75	158.0	81.0	
				9/19/75	159.9	79.1	
05S/05E-03A01 S	33		260.0	1/31/75	162.3	97.7	5135
				5/21/75	163.5	96.5	
				9/19/75	165.5	94.5	
05S/05E-11A01 S	33		234.0	10/10/74	155.9	78.1	5135
				3/05/75	153.9	80.1	
				6/20/75	157.0	77.0	
05S/05E-12C01 S	33		261.0	1/30/75	153.4	107.6	5135
				6/20/75	159.5	101.5	
05S/05E-12C02 S	33		230.0	1/31/75	150.0	80.0	5135
				5/21/75	152.1	77.9	
				9/22/75	154.0	76.0	
05S/05E-12D01 S	33		239.0	1/30/75	153.7	85.3	5135
				5/21/75	156.4	82.6	
				9/19/75	158.2	80.8	
05S/05E-12H01 S	33		222.0	1/31/75	144.3	77.7	5135
				5/21/75	143.8	78.2	
				9/19/75	145.1	76.9	
05S/05E-12H02 S	33		220.0	10/10/74	149.7	70.3	5135
				3/05/75	149.8	70.2	
				6/20/75	152.9	67.1	
05S/05E-12J01 S	33		220.0	10/10/74	153.9	66.1	5135
				6/24/75	157.6	62.4	
05S/05E-12L02 S	33		240.0	10/10/74	159.0	81.0	5135
				3/05/75	157.5	82.5	
				5/14/75	158.8	81.2	
				6/20/75	161.2	78.8	
05S/05E-12Q01 S	33		235.0	10/10/74	156.2	78.8	5135
				3/05/75	154.8	80.2	
				6/20/75	158.5	76.5	
				7/01/75	158.8	76.2	
05S/06E-02A01 S	33		140.0	10/04/74	98.2	41.8	5135
				2/27/75	98.0	42.0	
				6/13/75	97.5	42.5	
05S/06E-05C01 S	33		245.0	10/10/74	182.7	62.3	5135
				3/03/75	181.7	63.3	
				6/17/75	184.0	61.0	
05S/06E-06D01 S	33		220.3	10/09/74	151.1	69.2	5135
				3/03/75	149.6	70.7	
				6/17/75	153.2	67.1	
05S/06E-07J01 S	33		210.0	2/04/75	138.6	71.4	5135
				6/04/75	141.2	68.8	
				9/29/75	143.1	66.9	
05S/06E-07Q02 S	33		206.0	10/10/74	140.2	65.8	5135
				2/28/75	139.5	66.5	
				6/18/75	142.4	63.6	
				7/01/75	142.9	63.1	
05S/06E-07Q03 S	33		210.0	10/09/74	142.1	67.9	5135
				2/28/75	141.0	69.0	
				6/18/75	144.0	66.0	
				7/01/75	144.8	65.2	
05S/06E-08L02 S	33		204.5	2/04/75	135.2	69.3	5135
				6/03/75	135.8	68.7	
				9/22/75	137.5	67.0	
05S/06E-13C01 S	33		178.0	10/08/74	149.1	28.9	5135
				2/25/75	147.1	30.9	
				6/11/75	152.9	25.1	
05S/06E-13D01 S	33		178.0	10/08/74	149.1	28.9	5135

WHITEWATER HYDRO UNIT
COACHELLA HYDRO SUBUNIT
INDIO HYDRO SUBAREA

X-19
X-19.0
X-19.07

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
05S/06E-13K01 S	33		160.0	10/08/74	135.1	24.9	5135
05S/06E-14Q01 S	33		165.0	10/08/74	132.0	33.0	5135
				2/25/75	129.5	35.5	
				6/11/75	131.3	33.7	
05S/06E-16A01 S	33		181.0	10/09/74	134.5	46.5	5135
				2/28/75	133.3	47.7	
				6/12/75	135.3	45.7	
				8/22/75	136.4	44.6	
05S/06E-16H01 S	33		160.0	10/09/74	110.7	49.3	5135
				2/28/75	109.1	50.9	
				6/12/75	111.5	48.5	
				7/25/75	115.0	45.0	
05S/06E-16M01 S	33		179.0	2/05/75	126.9	52.1	5135
				6/03/75	129.1	49.9	
				9/22/75	131.1	47.9	
05S/06E-18L02 S	33		198.0	10/08/74	146.8	51.2	5135
				2/28/75	145.6	52.4	
				5/14/75	148.0	50.0	
				6/17/75	149.8	48.2	
05S/06E-18P01 S	33		193.0	10/07/74	142.0	51.0	5135
				2/28/75	141.5	51.5	
				6/16/75	142.8	50.2	
05S/06E-18R02 S	33		193.0	10/07/74	143.0	50.0	5135
				2/28/75	142.3	50.7	
				5/14/75	142.5	50.5	
				6/16/75	143.5	49.5	
05S/06E-20P01 S	33		267.0	10/04/74	218.0	49.0	5135
				2/21/75	215.4	51.6	
				5/29/75	215.8	51.2	
				6/17/75	217.8	49.2	
05S/06E-21N02 S	33		248.0	10/09/74	199.0	49.0	5135
				2/21/75	195.2	52.8	
				6/16/75	203.3	44.7	
				8/22/75	199.0	49.0	
05S/06E-22A01 S	33		160.0	2/05/75	119.3	40.7	5135
				6/03/75	121.8	38.2	
				9/23/75	122.7	37.3	
05S/06E-22N01 S	33		211.0	10/09/74	162.9	48.1	5135
				2/28/75	160.7	50.3	
				6/12/75	162.4	48.6	
05S/06E-22P01 S	33		198.0	10/09/74	150.9	47.1	5135
				2/28/75	148.6	49.4	
				6/12/75	151.2	46.8	
				8/22/75	152.3	45.7	
05S/06E-22P02 S	33		205.0	10/09/74	151.4	53.6	5135
				2/28/75	149.9	55.1	
				6/12/75	151.9	53.1	
				8/29/75	152.7	52.3	
05S/06E-22Q01 S	33		175.0	2/05/75	144.6	30.4	5135
				6/03/75	NM-3		
				9/23/75	NM-3		
05S/06E-23L03 S	33		144.0	2/05/75	98.9	45.1	5135
				6/03/75	99.8	44.2	
				9/22/75	105.5	38.5	
05S/06E-23M01 S	33		160.0	10/08/74	113.3	46.7	5135
				2/28/75	110.4	49.6	
				6/12/75	115.6	44.4	
				7/29/75	113.9	46.1	
05S/06E-24G01 S	33		108.0	10/08/74	99.8	8.2	5135
				2/25/75	98.1	9.9	
				6/12/75	101.6	6.4	
				7/15/75	102.9	5.1	
05S/06E-25A01 S	33		85.0	2/05/75	78.3	6.7	5135
				6/03/75	80.9	4.1	
				9/23/75	82.0	3.0	
05S/06E-27B01 S	33		180.0	10/09/74	134.7	45.3	5135
				2/28/75	134.5	45.5	
				6/12/75	135.5	44.5	
05S/06E-27C01 S	33		204.0	10/09/74	148.7	55.3	5135
				2/28/75	146.3	57.7	
				6/12/75	147.8	56.2	
				8/22/75	149.6	54.4	
05S/06E-27C02 S	33		211.0	10/09/74	160.0	51.0	5135
				2/28/75	158.4	52.6	
				6/12/75	159.6	51.4	
				8/22/75	160.8	50.2	
05S/06E-28C02 S	33		262.0	10/09/74	210.7	51.3	5135
				2/25/75	207.4	54.6	
				3/24/75	208.2	53.8	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

WHITEWATER HYDRO UNIT
COACHELLA HYDRO SUBUNIT
INDIO HYDRO SUBAREA

X-19
X-19.D
X-19.D7

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
05S/06E-28C02 S	33		262.0	6/16/75	210.4	51.6	5135
05S/06E-28E01 S	33		332.0	2/05/75	273.3	58.7	5135
				6/03/75	275.3	56.7	
				9/22/75	277.8	54.2	
05S/06E-29B01 S	33		310.0	2/04/75	255.2	54.8	5135
				6/03/75	257.0	53.0	
				9/22/75	260.2	49.8	
05S/06E-29C01 S	33		337.0	10/04/74	290.8	46.2	5135
				2/21/75	289.0	48.0	
				6/16/75	290.5	46.5	
05S/06E-29C02 S	33		340.0	10/04/74	293.6	46.4	5135
				2/21/75	291.2	48.8	
				6/16/75	293.6	46.4	
				7/30/75	296.3	43.7	
05S/06E-29M01 S	33		405.0	10/04/74	356.0	49.0	5135
				2/21/75	353.5	51.5	
				5/29/75	355.8	49.2	
				6/16/75	356.4	48.6	
05S/06E-29P01 S	33		454.7	10/04/74	412.5	42.2	5135
				2/21/75	409.5	45.2	
				6/16/75	411.9	42.8	
05S/06E-29R01 S	33		395.0	10/09/74	352.9	42.1	5135
				2/28/75	NM-9		
05S/06E-32G01 S	33		455.0	2/05/75	403.1	51.9	5135
				6/03/75	404.0	51.0	
				9/22/75	408.3	46.7	
05S/07E-04M01 S	33		50.0	6/05/75	50.7	-0.7	5135
05S/07E-05K01 S	33		60.0	2/14/75	58.6	1.4	5135
				6/05/75	61.6	-1.6	
				9/23/75	64.1	-4.1	
05S/07E-06B01 S	33		92.9	6/04/75	76.2	16.7	5135
05S/07E-06H01 S	33		83.0	2/14/75	67.9	15.1	5135
				6/04/75	74.1	8.9	
				9/26/75	80.6	2.4	
05S/07E-06M01 S	33		102.0	10/04/74	84.6	17.4	5135
				2/27/75	82.8	19.2	
				6/11/75	85.8	16.2	
05S/07E-07F01 S	33		103.0	6/10/75	84.8	18.2	5135
05S/07E-07J01 S	33		100.0	2/06/75	107.4	-7.4	5135
				6/10/75	109.8	-9.8	
				9/26/75	111.1	-11.1	
05S/07E-07P01 S	33		97.0	10/04/74	90.3	6.7	5135
				2/27/75	88.8	8.2	
				6/09/75	90.4	6.6	
				8/04/75	91.3	5.7	
05S/07E-08G01 S	33		90.0	2/14/75	83.0	7.0	5135
				6/05/75	NM-4		
				9/24/75	NM-4		
05S/07E-08Q01 S	33		50.0	10/01/74	60.8	-10.8	5135
				2/04/75	55.0	-5.0	
				6/05/75	61.0	-11.0	
				9/23/75	61.2	-11.2	
05S/07E-09F01 S	33		44.0	2/14/75	41.7	2.3	5135
				6/04/75	44.9	-0.9	
				9/26/75	53.6	-9.6	
05S/07E-10F01 S	33		28.0	2/14/75	33.9	-5.9	5135
				6/04/75	37.4	-9.4	
				9/26/75	44.6	-16.6	
05S/07E-11C01 S	33		29.0	2/14/75	41.0	-12.0	5135
				6/10/75	46.4	-17.4	
				9/23/75	44.6	-15.6	
05S/07E-12P01 S	33		3.0	2/18/75	31.3	-28.3	5135
				6/10/75	30.0	-27.0	
				9/25/75	37.3	-34.3	
05S/07E-13D01 S	33		11.0	2/18/75	15.8	-4.8	5135
				6/04/75	11.9	-0.9	
				9/25/75	11.6	-0.6	
05S/07E-14J02 S	33		-12.0	2/14/75	15.9	-27.9	5135
				6/10/75	22.8	-34.8	
				9/25/75	19.8	-31.8	
05S/07E-14K01 S	33		5.0	2/14/75	20.7	-15.7	5135
				6/10/75	27.2	-22.2	
				9/25/75	24.5	-19.5	
05S/07E-15D01 S	33		5.5	2/14/75	26.9	-21.4	5135
				6/10/75	30.6	-25.1	
				9/25/75	29.7	-24.2	

WHITEWATER HYDRO UNIT
COACHELLA HYDRO SUBUNIT
INDIO HYDRO SUBAREA

X-19
X-19.D
X-19.D7

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
05S/07E-16C01 S	33		30.0	2/14/75	44.2	-14.2	5135
				6/09/75	46.7	-16.7	
				9/24/75	NM-8		
05S/07E-16K02 S	33		33.0	10/04/74	41.7	-8.7	5135
				2/27/75	40.3	-7.3	
				6/09/75	41.5	-8.5	
				8/09/75	44.0	-11.0	
05S/07E-18D01 S	33		125.0	2/14/75	114.5	10.5	5135
				6/05/75	115.8	9.2	
				9/25/75	117.0	8.0	
05S/07E-18M02 S	33		120.0	10/03/74	119.3	0.7	5135
				2/27/75	117.8	2.2	
				6/12/75	118.7	1.3	
05S/07E-21F02 S	33		40.0	2/14/75	44.0	-4.0	5135
				6/09/75	47.6	-7.6	
				9/24/75	49.0	-9.0	
05S/07E-22H02 S	33		5.0	6/10/75	48.0	-43.0	5135
05S/07E-27B01 S	33		16.5	6/06/75	42.7	-26.2	5135
05S/07E-27B02 S	33		13.5	2/14/75	36.2	-22.7	5135
				6/06/75	38.0	-24.5	
				9/24/75	38.3	-24.8	
05S/07E-27L01 S	33		20.0	2/14/75	50.0	-30.0	5135
				6/09/75	58.4	-38.4	
				9/24/75	58.7	-38.7	
05S/07E-28E01 S	33		43.0	10/03/74	63.3	-20.3	5135
				2/27/75	61.5	-18.5	
				6/09/75	63.0	-20.0	
05S/07E-30C02 S	33		75.0	2/14/75	80.3	-5.3	5135
				6/06/75	NM-8		
				9/25/75	84.5	-9.5	
05S/07E-30F01 S	33		74.0	10/03/74	80.2	-4.2	5135
				2/27/75	77.2	-1.2	
				6/13/75	78.6	-2.6	
05S/07E-30F02 S	33		76.0	10/03/74	80.5	-4.5	5135
				2/27/75	77.3	-1.3	
				6/13/75	78.8	-2.8	
05S/07E-33D02 S	33		43.0	2/14/75	65.0	-22.0	5135
				6/04/75	72.0	-29.0	
				9/24/75	72.2	-29.2	
05S/07E-33F02 S	33		40.5	6/05/75	66.7	-26.2	5135
05S/07E-33M01 S	33		40.0	2/14/75	64.8	-24.8	5135
				6/05/75	71.7	-31.7	
				9/24/75	73.0	-33.0	
05S/07E-36D01 S	33		-21.8	2/14/75	18.9	-39.9	5135
				6/05/75	22.6	-43.6	
				9/25/75	22.2	-43.2	
05S/07E-36G01 S	33		-32.0	2/14/75	12.7	-44.7	5135
				6/05/75	13.8	-45.8	
				9/25/75	13.9	-45.9	
05S/07E-36Q01 S	33		-34.0	2/18/75	12.1	-46.1	5135
				6/05/75	12.9	-46.9	
				9/25/75	13.5	-47.5	
05S/08E-17N01 S	33		30.0	2/06/75	67.1	-37.1	5135
				6/04/75	71.3	-41.3	
				9/25/75	73.0	-43.0	
05S/08E-19H02 S	33			2/05/75	65.0	-65.0	5135
				6/05/75	63.4	-63.4	
				9/25/75	66.0	-66.0	
05S/08E-20C02 S	33		20.0	2/06/75	67.9	-47.9	5135
				6/04/75	74.2	-54.2	
				9/25/75	75.5	-55.5	
05S/08E-20M01 S	33			2/05/75	47.1	-47.1	5135
				6/04/75	60.1	-60.1	
				9/25/75	60.1	-60.1	
05S/08E-28M01 S	33		25.0	2/05/75	46.3	-21.3	5135
				6/04/75	58.6	-33.6	
				9/25/75	55.7	-30.7	
05S/08E-28M02 S	33		40.0	6/04/75	20.5	19.5	5135
05S/08E-29G01 S	33		28.0	2/05/75	25.7	2.3	5135
				6/05/75	28.2	-0.2	
				9/25/75	27.4	0.6	
05S/08E-29P01 S	33		50.0	6/04/75	24.5	25.5	5135
05S/08E-31J01 S	33		-52.0	2/05/75	8.9	-60.9	5135
				9/25/75	10.4	-62.4	

See page 79 for key to terms & abbreviations.

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
WHITEWATER HYDRO UNIT COACHELLA HYDRO SUBUNIT INDIO HYDRO SUBAREA						X-19 X-19.D X-19.D7	
05S/08E-33D01 S	33		60.0	2/05/75	6.3	53.7	5135
				6/04/75	8.5	51.5	
				9/25/75	7.8	52.2	
05S/08E-34G01 S	33		25.0	2/05/75	124.0	-99.0	5135
				6/05/75	141.2	-116.2	
				9/25/75	109.0	-84.0	
06S/06E-01G01 S	33		50.0	2/19/75	76.5	-26.5	5135
				6/03/75	76.5	-26.5	
				9/29/75	79.3	-29.3	
06S/06E-01N01 S	33		55.0	2/19/75	82.0	-27.0	5135
				6/03/75	82.0	-27.0	
				9/29/75	83.6	-28.6	
06S/06E-12G01 S	33		90.0	2/21/75	121.0	-31.0	5135
				6/03/75	121.0	-31.0	
				9/29/75	122.5	-32.5	
06S/06E-17K01 S	33		975.0	2/25/75	227.5	747.5	5135
				6/05/75	216.3	758.7	
				9/26/75	219.7	755.3	
06S/07E-01H01 S	33		-45.5	2/20/75	15.5	-61.0	5135
				6/03/75	26.0	-71.5	
06S/07E-01P01 S	33		-50.0	2/20/75	6.8	-56.8	5135
				6/03/75	7.6	-57.6	
06S/07E-02G01 S	33		-11.2	2/19/75	22.5	-33.7	5135
				6/03/75	23.0	-34.2	
06S/07E-04D02 S	33		32.0	2/19/75	61.0	-29.0	5135
				6/03/75	69.4	-37.4	
06S/07E-05R01 S	33		45.0	2/19/75	73.3	-28.3	5135
				6/05/75	87.3	-42.3	
				9/29/75	77.2	-32.2	
06S/07E-07R01 S	33		50.0	2/19/75	72.0	-22.0	5135
				5/29/75	72.1	-22.1	
				9/29/75	73.7	-23.7	
06S/07E-08R02 S	33		31.0	2/19/75	55.5	-24.5	5135
				5/29/75	57.2	-26.2	
				9/29/75	57.2	-26.2	
06S/07E-09L02 S	33		9.5	2/19/75	33.6	-24.1	5135
				5/29/75	33.7	-24.2	
				9/29/75	31.5	-22.0	
06S/07E-10G01 S	33		-15.0	2/19/75	15.4	-30.4	5135
				5/29/75	14.6	-29.6	
				9/29/75	12.9	-27.9	
06S/07E-12E01 S	33		-45.0	2/19/75	8.3	-53.3	5135
				5/29/75	8.9	-53.9	
06S/07E-13H02 S	33		-56.0	10/03/74	9.4	-65.4	5135
06S/07E-17P01 S	33		-5.0	2/19/75	48.9	-53.9	5135
				5/29/75	50.1	-55.1	
				9/29/75	50.8	-55.8	
06S/07E-22R01 S	33		-42.0	2/20/75	10.8	-52.8	5135
				5/29/75	10.9	-52.9	
				9/29/75	13.0	-55.0	
06S/07E-23D03 S	33		-52.0	2/20/75	17.0	-69.0	5135
				5/29/75	22.0	-74.0	
				9/29/75	21.5	-73.5	
06S/07E-23F01 S	33		-55.0	2/20/75	15.4	-70.4	5135
				5/29/75	20.1	-75.1	
				9/29/75	19.6	-74.6	
06S/08E-02D01 S	33		9.0	2/07/75	89.4	-80.4	5135
				5/21/75	97.2	-88.2	
				9/25/75	88.1	-79.1	
06S/08E-02F01 S	33		11.0	5/21/75	114.8	-103.8	5135
06S/08E-03C01 S	33		-69.5	2/07/75	5.3	-74.8	5135
				5/21/75	13.0	-82.5	
				9/25/75	10.6	-80.1	
06S/08E-05P01 S	33		-75.0	2/07/75	6.4	-81.4	5135
				5/21/75	7.6	-82.6	
				9/25/75	8.8	-83.8	
06S/08E-05P01 S	33		-80.5	10/03/74	6.5	-87.0	5135
				6/13/75	9.7	-90.2	
				7/26/75	8.8	-89.3	
06S/08E-05P02 S	33		-82.2	10/03/74	6.3	-88.5	5135
				2/27/75	0.4	-82.6	
				6/13/75	9.3	-91.5	
				7/26/75	8.1	-90.3	
06S/08E-06G03 S	33		-62.5	2/07/75	7.8	-70.3	5135
06S/08E-06G03 S (CONTINUED)	33		-62.5	5/21/75	9.2	-71.7	5135
				9/25/75	9.7	-72.2	
06S/08E-09K02 S	33		-98.0	2/07/75	-7.6	-90.4	5135
				5/21/75	1.0	-99.0	
				9/00/75	-3.3	-94.7	
06S/08E-09N04 S	33		-102.0	2/07/75	-9.3	-92.7	5135
				5/21/75	-1.1	-100.9	
				9/25/75	-4.1	-97.9	
06S/08E-10F01 S	33		-99.0	2/07/75	-7.5	-91.5	5135
				5/21/75	0.1	-99.1	
				9/25/75	-4.3	-94.7	
06S/08E-17R01 S	33		-109.5	2/07/75	-1.3	-108.2	5135
				5/21/75	-1.9	-107.6	
				9/25/75	-6.6	-102.9	
06S/08E-19D01 S	33		-85.0	2/07/75	-16.0	-69.0	5135
				5/21/75	-12.1	-72.9	
				9/25/75	-11.6	-73.4	
06S/08E-19D02 S	33		-87.0	2/07/75	1.5	-88.5	5135
				5/21/75	7.6	-94.6	
				9/25/75	7.1	-94.1	
06S/08E-19R01 S	33		-105.0	2/07/75	-29.1	-75.9	5135
				5/21/75	-27.4	-77.6	
				9/25/75	-23.2	-81.8	
06S/08E-22D02 S	33		-120.0	10/03/74	-4.2	-115.8	5135
				2/26/75	-12.2	-107.8	
				6/13/75	-3.0	-117.0	
06S/08E-22K01 S	33		-128.0	2/14/75	-13.0	141.0	5135
				5/21/75	-5.8	-122.2	
				9/26/75	-5.8	-122.2	
06S/08E-25P01 S	33		-140.0	2/14/75	8.7	-148.7	5135
				5/22/75	10.0	-150.0	
				9/26/75	10.5	-150.5	
06S/08E-27C01 S	33		-135.0	2/14/75	-24.9	-110.1	5135
				5/21/75	-20.6	-114.4	
				9/25/75	-15.9	-119.1	
06S/08E-27N01 S	33		-145.5	2/14/75	-16.2	-129.3	5135
				5/22/75	-7.3	-138.2	
				9/26/75	-11.6	-133.9	
06S/08E-30P01 S	33		-99.5	2/18/75	9.6	-109.1	5135
				5/21/75	NM-9		
				9/26/75	17.1	-116.6	
06S/08E-32R01 S	33		-140.0	2/14/75	-42.9	-97.1	5135
				5/21/75	-42.9	-97.1	
				9/26/75	-40.6	-99.4	
06S/08E-34C01 S	33		-146.0	5/22/75	-12.1	-133.9	5135
06S/08E-35J01 S	33		-153.4	5/22/75	-7.7	-145.7	5135
06S/08E-36H01 S	33		-155.0	2/14/75	-19.7	-135.3	5135
				5/22/75	-15.3	-139.7	
				9/26/75	-13.8	-141.2	
06S/09E-19L01 S	33		-38.0	2/14/75	126.7	-164.7	5135
				5/22/75	127.9	-165.9	
				9/26/75	133.0	-171.0	
06S/09E-30A01 S	33		-51.0	2/14/75	62.1	-113.1	5135
				5/22/75	61.9	-112.9	
				9/26/75	58.0	-109.0	
06S/09E-32A01 S	33		20.8	2/14/75	178.8	-158.8	5135
				5/22/75	179.3	-159.3	
				9/26/75	192.3	-172.3	
06S/09E-32D01 S	33		-100.0	2/14/75	59.3	-159.3	5135
				5/22/75	70.6	-170.6	
				9/26/75	74.6	-174.6	
06S/09E-33K01 S	33		25.0	2/14/75	184.0	-159.0	5135
				5/22/75	189.8	-164.8	
				9/26/75	195.8	-170.8	
07S/07E-01C01 S	33		-112.0	2/06/75	-8.1	-103.9	5135
				5/20/75	-4.7	-107.3	
				9/26/75	-3.5	-108.5	
07S/07E-02H01 S	33		-105.0	2/06/75	-4.6	-100.4	5135
				5/20/75	-3.5	-101.5	
				9/26/75	-4.6	-100.4	
07S/07E-03A01 S	33		-72.0	2/06/75	18.1	-90.1	5135
				5/20/75	17.8	-89.8	
				9/25/75	17.4	-89.4	
07S/08E-02R01 S	33		-161.0	2/06/75	-18.1	-142.9	5135
				5/20/75	-29.7	-131.3	
				9/29/75	-18.1	-142.9	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

WHITEWATER HYDRO UNIT
COACHELLA HYDRO SUBUNIT
INDIO HYDRO SUBAREA

X-19
X-19.D
X-19.D7

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
07S/08E-03A01 S	33		-159.5	2/06/75	-19.2	-140.3	5135
				5/20/75	-15.4	-144.1	
				9/29/75	-16.0	-143.5	
07S/08E-07R01 S	33		-90.0	2/06/75	31.3	-121.3	5135
				5/20/75	32.1	-122.1	
				9/29/75	32.6	-122.6	
07S/08E-08N01 S	33		-92.0	5/31/75	31.3	-123.3	5135
07S/08E-09H01 S	33		-147.0	2/06/75	-28.0	-119.0	5135
				5/20/75	-18.8	-128.2	
				9/29/75	-22.9	-124.1	
07S/08E-17A01 S	33		-115.0	2/06/75	5.4	-120.4	5135
				5/20/75	6.1	-121.1	
				9/29/75	6.4	-121.4	
07S/08E-17F01 S	33		-79.0	2/06/75	41.3	-120.3	5135
				5/20/75	42.2	-121.2	
				9/29/75	42.6	-121.6	
07S/08E-17G01 S	33		-78.0	10/03/74	42.2	-120.2	5135
				2/26/75	40.7	-118.7	
				6/17/75	42.0	-120.0	
07S/08E-18C01 S	33		-73.0	2/06/75	41.1	-114.1	5135
				5/20/75	45.4	-118.4	
				9/29/75	46.1	-119.1	
07S/08E-18C02 S	33		-74.0	5/20/75	43.5	-117.5	5135
07S/08E-20B01 S	33		-20.0	2/14/75	105.7	-125.7	5135
				5/20/75	108.6	-128.6	
				9/30/75	106.9	-126.9	
07S/08E-20H01 S	33		-22.0	2/19/75	95.0	-117.0	5135
				5/21/75	96.7	-118.7	
				9/30/75	100.5	-122.5	
07S/08E-22K01 S	33		-124.0	2/19/75	15.6	-139.6	5135
				5/21/75	79.2	-203.2	
				9/30/75	19.7	-143.7	
07S/08E-23B01 S	33		-180.5	2/19/75	-16.7	-163.8	5135
				5/19/75	-13.0	-167.5	
				9/30/75	-10.4	-170.1	
07S/08E-23B02 S	33		-171.0	5/19/75	-2.7	-168.3	5135
07S/08E-28G01 S	33		-16.5	2/19/75	112.0	-128.5	5135
				5/21/75	113.2	-129.7	
				9/30/75	114.4	-130.9	
07S/08E-33B01 S	33		21.8	5/21/75	NM-1		5135
				6/11/75	152.8	-131.0	
07S/08E-33E01 S	33		75.0	2/19/75	208.1	-133.1	5135
				5/29/75	195.1	-120.1	
				9/30/75	181.9	-106.9	
07S/08E-34G01 S	33		-92.3	2/19/75	41.4	-133.7	5135
				5/19/75	41.5	-133.8	
				9/30/75	41.5	-133.8	
07S/08E-34K01 S	33		-84.7	5/19/75	53.7	-138.4	5135
07S/08E-35K01 S	33		-161.1	2/19/75	-22.6	-138.5	5135
				5/19/75	-23.5	-137.6	
				9/30/75	-22.3	-138.8	
07S/09E-03B01 S	33		31.0	2/25/75	199.3	-168.3	5135
				5/15/75	205.8	-174.8	
07S/09E-04C01 S	33		-42.0	2/24/75	129.0	-171.0	5135
				5/15/75	134.5	-176.5	
07S/09E-04K01 S	33		-65.0	2/26/75	NM-8		5135
				5/14/75	NM-8		
07S/09E-05H01 S	33		-152.5	2/24/75	36.8	-189.3	5135
				5/14/75	19.2	-171.7	
07S/09E-07H02 S	33		-188.0	2/24/75	-14.6	-173.4	5135
				5/14/75	-11.1	-176.9	
07S/09E-08P01 S	33		-180.0	5/14/75	17.8	-197.8	5135
07S/09E-13N01 S	33		-101.0	2/26/75	44.3	-145.3	5135
				5/14/75	42.9	-143.9	
07S/09E-16H02 S	33		-186.0	2/26/75	-1.0	-185.0	5135
				5/14/75	-1.4	-184.6	
07S/09E-17K01 S	33		-195.0	10/03/74	-2.0	-193.0	5135
				3/03/75	-11.2	-183.8	
				6/19/75	-5.5	-189.5	
				7/26/75	-10.0	-185.0	
07S/09E-22G02 S	33		-173.0	2/26/75	21.3	-194.3	5135
				5/14/75	21.8	-194.8	

WHITEWATER HYDRO UNIT
COACHELLA HYDRO SUBUNIT
INDIO HYDRO SUBAREA

X-19
X-19.D
X-19.D7

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
07S/09E-23N01 S	33		-187.7	10/03/74	21.0	-208.7	5135
				2/26/75	13.0	-200.7	
				6/19/75	10.8	-198.5	
07S/09E-26G02 S	33		-205.0	2/26/75	-24.1	-180.9	5135
				5/14/75	-25.2	-179.8	
07S/09E-30H01 S	33		-213.0	2/24/75	-29.0	-184.0	5135
				5/15/75	-34.8	-178.2	
07S/10E-27A01 S	33		34.0	2/26/75	52.2	-18.2	5135
				5/14/75	52.5	-18.5	
08S/08E-03A01 S	33		-95.1	10/02/74	47.7	-142.8	5135
				2/20/75	43.0	-138.1	
				5/14/75	43.7	-138.8	
				9/30/75	45.4	-140.5	
08S/08E-03L01 S	33		-59.5	10/02/74	77.4	-136.9	5135
				2/20/75	73.8	-133.3	
				5/15/75	75.5	-135.0	
08S/08E-11H01 S	33		-166.0	10/02/74	-7.1	-158.9	5135
				2/20/75	-12.9	-153.1	
				5/15/75	-12.6	-153.4	
08S/08E-24A01 S	33		-155.2	10/02/74	8.3	-163.5	5135
				2/20/75	5.9	-161.1	
				5/15/75	6.7	-161.9	
08S/08E-24A02 S	33		-154.0	5/15/75	9.0	-163.0	5135
08S/08E-24J01 S	33		-148.1	10/02/74	18.5	-166.6	5135
				2/20/75	18.3	-166.4	
				5/15/75	17.0	-165.1	
08S/08E-24L01 S	33		-110.8	10/02/74	49.7	-160.5	5135
				2/20/75	47.7	-158.5	
				5/19/75	47.7	-158.5	
08S/09E-30A01 S	33		-152.3	10/02/74	16.5	-168.8	5135
				2/20/75	15.5	-167.8	
				5/19/75	16.5	-168.8	
08S/09E-31Q01 S	33		-6.0	2/27/75	178.8	-184.8	5135
				6/19/75	180.5	-186.5	
				7/26/75	182.2	-188.2	
08S/09E-31R01 S	33		-17.8	2/27/75	156.2	-174.0	5135
				6/19/75	156.7	-174.5	
08S/09E-31R02 S	33		-18.5	2/27/75	153.8	-172.3	5135
				6/19/75	155.3	-173.8	
				8/26/75	155.2	-173.7	
08S/09E-33N01 S	33		-133.6	10/03/74	40.5	-174.1	5135
				2/20/75	39.8	-173.4	
				5/19/75	33.5	-167.1	

See page 79 for key to terms a abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
ANZA-BORREGO HYDRO UNIT						X-22	
BORREGO HYDRO SUBUNIT						X-22.A	
TERWILLIGER HYDRO SUBAREA						X-22.A1	
08S/03E-02D01 S	33		3900.0	10/03/74	69.7	3830.3	5000
				11/11/74	68.9	3831.1	
				12/27/74	67.2	3832.8	
				1/28/75	66.9	3833.1	
				2/26/75	67.4(2)	3832.6	
				4/10/75	67.2(2)	3832.8	
				5/07/75	67.7	3832.3	
				6/02/75	69.4	3830.6	
				7/24/75	70.6(2)	3829.4	
				8/28/75	70.8	3829.2	
				9/29/75	69.8	3830.2	
08S/03F-02K01 S	33		3870.0	10/03/74	54.7	3815.3	5000
				11/11/74	49.1	3820.9	
				12/27/74	45.3	3824.7	
				1/28/75	44.1	3825.9	
				2/26/75	43.3	3826.7	
				4/10/75	43.3	3826.7	
				5/07/75	44.3	3825.7	
				6/02/75	46.9	3823.1	
				7/24/75	53.5	3816.5	
				8/28/75	54.9	3815.1	
				9/29/75	51.2	3818.8	
BORREGO HYDRO SUBAREA						X-22.A3	
10S/06F-21A01 S	37		640.0	10/29/74	168.8	471.2	5050
				1/30/75	168.9	471.1	
				5/08/75	169.9	470.1	
				8/05/75	171.6	468.4	

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
EAST SALTON SEA HYDRO UNIT						X-25	
07S/10E-35G01 S	33		-66.0	2/26/75	91.1	-157.1	5135
				5/14/75	92.0	-158.0	

See page 79 for key to terms a abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

SANTA ANA DRAINAGE PROVINCE — Y
SANTA ANA RIVER HYDRO UNIT — Y-01
LOWER SANTA ANA R HYDRO SUBUNIT — Y-01.A
EAST COASTAL PLAIN HYDRO SUBAREA — Y-01.A1

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
03S/09W-04G01 S	30		256.0	10/04/74	83.7(1)	172.3	4742
				11/01/74	80.1(1)	175.9	
				12/06/74	81.1(1)	174.9	
				1/01/75	82.7(1)	173.3	
				2/07/75	90.0(1)	166.0	
				3/07/75	96.8(1)	159.2	
				4/04/75	45.0	211.0	
				5/02/75	88.2(1)	167.8	
				6/06/75	92.8(1)	163.2	
				7/01/75	81.5(1)	174.5	
				8/01/75	93.8(1)	162.2	
				9/05/75	93.7(1)	162.3	
04S/09W-17D01 S	30		231.0	10/22/74	190.6	40.4	5102
				1/02/75	171.3	59.7	
				3/19/75	180.6	50.4	
				4/30/75	187.2	43.8	
				9/02/75	NM-7		
04S/09W-18F01 S	30		195.0	10/28/74	145.4	49.6	4715
04S/09W-18H01 S	30		195.5	1/02/75	NM-1		5102
				3/19/75	139.9	55.6	
				4/30/75	139.7	55.8	
				7/02/75	127.2	68.3	
				9/02/75	135.2	60.3	
04S/09W-23A01 S	30		409.0	10/22/74	NM-1		5102
				1/02/75	42.1	366.9	
				3/19/75	41.2	367.8	
				4/30/75	40.8	368.2	
				9/02/75	40.5	368.5	
04S/09W-27C01 S	30		305.0	10/22/74	NM-1		5102
04S/09W-28H02 S	30		290.0	10/28/74	266.4	23.6	4715
04S/09W-28P01 S	30		262.1	10/22/74	NM-1		5102
04S/09W-31R01 S	30		178.0	10/22/74	169.0	9.0	5102
				1/02/75	NM-1		
				3/19/75	NM-1		
				4/30/75	152.7	25.3	
				9/02/75	NM-1		
04S/09W-32P01 S	30		202.6	10/30/74	201.3	1.3	5102
				11/27/74	202.8	-0.2	
				12/30/74	197.0	5.6	
				1/30/75	198.3	4.3	
				2/27/75	196.8	5.8	
				3/27/75	189.6	13.0	
				4/29/75	193.9	8.7	
				5/27/75	199.1	3.5	
				6/26/75	200.3	2.3	
				7/29/75	208.3	-5.7	
				8/29/75	208.3	-5.7	
04S/09W-33H01 S	30		226.0	10/22/74	225.9	0.1	5102
				1/02/75	NM-7		
				3/19/75	219.7	6.3	
				4/30/75	216.5	9.5	
04S/10W-11D02 S	30		176.0	10/01/74	130.0	46.0	5102
				11/01/74	128.8	47.2	
				12/01/74	128.0	48.0	
				1/01/75	122.6	53.4	
				2/01/75	120.8	55.2	
				3/01/75	123.5	52.5	
				4/01/75	122.3	53.7	
				5/01/75	121.3	54.7	
				6/01/75	127.1	48.9	
				7/01/75	126.2	49.8	
				8/01/75	133.1	42.9	
				9/01/75	135.7	40.3	
04S/10W-14D02 S	30		166.4	10/01/74	139.3	27.1	4210
				11/01/74	138.7	27.7	
				12/01/74	138.5	27.9	
				1/01/75	142.5	23.9	
				2/01/75	135.6	30.8	
				3/01/75	132.5	33.9	
				4/01/75	133.7	32.7	
				5/01/75	133.0	33.4	
				6/01/75	138.7	27.7	
				7/01/75	138.2	28.2	
				8/01/75	139.8	26.6	
				9/01/75	147.7	18.7	
04S/10W-14H02 S	30		173.4	10/01/74	128.5	44.9	4210
				11/01/74	124.7	48.7	
				12/01/74	125.9	47.5	
				1/01/75	134.9	38.5	
				2/01/75	124.6	48.8	
				3/01/75	123.0	50.4	
				4/01/75	121.8	51.6	
				5/01/75	126.7	46.7	
				6/01/75	127.5	45.9	
				7/01/75	132.0	41.4	
				8/01/75	137.7	35.7	
				9/01/75	137.0	36.4	
04S/10W-14H01 S	30		163.1	10/01/74	128.7	34.4	4210

SANTA ANA RIVER HYDRO UNIT — Y-01
LOWER SANTA ANA R HYDRO SUBUNIT — Y-01.A
EAST COASTAL PLAIN HYDRO SUBAREA — Y-01.A1

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
04S/10W-14H01 S (CONTINUED)	30		163.1	11/01/74	123.2	39.9	4210
				12/01/74	126.3	36.8	
				1/01/75	134.8	28.3	
				2/01/75	121.3	41.8	
				3/01/75	123.5	39.6	
				4/01/75	121.0	42.1	
				5/01/75	117.6	45.5	
				6/01/75	127.0	36.1	
				7/01/75	128.2	34.9	
				8/01/75	131.6	31.5	
				9/01/75	134.8	28.3	
04S/10W-15R01 S	30		152.6	10/01/74	130.5	22.1	4210
				11/01/74	130.5	22.1	
				12/01/74	128.5	24.1	
				1/01/75	130.7	21.9	
				2/01/75	119.6	33.0	
				3/01/75	123.3	29.3	
				4/01/75	118.3	34.3	
				5/01/75	123.3	29.3	
				6/01/75	127.5	25.1	
				7/01/75	132.3	20.3	
				8/01/75	133.5	19.1	
				9/01/75	134.7	17.9	
04S/10W-15R05 S	30		157.0	10/01/74	134.0	23.0	5102
				11/01/74	131.3	25.7	
				12/01/74	132.0	25.0	
				1/01/75	122.7	34.3	
				2/01/75	121.7	35.3	
				3/01/75	123.8	33.2	
				4/01/75	122.0	35.0	
				5/01/75	125.0	32.0	
				6/01/75	129.5	27.5	
				7/01/75	131.8	25.2	
				8/01/75	133.3	23.7	
				9/01/75	136.3	20.7	
04S/10W-15P01 S	30		142.0	10/22/74	NM-3		5102
				1/02/75	137.7	4.3	
				3/19/75	136.0	6.0	
				4/30/75	NM-3		
				9/02/75	NM-3		
04S/10W-17H01 S	30		123.0	10/01/74	127.3	-4.3	5102
				11/01/74	123.7	-0.7	
				12/01/74	124.5	-1.5	
				1/01/75	118.0	5.0	
				2/01/75	119.5	3.5	
				3/01/75	119.7	3.3	
				4/01/75	117.8	5.2	
				5/01/75	121.3	1.7	
				6/01/75	127.0	-4.0	
				7/01/75	131.5	-8.5	
				8/01/75	134.2	-11.2	
				9/01/75	135.5	-12.5	
04S/10W-17J02 S	30		116.1	10/01/74	116.1	0.0	4210
				11/01/74	128.7	-12.6	
				12/01/74	126.3	-10.2	
				1/01/75	131.0	-14.9	
				2/01/75	123.0	-6.9	
				3/01/75	123.1	-7.0	
				4/01/75	110.2	5.9	
				5/01/75	119.8	-3.7	
				6/01/75	128.2	-12.1	
				7/01/75	130.9	-14.8	
				8/01/75	133.8	-17.7	
				9/01/75	135.2	-19.1	
04S/10W-17L02 S	30		110.6	10/01/74	108.2	2.4	4210
				11/01/74	112.5	-1.9	
				12/01/74	114.1	-3.5	
				1/01/75	127.5	-16.9	
				2/01/75	112.5	-1.9	
				3/01/75	112.5	-1.9	
				4/01/75	110.5	0.1	
				5/01/75	114.5	-3.9	
				6/01/75	115.5	-4.9	
				7/01/75	117.5	-6.9	
				8/01/75	122.5	-11.9	
				9/01/75	123.5	-12.9	
04S/10W-17Q01 S	30		112.0	10/30/74	92.6	19.4	5102
				1/03/75	91.5	20.5	
				3/18/75	91.2	20.8	
				4/29/75	91.9	20.1	
				6/27/75	92.6	19.4	
				8/29/75	90.8	21.2	
04S/10W-18P01 S	30		92.0	10/01/74	90.6	1.4	4210
				11/01/74	94.4	-2.4	
				12/01/74	94.7	-2.7	
				1/01/75	80.2	11.8	
				2/01/75	93.3	-1.3	
				3/01/75	92.5	-0.5	
				4/01/75	91.7	0.3	
				5/01/75	92.2	-0.2	
				6/01/75	94.5	-2.5	
				7/01/75	97.4	-5.4	
				8/01/75	92.6	-0.6	
				9/01/75	95.8	-3.8	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

SANTA ANA RIVER HYDRO UNIT — Y-01
LOWER SANTA ANA R HYDRO SUBUNIT — Y-01.A
EAST COASTAL PLAIN HYDRO SUBAREA — Y-01.A1

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
04S/10W-19G02 S	30		93.0	10/30/74	77.1	15.9	5102
				1/03/75	81.5	11.5	
				3/18/75	78.9	14.1	
				6/26/75	84.0	9.0	
				8/29/75	85.5	7.5	
04S/10W-19H03 S	30		92.0	1/01/75	98.3	-6.3	5102
				2/01/75	100.2	-8.2	
				3/01/75	98.3	-6.3	
				4/01/75	98.1	-6.1	
				5/01/75	97.9	-5.9	
				6/01/75	98.2	-6.2	
				7/01/75	101.4	-9.4	
				8/01/75	101.3	-9.3	
				9/01/75	102.3	-10.3	
04S/10W-20H02 S	30		100.0	10/01/74	87.6	12.4	4210
				11/01/74	86.1	13.9	
				12/01/74	87.0	13.0	
				1/01/75	NM-6		
				2/01/75	85.1	14.9	
				3/01/75	85.2	14.8	
				4/01/75	83.5	16.5	
				5/01/75	84.0	16.0	
				6/01/75	85.5	14.5	
				7/01/75	86.0	14.0	
				8/01/75	87.0	13.0	
				9/01/75	87.5	12.5	
04S/10W-21F01 S	30		118.0	1/03/75	99.8	18.2	5102
				3/18/75	100.8	17.2	
				4/29/75	NM-3		
				8/29/75	NM-3		
04S/10W-23B02 S	30		165.0	10/01/74	129.7	35.3	4210
				11/01/74	123.7	41.3	
				12/01/74	126.8	38.2	
				1/01/75	148.2	16.8	
				2/01/75	126.6	38.4	
				3/01/75	128.6	36.4	
				4/01/75	122.2	42.8	
				5/01/75	118.7	46.3	
				6/01/75	124.3	40.7	
				7/01/75	136.3	28.7	
				8/01/75	139.6	25.4	
				9/01/75	141.2	23.8	
04S/10W-23R01 S	30		163.0	10/22/74	119.6	43.4	5102
				1/02/75	120.4	42.6	
				3/18/75	115.8	47.2	
				4/30/75	116.1	46.9	
				7/02/75	117.3	45.7	
				9/02/75	122.4	40.6	
04S/10W-24R03 S	30		172.0	10/22/74	NM-1		5102
				1/02/75	NM-1		
				3/19/75	148.0	24.0	
				4/30/75	NM-1		
				9/02/75	NM-1		
04S/10W-25F01 S	30		144.5	10/22/74	115.4	29.1	5102
				1/02/75	116.6	27.9	
				3/19/75	117.9	26.6	
				4/30/75	121.5	23.0	
				7/02/75	132.0	12.5	
				9/02/75	NM-2		
04S/10W-25F01 S	30		152.0	10/01/74	134.3	17.7	5102
				11/01/74	133.7	18.3	
				12/01/74	133.8	18.2	
				1/01/75	130.0	22.0	
				2/01/75	131.2	20.8	
				3/01/75	132.3	19.7	
				4/01/75	120.5	31.5	
				5/01/75	128.2	23.8	
				6/01/75	129.4	22.6	
				7/01/75	131.2	20.8	
				8/01/75	135.8	16.2	
				9/01/75	136.3	15.7	
04S/10W-27C02 S	30		129.0	10/22/74	105.0	24.0	5102
				1/02/75	103.9	25.1	
				3/19/75	103.3	25.7	
				4/30/75	102.5	26.5	
				7/02/75	106.3	22.7	
				9/02/75	105.0	24.0	
04S/10W-31R02 S	30		80.0	10/30/74	70.6	9.4	5102
				1/03/75	68.2	11.8	
				3/18/75	67.0	13.0	
04S/10W-34H03 S	30		95.9	10/22/74	78.0	17.9	5102
				1/02/75	NM-9		
				3/19/75	NM-9		
				4/30/75	NM-9		
				9/02/75	65.6	30.3	
04S/11W-24A01 S	30		82.5	10/01/74	90.2	-7.7	4210
				11/01/74	87.2	-4.7	
				12/01/74	87.8	-5.3	
				1/01/75	86.2	-3.7	

SANTA ANA RIVER HYDRO UNIT — Y-01
LOWER SANTA ANA R HYDRO SUBUNIT — Y-01.A
EAST COASTAL PLAIN HYDRO SUBAREA — Y-01.A1

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
04S/11W-24A01 S (CONTINUED)	30		82.5	2/01/75	81.8	0.7	4210
				3/01/75	81.2	1.3	
				4/01/75	81.7	0.8	
				5/01/75	82.0	0.5	
				6/01/75	86.8	-4.3	
				7/01/75	90.3	-7.8	
				8/01/75	105.2	-22.7	
				9/01/75	95.8	-13.3	
04S/11W-24H01 S	30		71.0	10/30/74	NM-1		5102
04S/11W-26R01 S	30		59.8	10/30/74	43.2	16.6	5102
				1/03/75	41.5	18.3	
				3/18/75	41.8	18.0	
				4/29/75	41.6	18.2	
				6/26/75	42.7	17.1	
				8/29/75	44.8	15.0	
04S/11W-26J01 S	30		66.0	10/30/74	78.7	-12.7	5102
				1/03/75	72.1	-6.1	
				3/18/75	64.4	1.6	
				4/29/75	63.6	2.4	
				6/26/75	77.9	-11.9	
				8/29/75	78.4	-12.4	
05S/08W-19H01 S	30		254.3	10/25/74	137.2	117.1	5102
				12/30/74	134.9	119.4	
				3/04/75	132.3	122.0	
				5/01/75	130.5	123.8	
				6/26/75	141.0	113.3	
				9/04/75	141.7	112.6	
05S/08W-24P01 S	30		266.5	10/25/74	154.4	112.1	5102
05S/08W-29P01 S	30		266.5	10/25/74	154.4	112.1	5102
				12/30/74	152.3	114.2	
				3/04/75	149.4	117.1	
				5/01/75	147.2	119.3	
				6/26/75	160.6	105.9	
				9/04/75	NM-1		
05S/08W-31K01 S	30		219.7	10/25/74	148.3	71.4	5102
				12/30/74	140.6	79.1	
				3/04/75	133.4	86.3	
				5/01/75	NM-1		
				6/26/75	NM-1		
				9/04/75	NM-1		
05S/08W-33A01 S	30		439.0	10/29/74	15.2	423.8	4709
				3/18/75	22.2	416.8	
05S/09W-04C01 S	30		203.0	10/22/74	NM-1		5102
				1/02/75	NM-1		
				3/19/75	218.8	-15.8	
				4/30/75	NM-1		
05S/09W-08R02 S	30		171.0	10/22/74	NM-1		5102
				1/02/75	NM-1		
				3/19/75	178.0	-7.0	
				4/30/75	174.8	-3.8	
				7/02/75	NM-1		
				9/02/75	NM-1		
05S/09W-10C01 S	30		189.1	10/22/74	NM-4		5102
05S/09W-10G01 S	30		180.4	10/22/74	174.6	5.8	5102
				1/02/75	169.4	11.0	
				3/19/75	164.0	16.4	
				4/30/75	161.8	18.6	
				7/02/75	165.8	14.6	
05S/09W-14Q01 S	30		123.1	11/08/74	99.0	24.1	4709
				3/21/75	76.0	47.1	
05S/09W-15J01 S	30		107.3	10/22/74	NM-1		5102
				11/08/74	106.0	1.3	4709
				3/19/75	87.5	19.8	5102
				4/30/75	84.4	22.9	
				7/02/75	106.3	1.0	
05S/09W-15R03 S	30		96.7	10/22/74	32.6	64.1	5102
				1/02/75	NM-1		
				3/19/75	27.1	69.6	
				4/30/75	26.7	70.0	
05S/09W-16R02 S	30		127.0	10/22/74	NM-1		5102
				1/21/75	144.3	-17.3	
				3/19/75	NM-1		
				4/30/75	122.7	4.3	
				7/02/75	NM-1		
				9/02/75	NM-1		
05S/09W-19H01 S	30		76.2	10/30/74	79.4	-3.2	5102
				11/27/74	79.7	-3.5	
				12/30/74	71.7	4.5	
				1/30/75	74.0	2.2	
				2/27/75	71.3	4.9	
				3/27/75	69.0	7.2	
				4/29/75	70.9	5.3	
				5/27/75	79.2	-3.0	
				6/26/75	86.5	-10.3	
				7/29/75	90.1	-13.9	

See page 79 for key to terms a abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA ANA RIVER HYDRO UNIT LOWER SANTA ANA R HYDRO SUBUNIT EAST COASTAL PLAIN HYDRO SUBAREA						Y-01 Y-01.A Y-01.A1	
05S/09W-19H01 S	30		76.2	8/29/75	90.7	-14.5	5102
05S/09W-21R01 S	30		94.0	10/29/74	118.6	-24.6	5102
				12/30/74	109.4	-15.4	
				3/04/75	85.8	8.2	
				5/01/75	82.9	11.1	
				6/26/75	115.5	-21.5	
				9/04/75	114.4	-20.4	
05S/09W-21P02 S	30		74.5	10/25/74	23.6	50.9	5102
				12/30/74	23.2	51.3	
				3/04/75	30.7	43.8	
				5/01/75	22.4	52.1	
				6/26/75	32.9	41.6	
				9/04/75	23.1	51.4	
05S/09W-22A02 S	30		86.8	11/08/74	92.0	-5.2	4709
				3/20/75	54.0	32.8	
05S/09W-23A01 S	30		118.7	11/08/74	98.0	20.7	4709
				3/18/75	80.0	38.7	
05S/09W-23N01 S	30		77.0	10/25/74	53.9	23.1	5102
			77.2	11/08/74	51.0	26.2	4709
			77.0	12/30/74	52.7	24.3	5102
				3/04/75	36.0	41.0	
				5/01/75	NM-9		
				6/26/75	NM-1		
				9/04/75	55.0	22.0	
05S/09W-25F01 S	30		109.0	10/25/74	NM-1		5102
			109.9	11/08/74	69.0	40.9	4709
			109.0	12/30/74	65.7	43.3	5102
				3/04/75	44.3	64.7	
				5/01/75	40.3	68.7	
				6/26/75	NM-1		
				9/04/75	49.4	59.6	
05S/09W-30F01 S	30		53.7	10/25/74	26.2	27.5	5102
				12/30/74	25.3	28.4	
				3/04/75	24.6	29.1	
				5/01/75	24.8	28.9	
				6/26/75	24.8	28.9	
				9/04/75	26.6	27.1	
05S/09W-30F02 S	30		53.8	10/25/74	NM-7		5102
05S/09W-31B01 S	30		40.4	11/08/74	36.0	4.4	4709
				3/20/75	37.0	3.4	
05S/09W-31H02 S	30		34.3	10/25/74	43.6	-9.3	5102
				12/30/74	35.5	-1.2	
				3/04/75	46.8	-12.5	
				5/01/75	36.2	-1.9	
				6/26/75	39.1	-4.8	
				9/04/75	NM-9		
05S/09W-34J01 S	30		67.9	10/25/74	60.9	7.0	5102
				11/08/74	59.0	8.9	4709
				12/30/74	27.4	40.5	5102
				3/04/75	NM-1		
				5/01/75	3.4	64.5	
				6/26/75	NM-1		
				9/04/75	NM-1		
05S/09W-34Q01 S	30		69.7	11/08/74	55.0	14.7	4709
				3/22/75	33.0	36.7	
05S/09W-35J01 S	30		99.0	10/25/74	NM-5		5102
05S/09W-36R01 S	30		157.0	10/25/74	101.8	55.2	5102
				12/30/74	102.3	54.7	
				3/04/75	77.9	79.1	
				5/01/75	82.1	74.9	
				6/26/75	113.5	43.5	
				9/04/75	103.0	54.0	
05S/09W-36K01 S	30		147.6	10/25/74	76.3	71.3	5102
				12/30/74	65.1	82.5	
				3/04/75	59.2	88.4	
				5/01/75	57.3	90.3	
				6/26/75	65.8	81.8	
				9/04/75	71.4	76.2	
05S/09W-36Q01 S	30		158.0	10/25/74	89.9	68.1	5102
				12/30/74	79.9	78.1	
				3/04/75	74.2	83.8	
				5/01/75	71.5	86.5	
				6/26/75	88.8(1)	69.2	
				9/04/75	NM-5		
05S/10W-01F01 S	30		120.0	1/30/75	118.6	1.4	5102
				2/27/75	118.6	1.4	
				3/27/75	115.5	4.5	
				4/29/75	119.4	0.6	
				5/27/75	123.3	-3.3	
				6/26/75	127.7	-7.7	
				7/29/75	130.9	-10.9	
				8/29/75	132.2	-12.2	
05S/10W-01F02 S	30		123.2	10/30/74	128.3	-5.1	5102
				11/27/74	129.8	-6.6	
SANTA ANA RIVER HYDRO UNIT LOWER SANTA ANA R HYDRO SUBUNIT EAST COASTAL PLAIN HYDRO SUBAREA						Y-01 Y-01.A Y-01.A1	
05S/10W-01E02 S (CONTINUED)	30		123.2	12/30/74	122.1	1.1	5102
				1/30/75	122.9	0.3	
				2/27/75	122.7	0.5	
				3/27/75	119.8	3.4	
				4/29/75	123.9	-0.7	
				5/27/75	126.9	-3.7	
				6/26/75	131.3	-8.1	
				7/29/75	134.5	-11.3	
				8/29/75	135.9	-12.7	
05S/10W-02R02 S	30		114.0	10/22/74	93.6	20.4	5102
				1/02/75	93.3	20.7	
				3/19/75	88.9	25.1	
				4/30/75	88.9	25.1	
				7/02/75	89.0	25.0	
				9/02/75	90.0	24.0	
05S/10W-02L01 S	30		107.7	10/30/74	116.6	-8.9	5102
				11/27/74	118.0	-10.3	
				12/30/74	108.3	-0.6	
				1/30/75	110.0	-2.3	
				2/27/75	109.8	-2.1	
				3/27/75	106.3	1.4	
				4/29/75	110.3	-2.6	
				5/27/75	115.6	-7.9	
				6/26/75	120.1	-12.4	
				7/29/75	124.0	-16.3	
				8/29/75	124.8	-17.1	
05S/10W-09N04 S	30		67.8	10/23/74	63.3	4.5	5102
				1/09/75	62.6	5.2	
				3/14/75	60.7	7.1	
				5/05/75	60.1	7.7	
				7/08/75	63.5	4.3	
				8/27/75	63.7	4.1	
05S/10W-09R01 S	30		74.2	10/23/74	61.0	13.2	5102
				1/09/75	57.6	16.6	
				3/14/75	57.8	16.4	
				5/05/75	57.7	16.5	
				7/08/75	59.0	15.2	
				8/27/75	61.1	13.1	
05S/10W-10A05 S	30		96.2	10/23/74	75.1	21.1	5102
				1/09/75	73.7	22.5	
				3/14/75	72.6	23.6	
				5/05/75	71.7	24.5	
				7/08/75	77.6	18.6	
				8/27/75	NM-9		
05S/10W-10D04 S	30		84.0	10/23/74	70.1	13.9	5102
				1/09/75	69.1	14.9	
				3/14/75	67.8	16.2	
				5/05/75	65.6	18.4	
				7/08/75	72.4	11.6	
				8/27/75	NM-8		
05S/10W-10P01 S	30		82.4	10/23/74	70.5	11.9	5102
				1/09/75	68.4	14.0	
				3/14/75	74.0	8.4	
				5/05/75	71.1	11.3	
				7/08/75	66.2	16.2	
				8/27/75	NM-3		
05S/10W-13C01 S	30		103.0	10/30/74	108.8	-5.8	5102
				11/27/74	110.5	-7.5	
				12/30/74	101.5	1.5	
				1/30/75	102.9	0.1	
				2/27/75	105.0	-2.0	
				3/27/75	99.8	3.2	
				4/29/75	103.5	-0.5	
				5/27/75	107.9	-4.9	
				6/26/75	115.3	-12.3	
				7/29/75	117.1	-14.1	
				8/29/75	115.1	-12.1	
05S/10W-15R02 S	30		79.0	10/23/74	65.0	14.0	5102
				1/09/75	60.5	18.5	
				3/14/75	60.3	18.7	
				5/05/75	61.3	17.7	
				7/08/75	64.9	14.1	
				8/27/75	65.0	14.0	
05S/10W-16H02 S	30		56.4	10/30/74	55.1	1.3	5102
				11/27/74	55.0	1.4	
				12/30/74	51.3	5.1	
				1/30/75	51.2	5.2	
				2/27/75	50.9	5.5	
				3/27/75	49.5	6.9	
				4/29/75	50.9	5.5	
				5/27/75	53.3	3.1	
				6/26/75	55.1	1.3	
				7/29/75	56.6	-0.2	
				8/29/75	58.0	-1.6	
05S/10W-17Q01 S	30		46.0	10/23/74	51.9	-5.9	5102
				1/09/75	42.0	4.0	
				3/14/75	41.0	5.0	
				5/05/75	NM-1		
				7/08/75	NM-1		
				8/27/75	NM-1		
05S/10W-20H03 S	30		47.5	10/23/74	NM-2		5102

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA ANA RIVER HYDRO UNIT LOWER SANTA ANA R HYDRO SUBUNIT EAST COASTAL PLAIN HYDRO SUBAREA						Y-01 Y-01.A Y-01.A1	
05S/10W-20H03 S (CONTINUED)	30		47.5	1/09/75	42.2	5.3	5102
				3/14/75	42.2	5.3	
				5/05/75	43.9	3.6	
				7/08/75	NM-2		
				8/27/75	NM-2		
05S/10W-21H02 S	30		40.0	10/23/74	42.3	-2.3	5102
				1/09/75	36.5	3.5	
				3/14/75	36.1	3.9	
				5/05/75	38.1	1.9	
				7/08/75	41.7	-1.7	
				8/27/75	44.1	-4.1	
05S/10W-23C01 S	30		61.4	10/25/74	44.7	16.7	5102
				12/30/74	42.8	18.6	
				3/04/75	41.8	19.6	
				5/01/75	41.7	19.7	
				9/04/75	48.1	13.3	
05S/10W-26D02 S	30		44.5	10/23/74	59.6	-15.1	5102
				1/09/75	60.3	-15.8	
				3/14/75	56.0	-11.5	
				5/05/75	55.8	-11.3	
				7/08/75	58.5	-14.0	
				8/27/75	60.5	-16.0	
05S/10W-26R02 S	30		37.2	10/23/74	16.2	21.0	5102
				1/09/75	14.8	22.4	
				3/14/75	NM-1		
				5/05/75	NM-1		
				7/08/75	NM-1		
				8/27/75	NM-1		
05S/10W-28P01 S	30		45.0	10/23/74	NM-7		5102
				1/09/75	42.0	3.0	
				3/14/75	NM-8		
				5/05/75	46.3	-1.3	
				7/08/75	49.8	-4.8	
				8/27/75	NM-9		
05S/10W-31P04 S	30		20.0	10/29/74	29.7	-9.7	5102
05S/10W-33D01 S	30		37.6	1/09/75	38.3	-0.7	5102
				3/14/75	37.4	0.2	
				5/05/75	36.6	1.0	
				7/08/75	38.5	-0.9	
				8/27/75	39.3	-1.7	
05S/10W-35K01 S	30		32.7	10/23/74	43.6	-10.9	5102
				1/09/75	41.3	-8.6	
				3/14/75	36.2	-3.5	
				5/05/75	35.2	-2.5	
				7/08/75	47.3	-14.6	
				8/27/75	46.5	-13.8	
05S/11W-04A01 S	30		32.0	10/29/74	57.6(3)	-25.6	5102
				1/07/75	41.8	-9.8	
				3/13/75	41.9	-9.9	
				5/02/75	42.1	-10.1	
				8/26/75	57.3	-25.3	
05S/11W-07C01 S	30		10.0	10/29/74	NM-2		5102
				1/07/75	NM-1		
				2/13/75	32.2	-22.2	
				5/02/75	39.3	-29.3	
				7/07/75	NM-1		
				8/26/75	NM-1		
05S/11W-07R01 S	30		10.5	10/29/74	NM-2		5102
				1/07/75	NM-1		
				3/13/75	34.7	-24.2	
				5/07/75	NM-1		
				7/07/75	NM-1		
				8/26/75	59.6	-49.1	
05S/11W-08J02 S	30		17.0	10/29/74	NM-9		5102
				1/07/75	28.6	-11.6	
				3/13/75	25.7	-8.7	
				5/02/75	33.9	-16.9	
				7/07/75	43.8	-26.8	
				8/26/75	45.3	-28.3	
05S/11W-12L01 S	30		42.0	10/22/74	46.0	-4.0	5102
				1/07/75	36.9	5.1	
				3/13/75	35.0	7.0	
				5/02/75	37.1	4.9	
				7/07/75	NM-1		
05S/11W-13A02 S	30		42.0	10/22/74	56.4	-14.4	5102
				1/07/75	52.9	-10.9	
				3/13/75	46.5	-4.5	
				5/02/75	50.0	-8.0	
				7/07/75	56.6	-14.6	
05S/11W-16A02 S	30		16.0	10/29/74	35.5	-19.5	5102
				1/07/75	29.3	-13.3	
				3/13/75	29.0	-13.0	
				5/02/75	29.5	-13.5	
				7/07/75	42.2	-26.2	
				8/26/75	45.2	-29.2	
05S/11W-16R02 S	30		14.0	10/22/74	39.7	-25.7	5102

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA ANA RIVER HYDRO UNIT LOWER SANTA ANA R HYDRO SUBUNIT EAST COASTAL PLAIN HYDRO SUBAREA						Y-01 Y-01.A Y-01.A1	
05S/11W-16R02 S (CONTINUED)	30		14.0	1/07/75	NM-1		5102
				3/13/75	28.7	-14.7	
				5/02/75	29.8	-15.8	
				7/07/75	NM-1		
				8/26/75	NM-1		
05S/11W-24A05 S	30		35.0	10/29/74	48.4	-13.4	5102
				1/07/75	45.0	-10.0	
				3/13/75	45.7	-10.7	
				5/02/75	NM-1		
				7/07/75	NM-1		
05S/11W-24N02 S	30		25.0	10/22/74	18.8	6.2	5102
				1/07/75	16.1	8.9	
				3/13/75	11.0	14.0	
				5/02/75	12.7	12.3	
				7/07/75	16.7	8.3	
				8/26/75	20.2	4.8	
05S/11W-25P01 S	30		47.6	1/07/75	56.9	-9.3	5102
				3/13/75	55.7	-8.1	
				5/02/75	62.8	-15.2	
				7/07/75	57.2	-9.6	
				8/26/75	61.4	-13.8	
05S/11W-29R09 S	30		36.0	10/22/74	53.8	-17.8	5102
				1/07/75	47.3	-11.3	
				3/13/75	44.1	-8.1	
				5/02/75	45.9	-9.9	
				7/07/75	54.0	-18.0	
05S/11W-29C01 S	30		47.0	10/28/74	93.9	-46.9	5102
				1/07/75	NM-1		
				3/13/75	68.2	-21.2	
				5/02/75	37.0	10.0	
				7/07/75	NM-1		
				8/26/75	DRY		
06S/08W-05E02 S	30		285.4	10/29/74	228.0	57.4	4709
				3/17/75	218.0	67.4	
06S/08W-06J01 S	30		238.9	10/29/74	160.0	78.9	4709
				3/17/75	150.8	88.9	
06S/08W-06P01 S	30		203.0	10/25/74	116.9	86.1	5102
				12/30/74	111.9	91.1	
				3/04/75	108.9	94.1	
				5/01/75	107.4	95.6	
				6/26/75	NM-2		
				9/04/75	NM-2		
06S/08W-07E01 S	30		177.0	10/25/74	116.6	60.4	5102
				12/30/74	95.6	81.4	
				3/04/75	86.2	90.8	
				6/26/75	NM-6		
06S/08W-07Q01 S	30		202.2	10/25/74	116.0	86.2	5102
				12/30/74	108.7	93.5	
				3/04/75	NM-1		
				5/01/75	101.5	100.7	
				6/26/75	NM-1		
				9/04/75	NM-1		
06S/08W-08M01 S	30		244.4	10/25/74	168.9	75.5	5102
				12/30/74	162.9	81.5	
				3/04/75	161.1	83.3	
				5/01/75	NM-1		
				6/26/75	NM-1		
				9/04/75	NM-1		
06S/08W-14L01 S	30		490.0	10/14/74	20.6	469.4	5102
06S/09W-01L01 S	30		142.4	11/12/74	80.0	62.4	4709
				3/17/75	63.6	78.8	
06S/09W-02A04 S	30		101.7	11/12/74	57.0	44.7	4709
				3/17/75	37.6	64.1	
06S/09W-02D01 S	30		84.0	10/25/74	68.7	15.3	5102
				11/12/74	52.0	32.0	4709
				12/30/74	38.3	45.7	5102
				3/04/75	35.6	48.4	
				5/01/75	27.6	56.4	
				6/26/75	50.9	33.1	
				9/04/75	41.0	43.0	
06S/09W-04L01 S	30		48.3	11/12/74	47.0	1.3	4709
				3/20/75	41.0	7.3	
06S/09W-08L01 S	30		10.0	10/25/74	NM-1		5102
				12/30/74	3.2	6.8	
				3/04/75	0.2	9.8	
				5/01/75	1.4	8.6	
				6/26/75	-5.0	15.0	
				9/04/75	1.2	8.8	
06S/09W-09A01 S	30		67.0	10/25/74	70.4	-3.4	5102
				12/30/74	58.0	9.0	
				3/04/75	55.8	11.2	
				5/01/75	61.1	5.9	
				9/04/75	NM-1		
06S/09W-12K01 S	30		146.0	10/25/74	51.5	94.5	5102

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA ANA RIVER HYDRO UNIT						Y-01	
LOWER SANTA ANA R HYDRO SURUNIT						Y-01.A	
EAST COASTAL PLAIN HYDRO SUBAREA						Y-01.A1	
06S/09W-12K01 S (CONTINUED)	30		146.0	12/30/74	49.4	96.6	5102
				3/04/75	47.0	99.0	
				5/01/75	43.1	102.9	
				6/26/75	47.3	98.7	
				9/04/75	NM-7		
06S/09W-18E01 S	30		20.0	1/09/75	NM-2		5102
				3/14/75	NM-2		
				5/05/75	5.7	14.3	
06S/09W-18F02 S	30		18.0	10/23/74	13.8	4.2	5102
				1/09/75	NM-2		
				3/14/75	NM-2		
				5/05/75	11.3	6.7	
06S/10W-01E02 S	30		35.0	10/23/74	NM-2		5102
06S/10W-01F05 S	30		35.0	10/23/74	43.3	-8.3	5102
				1/09/75	34.3	0.7	
				3/14/75	33.2	1.8	
				5/05/75	NM-7		
06S/10W-04Q02 S	30		60.0	10/23/74	65.2	-5.2	5102
				1/09/75	64.2	-4.2	
				3/14/75	64.9	-4.9	
				5/05/75	63.5	-3.5	
				7/08/75	64.2	-4.2	
				8/27/75	64.7	-4.7	
06S/10W-05R03 S	30		18.4	10/23/74	36.2	-17.8	5102
				1/09/75	34.9	-16.5	
				3/14/75	28.2	-9.8	
				5/05/75	NM-1		
				7/08/75	NM-1		
				8/27/75	29.6	-11.2	
06S/10W-05R05 S	30		20.0	10/23/74	NM-1		5102
				1/09/75	28.2	-8.2	
				3/14/75	28.0	-8.0	
				5/05/75	NM-1		
				7/08/75	35.5	-15.5	
				8/27/75	NM-1		
06S/10W-11G01 S	30		52.0	10/23/74	NM-7		5102
06S/10W-13E01 S			11.4	10/23/74	10.0	1.4	5102
06S/10W-13K01 S	30		19.0	10/23/74	17.6	1.4	5102
				1/09/75	15.7	3.3	
				3/14/75	15.3	3.7	
				5/05/75	NM-2		
SANTIAGO HYDRO SUBAREA						Y-01.A2	
05S/07W-19R01 S	30		1140.0	10/14/74	32.0	1108.0	5102
05S/07W-29F01 S	30		1245.0	10/14/74	14.0	1231.0	5102
05S/08W-01N01 S	30		905.0	10/14/74	38.5	866.5	5102
SANTA ANA NARROWS HYDRO SUBAREA						Y-01.A3	
03S/08W-26N02 S	30		387.0	10/21/74	13.6	373.4	5102
				1/09/75	13.7	373.3	
				2/28/75	16.5	370.5	
				5/06/75	15.9	371.1	
				6/24/75	NM-1		
				8/25/75	NM-1		
03S/08W-29K01 S	30		340.0	10/21/74	14.2	325.8	5102
				1/09/75	13.6	326.4	
				2/28/75	12.3	327.7	
				5/06/75	12.9	327.1	
				6/24/75	14.1	325.9	
				8/25/75	12.5	327.5	
03S/08W-29N01 S	33		320.0	10/28/74	13.4	306.6	4715
03S/08W-29P01 S	30		336.0	10/21/74	NM-1		5102
				1/09/75	11.7	324.3	
				2/28/75	13.7	322.3	
				5/06/75	13.9	322.1	
				6/24/75	15.3	320.7	
				8/25/75	13.1	322.9	
03S/08W-29Q01 S	30		339.0	10/21/74	17.0	322.0	5102
				1/09/75	16.3	322.7	
				2/28/75	14.0	325.0	
				5/06/75	14.2	324.8	
				6/24/75	NM-1		
				8/25/75	14.0	325.0	
03S/08W-29Q02 S	33		338.0	10/28/74	16.7	321.3	4715
03S/08W-30N01 S	30		329.7	10/21/74	32.6	297.1	5102
				1/09/75	28.6	301.1	
				2/28/75	NM-1		
				5/06/75	30.1	299.6	
				8/25/75	31.9	297.8	
03S/08W-30N02 S	30		329.0	10/21/74	34.0	295.0	5102
SANTA ANA RIVER HYDRO UNIT						Y-01	
LOWER SANTA ANA R HYDRO SURUNIT						Y-01.A	
SANTA ANA NARROWS HYDRO SUBAREA						Y-01.A3	
03S/08W-30N02 S (CONTINUED)	30		329.0	1/09/75	30.6	298.4	5102
				2/28/75	32.9	296.1	
				5/06/75	30.3	298.7	
				8/25/75	30.5	298.5	
03S/08W-30Q01 S	30		350.0	10/21/74	49.4	300.6	5102
				2/28/75	47.0	303.0	
				5/06/75	45.8	304.2	
				8/25/75	48.7	301.3	
03S/08W-30R01 S	30		327.0	10/21/74	16.8	310.2	5102
				1/09/75	15.8	311.2	
				2/28/75	15.4	311.6	
				5/06/75	15.6	311.4	
				6/24/75	NM-5		
03S/08W-31D01 S	30		327.0	10/21/74	NM-1		5102
				1/09/75	20.8	306.2	
				2/28/75	22.6	304.4	
				5/06/75	22.1	304.9	
				8/25/75	NM-1		
03S/08W-31F04 S	30		390.0	10/21/74	22.2	367.8	5102
				1/09/75	NM-1		
				2/28/75	NM-2		
				5/06/75	NM-2		
				6/24/75	19.5	370.5	
				8/25/75	NM-2		
03S/08W-31N01 S	30		325.0	10/21/74	30.4	294.6	5102
				1/09/75	29.9	295.1	
				2/28/75	29.9	295.1	
				5/06/75	30.0	295.0	
				6/24/75	29.0	296.0	
				8/25/75	28.4	296.6	
03S/08W-32D01 S	33		360.0	10/28/74	18.3	341.7	4715
03S/08W-33C01 S	30		360.0	10/21/74	10.1	349.9	5102
				1/09/75	NM-1		
				2/28/75	11.1	348.9	
				5/06/75	11.4	348.6	
				6/24/75	NM-1		
03S/08W-34C01 S	30		368.0	10/21/74	10.5	357.5	5102
				1/09/75	8.8	359.2	
				2/28/75	9.7	358.3	
				5/06/75	9.9	358.1	
				6/24/75	10.1	357.9	
				8/25/75	9.4	358.6	
03S/08W-35R01 S	30		400.0	10/21/74	49.8	350.2	5102
				1/09/75	NM-1		
				2/28/75	46.2	353.8	
				5/06/75	47.4	352.6	
				6/24/75	47.0	353.0	
				8/25/75	46.9	353.1	
03S/08W-35R02 S	30		400.0	10/21/74	34.5	365.5	5102
				1/09/75	36.1	363.9	
				2/28/75	31.7	368.3	
				5/06/75	32.2	367.8	
				6/24/75	30.9	369.1	
				8/25/75	29.5	370.5	
04S/08W-06D01 S	30		334.4	10/21/74	49.3	285.1	5102
				1/09/75	49.3	285.1	
				2/28/75	49.5	284.9	
				5/06/75	49.3	285.1	
				6/24/75	50.2	284.2	
				8/25/75	50.1	284.3	
04S/09W-01F03 S	30		318.7	10/21/74	44.5	274.2	5102
				1/09/75	44.2	274.5	
				2/28/75	57.4	261.3	
				5/06/75	47.4	271.3	
				6/24/75	49.8	268.9	
				8/25/75	52.3	266.4	
MIDDLE SANTA ANA RIV HYDR SURUNIT						Y-01.B	
CHINO HYDRO SUBAREA						Y-01.B1	
01N/08W-35A01 S	36		1438.0	12/01/74	540.4	897.6	4706
				3/01/75	537.4	900.6	
				6/01/75	536.4	901.6	
				9/01/75	529.4	908.6	
01N/08W-25K03 S	36		1830.0	10/29/74	292.0	1538.0	1101
				11/30/74	286.0	1544.0	
				12/19/74	278.0	1552.0	
				1/19/75	275.0(1)	1555.0	3719
				2/28/75	272.0	1558.0	1101
				3/31/75	274.0	1556.0	
				4/30/75	277.0	1553.0	
				5/30/75	277.0	1553.0	
				6/30/75	285.0(1)	1545.0	
				9/30/75	334.0(1)	1496.0	
01N/08W-35J02 S	36		1607.0	12/19/74	370.0	1237.0	1101
				1/29/75	369.0	1238.0	
				2/27/75	367.0	1240.0	
				3/29/75	366.0	1241.0	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA ANA RIVER HYDRO UNIT MIDDLE SANTA ANA PIV HYDR SUBUNIT CHINO HYDRO SUBAREA						Y-01 Y-01.R Y-01.81	
01N/08W-35J02 S (CONTINUED)	36		1607.0	4/30/75	362.0	1245.0	1101
				5/29/75	364.0	1243.0	
				6/29/75	367.0	1240.0	
				7/29/75	370.0	1237.0	
				8/28/75	375.0	1232.0	
				9/30/75	378.0	1229.0	
01N/08W-35J03 S	36		1618.0	10/29/74	307.0	1311.0	4748
				12/19/74	296.0	1322.0	
				1/29/75	295.0	1323.0	
				2/27/75	300.0	1318.0	
				3/29/75	289.0	1329.0	
				4/30/75	289.0	1329.0	
				6/29/75	292.0	1326.0	
				7/24/75	303.0	1315.0	
				8/28/75	402.0(1)	1216.0	
				9/30/75	382.0(1)	1236.0	
01N/08W-35Q01 S	36		1574.0	11/15/74	233.5	1340.5	1101
				4/17/75	NM-1		
01N/08W-35R01 S	36		1605.0	12/19/74	370.0	1235.0	4748
				1/29/75	369.0	1236.0	
				2/27/75	367.0	1238.0	
				3/29/75	366.0	1239.0	
				4/30/75	362.0	1243.0	
				6/29/75	367.0	1238.0	
				7/24/75	370.0	1235.0	
				8/28/75	375.0	1230.0	
				9/30/75	378.0	1227.0	
01S/05W-06J01 S	36		1364.0	12/01/74	578.2	785.8	4706
				3/01/75	578.2	785.8	
				6/01/75	582.9	781.1	
				9/01/75	575.9	788.1	
01S/05W-07N01 S	36		1235.2	12/01/74	471.6	763.6	4706
				3/01/75	471.6	763.6	
				6/01/75	469.3	765.9	
				9/01/75	469.3	765.9	
01S/05W-07R01 S	36		1247.8	12/01/74	488.7	759.1	4706
				3/01/75	484.1	763.7	
				6/01/75	484.1	763.7	
				9/01/75	521.1(1)	726.7	
01S/05W-15G01 S	36		1175.0	5/01/75	348.0(1)	827.0	4124
				6/01/75	350.0(1)	825.0	
				7/01/75	351.0	824.0	
				8/01/75	335.0	840.0	
				9/01/75	337.0	838.0	
01S/05W-16C01 S	36		1227.3	10/01/74	421.5	805.8	4706
				11/01/74	420.6	806.7	
				12/01/74	423.0	804.3	
				1/01/75	422.5	804.8	
				2/01/75	421.0	806.3	
01S/05W-19A01 S	36		1156.9	12/01/74	405.1	751.8	4706
				3/01/75	402.8	754.1	
				6/01/75	400.5	756.4	
				9/01/75	395.9	761.0	
01S/05W-19J01 S	36		1106.9	12/01/74	355.1	751.8	4706
				3/01/75	355.1	751.8	
				6/01/75	352.8	754.1	
				9/01/75	350.5	756.4	
01S/05W-22E01 S	36		1106.6	11/08/74	285.7	820.9	3718
				2/28/75	285.3	821.3	
01S/05W-22M01 S	36		1091.0	6/01/75	262.0	829.0	4124
				7/01/75	280.0(1)	811.0	
				8/01/75	270.0	821.0	
				9/01/75	270.0(1)	821.0	
01S/05W-29A01 S	36		1082.4	10/01/74	287.0	795.4	4124
				11/01/74	292.0	790.4	
				12/01/74	291.0	791.4	
				1/02/75	291.0	791.4	
				2/01/75	291.0	791.4	
				3/01/75	291.0	791.4	
				4/01/75	290.0	792.4	
				5/01/75	291.0	791.4	
				6/01/75	291.0	791.4	
				7/01/75	292.0	790.4	
				8/01/75	291.0	791.4	
				9/01/75	286.0	796.4	
01S/05W-30L01 S	36		1049.0	12/01/74	302.8	746.2	4706
				3/01/75	302.0	747.0	
				6/01/75	301.8	747.2	
				9/01/75	300.8	748.2	
01S/06W-11P01 S	36		1246.5	3/01/75	486.1	760.4	4706
				6/01/75	481.5	765.0	
				9/01/75	509.2(1)	737.3	
01S/06W-11N01 S	36		1165.8	12/01/74	426.1	739.7	4706
				3/01/75	435.4(1)	730.4	
				6/01/75	433.1(1)	732.7	
				9/01/75	430.7	735.1	

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA ANA RIVER HYDRO UNIT MIDDLE SANTA ANA PIV HYDR SUBUNIT CHINO HYDRO SUBAREA						Y-01 Y-01.R Y-01.81	
01S/06W-12P01 S	36		1209.7	11/01/74	472.0	737.7	4706
				12/01/74	468.8	740.9	
				3/01/75	473.4	736.3	
				6/01/75	464.1	745.6	
				9/01/75	466.4(1)	743.3	
01S/06W-16A01 S	36		1112.6	1/03/75	397.6	715.0	4850
01S/06W-16G01 S	36		1091.6	1/03/75	381.0	710.6	4850
01S/06W-16L01 S	36		1075.0	12/01/74	340.0	735.0	4706
				3/01/75	340.0	735.0	
				6/01/75	343.0	732.0	
				9/01/75	348.0	727.0	
01S/06W-23D01 S	36		1079.0	12/01/74	354.4	724.6	4706
				3/01/75	352.1	726.9	
				6/01/75	368.3(1)	710.7	
				9/01/75	308.2	770.8	
01S/06W-25C01 S	36		1050.0	12/01/74	311.5	738.5	4706
				3/01/75	310.0	740.0	
				6/01/75	311.5	738.5	
				9/01/75	313.5	736.5	
01S/06W-27L01 S	36		955.1	12/01/74	245.6	709.5	4706
				3/01/75	244.6	710.5	
				6/01/75	244.6	710.5	
				9/01/75	244.6	710.5	
01S/06W-36D01 S	36		979.0	12/01/74	241.9	737.1	4706
				3/01/75	241.4	737.6	
				6/01/75	240.9	738.1	
				9/01/75	242.1	736.9	
01S/07W-08N01 S	36		1212.2	11/04/74	644.4(1)	567.8	4205
				5/22/75	655.4(1)	556.8	
01S/07W-14D01 S	36		1094.0	10/00/74	424.0	670.0	4702
				11/00/74	423.0	671.0	
				12/00/74	418.0	676.0	
				1/00/75	416.0	678.0	
				2/00/75	415.0	679.0	
				3/00/75	416.0	678.0	
				4/00/75	412.0	682.0	
				5/00/75	415.0	679.0	
				6/00/75	436.0	658.0	
				7/00/75	435.0	659.0	
				8/00/75	435.0	659.0	
				9/00/75	428.0	666.0	
01S/07W-14F01 S	36		1080.0	10/00/74	413.0	667.0	4702
				11/00/74	412.0	668.0	
				12/00/74	411.0	669.0	
				1/00/75	409.0	671.0	
				2/00/75	409.0	671.0	
				3/00/75	412.0	668.0	
				4/00/75	406.0	674.0	
				5/00/75	409.0	671.0	
				6/00/75	421.0	659.0	
				7/00/75	421.0	659.0	
				8/00/75	423.0	657.0	
				9/00/75	422.0	658.0	
01S/07W-14G01 S	36		1085.0	10/00/74	426.0	659.0	4702
				11/00/74	424.0	661.0	
				12/00/74	417.0	668.0	
				1/00/75	414.0	671.0	
				2/00/75	414.0	671.0	
				3/00/75	421.0	664.0	
				4/00/75	416.0	669.0	
				5/00/75	419.0	666.0	
				6/00/75	431.0	654.0	
				7/00/75	430.0	655.0	
				8/00/75	431.0	654.0	
				9/00/75	429.0	656.0	
01S/07W-17J01 S	36		1128.3	10/29/74	505.9	622.4	4748
				12/19/74	505.9	622.4	
				1/29/75	505.9	622.4	
				2/27/75	505.9	622.4	
				3/29/75	499.0	629.3	
				4/30/75	505.9	622.4	
01S/07W-18E01 S	36		1173.0	11/08/74	555.5	617.5	4228
01S/07W-18G01 S	36		1153.0	11/08/74	538.0	615.0	4228
01S/07W-19D01 S	36		1080.8	10/29/74	479.2	600.8	4748
				12/19/74	479.2	600.8	
				1/29/75	476.9	603.1	
				2/27/75	479.0	601.0	
				3/29/75	476.9	603.1	
				4/30/75	476.0	604.0	
				6/29/75	480.0	600.0	
				7/24/75	480.0	600.0	
				8/28/75	495.0(1)	585.0	
				9/30/75	486.2(1)	593.8	
01S/07W-19D02 S	36		1092.3	10/29/74	489.5	602.8	4748
				12/19/74	487.2	605.1	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA ANA RIVER HYDRO UNIT MIDDLE SANTA ANA RIV HYDR SUBUNIT CHINO HYDRO SUBAREA						Y-01 Y-01.8 Y-01.81	
01S/07W-19H02 S (CONTINUED)	36		1092.3	1/29/75	484.9	607.4	4748
				2/27/75	489.3	603.0	
				3/29/75	482.6	609.7	
				4/30/75	484.3	608.0	
				6/29/75	485.3	607.0	
				7/24/75	486.3	606.0	
				8/28/75	486.3	606.0	
				9/30/75	519.5(1)	572.8	
01S/07W-21C01 S	36		1053.0	11/08/74	433.0	620.0	4228
01S/07W-21N01 S	36		1056.0	11/08/74	454.3	601.7	4228
01S/07W-22R01 S	36		1020.0	11/08/74	367.0	653.0	4228
01S/07W-27D01 S	36		958.0	11/08/74	335.0	623.0	4228
01S/07W-28M02 S	36		937.0	11/08/74	347.0	590.0	4228
01S/07W-28R02 S	36		907.0	11/08/74	299.0	608.0	4228
01S/07W-29A01 S	36		962.0	11/08/74	340.0	622.0	4228
01S/07W-30D01 S	36		921.6	11/08/74	325.0	596.6	4228
01S/07W-30R01 S	36		930.4	11/08/74	336.9	593.5	4228
01S/07W-34A01 S	36		891.0	11/08/74	250.0	641.0	4228
01S/08W-01D02 S	36		1542.0	10/29/74	329.0	1213.0	3719
				11/30/74	323.0	1219.0	
				12/19/74	315.0	1227.0	
				1/19/75	315.5	1226.5	
				2/28/75	311.0	1231.0	
				3/31/75	308.5	1233.5	
				4/30/75	307.0	1235.0	
				5/30/75	347.5(1)	1194.5	
				6/30/75	347.5	1194.5	
				9/30/75	360.5(1)	1181.5	
01S/08W-02R01 S	36		1552.0	10/29/74	225.0	1327.0	1101
				11/30/74	235.5	1316.5	
				1/19/75	226.0	1326.0	3719
				2/28/75	226.0	1326.0	1101
				3/31/75	221.0	1331.0	
				4/30/75	221.0	1331.0	
				5/30/75	222.5	1329.5	
				6/30/75	222.5	1329.5	
				9/30/75	253.0	1299.0	
01S/08W-02W03 S	36		1396.7	11/15/74	80.1	1316.6	1101
				4/17/75	80.0	1316.7	
01S/08W-10R01 S	19		1300.0	10/21/74	481.4(5)	818.6	1101
				11/14/74	426.8(5)	873.2	
				12/14/74	495.8(1)	804.2	
				1/21/75	500.8(1)	799.2	
				2/14/75	500.8(1)	799.2	
				3/14/75	512.8(1)	787.2	
				4/14/75	516.8(1)	783.2	
				5/28/75	518.8(1)	781.2	
				6/21/75	508.8(1)	791.2	
				7/14/75	518.8(1)	781.2	
				8/21/75	516.8(1)	783.2	
				9/14/75	523.8(1)	776.2	
01S/08W-10N07 S	19		1149.0	10/21/74	336.1(1)	812.9	1101
				11/14/74	344.5(1)	804.5	
				12/07/74	350.5(1)	798.5	
				1/07/75	375.5(1)	773.5	
				2/14/75	358.5(1)	790.5	
				3/28/75	355.5(1)	793.5	
				4/14/75	348.5(1)	800.5	
				5/21/75	341.5(1)	807.5	
				6/21/75	343.5(1)	805.5	
				7/07/75	310.5(5)	838.5	
				8/21/75	348.5(1)	800.5	
				9/14/75	312.5(5)	836.5	
01S/08W-10N12 S	19		1137.6	10/21/74	377.8(1)	759.8	1101
				11/14/74	387.8(1)	749.8	
				12/14/74	390.8(1)	746.8	
				1/21/75	395.8(1)	741.8	
				2/14/75	393.8(1)	743.8	
				3/07/75	378.8(1)	758.8	
				4/14/75	393.8(1)	743.8	
				5/28/75	387.8(1)	749.8	
				6/21/75	355.8(5)	781.8	
				7/07/75	310.8(5)	826.8	
				8/07/75	361.8(5)	775.8	
				9/28/75	348.8(5)	788.8	
01S/08W-11P01 S	36		1219.9	11/04/74	617.0	602.9	4205
				5/22/75	627.0(1)	592.9	
01S/08W-12J01 S	36		1040.9	10/04/74	321.2	719.7	1101
				11/08/74	322.7	718.2	
				12/11/74	322.3	718.6	
				1/10/75	323.7	717.2	
				2/04/75	323.1	717.8	
				3/04/75	323.1	717.8	
				4/02/75	323.1	717.8	
SANTA ANA RIVER HYDRO UNIT MIDDLE SANTA ANA RIV HYDR SUBUNIT CHINO HYDRO SUBAREA						Y-01 Y-01.8 Y-01.81	
01S/08W-12J01 S (CONTINUED)	36		1040.9	5/07/75	322.9	718.0	1101
				6/11/75	320.5	720.4	
				7/09/75	324.8	716.1	
				8/12/75	326.8	714.1	
				9/11/75	327.7	713.2	
01S/08W-12K01 S	36		1255.0	12/19/74	637.0	618.0	3719
				1/19/75	630.0	625.0	
				2/28/75	632.0	623.0	
				3/31/75	634.0	621.0	
				4/30/75	634.0	621.0	
				5/30/75	634.0	621.0	
				6/30/75	634.0	621.0	
				9/30/75	639.0(1)	616.0	
01S/08W-12P01 S	36		1214.6	10/29/74	598.1	616.5	3719
				11/30/74	596.6	618.0	
				12/19/74	596.6	618.0	
				1/19/75	596.6	618.0	
				2/28/75	595.6	619.0	
				3/31/75	593.1	621.5	
				4/30/75	593.6	621.0	
				5/30/75	593.1	621.5	
				6/30/75	593.1	621.5	
				9/30/75	604.6	610.0	
01S/08W-13P01 S	36		1115.0	11/08/74	520.0	595.0	4228
01S/08W-14A02 S	36		1192.0	5/21/75	554.7	637.3	5125
01S/08W-14A03 S	36		1192.8	5/21/75	580.8	611.2	5125
01S/08W-14D01 S	36		1172.2	10/14/74	684.0(1)	488.2	1101
				12/17/74	686.6(1)	485.6	
				1/15/75	685.0(1)	487.2	
				2/12/75	636.0(5)	536.2	
				3/12/75	678.0(1)	494.2	
				4/18/75	666.0(1)	506.2	
				5/15/75	676.0(1)	496.2	
				6/20/75	685.6(1)	486.6	
				7/14/75	686.0(1)	486.2	
				8/14/75	687.0(1)	485.2	
01S/08W-14N01 S	36		1057.6	5/15/75	492.5(5)	565.1	1101
01S/08W-15H01 S	36		1125.8	10/14/74	548.6(5)	576.4	1101
				11/15/74	548.3(5)	576.7	
				4/18/75	533.0(5)	592.0	
				5/15/75	577.0(1)	548.0	
				6/20/75	544.0(5)	581.0	
				7/18/75	582.0(1)	543.0	
				9/17/75	590.0(1)	535.0	
01S/08W-15J01 S	36		1101.0	10/14/74	548.1(5)	552.9	1101
				12/17/74	545.5(5)	555.5	
				1/14/75	546.5(5)	554.5	
				3/12/75	544.5(5)	556.5	
				4/18/75	543.5(5)	557.5	
				5/19/75	547.5(5)	553.5	
				6/20/75	575.5(1)	525.5	
				7/18/75	552.5(5)	548.5	
				8/14/75	579.5(1)	521.5	
				9/17/75	577.5(1)	523.5	
01S/08W-15P02 S	36		1062.0	10/28/74	554.6(1)	507.4	1101
				12/14/74	366.0(5)	696.0	
				1/14/75	548.0(1)	514.0	
				2/21/75	408.0(1)	654.0	
				3/07/75	551.0(1)	511.0	
				4/14/75	547.0(1)	515.0	
				5/07/75	550.0(1)	512.0	
				6/21/75	550.0(1)	512.0	
				7/28/75	551.0(1)	511.0	
				8/21/75	553.0(1)	509.0	
				9/14/75	559.0(1)	503.0	
01S/08W-15Q02 S	36		1047.6	5/21/75	NM-9		5125
01S/08W-23A03 S	36		1073.0	5/21/75	473.0	600.0	5125
01S/08W-24E01 S	36		1031.5	5/21/75	454.7(1)	576.8	5125
01S/08W-25Q02 S	36		915.0	11/08/74	326.0	589.0	4228
01S/08W-26B01 S	36		980.0	5/21/75	409.0(1)	571.0	5125
01S/08W-27H01 S	36		935.0	5/21/75	NM-9		5125
01S/08W-28F01 S	19		882.0	10/01/74	399.7(1)	482.3	1101
				11/01/74	365.1(5)	516.9	
				12/01/74	379.0(5)	503.0	
				1/01/75	368.6(5)	513.4	
				2/01/75	351.2(5)	530.8	
				3/01/75	360.5(5)	521.5	
				4/01/75	353.5(5)	528.5	
				5/15/75	369.7(5)	512.3	
				6/01/75	384.7(1)	497.3	
				7/01/75	397.4(1)	484.6	
				8/01/75	457.5(1)	424.5	
				9/01/75	415.9(1)	466.1	
01S/08W-28F02 S	19		890.0	12/01/74	387.9(5)	502.1	1101

See page 79 for key to terms a abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

SANTA ANA RIVER HYDRO UNIT — Y-01
MIDDLE SANTA ANA RIV HYDR SUBUNIT — Y-01.8
CHINO HYDRO SUBAREA — Y-01.81

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
01S/08W-28E02 S (CONTINUED)	19		890.0	1/01/75	394.6(1)	495.4	1101
				2/01/75	356.4(5)	533.6	
				3/01/75	365.7(5)	524.3	
				4/01/75	355.3(5)	534.7	
				5/15/75	372.6(5)	517.4	
				6/01/75	371.4(5)	518.6	
				7/01/75	388.8(5)	501.2	
				8/01/75	424.6(1)	465.4	
				9/01/75	426.9(1)	463.1	
01S/08W-28F02 S	19		887.5	10/01/74	395.9(1)	491.6	1101
				11/01/74	380.9(1)	506.6	
				12/01/74	375.1(5)	512.4	
				1/01/75	367.0(5)	520.5	
				2/01/75	358.9(5)	528.6	
				3/01/75	373.9(1)	513.6	
				4/01/75	358.9(5)	528.6	
				5/15/75	383.2(1)	504.3	
				6/01/75	380.9(1)	506.6	
				7/01/75	394.7(1)	492.8	
				8/01/75	410.9(1)	476.6	
				9/01/75	413.2(1)	474.3	
01S/08W-28G01 S	19		894.0	10/01/74	380.6(5)	513.4	1101
				11/01/74	371.4(5)	522.6	
				12/01/74	377.2(5)	516.8	
				1/01/75	372.5(5)	521.5	
				2/01/75	366.8(5)	527.2	
				3/01/75	394.5(1)	499.5	
				4/01/75	355.2(5)	538.8	
				5/15/75	369.1(5)	524.9	
				6/01/75	366.8(5)	527.2	
				7/01/75	402.6(1)	491.4	
				8/01/75	411.8(1)	482.2	
				9/01/75	416.4(1)	477.6	
01S/08W-28G02 S	19		903.0	10/01/74	395.6(1)	507.4	1101
				11/01/74	374.8(5)	528.2	
				12/01/74	380.6(5)	522.4	
				1/01/75	376.0(5)	527.0	
				2/01/75	369.1(5)	533.9	
				3/01/75	384.1(1)	518.9	
				4/01/75	356.4(5)	546.6	
				5/15/75	370.2(5)	532.8	
				6/01/75	365.6(5)	537.4	
				7/01/75	379.5(5)	523.5	
				8/01/75	387.5(5)	515.5	
				9/01/75	410.6(1)	492.4	
01S/08W-28L01 S	19		873.7	10/01/74	386.1(1)	487.6	1101
				11/01/74	354.9(5)	518.8	
				12/01/74	365.3(5)	508.4	
				1/01/75	358.4(5)	515.3	
				2/01/75	350.3(5)	523.4	
				3/01/75	365.3(1)	508.4	
				4/01/75	335.3(5)	538.4	
				5/15/75	364.2(5)	509.5	
				6/01/75	359.6(5)	514.1	
				7/01/75	386.1(1)	487.6	
				8/01/75	393.0(1)	480.7	
				9/01/75	404.6(1)	469.1	
01S/08W-28M01 S	19		868.0	10/01/74	372.0(5)	496.0	1101
				11/01/74	353.5(5)	514.5	
				12/01/74	359.3(5)	508.7	
				1/01/75	354.7(5)	513.3	
				2/01/75	347.8(5)	520.2	
				3/01/75	348.9(5)	519.1	
				4/01/75	335.1(5)	532.9	
				5/15/75	368.6(5)	499.4	
				6/01/75	358.2(5)	509.8	
				7/01/75	374.3(5)	493.7	
				8/01/75	382.4(5)	485.6	
				9/01/75	407.8(1)	460.2	
01S/08W-28N02 S	19		870.1	10/01/74	369.1(5)	501.0	1101
				11/01/74	354.0(5)	516.1	
				12/01/74	359.8(5)	510.3	
				1/01/75	354.0(5)	516.1	
				2/01/75	347.1(5)	523.0	
				3/01/75	348.3(5)	521.8	
				4/01/75	337.9(5)	532.2	
				5/15/75	359.8(5)	510.3	
				6/01/75	356.4(5)	513.7	
				7/01/75	384.1(1)	486.0	
				8/01/75	393.3(1)	476.6	
				9/01/75	407.2(1)	462.9	
01S/08W-28N03 S	19		864.0	10/01/74	381.8(5)	482.2	1101
				11/01/74	347.0(5)	517.0	
				12/01/74	351.6(5)	512.4	
				1/01/75	349.3(5)	514.7	
				2/01/75	340.0(5)	524.0	
				3/01/75	341.2(5)	522.8	
				4/01/75	328.5(5)	535.5	
				5/15/75	379.3(1)	484.7	
				6/01/75	366.6(1)	497.4	
				7/01/75	379.3(1)	484.7	
				8/01/75	386.2(1)	477.8	
				9/01/75	397.8(1)	466.2	
01S/08W-28N01 S	19		857.0	10/01/74	384.2(1)	472.8	1101

SANTA ANA RIVER HYDRO UNIT — Y-01
MIDDLE SANTA ANA RIV HYDR SUBUNIT — Y-01.8
CHINO HYDRO SUBAREA — Y-01.81

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
01S/08W-28N01 S (CONTINUED)	19		857.0	11/01/74	337.1(5)	519.9	1101
				12/01/74	355.6(5)	501.4	
				1/01/75	341.7(5)	515.3	
				2/01/75	332.5(5)	524.5	
				3/01/75	333.6(5)	523.4	
				4/01/75	324.4(5)	532.6	
				5/15/75	347.5(5)	509.5	
				6/01/75	347.5(5)	509.5	
				7/01/75	359.0(5)	498.0	
				8/01/75	367.1(5)	489.9	
				9/01/75	387.9(1)	469.1	
01S/08W-28N02 S	19		859.0	10/01/74	360.5(5)	498.5	1101
				11/01/74	343.2(5)	515.8	
				12/01/74	360.6(5)	498.4	
				1/01/75	347.8(5)	511.2	
				2/01/75	351.3(5)	507.7	
				3/01/75	339.0(5)	520.0	
				4/01/75	327.4(5)	531.6	
				5/15/75	378.2(5)	480.8	
				6/01/75	369.0(1)	490.0	
				7/01/75	380.5(1)	478.5	
				8/01/75	386.3(1)	472.7	
				9/01/75	395.6(1)	463.4	
01S/08W-29F02 S	19		872.0	11/12/74	316.4	555.6	1101
				4/07/75	308.7	563.3	
01S/08W-29H02 S	19		886.0	11/18/74	339.2(9)	546.8	1101
				4/10/75	340.5(8)	545.5	
01S/08W-30K01 S	19		844.6	10/01/74	260.4(5)	584.2	1101
				11/01/74	260.4(5)	584.2	
				12/01/74	261.6(5)	583.0	
				1/01/75	262.7(5)	581.9	
				2/01/75	260.4(5)	584.2	
				3/01/75	259.7(5)	584.9	
				4/01/75	261.8(5)	582.8	
				5/01/75	261.6(5)	583.0	
				6/01/75	261.6(5)	583.0	
				7/01/75	260.2(5)	584.4	
				8/01/75	260.4(5)	584.2	
				9/01/75	259.3(5)	585.3	
01S/08W-31J01 S	19		808.0	10/01/74	204.0(1)	604.0	1101
				11/01/74	205.1(1)	602.9	
				12/01/74	189.0(5)	619.0	
				1/01/75	187.8(5)	620.2	
				2/01/75	208.6(1)	599.4	
				3/01/75	210.9(1)	597.1	
				4/01/75	191.3(5)	616.7	
				5/15/75	216.7(1)	591.3	
				6/01/75	217.8(1)	590.2	
				7/01/75	191.3(5)	616.7	
				8/01/75	201.7(1)	606.3	
				9/01/75	201.7(1)	606.3	
01S/08W-31Q01 S	19		783.0	10/04/74	133.8	649.2	1101
				11/08/74	134.3	648.7	
				12/13/74	134.1	648.9	
				1/10/75	135.8	647.2	
				2/06/75	136.0	647.0	
				3/06/75	135.7	647.3	
				4/10/75	136.7	646.3	
01S/08W-32G01 S	19		816.5	10/01/74	309.6(1)	506.9	1101
				11/01/74	303.8(1)	512.7	
				12/01/74	279.6(5)	536.9	
				1/01/75	279.6(5)	536.9	
				2/01/75	308.4(1)	508.1	
				3/01/75	306.1(1)	510.4	
				4/01/75	280.7(5)	535.8	
				5/15/75	311.9(1)	504.6	
				6/01/75	311.9(1)	504.6	
				7/01/75	322.3(1)	494.2	
				8/01/75	303.8(1)	512.7	
				9/01/75	303.8(1)	512.7	
01S/08W-32P05 S	19		797.0	11/12/74	271.6	525.4	1101
				4/10/75	239.0(3)	558.0	
01S/08W-33C01 S	36		836.6	1/01/75	303.6(5)	533.0	1101
				2/01/75	351.0(1)	485.6	
				3/01/75	351.0(1)	485.6	
				4/01/75	301.3(5)	535.3	
				5/15/75	357.9(1)	478.7	
				6/01/75	354.4(1)	482.2	
				7/01/75	367.2(1)	469.4	
				8/01/75	369.5(1)	467.1	
				9/01/75	376.4(1)	460.2	
01S/08W-33D01 S	19		840.4	10/01/74	406.7(1)	433.9	1101
				11/01/74	403.2(1)	437.4	
				12/01/74	331.6(5)	509.0	
				1/01/75	388.2(1)	452.4	
				2/01/75	383.6(1)	457.0	
				3/01/75	391.7(1)	448.9	
				4/01/75	312.0(5)	528.6	
				5/15/75	400.9(1)	439.7	
				6/01/75	403.2(1)	437.4	
				7/01/75	424.0(1)	416.6	
				8/01/75	344.3(5)	496.3	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA ANA RIVER HYDRO UNIT MIDDLE SANTA ANA RIV HYDR SUBUNIT CHINO HYDRO SUBAREA						Y-01 Y-01.8 Y-01.81	
01S/08W-33D01 S	19		840.6	9/01/75	344.3(5)	496.3	1101
01S/08W-33F03 S	19		831.8	10/01/74	364.1(1)	467.7	1101
				11/01/74	354.9(1)	476.9	
				12/01/74	319.1(5)	512.7	
				1/01/75	304.0(5)	527.8	
				2/01/75	351.4(1)	480.4	
				3/01/75	353.7(1)	478.1	
				4/01/75	299.4(5)	532.4	
				5/15/75	364.1(1)	467.7	
				6/01/75	359.5(1)	472.3	
				7/01/75	375.7(1)	456.1	
				8/01/75	373.4(1)	458.4	
				9/01/75	380.3(1)	451.5	
01S/08W-33L06 S	19		816.3	10/04/74	290.3	526.0	1101
				11/08/74	298.3	518.0	
				12/11/74	282.8	533.5	
				1/10/75	327.8(6)	488.5	
				2/06/75	284.8	531.5	
				3/06/75	284.6	531.7	
				4/02/75	283.1	533.2	
				5/07/75	284.9	531.4	
				6/11/75	291.8	524.5	
				7/09/75	293.9	522.4	
				8/12/75	298.6	517.7	
				9/11/75	297.6	518.7	
01S/08W-34A01 S	36		868.0	5/21/75	363.0	505.0	5125
02S/05W-07F01 S	33		900.0	10/21/74	40.1	859.9	5103
				3/26/75	41.4	858.6	
02S/05W-07H01 S	33		851.0	12/16/74	19.1	831.9	3718
				5/06/75	NM-7		
02S/05W-07R03 S	33		878.0	12/30/74	15.5	862.5	3718
				5/07/75	15.3	862.7	
02S/05W-18C02 S	33		861.0	12/16/74	43.7	817.3	3718
				5/07/75	46.1	814.9	
02S/05W-19Q01 S	33		847.0	12/12/74	46.9	800.1	3718
				5/02/75	50.2	796.8	
02S/05W-20H05 S	33		743.8	3/26/75	5.8	738.0	5103
02S/06W-01Q01 S	33		880.0	10/21/74	42.2	837.8	5103
				3/26/75	42.5	837.5	
02S/06W-05R01 S	33		845.3	10/21/74	201.3	644.0	5103
				4/01/75	200.9	644.4	
02S/06W-05R02 S	33		830.0	10/21/74	203.5	626.5	5103
				4/01/75	203.3	626.7	
02S/06W-06N02 S	33		806.0	10/21/74	NM-1		5103
				4/01/75	189.3	616.7	
02S/06W-08D03 S	33		782.0	10/21/74	163.3	618.7	5103
				4/01/75	169.3	612.7	
02S/06W-10N02 S	33		745.0	11/30/74	137.9	607.1	8208
				4/30/75	137.9	607.1	
02S/06W-10N03 S	33		745.0	11/30/74	138.8	606.2	8208
				4/30/75	137.8	607.2	
02S/06W-10N04 S	33		745.0	11/30/74	138.4	606.6	8208
				4/30/75	138.4	606.6	
02S/06W-11J02 S	33		770.0	12/16/74	25.8	744.2	3718
				5/06/75	25.7	744.3	
02S/06W-11K03 S	33		755.0	12/13/74	23.0	732.0	3718
				5/06/75	21.4	733.6	
02S/06W-11Q01 S	33		745.0	12/16/74	25.7	719.3	3718
				5/06/75	25.7	719.3	
02S/06W-12L01 S	33		817.0	12/16/74	49.8	767.2	3718
				5/06/75	51.4	765.6	
02S/06W-12M03 S	33		795.9	10/21/74	23.9	772.0	5103
				12/16/74	24.0	771.9	3718
				3/26/75	24.9	771.0	5103
				5/06/75	25.2	770.7	3718
02S/06W-13B04 S	33		784.5	12/16/74	26.9	757.6	3718
				5/07/75	27.0	757.5	
02S/06W-13B06 S	33		783.0	12/30/74	34.0	749.0	3718
				5/05/75	35.5	747.5	
02S/06W-13C06 S	33		774.0	12/16/74	32.4	741.6	3718
				5/07/75	32.9	741.1	
02S/06W-13C07 S	33		775.0	12/16/74	NM-1		3718
				5/07/75	NM-1		
02S/06W-13F01 S	33		764.0	12/13/74	30.6	733.4	3718
				5/05/75	30.9	733.1	
SANTA ANA RIVER HYDRO UNIT MIDDLE SANTA ANA RIV HYDR SUBUNIT CHINO HYDRO SUBAREA						Y-01 Y-01.8 Y-01.81	
02S/06W-13F02 S	33		755.0	12/13/74	20.8	734.2	3718
				5/07/75	21.1	733.9	
02S/06W-13F03 S	33		770.0	12/13/74	32.8	737.2	3718
				5/05/75	33.0	737.0	
02S/06W-13F05 S	33		775.8	12/13/74	42.6	733.2	3718
				5/05/75	41.8	734.0	
02S/06W-13G03 S	33		775.0	12/16/74	32.9	742.1	3718
				5/07/75	33.1	741.9	
02S/06W-13M02 S	33		753.0	12/13/74	23.5	729.5	3718
				5/07/75	23.4	729.6	
02S/06W-13M03 S	33		753.0	12/30/74	22.8	730.2	3718
				5/07/75	22.8	730.2	
02S/06W-14C02 S	33		734.5	12/16/74	31.4	703.1	3718
				5/06/75	32.4	702.1	
02S/06W-14G02 S	33		734.0	12/16/74	24.1	709.9	3718
				5/06/75	24.0	710.0	
02S/06W-14H02 S	33		737.0	12/12/74	20.2	716.8	3718
				5/05/75	20.7	716.3	
02S/06W-14L01 S	33		711.0	12/16/74	13.5	697.5	3718
				5/06/75	13.3	697.7	
02S/06W-16R02 S	33		727.6	12/17/74	121.9	605.7	3718
				5/07/75	120.7	606.9	
02S/06W-16D02 S	33		735.0	12/17/74	131.6	603.4	3718
				5/07/75	129.7	605.3	
02S/06W-21D03 S	33		712.2	10/21/74	109.8	602.4	5103
				11/13/74	110.1	602.1	
				12/09/74	108.8	603.4	
				3/26/75	107.3	604.9	
			711.1	5/13/75	NM-1		3718
			712.2	7/03/75	NM-9		5103
				8/07/75	NM-1		
				9/11/75	NM-1		
02S/06W-21F01 S	33		665.1	12/30/74	91.3	573.8	3718
				5/13/75	89.6	575.5	
02S/06W-22G01 S	33		698.0	10/21/74	NM-1		5103
				3/26/75	41.7	650.3	
02S/06W-23A01 S	33		748.0	12/12/74	43.6	704.4	3718
				5/05/75	41.7	706.3	
02S/06W-23G01 S	33		707.0	10/21/74	49.4	657.6	5103
				12/23/74	44.3	662.7	3718
				4/01/75	35.8	671.2	5103
				5/08/75	40.3	666.7	3718
02S/06W-23G04 S	33		708.6	12/23/74	44.9	663.7	3718
				5/08/75	41.0	667.6	
02S/06W-25C01 S	33		736.0	12/12/74	20.4	715.6	3718
				5/02/75	18.6	717.4	
02S/06W-26D01 S	33		684.1	12/23/74	53.3	630.8	3718
				5/08/75	51.8	632.3	
02S/06W-26D02 S	33		686.0	10/21/74	73.2	612.8	5103
				12/23/74	55.2	630.8	3718
				4/01/75	52.3	633.7	5103
				5/08/75	53.6	632.4	3718
02S/06W-27A01 S	33		686.0	12/17/74	19.9	666.1	3718
				5/07/75	19.7	666.3	
02S/06W-27D04 S	33		640.0	12/17/74	23.6	616.4	3718
				5/07/75	23.3	616.7	
02S/06W-28F01 S	33		626.0	10/21/74	NM-9		5103
				11/13/74	13.0	613.0	
				12/09/74	12.9	613.1	
				3/26/75	13.0	613.0	
				5/30/75	13.2	612.8	
02S/06W-30P03 S	33		617.7	10/21/74	27.4	590.3	5103
				11/13/74	27.2	590.5	
				12/09/74	NM-9		
				4/01/75	29.7	588.0	
				5/30/75	30.0	587.7	
				7/03/75	NM-8		
				8/07/75	28.0	589.7	
				9/11/75	26.0	591.7	
02S/06W-31C01 S	33		601.0	10/21/74	33.1	567.9	5103
				11/13/74	32.3	568.7	
				12/09/74	NM-9		
				4/01/75	28.5	572.5	
				5/30/75	29.2	571.8	
				7/03/75	32.8	568.2	
				8/07/75	NM-8		

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA ANA RIVER HYDRO UNIT MIDDLE SANTA ANA RIV HYDR SUBUNIT CHINO HYDRO SUBAREA						Y-01 Y-01.8 Y-01.81	
02S/06W-31C01 S	33		601.0	9/11/75	NM-8		5103
02S/06W-31D01 S	33		628.6	10/21/74	59.0(4)	569.6	5103
				4/01/75	53.9	574.7	
02S/06W-33F01 S	33		715.9	12/17/74	54.6	661.3	3718
				5/08/75	50.3	665.6	
02S/06W-33F02 S	33		743.6	12/17/74	33.8	709.8	3718
				5/08/75	33.4	710.2	
02S/07W-25M01 S	33		624.4	10/21/74	NM-8		5103
				4/01/75	53.1	571.3	
02S/07W-27P01 S	33		617.4	10/18/74	NM-1		5103
				3/28/75	49.2(4)	568.2	
02S/07W-34M01 S	33		595.5	10/18/74	42.8	552.7	5103
				3/28/75	33.1	562.4	
02S/07W-34J01 S	33		585.2	10/18/74	NM-1		5103
				3/28/75	NM-1		
02S/07W-34R01 S	33		580.9	10/18/74	NM-8		5103
				3/28/75	NM-2		
02S/07W-35C02 S	33		613.1	10/18/74	56.3	556.8	5103
				3/28/75	46.8	566.3	
02S/07W-36A07 S	33		627.0	1/10/75	53.0	574.0	8027
02S/07W-36D01 S	33		611.6	10/21/74	51.4	560.2	5103
				4/01/75	44.3	567.3	
02S/07W-36F01 S	33		601.5	10/18/74	NM-1		5103
				4/01/75	37.6	563.9	
02S/07W-36H02 S	33		615.0	1/10/75	31.0	584.0	8027
				6/10/75	31.6	583.4	
02S/07W-36L01 S	33		570.5	10/21/74	NM-7		5103
02S/07W-36M02 S	33		613.1	10/18/74	57.1	556.0	5103
				4/01/75	52.2	560.9	
02S/08W-04P01 S	19		745.5	10/04/74	215.0	530.5	1101
				11/08/74	210.5	535.0	
				12/11/74	211.8	533.7	
				1/16/75	210.9	534.6	
				2/06/75	210.1	535.4	
				3/06/75	209.2	536.3	
				4/02/75	NM-0		
				5/07/75	208.2	537.3	
				6/11/75	213.3	532.2	
				7/09/75	215.2	530.3	
				8/12/75	216.8	528.7	
				9/17/75	217.5	528.0	
02S/08W-05G01 S	19		775.0	11/12/74	234.2	540.8	1101
				4/07/75	232.9	542.1	
02S/08W-05M01 S	19		763.0	10/04/74	20.7	742.3	1101
				11/08/74	23.1	739.9	
				12/11/74	21.1	741.9	
				1/10/75	23.2	739.8	
02S/08W-11L01 S	36		710.0	5/19/75	170.2	539.8	1437
02S/08W-11M01 S	36		746.0	5/19/75	170.0	576.0	1437
03S/07W-03J01 S	33		581.0	10/18/74	NM-1		5103
				3/28/75	41.0	540.0	
03S/07W-03N01 S	33		561.5	10/18/74	NM-1		5103
				3/28/75	33.9	527.6	
03S/07W-08L01 S	33		533.4	10/18/74	43.1	490.3	5103
				11/13/74	43.0	490.4	
				12/09/74	42.7	490.7	
				3/28/75	42.3	491.1	
				5/30/75	42.5	490.9	
				7/03/75	42.7	490.7	
				8/06/75	42.6	490.8	
				9/11/75	43.0	490.4	
03S/07W-09J01 S	33		515.0	10/18/74	10.2	504.8	5103
				3/28/75	8.0	507.0	
03S/07W-10D01 S	33		553.6	10/18/74	32.4	521.2	5103
				3/28/75	31.6	522.0	
03S/07W-11F01 S	33		578.0	1/10/75	45.0	533.0	8027
				6/10/75	52.0	526.0	
HARRISON HYDRO SUBAREA						Y-01.82	
01S/08W-08H01 S	19		1176.0	10/01/74	360.3(5)	815.7	1101
				11/01/74	351.0(5)	825.0	
				12/01/74	340.6(5)	835.4	
				1/01/75	331.4(5)	844.6	
				2/01/75	326.8(5)	849.2	
				3/01/75	319.8(5)	856.2	
SANTA ANA RIVER HYDRO UNIT MIDDLE SANTA ANA RIV HYDR SUBUNIT HARRISON HYDRO SUBAREA						Y-01 Y-01.8 Y-01.82	
01S/08W-08H01 S (CONTINUED)	19		1176.0	4/01/75	309.5(5)	866.5	1101
				5/15/75	318.7(5)	857.3	
				6/01/75	321.0(5)	855.0	
				7/01/75	340.6(5)	835.4	
				8/01/75	470.0(1)	706.0	
				9/01/75	400.7(1)	775.3	
01S/08W-09D01 S	19		1225.0	10/01/74	381.2(1)	843.8	1101
				11/01/74	330.4(5)	894.6	
				12/01/74	322.3(5)	902.7	
				1/01/75	318.8(5)	906.2	
				2/01/75	316.5(5)	908.5	
				3/01/75	311.9(5)	913.1	
				4/01/75	308.4(5)	916.6	
				5/15/75	309.6(5)	915.4	
				6/01/75	315.4(5)	909.6	
				7/01/75	313.1(5)	911.9	
				8/01/75	374.3(1)	850.7	
				9/01/75	392.8(1)	832.2	
01S/08W-09E01 S	19		1202.0	10/21/74	212.0(5)	990.0	1101
				11/28/74	300.0(5)	902.0	
				12/21/74	287.0(5)	915.0	
				1/23/75	373.0(1)	829.0	
				2/14/75	298.0(5)	904.0	
				3/21/75	300.0(5)	902.0	
				4/14/75	288.0(5)	914.0	
				5/14/75	355.0(1)	847.0	
			1201.0	6/07/75	378.0(1)	823.0	
				7/07/75	376.0(1)	825.0	
				8/21/75	386.0(1)	815.0	
				9/21/75	407.0(1)	794.0	
01S/08W-09F05 S	19		1176.0	1/21/75	351.3(1)	824.7	1101
				2/14/75	303.3(5)	872.7	
				3/14/75	298.3(5)	877.7	
				4/14/75	328.3(1)	847.7	
				5/21/75	340.3(1)	835.7	
				6/21/75	348.3(1)	827.7	
				7/21/75	345.3(1)	830.7	
				8/21/75	348.3(1)	827.7	
				9/21/75	368.3(1)	807.7	
01S/08W-09G03 S	19		1188.0	10/21/74	60.6(1)	1127.4	1101
				11/07/74	52.0(5)	1136.0	
				12/14/74	61.0(1)	1127.0	
				1/14/75	60.5(1)	1127.5	
				2/14/75	62.0(1)	1126.0	
				3/28/75	50.0(5)	1138.0	
				4/14/75	63.0(1)	1125.0	
				5/28/75	65.0(1)	1123.0	
				6/21/75	63.0(1)	1125.0	
				7/14/75	66.0(1)	1122.0	
				8/14/75	68.0(1)	1120.0	
				9/21/75	70.0(1)	1118.0	
01S/08W-09H01 S	19		1230.0	10/03/74	286.4	943.6	1101
				12/11/74	285.0	945.0	
				1/10/75	285.0	945.0	
				2/07/75	286.1	943.9	
				3/06/75	284.9	945.1	
				4/17/75	282.5	947.5	
01S/08W-09H03 S	19		1230.0	10/03/74	78.3	1151.7	1101
				12/11/74	78.5	1151.5	
				1/10/75	78.3	1151.7	
				2/07/75	80.6	1149.4	
				3/06/75	79.1	1150.9	
				4/17/75	79.5	1150.5	
01S/08W-09L01 S	19		1174.0	6/17/75	NM-0		1101
				7/14/75	291.5(1)	882.5	
				8/07/75	298.5(1)	875.5	
				9/21/75	307.5(1)	866.5	
01S/08W-09M01 S	19		1154.0	10/07/74	280.1(5)	873.9	1101
				11/07/74	290.5(5)	863.5	
				12/14/74	323.5(1)	830.5	
				1/07/75	266.5(5)	887.5	
				3/21/75	253.5(5)	900.5	
				4/14/75	248.5(5)	905.5	
				5/21/75	266.5(5)	887.5	
				6/21/75	328.5(1)	825.5	
				7/21/75	327.5(1)	826.5	
				8/07/75	331.5(1)	822.5	
				9/07/75	363.5(1)	790.5	
01S/08W-09P01 S	19		1118.0	11/12/74	299.0	819.0	1101
01S/08W-16R01 S	19		1114.0	10/21/74	403.5(1)	710.5	1101
				11/14/74	420.5(5)	693.5	
				6/07/75	350.5(1)	763.5	
				7/14/75	367.5(1)	746.5	
				8/21/75	373.5(1)	740.5	
				9/21/75	384.5(1)	729.5	
01S/08W-16F01 S	19		1062.0	11/12/74	256.3	805.7	1101
				5/08/75	237.6	824.4	
01S/08W-17K01 S	19		1015.0	11/01/74	457.7	557.3	1101
				12/01/74	430.0	585.0	
				1/15/75	401.0	614.0	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA ANA RIVER HYDRO UNIT						Y-01	
MIDDLE SANTA ANA RIV HYDR SUBUNIT						Y-01.8	
HARRISON HYDRO SUBAREA						Y-01.82	
01S/08W-17K01 S (CONTINUED)	19		1015.0	2/01/75	396.0	619.0	1101
				3/01/75	386.1	628.9	
				4/01/75	409.2(1)	605.8	
				5/01/75	373.4	641.6	
				6/01/75	382.6	632.4	
				7/01/75	438.1(1)	576.9	
				8/01/75	461.2(1)	553.8	
				9/01/75	475.0	540.0	
01S/08W-17K02 S	19		999.4	10/01/74	538.3(1)	461.1	1101
				11/01/74	540.6(1)	458.8	
				12/01/74	440.1(5)	559.3	
				1/01/75	420.4(5)	579.0	
				2/01/75	398.5(5)	600.9	
				3/01/75	391.6(5)	607.8	
				4/01/75	384.6(5)	614.8	
				5/15/75	380.0(5)	619.4	
				6/01/75	389.3(5)	610.1	
				7/01/75	398.5(5)	600.9	
				8/01/75	495.5(1)	503.9	
				9/01/75	504.8(1)	494.6	
01S/08W-17K03 S	19		999.4	11/08/74	NM-2		1101
				4/21/75	215.4	784.0	
01S/08W-17P02 S	19		969.1	11/12/74	182.4	786.7	1101
				4/07/75	NM-1		
01S/08W-17P04 S	19		991.2	10/01/74	633.5(1)	357.7	1101
				11/01/74	593.1(5)	398.1	
				12/01/74	575.8(5)	415.4	
				1/01/75	558.4(5)	432.8	
				2/01/75	548.0(5)	443.2	
				3/01/75	540.0(5)	451.2	
				4/01/75	527.3(5)	463.9	
				5/15/75	448.2(5)	543.0	
				6/01/75	448.2(5)	543.0	
				7/01/75	507.6(1)	483.6	
				8/11/75	521.5(1)	469.7	
				9/01/75	526.1(1)	465.1	
01S/08W-20R02 S	19		948.0	11/27/74	NM-7		1101
				4/07/75	NM-7		
CLAREMONT HEIGHTS HYDRO SUBAREA						Y-01.83	
01N/08W-24E01 S	36		2141.7	10/01/74	143.0(5)	1998.7	1101
				11/04/74	144.0(5)	1997.7	
				12/18/74	142.0(5)	1999.7	
				1/03/75	143.0(5)	1998.7	
				2/05/75	143.0(5)	1998.7	
				3/04/75	143.0(5)	1998.7	
				4/03/75	145.0(5)	1996.7	
				5/22/75	140.0(5)	2001.7	
				6/06/75	143.0(5)	1998.7	
				7/03/75	143.0(5)	1998.7	
				8/01/75	142.0(5)	1999.7	
				9/04/75	143.0(5)	1998.7	
01N/08W-24L01 S	36		2137.6	10/01/74	207.0(5)	1930.6	1101
				11/04/74	206.0(5)	1931.6	
				12/18/74	207.0(5)	1930.6	
				1/03/75	207.0(5)	1930.6	
				2/05/75	207.0(5)	1930.6	
				3/04/75	207.0(5)	1930.6	
				4/03/75	207.0(5)	1930.6	
				5/22/75	205.0(5)	1932.6	
				6/06/75	206.0(5)	1931.6	
				7/03/75	208.0(5)	1929.6	
				8/01/75	208.0(5)	1929.6	
				9/04/75	208.0(5)	1929.6	
01N/08W-25K02 S	36		1855.0	1/07/75	NM-0		1101
				7/03/75	252.0(5)	1603.0	
				8/01/75	334.0(1)	1521.0	
				9/04/75	347.0(1)	1508.0	
01N/08W-25L01 S	36		1861.6	10/29/74	242.6	1619.0	3719
				11/30/74	205.6	1656.0	
				12/19/74	224.6	1637.0	
				1/19/75	226.6	1635.0	
				2/28/75	221.6	1640.0	
				3/31/75	224.6	1637.0	
				4/30/75	221.6	1640.0	
				5/30/75	238.6	1623.0	
				6/30/75	247.6	1614.0	
				9/30/75	429.6(1)	1432.0	
01N/08W-25M01 S	36		1864.9	10/29/74	231.0	1633.9	1101
				11/30/74	241.0	1623.9	
				12/19/74	223.0	1641.9	
				1/19/75	227.0	1637.9	3719
				2/28/75	226.0	1638.9	1101
				3/31/75	227.0	1637.9	
				4/30/75	227.0	1637.9	
				5/30/75	228.5	1636.4	
				6/30/75	235.0	1629.9	
				9/30/75	241.0	1623.9	
01N/08W-25N01 S	36		1831.7	11/15/74	201.3	1630.4	1101
				4/11/75	188.6	1643.1	
01N/08W-26P01 S	36		1740.3	10/03/74	266.0	1474.3	1101
01N/08W-26P01 S (CONTINUED)	36		1740.3	12/11/74	265.5	1474.8	1101
				1/09/75	267.0	1473.3	
				2/07/75	268.9	1471.4	
				3/06/75	267.7	1472.6	
				4/01/75	271.3	1469.0	
				5/07/75	268.3	1472.0	
				6/10/75	270.6	1469.7	
				7/09/75	270.5	1469.8	
				8/12/75	271.2	1469.1	
				9/11/75	271.0	1469.3	
01N/08W-34A01 S	19		1670.0	11/14/74	NM-1		1101
				4/11/75	NM-9		
01N/08W-34A02 S	19		1648.0	10/03/74	NM-1		1101
				12/11/74	216.8(8)	1431.2	
				1/09/75	216.0(8)	1432.0	
				2/07/75	219.4	1428.6	
				3/06/75	217.3	1430.7	
				4/11/75	215.9	1432.1	
01N/08W-34A03 S	19		1635.0	10/03/74	NM-2		1101
				12/13/74	NM-2		
				3/06/75	255.1	1379.9	
				4/17/75	258.0	1377.0	
01N/08W-34H01 S	19		1589.0	11/14/74	228.1	1360.9	1101
				4/11/75	221.8	1367.2	
01N/08W-34K01 S	19		1518.0	11/14/74	NM-2		1101
				4/14/75	NM-9		
				5/30/75	NM-1		
01N/08W-34L01 S	19		1503.0	4/14/75	NM-9		1101
				5/30/75	NM-1		
01N/08W-35F01 S	36		1631.0	11/15/74	NM-1		1101
				4/11/75	276.3	1354.7	
01N/08W-35J01 S	36		1613.0	10/29/74	302.0	1311.0	1101
				11/30/74	362.0	1256.0	
				12/19/74	296.0	1322.0	
				1/29/75	295.0	1323.0	
				2/27/75	300.0	1318.0	
				3/29/75	289.0	1329.0	
				4/30/75	289.0	1329.0	
				5/29/75	292.0	1326.0	
				6/29/75	292.0	1326.0	
				7/29/75	303.0	1315.0	
				8/28/75	402.0(1)	1216.0	
				9/30/75	382.0(1)	1236.0	
01N/08W-35K01 S	36		1638.0	11/30/74	401.0	1237.0	1101
				12/19/74	311.0	1327.0	
				1/29/75	307.5	1330.5	
				2/27/75	303.0	1335.0	
				3/29/75	301.5	1336.5	
				4/30/75	301.0	1337.0	
				5/29/75	306.0	1332.0	
				6/29/75	307.0	1331.0	
				7/29/75	315.5	1322.5	
				8/28/75	407.0(1)	1231.0	
				9/30/75	407.0(1)	1231.0	
01N/08W-35K02 S	36		1635.0	10/29/74	320.0	1315.0	4748
				12/19/74	311.0	1324.0	
				1/29/75	307.5	1327.5	
				2/27/75	303.0	1332.0	
				3/29/75	301.5	1333.5	
				4/30/75	301.0	1334.0	
				6/29/75	307.0	1328.0	
				7/24/75	315.5	1319.5	
				8/28/75	407.0(1)	1228.0	
				9/30/75	407.0(1)	1228.0	
01N/08W-36D01 S	36		1760.0	11/15/74	276.0	1484.0	1101
				4/11/75	273.8	1486.2	
01S/08W-02B02 S	36		1550.0	10/29/74	225.0	1325.0	1101
				11/30/74	230.0	1320.0	
				12/19/74	230.5	1319.5	
			1549.3	1/19/75	222.3	1327.0	3719
			1550.0	2/28/75	223.0	1327.0	1101
				3/31/75	218.0	1332.0	
				4/30/75	218.0	1332.0	
				5/30/75	219.5	1330.5	
				6/30/75	219.5	1330.5	
				9/30/75	302.0(1)	1248.0	
01S/08W-02D01 S	36		1481.8	10/29/74	166.3	1315.5	3719
				11/30/74	177.8	1304.0	
				12/19/74	160.3	1321.5	
				1/19/75	159.8	1322.0	
				2/28/75	160.3	1321.5	
				3/31/75	160.3	1321.5	
				4/30/75	159.3	1322.5	
				6/30/75	174.3(1)	1307.5	
				9/30/75	175.3(1)	1306.5	
01S/08W-02D02 S	36		1476.1	10/03/74	169.6(2)	1306.5	1101
				12/11/74	154.2	1321.9	
				1/10/75	153.0	1323.1	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA ANA RIVER HYDRO UNIT MIDDLE SANTA ANA RIV HYDR SUBUNIT CLAREMONT HEIGHTS HYDRO SUBAREA						Y-01 Y-01.8 Y-01.83	
01S/08W-02D02 S (CONTINUED)	36		1476.1	2/07/75	153.6	1322.5	1101
				3/03/75	153.2	1322.9	
				4/01/75	151.4	1324.7	
				5/07/75	152.0	1324.1	
				6/10/75	161.8	1314.3	
				7/09/75	170.9(2)	1305.2	
				8/12/75	175.0(2)	1301.1	
				9/11/75	176.9(2)	1299.2	
01S/08W-02F01 S	36		1470.0	10/29/74	140.0	1330.0	3719
				11/30/74	142.5	1327.5	
				12/19/74	140.0	1330.0	
				1/19/75	141.5	1328.5	
				2/28/75	142.0	1328.0	
				3/31/75	140.0	1330.0	
				4/30/75	146.0(1)	1324.0	
				9/30/75	161.0(1)	1309.0	
01S/08W-03A01.S	19		1511.8	11/15/74	184.3	1327.5	1101
				4/14/75	183.3	1328.5	
01S/08W-03F01 S	19		1372.0	10/01/74	184.3(6)	1187.7	1101
				11/01/74	184.3(6)	1187.7	
				12/01/74	184.3(6)	1187.7	
				1/01/75	184.3(5)	1187.7	
				2/01/75	185.5(5)	1186.5	
				3/01/75	185.5(5)	1186.5	
				4/01/75	183.1(5)	1188.9	
				5/15/75	183.1(5)	1188.9	
				6/01/75	187.8(5)	1184.2	
				7/01/75	187.8(5)	1184.2	
				8/01/75	185.5(5)	1186.5	
				9/01/75	186.6(5)	1185.4	
01S/08W-03F02 S	19		1374.5	10/01/74	216.2(1)	1158.3	1101
				11/01/74	225.5(1)	1149.0	
				12/01/74	118.0(5)	1256.5	
				1/01/75	112.3(5)	1262.2	
				2/01/75	208.1(1)	1166.4	
				3/01/75	212.7(1)	1161.8	
				4/01/75	213.9(1)	1160.6	
				5/15/75	169.8(1)	1204.7	
				6/01/75	220.8(1)	1153.7	
				7/01/75	223.1(1)	1151.4	
				8/01/75	232.4(1)	1142.1	
				9/01/75	238.2(1)	1136.3	
01S/08W-03F03 S	19		1377.5	10/01/74	214.1(1)	1163.4	1101
				11/01/74	216.4(1)	1161.1	
				12/01/74	119.4(5)	1258.1	
				1/01/75	117.0(5)	1260.5	
				2/01/75	208.1(1)	1169.4	
				3/01/75	206.0(1)	1171.5	
				4/01/75	209.4(1)	1168.1	
				5/15/75	207.1(1)	1170.4	
				6/01/75	212.9(1)	1164.6	
				7/01/75	216.4(1)	1161.1	
				8/01/75	219.8(1)	1157.7	
				9/01/75	224.5(1)	1153.0	
01S/08W-03G04 S	19		1442.0	10/03/74	125.4	1316.6	1101
				12/11/74	126.6	1315.4	
				1/10/75	126.0	1316.0	
				2/07/75	127.1	1314.9	
				3/06/75	126.6	1315.4	
				4/01/75	125.0	1317.0	
				5/07/75	124.5	1317.5	
				6/10/75	128.7	1313.3	
				7/09/75	131.5	1310.5	
				8/12/75	135.7(6)	1306.3	
				9/11/75	137.8	1304.2	
01S/08W-03J01 S	19		1411.2	11/15/74	85.7	1325.5	1101
				4/17/75	86.0	1325.2	
01S/08W-03L02 S	19		1344.0	10/03/74	89.1	1254.9	1101
				12/11/74	83.1	1260.9	
			1330.9	1/10/75	61.7	1269.2	
01S/08W-04K01 S	19		1323.0	10/16/74	212.9	1110.1	1101
				12/11/74	208.0(3)	1115.0	
			1318.3	1/02/75	172.0	1146.3	
				2/07/75	NM-9		
				6/10/75	187.1	1131.2	
				7/09/75	183.2	1135.1	
				8/12/75	190.1	1128.2	
				9/11/75	194.9	1123.4	
CUCAMONGA HYDRO SUBAREA						Y-01.84	
01N/07W-27H01 S	36		1654.0	11/00/74	314.1	1339.9	4702
				12/00/74	299.1	1354.9	
				1/00/75	311.1	1342.9	
				2/00/75	310.1	1343.9	
				3/00/75	296.1	1357.9	
				4/00/75	297.1	1356.9	
				5/00/75	366.1(1)	1287.9	
				6/00/75	338.1	1315.9	
				7/00/75	349.1	1304.9	
				8/00/75	360.1	1293.9	
				9/00/75	364.1	1289.9	
01N/07W-27Q01 S	36		1574.0	11/00/74	220.0	1354.0	4702

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA ANA RIVER HYDRO UNIT MIDDLE SANTA ANA RIV HYDR SUBUNIT CUCAMONGA HYDRO SUBAREA						Y-01 Y-01.8 Y-01.84	
01N/07W-27Q01 S (CONTINUED)	36		1574.0	12/00/74	215.0	1359.0	4702
				1/00/75	213.0	1361.0	
				2/00/75	212.0	1362.0	
				3/00/75	214.0	1360.0	
				4/00/75	213.0	1361.0	
				5/00/75	294.0(1)	1280.0	
				6/00/75	255.0	1319.0	
				7/00/75	265.0	1309.0	
				8/00/75	299.0	1275.0	
				9/00/75	304.0	1270.0	
01N/07W-28H01 S	36		1674.8	2/00/75	309.4	1364.6	4702
				5/00/75	306.4	1367.6	
				6/00/75	309.4	1364.6	
01N/07W-29E01 S	36		1839.9	10/29/74	341.5	1498.4	1101
				11/30/74	310.5	1529.4	
				12/19/74	291.5	1548.4	
				1/29/75	394.5	1445.4	
				2/27/75	389.5	1450.4	
				3/29/75	379.5	1460.4	
				4/30/75	366.5	1473.4	
				5/29/75	326.5	1513.4	
				6/29/75	328.5	1511.4	
			1840.4	7/24/75	324.0	1516.4	4748
			1839.9	9/30/75	381.5	1458.4	1101
01N/07W-29R03 S	36		1702.3	10/29/74	323.0	1379.3	4748
				12/19/74	313.0	1389.3	
				1/29/75	315.0	1387.3	
				2/27/75	318.0	1384.3	
				3/29/75	310.0	1392.3	
				4/30/75	301.0	1401.3	
				6/29/75	310.0	1392.3	
				7/24/75	330.0	1372.3	
				8/28/75	383.0(1)	1319.3	
				9/30/75	326.0	1376.3	
01N/07W-29R04 S	36		1684.4	10/29/74	316.8	1367.6	4748
				12/19/74	312.3	1372.1	
				1/29/75	352.8(1)	1331.6	
				2/27/75	308.8	1375.6	
				3/29/75	301.8	1382.6	
				4/30/75	293.8	1390.6	
				6/29/75	313.8	1370.6	
				7/24/75	359.8(1)	1324.6	
				8/28/75	373.8	1310.6	
				9/30/75	334.8	1349.6	
01N/07W-32R02 S	36		1490.0	10/29/74	214.5	1275.5	4748
				12/19/74	249.1	1240.9	
				1/29/75	249.1(1)	1240.9	
				2/27/75	251.4(1)	1238.6	
				3/29/75	172.9	1317.1	
				4/30/75	156.7	1333.3	
				6/29/75	179.8(1)	1310.2	
				7/24/75	179.8(1)	1310.2	
				8/28/75	202.9(1)	1287.1	
				9/30/75	179.8	1310.2	
01N/07W-32R03 S	36		1496.0	10/29/74	156.0	1340.0	4748
				12/19/74	153.0	1343.0	
				1/29/75	163.0	1333.0	
				2/27/75	145.0	1351.0	
				3/29/75	140.0	1356.0	
				4/30/75	136.0	1360.0	
				6/29/75	165.0	1331.0	
				7/24/75	160.0	1336.0	
				8/28/75	172.0	1324.0	
				9/30/75	172.0	1324.0	
01N/07W-33A01 S	36		1541.5	10/29/74	198.6	1342.9	3719
				12/19/74	197.6	1343.9	
				1/19/75	194.6	1346.9	
				3/31/75	190.6	1350.9	
				4/30/75	190.6	1350.9	
				5/30/75	190.6	1350.9	
				6/30/75	192.6	1348.9	
				9/30/75	206.6	1334.9	
01N/07W-33N01 S	36		1488.2	10/29/74	159.0	1329.2	4748
				12/19/74	156.0	1332.2	
				1/29/75	166.0(1)	1322.2	
				2/27/75	159.0	1329.2	
				3/29/75	143.5	1344.7	
				4/30/75	138.5	1349.7	
				6/29/75	182.0(1)	1306.2	
				7/24/75	182.0(1)	1306.2	
				8/28/75	185.5	1302.7	
				9/30/75	189.0	1299.2	
01N/07W-33N03 S	36		1490.0	10/29/74	158.0	1332.0	4748
				12/19/74	157.0	1333.0	
				1/29/75	155.0	1335.0	
				2/27/75	150.0	1340.0	
				3/29/75	146.0	1344.0	
				4/30/75	136.5	1353.5	
				6/29/75	195.0(1)	1295.0	
				7/24/75	195.0(1)	1295.0	
				8/28/75	216.0(1)	1274.0	
				9/30/75	180.0	1310.0	
01N/07W-33P01 S	36		1485.0	10/29/74	158.0	1327.0	4748

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA ANA RIVER HYDRO UNIT MIDDLE SANTA ANA RIV HYDR SUBUNIT CUCAMONGA HYDRO SUBAREA						Y-01 Y-01.8 Y-01.84	
01N/07W-33P01 S (CONTINUED)	36		1485.0	12/19/74	154.0	1331.0	4748
				1/29/75	152.0	1333.0	
				2/27/75	148.0	1337.0	
				3/29/75	142.0	1343.0	
				4/30/75	138.0	1347.0	
				6/29/75	189.0(1)	1296.0	
				7/24/75	189.0(1)	1296.0	
				8/28/75	207.0(1)	1278.0	
				9/30/75	204.0(1)	1281.0	
01N/07W-34A05 S	36		1421.0	10/00/74	211.1	1209.9	4702
				11/00/74	210.1	1210.9	
				12/00/74	205.1	1215.9	
				1/00/75	203.1	1217.9	
				2/00/75	202.1	1218.9	
				3/00/75	204.1	1216.9	
				4/00/75	203.1	1217.9	
				5/00/75	284.1(1)	1136.9	
				6/00/75	245.1	1175.9	
				7/00/75	255.1	1165.9	
				8/00/75	289.1	1131.9	
				9/00/75	294.1	1126.9	
01S/07W-04A01 S	36		1428.2	10/00/74	137.0(1)	1291.2	4702
				11/00/74	125.0	1303.2	
				12/00/74	111.0	1317.2	
				1/00/75	109.0	1319.2	
				2/00/75	107.0	1321.2	
				3/00/75	101.0	1327.2	
				4/00/75	104.0	1324.2	
				5/00/75	137.0(1)	1291.2	
				6/00/75	127.0	1301.2	
				7/00/75	134.0	1294.2	
				8/00/75	139.0	1289.2	
				9/00/75	147.0	1281.2	
01S/07W-04A02 S	36		1428.2	10/00/74	116.8	1311.4	4702
				11/00/74	124.8	1303.4	
				12/00/74	102.8	1325.4	
				1/00/75	100.8	1327.4	
				2/00/75	97.8	1330.4	
				3/00/75	96.8	1331.4	
				4/00/75	99.8	1328.4	
				5/00/75	146.8(1)	1281.4	
				6/00/75	127.8	1300.4	
				7/00/75	135.8	1292.4	
				8/00/75	139.8	1288.4	
				9/00/75	148.8	1279.4	
01S/07W-04A03 S	36		1451.8	10/00/74	177.3(1)	1274.5	4702
				11/00/74	141.3	1310.5	
				12/00/74	133.3	1318.5	
				1/00/75	131.3	1320.5	
				2/00/75	129.3	1322.5	
				3/00/75	123.3	1328.5	
				4/00/75	121.3	1330.5	
				5/00/75	145.3	1306.5	
				6/00/75	155.3	1296.5	
				7/00/75	163.3	1288.5	
				8/00/75	169.3	1282.5	
				9/00/75	176.3	1275.5	
01S/07W-04F02 S	36		1395.9	10/00/74	80.8	1315.1	4702
				11/00/74	79.8	1316.1	
				12/00/74	67.8	1328.1	
				1/00/75	64.8	1331.1	
				2/00/75	63.8	1332.1	
				3/00/75	58.8	1337.1	
				4/00/75	56.8	1339.1	
				5/00/75	76.8	1319.1	
				6/00/75	85.8	1310.1	
				7/00/75	98.8	1297.1	
				8/00/75	101.8	1294.1	
				9/00/75	106.8	1289.1	
01S/07W-04F03 S	36		1417.4	10/29/74	105.0	1312.4	4748
				12/19/74	98.0	1319.4	
				1/29/75	92.0	1325.4	
				2/27/75	87.0	1330.4	
				3/29/75	85.0	1332.4	
				4/30/75	79.5	1337.9	
				6/29/75	107.0	1310.4	
				7/24/75	107.0	1310.4	
				8/28/75	130.0(1)	1287.4	
				9/30/75	125.0	1292.4	
TEMESCAL HYDRO SUBAREA						Y-01.85	
03S/06W-06K02 S	33		629.0	10/21/74	39.9	589.1	5103
				11/13/74	39.8	589.2	
				12/09/74	41.3	587.7	
				4/01/75	40.0	589.0	
				5/30/75	40.7	588.3	
03S/06W-28A02 S	33		677.2	12/30/74	44.2	633.0	3718
				5/09/75	NM-1		
03S/06W-28L03 S	33		673.0	12/19/74	51.0	622.0	3718
				5/09/75	49.2	623.8	
03S/06W-28L04 S	33		674.8	12/19/74	52.9	621.9	3718
				5/09/75	51.2	623.6	
SANTA ANA RIVER HYDRO UNIT MIDDLE SANTA ANA RIV HYDR SUBUNIT TEMESCAL HYDRO SUBAREA						Y-01 Y-01.8 Y-01.85	
03S/06W-28M01 S	33		665.7	12/19/74	48.1	617.6	3718
				5/09/75	46.8	618.9	
03S/06W-28M02 S	33		666.1	12/19/74	50.0	616.1	3718
				5/09/75	51.8	614.3	
03S/06W-29D04 S	33		655.0	10/05/74	40.0	615.0	5272
				11/06/74	40.0	615.0	
				12/01/74	30.9	624.1	
				1/04/75	41.2	613.8	
				2/01/75	61.2	593.8	
				3/08/75	40.9	614.1	
				5/02/75	40.2	614.8	
				6/06/75	39.8	615.2	
				7/02/75	39.5	615.5	
				8/03/75	39.4	615.6	
03S/06W-30K01 S	33		612.3	10/18/74	NM-1		5103
				3/27/75	58.9(1)	553.4	
03S/06W-31D01 S	33		690.0	10/05/74	135.1	554.9	5272
				11/06/74	142.8	547.2	
				12/01/74	142.6	547.4	
03S/06W-31D02 S	33		690.0	10/05/74	135.1	554.9	5272
				11/06/74	142.8(1)	547.2	
				12/01/74	142.6(1)	547.4	
				1/04/75	132.9	557.1	
				2/01/75	132.4	557.6	
				3/08/75	138.9(1)	551.1	
				5/02/75	135.1(1)	554.9	
				6/06/75	134.9(1)	555.1	
				7/02/75	139.6(1)	550.4	
				8/03/75	142.1(1)	547.9	
03S/06W-32H01 S	33		663.7	10/18/74	59.4	604.3	5103
				3/27/75	60.3	603.4	
03S/07W-11L03 S	33		575.7	1/10/75	49.9	525.8	8027
				6/10/75	56.6	519.1	
03S/07W-14J02 S	33		582.2	1/10/75	25.4	556.8	8027
				6/10/75	68.4(1)	513.8	
03S/07W-21G01 S	33		505.2	10/18/74	4.4	500.8	5103
				3/28/75	4.0	501.2	
03S/07W-21H02 S	33		492.0	10/18/74	NM-8		5103
				11/13/74	0.0	492.0	
				12/09/74	NM-9		
				3/28/75	NM-1		
				5/30/75	-0.2	492.2	
03S/07W-21N01 S	33		506.6	10/18/74	10.3	496.3	5103
				3/28/75	9.3	497.3	
03S/07W-22J02 S	33		534.8	10/18/74	10.8	524.0	5103
				3/28/75	7.9	526.9	
03S/07W-22L01 S	33		527.8	10/18/74	11.7	516.1	5103
				3/28/75	10.0	517.8	
03S/07W-23C03 S	33		546.2	10/18/74	NM-1		5103
				3/27/75	17.4	528.8	
03S/07W-23L01 S	33		576.0	10/05/74	45.4	530.6	5272
				11/06/74	45.0	531.0	
				12/01/74	44.6	531.4	
				1/04/75	42.8	533.2	
				3/08/75	42.1	533.9	
				4/05/75	41.6	534.4	
				5/02/75	40.6	535.4	
				6/06/75	41.4	534.6	
				7/02/75	42.4	533.6	
				8/03/75	43.3	532.7	
03S/07W-23M02 S	33		551.1	10/18/74	26.3	524.8	5103
				3/27/75	22.9	528.2	
03S/07W-24L01 S	33		583.2	10/18/74	50.2	533.0	5103
				3/27/75	41.0	542.2	
03S/07W-24D03 S	33		588.8	1/10/75	49.0	539.0	8027
				6/10/75	45.5	542.5	
03S/07W-24D04 S	33		588.0	1/10/75	48.5	539.5	8027
				6/10/75	45.0	543.0	
03S/07W-24D05 S	33		589.8	1/10/75	50.8	539.0	8027
				6/10/75	47.4	541.6	
03S/07W-25D01 S	33		582.0	10/02/74	175.6	406.4	4701
				11/01/74	176.4	405.6	
				12/02/74	165.0	417.0	
				1/02/75	131.0	451.0	
				2/01/75	170.0	412.0	
				3/01/75	131.0	451.0	
				4/02/75	136.0	446.0	
				5/01/75	170.0(1)	412.0	
				6/02/75	160.0	422.0	
				7/01/75	150.0	432.0	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA ANA RIVER HYDRO UNIT						Y-01	
MIDDLE SANTA ANA RIV HYDR SUBUNIT						Y-01.8	
TEMESCAL HYDRO SUBAREA						Y-01.85	
03S/07W-25D03 S (CONTINUED)	33		582.0	8/01/75	160.0	422.0	4701
				9/02/75	170.0	412.0	
03S/07W-25F01 S	33		604.0	10/02/74	102.0	502.0	4701
				11/01/74	98.0	506.0	
				12/02/74	98.5	505.5	
				1/02/75	72.0	532.0	
				2/01/75	75.0	529.0	
				3/01/75	69.0	535.0	
				4/02/75	68.0	536.0	
				5/01/75	71.0	533.0	
				6/02/75	98.0	506.0	
				7/01/75	99.0	505.0	
				8/01/75	99.5	504.5	
				9/02/75	101.0	503.0	
03S/07W-25H01 S	33		606.9	10/18/74	64.9	542.0	5103
				3/27/75	58.6	548.3	
03S/07W-25J01 S	33		642.0	10/05/74	96.4	545.6	5272
				11/06/74	96.1	545.9	
				12/01/74	97.1	544.9	
				1/04/75	93.9	548.1	
				2/01/75	106.3	535.7	
				3/08/75	91.2	550.8	
				4/05/75	89.7	552.3	
				5/02/75	88.8	553.2	
				6/06/75	93.9(1)	548.1	
				7/02/75	95.6(1)	546.4	
				8/03/75	97.0(1)	545.0	
03S/07W-25M01 S	33		629.0	10/02/74	103.5	525.5	4701
				11/01/74	102.5	526.5	
				12/02/74	102.5	526.5	
				1/02/75	97.5	531.5	
				2/01/75	99.5(1)	529.5	
				3/01/75	97.5(1)	531.5	
				4/02/75	87.9	541.1	
				5/01/75	97.5(1)	531.5	
				6/02/75	98.5	530.5	
				7/01/75	99.3	529.7	
				8/01/75	104.3	524.7	
				9/02/75	105.5	523.5	
03S/07W-25M02 S	33		661.0	10/05/74	154.1(1)	506.9	5272
				11/06/74	150.0(1)	511.0	
				12/01/74	149.6(1)	511.4	
				1/04/75	147.3(1)	513.7	
				3/08/75	120.5	540.5	
				4/05/75	141.3(1)	519.7	
				5/02/75	139.1(1)	521.9	
				6/06/75	141.5(1)	519.5	
				7/02/75	143.7(1)	517.3	
				8/03/75	145.4(1)	515.6	
03S/07W-26C01 S	33		628.0	10/02/74	111.2	516.8	4701
				11/01/74	111.2	516.8	
				12/02/74	106.2	521.8	
				1/02/75	97.2	530.8	
				2/01/75	99.2	528.8	
				3/01/75	95.2	532.8	
				4/02/75	93.2	534.8	
				5/01/75	110.0	518.0	
				6/02/75	99.2	528.8	
				7/01/75	108.2	519.8	
				8/01/75	109.2	518.8	
				9/02/75	109.2	518.8	
03S/07W-26G01 S	33		640.0	10/02/74	114.4	525.6	4701
				11/01/74	119.0	521.0	
				12/02/74	115.0	525.0	
				1/02/75	105.6	534.4	
				2/01/75	105.0	535.0	
				3/01/75	106.0	534.0	
				4/02/75	104.0	536.0	
				5/01/75	121.0(1)	519.0	
				6/02/75	114.0	526.0	
				7/01/75	117.0	523.0	
				8/01/75	118.0	522.0	
				9/02/75	118.0	522.0	
03S/07W-26K01 S	33		677.8	10/02/74	151.0	526.8	4701
				11/01/74	151.0	526.8	
				12/02/74	149.0	528.8	
				1/02/75	137.0	540.8	
				2/01/75	140.0	537.8	
				3/01/75	143.5	534.3	
				4/02/75	143.0	534.8	
				5/01/75	139.0	538.8	
				6/02/75	140.0	537.8	
				7/01/75	142.0	535.8	
				8/01/75	145.0	532.8	
				9/02/75	146.0	531.8	
03S/07W-27F01 S	33		658.0	10/05/74	160.9(1)	497.1	5272
				11/06/74	160.0(1)	498.0	
				12/01/74	161.2(1)	496.8	
				1/04/75	158.9(1)	499.1	
				3/08/75	158.2(1)	499.8	
				4/05/75	157.4(1)	500.6	
				5/02/75	161.2(1)	496.8	
				6/06/75	158.0(1)	500.0	
SANTA ANA RIVER HYDRO UNIT						Y-01	
MIDDLE SANTA ANA RIV HYDR SUBUNIT						Y-01.8	
TEMESCAL HYDRO SUBAREA						Y-01.85	
03S/07W-27F01 S (CONTINUED)	33		658.0	7/02/75	155.7(1)	502.3	5272
				8/03/75	160.6(1)	497.4	
03S/07W-27G01 S	33		650.0	10/05/74	132.8	517.2	5272
				11/06/74	132.4	517.6	
				12/01/74	132.5	517.5	
				6/06/75	134.0(1)	516.0	
				7/02/75	135.0(1)	515.0	
				8/03/75	135.0(1)	515.0	
03S/07W-27H01 S	33		661.5	10/18/74	136.3	525.2	5103
				3/28/75	131.9	529.6	
03S/07W-28F01 S	33		571.7	10/18/74	63.6	508.1	5103
				11/13/74	NM-9		
				12/09/74	NM-8		
				3/28/75	62.4	509.3	
				5/30/75	62.6	509.1	
				7/03/75	65.4	506.3	
				8/06/75	66.7	505.0	
				9/11/75	NM-3		
03S/07W-35C01 S	33		728.0	10/05/74	190.0	538.0	5272
				11/06/74	193.2(1)	534.8	
				12/01/74	194.1	533.9	
				1/04/75	189.3(1)	538.7	
				3/08/75	185.0	543.0	
				4/05/75	183.3	544.7	
				5/02/75	182.8	545.2	
				6/06/75	188.9(1)	539.1	
				7/02/75	191.0(1)	537.0	
				8/03/75	190.0(1)	538.0	
04S/07W-03L01 S	33		969.1	10/18/74	NM-1		5103
				3/28/75	116.9	852.2	
04S/07W-03L02 S	33		980.9	10/18/74	NM-1		5103
				3/28/75	139.2	841.7	
ARLINGTON HYDRO SUBAREA						Y-01.86	
02S/06W-36R01 S	33		733.0	12/20/74	7.1	725.9	3718
				5/09/75	7.3	725.7	
03S/05W-05R01 S	33		766.3	10/11/74	21.2	745.1	5103
				11/12/74	21.2	745.1	
				12/09/74	21.2	745.1	
				3/27/75	20.9	745.4	
				5/08/75	20.7	745.6	3718
03S/05W-05M03 S	33		756.6	10/11/74	9.4	747.2	5103
				11/12/74	9.2	747.4	
				12/09/74	9.2	747.4	
				3/27/75	8.5	748.1	
				5/29/75	8.8	747.8	
03S/05W-06Q02 S	33		752.0	10/01/74	9.7	742.3	5208
				11/01/74	10.7	741.3	
03S/05W-06Q03 S	33		750.0	10/01/74	7.0	743.0	5208
				11/01/74	7.6	742.4	
03S/05W-06Q04 S	33		752.0	10/01/74	8.2	743.8	5208
				11/01/74	8.9	743.1	
03S/05W-06Q05 S	33		752.0	10/01/74	8.9	743.1	5208
				11/01/74	8.7	743.3	
03S/05W-07J01 S	33		788.0	12/20/74	NM-6		3718
03S/05W-08R02 S	33		800.0	10/11/74	42.1	757.9	5103
				11/12/74	42.0	758.0	
				12/09/74	42.0	758.0	
				3/27/75	41.3	758.7	
			803.0	5/09/75	44.3	758.7	3718
03S/05W-08F02 S	33		786.0	12/20/74	30.5	755.5	3718
				5/12/75	30.0	756.0	
03S/05W-09A01 S	33		887.0	10/11/74	118.8	768.2	5103
				11/12/74	NM-1		
				12/09/74	NM-8		
				3/27/75	117.9	769.1	
				5/29/75	118.3	768.7	
03S/05W-09F01 S	33		856.5	10/11/74	NM-1		5103
				11/12/74	89.4	767.1	
				12/09/74	89.7	766.8	
				3/27/75	90.8	765.7	
			656.0	5/19/75	90.7	565.3	3718
03S/05W-09M01 S	33		859.1	12/19/74	92.7	766.4	3718
				5/09/75	NM-1		
03S/05W-14F01 S	33		1111.4	12/20/74	11.2	1100.2	3718
				5/08/75	13.0	1098.4	
03S/05W-17G01 S	33		892.7	3/27/75	53.0	839.7	5103
03S/05W-17K02 S	33		878.9	12/19/74	53.3	825.6	3718
				5/09/75	53.2	825.7	
03S/05W-17Q01 S	33		892.4	10/11/74	53.7	838.7	5103

See page 79 for key to terms & abbreviations

TABLE G-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA ANA RIVER HYDRO UNIT						Y-01	
MIDDLE SANTA ANA RIV HYDR SUBUNIT						Y-01.8	
ARLINGTON HYDRO SUBAREA						Y-01.86	
03S/05W-17D01 S (CONTINUED)	33		892.7	12/19/74	53.8	838.9	3718
				5/09/75	53.4	839.3	
03S/05W-19F04 S	33		834.2	12/19/74	8.4	825.8	3718
				5/12/75	8.8	825.4	
03S/05W-19P01 S	33		903.0	12/19/74	DRY		3718
				5/12/75	DRY		
03S/05W-19P02 S	33		908.9	12/19/74	DRY		3718
				5/12/75	DRY		
03S/06W-03L01 S	33		802.0	10/11/74	15.2	786.8	5103
				11/13/74	15.6	786.4	
				12/09/74	16.0	786.0	
				3/27/75	19.0	783.0	
				5/29/75	20.2	781.8	
				7/03/75	19.7	782.3	
				8/07/75	19.5	782.5	
				9/11/75	19.0	783.0	
03S/06W-10G01 S	33		742.6	12/17/74	16.2	726.4	3718
				5/08/75	17.1	725.5	
03S/06W-13A01 S	33		756.7	10/11/74	38.7	718.0	5103
				11/12/74	38.1	718.6	
				12/09/74	NM-3		
				3/27/75	34.9	721.8	
				5/29/75	36.2	720.5	
03S/06W-23H01 S	33		748.4	10/11/74	56.1	692.3	5103
				11/12/74	NM-3		
				12/09/74	54.2	694.2	
				3/27/75	50.1	698.3	
				5/29/75	49.1	699.3	
03S/06W-24G01 S	33		804.6	10/11/74	9.6	795.0	5103
				3/27/75	8.6	796.0	
03S/06W-24Q01 S	33		811.7	10/11/74	NM-8		5103
				11/12/74	5.7	806.0	
				12/09/74	5.2	806.5	
				3/27/75	NM-1		
				5/12/75	5.8	805.9	3718
RIVERSIDE HYDRO SUBAREA						Y-01.87	
01S/04W-28L01 S	36		941.0	10/05/74	53.6	887.4	5783
				11/08/74	52.2	888.8	
			940.0	12/07/74	52.0	888.0	3718
			941.0	1/04/75	53.2	887.8	5783
				2/08/75	53.7	887.3	
				3/08/75	53.7	887.3	
				4/05/75	54.2	886.8	
			940.0	5/03/75	54.0	886.0	3718
			941.0	6/07/75	54.2	886.8	5783
				7/05/75	54.3	886.7	
				8/08/75	54.5	886.5	
				9/05/75	55.7	885.3	
01S/04W-28L02 S	36		940.0	10/05/74	75.2	864.8	5783
				11/08/74	77.3	862.7	
				12/07/74	81.2(1)	858.8	
				1/04/75	82.0(1)	858.0	
				2/08/75	83.3(1)	856.7	
				3/08/75	83.0(1)	857.0	
				4/05/75	83.6(1)	856.4	
				5/03/75	83.1(1)	856.9	
				6/07/75	83.9(1)	856.1	
				7/05/75	83.8(1)	856.2	
				8/08/75	85.0(1)	855.0	
				9/05/75	86.1(1)	853.9	
01S/04W-28M01 S	36		935.0	12/05/74	63.8	871.2	3718
				4/08/75	53.4	881.6	
01S/04W-28N05 S	36		927.0	10/05/74	67.2(1)	859.8	5783
				11/08/74	70.4	856.6	
			930.2	12/07/74	69.1	861.1	3718
			927.0	1/04/75	68.0	859.0	5783
				2/08/75	67.8	859.2	
				3/08/75	66.0	861.0	
				4/05/75	66.2	860.8	
			930.2	5/03/75	66.1	864.1	3718
			927.0	6/07/75	66.1	860.9	5783
				7/05/75	66.1	860.9	
				8/08/75	69.8(1)	857.2	
				9/05/75	71.0(1)	856.0	
01S/04W-28P01 S	36		994.0	12/05/74	111.6	882.4	3718
				4/28/75	111.9	882.1	
01S/04W-29H01 S	36		932.0	10/01/74	99.6(1)	832.4	5208
				11/05/74	67.2	864.8	
				12/01/74	65.1	866.9	
				1/07/75	58.9	873.1	
				2/11/75	57.6	874.4	
				3/11/75	55.0	877.0	
				4/01/75	53.9	878.1	
				5/22/75	87.8(1)	844.2	
				6/13/75	NM-1		5412
				7/09/75	58.1	873.9	5208
SANTA ANA RIVER HYDRO UNIT						Y-01	
MIDDLE SANTA ANA RIV HYDR SUBUNIT						Y-01.8	
RIVERSIDE HYDRO SUBAREA						Y-01.87	
01S/04W-29H01 S (CONTINUED)	36		932.0	8/10/75	64.3	867.7	5208
				9/10/75	66.3	865.7	
01S/04W-29H02 S	36		937.1	10/01/74	70.4	866.7	5208
				11/05/74	70.6	866.5	
				12/01/74	67.1	870.0	
			934.4	1/07/75	60.5	873.9	5000
				2/03/75	62.6	871.8	
				3/11/75	56.5	877.9	
				4/01/75	54.5	879.9	
				5/06/75	53.6	880.8	
				6/03/75	50.3	884.1	
				7/01/75	57.7	876.7	
				8/04/75	60.0	874.4	
				9/10/75	64.5	869.9	
01S/04W-29Q01 S	36		924.5	10/01/74	63.6	860.9	5208
				11/05/74	61.2	863.3	
				12/01/74	62.9	861.6	
				1/07/75	55.1	869.4	
				2/11/75	54.2	870.3	
				3/12/75	49.3	875.2	5412
				4/01/75	51.9	872.6	5208
				5/15/75	55.0	869.5	5412
				6/13/75	56.3	868.2	
				7/09/75	56.8	867.7	5208
				8/14/75	55.5	869.0	5412
				9/18/75	53.4	871.1	
01S/04W-29Q03 S	36		928.0	10/01/74	67.2	860.8	5208
				11/05/74	66.3	861.7	
				12/01/74	67.5	860.5	
				1/07/75	58.9	869.1	
				2/11/75	64.5	863.5	
				3/11/75	54.4	873.6	
				4/01/75	53.7	874.3	
				5/22/75	55.5	872.5	
				6/24/75	57.9	870.1	
				7/09/75	59.2	868.8	
				8/10/75	64.6	863.4	
				9/10/75	68.1	859.9	
01S/04W-29Q04 S	36		924.5	10/24/74	63.0	861.5	5412
				11/21/74	61.2	863.3	
				12/19/74	57.8	866.7	
				1/16/75	59.2	865.3	
				2/12/75	60.3	864.2	
				3/12/75	60.9	863.6	
				4/09/75	60.7	863.8	
				5/15/75	63.5	861.0	
				6/11/75	61.8	862.7	
				7/10/75	59.3	865.2	
				8/14/75	60.2	864.3	
				9/18/75	60.1	864.4	
01S/04W-29R01 S	36		931.0	10/01/74	68.9	862.1	5208
				11/05/74	68.1	862.9	
				12/01/74	95.7(1)	835.3	
				1/07/75	54.2	876.8	
				2/11/75	56.2	874.8	
				3/11/75	54.8	876.2	
				4/01/75	54.6	876.4	
				5/22/75	57.1	873.9	
				6/24/75	58.5	872.5	
				7/09/75	59.7	871.3	
				8/10/75	60.9	870.1	
				9/10/75	67.8	863.2	
01S/04W-30D04 S	36		985.9	12/09/74	131.3	854.6	3718
				5/06/75	130.9	855.0	
01S/04W-31J01 S	36		935.5	12/06/74	81.4	854.1	3718
				4/29/75	73.2	862.3	
01S/04W-32B01 S	36		917.0	12/06/74	58.3	858.7	3718
				4/29/75	NM-1		
01S/04W-32B02 S	36		922.0	12/06/74	58.8	863.2	3718
				4/28/75	48.1	873.9	
01S/04W-32F07 S	36		905.6	12/09/74	45.4	860.2	3718
				4/29/75	39.8	865.8	
01S/04W-32F10 S	36		906.0	12/07/74	41.9	864.1	3718
				5/03/75	42.2	863.8	
01S/04W-32E11 S	36		906.0	12/09/74	45.8	860.2	3718
				4/29/75	NM-1		
01S/04W-32G04 S	36		917.8	12/06/74	56.7	861.1	3718
				4/29/75	45.4	872.4	
01S/04W-32N01 S	36		935.8	10/05/74	64.8	870.2	5783
				11/08/74	64.8	870.2	
			923.7	12/06/74	67.6	856.1	3718
			935.0	1/04/75	64.8	870.2	5783
				2/08/75	64.8	870.2	
				3/08/75	64.8	870.2	
				4/05/75	64.5	870.5	
				5/03/75	65.0	870.0	
				6/07/75	65.0	870.0	
				7/05/75	65.0	870.0	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA ANA RIVER HYDRO UNIT						Y-01	
MIDDLE SANTA ANA RIV HYDR SUBUNIT						Y-01.8	
RIVERSIDE HYDRO SUBAREA						Y-01.87	
01S/04W-32M01 S (CONTINUED)	36		935.0	8/08/75	65.0	870.0	5783
				9/05/75	65.3	869.7	
01S/04W-32Q02 S	36		1011.3	12/06/74	158.7	852.6	3718
				4/29/75	151.2	860.1	
01S/04W-33R03 S	36		974.0	12/05/74	94.7	879.3	3718
				4/28/75	94.7	879.3	
01S/04W-33R05 S	36		940.0	10/05/74	57.8	882.2	5783
				11/08/74	57.7	882.3	
			944.5	12/07/74	56.2	888.3	3718
			940.0	1/04/75	57.1	882.9	5783
				2/08/75	57.2	882.8	
				3/08/75	57.3	882.7	
				4/05/75	57.2	882.8	
			944.5	5/03/75	56.4	888.1	3718
			940.0	6/07/75	53.6	886.4	5783
				7/05/75	53.6	886.4	
				8/08/75	55.8	884.2	
				9/05/75	57.2	882.8	
01S/05W-24E01 S	36		1070.6	12/09/74	219.1	851.5	3718
				4/30/75	218.8	851.8	
01S/05W-25A02 S	36		1009.0	12/09/74	155.4	853.6	3718
				5/06/75	154.0	855.0	
01S/05W-25A03 S	36		997.0	12/09/74	147.1	849.9	3718
				5/06/75	140.9	856.1	
01S/05W-25R02 S	36		998.9	12/09/74	146.3	852.6	3718
				4/30/75	147.8	851.1	
01S/05W-25L02 S	36		940.0	12/09/74	96.9	843.1	3718
				4/30/75	95.2	844.8	
01S/05W-25R04 S	36		880.0	12/06/74	31.3	848.7	3718
				4/30/75	NM-1		
01S/05W-33A01 S	36		1006.0	12/11/74	189.3	816.7	3718
				5/02/75	186.8	819.2	
01S/05W-33A02 S	36		1005.8	12/11/74	189.6	816.2	3718
				5/02/75	186.6	819.2	
01S/05W-33F01 S	36		1029.0	12/11/74	104.7	924.3	3718
				4/30/75	105.1	923.9	
01S/05W-33L01 S	36		1016.0	12/10/74	87.2	928.8	3718
				4/30/75	87.3	928.7	
01S/05W-34D01 S	36		995.0	10/01/74	181.0	814.0	4124
				11/01/74	181.0	814.0	
				12/01/74	174.0	821.0	
				1/02/75	179.0	816.0	
				2/01/75	179.0	816.0	
				3/01/75	179.0	816.0	
				4/01/75	178.0	817.0	
				5/01/75	177.0	818.0	
				6/01/75	185.0(1)	810.0	
				7/01/75	187.0(1)	808.0	
				8/01/75	185.0(1)	810.0	
				9/01/75	187.0(1)	808.0	
01S/05W-34L02 S	36		958.7	12/09/74	145.6	813.1	3718
				4/30/75	139.5	819.2	
01S/05W-34M01 S	36		951.2	12/09/74	133.8	817.4	3718
				4/30/75	131.1	820.1	
01S/05W-35G02 S	36		920.0	12/09/74	91.8	828.2	3718
				4/30/75	89.9	830.1	
01S/05W-36C11 S	36		886.0	12/06/74	52.2	833.8	3718
				5/06/75	52.5	833.5	
02S/04W-05F01 S	36		976.0	10/01/74	134.9	841.1	3847
				11/05/74	129.9	846.1	
				12/03/74	130.7	845.3	
				1/07/75	127.9	848.1	
				2/04/75	126.8	849.2	
				3/04/75	124.4	851.6	
				4/01/75	123.9	852.1	
				5/06/75	128.7	847.3	
				6/03/75	122.9	853.1	
				7/01/75	143.9(1)	832.1	
				8/04/75	145.9(1)	830.1	
				9/02/75	146.9(1)	829.1	
02S/04W-05F01 S	36		981.5	12/06/74	134.3	847.2	3718
				4/29/75	130.1	851.4	
02S/04W-05N01 S	36		946.0	10/05/74	114.0(1)	832.0	5783
				11/08/74	115.8(1)	830.2	
				12/07/74	108.6	837.4	
				1/04/75	105.2	840.8	
				2/08/75	104.9	841.1	
				3/08/75	111.2(1)	834.8	
				4/05/75	103.8	842.2	
				5/03/75	109.6(1)	836.4	
				6/07/75	110.2(1)	835.8	
SANTA ANA RIVER HYDRO UNIT						Y-01	
MIDDLE SANTA ANA RIV HYDR SUBUNIT						Y-01.8	
RIVERSIDE HYDRO SUBAREA						Y-01.87	
02S/04W-05N01 S (CONTINUED)	36		946.0	7/05/75	111.1(1)	834.9	5783
				8/08/75	111.7(1)	834.3	
				9/05/75	112.3(1)	833.7	
02S/04W-06K02 S	36		920.4	12/06/74	78.5	841.9	3718
				4/29/75	69.8	850.6	
02S/04W-06R01 S	36		946.0	12/07/74	107.8	838.2	3718
				4/05/75	102.9	843.1	
02S/04W-06R05 S	36		946.9	12/06/74	103.7	843.2	3718
				4/29/75	97.4	849.5	
02S/04W-06R06 S	36		943.9	12/06/74	100.8	843.1	3718
				4/29/75	94.4	849.5	
02S/04W-07L01 S	33		883.1	10/08/74	76.2	806.9	5208
				11/05/74	77.8	805.3	
				12/02/74	76.8	806.3	
				1/01/75	75.8	807.3	
				2/11/75	74.5	808.6	
				3/18/75	72.3	810.8	
				4/01/75	71.5	811.6	
				5/14/75	77.8	805.3	
				7/23/75	79.8	803.3	
				8/20/75	76.0	807.1	
				9/30/75	75.2	807.9	
02S/04W-07N03 S	33		875.0	10/08/74	77.8	797.2	5208
				11/20/74	78.9	796.1	
				12/02/74	78.0	797.0	
				1/01/75	76.5	798.5	
				2/11/75	75.8	799.2	
				3/12/75	71.0	804.0	
				4/01/75	73.2	801.8	
				5/14/75	74.0	801.0	
				6/04/75	77.0	798.0	
				7/16/75	79.6	795.4	
				8/13/75	75.5	799.5	
				9/30/75	76.0	799.0	
02S/04W-08B04 S	33		964.7	10/30/74	120.5	844.2	5208
				12/02/74	121.8	842.9	
				4/29/75	115.0	849.7	
				5/27/75	117.3	847.4	
				7/30/75	118.0	846.7	
				8/27/75	119.8	844.9	
02S/04W-08E01 S	33		987.0	10/30/74	143.0	844.0	5208
				12/02/74	144.0	843.0	
				2/25/75	140.3	846.7	
				4/29/75	137.8	849.2	
				5/27/75	138.0	849.0	
				7/30/75	139.8	847.2	
				8/27/75	140.5	846.5	
02S/04W-08H01 S	33		1000.0	10/05/74	158.5(1)	841.5	5783
				11/08/74	161.2(1)	838.8	
				12/07/74	151.3	848.7	3718
				1/04/75	150.3	849.7	5783
				2/08/75	150.1	849.9	
				3/08/75	150.1	849.9	
				4/05/75	150.2	849.8	
				5/03/75	149.6	850.4	3718
				6/07/75	150.6	849.4	5783
				7/05/75	150.6	849.4	
				8/08/75	151.0	849.0	
				9/05/75	150.7	849.3	
02S/04W-08H02 S	33		987.0	10/05/74	136.2(1)	846.8	5783
				11/08/74	138.0(1)	845.0	
			984.1	12/07/74	136.2	847.9	3718
			983.0	1/04/75	133.0	850.0	5783
				2/08/75	133.2	849.8	
				3/08/75	133.4	849.6	
			984.1	4/05/75	134.1	850.0	3718
			983.0	5/03/75	143.2(1)	839.8	5783
				6/07/75	143.7(1)	839.3	
				7/05/75	138.5	844.5	
				8/08/75	139.2(1)	843.8	
				9/05/75	139.4(1)	843.6	
02S/04W-18F01 S	33		907.7	10/10/74	100.5	807.2	5103
			907.9	12/23/74	99.2	808.7	3718
			907.7	3/26/75	98.6	809.1	5103
			907.9	5/12/75	99.5	808.4	3718
02S/04W-19A01 S	33		994.0	12/23/74	182.2	811.8	3718
				5/14/75	181.4	812.6	
02S/04W-19E01 S	33		938.5	12/23/74	DRY		3718
				5/12/75	132.5	806.0	
02S/04W-19J02 S	33		1027.0	1/14/75	199.9	827.1	3718
				5/09/75	201.3	825.7	
02S/04W-19M02 S	33		954.0	1/07/75	150.7	805.3	3718
				5/12/75	148.3	807.7	
02S/04W-29M01 S	33		1050.0	12/23/74	63.8	986.2	3718
				5/12/75	65.4	984.6	
02S/04W-33P02 S	33		1496.0	10/15/74	19.8	1476.2	5103

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

SANTA ANA RIVER HYDRO UNIT
MIDDLE SANTA ANA RIV HYDR SUBUNIT
RIVERSIDE HYDRO SUBAREA

Y-01
Y-01.B
Y-01.B7

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
02S/04W-33R02 S	33		1496.0	4/01/75	19.6	1476.4	5103
02S/05W-01J01 S	36		842.8	11/08/74	NM-7		3718
				2/28/75	37.9	804.9	
02S/05W-01J02 S	36		843.0	11/08/74	NM-7		3718
				2/28/75	NM-7		
02S/05W-02C01 S	33		936.2	12/10/74	DRY		3718
				4/30/75	DRY		
02S/05W-02F01 S	33		953.5	11/08/74	NM-7		3718
				2/28/75	179.5(3)	774.0	
02S/05W-02F02 S	33		897.8	2/28/75	89.3	808.5	3718
02S/05W-02L01 S	33		896.2	11/08/74	102.5	793.7	3718
				2/28/75	108.3	787.9	
02S/05W-02L02 S	33		909.0	11/08/74	103.1	805.9	3718
				2/28/75	109.3	799.7	
02S/05W-02L05 S	33		894.4	11/08/74	103.3	791.1	3718
				2/28/75	99.1	795.3	
02S/05W-02M06 S	33		926.7	11/08/74	NM-6		3718
02S/05W-02Q07 S	33		826.0	10/01/74	28.3	797.7	5208
				11/12/74	26.4	799.6	
				12/10/74	22.0	804.0	
				1/07/75	23.2	802.8	
				2/05/75	23.3	802.7	
				3/11/75	25.0	801.0	
				4/01/75	21.5	804.5	
				5/06/75	24.6	801.4	
				6/03/75	26.1	799.9	
				7/01/75	25.9	800.1	
				8/19/75	26.3	799.7	
				9/30/75	28.9	797.1	
02S/05W-02P01 S	33		823.0	10/01/74	36.9	786.1	5208
				11/12/74	34.4	788.6	
				12/10/74	22.0	801.0	
				1/07/75	20.5	802.5	
				2/05/75	20.5	802.5	
				3/11/75	21.5	801.5	
				4/01/75	18.8	804.2	
				5/06/75	33.6(1)	789.4	
				6/03/75	35.5(1)	787.5	
				7/01/75	35.0(1)	788.0	
				8/19/75	35.0(1)	788.0	
				9/30/75	35.2(1)	787.8	
02S/05W-02P02 S	33		823.0	10/01/74	34.6(1)	788.4	5208
				11/12/74	32.6	790.4	
				12/10/74	18.9	804.1	
				1/07/75	17.9	805.1	
				2/05/75	20.0	803.0	
				3/11/75	19.2	803.8	
				4/01/75	18.2	804.8	
				5/06/75	32.5(1)	790.5	
				6/03/75	34.3(1)	788.7	
				7/01/75	33.8(1)	789.2	
				8/19/75	34.4(1)	788.6	
				9/30/75	26.9	796.1	
02S/05W-02Q03 S	33		826.0	10/01/74	31.0(1)	795.0	5208
				11/12/74	29.7(1)	796.3	
				12/10/74	17.7	808.3	
				1/07/75	19.0	807.0	
				2/05/75	19.6	806.4	
				3/11/75	20.4	805.6	
				4/01/75	16.2	809.8	
				5/06/75	33.6(1)	792.4	
				6/17/75	31.4(1)	794.6	
				7/01/75	30.9(1)	795.1	
				8/19/75	32.0(1)	794.0	
				9/30/75	32.1(1)	793.9	
02S/05W-03A01 S	33		953.4	12/09/74	141.1	812.3	3718
				4/30/75	138.6	814.8	
02S/05W-03G02 S	33		904.4	11/08/74	97.0	807.4	3718
				2/28/75	99.5	804.9	
02S/05W-08G01 S	33		903.0	12/11/74	167.2	735.8	3718
				5/02/75	162.6	740.4	
02S/05W-08G04 S	33		903.7	12/11/74	167.4	736.3	3718
				5/02/75	163.5	740.2	
02S/05W-08K02 S	33		892.6	12/11/74	153.5	739.1	3718
				5/02/75	150.5	742.1	
02S/05W-10G01 S	33		849.8	3/26/75	61.3	788.5	5103
02S/05W-10G07 S	33		842.0	12/10/74	56.3	785.7	3718
				3/26/75	55.8	786.2	5103
				5/13/75	55.8	786.2	3718
				7/03/75	56.6	785.4	5103
				8/06/75	57.1	784.9	
				9/11/75	57.4	784.6	

SANTA ANA RIVER HYDRO UNIT
MIDDLE SANTA ANA RIV HYDR SUBUNIT
RIVERSIDE HYDRO SUBAREA

Y-01
Y-01.B
Y-01.B7

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
02S/05W-10L05 S	33		867.7	12/10/74	83.4	784.3	3718
				5/01/75	84.9	782.8	
02S/05W-10P01 S	33		857.5	12/12/74	80.7	776.8	3718
				5/13/75	80.2	777.3	
02S/05W-10Q0A S	33		822.6	3/26/75	41.7	780.9	5103
				5/29/75	42.5	780.1	
				7/03/75	42.9	779.7	
				8/06/75	NM-2		
				9/11/75	43.8	778.8	
02S/05W-11A01 S	33		824.8	10/01/74	22.8	802.0	5208
				11/12/74	21.6	803.2	
				12/10/74	17.8	807.0	
				1/07/75	19.1	805.7	
				2/05/75	19.0	805.8	
				3/11/75	15.7	809.1	
				4/01/75	18.2	806.6	
				5/06/75	20.6	804.2	
				6/03/75	22.6	802.2	
				7/01/75	22.7	802.1	
				8/18/75	23.0	801.8	
				9/30/75	36.3(1)	788.5	
02S/05W-11K02 S	33		814.8	10/10/74	17.3	797.5	5103
				11/12/74	17.9	796.9	
				12/09/74	NM-8		
				3/26/75	16.9	797.9	
			817.0	5/13/75	20.0	797.0	3718
02S/05W-12A01 S	33		834.8	10/31/74	29.2	807.6	5208
				12/29/74	28.2	808.6	
				2/27/75	28.6	808.2	
				3/30/75	33.4	803.4	
				4/28/75	30.6	806.2	
				6/01/75	28.4	808.4	
				7/10/75	28.4	808.4	
				8/31/75	32.4	804.4	
				9/29/75	33.6	803.2	
02S/05W-12J01 S	33		849.2	10/10/74	47.5	801.7	5103
				11/12/74	NM-9		
				12/09/74	NM-9		
				3/26/75	NM-9		
				5/29/75	NM-9		
02S/05W-12K02 S	33		836.2	10/30/74	29.7	806.5	5208
				12/29/74	28.0	808.2	
				2/27/75	31.0	805.2	
				4/28/75	31.5	804.7	
				6/01/75	30.0	806.2	
				7/28/75	33.3	802.9	
				9/29/75	33.8	802.4	
02S/05W-12P01 S	33		823.2	10/31/74	28.9	794.3	5208
				12/02/74	39.7	783.5	
				1/02/75	28.8	794.4	
				6/01/75	27.5	795.7	
				9/29/75	29.0	794.2	
02S/05W-13Q02 S	33		880.0	10/15/74	103.3	776.7	5208
				11/26/74	101.6	778.4	
				12/10/74	104.7	775.3	
				1/15/75	100.4	779.6	
				2/05/75	100.0	780.0	
				3/04/75	99.7	780.3	
				4/01/75	98.5	781.5	
				5/06/75	98.4	781.6	
				6/03/75	99.6	780.4	
				7/01/75	98.6	781.4	
				8/05/75	98.9	781.1	
				9/02/75	98.6	781.4	
02S/05W-14Q01 S	33		802.0	10/10/74	15.4	786.6	5103
				11/12/74	NM-1		
				12/09/74	15.2	786.8	
				3/26/75	15.8	786.2	
				5/29/75	NM-1		
				7/03/75	15.5	786.5	
				8/06/75	15.6	786.4	
				9/11/75	16.4	785.6	
02S/05W-14G01 S	33		790.0	10/10/74	15.4	774.6	5103
				3/26/75	14.9	775.1	
02S/05W-15R0A S	33		796.1	3/26/75	14.3	781.8	5103
02S/05W-15H01 S	33		775.1	12/12/74	12.7	762.4	3718
				5/13/75	12.7	762.4	
02S/05W-16G04 S	33		774.1	12/12/74	15.5	758.6	3718
				5/13/75	16.1	758.0	
02S/05W-16P01 S	33		750.0	3/26/75	3.8	746.2	5103
				5/29/75	5.6(4)	744.4	
				7/03/75	5.2	744.8	
				8/06/75	5.4	744.6	
				9/11/75	5.7	744.3	
02S/05W-16R01 S	33		767.5	12/10/74	9.8	757.7	3718

See page 79 for key to terms a abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA ANA RIVER HYDRO UNIT MIDDLE SANTA ANA PIV HYDR SUBUNIT RIVERSIDE HYDRO SUBAREA						Y-01 Y-01.B Y-01.B7	
02S/05W-16R01 S	33		767.5	5/01/75	9.7	757.8	3718
02S/05W-17A01 S	33		815.0	10/10/74	68.1	746.9	5103
				11/12/74	NM-8		
				12/09/74	NM-8		
				3/26/75	67.0	748.0	
				5/29/75	66.7	748.3	
				7/03/75	67.8	747.2	
				8/07/75	67.2	747.8	
				9/11/75	67.5	747.5	
02S/05W-17A02 S	33		825.0	12/10/74	77.6	747.4	3718
				5/01/75	76.4	748.6	
02S/05W-17K01 S	33		809.0	12/10/74	60.3	748.7	3718
				5/01/75	60.2	748.8	
02S/05W-20A02 S	33		752.3	10/10/74	10.0	742.3	5103
				11/12/74	9.2	743.1	
				12/09/74	8.8	743.5	
				3/26/75	9.3	743.0	
				5/29/75	NM-1		
				7/03/75	NM-1		
				8/07/75	NM-8		
				9/11/75	10.7	741.6	
02S/05W-20J02 S	33		740.0	12/12/74	4.4	735.6	3718
				5/13/75	4.8	735.2	
02S/05W-20J03 S	33		735.7	12/30/74	2.5	733.2	3718
				5/01/75	2.9	732.8	
02S/05W-20K01 S	33		758.9	10/10/74	27.6	731.3	5103
				12/11/74	22.8	736.1	3718
				3/26/75	30.1	728.8	5103
				5/01/75	23.8	735.1	3718
02S/05W-20K03 S	33		768.3	12/11/74	31.7	736.6	3718
				5/01/75	33.8	734.5	
02S/05W-21A01 S	33		760.5	12/10/74	4.6	755.9	3718
				5/01/75	4.1	756.4	
02S/05W-21F01 S	33		747.3	12/11/74	6.6	740.7	3718
				5/01/75	6.1	741.2	
02S/05W-22D01 S	33		763.8	12/10/74	5.3	758.5	3718
				5/01/75	4.7	759.1	
02S/05W-22P02 S	33		795.0	12/23/74	34.7	760.3	3718
				5/12/75	31.4	763.6	
02S/05W-23F01 S	33		843.8	10/10/74	81.1	762.7	5103
				11/12/74	79.4	764.4	
				12/09/74	80.1	763.7	
				3/27/75	76.3	767.5	
				5/12/75	75.6	768.2	3718
02S/05W-23J01 S	33		869.4	10/31/74	101.6	767.8	5208
				2/02/75	101.0	768.4	
				3/31/75	96.8	772.6	
				7/10/75	99.5	769.9	
				8/31/75	101.0	768.4	
				9/28/75	99.1	770.3	
02S/05W-23P01 S	33		864.2	10/31/74	110.5	753.7	5208
				12/31/74	108.4	755.8	
				2/03/75	110.8	753.4	
				4/01/75	106.8	757.4	
				5/28/75	106.2	758.0	
02S/05W-24D01 S	33		873.7	1/02/75	101.3	772.4	5208
				2/02/75	101.3	772.4	
				7/25/75	100.0	773.7	
				9/28/75	99.3	774.4	
02S/05W-25A01 S	33		948.4	10/11/74	175.1	773.3	5103
				3/27/75	170.5	777.9	
02S/05W-26E02 S	33		820.0	10/01/74	85.3(1)	734.7	3847
				11/05/74	59.4	760.6	
				12/03/74	60.5	759.5	
				1/07/75	57.4	762.6	
				2/04/75	61.4	758.6	
				3/04/75	57.4	762.6	
				4/01/75	56.4	763.6	
				5/06/75	53.9	766.1	
				6/03/75	82.4(1)	737.6	
				7/01/75	85.0(1)	735.0	
				8/04/75	58.5	761.5	
				9/02/75	57.4	762.6	
02S/05W-26F01 S	33		810.0	10/01/74	54.4	755.6	3847
				11/05/74	51.4	758.6	
				12/03/74	53.4	756.6	
				1/07/75	49.4	760.6	
				2/04/75	51.4	758.6	
				3/04/75	48.9	761.1	
				4/01/75	48.4	761.6	
				5/06/75	46.5	763.5	
				6/03/75	61.4(1)	748.6	
				7/01/75	65.4(1)	744.6	
SANTA ANA RIVER HYDRO UNIT MIDDLE SANTA ANA PIV HYDR SUBUNIT RIVERSIDE HYDRO SUBAREA						Y-01 Y-01.B Y-01.B7	
02S/05W-26F01 S (CONTINUED)	33		810.0	8/04/75	50.3	759.7	3847
				9/02/75	50.4	759.6	
02S/05W-26H01 S	33		820.0	10/01/74	56.3	763.7	3847
				11/05/74	53.3	766.7	
				12/03/74	54.2	765.8	
				1/07/75	50.4	769.6	
				2/04/75	53.2	766.8	
				3/04/75	50.4	769.6	
				4/01/75	50.3	769.7	
				5/06/75	47.0	773.0	
				6/03/75	52.4	767.6	
				7/01/75	66.8(1)	753.2	
				8/04/75	51.3	768.7	
				9/02/75	50.2	769.8	
02S/05W-28A01 S	33		762.8	3/27/75	11.7	751.1	5103
				5/29/75	12.3	750.5	
				7/03/75	NM-9		
				8/07/75	NM-8		
				9/11/75	NM-9		
02S/05W-29E02 S	33		717.4	10/10/74	8.4	709.0	5103
				11/12/74	8.4	709.0	
				12/09/74	NM-8		
				3/26/75	8.3	709.1	
			717.3	5/01/75	6.2	711.1	3718
02S/05W-29F04 S	33		738.3	12/11/74	25.2	713.1	3718
				5/01/75	25.8	712.5	
02S/05W-32A01 S	33		783.0	12/23/74	54.4	728.6	3718
				5/08/75	52.1	730.9	
02S/05W-32R01 S	33		780.1	12/20/74	50.8	729.3	3718
				5/08/75	50.7	729.4	
02S/05W-32K01 S	33		776.8	10/11/74	39.2	737.6	5103
				11/12/74	39.2	737.6	
				12/09/74	39.2	737.6	
				3/27/75	38.6	738.2	
			777.5	5/08/75	38.6	738.9	3718
02S/05W-36A01 S	33		915.0	10/10/74	64.4	850.6	5103
				3/26/75	64.4	850.6	
LAKE MATHEWS HYDRO SUBUNIT COLDWATER HYDRO SUBAREA						Y-01.C Y-01.C1	
05S/06W-02P01 S	33		1110.3	10/05/74	111.8	998.5	5717
				11/02/74	127.7	982.6	
				12/07/74	107.7	1002.6	
				1/03/75	105.3	1005.0	
				2/01/75	114.1	996.2	
				3/28/75	111.4	998.9	
				4/11/75	110.2	1000.1	
				5/03/75	113.2	997.1	
				6/07/75	123.0(1)	987.3	
				7/05/75	126.1(1)	984.2	
				8/09/75	127.9(1)	982.4	
				9/06/75	130.3(1)	980.0	
05S/06W-03C01 S	33		1121.0	10/12/74	199.7	921.3	5717
				11/02/74	205.8	915.2	
				12/07/74	150.1	970.9	
				1/03/75	184.8	936.2	
				2/01/75	188.7	932.3	
				3/28/75	194.6	926.4	
				4/11/75	193.4	927.6	
				5/03/75	190.0	931.0	
				6/07/75	193.8	927.2	
				7/05/75	199.8	921.2	
				8/09/75	204.7	916.3	
				9/06/75	200.0	921.0	
05S/06W-03G01 S	33		1100.0	11/16/74	153.5	946.5	5717
				12/07/74	153.9	946.1	
				1/03/75	152.4	947.6	
				2/01/75	152.7	947.3	
				4/11/75	152.0	948.0	
				5/03/75	172.9	927.1	
				6/07/75	175.5	924.5	
				7/05/75	178.4	921.6	
				8/09/75	175.8	924.2	
				9/06/75	181.5	918.5	
05S/06W-03J01 S	33		1110.0	10/05/74	196.1	913.9	5717
				11/02/74	199.8	910.2	
				12/07/74	171.3	938.7	
				1/03/75	170.0	940.0	
				2/01/75	172.1	937.9	
				3/28/75	174.1	935.9	
				4/25/75	193.5	916.5	
				5/03/75	193.5	916.5	
				6/07/75	198.0	912.0	
				7/05/75	199.4	910.6	
				8/17/75	200.0	910.0	
				9/06/75	200.0	910.0	
05S/06W-03J04 S	33		1115.6	10/05/74	227.3(1)	887.7	5272
				11/06/74	231.2(1)	883.8	
				12/01/74	232.9(1)	882.1	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA ANA RIVER HYDRO UNIT LAKE MATHEWS HYDRO SUBUNIT COLDWATER HYDRO SUBAREA						Y-01 Y-01.C Y-01.C1	
05S/06W-03J04 S (CONTINUED)	33		1115.0	1/04/75	215.0	900.0	5272
				2/01/75	215.3	899.7	
				3/08/75	213.6	901.4	
				4/05/75	208.2	906.8	
				5/02/75	204.2	910.8	
				6/06/75	207.4	907.6	
				7/02/75	210.0	905.0	
				8/03/75	214.7	900.3	
05S/06W-03K01 S	33		1122.0	10/05/74	227.5	894.5	5272
				11/06/74	229.9	892.1	
				12/01/74	231.3	890.7	
				1/04/75	233.1(1)	888.9	
				2/01/75	233.3(1)	888.7	
				3/08/75	231.4(1)	890.6	
				4/05/75	225.8(1)	896.2	
				5/02/75	221.4(1)	900.6	
				6/06/75	225.4(1)	896.6	
				7/02/75	227.6(1)	894.4	
				8/03/75	232.0(1)	890.0	
05S/06W-03Q01 S	33		1285.0	10/05/74	254.7(1)	1030.3	5272
				11/06/74	257.5(1)	1027.5	
				12/01/74	260.3(1)	1024.7	
				1/04/75	259.2(1)	1025.8	
				2/01/75	255.8(1)	1029.2	
				3/08/75	257.4(1)	1027.6	
				4/05/75	251.8(1)	1033.2	
				5/02/75	247.8(1)	1037.2	
				6/06/75	237.6(1)	1047.4	
				7/02/75	239.2(1)	1045.8	
				8/03/75	242.1(1)	1042.9	
BEDFORD HYDRO SUBAREA						Y-01.C2	
04S/06W-16C01 S	33		781.0	10/05/74	35.8	745.2	5272
				11/06/74	36.1	744.9	
				12/01/74	35.2	745.8	
				1/04/75	26.8	754.2	
				2/01/75	27.5	753.5	
				3/08/75	25.3	755.7	
				4/05/75	21.8	759.2	
				5/02/75	20.8	760.2	
				6/06/75	29.7	751.3	
				7/02/75	33.3	747.7	
				8/03/75	36.5	744.5	
04S/06W-16C02 S	33		790.0	10/05/74	74.7(1)	715.3	5717
				11/02/74	85.0(1)	705.0	
				12/07/74	46.3	743.7	
				1/03/75	26.0	764.0	
				2/01/75	59.3(1)	730.7	
				3/28/75	21.0	769.0	
				4/11/75	19.1	770.9	
				5/03/75	19.1	770.9	
				6/07/75	81.3(1)	708.7	
				7/05/75	87.3(1)	702.7	
				8/09/75	70.5(1)	719.5	
				9/06/75	75.0(1)	715.0	
04S/06W-16F01 S	33		800.0	10/05/74	41.0(1)	759.0	5717
				11/02/74	56.3(1)	743.7	
				12/07/74	31.2	768.8	
				1/03/75	20.8	779.2	
				2/01/75	15.2	784.8	
				3/28/75	14.8	785.2	
				4/11/75	14.2	785.8	
				5/03/75	13.0	787.0	
				6/07/75	26.1(1)	773.9	
				7/05/75	33.0(1)	767.0	
				8/09/75	40.0(1)	760.0	
				9/06/75	48.3(1)	751.7	
04S/06W-35G01 S	33		956.0	10/05/74	55.9	900.1	5717
				11/02/74	84.0	872.0	
				12/07/74	49.7	906.3	
				1/03/75	32.7	923.3	
				2/01/75	45.2(1)	910.8	
				3/28/75	29.7	926.3	
				4/11/75	29.0	927.0	
				5/03/75	25.0	931.0	
				6/07/75	64.8	891.2	
				7/05/75	69.9	886.1	
				8/09/75	50.0	906.0	
				9/06/75	67.5	888.5	
04S/06W-35G02 S	33		956.0	10/05/74	60.0	896.0	5717
				11/02/74	55.3	900.7	
				12/07/74	49.9	906.1	
				1/03/75	32.7	923.3	
				2/01/75	45.0	911.0	
				3/28/75	29.7	926.3	
				4/11/75	29.0	927.0	
				5/03/75	25.0	931.0	
				6/07/75	64.9(1)	891.1	
				7/05/75	69.5	886.5	
				8/09/75	50.0	906.0	
				9/06/75	67.5	888.5	

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA ANA RIVER HYDRO UNIT LAKE MATHEWS HYDRO SUBUNIT LEE LAKE HYDRO SUBAREA						Y-01 Y-01.C Y-01.C4	
05S/05W-07C01 S	33		1095.0	10/05/74	24.0	1071.0	5717
				11/02/74	23.7	1071.3	
				12/07/74	12.0	1083.0	
				1/03/75	10.3	1084.7	
				2/01/75	13.8	1081.2	
				3/28/75	8.8	1086.2	
				4/11/75	6.8	1088.2	
				5/03/75	5.5	1089.5	
				6/07/75	11.4	1083.6	
				7/05/75	17.0	1078.0	
				8/09/75	17.4	1077.6	
				9/06/75	19.3	1075.7	
05S/05W-08N01 S	33		1175.0	10/05/74	92.8(1)	1082.2	5717
				11/02/74	106.4(1)	1068.6	
				12/07/74	53.5	1121.5	
				1/03/75	46.1	1128.9	
				2/01/75	80.5(1)	1094.5	
				3/28/75	37.0	1138.0	
				4/11/75	35.1	1139.9	
				5/03/75	37.0	1138.0	
				6/07/75	81.7(1)	1093.3	
				7/05/75	87.4(1)	1087.6	
				8/09/75	96.8(1)	1078.2	
				9/06/75	97.3(1)	1077.7	
05S/05W-08P01 S	33		1190.0	10/05/74	79.9(1)	1110.1	5717
				11/02/74	92.0(1)	1098.0	
				12/07/74	51.4	1138.6	
				1/03/75	53.8	1136.2	
				2/01/75	73.4(1)	1116.6	
				3/28/75	45.0	1145.0	
				4/11/75	43.8	1147.0	
				5/03/75	45.5	1144.5	
				6/07/75	75.8(1)	1114.2	
				7/05/75	83.0(1)	1107.0	
				8/09/75	78.5(1)	1111.5	
				9/06/75	80.3(1)	1109.7	
05S/05W-27P02 S	33		1503.5	10/24/74	40.5	1463.0	5103
				11/14/74	NM-1		
				12/11/74	38.5	1465.0	
				4/10/75	38.0	1465.5	
				6/02/75	NM-1		
TERRA COTTA HYDRO SUBAREA						Y-01.C5	
05S/04W-31E03 S	33		1275.0	10/24/74	30.2	1244.8	5103
				4/10/75	28.4	1246.6	
05S/05W-36H02 S	33		1254.0	10/24/74	NM-5		5103
				4/10/75	NM-6		
05S/05W-36J01 S	33		1260.0	10/24/74	9.8	1250.2	5103
				4/10/75	7.5	1252.5	
06S/04W-06G01 S	33		1270.0	10/24/74	20.3	1249.7	5103
				11/14/74	20.4	1249.6	
				12/11/74	20.5	1249.5	
				4/10/75	18.2	1251.8	
				6/02/75	17.6	1252.4	
COLTON-RIALTO HYDRO SUBUNIT UPPER LYTLE HYDRO SUBAREA						Y-01.D Y-01.D1	
02N/06W-21R01 S	33		3400.0	10/01/74	46.0	3354.0	4706
				11/01/74	44.8	3355.2	
				2/01/75	46.5	3353.5	
				3/01/75	47.0	3353.0	
				4/01/75	45.5	3354.5	
				5/01/75	44.2	3355.8	
				6/01/75	47.0	3353.0	
				7/01/75	40.0	3360.0	
				8/01/75	46.0	3354.0	
				9/01/75	46.0	3354.0	
02N/06W-26L01 S	33		2760.0	10/01/74	40.3(1)	2719.7	4706
				11/01/74	39.2(1)	2720.8	
				2/01/75	43.5(1)	2716.5	
				3/01/75	44.5(1)	2715.5	
				4/01/75	36.6(1)	2723.4	
				5/01/75	39.0(1)	2721.0	
				6/01/75	42.0(1)	2718.0	
				7/01/75	43.0(1)	2717.0	
				8/01/75	42.0(1)	2718.0	
				9/01/75	45.0(1)	2715.0	
LOWER LYTLE HYDRO SUBAREA						Y-01.D2	
01N/05W-06G01 S	36		2242.5	10/01/74	92.2(1)	2150.3	4706
				11/01/74	79.9	2162.6	
				2/01/75	86.2(1)	2156.3	
				3/01/75	80.9(1)	2161.6	
				4/01/75	67.0(1)	2175.5	
				5/01/75	73.8(1)	2168.7	
				6/01/75	77.4(1)	2165.1	
				7/01/75	86.4(1)	2156.1	
				8/01/75	89.4(1)	2153.1	
				9/01/75	95.4(1)	2147.1	
01N/05W-06K02 S	36		2153.0	10/01/74	108.5	2044.5	4706
				11/01/74	101.0	2052.0	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA ANA RIVER HYDRO UNIT						Y-01	
COLTON-RIALTO HYDRO SUBUNIT						Y-01.D	
LOWER LYTLE HYDRO SUBAREA						Y-01.D2	
01N/05W-06K02 S (CONTINUED)	36		2153.0	2/01/75	92.3	2060.7	4706
				3/01/75	80.7	2072.3	
				4/01/75	55.3	2097.7	
				5/01/75	62.3	2090.7	
				6/01/75	76.1	2076.9	
				7/01/75	NM-1		
				9/01/75	99.0	2054.0	
01N/05W-07H01 S	36		2065.5	2/01/75	113.1	1952.4	4706
				3/01/75	108.2	1957.3	
				4/01/75	81.5	1984.0	
				5/01/75	82.8	1982.7	
				6/01/75	90.5	1975.0	
				7/01/75	101.5	1964.0	
				8/01/75	112.5	1953.0	
				9/01/75	117.5	1948.0	
01N/05W-16K01 S	36		1720.0	2/01/75	266.5	1453.5	4706
				3/01/75	303.4(1)	1416.6	
				4/01/75	266.5	1453.5	
				5/01/75	261.9	1458.1	
				6/01/75	261.9	1458.1	
				7/01/75	298.8(1)	1421.2	
				8/01/75	303.4(1)	1416.6	
01N/05W-22C02 S	36		1591.5	2/01/75	231.7	1359.8	4706
				3/01/75	250.2(1)	1341.3	
				4/01/75	240.9(1)	1350.6	
				5/01/75	238.6(1)	1352.9	
				6/01/75	252.5(1)	1339.0	
				7/01/75	268.7(1)	1322.8	
				8/01/75	280.2(1)	1311.3	
				9/01/75	289.4(1)	1302.1	
01N/05W-22F01 S	36		1596.5	5/01/75	179.0	1417.5	4706
				6/01/75	217.8(1)	1378.7	
				7/01/75	220.1(1)	1376.4	
				8/01/75	201.7	1394.8	
				9/01/75	202.7	1393.8	
01N/05W-22F02 S	36		1583.0	2/01/75	228.6	1354.4	4706
				3/01/75	228.6	1354.4	
				4/01/75	230.9	1352.1	
				5/01/75	226.2(1)	1356.8	
				6/01/75	240.1(1)	1342.9	
				7/01/75	254.0(1)	1329.0	
				8/01/75	263.2(1)	1319.8	
				9/01/75	265.5(1)	1317.5	
01N/05W-23P04 S	36		1470.0	10/01/74	127.0	1343.0	4124
				11/01/74	122.0	1348.0	
				12/01/74	140.0(1)	1330.0	
				1/02/75	140.0(1)	1330.0	
				2/01/75	121.0	1349.0	
				3/01/75	115.0	1355.0	
				4/01/75	122.0	1348.0	
				5/01/75	133.0(1)	1337.0	
				6/01/75	139.0(1)	1331.0	
				7/01/75	147.0(1)	1323.0	
				8/01/75	129.0	1341.0	
				9/01/75	154.0(1)	1316.0	
UPPER COLTON-RIALTO HYDRO SUBAREA						Y-01.D3	
01N/05W-17G01 S	36		1850.0	11/01/74	58.0	1792.0	4124
				1/02/75	59.0	1791.0	
				3/01/75	59.0	1791.0	
				4/01/75	58.0	1792.0	
				6/01/75	57.0	1793.0	
				7/01/75	59.0	1791.0	
01N/05W-17K01 S	36		1852.7	12/01/74	65.0	1787.7	4124
				5/01/75	57.0	1795.7	
				7/01/75	57.0	1795.7	
				8/01/75	55.0	1797.7	
			1854.1	9/01/75	55.0	1799.1	4706
01N/05W-17K02 S	36		1852.6	10/01/74	58.5	1794.1	4124
				11/01/74	58.5	1794.1	
				12/01/74	57.5	1795.1	
				1/02/75	58.5	1794.1	
				2/01/75	58.5	1794.1	
				3/01/75	58.5	1794.1	
				4/01/75	55.5	1797.1	
				5/01/75	74.5(1)	1778.1	
				6/01/75	78.5(1)	1774.1	
				7/01/75	83.5(1)	1769.1	
				8/01/75	80.5(1)	1772.1	
				9/01/75	88.5(1)	1764.1	
COLTON-RIALTO HYDRO SUBAREA						Y-01.D4	
01N/05W-28J01 S	36		1514.2	10/01/74	421.0	1093.2	4124
				11/01/74	421.0	1093.2	
				12/01/74	420.0	1094.2	
				1/02/75	421.0	1093.2	
				3/01/75	425.0	1089.2	
				4/01/75	427.0	1087.2	
				5/01/75	421.0	1093.2	
				6/01/75	420.0	1094.2	
				7/01/75	421.0	1093.2	
				8/01/75	422.0	1092.2	

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA ANA RIVER HYDRO UNIT						Y-01	
COLTON-RIALTO HYDRO SUBUNIT						Y-01.D	
COLTON-RIALTO HYDRO SUBAREA						Y-01.D4	
01S/04W-18B01 S	36		1135.3	10/01/74	243.0	892.3	4201
				12/01/74	241.0	894.3	
				1/02/75	243.0	892.3	
				2/01/75	238.0	897.3	
				3/04/75	238.0	897.3	
				5/01/75	238.0	897.3	
				6/02/75	236.0	899.3	
				7/01/75	238.0	897.3	
				8/01/75	242.0	893.3	
				9/02/75	238.0	897.3	
01S/04W-18F01 S	36		1099.4	10/01/74	207.0	892.4	4201
				12/01/74	205.0	894.4	
				1/02/75	207.0	892.4	
				2/01/75	196.0	903.4	
				3/04/75	208.0	891.4	
				4/03/75	204.0	895.4	
				5/01/75	206.0	893.4	
				6/02/75	203.0	896.4	
				7/01/75	205.0	894.4	
				8/01/75	206.0	893.4	
				9/02/75	205.0	894.4	
01S/04W-18G01 S	36		1093.5	10/01/74	207.0	886.5	4201
				12/01/74	205.0	888.5	
				1/02/75	207.0	886.5	
				2/01/75	196.0	897.5	
				3/04/75	207.0	886.5	
				4/03/75	204.0	889.5	
				5/01/75	205.0	888.5	
				6/02/75	203.0	890.5	
				7/01/75	205.0	888.5	
				8/01/75	206.0	887.5	
				9/02/75	206.0	887.5	
01S/04W-21K11 S	36		961.0	10/24/74	68.5	892.5	5412
				11/21/74	69.7	891.3	
				12/19/74	69.8	891.2	
				1/16/75	70.2	890.8	
				2/12/75	71.4	889.6	
				3/12/75	70.8	890.2	
				4/09/75	69.3	891.7	
				5/15/75	67.0	894.0	
				6/13/75	68.3	892.7	
				7/10/75	69.3	891.7	
				8/14/75	67.3	893.7	
				9/18/75	64.2	896.8	
01S/04W-21L01 S	36		956.0	10/01/74	68.3	887.7	5208
				11/05/74	65.9	890.1	
				12/10/74	67.8	888.2	
				1/07/75	65.8	890.2	
				2/11/75	67.4	888.6	
				3/11/75	65.7	890.3	
				4/01/75	65.6	890.4	
				5/27/75	NM-1		3730
				6/17/75	134.0(1)	822.0	5208
				7/15/75	77.5	878.5	
				8/10/75	92.5	863.5	
				9/01/75	104.5	851.5	
01S/04W-21Q03 S	36		955.2	10/24/74	68.1	887.1	5412
				11/21/74	77.7	877.5	
				12/19/74	64.9	890.3	
				1/16/75	71.5	883.7	
				2/12/75	73.1	882.1	
				3/12/75	70.4	884.8	
				4/09/75	69.6	885.6	
				5/15/75	67.3	887.9	
				6/11/75	69.1	886.1	
				7/10/75	68.5	886.7	
				8/14/75	67.8	887.4	
				9/18/75	62.3	892.9	
01S/04W-27L01 S	36		993.0	12/05/74	87.6	905.4	3718
				4/28/75	87.6	905.4	
01S/04W-28A05 S	36		960.0	12/05/74	58.5	901.5	3718
				4/28/75	55.1	904.9	
01S/04W-28C01 S	36		948.0	10/08/74	62.5	885.5	5208
				11/20/74	66.4	881.6	
				12/10/74	61.9	886.1	
				1/07/75	57.8	890.2	
				2/11/75	67.5	880.5	
				3/11/75	61.5	886.5	
				4/01/75	58.8	889.2	
				5/22/75	70.3	877.7	
				6/17/75	68.8	879.2	
				7/01/75	69.3	878.7	
				8/10/75	157.9(1)	790.1	
				9/23/75	162.8(1)	785.2	
01S/04W-28D01 S	36		942.8	10/08/74	56.8	885.2	5208
				12/10/74	61.3	880.7	
				1/07/75	55.8	886.2	
				2/03/75	56.2	885.8	
				3/11/75	64.3	877.7	
				4/01/75	55.2	886.8	
				5/06/75	55.2	886.8	
				6/10/75	58.8	883.2	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA ANA RIVER HYDRO UNIT						Y-01	
COLTON-RIALTO HYDRO SUBUNIT						Y-01.D	
COLTON-RIALTO HYDRO SUBAREA						Y-01.D4	
01S/04W-28R01 S (CONTINUED)	36		942.0	7/01/75	62.7	879.3	5208
				8/10/75	61.4	880.6	
				9/01/75	62.8	879.2	
01S/04W-28F01 S	36		936.0	12/05/74	42.4	893.6	3718
				4/28/75	34.1	901.9	
01S/04W-28G01 S	36		954.0	12/05/74	60.6	893.4	3718
				4/28/75	57.0	897.0	
01S/04W-28K01 S	36		947.0	10/05/74	61.1	885.9	5783
				11/08/74	60.5	886.5	
			946.6	12/07/74	64.8(1)	881.8	3718
			947.0	1/04/75	63.0(1)	884.0	5783
				2/08/75	62.0(1)	885.0	
				3/08/75	62.2(1)	884.8	
				4/05/75	63.8(1)	883.2	
			946.6	5/03/75	63.0	883.6	3718
			947.0	6/07/75	64.0(1)	883.0	5783
				7/05/75	64.9(1)	882.1	
				8/08/75	65.1(1)	881.9	
				9/05/75	65.8(1)	881.2	
01S/04W-28K02 S	36		952.4	10/05/74	52.4	900.0	5783
				11/08/74	54.9	897.5	
			945.8	12/07/74	56.2	889.6	3718
			952.4	1/04/75	54.4	898.0	5783
				2/08/75	54.4	898.0	
				3/08/75	54.8	897.6	
				4/05/75	54.3	898.1	
			945.8	5/03/75	56.0	889.8	3718
			952.4	6/07/75	54.6	897.8	5783
				7/05/75	54.3	898.1	
				8/08/75	58.3(1)	894.1	
				9/05/75	56.9	895.5	
01S/05W-02K01 S	36		1287.0	10/01/74	322.0	965.0	4124
				11/01/74	321.0	966.0	
				12/01/74	320.0	967.0	
				1/02/75	316.0	971.0	
				2/01/75	322.0	965.0	
				3/01/75	321.0	966.0	
				4/01/75	319.0	968.0	
				5/01/75	319.0	968.0	
				6/01/75	320.0	967.0	
				7/01/75	319.0	968.0	
				9/01/75	308.0	979.0	
01S/05W-04D02 S	36		1392.0	2/01/75	397.0	995.0	4706
				3/01/75	371.0	1021.0	
				4/01/75	376.0	1016.0	
				5/01/75	377.0	1015.0	
				6/01/75	377.0	1015.0	
				7/01/75	370.9	1021.1	
				8/01/75	412.4	979.6	
				9/01/75	410.1(1)	981.9	
01S/05W-05A02 S	36		1407.0	2/01/75	262.8	1144.2	4706
				3/01/75	260.5	1146.5	
				4/01/75	260.5	1146.5	
				5/01/75	255.8	1151.2	
				6/01/75	274.3	1132.7	
				7/01/75	283.6	1123.4	
				8/01/75	272.0	1135.0	
				9/01/75	288.2	1118.8	
01S/05W-05A03 S	36		1406.0	2/01/75	258.0	1148.0	4706
				3/01/75	258.0	1148.0	
				4/01/75	258.0	1148.0	
				5/01/75	253.4	1152.6	
				6/01/75	304.2(1)	1101.8	
				7/01/75	308.8(1)	1097.2	
				8/01/75	311.2	1094.8	
				9/01/75	318.1(1)	1087.9	
01S/05W-12L01 S	36		1180.0	10/01/74	275.8(1)	904.2	4124
				11/01/74	252.8	927.2	
				12/01/74	274.8(1)	905.2	
				1/02/75	271.8(1)	908.2	
				2/01/75	250.8	929.2	
				3/01/75	251.8(1)	928.2	
				4/01/75	252.8	927.2	
				5/01/75	271.8(1)	908.2	
				6/01/75	294.8(1)	885.2	
				7/01/75	255.8	924.2	
				8/01/75	267.8(1)	912.2	
				9/01/75	246.8	933.2	
01S/05W-12N01 S	36		1173.0	10/01/74	244.3	928.7	4124
				11/01/74	243.3	929.7	
				12/01/74	242.3	930.7	
				1/02/75	240.3	932.7	
				2/01/75	241.3	931.7	
				3/01/75	242.3	930.7	
				4/01/75	243.3	929.7	
				5/01/75	240.3	932.7	
				6/01/75	239.3	933.7	
				7/01/75	245.3(1)	927.7	
				8/01/75	237.3	935.7	
				9/01/75	252.3(1)	920.7	

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA ANA RIVER HYDRO UNIT						Y-01	
COLTON-RIALTO HYDRO SUBUNIT						Y-01.D	
RECHE HYDRO SUBAREA						Y-01.D5	
02S/03W-18B02 S	33		1660.0	11/05/74	51.9(4)	1608.1	5103
				4/02/75	64.3	1595.7	
02S/03W-18K01 S	33		1900.0	11/05/74	74.2	1825.8	5103
				4/02/75	74.3	1825.7	
02S/03W-20N01 S	33		2000.0	11/05/74	50.0	1950.0	5103
				4/02/75	52.0	1948.0	
02S/04W-12P02 S	36		1502.0	11/05/74	47.3	1454.7	5103
				4/02/75	NM-1		
UPPER SANTA ANA R HYDRO SUBUNIT						Y-01.E	
BUNKER HILL HYDRO SUBAREA						Y-01.E2	
01N/03W-27N02 S	36		1490.0	10/07/74	64.0	1426.0	4776
				11/07/74	61.0	1429.0	
				12/07/74	61.0	1429.0	
				1/08/75	34.0	1456.0	
				2/08/75	31.0	1459.0	
				3/07/75	31.0	1459.0	
				4/07/75	30.0	1460.0	
				5/07/75	31.0	1459.0	
				6/07/75	34.0	1456.0	
				7/07/75	36.0	1454.0	
				8/07/75	50.0	1440.0	
				9/07/75	51.0	1439.0	
01N/03W-27N05 S	36		1494.0	10/07/74	44.0	1450.0	4776
				11/07/74	44.0	1450.0	
				12/07/74	40.0	1454.0	
				1/08/75	53.0	1441.0	
				2/08/75	31.0	1463.0	
				3/07/75	34.0	1460.0	
				4/07/75	26.0	1468.0	
				5/07/75	45.0	1449.0	
				6/07/75	NM-7		
				7/07/75	23.0	1471.0	
				8/07/75	92.0	1402.0	
				9/07/75	90.0	1404.0	
01N/03W-28P01 S	36		1496.2	10/31/74	464.9(1)	1031.3	4104
				11/26/74	462.6(1)	1033.6	
				12/26/74	467.9(1)	1028.3	
				1/30/75	465.4(1)	1030.8	
				2/28/75	466.7(1)	1029.5	
				4/15/75	468.9(1)	1027.3	
				5/08/75	466.5(1)	1029.7	
				6/09/75	463.9(1)	1032.3	
				7/18/75	463.3(1)	1032.9	
				9/29/75	458.2(1)	1038.0	
01N/03W-29M01 S	36		1345.2	11/12/74	325.7	1019.5	5060
				12/09/74	325.2	1020.0	
				1/07/75	323.2	1022.0	
				2/06/75	322.1	1023.1	
				3/12/75	322.4	1022.8	
				4/14/75	321.0	1024.2	
				5/13/75	319.7	1025.5	
				6/10/75	320.9	1024.3	
				7/08/75	325.5	1019.7	
				8/03/75	329.0	1016.2	
				9/10/75	331.7	1013.5	
01N/03W-29N01 S	36		1291.0	11/12/74	287.8	1003.2	5060
				12/10/74	286.2	1004.8	
				1/14/75	283.2	1007.8	
				2/05/75	282.6	1008.4	
				3/12/75	280.9	1010.1	
				4/11/75	280.0	1011.0	
				5/12/75	279.0	1012.0	
				6/10/75	280.6	1010.4	
				7/09/75	283.5	1007.5	
				8/03/75	285.2	1005.8	
				9/11/75	287.8	1003.2	
01N/03W-30C02 S	36		1355.6	10/28/74	219.6	1136.0	4104
				11/25/74	210.1	1145.5	
				12/23/74	219.6	1136.0	
				1/27/75	224.8	1130.8	
				2/24/75	222.6	1133.0	
				4/16/75	221.3	1134.3	
				5/19/75	219.2	1136.4	
				6/12/75	219.9	1135.7	
				7/18/75	222.6	1133.0	
				9/22/75	215.1	1140.5	
01N/03W-30J05 S	36		1340.0	10/28/74	318.5(1)	1021.5	4104
				11/26/74	314.2(1)	1025.8	
				12/23/74	322.0(1)	1018.0	
				1/28/75	325.7(1)	1014.3	
				2/25/75	323.3(1)	1016.7	
				4/28/75	320.1(1)	1019.9	
				5/19/75	319.4(1)	1020.6	
				6/19/75	320.8(1)	1019.2	
				7/09/75	323.0(1)	1017.0	
				9/23/75	318.6(1)	1021.4	
01N/03W-30N01 S	36		1234.7	10/28/74	273.9(1)	960.8	4104
				11/26/74	269.2(1)	965.5	
				12/30/74	272.7(1)	962.0	
				1/28/75	268.7(1)	966.0	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA ANA RIVER HYDRO UNIT						Y-01	
UPPER SANTA ANA R HYDRO SUBUNIT						Y-01.E	
BUNKER HILL HYDRO SUBAREA						Y-01.E2	
01N/03W-30N01 S (CONTINUED)	36		1234.7	2/26/75	267.0(1)	967.7	4104
				4/28/75	267.7(1)	967.0	
				5/19/75	266.4(1)	968.3	
				6/14/75	266.5(1)	968.2	
				7/11/75	267.1(1)	967.6	
				9/23/75	260.7(1)	974.0	
01N/03W-31C02 S	36		1210.0	10/29/74	NM-3		4104
				11/26/74	NM-3		
				12/23/74	NM-3		
				1/27/75	NM-3		
				2/25/75	NM-3		
				4/25/75	NM-3		
				5/19/75	NM-3		
				6/17/75	NM-3		
				7/09/75	NM-3		
				9/26/75	NM-3		
01N/03W-32C02 S	36		1278.0	11/12/74	252.5	1017.5	5060
				12/10/74	251.1	1018.9	
				1/07/75	250.0	1020.0	
				2/05/75	249.1	1020.9	
				3/12/75	250.0	1020.0	
				4/14/75	249.7	1020.3	
				5/12/75	245.0	1025.0	
				6/10/75	245.9	1024.1	
				7/08/75	248.0	1022.0	
				8/02/75	249.8	1020.2	
				9/10/75	253.8	1016.2	
01N/03W-33M01 S	36		1290.0	10/07/74	265.0	1025.0	4776
				11/07/74	260.0	1030.0	
				12/07/74	260.0	1030.0	
				1/08/75	260.0	1030.0	
				2/08/75	260.0	1030.0	
				3/07/75	257.0	1033.0	
				4/07/75	257.0	1033.0	
				5/07/75	256.0	1034.0	
				6/07/75	256.0	1034.0	
				7/07/75	251.0	1039.0	
				8/07/75	256.0	1034.0	
				9/07/75	256.0	1034.0	
01N/03W-33M02 S	36		1294.0	10/07/74	270.0	1024.0	4776
				11/07/74	268.0	1026.0	
				12/07/74	268.0	1026.0	
				1/08/75	266.0	1028.0	
				2/08/75	265.0	1029.0	
				3/07/75	260.0	1034.0	
				4/07/75	258.0	1036.0	
				5/07/75	263.0	1031.0	
				6/07/75	261.0	1033.0	
				7/07/75	262.0	1032.0	
				8/07/75	254.0	1040.0	
				9/07/75	254.0	1040.0	
01N/04W-06H01 S	36		1902.4	10/17/74	44.2	1858.2	3230
				1/15/75	37.3	1865.1	
01N/04W-06H02 S	36		1887.7	10/17/74	30.0	1857.7	3230
				1/15/75	26.6	1861.1	
01N/04W-07F01 S	36		1622.0	10/17/74	179.9	1442.1	3230
				11/12/74	165.3	1456.7	
				12/28/74	165.1	1456.9	
				1/16/75	163.2	1458.8	
				2/28/75	164.7	1457.3	
				3/26/75	165.4	1456.6	
				5/01/75	156.0	1466.0	
				6/05/75	162.1	1459.9	5412
				7/01/75	NM-1		
				8/07/75	164.2	1457.8	
				9/04/75	164.8	1457.2	
01N/04W-08M01 S	36		1529.8	10/17/74	140.1	1389.7	3230
				11/12/74	143.2	1386.6	
				12/28/74	145.7	1384.1	
				1/15/75	152.2	1377.6	
				2/28/75	157.7	1372.1	
				3/26/75	155.5	1374.3	
				5/01/75	157.1	1372.7	
				6/04/75	161.0	1368.8	5412
				7/01/75	164.6	1365.2	
				8/07/75	160.1	1369.7	
				9/04/75	155.4	1374.4	
01N/04W-08P01 S	36		1476.7	10/17/74	152.1	1324.6	3230
				11/12/74	153.7	1323.0	
				12/28/74	153.8	1322.9	
				1/16/75	159.0	1317.7	
				2/28/75	162.2	1314.5	
				3/26/75	161.9	1314.8	
				5/01/75	163.9	1312.8	
				6/05/75	166.0	1310.7	5412
				7/01/75	168.2(1)	1308.5	
				8/07/75	169.5	1307.2	
				9/04/75	168.1	1308.6	
01N/04W-14P08 S	36		1409.1	11/13/74	13.9	1395.2	3230
				1/15/75	13.1	1396.0	
				3/21/75	11.1	1398.0	
01N/04W-16F01 S	36		1411.9	10/18/74	143.3(4)	1268.6	3230

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA ANA RIVER HYDRO UNIT						Y-01	
UPPER SANTA ANA R HYDRO SUBUNIT						Y-01.E	
BUNKER HILL HYDRO SUBAREA						Y-01.E2	
01N/04W-16F01 S (CONTINUED)	36		1411.9	11/15/74	177.0(2)	1234.9	3230
				12/28/74	176.2	1235.7	
				1/17/75	181.1(2)	1230.8	
				2/28/75	172.2	1239.7	
				3/26/75	172.2	1239.7	
				5/01/75	174.7	1237.2	
				6/18/75	174.3	1237.6	
				7/17/75	179.6	1232.3	
				8/21/75	181.6	1230.3	
01N/04W-16F02 S	36		1403.3	10/18/74	147.4(2)	1255.9	3230
				11/15/74	170.7(2)	1232.6	
				12/28/74	171.3(2)	1232.0	
				1/17/75	168.6(2)	1234.7	
				2/28/75	145.6(2)	1257.7	
				3/26/75	166.8	1236.5	
				5/23/75	NM-1		
				6/18/75	166.9	1236.4	
				7/17/75	NM-1		
				8/22/75	174.3	1229.0	
01N/04W-16F03 S	36		1407.0	10/18/74	175.8(2)	1231.2	3230
				11/15/74	194.7(2)	1212.3	
				12/28/74	169.7(2)	1237.3	
				1/17/75	179.8(2)	1227.2	
				2/28/75	169.8(2)	1237.2	
				3/26/75	169.0	1238.0	
				5/23/75	NM-1		
				6/18/75	169.8	1237.2	
				7/17/75	172.4	1234.6	
				8/22/75	176.6	1230.4	
01N/04W-20N01 S	36		1330.9	11/14/74	278.6	1052.3	3230
				1/14/75	284.4	1046.5	
				3/20/75	281.6	1049.3	
				5/23/75	282.7	1048.2	
				7/14/75	253.1	1077.8	
01N/04W-21R02 S	36		1322.4	5/01/75	138.0	1184.4	5412
				6/04/75	140.8	1181.6	
				7/01/75	143.5	1178.9	
				8/07/75	142.2	1180.2	
				9/04/75	143.8	1178.6	
01N/04W-23B01 S	36		1365.0	5/01/75	191.3	1173.7	5412
				6/04/75	191.6	1173.4	
				7/01/75	197.5	1167.5	
				8/07/75	208.9	1156.1	
				9/04/75	215.8	1149.2	
01N/04W-23F01 S	36		1300.3	5/01/75	251.9	1048.4	5412
				6/04/75	253.1	1047.2	
				7/01/75	258.6	1041.7	
				8/07/75	258.1	1042.2	
				9/04/75	261.0	1039.3	
01N/04W-23G01 S	36		1345.0	5/01/75	258.1	1086.9	5412
				6/05/75	255.8	1089.2	
				7/01/75	255.9	1089.1	
				8/07/75	258.0	1087.0	
				9/04/75	259.2	1085.8	
01N/04W-23K01 S	36		1294.4	11/13/74	211.9	1082.5	3230
				1/15/75	229.4	1065.0	
				3/21/75	262.5	1031.9	
01N/04W-23M01 S	36		1294.8	11/13/74	249.0	1045.8	3230
				1/14/75	254.3	1040.5	
				3/21/75	254.7	1040.1	
				5/01/75	253.0	1041.8	5412
				6/04/75	252.5	1042.3	
				7/01/75	253.7	1041.1	
				8/07/75	261.0	1033.8	
				9/04/75	263.8	1031.0	
01N/04W-23Q02 S	36		1284.4	5/01/75	258.4	1026.0	5412
				6/04/75	261.0	1023.4	
				7/01/75	263.3	1021.1	
				8/07/75	268.6	1015.8	
				9/04/75	271.4	1013.0	
01N/04W-23R02 S	36		1269.0	5/01/75	216.6	1052.4	5412
				6/04/75	220.4	1048.6	
				7/01/75	222.4	1046.6	
				8/07/75	225.0	1044.0	
				9/04/75	226.9	1042.1	
01N/04W-25A01 S	36		1295.6	10/28/74	239.3	1056.3	4104
				11/27/74	232.0	1063.6	
				12/30/74	236.5	1059.1	
				1/27/75	234.8	1060.8	
				2/24/75	234.0	1061.6	
				4/14/75	233.2	1062.4	
				5/14/75	231.6	1064.0	
				6/11/75	232.8	1062.8	
				7/11/75	233.1	1062.5	
				9/29/75	228.0	1067.6	
01N/04W-25C02 S	36		1248.3	10/28/74	300.3(1)	946.0	4104
				11/27/74	293.6(1)	952.7	
				12/30/74	297.6(1)	948.7	
				1/28/75	293.2(1)	953.1	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA ANA RIVER HYDRO UNIT UPPER SANTA ANA R HYDRO SUBUNIT BUNKER HILL HYDRO SUBAREA						Y-01 Y-01.E Y-01.E2	
01N/04W-25C02 S (CONTINUED)	36		1246.3	2/24/75	293.1(1)	953.2	4104
				4/14/75	293.8(1)	952.5	
				5/14/75	292.1(1)	954.2	
				6/11/75	294.9(1)	951.4	
				7/11/75	297.6(1)	948.7	
				9/25/75	294.3(1)	952.0	
01N/04W-25C04 S	36		1245.0	10/28/74	268.2(1)	976.8	4104
				11/27/74	270.0(1)	975.0	
				12/30/74	274.4(1)	970.6	
				1/27/75	279.0(1)	966.0	
				2/24/75	277.5(1)	967.5	
				4/17/75	274.3(1)	970.7	
				5/15/75	270.7(1)	974.3	
				6/18/75	272.0(1)	973.0	
				7/15/75	276.4(1)	968.6	
				9/24/75	260.3	984.7	
01N/04W-25M03 S	36		1208.0	10/30/74	210.0	998.0	4104
				11/27/74	186.0	1022.0	
				12/30/74	189.7	1018.3	
				1/31/75	197.7	1010.3	
				2/26/75	196.5	1011.5	
				4/10/75	193.0	1015.0	
				5/01/75	188.3	1019.7	5412
				6/05/75	186.9	1021.1	
				7/01/75	191.6	1016.4	
				8/07/75	187.4	1020.6	
				9/04/75	187.9	1020.1	
01N/04W-25P04 S	36		1190.4	10/28/74	193.5	996.9	4104
				11/26/74	187.5	1002.9	
				12/27/74	192.0	998.4	
				1/28/75	190.7	999.7	
				2/25/75	190.2	1000.2	
				4/25/75	188.6	1001.8	
				5/19/75	189.4	1001.0	
				6/18/75	190.8	999.6	
				7/16/75	193.0	997.4	
				9/24/75	190.5	999.9	
01N/04W-26A01 S	36		1243.5	10/28/74	270.7	972.8	4104
				11/27/74	261.5	982.0	
				12/30/74	265.0	978.5	
				1/28/75	260.2	983.3	
				2/25/75	259.5	984.0	
				4/10/75	263.3	980.2	
				5/14/75	262.0	981.5	
				6/11/75	265.7	977.8	
				7/11/75	269.3	974.2	
				9/25/75	262.5	981.0	
01N/04W-26A02 S	36		1241.0	10/28/74	243.2	997.8	4104
				11/27/74	236.5	1004.5	
				12/30/74	241.0	1000.0	
				1/28/75	238.7	1002.3	
				2/25/75	238.0	1003.0	
				4/10/75	240.5	1000.5	
				5/14/75	239.2	1001.8	
				6/11/75	241.0	1000.0	
				7/11/75	245.6	995.4	
				9/25/75	238.7	1002.3	
01N/04W-26A03 S	36		1244.0	10/28/74	284.0(1)	960.0	4104
				11/27/74	277.8(1)	966.2	
				12/30/74	282.0(1)	962.0	
				1/28/75	278.5(1)	965.5	
				2/25/75	277.0(1)	967.0	
				4/10/75	279.2(1)	964.8	
				5/14/75	277.9(1)	966.1	
				6/11/75	280.0(1)	964.0	
				7/11/75	283.5(1)	960.5	
				9/25/75	275.0	969.0	
01N/04W-26F02 S	36		1236.2	10/17/74	241.7	994.5	3230
				11/15/74	234.2	1002.0	
				12/23/74	234.3	1001.9	
				1/14/75	234.9	1001.3	
				2/27/75	242.8	993.4	
				3/21/75	232.7	1003.5	
				4/30/75	220.8	1015.4	
01N/04W-26N02 S	36		1193.7	11/13/74	219.5	974.2	3230
				1/13/75	195.3	998.4	
				3/20/75	192.2	1001.5	
01N/04W-26P03 S	36		1173.9	10/16/74	195.9	978.0	3230
				11/12/74	183.3	990.6	
				12/23/74	183.1	990.8	
				1/14/75	179.3	994.6	
				2/26/75	176.9	997.0	
				3/20/75	180.7	993.2	
				4/30/75	182.9	991.0	
01N/04W-27A01 S	36		1244.4	10/17/74	246.7	997.7	3230
				11/15/74	267.0	977.4	
				12/23/74	267.3	977.1	
				1/15/75	222.6(1)	1021.8	
				2/27/75	237.0	1007.4	
				3/21/75	236.7	1007.7	
01N/04W-27A02 S	36		1240.0	10/17/74	243.0	997.0	3230
SANTA ANA RIVER HYDRO UNIT UPPER SANTA ANA R HYDRO SUBUNIT BUNKER HILL HYDRO SUBAREA						Y-01 Y-01.E Y-01.E2	
01N/04W-27A02 S (CONTINUED)	36		1240.0	11/15/74	241.6	998.4	3230
				12/26/74	237.9	1002.1	
				1/15/75	239.8	1000.2	
				2/27/75	234.4	1005.6	
				3/21/75	237.1	1002.9	
				5/01/75	232.8	1007.2	
				6/17/75	NM-1		
				7/17/75	NM-1		
				8/14/75	NM-1		
01N/04W-27B01 S	36		1233.0	10/17/74	251.7	981.3	3230
				11/13/74	236.2	996.8	
				12/26/74	235.9	997.1	
				1/15/75	235.0	998.0	
				2/27/75	240.6	992.4	
				3/26/75	237.3	995.7	
				4/30/75	227.5	1005.5	
01N/04W-27G01 S	36		1226.4	10/17/74	250.3	976.1	3230
				11/12/74	230.7	995.7	
				12/26/74	231.3	995.1	
				1/15/75	251.2	975.2	
				2/27/75	256.8	969.6	
				3/26/75	256.1	970.3	
				5/01/75	258.3	968.1	
				6/18/75	259.1	967.3	
				7/07/75	NM-1		
				8/22/75	NM-1		
				9/19/75	241.7	984.7	
01N/04W-27M01 S	36		1189.1	10/18/74	196.8	992.3	3230
				11/13/74	205.3	983.8	
				12/26/74	205.6	983.5	
				1/16/75	192.6	996.5	
				2/27/75	192.6	996.5	
				3/24/75	200.6	988.5	
				5/01/75	195.0	994.1	
01N/04W-27M02 S	36		1184.1	10/18/74	198.1	986.0	3230
				11/13/74	195.2	988.9	
				12/26/74	196.2	987.9	
				1/15/75	197.9	986.2	
				2/27/75	214.2	969.9	
				3/24/75	185.4	998.7	
				4/30/75	185.2	998.9	
				5/22/75	187.0	997.1	
				6/19/75	193.9	990.2	
				7/17/75	196.2	987.9	
01N/04W-28J02 S	36		1185.0	10/18/74	192.1	992.9	3230
				11/13/74	190.3	994.7	
				12/28/74	190.5	994.5	
				1/15/75	185.1	999.9	
				2/27/75	186.6	998.4	
				3/24/75	191.7	993.3	
				4/30/75	NM-9		
01N/04W-29E01 S	36		1303.7	10/07/74	267.0	1036.7	4776
				11/07/74	267.0	1036.7	
				12/07/74	266.0	1037.7	
				1/08/75	265.0	1038.7	
				2/08/75	266.0	1037.7	
				3/07/75	265.0	1038.7	
				4/07/75	266.0	1037.7	
				5/07/75	266.0	1037.7	
				6/07/75	265.0	1038.7	
				7/07/75	266.0	1037.7	
				8/14/75	270.0	1033.7	
				9/07/75	269.0	1034.7	
01N/04W-29F01 S	36		1278.0	10/07/74	244.0	1034.0	4776
				3/07/75	NM-7		
01N/04W-31A01 S	36		1258.1	10/18/74	238.0	1020.1	3230
				11/13/74	238.9	1019.2	
				12/28/74	236.4	1021.7	
				1/14/75	236.8(1)	1021.3	
				2/27/75	229.7	1028.4	
				3/21/75	227.0	1031.1	
				5/01/75	227.2	1030.9	
				6/17/75	NM-1		
				7/11/75	NM-1		
				8/21/75	NM-1		
01N/04W-31F01 S	36		1269.0	12/07/74	103.1	1165.9	3718
				4/05/75	100.5	1168.5	
01N/04W-31H01 S	36		1225.0	10/07/74	204.0	1021.0	4776
				11/07/74	202.0	1023.0	
				12/07/74	204.0	1021.0	
				1/08/75	202.0	1023.0	
				2/08/75	203.0	1022.0	
				3/07/75	202.0	1023.0	
				4/07/75	201.0	1024.0	
				5/07/75	202.0	1023.0	
				6/07/75	202.0	1023.0	
				7/07/75	202.0	1023.0	
				8/07/75	206.0	1019.0	
				9/07/75	205.0	1020.0	
01N/04W-32D03 S	36		1230.3	10/18/74	201.2	1029.1	3230
				11/14/74	195.7	1034.6	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA ANA RIVER HYDRO UNIT UPPER SANTA ANA R HYDRO SUBUNIT BUNKER HILL HYDRO SUBAREA						Y-01 Y-01.E Y-01.E2	
01N/04W-32D03 S (CONTINUED)	36		1230.3	12/28/74	196.1	1034.2	3230
				1/14/75	209.9	1020.4	
				2/27/75	202.1	1028.2	
				3/24/75	204.7	1025.6	
				5/01/75	208.7	1021.6	
				6/17/75	212.6	1017.7	
				7/15/75	215.2	1015.1	
				8/21/75	221.4	1008.9	
01N/04W-32D04 S	36		1236.3	10/18/74	211.9	1024.4	3230
				11/14/74	216.1	1020.2	
				12/28/74	216.6	1019.7	
				1/14/75	201.1	1035.2	
				2/27/75	211.2	1025.1	
				3/24/75	209.4	1026.9	
				5/01/75	210.4	1025.9	
				6/17/75	NM-1		
				7/15/75	NM-1		
				8/21/75	NM-1		
01N/04W-32N01 S	36		1184.8	10/18/74	181.5(1)	1003.3	3230
				11/14/74	168.1	1016.7	
				12/14/74	169.8	1015.0	
				1/14/75	165.6	1019.2	
				2/27/75	170.1	1014.7	
				3/20/75	157.4(1)	1027.4	
				5/01/75	172.3	1012.5	
				6/17/75	NM-1		
				7/17/75	NM-1		
				8/22/75	NM-1		
01N/04W-33M01 S	36		1161.0	11/13/74	148.1	1012.9	3230
				1/14/75	149.8	1011.2	
				3/20/75	149.3	1011.7	
				5/27/75	147.4	1013.6	
				7/15/75	149.6	1011.4	
01N/04W-34G01 S	36		1141.9	10/16/74	166.7	975.2	3230
				11/12/74	160.7	981.2	
				12/20/74	151.7	990.2	
				1/14/75	151.1	990.8	
				2/26/75	150.9	991.0	
				3/20/75	147.5	994.4	
				4/29/75	148.9	993.0	
01N/04W-34G03 S	36		1136.2	10/16/74	158.6	977.6	3230
				11/12/74	153.7	982.5	
				12/12/74	146.0	990.2	
				1/14/75	133.3	1002.9	
				2/26/75	125.3	1010.9	
				3/20/75	142.5	993.7	
				4/29/75	144.7	991.5	
01N/04W-35C01 S	36		1153.2	10/16/74	168.5	984.7	3230
				11/12/74	167.1	986.1	
				12/23/74	177.1	976.1	
				1/14/75	163.6	989.6	
				2/26/75	159.2	994.0	
				3/20/75	155.9	997.3	
				4/30/75	157.2	996.0	
01N/04W-35C02 S	36		1164.5	10/16/74	177.3	987.2	3230
				11/12/74	183.3	981.2	
				12/23/74	184.2	980.3	
				1/14/75	179.2	985.3	
				2/26/75	177.1	987.4	
				3/20/75	190.4	974.1	
				4/30/75	172.1	992.4	
01N/04W-35C03 S	36		1168.0	10/16/74	182.5	985.5	3230
				11/12/74	180.1	987.9	
				12/23/74	181.2	986.8	
				1/14/75	163.0	1005.0	
				2/26/75	172.3	995.7	
				3/20/75	176.8	991.2	
				4/30/75	170.8	997.2	
01N/04W-35L01 S	36		1130.3	10/01/74	159.2	971.1	3230
				11/05/74	154.0	976.3	
				12/03/74	153.7	976.6	
				1/07/75	144.3	986.0	
				2/03/75	145.7	984.6	
				3/07/75	147.2	983.1	
				4/01/75	142.4	987.9	
				5/01/75	143.1	987.2	5412
				6/03/75	150.6	979.7	3230
				7/01/75	157.8	972.5	
				8/07/75	168.6	961.7	5412
				9/02/75	166.4	963.9	3230
01N/04W-35L06 S	36		1127.0	11/13/74	156.2	970.8	3230
				1/21/75	156.0(1)	971.0	
				3/21/75	151.0	976.0	
				5/22/75	NM-1		
01N/04W-35M03 S	36		1122.7	10/16/74	153.9	968.8	3230
				11/12/74	153.9	968.8	
				12/20/74	137.8	984.9	
				1/14/75	138.9	983.8	
				2/25/75	140.7	982.0	
				3/20/75	135.9	986.8	
				4/29/75	138.5	984.2	
SANTA ANA RIVER HYDRO UNIT UPPER SANTA ANA R HYDRO SUBUNIT BUNKER HILL HYDRO SUBAREA						Y-01 Y-01.E Y-01.E2	
01N/04W-35M03 S	36		1122.7	5/22/75	141.4	981.3	3230
01N/04W-36K07 S	36		1120.0	10/28/74	141.2	978.8	4104
				11/25/74	135.7	984.3	
				12/30/74	133.5	986.5	
				1/29/75	139.0	981.0	
				2/26/75	136.8	983.2	
				4/25/75	138.3	981.7	
				5/09/75	139.5	980.5	
				6/09/75	141.7	978.3	
				7/07/75	144.0	976.0	
				9/25/75	138.2	981.8	
01N/04W-36Q01 S	36		1098.0	10/30/74	127.6	970.4	4104
				11/25/74	123.4	974.6	
				12/30/74	119.0	979.0	
				1/29/75	122.5	975.5	
				2/26/75	120.0	978.0	
				4/25/75	121.3	976.7	
				5/09/75	123.7	974.3	
				6/09/75	125.0	973.0	
				7/07/75	125.4	972.6	
				9/24/75	119.8	978.2	
01N/05W-03H01 S	36		1878.3	10/17/74	139.2	1739.1	3230
				11/12/74	133.4	1744.9	
				12/28/74	134.6	1743.7	
				1/16/75	138.0	1740.3	
				2/28/75	146.8	1731.5	
				3/26/75	141.7	1736.6	
				5/01/75	150.1	1728.2	
				6/17/75	144.7	1733.4	
				7/10/75	147.2	1731.1	
				8/22/75	157.7	1720.6	
02N/05W-19K02 S	36		2327.5	10/17/74	16.3	2311.2	3230
				11/12/74	16.4	2311.1	
				12/28/74	16.5	2311.0	
				1/16/75	18.2	2309.3	
				2/28/75	13.4	2314.1	
				3/26/75	14.6	2312.9	
				5/01/75	13.1	2314.4	
				6/19/75	12.9	2314.6	
				7/10/75	14.4	2313.1	
				8/21/75	19.3	2308.2	
02N/05W-19Q01 S	36		2311.3	10/17/74	9.2	2302.1	3230
				11/12/74	9.3	2302.0	
				12/28/74	9.6	2301.7	
				1/16/75	11.6	2299.7	
				2/28/75	12.1	2299.2	
				3/24/75	13.1	2298.2	
				5/01/75	8.2	2303.1	
				6/19/75	7.6	2303.7	
				7/10/75	8.7	2302.6	
				8/21/75	NM-1		
01S/02W-06M01 S	36		1585.0	10/10/74	NM-3		5412
				11/07/74	378.9	1206.1	
				12/03/74	247.9	1337.1	
				1/03/75	250.3	1334.7	
				2/12/75	254.8	1330.2	
				3/12/75	251.5	1333.5	
				4/10/75	254.4	1330.6	
				5/02/75	250.5	1334.5	
				6/11/75	256.4	1328.6	
				7/10/75	259.4	1325.6	
				8/06/75	253.9	1331.1	
				9/04/75	254.3	1330.7	
01S/02W-08C02 S	36		1806.7	10/10/74	82.3	1724.4	5412
				11/07/74	75.1	1731.6	
				12/03/74	69.6	1737.1	
				1/03/75	72.7	1734.0	
				2/12/75	71.9	1734.8	
				3/12/75	70.5	1736.2	
				4/10/75	61.6	1745.1	
				5/02/75	78.2	1728.5	
				6/11/75	72.6	1734.1	
				7/10/75	82.2	1724.5	
				8/06/75	79.3	1727.4	
				9/04/75	80.5	1726.2	
01S/03W-02J01 S	36		1397.4	10/10/74	132.8	1264.6	5412
				11/07/74	133.3	1264.1	
				12/03/74	134.9	1262.5	
				1/03/75	136.3	1261.1	
				2/12/75	135.9	1261.5	
				3/12/75	131.7	1265.7	
				4/10/75	140.9	1256.5	
				5/01/75	138.1	1259.3	
				6/11/75	136.7	1260.7	
				7/10/75	137.1	1260.3	
				8/07/75	138.5	1258.9	
				9/04/75	139.2	1258.2	
01S/03W-02P02 S	36		1345.3	10/10/74	NM-1		5412
				11/07/74	NM-1		
				12/03/74	150.4	1194.9	
				1/03/75	149.6	1195.7	
				2/12/75	NM-1		
				3/12/75	149.5	1195.8	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

SANTA ANA RIVER HYDRO UNIT — Y-01
UPPER SANTA ANA R HYDRO SUBUNIT — Y-01.E
BUNKER HILL HYDRO SUBAREA — Y-01.E2

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
01S/03W-02P02 S (CONTINUED)	36		1345.3	4/10/75	149.6	1195.7	5412
				5/01/75	151.7	1193.6	
				6/11/75	NM-1		
				7/10/75	149.1	1196.2	
				8/07/75	NM-1		
				9/04/75	NM-1		
01S/03W-03N03 S	36		1284.0	10/31/74	226.6	1057.4	4104
				11/26/74	220.4	1063.6	
				12/26/74	229.4	1054.6	
				1/30/75	227.6	1056.4	
				2/28/75	225.9	1058.1	
				4/10/75	229.8	1054.2	
				5/06/75	228.5	1055.5	
				6/13/75	228.9	1055.1	
				7/17/75	229.5	1054.5	
				9/30/75	225.3	1058.7	
01S/03W-03N07 S	36		1241.0	10/31/74	196.4	1044.6	4104
				11/26/74	188.2	1052.8	
				12/26/74	194.0	1047.0	
				1/30/75	192.7	1048.3	
				2/28/75	189.8	1051.2	
				4/10/75	192.3	1048.7	
				5/06/75	190.9	1050.1	
				6/13/75	192.5	1048.5	
				7/17/75	194.0	1047.0	
				9/30/75	189.8	1051.2	
01S/03W-04G02 S	36		1240.0	10/07/74	213.0	1027.0	4776
				11/07/74	213.0	1027.0	
				12/07/74	213.0	1027.0	
				1/08/75	214.0	1026.0	
				2/08/75	216.0	1024.0	
				3/07/75	210.0	1030.0	
				4/07/75	209.0	1031.0	
				5/07/75	210.0	1030.0	
				6/07/75	210.0	1030.0	
				7/07/75	210.0	1030.0	
				8/07/75	211.0	1029.0	
				9/07/75	212.0	1028.0	
01S/03W-04N01 S	36		1194.0	10/31/74	170.0	1024.0	4104
				11/25/74	164.7	1029.3	
				12/23/74	171.5	1022.5	
				1/30/75	168.8	1025.2	
				2/28/75	169.5	1024.5	
				4/10/75	171.0	1023.0	
				5/08/75	172.2	1021.8	
				6/09/75	172.5	1021.5	
				7/09/75	172.9	1021.1	
				9/30/75	167.4	1026.6	
01S/03W-05D01 S	36		1153.5	10/07/74	161.0	992.5	4776
				11/07/74	159.0	994.5	
				12/07/74	159.0	994.5	
				1/08/75	156.0	997.5	
				2/08/75	153.0	1000.5	
				3/07/75	150.0	1003.5	
				4/07/75	147.0	1006.5	
				5/07/75	149.0	1004.5	
				6/07/75	150.0	1003.5	
				7/07/75	152.0	1001.5	
				8/07/75	161.0	992.5	
				9/07/75	163.0	990.5	
01S/03W-05D04 S	36		1148.0	10/07/74	164.0	984.0	4776
				11/07/74	162.0	986.0	
				12/07/74	162.0	986.0	
				1/08/75	157.0	991.0	
				2/08/75	154.0	994.0	
				3/07/75	153.0	995.0	
				4/07/75	150.0	998.0	
				5/07/75	152.0	996.0	
				6/07/75	153.0	995.0	
				7/07/75	153.0	995.0	
				8/07/75	163.0	985.0	
				9/07/75	164.0	984.0	
01S/03W-05D05 S	36		1150.0	10/07/74	162.0	988.0	4776
				11/07/74	161.0	989.0	
				12/07/74	160.0	990.0	
				1/08/75	155.0	995.0	
				2/08/75	149.0	1001.0	
				3/07/75	150.0	1000.0	
				4/07/75	147.0	1003.0	
				5/07/75	152.0	998.0	
				6/07/75	153.0	997.0	
				7/07/75	154.0	996.0	
				8/07/75	162.0	988.0	
				9/07/75	166.0	984.0	
01S/03W-06H04 S	36		1148.6	10/31/74	177.2(1)	971.4	4104
				11/26/74	172.8(1)	975.8	
				12/26/74	178.0(1)	970.6	
				1/30/75	175.5(1)	973.1	
				2/26/75	169.2(1)	979.4	
				4/10/75	171.0(1)	977.6	
				5/08/75	173.4(1)	975.2	
				6/09/75	174.8(1)	973.8	
				7/09/75	177.0(1)	971.6	
				9/29/75	171.7(1)	976.9	

SANTA ANA RIVER HYDRO UNIT — Y-01
UPPER SANTA ANA R HYDRO SUBUNIT — Y-01.E
BUNKER HILL HYDRO SUBAREA — Y-01.E2

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
01S/03W-06K01 S	36		1132.0	10/30/74	150.7	981.3	4104
				11/27/74	144.0	988.0	
				12/23/74	148.0	984.0	
				1/28/75	153.6	978.4	
				2/28/75	151.5	980.5	
				4/23/75	152.8	979.2	
				5/15/75	154.0	978.0	
				6/16/75	152.5	979.5	
				7/11/75	148.0	984.0	
				9/25/75	147.2	984.8	
01S/03W-09D01 S	36		1197.0	10/31/74	170.4	1026.6	4104
				11/26/74	165.2	1031.8	
				12/26/74	175.0(1)	1022.0	
				1/30/75	173.0(1)	1024.0	
				2/28/75	164.5	1032.5	
				4/10/75	168.0	1029.0	
				5/08/75	170.7(1)	1026.3	
				6/17/75	173.0(1)	1024.0	
				7/17/75	176.7(1)	1020.3	
				9/30/75	172.5(1)	1024.5	
01S/03W-10D01 S	36		1255.0	10/31/74	205.1	1049.9	4104
				11/26/74	198.0(1)	1057.0	
				12/23/74	207.5(1)	1047.5	
				1/30/75	205.3	1049.7	
				2/28/75	203.0	1052.0	
				4/10/75	206.8	1048.2	
				5/06/75	206.2	1048.8	
				6/13/75	204.5	1050.5	
				7/17/75	203.0	1052.0	
				9/30/75	198.7	1056.3	
01S/03W-15F01 S	36		1280.0	10/10/74	125.3	1154.7	5412
				11/07/74	125.5	1154.5	
				12/03/74	125.4	1154.6	
				1/03/75	125.0	1155.0	
				2/12/75	122.4	1157.6	
				3/12/75	121.6	1158.4	
				4/10/75	119.4	1160.6	
				5/01/75	117.8	1162.2	
				6/11/75	121.1	1158.9	
				7/10/75	124.9	1155.1	
				8/07/75	125.3	1154.7	
				9/04/75	127.6	1152.4	
01S/03W-17C03 S	36		1175.9	10/07/74	169.8	1006.1	3847
				11/04/74	169.9	1006.0	
				12/02/74	169.5	1006.4	
				1/06/75	166.9	1009.0	
				2/03/75	165.7	1010.2	
				3/03/75	163.6	1012.3	
				4/07/75	160.8	1015.1	
				5/05/75	158.8	1017.1	
				6/02/75	158.3	1017.6	
				7/07/75	160.0	1015.9	
				8/04/75	161.9	1014.0	
				9/02/75	163.8	1012.1	
01S/03W-19G02 S	36		1135.2	11/28/74	163.8	971.4	5412
				12/23/74	164.7	970.5	
				1/16/75	164.1	971.1	
				2/12/75	163.6	971.6	
				3/13/75	161.1	974.1	
				4/11/75	160.7	974.5	
				5/15/75	167.3	967.9	
				6/13/75	169.3	965.9	
				7/10/75	171.9	963.3	
				8/14/75	172.6	962.6	
				9/18/75	177.7	957.5	
01S/03W-21H01 S	36		1318.1	10/30/74	188.0	1130.1	5206
				11/30/74	185.0	1133.1	
				12/06/74	186.0	1132.1	
				1/27/75	184.0	1134.1	
				2/26/75	176.0	1142.1	
				3/27/75	173.0	1145.1	
				4/30/75	172.0	1146.1	
				5/27/75	174.0	1144.1	
				6/30/75	177.0	1141.1	
				7/28/75	186.0	1132.1	
				8/27/75	191.0	1127.1	
01S/03W-21H06 S	36		1320.0	10/30/74	187.0	1133.0	5206
				11/30/74	183.0	1137.0	
				12/06/74	185.0	1135.0	
				1/27/75	184.0	1136.0	
				2/26/75	176.0	1144.0	
				3/27/75	172.0	1148.0	
				4/30/75	171.0	1149.0	
				6/30/75	178.0	1142.0	
				7/29/75	187.0	1133.0	
				8/27/75	188.0	1132.0	
01S/03W-21H07 S	36		1319.0	10/30/74	188.0	1131.0	5206
				11/30/74	184.0	1135.0	
				12/06/74	186.0	1133.0	
				1/27/75	179.0	1140.0	
				2/26/75	176.0	1143.0	
				3/27/75	172.0	1147.0	
				4/29/75	171.0	1148.0	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA ANA RIVER HYDRO UNIT						Y-01	
UPPER SANTA ANA R HYDRO SUBUNIT						Y-01.E	
BUNKER HILL HYDRO SUBAREA						Y-01.E2	
01S/03W-21H07 S (CONTINUED)	36		1319.0	5/27/75	173.0	1146.0	5206
				6/30/75	190.0(1)	1129.0	
				7/29/75	192.0(1)	1127.0	
				8/27/75	194.0(1)	1125.0	
01S/03W-22A02 S	36		1390.0	10/30/74	221.0(1)	1169.0	5206
				11/30/74	212.0	1178.0	
				12/06/74	212.0	1178.0	
				1/27/75	210.0	1180.0	
				2/24/75	209.0	1181.0	
				3/27/75	206.0	1184.0	
				4/01/75	205.0	1185.0	
				5/27/75	221.0(1)	1169.0	
				6/30/75	214.0(1)	1176.0	
				7/30/75	216.0(1)	1174.0	
				8/27/75	216.0(1)	1174.0	
01S/03W-23A03 S	36		1475.0	10/10/74	245.8	1229.2	5412
				11/07/74	246.6	1228.4	
				12/03/74	244.8	1230.2	
				1/03/75	244.3	1230.7	
				2/12/75	246.2	1228.8	
				3/12/75	245.1	1229.9	
				4/10/75	241.4	1233.6	
				5/01/75	241.0	1234.0	
				6/11/75	247.1	1227.9	
				7/10/75	251.5	1223.5	
				8/07/75	247.4	1227.6	
				9/04/75	249.0	1226.0	
01S/03W-27F02 S	36		1311.1	10/30/74	173.2	1137.9	5206
				11/30/74	166.2	1144.9	
				12/06/74	169.2	1141.9	
				1/27/75	194.2(1)	1116.9	
				2/26/75	159.2	1151.9	
				3/27/75	156.2	1154.9	
				4/30/75	153.2	1157.9	
				5/27/75	195.2(1)	1115.9	
				6/30/75	194.2(1)	1116.9	
				7/30/75	201.2(1)	1109.9	
				8/27/75	203.2(1)	1107.9	
01S/03W-28H01 S	36		1308.0	10/30/74	175.0	1133.0	5206
				11/30/74	170.0	1138.0	
				12/06/74	170.0	1138.0	
				1/27/75	187.0(1)	1121.0	
				2/26/75	164.0	1144.0	
				3/27/75	157.0	1151.0	
				4/30/75	154.0	1154.0	
				6/30/75	194.0(1)	1114.0	
				7/30/75	198.0(1)	1110.0	
				8/27/75	203.0(1)	1105.0	
01S/04W-01A06 S	36		.....	11/13/74	NW-1		3230
			1096.0	1/07/75	115.9	980.1	5000
				2/03/75	116.9	979.1	
				3/07/75	117.2	978.8	
				4/01/75	115.2	980.8	
				5/06/75	113.8	982.2	
				6/03/75	113.9	982.1	
				7/01/75	116.0	980.0	
				8/10/75	114.5	981.5	
01S/04W-01B04 S	36		1096.8	10/30/74	124.3	972.5	4104
				11/25/74	121.5	975.3	
				12/30/74	115.0	981.8	
				1/29/75	119.8	977.0	
				2/26/75	117.0	979.8	
				4/25/75	118.1	978.7	
				5/09/75	120.5	976.3	
				6/09/75	121.3	975.5	
				7/07/75	122.0	974.8	
				9/24/75	117.5	979.3	
01S/04W-01F01 S	36		1068.0	10/29/74	91.6	976.4	5208
				1/01/75	77.2	990.8	
				4/01/75	75.9	992.1	
				6/01/75	76.1	991.9	
				8/01/75	91.1	976.9	
				9/01/75	91.1	976.9	
01S/04W-01F02 S	36		1070.0	10/29/74	153.0	917.0	4104
				11/22/74	148.5	921.5	
				12/27/74	152.5	917.5	
				1/31/75	148.0	922.0	
				2/27/75	150.2	919.8	
				4/22/75	151.0	919.0	
				5/13/75	153.3	916.7	
				6/10/75	152.7	917.3	
				7/10/75	152.0	918.0	
				9/23/75	148.2	921.8	
01S/04W-01G01 S	36		1097.0	10/30/74	111.5	985.5	4104
				11/22/74	113.0	984.0	
				12/26/74	119.0	978.0	
				1/29/75	115.5	981.5	
				2/27/75	114.2	982.8	
				4/18/75	116.6	980.4	
				5/14/75	114.5	982.5	
				6/11/75	113.4	983.6	
				7/01/75	113.8	983.2	
				9/24/75	109.0	988.0	
SANTA ANA RIVER HYDRO UNIT						Y-01	
UPPER SANTA ANA R HYDRO SUBUNIT						Y-01.E	
BUNKER HILL HYDRO SUBAREA						Y-01.E2	
01S/04W-01K04 S	36		1092.0	10/29/74	93.3	998.7	4104
				11/22/74	89.8	1002.2	
				12/27/74	94.8	997.2	
				1/31/75	91.0	1001.0	
				2/27/75	92.8	999.2	
				4/22/75	94.3	997.7	
				5/20/75	95.8	996.2	
				6/17/75	97.5	994.5	
				7/10/75	98.0	994.0	
				9/23/75	92.3	999.7	
01S/04W-02A03 S	36		1072.0	10/01/74	125.0(1)	947.0	5208
				1/01/75	110.4(1)	961.6	
				4/01/75	109.2(1)	962.8	
				6/01/75	112.3(1)	959.7	
				8/01/75	131.4(1)	940.6	
				9/01/75	135.1(1)	936.9	
01S/04W-02A05 S	36		1087.0	10/31/74	141.3	945.7	4104
				11/27/74	135.2	951.8	
				12/30/74	138.5	948.5	
				1/31/75	139.0	948.0	
				2/26/75	137.7	949.3	
				4/26/75	135.2	951.8	
				5/19/75	136.4	950.6	
				6/12/75	138.3	948.7	
				7/18/75	139.5	947.5	
				9/29/75	136.0	951.0	
01S/04W-02K01 S	36		1056.3	10/16/74	103.8	952.5	3230
				11/12/74	100.7	955.6	
				12/19/74	76.7	979.6	
				1/13/75	80.6	975.7	
				2/25/75	88.1	968.2	
				3/19/75	81.6	974.7	
				4/29/75	86.0	970.3	
				5/21/75	87.5	968.8	
01S/04W-02K03 S	36		1053.2	10/16/74	102.2	951.0	3230
				11/12/74	92.7	960.5	
				12/19/74	59.6	993.6	
				1/13/75	76.2	977.0	
				2/25/75	79.2	974.0	
				3/19/75	72.5	980.7	
				4/29/75	75.9	977.3	
				5/21/75	80.1	973.1	
				6/17/75	93.4	959.8	
				7/01/75	96.0	957.2	
				8/14/75	104.1	949.1	
01S/04W-02K08 S	36		1052.9	10/16/74	96.1	956.8	3230
				11/12/74	94.3	958.6	
				12/19/74	94.2	958.7	
				1/13/75	76.7	976.2	
				2/25/75	80.7	972.2	
				3/19/75	74.3	978.6	
				4/29/75	77.7	975.2	
				5/21/75	82.2	970.7	
				6/17/75	93.0	959.9	
				7/01/75	98.8	954.1	
				8/21/75	107.2	945.7	
01S/04W-02L07 S	36		1048.0	10/29/74	85.8	962.2	5209
				1/01/75	81.4	966.6	
				4/01/75	95.4(1)	952.6	
				6/01/75	79.5	968.5	
				8/01/75	120.9(1)	927.1	
				9/01/75	174.2(1)	873.8	
01S/04W-02M01 S	36		1048.6	11/13/74	72.5	976.1	3230
				1/13/75	67.1	981.5	
				3/20/75	71.9	976.7	
				5/22/75	70.4	978.2	
01S/04W-02M01 S	36		1037.0	10/29/74	50.1	986.9	4104
				11/22/74	45.0	992.0	
				12/27/74	38.5	998.5	
				1/31/75	35.7	1001.3	
				2/27/75	37.0	1000.0	
				4/18/75	40.2	996.8	
				5/13/75	42.5	994.5	
				6/16/75	44.5	992.5	
				7/15/75	47.8	989.2	
				9/23/75	43.0	994.0	
01S/04W-02P05 S	36		1045.4	10/29/74	117.0(1)	928.4	5208
				1/01/75	102.1(1)	943.3	
				4/01/75	105.6	939.8	
				6/01/75	103.5	941.9	
				8/01/75	121.4	924.0	
				9/01/75	127.5	917.9	
01S/04W-02P04 S	36		1047.0	10/25/74	106.0(1)	941.0	5208
				1/01/75	90.8(1)	956.2	
				4/01/75	96.9(1)	950.1	
				6/01/75	97.2(1)	949.8	
				8/01/75	113.9(1)	933.1	
				9/01/75	117.6(1)	929.4	
01S/04W-02Q03 S	36		1052.0	10/29/74	99.3	952.7	5208
				1/01/75	77.5	974.5	

See page 79 for key to terms a abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

SANTA ANA RIVER HYDRO UNIT — Y-01
UPPER SANTA ANA R HYDRO SUBUNIT — Y-01.E
BUNKER HILL HYDRO SUBAREA — Y-01.E2

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
01S/04W-02J03 S (CONTINUED)	36		1052.0	4/01/75	82.1	969.9	5208
				6/01/75	102.3(1)	949.7	
				8/01/75	117.5(1)	934.5	
				9/01/75	120.8(1)	931.2	
01S/04W-02J04 S	36		1057.5	10/29/74	96.0	961.5	4104
				11/22/74	91.6	965.9	
				12/27/74	86.0	971.5	
				1/29/75	88.4	969.1	
				2/27/75	90.0	967.5	
				4/18/75	91.2	966.3	
				5/13/75	92.5	965.0	
				6/16/75	93.3	964.2	
				7/15/75	94.1	963.4	
				9/25/75	89.8	967.7	
01S/04W-02J06 S	36		1057.0	1/01/75	78.5	978.5	5208
				4/01/75	92.0(1)	965.0	
				6/01/75	97.7(1)	959.3	
				9/01/75	NM-3		
01S/04W-02J08 S	36		1055.0	10/29/74	128.7	926.3	4104
				11/22/74	123.5	931.5	
				12/27/74	116.0	939.0	
				1/29/75	118.3	936.7	
				2/27/75	119.5	935.5	
				4/18/75	120.8	934.2	
				5/13/75	122.0	933.0	
				6/16/75	123.9	931.1	
				7/15/75	124.5	930.5	
				9/25/75	120.2	934.8	
01S/04W-02J09 S	36		1055.5	10/29/74	93.8	961.7	4104
				11/22/74	88.0	967.5	
				12/27/74	82.0	973.5	
				1/29/75	84.5	971.0	
				2/27/75	86.0	969.5	
				4/18/75	87.3	968.2	
				5/13/75	89.1	966.4	
				6/16/75	92.0	963.5	
				7/15/75	91.7	963.8	
				9/25/75	87.6	967.9	
01S/04W-03J01 S	36		1096.4	11/13/74	104.0	992.4	3230
				1/16/75	96.9	999.5	
				2/28/75	102.2	994.2	5412
				3/21/75	102.3	994.1	3230
				4/11/75	100.4	996.0	5412
				5/15/75	101.8	994.6	
				6/13/75	101.9	994.5	
				7/10/75	102.5	993.9	
				8/14/75	101.7	994.7	
				9/18/75	102.2	994.2	
01S/04W-03J05 S	36		1034.1	10/16/74	93.4	940.7	3230
				11/12/74	90.2	943.9	
				12/19/74	92.2	941.9	
				1/13/75	74.1	960.0	
				2/25/75	76.5	957.6	
				3/20/75	67.3	966.8	
				4/30/75	73.1	961.0	
01S/04W-03J01 S	36		1041.8	11/13/74	64.5	977.3	3230
				1/13/75	62.5	979.3	
				3/20/75	60.5	981.3	
				5/01/75	61.5	980.3	5412
				6/19/75	63.8	978.0	
				7/01/75	64.0	977.8	
				9/04/75	64.3	977.5	
01S/04W-04F03 S	36		1116.0	9/26/75	174.0	942.0	5412
01S/04W-05C03 S	36		1176.0	11/14/74	174.0	1002.0	3230
				1/14/75	182.3	993.7	
				3/24/75	161.0	1015.0	
				5/27/75	168.7	1007.3	
				7/17/75	171.5	1004.5	
01S/04W-05F05 S	36		1170.0	10/01/74	141.0	1029.0	4124
				11/01/74	136.0	1034.0	
				12/01/74	140.0	1030.0	
				1/02/75	137.0	1033.0	
				2/01/75	131.0	1039.0	
				3/01/75	131.0	1039.0	
				4/01/75	134.0	1036.0	
				5/01/75	135.0	1035.0	
				6/01/75	140.0(1)	1030.0	
				7/01/75	142.0(1)	1028.0	
				8/01/75	142.0(1)	1028.0	
				9/01/75	144.0	1026.0	
01S/04W-06H01 S	36		1160.0	12/01/74	140.0	1020.0	4124
				1/02/75	141.0	1019.0	
				4/01/75	129.0	1031.0	
				5/01/75	129.0	1031.0	
				6/01/75	130.0	1030.0	
				7/01/75	134.0	1026.0	
				8/01/75	133.0	1027.0	
				9/01/75	135.0	1025.0	
01S/04W-08A01 S	36		1093.9	11/14/74	101.6	992.3	3230
				1/17/75	100.5	993.4	

SANTA ANA RIVER HYDRO UNIT — Y-01
UPPER SANTA ANA R HYDRO SUBUNIT — Y-01.E
BUNKER HILL HYDRO SUBAREA — Y-01.E2

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
01S/04W-08A01 S (CONTINUED)	36		1093.9	3/24/75	103.4	990.5	3230
				5/27/75	99.7	994.2	
				7/17/75	101.8	992.1	
01S/04W-08C01 S	36		1104.1	10/01/74	125.5	978.6	4201
				12/01/74	119.5	984.6	
				1/02/75	104.5	999.6	
				2/01/75	100.5	1003.6	
				3/04/75	119.5	984.6	
				5/01/75	113.5	990.6	
				6/02/75	125.5	978.6	
				7/01/75	143.5	960.6	
				8/01/75	155.5	948.6	
01S/04W-08F07 S	36		1095.1	10/01/74	152.0	943.1	4201
				12/01/74	123.0	972.1	
				1/02/75	109.0	986.1	
				2/01/75	99.0	996.1	
				3/04/75	120.0	975.1	
				4/03/75	117.0	978.1	
				5/01/75	117.0	978.1	
				6/02/75	131.0	964.1	
				7/01/75	145.0	950.1	
				8/01/75	166.0	929.1	
				9/02/75	151.0	944.1	
01S/04W-08F08 S	36		1096.5	10/01/74	155.0	941.5	4201
				12/01/74	126.0	970.5	
				1/02/75	112.0	984.5	
				2/01/75	102.0	994.5	
				3/04/75	122.0	974.5	
				4/03/75	120.0	976.5	
				5/01/75	120.0	976.5	
				6/02/75	134.0	962.5	
				7/01/75	148.0	948.5	
				8/01/75	169.0	927.5	
				9/02/75	154.0	942.5	
01S/04W-08F10 S	36		1096.2	10/01/74	155.0	941.2	4201
				12/01/74	126.0	970.2	
				1/02/75	112.0	984.2	
				2/01/75	102.0	994.2	
				3/04/75	122.0	974.2	
				4/03/75	120.0	976.2	
				5/01/75	120.0	976.2	
				6/02/75	139.0	957.2	
				7/01/75	148.0	948.2	
				8/01/75	169.0	927.2	
				9/02/75	154.0	942.2	
01S/04W-08G01 S	36		1075.8	10/01/74	127.0	948.8	4201
				12/01/74	116.0	959.8	
				1/02/75	104.0	971.8	
				2/01/75	103.0	972.8	
				3/04/75	108.0	967.8	
				4/03/75	106.0	969.8	
				5/01/75	107.0	968.8	
				6/02/75	119.0	956.8	
				7/01/75	129.0	946.8	
				8/01/75	142.0	933.8	
				9/02/75	142.0	933.8	
01S/04W-08G03 S	36		1074.4	11/14/74	107.9	966.5	3230
				1/17/75	107.7	966.7	
				3/26/75	101.6	972.8	
				5/27/75	111.5	962.9	
				7/16/75	123.7	950.7	
01S/04W-08H01 S	36		1075.7	10/01/74	127.4	948.3	4201
				12/01/74	117.4	958.3	
				1/02/75	105.4	970.3	
				2/01/75	104.4	971.3	
				3/04/75	108.4	967.3	
				4/03/75	106.4	969.3	
				5/01/75	107.4	968.3	
				6/02/75	119.4	956.3	
				7/01/75	130.4	945.3	
				8/01/75	142.4	933.3	
				9/02/75	143.4	932.3	
01S/04W-08H04 S	36		1075.7	10/01/74	127.4	948.3	4201
				12/01/74	117.4	958.3	
				1/02/75	106.4	969.3	
				2/01/75	104.4	971.3	
				3/04/75	110.4	965.3	
				4/03/75	107.4	968.3	
				5/01/75	108.4	967.3	
				6/02/75	121.4	954.3	
				7/01/75	130.4	945.3	
				8/01/75	142.4	933.3	
				9/02/75	143.4	932.3	
01S/04W-08H05 S	36		1076.0	10/01/74	122.5	953.5	4201
				12/01/74	112.5	963.5	
				1/02/75	100.5	975.5	
				2/01/75	99.5	976.5	
				3/04/75	105.5	970.5	
				4/03/75	102.5	973.5	
				5/01/75	103.5	972.5	
				6/02/75	116.5	959.5	
				7/01/75	125.5	950.5	
				8/01/75	137.5	938.5	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA ANA RIVER HYDRO UNIT UPPER SANTA ANA R HYDRO SUBUNIT BUNKER HILL HYDRO SUBAREA						Y-01 Y-01.E Y-01.E2	
01S/04W-08R05 S	36		1076.0	9/02/75	138.5	937.5	4201
01S/04W-09A01 S	36		1069.5	11/15/74	84.2	985.3	3230
				1/17/75	72.2	997.3	
				3/25/75	73.8	995.7	
				5/28/75	72.3	997.2	
				7/17/75	79.5	990.0	
01S/04W-09B03 S	36		1071.6	11/15/74	85.6	986.0	3230
				1/17/75	87.1(1)	984.5	
				3/25/75	86.9	984.7	
				5/24/75	NM-1		
				7/17/75	NM-1		
01S/04W-09F02 S	36		1075.0	10/01/74	122.0	953.0	4201
				12/01/74	112.0	963.0	
				1/02/75	100.0	975.0	
				2/01/75	99.0	976.0	
				3/04/75	102.0	973.0	
				4/03/75	102.0	973.0	
				5/01/75	103.0	972.0	
				6/02/75	115.0	960.0	
				7/01/75	125.0	950.0	
				8/01/75	138.0	937.0	
				9/02/75	138.0	937.0	
01S/04W-09J01 S	36		1029.5	10/18/74	53.7	975.8	3230
				11/12/74	52.8	976.7	
				12/19/74	57.7	971.8	
				1/13/75	50.9	978.6	
				2/26/75	50.1	979.4	
				3/19/75	49.0	980.5	
				4/29/75	48.0	981.5	
				5/21/75	49.1	980.4	
				6/17/75	50.1	979.4	
				7/01/75	52.5	977.0	
				8/14/75	57.1	972.4	
01S/04W-09N06 S	36		1060.2	11/14/74	93.6	966.6	3230
				1/17/75	92.5	967.7	
				3/26/75	92.1	968.1	
				5/27/75	85.8	974.4	
				7/17/75	92.6	967.6	
01S/04W-09P01 S	36		1052.4	10/16/74	76.6	975.8	3230
				11/12/74	75.7	976.7	
				12/19/74	76.2	976.2	
				1/13/75	73.2	979.2	
				2/25/75	72.9	979.5	
				3/19/75	72.3	980.1	
				4/29/75	71.0	981.4	
				5/21/75	72.4	980.0	
				6/18/75	73.0	979.4	
				7/01/75	74.4	978.0	
				8/01/75	79.6	972.8	
01S/04W-10F01 S	36		1028.0	2/28/75	52.7	975.3	5412
				3/14/75	52.3	975.7	
				4/18/75	51.9	976.1	
				5/02/75	52.3	975.7	
				6/11/75	53.7	974.3	
				7/16/75	54.9	973.1	
				8/07/75	55.0	973.0	
				9/04/75	55.5	972.5	
01S/04W-10N06 S	36		1001.4	10/16/74	37.1	964.3	3230
				11/12/74	34.7	966.7	
				12/19/74	37.1	964.3	
				1/21/75	31.8	969.6	
				2/25/75	31.8	969.6	
				3/19/75	28.6	972.8	
				4/29/75	27.2	974.2	
				5/21/75	29.8	971.6	
				6/17/75	29.1	972.3	
				7/01/75	NM-1		
				8/22/75	NM-1		
01S/04W-11D02 S	36		1034.5	12/01/74	114.2	920.3	5208
01S/04W-11D03 S	36		1033.3	12/01/74	103.2	930.1	5208
01S/04W-11H01 S	36		1051.8	11/13/74	78.0	973.8	3230
				1/13/75	64.1	987.7	
				3/19/75	60.3	991.5	
				5/21/75	68.2	983.6	
				7/01/75	77.5	974.3	
01S/04W-11Q01 S	36		1041.7	11/13/74	NM-0		3230
01S/04W-12R06 S	36		1089.3	10/31/74	105.2	984.1	4104
				11/26/74	108.7	980.6	
				12/26/74	114.0	975.3	
				1/31/75	112.5	976.8	
				2/27/75	112.5	976.8	
				4/10/75	113.0	976.3	
				5/13/75	115.2	974.1	
				6/13/75	114.8	974.5	
				7/10/75	114.1	975.2	
				9/24/75	109.6	979.7	
01S/04W-13F02 S	36		1054.0	10/01/74	129.2(1)	924.8	3847
				11/05/74	109.1	944.9	

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA ANA RIVER HYDRO UNIT UPPER SANTA ANA R HYDRO SUBUNIT BUNKER HILL HYDRO SUBAREA						Y-01 Y-01.E Y-01.E2	
01S/04W-13F02 S (CONTINUED)	36		1054.0	12/03/74	99.3	954.7	3847
				1/07/75	97.1	956.9	
				3/04/75	91.3	962.7	
				4/01/75	89.2	964.8	
				5/06/75	88.0	966.0	
				6/03/75	94.2	959.8	
				7/01/75	99.3	954.7	
				8/04/75	123.3(1)	930.7	
				9/02/75	124.2(1)	929.8	
01S/04W-13G02 S	36		1065.0	10/01/74	136.8(1)	928.2	3847
				11/05/74	114.8	950.2	
				12/03/74	110.7	954.3	
				1/07/75	104.7	960.3	
				2/04/75	102.7	962.3	
				3/04/75	98.9	966.1	
				4/01/75	97.8	967.2	
				5/06/75	98.2	966.8	
				6/03/75	98.7	966.3	
				7/01/75	119.7(1)	945.3	
				8/04/75	127.7(1)	937.3	
				9/02/75	132.8(1)	932.2	
01S/04W-13G03 S	36		1065.0	10/01/74	171.8(1)	893.2	3847
				11/05/74	128.7(1)	936.3	
				12/03/74	122.7(1)	942.3	
				1/07/75	88.7	976.3	
				2/04/75	103.7(1)	961.3	
				3/04/75	105.8(1)	959.2	
				4/01/75	82.7	982.3	
				5/06/75	119.5(1)	945.5	
				6/03/75	143.8(1)	921.2	
				7/01/75	146.8(1)	918.2	
				8/04/75	154.7(1)	910.3	
				9/02/75	158.7(1)	906.3	
01S/04W-13L02 S	36		1050.0	10/01/74	NM-1		3847
				11/05/74	97.5	952.5	
				12/03/74	97.5	952.5	
				1/07/75	92.1	957.9	
				2/04/75	91.0	959.0	
				3/04/75	86.6	963.4	
				4/01/75	83.4	966.6	
				5/06/75	85.5	964.5	
				6/03/75	91.6	958.4	
				7/01/75	131.5(1)	918.5	
				8/04/75	147.6(1)	902.4	
				9/02/75	149.5(1)	900.5	
01S/04W-13M02 S	36		1054.0	10/01/74	156.0(1)	898.0	3847
				11/05/74	144.1(1)	909.9	
				12/03/74	111.1	942.9	
				1/07/75	92.1	961.9	
				2/04/75	132.2(1)	921.8	
				3/04/75	129.2(1)	924.8	
				4/01/75	81.0	973.0	
				5/06/75	81.8	972.2	
				6/03/75	100.0	954.0	
				7/01/75	107.0	947.0	
				8/04/75	147.0(1)	907.0	
				9/02/75	146.0(1)	908.0	
01S/04W-13N01 S	36		1039.0	10/01/74	111.5	927.5	3847
				11/05/74	106.5	932.5	
				12/03/74	101.5	937.5	
				1/07/75	94.0	945.0	
				2/04/75	91.4	947.6	
				3/04/75	87.4	951.6	
				4/01/75	84.4	954.6	
				5/06/75	105.9(1)	933.1	
				6/03/75	113.4(1)	925.6	
				7/01/75	117.3(1)	921.7	
				8/04/75	121.3(1)	917.7	
				9/02/75	125.3(1)	913.7	
01S/04W-13N02 S	36		1040.0	10/01/74	136.6(1)	903.4	3847
				11/05/74	106.6	933.4	
				12/03/74	100.5	939.5	
				1/07/75	94.5	945.5	
				2/04/75	92.5	947.5	
				3/04/75	88.5	951.5	
				4/01/75	85.6	954.4	
				5/06/75	114.4(1)	925.6	
				6/03/75	116.6(1)	923.4	
				7/01/75	121.6(1)	918.4	
				8/04/75	125.6(1)	914.4	
				9/02/75	127.6(1)	912.4	
01S/04W-14P06 S	36		1027.1	12/01/74	125.9(1)	901.2	5208
01S/04W-15H02 S	36		984.6	11/15/74	157.9(4)	826.7	3230
				1/17/75	99.2	885.4	
				3/25/75	89.6	895.0	
				5/28/75	92.0	892.6	
				7/16/75	89.3	895.3	
01S/04W-21A01 S	36		970.2	11/14/74	117.1	853.1	3230
				1/20/75	78.1	892.1	
				3/24/75	113.4	856.8	
01S/04W-22R01 S	36		1000.0	10/01/74	73.0	927.0	5208
				12/01/74	65.1	934.9	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA ANA RIVER HYDRO UNIT UPPER SANTA ANA R HYDRO SUBUNIT BUNKER HILL HYDRO SUBAREA						Y-01 Y-01.E Y-01.E2	
01S/04W-22R01 S (CONTINUED)	36		1000.0	2/07/75	56.6	943.4	5208
				4/01/75	42.5	957.5	
				6/03/75	46.9	953.1	
				7/01/75	51.0	949.0	
				8/03/75	55.2	944.8	
				9/01/75	56.9	943.1	
01S/04W-22R03 S	36		999.0	10/01/74	68.6	930.4	5208
				11/05/74	65.9	933.1	
				12/01/74	64.1	934.9	
				1/07/75	56.0	943.0	
				2/03/75	57.3	941.7	
				3/11/75	46.9	952.1	
				4/01/75	44.4	954.6	
				5/01/75	46.1	952.9	5412
				6/03/75	49.2	949.8	5208
				7/01/75	56.0	943.0	
				8/04/75	62.1	936.9	
				9/04/75	71.4	927.6	5412
01S/04W-22R05 S	36		996.0	10/01/74	66.8	929.2	5208
				11/05/74	65.6	930.4	
				12/01/74	62.8	933.2	
				1/07/75	54.6	941.4	
				2/03/75	55.0	941.0	
				3/11/75	46.4	949.6	
				4/01/75	42.3	953.7	
				5/06/75	39.4	956.6	
				6/03/75	48.3	947.7	
				7/01/75	55.8	940.2	
				8/04/75	61.5	934.5	
				9/10/75	64.0	932.0	
01S/04W-22R07 S	36		995.0	1/01/75	56.1	938.9	5208
				4/01/75	67.9	927.1	
				6/01/75	68.6	926.4	
				8/01/75	76.8	918.2	
				9/01/75	80.6(1)	914.4	
01S/04W-22C02 S	36		988.5	11/14/74	79.5	909.0	3230
				1/20/75	58.3	930.2	
				3/25/75	56.8	931.7	
				5/29/75	46.8	941.7	
				7/17/75	63.8	924.7	
01S/04W-22D01 S	36		975.0	9/26/75	40.5	934.5	5412
01S/04W-22D02 S	36		972.0	9/26/75	74.4	897.6	5412
01S/04W-22G14 S	36		994.0	6/03/75	45.3	948.7	5208
				8/04/75	67.4(1)	926.6	
				9/01/75	69.8(1)	924.2	
01S/04W-22G16 S	36		994.0	10/01/74	68.2	925.8	5208
				12/01/74	63.1	930.9	
				2/03/75	57.9	936.1	
				4/01/75	42.5	951.5	
				6/03/75	45.3	948.7	
				8/04/75	67.6(1)	926.4	
				9/01/75	69.6(1)	924.4	
01S/04W-22G17 S	36		994.0	10/01/74	67.1	926.9	5208
				12/01/74	62.1	931.9	
				2/03/75	56.5	937.5	
				4/01/75	40.4	953.6	
				6/03/75	44.5	949.5	
				7/01/75	51.6	942.4	
				8/04/75	57.9	936.1	
				9/01/75	59.8	934.2	
01S/04W-22G18 S	36		995.0	10/01/74	68.5	926.5	5208
				12/01/74	63.8	931.2	
				2/03/75	58.0	937.0	
				4/01/75	41.8	953.2	
				6/03/75	45.8	949.2	
				7/01/75	52.3	942.7	
				8/04/75	57.7	937.3	
				9/01/75	59.5	935.5	
01S/04W-22G19 S	36		995.0	10/01/74	82.0(1)	913.0	5208
				12/01/74	64.3	930.7	
				2/03/75	56.5	938.5	
				4/01/75	42.0	953.0	
				6/03/75	45.5	949.5	
				7/01/75	52.7	942.3	
				8/03/75	58.0	937.0	
				9/01/75	67.9	927.1	
01S/04W-22H01 S	36		1004.3	12/01/74	84.8(1)	919.5	5208
01S/04W-22H03 S	36		997.0	12/01/74	72.8	924.2	5208
01S/04W-22H04 S	36		998.6	12/01/74	129.7(1)	868.9	5208
01S/04W-22L05 S	36		983.0	10/05/74	72.7(1)	910.3	5783
				11/08/74	72.5(1)	910.5	
				12/07/74	73.6	909.4	3718
				1/04/75	67.8	915.2	5783
				2/08/75	66.9	916.1	
				3/08/75	69.3(1)	913.7	
				4/05/75	74.7	908.3	3718
				5/03/75	73.4(1)	909.6	5783
SANTA ANA RIVER HYDRO UNIT UPPER SANTA ANA R HYDRO SUBUNIT BUNKER HILL HYDRO SUBAREA						Y-01 Y-01.E Y-01.E2	
01S/04W-22L05 S (CONTINUED)	36		983.0	6/07/75	73.6(1)	909.4	5783
				7/05/75	73.8(1)	909.2	
				8/08/75	74.3(1)	908.7	
				9/05/75	75.3(1)	907.7	
01S/04W-22L08 S	36		980.2	12/07/74	65.2	915.0	3718
				4/05/75	65.1	915.1	
01S/04W-22L09 S	36		986.0	10/05/74	61.0	925.0	5783
				11/08/74	61.3	924.7	
				12/07/74	60.6	925.4	
				1/04/75	60.6	925.4	
				2/08/75	59.6	926.4	
				3/08/75	65.7(1)	920.3	
				4/05/75	60.6	925.4	
				5/03/75	60.7	925.3	
				6/07/75	64.9(1)	921.1	
				7/05/75	65.2(1)	920.8	
				8/08/75	65.0	921.0	
				9/05/75	65.3	920.7	
01S/04W-22M06 S	36		982.0	10/05/74	72.5(1)	909.5	5783
				11/08/74	73.2(1)	908.8	
				12/07/74	70.3	911.7	
				1/04/75	70.3	911.7	
				2/08/75	70.1	911.9	
				3/08/75	70.8	911.2	
				4/05/75	70.2	911.8	
				5/03/75	78.2(1)	903.8	
				6/07/75	78.0(1)	904.0	
				7/05/75	78.2(1)	903.8	
				8/08/75	78.5(1)	903.5	
				9/05/75	79.4(1)	902.6	
01S/04W-22P05 S	36		987.0	10/05/74	92.3(1)	894.7	5783
				11/08/74	92.3(1)	894.7	
				12/07/74	76.6	910.4	3718
				1/04/75	75.8	911.2	5783
				2/08/75	75.2	911.8	
				3/08/75	86.2(1)	900.8	
				4/05/75	76.8	910.2	3718
				5/03/75	85.5(1)	901.5	5783
				6/07/75	85.8(1)	901.2	
				7/05/75	86.0(1)	901.0	
				8/08/75	86.6(1)	900.4	
				9/05/75	87.3(1)	899.7	
01S/04W-23A02 S	36		1045.0	10/01/74	115.0	930.0	3847
				11/05/74	106.9	938.1	
				12/03/74	103.0(1)	942.0	
				1/07/75	98.1	946.9	
				2/04/75	94.0	951.0	
				3/04/75	89.0	956.0	
				4/01/75	88.0	957.0	
				5/06/75	89.9	955.1	
				6/03/75	97.0	948.0	
				7/01/75	102.9	942.1	
				8/04/75	117.9(1)	927.1	
				9/02/75	109.0	936.0	
01S/04W-23A05 S	36		1044.0	10/01/74	132.6	911.4	3847
				11/05/74	113.7	930.3	
				12/03/74	103.5(1)	940.5	
				1/07/75	92.6	951.4	
				2/04/75	93.7	950.3	
				3/04/75	93.7	950.3	
				4/01/75	79.8	964.2	
				5/06/75	70.1	973.9	
				6/03/75	104.7	939.3	
				7/01/75	112.6	931.4	
				8/04/75	116.6	927.4	
				9/02/75	120.7	923.3	
01S/04W-23C02 S	36		1025.0	12/01/74	176.2(1)	848.8	5208
01S/04W-23C03 S	36		1022.8	12/01/74	122.4(1)	900.4	5208
01S/04W-23G01 S	36		1044.7	10/01/74	121.3	923.4	3847
				11/05/74	113.3	931.4	
				12/03/74	104.2	940.5	
				1/07/75	92.3	952.4	
				2/04/75	97.3	947.4	
				3/04/75	95.1	949.6	
				4/01/75	80.3	964.4	
				5/06/75	77.1	967.6	
				6/03/75	116.4	928.3	
				7/01/75	124.3	920.4	
				8/04/75	134.3	910.4	
				9/02/75	129.3	915.4	
01S/04W-23G03 S	36		1044.0	10/01/74	153.5(1)	890.5	3847
				11/05/74	114.4	929.6	
				12/03/74	104.7	939.3	
				1/07/75	92.4	951.6	
				2/04/75	95.5	948.5	
				3/04/75	94.4	949.6	
				4/01/75	80.0	964.0	
				5/06/75	76.2	967.8	
				6/03/75	132.6(1)	911.4	
				7/01/75	141.5(1)	902.5	
				8/04/75	149.5(1)	894.5	
				9/02/75	141.6(1)	902.4	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA ANA RIVER HYDRO UNIT						Y-01	
UPPER SANTA ANA R HYDRO SUBUNIT						Y-01.E	
BUNKER HILL HYDRO SUBAREA						Y-01.E2	
01S/04W-23H01 S	36		1044.0	10/01/74	126.7(1)	917.3	3847
				11/05/74	106.7	937.3	
				12/03/74	103.6	940.4	
				1/07/75	95.7	948.3	
				2/04/75	93.7	950.3	
				3/04/75	89.6	954.4	
				4/01/75	87.6	956.4	
				5/06/75	89.7	954.3	
				6/03/75	108.7(1)	935.3	
				7/01/75	113.7(1)	930.3	
				8/04/75	103.6	940.4	
				9/02/75	120.7(1)	923.3	
01S/04W-23K01 S	36		1044.0	10/01/74	128.8(1)	915.2	3847
				11/05/74	107.7	936.3	
				12/03/74	103.7	940.3	
				1/07/75	95.7	948.3	
				2/04/75	94.3	949.7	
				3/04/75	90.6	953.4	
				4/01/75	88.6	955.4	
				5/06/75	95.0(1)	949.0	
				6/03/75	105.7(1)	938.3	
				7/01/75	112.7(1)	931.3	
				8/04/75	102.7	941.3	
				9/02/75	119.7(1)	924.3	
01S/04W-23K02 S	36		1044.0	10/01/74	133.0(1)	911.0	3847
				11/05/74	108.8	935.2	
				12/03/74	103.8	940.2	
				1/07/75	96.0	948.0	
				2/04/75	94.8	949.2	
				3/04/75	91.4	952.6	
				4/01/75	87.8	956.2	
				5/06/75	105.6(1)	938.4	
				6/03/75	97.9	946.1	
				7/01/75	101.9	942.1	
				8/04/75	103.8	940.2	
				9/02/75	109.8	934.2	
01S/04W-23K03 S	36		1040.2	10/01/74	125.3	914.9	3847
				11/05/74	112.3	927.9	
				12/03/74	106.4	933.8	
				1/07/75	89.3	950.9	
				2/04/75	93.2	947.0	
				3/04/75	92.1	948.1	
				4/01/75	74.3	965.9	
				5/06/75	73.4	966.8	
				6/03/75	100.4	939.8	
				7/01/75	118.4	921.8	
				8/04/75	126.4	913.8	
				9/02/75	123.8	916.4	
01S/04W-23J01 S	36		1040.8	10/01/74	131.1	909.7	3847
				11/05/74	116.1	924.7	
				12/03/74	114.1	926.7	
				1/07/75	93.1	947.7	
				2/04/75	96.7	944.1	
				3/04/75	95.1	945.7	
				4/01/75	78.1	962.7	
				5/06/75	78.3	962.5	
				6/03/75	100.1	940.7	
				7/01/75	120.1	920.7	
				8/04/75	129.1	911.7	
				9/02/75	124.4	916.4	
01S/04W-25G01 S	36		1108.0	10/30/74	144.0	964.0	5206
				11/30/74	125.0	983.0	
				12/04/74	128.0	980.0	
				1/27/75	123.0	985.0	
				2/26/75	118.0	990.0	
				3/27/75	109.0	999.0	
				4/30/75	108.0	1000.0	
				5/27/75	127.0	981.0	
				6/30/75	128.0	980.0	
				7/30/75	143.0	965.0	
				8/27/75	140.0	968.0	
01S/04W-26J01 S	36		1080.0	11/26/74	138.4	941.6	5412
				12/19/74	123.0	957.0	
				1/16/75	128.5	951.5	
				2/19/75	131.8	948.2	
				3/12/75	127.4	952.6	
				4/11/75	124.9	955.1	
				5/15/75	128.6	951.4	
				6/13/75	134.7	945.3	
				7/19/75	135.6	944.4	
				8/14/75	136.3	943.7	
				9/19/75	137.3	942.7	
01S/04W-27A09 S	36		1015.2	11/02/74	172.7(1)	842.5	5208
				1/01/75	157.3(1)	857.9	
				2/01/75	140.4(1)	874.8	
				4/01/75	90.8	924.4	
				7/01/75	172.7	842.5	
01S/04W-27A10 S	36		1015.7	10/01/74	136.6	885.1	5208
				11/02/74	129.8	885.9	
				12/01/74	128.0	887.7	
				1/01/75	96.1	919.6	
				2/01/75	84.0	931.7	
				3/01/75	81.6	934.1	
SANTA ANA RIVER HYDRO UNIT						Y-01	
UPPER SANTA ANA R HYDRO SUBUNIT						Y-01.E	
BUNKER HILL HYDRO SUBAREA						Y-01.E2	
01S/04W-27A10 S (CONTINUED)	36		1015.7	4/01/75	74.9	940.8	5208
				6/01/75	102.8	912.9	
				7/01/75	112.4	903.3	
				8/01/75	114.6	901.1	
				9/01/75	119.9	895.8	
01S/04W-27A11 S	36		1015.0	12/01/74	166.0(1)	849.0	5208
				1/01/75	106.5	908.5	
				2/01/75	100.5	914.5	
				3/01/75	101.5	913.5	
				4/01/75	83.7	931.3	
				7/01/75	123.1	891.9	
RFDLANDS HYDRO SUBAREA						Y-01.E3	
01S/03W-13R01 S	36		1520.3	10/10/74	NM-1		5412
				11/07/74	NM-1		
				12/03/74	215.0	1305.3	
				1/03/75	NM-1		
				2/12/75	NM-1		
				3/12/75	211.2	1309.1	
				4/10/75	210.1	1310.2	
				5/29/75	NM-1		
				6/11/75	NM-1		
				7/10/75	219.1	1301.2	
				8/07/75	NM-1		
				9/04/75	NM-1		
01S/03W-24C01 S	36		1519.7	10/10/74	239.0	1280.7	5412
				11/07/74	239.8	1279.9	
				12/03/74	237.5	1282.2	
				1/03/75	238.1	1281.6	
				2/12/75	237.2	1282.5	
				3/12/75	236.3	1283.4	
				4/10/75	229.9	1289.8	
				5/01/75	229.2	1290.5	
				6/11/75	235.5	1284.2	
				7/10/75	239.1	1280.6	
				8/06/75	239.0	1280.7	
				9/04/75	240.5	1279.2	
01S/03W-26C01 S	36		1440.0	11/04/74	212.0	1228.0	5206
				12/06/74	212.0	1228.0	
				1/27/75	212.0	1228.0	
				2/26/75	211.0	1229.0	
				3/27/75	211.0	1229.0	
				4/01/75	210.0	1230.0	
				5/28/75	211.0	1229.0	
				6/30/75	209.0	1231.0	
				7/29/75	209.0	1231.0	
				8/28/75	209.0	1231.0	
02S/03W-05A02 S	36		1291.0	11/21/74	116.0	1175.0	5412
				12/23/74	109.1	1181.9	
				1/17/75	110.4	1180.6	
				2/12/75	112.2	1178.8	
				3/13/75	109.8	1181.2	
				4/11/75	109.1	1181.9	
				5/15/75	114.6	1176.4	
				6/12/75	114.3	1176.7	
				7/10/75	116.3	1174.7	
				8/14/75	115.2	1175.8	
				9/18/75	115.8	1175.2	
MENTONE HYDRO SUBAREA						Y-01.E4	
01S/02W-18R01 S	36		1762.6	10/10/74	181.3	1581.3	5412
				11/07/74	182.4	1580.2	
				12/03/74	184.0	1578.6	
				1/03/75	184.5	1578.1	
				2/12/75	185.7	1576.9	
				3/12/75	183.4	1579.2	
				4/10/75	191.4	1571.2	
				5/02/75	183.8	1578.8	
				6/11/75	182.5	1580.1	
				7/10/75	186.7	1575.9	
				8/07/75	NM-2		
				9/04/75	199.3	1563.3	
01S/02W-19D01 S	36		1608.4	1/31/75	278.0	1330.4	5412
				2/02/75	275.5	1332.9	
				3/14/75	276.4	1332.0	
				4/11/75	274.8	1333.6	
				5/15/75	276.2	1332.2	
				6/13/75	277.6	1330.8	
				7/10/75	278.1	1330.3	
				8/14/75	277.9	1330.5	
				9/18/75	279.9	1328.5	
01S/02W-21D01 S	36		1965.0	11/30/74	57.0	1908.0	5206
				12/07/74	60.0	1905.0	
				1/28/75	55.0	1910.0	
				2/27/75	53.0	1912.0	
				3/27/75	39.0	1926.0	
				4/01/75	52.0	1913.0	
				5/28/75	43.0	1922.0	
				7/02/75	52.0	1913.0	
				8/28/75	57.0	1908.0	
01S/02W-30C01 S	36		1649.0	11/21/74	118.7	1530.3	5412
				12/23/74	115.7	1533.3	
				1/16/75	116.4	1532.6	

See page 79 for key to terms a abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA ANA RIVER HYDRO UNIT						Y-01	
UPPER SANTA ANA R HYDRO SUBUNIT						Y-01.E	
MENTONE HYDRO SUBAREA						Y-01.E4	
01S/02W-30C01 S (CONTINUED)	36		1649.0	2/12/75	116.0	1533.0	5412
				3/13/75	115.6	1533.4	
				4/09/75	115.1	1533.9	
				5/15/75	117.0	1532.0	
				6/13/75	116.7	1532.3	
				7/10/75	117.4	1531.6	
				8/14/75	119.2	1529.8	
				9/18/75	122.3	1526.7	
RESERVOIR HYDRO SUBAREA						Y-01.E5	
01S/02W-29H01 S	36		1851.8	11/21/74	252.4	1599.4	5412
				12/23/74	NM-1		
				1/16/75	249.2	1602.6	
				2/14/75	247.5	1604.3	
				3/13/75	246.9	1604.9	
				4/11/75	245.5	1606.3	
				5/15/75	249.5	1602.3	
				6/13/75	250.0	1601.8	
				7/18/75	254.2	1597.6	
				8/14/75	250.9	1600.9	
				9/18/75	252.4	1599.4	
01S/03W-35G08 S	36		1565.8	10/29/74	107.0	1458.8	5206
				12/16/74	92.0	1473.8	
				1/27/75	108.0	1457.8	
				2/26/75	98.0	1467.8	
				3/26/75	95.0	1470.8	
				4/29/75	94.0	1471.8	
				5/27/75	108.0	1457.8	
				6/30/75	107.0	1458.8	
				7/30/75	105.0	1460.8	
				8/27/75	103.0	1462.8	
01S/03W-35G09 S	36		1576.7	10/29/74	129.5	1447.2	5206
				11/30/74	126.5	1450.2	
				12/06/74	124.5	1452.2	
				1/27/75	173.5(1)	1403.2	
				2/26/75	124.5	1452.2	
				3/26/75	126.5	1450.2	
				4/29/75	122.5	1454.2	
				5/27/75	126.5	1450.2	
				6/30/75	122.5	1454.2	
				7/30/75	124.5	1452.2	
				8/27/75	126.5	1450.2	
01S/03W-35G11 S	36		1560.0	10/29/74	89.0	1471.0	5206
				11/30/74	82.0	1478.0	
				12/06/74	84.0	1476.0	
				1/27/75	87.0	1473.0	
				2/26/75	81.0	1479.0	
				3/26/75	79.0	1481.0	
				4/29/75	76.0	1484.0	
				5/27/75	86.0	1474.0	
				6/30/75	83.0	1477.0	
				7/30/75	86.0	1474.0	
				8/27/75	89.0	1471.0	
01S/03W-35H02 S	36		1568.0	10/29/74	107.9	1460.1	5206
				11/30/74	100.9	1467.1	
				1/27/75	96.9	1471.1	
				2/26/75	101.9	1466.1	
				3/26/75	103.9	1464.1	
				4/29/75	96.9	1471.1	
				5/27/75	112.9	1455.1	
				6/30/75	108.9	1459.1	
				7/30/75	106.9	1461.1	
				8/27/75	84.9	1483.1	
01S/03W-35H03 S	36		1571.1	10/29/74	112.9	1458.2	5206
				11/30/74	103.9	1467.2	
				12/06/74	107.9	1463.2	
				1/27/75	108.9	1462.2	
				2/26/75	119.9(1)	1451.2	
				3/26/75	102.9	1468.2	
				4/29/75	99.9	1471.2	
				5/27/75	145.9(1)	1425.2	
				6/20/75	117.9(1)	1453.2	
				7/29/75	110.9	1460.2	
				8/27/75	111.9	1459.2	
01S/03W-35H04 S	36		1585.3	10/29/74	120.0	1465.3	5206
				11/30/74	113.0	1472.3	
				12/06/74	115.0	1470.3	
				1/27/75	117.0	1468.3	
				2/26/75	117.0	1468.3	
				3/26/75	112.0	1473.3	
				4/29/75	109.0	1476.3	
				5/27/75	124.0	1461.3	
				6/30/75	116.0	1469.3	
				7/29/75	120.0	1465.3	
				8/27/75	121.0	1464.3	
SANTA ANA CANYON HYDRO SUBAREA						Y-01.E7	
01S/02W-08C01 S	36		1811.0	10/10/74	78.0	1733.0	5412
				11/07/74	76.1	1734.9	
				12/03/74	68.3	1742.7	
				1/03/75	70.1	1740.9	
				2/12/75	71.3	1739.7	
				3/12/75	68.6	1742.4	
				4/10/75	61.7	1749.3	
SANTA ANA RIVER HYDRO UNIT						Y-01	
UPPER SANTA ANA R HYDRO SUBUNIT						Y-01.E	
SANTA ANA CANYON HYDRO SUBAREA						Y-01.E7	
01S/02W-08C01 S (CONTINUED)	36		1811.0	5/05/75	60.8	1750.2	5412
				6/12/75	67.0	1744.0	
				7/10/75	70.1	1740.9	
				8/07/75	77.2	1733.8	
				9/04/75	78.3	1732.7	
MILL CREEK HYDRO SUBAREA						Y-01.E8	
01S/01W-08E01 S	36		3570.0	1/28/75	32.0	3538.0	5206
				2/27/75	11.0	3559.0	
				3/28/75	11.0	3559.0	
				4/01/75	10.0	3560.0	
				5/28/75	12.0	3558.0	
				7/02/75	40.0	3530.0	
				8/28/75	118.0(1)	3452.0	
01S/01W-10L01 S	36		4140.0	11/05/74	120.0(1)	4020.0	5206
				12/07/74	120.0(1)	4020.0	
				1/28/75	123.0(1)	4017.0	
				2/27/75	120.0(1)	4020.0	
				3/28/75	31.0	4109.0	
				4/01/75	36.0	4104.0	
				5/28/75	44.0	4096.0	
				7/02/75	117.0(1)	4023.0	
				8/28/75	121.0(1)	4019.0	
01S/01W-11Q01 S	36		4575.0	11/05/74	120.0(1)	4455.0	5206
				12/07/74	110.0(1)	4465.0	
				1/28/75	117.0(1)	4458.0	
				2/27/75	120.0(1)	4455.0	
				3/28/75	65.0	4510.0	
				4/01/75	72.0	4503.0	
				5/28/75	68.0	4507.0	
				7/02/75	107.0(1)	4468.0	
				8/28/75	121.0(1)	4454.0	
01S/02W-09Q01 S	36		2155.0	11/20/74	159.8	1995.2	5412
				1/17/75	160.2	1994.8	
				2/12/75	157.8	1997.2	
				3/13/75	157.5	1997.5	
				4/11/75	155.8	1999.2	
				5/15/75	159.4	1995.6	
				6/13/75	161.9	1993.1	
				7/10/75	162.3	1992.7	
				8/14/75	161.4	1993.6	
				9/18/75	163.2	1991.8	
01S/02W-21B02 S	36		2090.0	11/04/74	35.2	2054.8	5206
				12/07/74	35.2	2054.8	
				1/28/75	26.2	2063.8	
				2/27/75	25.2	2064.8	
				3/27/75	25.2	2064.8	
				4/01/75	21.2	2068.8	
				5/28/75	27.2	2062.8	
				7/02/75	29.2	2060.8	
				8/28/75	35.2	2054.8	
01S/02W-21F01 S	36		2015.9	11/04/74	54.0	1961.9	5206
				12/07/74	53.0	1962.9	
				1/28/75	47.0	1968.9	
				2/27/75	45.0	1970.9	
				3/27/75	38.0	1977.9	
				4/01/75	30.0	1985.9	
				5/28/75	37.0	1978.9	
				7/02/75	47.0	1968.9	
				8/28/75	53.0	1962.9	
01S/02W-21H01 S	36		1955.3	11/04/74	31.6	1923.7	5206
				12/07/74	30.6	1924.7	
				1/28/75	25.6	1929.7	
				2/27/75	29.6	1925.7	
				3/27/75	23.6	1931.7	
				4/01/75	20.6	1934.7	
				5/28/75	21.6	1933.7	
				7/02/75	20.6	1934.7	
				8/28/75	26.6	1928.7	
01S/02W-22C02 S	36		2260.0	11/04/74	48.0	2212.0	5206
				12/07/74	46.0	2214.0	
				1/28/75	42.0	2218.0	
				2/27/75	44.0	2216.0	
				3/27/75	39.0	2221.0	
				4/01/75	38.0	2222.0	
				5/28/75	42.0	2218.0	
				7/02/75	46.0	2214.0	
				8/28/75	49.0	2211.0	
SYCAMORE HYDRO SUBAREA						Y-01.E9	
01N/05W-15K01 S	36		1598.3	2/01/75	283.7	1314.6	4706
				3/01/75	284.2	1314.1	
				4/01/75	283.3	1315.0	
				5/01/75	284.0	1314.3	
				6/01/75	284.2	1314.1	
				7/01/75	286.2	1312.1	
				8/01/75	289.7	1308.6	
				9/01/75	293.7	1304.6	
01N/05W-15Q02 S	36		1590.8	2/01/75	282.0	1308.8	4706
				3/01/75	280.8	1310.0	
				4/01/75	281.8	1309.0	
				5/01/75	280.1	1310.7	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA ANA RIVER HYDRO UNIT UPPER SANTA ANA R HYDRO SUBUNIT SYCAMORE HYDRO SUBAREA						Y-01 Y-01.F Y-01.E9	
01N/05W-15D02 S (CONTINUED)	36		1590.8	6/01/75	281.4	1309.4	4706
				7/01/75	283.5	1307.3	
				8/01/75	286.0	1304.8	
				9/01/75	293.0	1297.8	
01N/05W-22A01 S	36		1549.8	2/01/75	249.1(1)	1300.7	4706
				3/01/75	249.1(1)	1300.7	
				4/01/75	244.5(1)	1305.3	
				5/01/75	249.1(1)	1300.7	
				6/01/75	244.5(1)	1305.3	
				7/01/75	249.1(1)	1300.7	
				8/01/75	253.8(1)	1296.0	
				9/01/75	251.5(1)	1298.3	
01N/05W-23A01 S	36		1514.0	10/04/74	105.0	1409.0	4793
				11/01/74	85.0	1429.0	
				12/06/74	85.0	1429.0	
				1/03/75	80.0	1434.0	
				2/07/75	80.0	1434.0	
				3/07/75	80.0	1434.0	
				4/04/75	75.0	1439.0	
				5/02/75	75.0	1439.0	
				6/06/75	80.0	1434.0	
				7/03/75	80.0	1434.0	
				8/01/75	85.0	1429.0	
				9/05/75	90.0	1424.0	
01N/05W-23A02 S	36		1507.0	10/04/74	95.0	1412.0	4793
				11/01/74	135.0(1)	1372.0	
				12/06/74	85.0	1422.0	
				1/03/75	80.0	1427.0	
				2/07/75	80.0	1427.0	
				3/07/75	85.0	1422.0	
				4/04/75	80.0	1427.0	
				5/02/75	120.0(1)	1387.0	
				6/06/75	130.0(1)	1377.0	
				7/03/75	130.0(1)	1377.0	
				8/01/75	130.0(1)	1377.0	
				9/05/75	140.0(1)	1367.0	
01N/05W-23H01 S	36		1496.2	10/04/74	105.2(1)	1391.0	4793
				11/01/74	95.2	1401.0	
				12/06/74	105.2(1)	1391.0	
				1/03/75	85.2	1411.0	
				2/07/75	85.2	1411.0	
				3/07/75	85.2	1411.0	
				4/04/75	80.2	1416.0	
				5/02/75	100.2(1)	1396.0	
				6/06/75	100.2(1)	1396.0	
				7/03/75	100.2(1)	1396.0	
				8/01/75	95.2	1401.0	
				9/05/75	100.2	1396.0	
01N/05W-23K01 S	36		1454.2	2/01/75	157.5	1296.7	4706
				3/01/75	145.9	1308.3	
				4/01/75	155.2	1299.0	
				5/01/75	152.9	1301.3	
				6/01/75	152.9	1301.3	
				7/01/75	173.0(1)	1281.2	
				8/01/75	185.2(1)	1269.0	
				9/01/75	185.2(1)	1269.0	
01N/05W-23O01 S	36		1430.0	10/01/74	120.0	1310.0	4124
				11/01/74	110.0	1320.0	
				12/01/74	111.0	1319.0	
				1/02/75	110.0	1320.0	
				2/01/75	115.0	1315.0	
				3/01/75	121.0	1309.0	
				4/01/75	122.0	1308.0	
				5/01/75	113.0	1317.0	
				8/01/75	143.0	1287.0	
				9/01/75	173.0(1)	1257.0	
01N/05W-24E01 S	36		1472.0	10/04/74	160.0	1312.0	4793
				11/01/74	160.0(1)	1312.0	
				12/04/74	115.0	1357.0	
				1/03/75	130.0	1342.0	
				2/07/75	170.0(1)	1302.0	
				3/07/75	155.0(1)	1317.0	
				4/04/75	125.0	1347.0	
				5/02/75	125.0	1347.0	
				6/06/75	155.0(1)	1317.0	
				7/03/75	135.0	1337.0	
				8/01/75	170.0(1)	1302.0	
				9/05/75	190.0(1)	1282.0	
01N/05W-25F01 S	36		1383.4	10/01/74	136.0(1)	1247.4	4124
				11/01/74	126.0	1257.4	
				12/01/74	125.0	1258.4	
				1/02/75	123.0	1260.4	
				2/01/75	122.0	1261.4	
				3/01/75	121.0	1262.4	
				4/01/75	115.0	1268.4	
				5/01/75	115.0	1268.4	
				6/01/75	126.0(1)	1257.4	
				7/01/75	133.0(1)	1250.4	
				8/01/75	125.0	1258.4	
				9/01/75	125.0	1258.4	
01N/05W-26A03 S	36		1398.0	10/01/74	NM-1		4124
				11/01/74	NM-1		
				12/01/74	NM-1		
SANTA ANA RIVER HYDRO UNIT UPPER SANTA ANA R HYDRO SUBUNIT SYCAMORE HYDRO SUBAREA						Y-01 Y-01.E Y-01.E9	
01N/05W-26A03 S (CONTINUED)	36		1398.0	1/02/75	NM-1		4124
				2/01/75	NM-1		
				3/01/75	NM-1		
				4/01/75	119.0	1279.0	
				5/01/75	119.0	1279.0	
				7/01/75	NM-1		
				8/01/75	130.0	1268.0	
				9/01/75	129.0	1269.0	
01N/05W-36H04 S	36		1274.2	10/01/74	141.0(1)	1133.2	4124
				11/01/74	147.0	1127.2	
				12/01/74	148.0	1126.2	
				1/02/75	145.0	1129.2	
				2/01/75	147.0	1127.2	
				3/01/75	147.0	1127.2	
				4/01/75	139.0	1135.2	
				5/01/75	149.0	1125.2	
				6/01/75	150.0	1124.2	
				7/01/75	167.0	1107.2	
				8/01/75	178.0(1)	1096.2	
				9/01/75	154.0	1120.2	
01N/05W-36J03 S	36		1261.5	10/01/74	135.1	1126.4	4124
				11/01/74	136.1	1125.4	
				12/01/74	151.1	1110.4	
				1/02/75	147.1	1114.4	
				2/01/75	139.1	1122.4	
				3/01/75	144.1(1)	1117.4	
				4/01/75	135.1	1126.4	
				5/01/75	139.1	1122.4	
				6/01/75	141.1	1120.4	
				7/01/75	146.1(1)	1115.4	
				8/01/75	147.1	1114.4	
				9/01/75	153.1(1)	1108.4	
01N/05W-36R01 S	36		1247.4	10/18/74	129.1(1)	1118.3	3230
				11/14/74	154.1(1)	1093.3	
				12/28/74	148.4(1)	1099.0	
				1/14/75	136.2	1111.2	
				2/27/75	162.0	1085.4	
				3/24/75	182.9(1)	1064.5	
				5/01/75	144.7	1102.7	
				6/17/75	NM-1		
				7/17/75	NM-1		
				8/22/75	NM-1		
SAN TIMOTEO HYDRO SUBUNIT YUCAIPA HYDRO SUBAREA						Y-01.F Y-01.F1	
02S/01W-08F01 S	36		2812.6	10/09/74	62.5	2750.1	5419
				11/06/74	62.7	2749.9	
				12/09/74	63.0	2749.6	
				1/06/75	63.0	2749.6	
				2/07/75	187.0	2625.6	
				3/06/75	63.5	2749.1	
				4/03/75	63.2	2749.4	
				5/07/75	63.0	2749.6	
				6/05/75	63.2	2749.4	
				7/07/75	63.1	2749.5	
				8/04/75	63.1	2749.5	
				9/05/75	63.0(1)	2749.6	
02S/02W-15A03 S	33		2320.0	12/16/74	330.0(1)	1990.0	6224
				5/12/75	328.0(1)	1992.0	
SAN TIMOTEO HYDRO SUBAREA						Y-01.F2	
02S/01W-34M01 S	33		2656.8	10/22/74	NM-8		5103
				4/16/75	396.7	2260.1	
02S/02W-20K01 S	33		1877.7	10/30/74	NM-9		5103
				4/11/75	24.5	1853.2	
02S/02W-25R01 S	33		2299.1	10/25/74	85.6	2213.5	5103
				4/16/75	NM-7		
02S/02W-35Q01 S	33		2114.5	10/30/74	NM-7		5103
				4/11/75	NM-9		
02S/03W-10B01 S	33		1491.8	11/25/74	79.9	1411.9	5412
				12/23/74	79.6	1412.2	
				1/16/75	79.9	1411.9	
				2/12/75	77.3	1414.5	
				3/13/75	76.8	1415.0	
				4/09/75	74.4	1417.4	
				5/15/75	78.4	1413.4	
				6/11/75	78.2	1413.6	
				7/10/75	80.4	1411.4	
				8/10/75	79.1	1412.7	
				9/18/75	84.5	1407.3	
02S/03W-24R01 S	33		1692.8	10/30/74	56.8	1636.0	5103
				4/11/75	NM-3		
03S/01W-05D01 S	33		2532.7	10/25/74	NM-8		5103
				4/16/75	116.8	2415.9	
03S/01W-06F01 S	33		2333.0	10/25/74	114.8	2218.2	5103
				4/16/75	115.0	2218.0	
03S/01W-06L01 S	33		2334.8	10/25/74	47.0	2287.8	5103
				4/16/75	46.8	2288.0	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA ANA RIVER HYDRO UNIT						Y-01	
SAN TIMOTEO HYDRO SUBUNIT						Y-01.F	
SAN TIMOTEO HYDRO SUBAREA						Y-01.F2	
03S/01W-07C01 S	33		2333.9	10/25/74	5.1	2328.8	5103
				4/16/75	3.6	2330.3	
03S/01W-09001 S	33		2560.0	10/22/74	NM-R		5103
				11/15/74	88.0	2472.0	
				12/10/74	NM-1		
				4/14/75	85.7	2474.3	
				6/04/75	87.3	2472.7	
				7/08/75	88.5	2471.5	
				8/13/75	87.7	2472.3	
				9/15/75	88.4	2471.6	
CHERRY VALLEY HYDRO SUBAREA						Y-01.F3	
02S/02W-14J02 S	33		2419.0	10/25/74	198.4	2220.6	5103
				4/14/75	195.1	2223.9	
02S/02W-23H01 S	33		2387.1	10/25/74	222.8	2164.3	5103
				4/16/75	218.8	2168.3	
CHICKEN HILL HYDRO SUBAREA						Y-01.F4	
02S/02W-02D02 S	36		2360.0	10/09/74	379.0(1)	1981.0	5419
				11/06/74	304.5	2055.5	
				12/09/74	300.0	2060.0	
				1/06/75	296.8	2063.2	
				2/07/75	294.0	2066.0	
				3/06/75	292.5	2067.5	
				4/03/75	291.0	2069.0	
				5/07/75	289.0	2071.0	
				6/05/75	288.0	2072.0	
				7/07/75	323.0(1)	2037.0	
				8/04/75	337.0(1)	2023.0	
				9/05/75	344.5	2015.5	
02S/02W-02H02 S	36		2380.0	10/09/74	278.0	2102.0	5419
				11/06/74	279.5	2100.5	
				12/09/74	278.5	2101.5	
				1/06/75	277.9	2102.1	
				2/07/75	277.5	2102.5	
				3/06/75	286.5	2093.5	
				4/03/75	276.2	2103.8	
				5/07/75	276.0	2104.0	
				6/05/75	275.0	2105.0	
				7/07/75	274.0	2106.0	
				8/04/75	313.6(1)	2066.4	
				9/05/75	278.0(1)	2102.0	
02S/02W-02N01 S	36		2330.0	10/09/74	243.8	2086.2	5419
				11/06/74	244.0	2086.0	
				12/09/74	244.0	2086.0	
				1/06/75	243.8	2086.2	
				2/07/75	242.5	2087.5	
				3/06/75	241.3	2088.7	
				4/03/75	241.0	2089.0	
				5/07/75	240.5	2089.5	
				6/05/75	240.0	2090.0	
				7/07/75	239.0	2091.0	
				8/04/75	239.5	2090.5	
				9/05/75	241.0(1)	2089.0	
02S/02W-11H02 S	36		2320.0	10/09/74	207.5	2112.5	5419
				11/06/74	208.0	2112.0	
				12/09/74	207.5	2112.5	
				1/06/75	202.0	2118.0	
				2/07/75	200.5	2119.5	
				3/06/75	199.5	2120.5	
				4/03/75	198.5	2121.5	
				5/07/75	197.0	2123.0	
				6/05/75	196.7	2123.3	
				7/07/75	197.0	2123.0	
				8/04/75	198.0	2122.0	
				9/05/75	199.5(1)	2120.5	
GATEWAY HYDRO SUBAREA						Y-01.F5	
01S/01W-30E01 S	36		2816.9	10/09/74	308.0	2508.9	5419
				11/06/74	306.5	2510.4	
				12/09/74	306.5	2510.4	
				1/06/75	306.0	2510.9	
				2/07/75	306.0	2510.9	
				3/06/75	305.2	2511.7	
				4/03/75	304.5	2512.4	
				5/07/75	304.0	2512.9	
				6/05/75	328.0(1)	2488.9	
				7/07/75	303.5	2513.4	
				8/04/75	304.0	2512.9	
				9/05/75	303.0(1)	2513.9	
01S/01W-30G01 S	36		2933.0	12/09/74	188.5	2744.5	5419
				1/06/75	187.0	2746.0	
				2/07/75	163.5	2869.5	
				3/06/75	187.3	2745.7	
				4/03/75	187.4	2745.6	
				5/07/75	187.5	2745.5	
				6/05/75	187.6	2745.4	
				7/05/75	187.5	2745.5	
				8/04/75	188.0	2745.0	
				9/05/75	188.6(1)	2744.4	
01S/02W-25K02 S	36		2764.0	10/09/74	259.5	2504.5	5419
SANTA ANA RIVER HYDRO UNIT						Y-01	
SAN TIMOTEO HYDRO SUBUNIT						Y-01.F	
GATEWAY HYDRO SUBAREA						Y-01.F5	
01S/02W-25K02 S (CONTINUED)	36		2764.0	11/06/74	258.5	2505.5	5419
				12/09/74	257.5	2506.5	
				1/06/75	256.5	2507.5	
				2/07/75	256.0	2508.0	
				3/06/75	255.5	2508.5	
				4/03/75	255.0	2509.0	
				5/07/75	254.0	2510.0	
				6/05/75	254.0	2510.0	
				7/07/75	253.5	2510.5	
				8/04/75	253.0	2511.0	
				9/05/75	252.7(1)	2511.3	
01S/02W-25M02 S	36		2610.0	10/09/74	212.0	2398.0	5419
				11/06/74	210.5	2399.5	
				12/09/74	209.0	2401.0	
				1/06/75	208.0	2402.0	
				2/07/75	207.0	2403.0	
				3/06/75	205.5	2404.5	
				4/03/75	205.2	2404.8	
				5/07/75	205.0	2405.0	
				6/05/75	203.8	2406.2	
				7/07/75	202.5	2407.5	
				8/04/75	202.0	2408.0	
				9/05/75	201.0(1)	2409.0	
OAK GLEN HYDRO SUBAREA						Y-01.F6	
01S/02W-25P02 S	36		2740.0	10/09/74	372.0	2368.0	5419
				12/09/74	363.0	2377.0	
				4/03/75	358.0	2382.0	
01S/02W-36F01 S	36		2685.0	10/09/74	301.0(1)	2384.0	5419
				11/06/74	301.0(1)	2384.0	
				12/09/74	301.0(1)	2384.0	
				1/06/75	300.0(1)	2385.0	
				2/07/75	293.7(1)	2311.3	
				3/06/75	292.5(1)	2312.5	
				4/03/75	294.5(1)	2310.5	
				5/07/75	293.0(1)	2312.0	
				6/05/75	296.0(1)	2309.0	
				7/07/75	301.0(1)	2304.0	
				8/04/75	300.8(1)	2304.2	
01S/02W-36N01 S	36		2559.0	10/09/74	236.5	2322.5	5419
				11/06/74	239.5	2319.5	
				12/09/74	232.0	2327.0	
				1/06/75	230.8	2328.2	
				2/07/75	230.6	2328.4	
				3/06/75	246.2(1)	2312.8	
				4/03/75	230.0	2329.0	
				5/07/75	245.0(1)	2314.0	
				6/05/75	248.0(1)	2311.0	
				7/07/75	247.0(1)	2312.0	
				8/04/75	250.0(1)	2309.0	
				9/05/75	237.0(1)	2322.0	
01S/02W-36R01 S	36		2710.0	10/09/74	342.5	2367.5	5419
				11/06/74	343.0	2367.0	
				12/09/74	344.0	2366.0	
				1/06/75	342.5	2367.5	
				2/07/75	343.0	2367.0	
				3/06/75	342.5	2367.5	
				4/03/75	342.2	2367.8	
				5/07/75	342.0	2368.0	
				6/05/75	342.3	2367.7	
				7/07/75	343.5	2366.5	
				8/04/75	344.0	2366.0	
				9/05/75	345.0(1)	2365.0	
01S/03W-01H01 S	36		1541.3	10/10/74	NM-1		5412
				11/07/74	NM-5		
				12/03/74	236.1	1305.2	
				1/03/75	NM-1		
				2/12/75	241.0	1300.3	
				3/12/75	239.8	1301.5	
				4/10/75	244.7	1296.6	
				5/02/75	247.0	1294.3	
				6/11/75	242.5	1298.8	
				7/10/75	247.9	1293.4	
				8/07/75	235.8	1305.5	
				9/11/75	240.1	1301.2	
02S/02W-01F01 S	36		2560.0	10/09/74	233.0	2327.0	5419
				11/06/74	232.5	2327.5	
				12/09/74	232.5	2327.5	
				1/06/75	234.5	2325.5	
				2/07/75	233.0	2327.0	
				3/06/75	233.0	2327.0	
				4/03/75	232.5	2327.5	
				5/07/75	232.5	2327.5	
				6/05/75	233.0	2327.0	
				7/07/75	234.0	2326.0	
				8/04/75	234.0	2326.0	
				9/05/75	234.4(1)	2325.6	
SOUTH MESA HYDRO SUBAREA						Y-01.F7	
01S/01W-32A01 S	36		3338.0	10/09/74	28.7	3309.3	5419
				11/06/74	29.3	3308.7	
				12/09/74	46.0(1)	3292.0	
				1/06/75	32.0	3306.0	
				2/07/75	45.0	3293.0	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA ANA RIVER HYDRO UNIT SAN TIMOTEO HYDRO SUBUNIT SOUTH MESA HYDRO SUBAREA						Y-01 Y-01.F Y-01.F7	
01S/01W-32A01 S (CONTINUED)	36		3338.0	3/04/75	22.6	3315.4	5419
				4/03/75	36.0(1)	3302.0	
				5/07/75	48.5(1)	3289.5	
01S/01W-32C01 S	36		3175.0	10/09/74	60.0(1)	3115.0	5419
				11/06/74	59.5(1)	3115.5	
				12/09/74	59.0(1)	3116.0	
				1/06/75	54.5(1)	3120.5	
				2/07/75	55.0(1)	3120.0	
				3/06/75	49.0(1)	3126.0	
				4/03/75	54.6	3120.4	
				5/07/75	56.6(1)	3118.4	
				6/05/75	53.0(1)	3122.0	
				7/07/75	54.0(1)	3121.0	
				8/04/75	57.0(1)	3118.0	
				9/05/75	55.0(1)	3120.0	
02S/01W-03K02 S	36		2642.0	10/10/74	388.0	2254.0	5407
				11/11/74	407.0	2235.0	
				12/16/74	408.2	2233.8	
				1/12/75	406.2	2235.8	
				2/28/75	386.2	2255.8	
				3/28/75	383.4	2258.6	
				4/15/75	384.0	2258.0	
				5/06/75	384.0	2258.0	
				6/12/75	391.0	2251.0	
				7/03/75	388.0	2254.0	
				8/11/75	390.0	2252.0	
				9/18/75	392.0	2250.0	
02S/02W-11A01 S	36		2440.0	10/09/74	303.5	2136.5	5419
				11/06/74	300.0	2140.0	
				12/09/74	298.0	2142.0	
				1/06/75	295.5	2144.5	
				2/07/75	293.5	2146.5	
				3/06/75	292.3	2147.7	
				4/03/75	290.3	2149.7	
				5/07/75	289.3	2150.7	
				6/05/75	291.5	2148.5	
				7/07/75	334.0(1)	2106.0	
				8/04/75	334.0(1)	2106.0	
				9/05/75	301.5(1)	2138.5	
02S/02W-11R01 S	36		2415.0	10/09/74	297.5	2117.5	5419
				11/06/74	299.5	2115.5	
				12/09/74	293.0	2122.0	
				1/06/75	313.9(1)	2101.1	
				2/07/75	288.0	2127.0	
				3/06/75	286.5	2128.5	
				4/03/75	285.0	2130.0	
				5/07/75	307.6(1)	2107.4	
				6/05/75	318.0(1)	2097.0	
				7/07/75	320.0(1)	2095.0	
				8/04/75	331.0(1)	2084.0	
				9/05/75	334.0	2081.0	
02S/02W-11R02 S	36		2380.0	10/09/74	277.5	2102.5	5419
				11/06/74	272.3	2107.7	
				12/09/74	275.5	2104.5	
				1/06/75	256.1	2123.9	
				2/07/75	253.0	2127.0	
				3/06/75	251.0	2129.0	
				4/03/75	249.5	2130.5	
				5/07/75	247.8	2132.2	
				6/05/75	254.0	2126.0	
				7/07/75	315.0(1)	2065.0	
				8/04/75	326.0(1)	2054.0	
				9/05/75	331.7	2048.3	
02S/02W-14R01 S	33		2405.0	12/16/74	278.0	2127.0	6224
				5/12/75	274.0	2131.0	
02S/02W-14R01 S	33		2360.0	12/16/74	138.0	2222.0	6224
				5/12/75	133.0	2227.0	
TRIPLE FALLS CREEK HYDRO SUBAREA						Y-01.F8	
01S/01W-27C01 S	36		3850.0	10/09/74	45.2(1)	3804.8	5419
				11/06/74	45.0(1)	3805.0	
				12/09/74	43.0(1)	3807.0	
				1/06/75	45.3(1)	3804.7	
				2/07/75	45.0(1)	3805.0	
				3/06/75	42.0(1)	3808.0	
				4/03/75	41.0(1)	3809.0	
				5/07/75	38.5(1)	3811.5	
				6/05/75	42.0(1)	3808.0	
				7/07/75	42.7(1)	3807.3	
				8/04/75	42.5(1)	3807.5	
				9/05/75	44.0	3806.0	
NORTE CREEK HYDRO SUBAREA						Y-01.F9	
02S/01W-01F01 S	36		4355.0	10/10/74	28.6	4326.4	5407
				11/11/74	29.4	4325.6	
				12/16/74	24.0	4331.0	
				1/12/75	22.4	4332.6	
				2/28/75	20.0	4335.0	
				3/28/75	20.0	4335.0	
				4/15/75	27.0	4328.0	
				5/06/75	28.3	4326.7	
				6/12/75	26.4	4328.6	
				7/03/75	25.8	4329.2	
SANTA ANA RIVER HYDRO UNIT SAN TIMOTEO HYDRO SUBUNIT NORTE CREEK HYDRO SUBAREA						Y-01 Y-01.F Y-01.F9	
02S/01W-01F01 S (CONTINUED)	36		4355.0	8/11/75	28.0(1)	4327.0	5407
				9/18/75	26.4(1)	4328.6	
02S/01W-02G01 S	36		4408.0	10/10/74	13.3	4386.7	5407
				11/11/74	14.2	4385.8	
				12/16/74	16.7	4383.3	
				1/12/75	22.0	4378.0	
				2/28/75	18.6	4381.4	
				3/28/75	19.6	4380.4	
				4/15/75	18.3	4381.7	
				5/06/75	18.3	4381.7	
				6/12/75	19.2	4380.8	
				7/03/75	19.6	4380.4	
				8/11/75	108.3(1)	4291.7	
				9/18/75	19.6	4380.4	
02S/01W-02H01 S	36		4350.0	10/10/74	20.6	4329.4	5407
				11/11/74	22.0	4328.0	
				12/16/74	20.0	4330.0	
				1/12/75	19.4	4330.6	
				2/28/75	16.3	4333.7	
				3/28/75	16.2	4333.8	
				4/15/75	18.3	4331.7	
				5/06/75	20.0	4330.0	
				6/12/75	20.0	4330.0	
				7/03/75	17.4	4332.6	
				8/11/75	18.4	4331.6	
				9/18/75	20.3	4329.7	
02S/01W-02H03 S	36		4350.0	10/10/74	115.0(1)	4235.0	5407
				11/11/74	99.2(1)	4250.8	
				12/16/74	22.2	4327.8	
				1/02/75	18.4	4331.6	
				2/28/75	12.4	4337.6	
				3/28/75	12.0	4338.0	
				4/15/75	13.3	4336.7	
				5/06/75	12.0	4338.0	
				6/12/75	12.8	4337.2	
				7/03/75	13.4	4336.6	
				8/11/75	111.2(1)	4238.8	
				9/18/75	13.4	4336.6	
02S/01W-02J01 S	36		4234.5	10/10/74	30.0	4204.5	5407
				11/11/74	28.4	4206.1	
				12/16/74	27.2	4207.3	
				1/12/75	26.2	4208.3	
				2/28/75	22.0	4212.5	
				3/28/75	20.9	4213.6	
				4/15/75	21.3	4213.2	
				5/06/75	48.0(1)	4186.5	
				6/12/75	79.0(1)	4155.5	
				7/03/75	82.0(1)	4152.5	
				8/11/75	82.3(1)	4152.2	
				9/18/75	42.0	4192.5	
02S/01W-02K01 S	36		4235.0	10/10/74	63.0	4172.0	5407
				11/11/74	62.4	4172.6	
				12/16/74	60.4	4174.6	
				1/12/75	60.3	4174.7	
				2/28/75	60.0	4175.0	
				3/28/75	60.0	4175.0	
				4/15/75	59.4	4175.6	
				5/06/75	59.0	4176.0	
				6/12/75	60.0	4175.0	
				7/03/75	57.4	4177.6	
02S/01W-02K02 S	36		4080.0	10/10/74	135.0	3945.0	5407
				11/11/74	138.2	3941.8	
				12/16/74	133.4	3946.6	
				1/12/75	134.0	3946.0	
				2/28/75	130.0	3950.0	
				3/28/75	128.0	3952.0	
				4/15/75	131.2	3948.8	
				5/06/75	132.0	3948.0	
				6/12/75	129.3	3950.7	
				7/03/75	128.2	3951.8	
				8/11/75	129.3	3950.7	
				9/18/75	136.0	3944.0	
02S/01W-02P01 S	36		4160.0	10/10/74	521.0	3639.0	5407
				11/10/74	29.8(1)	4130.2	
				12/11/74	31.2(1)	4128.8	
				1/02/75	18.4	4141.6	
				2/03/75	16.4	4143.6	
				3/28/75	486.0	3674.0	
				4/15/75	22.0	4138.0	
				5/06/75	22.0	4138.0	
				6/12/75	22.0	4138.0	
				7/03/75	505.0	3655.0	
				8/11/75	508.2	3651.8	
				9/18/75	20.0	4140.0	
02S/01W-10J01 S	36		3660.3	10/10/74	36.3(1)	3624.0	5407
				11/11/74	23.0	3637.3	
				12/16/74	18.3	3642.0	
				1/12/75	28.4	3631.9	
				2/28/75	18.6	3641.7	
				3/28/75	25.0	3635.3	
				4/15/75	28.3(1)	3632.0	
				5/06/75	29.2(1)	3631.1	
				6/12/75	30.0(1)	3630.3	
				7/03/75	21.7	3638.6	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA ANA RIVER HYDRO UNIT						Y-01	
SAN TIMOTEO HYDRO SUBUNIT						Y-01.F	
NORTH CREEK HYDRO SUBAREA						Y-01.F9	
02S/01W-10J01 S (CONTINUED)	36		3660.3	8/11/75	23.4	3636.9	5407
				9/18/75	21.0	3639.3	
02S/01W-22H01 S	33		3160.0	10/10/74	173.0	2987.0	5407
				11/11/74	153.0	3007.0	
				12/16/74	136.4	3023.6	
				1/12/75	147.0	3013.0	
				2/28/75	146.2	3013.8	
				3/28/75	147.0	3013.0	
				4/15/75	143.0	3017.0	
				5/06/75	140.0	3020.0	
				6/12/75	144.0	3016.0	
				7/03/75	153.0	3007.0	
				8/11/75	142.0	3018.0	
				9/18/75	148.0	3012.0	
02S/01W-22H02 S	33		3120.0	10/10/74	192.0(1)	2928.0	5407
				11/11/74	187.0(1)	2933.0	
				12/16/74	169.4	2950.6	
				1/12/75	178.0(1)	2942.0	
				2/28/75	169.3(1)	2950.7	
				3/28/75	167.0(1)	2953.0	
				4/15/75	174.3(1)	2945.7	
				5/06/75	178.0(1)	2942.0	
				6/12/75	186.0(1)	2934.0	
				7/03/75	191.0(1)	2929.0	
				8/11/75	191.0(1)	2929.0	
				9/18/75	194.3(1)	2925.7	
02S/01W-22H01 S	33		2953.0	10/22/74	NM-1		5103
				11/15/74	100.8	2852.2	
				12/10/74	96.0	2857.0	
				4/16/75	92.9	2860.1	
				6/04/75	NM-1		
				7/07/75	NM-1		
				8/13/75	NM-1		
				9/15/75	NM-8		
02S/01W-22H02 S	33		2942.8	10/22/74	82.6	2860.2	5103
				4/16/75	78.3	2864.5	
02S/01W-23D01 S	33		3200.0	10/10/74	108.3(1)	3091.7	5407
				11/11/74	78.2	3121.8	
				12/16/74	84.3	3115.7	
				1/12/75	98.0	3102.0	
				2/28/75	93.0	3107.0	
				3/28/75	90.2	3109.8	
				4/15/75	90.0	3110.0	
				5/06/75	108.0(1)	3092.0	
				6/12/75	111.0(1)	3089.0	
				7/03/75	122.0(1)	3078.0	
				8/11/75	131.2(1)	3068.8	
				9/18/75	133.0(1)	3067.0	
02S/01W-27B02 S	33		2875.0	10/10/74	607.3	2267.7	5407
				11/11/74	605.0	2270.0	
				12/16/74	605.4	2269.6	
				1/12/75	603.0	2272.0	
				2/28/75	592.0	2283.0	
				3/28/75	589.0	2286.0	
				4/15/75	593.0	2282.0	
				5/06/75	594.0	2281.0	
				6/12/75	603.0	2272.0	
				7/03/75	597.0	2278.0	
				8/11/75	599.0	2276.0	
				9/18/75	602.0	2273.0	

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SAN JACINTO VALLEY HYDRO UNIT						Y-02	
PERRIS HYDRO SUBUNIT						Y-02.A	
PERRIS VALLEY HYDRO SUBAREA						Y-02.A1	
03S/03W-06D01 S	33		1650.8	10/15/74	221.1(4)	1428.9	5103
				4/02/75	198.9	1451.1	
03S/03W-07F01 S	33		1600.0	10/15/74	NM-8		5103
				11/13/74	141.9	1458.1	
				12/10/74	140.9	1459.1	
				4/02/75	NM-2		
				6/02/75	NM-1		
03S/03W-13D01 S	33		1595.5	10/15/74	136.4	1459.1	5103
				11/15/74	136.0	1459.5	
				12/10/74	135.7	1459.8	
				4/02/75	135.3	1460.2	
				6/02/75	135.1	1460.4	
				7/03/75	135.2	1460.3	
				8/06/75	135.6	1459.9	
				9/15/75	135.5	1460.0	
03S/03W-15F01 S	33		1539.2	10/15/74	131.3	1406.9	5103
				4/02/75	125.5	1412.7	
03S/03W-31C02 S	33		1475.4	10/15/74	215.1	1260.3	5103
				4/02/75	NM-6		
03S/04W-24D01 S	33		153.4	10/30/74	NM-5		5103
				11/19/74	NM-5		
				12/11/74	NM-5		
				4/03/75	97.9	55.5	
				6/05/75	103.7	49.7	
04S/03W-06H02 S	33		1460.0	10/30/74	298.7(5)	1161.3	5103
				11/19/74	297.8(5)	1162.2	
				12/11/74	298.7(5)	1161.3	
				4/03/75	293.9(5)	1166.1	
				6/05/75	310.9(5)	1149.1	
				7/09/75	304.4(5)	1155.6	
				8/13/75	NM-9		
				9/16/75	298.8(5)	1161.2	
04S/03W-29D01 S	33		1417.0	10/15/74	204.4	1212.6	5103
				11/13/74	203.8	1213.2	
				12/10/74	NM-3		
				4/02/75	197.9	1219.1	
				6/02/75	200.1	1216.9	
				7/07/75	202.6(2)	1214.4	
				8/06/75	203.9	1213.1	
				9/11/75	203.2	1213.8	
04S/03W-35F01 S	33		1431.9	10/15/74	198.0	1233.9	5103
				4/02/75	195.6	1236.3	
04S/04W-12E01 S	33		1540.0	10/15/74	NM-3		5103
				11/13/74	NM-1		
				12/10/74	36.6	1503.4	
				4/02/75	36.8	1503.2	
				6/02/75	37.0	1503.0	
05S/03W-05R02 S	33		1415.0	10/15/74	160.5	1254.5	5103
				11/13/74	160.3	1254.7	
				12/11/74	160.9	1254.1	
				4/02/75	160.5	1254.5	
				6/02/75	159.9	1255.1	
MENIFEE HYDRO SUBAREA						Y-02.A2	
06S/03W-01J01 S	33		1429.0	10/15/74	NM-8		5103
				11/14/74	NM-1		
				12/12/74	162.0	1267.0	
				4/02/75	158.9	1270.1	
				6/03/75	161.4	1267.6	
06S/03W-03H02 S	33		1430.0	10/15/74	163.4	1266.6	5103
				11/13/74	NM-1		
				12/11/74	NM-8		
				4/02/75	NM-1		
				6/02/75	152.5	1277.5	
06S/03W-14N01 S	33		1485.0	10/15/74	12.3	1472.7	5103
				11/14/74	12.2	1472.8	
				12/11/74	12.0	1473.0	
				4/02/75	11.6	1473.4	
				6/02/75	11.7	1473.3	
WINCHESTER HYDRO SUBAREA						Y-02.A3	
05S/02W-19N01 S	33		1459.0	11/04/74	NM-1		5103
				12/12/74	24.2	1434.8	
				4/03/75	24.2	1434.8	
				6/03/75	18.0	1441.0	
				7/07/75	17.1	1441.9	
				8/07/75	15.0	1444.0	
				9/15/75	NM-1		
05S/02W-22G02 S	33		1505.0	11/04/74	59.0	1446.0	5103
				12/12/74	58.7	1446.3	
				4/03/75	57.9	1447.1	
				6/03/75	57.6	1447.4	
05S/02W-27G01 S	33		1480.0	11/04/74	NM-8		5103
				12/13/74	NM-9		
				4/03/75	NM-2		
				6/03/75	NM-2		

See page 79 for key to terms & abbreviations

TABLE C-1.

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SAN JACINTO VALLEY HYDRO UNIT						Y-02	
PERRIS HYDRO SUBUNIT						Y-02.A	
WINCHESTER HYDRO SUBAREA						Y-02.A3	
05S/02W-35C01	S	33	1474.5	11/04/74	92.5	1382.0	5103
				4/03/75	88.4	1386.1	
05S/03W-25K01	S	33	1446.0	11/04/74	24.7	1421.3	5103
				4/03/75	24.6	1421.4	
LAKEVIEW HYDRO SUBAREA						Y-02.A4	
04S/02W-03P01	S	33	1436.3	11/04/74	NM-1		5103
				12/10/74	162.7	1273.6	
				4/04/75	160.9	1275.4	
				6/05/75	NM-1		
04S/02W-08F01	S	33	1452.0	11/05/74	245.6	1206.4	5103
				4/04/75	NM-1		
04S/02W-19J01	S	33	1579.0	11/05/74	NM-2		5103
				4/04/75	NM-6		
HEMET HYDRO SUBAREA						Y-02.A5	
05S/01E-20G03	S	33	1877.4	11/04/74	NM-9		5103
				12/13/74	263.6	1613.8	
				4/04/75	263.1	1614.3	
				6/05/75	NM-1		
04S/01W-31N01	S	33	1494.0	11/04/74	NM-1		5103
				4/04/75	137.8(1)	1356.2	
05S/01W-09L02	S	33	1549.0	11/04/74	199.2	1349.8	5103
				12/13/74	187.5	1361.5	
				4/03/75	190.2	1358.8	
				6/03/75	200.2	1348.8	
				7/07/75	199.6	1349.4	
				8/06/75	203.8	1345.2	
				9/15/75	209.5	1339.5	
05S/01W-10R01	S	33	1584.7	11/04/74	NM-3		5103
				12/13/74	216.6	1368.1	
				4/03/75	NM-1		
				6/03/75	NM-1		
05S/01W-13C01	S	33	1688.0	11/04/74	NM-1		5103
05S/01W-20P01	S	33	1524.0	11/04/74	140.3	1383.7	5103
				12/13/74	141.3	1382.7	
				4/03/75	140.3	1383.7	
				6/03/75	140.7	1383.3	
05S/02W-12D02	S	33	1498.5	10/04/74	63.6	1434.9	5103
				4/03/75	62.3	1436.2	
06S/01W-02D01	S	33	1684.0	11/04/74	82.8	1601.2	5103
				12/13/74	83.1	1600.9	
				4/03/75	82.7	1601.3	
				6/03/75	83.0	1601.0	
06S/01W-10A01	S	33	1698.0	11/04/74	NM-9		5103
				4/03/75	91.1	1696.9	
SAN JACINTO HYDRO SUBUNIT						Y-02.B	
SAN JACINTO HYDRO SUBAREA						Y-02.B1	
05S/01E-04P01	S	33	1676.0	11/04/74	205.0	1471.0	5103
				12/13/74	205.1	1470.9	
				4/04/75	205.0	1471.0	
				6/05/75	205.1	1470.9	
05S/01E-07K01	S	33	1725.2	11/04/74	NM-8		5103
				12/13/74	335.3	1389.9	
				4/04/75	336.7	1388.5	
				6/05/75	NM-8		
				7/07/75	337.6	1387.6	
				8/06/75	338.1	1387.1	
				9/15/75	338.6	1386.6	
05S/01E-09M01	S	33	1759.7	11/04/74	75.7	1684.0	5103
				4/03/75	75.9	1683.8	
05S/01E-14G01	S	33	1870.8	11/04/74	41.1	1829.7	5103
				12/13/74	39.9	1830.9	
				4/03/75	36.9	1833.9	
				6/05/75	38.3	1832.5	
				7/07/75	41.4	1829.4	
				8/06/75	44.9	1825.9	
				9/15/75	43.4	1827.4	
05S/01E-18F01	S	33	1730.0	11/04/74	NM-2		5103
05S/01E-21F01	S	33	1918.6	11/04/74	287.2	1631.4	5103
				4/04/75	287.5	1631.1	
02S/01W-34Q01	S	33	2663.0	10/10/74	419.7(1)	2243.3	5407
				11/11/74	420.7	2242.3	
				12/16/74	422.9	2240.1	
				1/12/75	418.7	2244.3	
				2/28/75	412.9	2250.1	
				3/28/75	410.7	2252.3	
				4/15/75	419.7	2243.3	
				5/06/75	421.7(1)	2241.3	
				6/12/75	428.7(1)	2234.3	
SAN JACINTO VALLEY HYDRO UNIT						Y-02	
SAN JACINTO HYDRO SUBUNIT						Y-02.B	
SAN JACINTO HYDRO SUBAREA						Y-02.B1	
02S/01W-34Q01 (CONTINUED)	S	33	2663.0	7/03/75	426.7(1)	2236.3	5407
				8/11/75	427.7	2235.3	
				9/18/75	428.7	2234.3	
03S/01W-03K01	S	33	2642.8	10/10/74	394.4	2246.4	5407
				11/11/74	400.0	2242.8	
				12/16/74	404.2	2238.6	
				1/12/75	401.2	2241.6	
				2/28/75	391.2	2251.6	
				3/28/75	388.2	2254.6	
				4/15/75	392.8	2250.8	
				5/06/75	393.2	2249.6	
				6/12/75	393.0	2249.8	
				7/03/75	390.0	2252.8	
				8/11/75	393.0	2249.8	
				9/18/75	389.0	2253.8	
03S/01W-03K03	S	33	2633.7	10/10/74	392.4	2241.3	5407
				11/11/74	397.4	2236.3	
				12/16/74	398.8	2234.9	
				1/12/75	393.4	2240.3	
				2/28/75	379.4	2254.3	
				3/28/75	378.6	2255.1	
				4/15/75	382.4	2251.3	
				5/06/75	391.4	2242.3	
				6/12/75	390.4	2243.3	
				7/03/75	382.8	2250.9	
				8/11/75	386.4	2247.3	
				9/18/75	388.4	2245.3	
03S/01W-10R01	S	33	2584.5	10/22/74	34.7	2549.8	5103
				4/16/75	34.7	2549.8	
03S/01W-12F01	S	33	2578.0	10/10/74	336.0	2242.0	5407
				11/11/74	334.2	2243.8	
				12/16/74	334.4	2243.6	
				1/12/75	334.0	2244.0	
				2/28/75	329.0	2249.0	
				3/28/75	331.2	2246.8	
				4/15/75	330.7	2247.3	
				5/06/75	339.0(1)	2239.0	
				7/21/75	331.0	2247.0	
03S/02W-07P01	S	33	1590.0	10/15/74	111.6	1478.4	5103
				4/02/75	109.4	1480.6	
04S/01W-09Q02	S	33	1476.0	11/04/74	68.3	1407.7	5103
				12/10/74	67.4	1408.6	
				4/04/75	66.6(2)	1409.4	
				6/05/75	69.5(2)	1406.5	
				7/07/75	70.0(2)	1406.0	
				8/06/75	NM-1		
				9/15/75	NM-1		
04S/01W-21P01	S	33	1494.0	11/04/74	68.5	1425.5	5103
				12/10/74	67.4	1426.6	
				4/04/75	75.7	1418.3	
				6/05/75	73.6	1420.4	
04S/01W-28F01	S	33	1498.7	11/04/74	147.2	1351.5	5103
				4/04/75	137.5	1361.2	
04S/02W-01M01	S	33	1436.5	11/05/74	138.0(3)	1298.5	5103
				4/04/75	136.5	1300.0	
ELSINORE HYDRO SUBUNIT						Y-02.C	
ELSINORE HYDRO SUBAREA						Y-02.C1	
05S/05W-34Q02	S	33	1385.0	10/29/74	NM-8		5103
				11/14/74	278.8	1106.2	
				12/12/74	278.8	1106.2	
				4/10/75	279.9	1105.1	
				6/02/75	282.3	1102.7	
06S/04W-05N01	S	33	1280.0	10/24/74	28.4	1251.6	5103
				11/14/74	27.8	1252.2	
				12/11/74	27.7	1252.3	
				4/10/75	26.0	1254.0	
				6/02/75	25.9	1254.1	
				7/07/75	26.7	1253.3	
				8/07/75	27.1	1252.9	
				9/12/75	27.3	1252.7	
06S/04W-06J01	S	33	1280.0	10/24/74	28.3	1251.7	5103
				4/10/75	25.9	1254.1	
06S/04W-07J03	S	33	1238.0	10/24/74	20.6	1217.4	5103
				11/14/74	20.6	1217.4	
				12/11/74	20.4	1217.6	
				4/10/75	20.4	1217.6	
				6/02/75	20.4	1217.6	
06S/04W-08L01	S	33	1272.4	10/24/74	67.5	1205.1	5103
				4/10/75	67.3	1205.3	
06S/04W-16N01	S	33	1269.0	10/24/74	NM-8		5103
				11/14/74	102.4	1157.6	
				12/11/74	102.5	1157.5	
				4/07/75	97.9	1162.1	
				6/02/75	97.6	1162.4	
06S/04W-16H01	S	33	1272.0	10/24/74	54.9	1217.1	5103

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SAN JACINTO VALLEY HYDRO UNIT						Y-02	
ELSINORE HYDRO SUBUNIT						Y-02.C	
ELSINORE HYDRO SUBAREA						Y-02.C1	
06S/04W-16H01 S	33		1272.0	4/07/75	55.0	1217.0	5103
06S/04W-19G01 S	33		1257.9	10/29/74	11.5	1246.4	5103
				4/11/75	9.8	1248.1	
06S/04W-20D01 S	33		1289.0	10/29/74	16.4	1272.6	5103
				11/14/74	16.5	1272.5	
				12/12/74	16.3	1272.7	
				4/11/75	15.6	1273.4	
				6/03/75	15.3	1273.7	
				7/07/75	15.5	1273.5	
				8/07/75	15.8	1273.2	
				9/12/75	16.1	1272.9	
06S/04W-20D02 S	33		1279.0	10/29/74	NM-9		5103
				4/11/75	NM-9		
06S/04W-20P01 S	33		1263.0	10/29/74	20.1	1242.9	5103
				4/11/75	13.4	1249.6	
06S/04W-22H01 S	33		1273.0	10/24/74	NM-9		5103
				4/07/75	226.1	1046.9	
06S/04W-23N01 S	33		1409.0	10/24/74	47.0	1362.0	5103
				4/07/75	48.7	1360.3	
06S/04W-29C01 S	33		1330.0	10/29/74	42.7	1287.3	5103
				4/11/75	42.8	1287.2	
06S/04W-29H04 S	33		1325.0	10/29/74	34.1	1290.9	5103
				4/11/75	34.5	1290.5	
06S/05W-02G01 S	33		1277.7	10/24/74	64.6	1213.1	5103
				4/10/75	65.0	1212.7	
06S/05W-02L01 S	33		1278.0	10/24/74	65.9	1212.1	5103
				4/10/75	66.0	1212.0	
06S/05W-02L02 S	33		1267.0	10/24/74	NM-1		5103
				11/14/74	NM-1		
				12/11/74	58.8	1208.2	
				4/10/75	57.1	1209.9	
				6/02/75	57.1	1209.9	
				7/07/75	57.2	1209.8	
				8/07/75	57.3	1209.7	
				9/12/75	NM-1		
06S/05W-02N03 S	33		1286.8	10/29/74	NM-3		5103
				4/10/75	NM-1		
06S/05W-03K02 S	33		1337.0	10/29/74	240.4	1096.6	5103
				4/10/75	245.1	1091.9	
06S/05W-03N01 S	33		1418.8	4/10/75	63.1	1355.7	5103
				6/03/75	NM-1		
06S/05W-03N01 S	33		1375.0	10/29/74	NM-9		5103
				11/14/74	64.1	1310.9	
				12/12/74	61.5	1313.5	
06S/05W-03P01 S	33		1327.5	10/29/74	82.4	1245.1	5103
				4/10/75	74.5	1253.0	
06S/05W-03Q01 S	33		1324.0	10/29/74	204.8	1119.2	5103
				4/10/75	204.6	1119.4	
06S/05W-10A01 S	33		1285.0	10/29/74	NM-8		5103
				4/10/75	8.9	1276.1	
06S/05W-10C01 S	33		1331.1	10/29/74	29.1	1302.0	5103
				4/10/75	29.3	1301.8	
06S/05W-11H02 S	33		1290.0	10/29/74	24.1	1265.9	5103
				4/10/75	23.6	1266.4	
06S/05W-11P02 S	33		1313.0	10/29/74	52.8	1260.2	5103
				4/11/75	53.4	1259.6	
06S/05W-13P01 S	33		1337.0	10/29/74	67.1	1269.9	5103
				4/11/75	69.2	1267.8	
06S/05W-13Q02 S	33		1270.0	10/29/74	43.3	1226.7	5103
				11/14/74	43.2	1226.8	
				12/12/74	43.1	1226.9	
				4/11/75	42.5	1227.5	
				6/03/75	42.8	1227.2	
06S/05W-14A01 S	33		1271.3	10/29/74	27.0	1244.3	5103
				4/11/75	24.2	1247.1	
06S/05W-14E01 S	33		1506.6	10/29/74	NM-8		5103
				4/10/75	42.9	1463.7	

See page 79 for key to terms a abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SAN DIEGO DRAINAGE PROVINCE SAN JUAN HYDRO UNIT LAGUNA HYDRO SUBUNIT ALISO HYDRO SUBAREA						Z Z-01 Z-01.A Z-01.A3	
06S/08W-23J01 S	30		507.5	11/11/74	20.2	487.3	5102
				1/23/75	22.0	485.5	
				3/17/75	21.6	485.9	
				5/19/75	23.1	484.4	
				7/21/75	20.5	487.0	
				9/15/75	20.5	487.0	
06S/08W-23J02 S	30		451.2	11/11/74	16.2	435.0	5102
				1/23/75	15.0	436.2	
				3/17/75	14.7	436.5	
				5/19/75	15.4	435.8	
				7/21/75	DRY		
				9/15/75	DRY		
06S/08W-23P01 S	30		461.0	11/11/74	6.3	454.7	5102
				1/23/75	5.2	455.8	
				3/17/75	4.6	456.4	
				5/19/75	6.4	454.6	
				7/21/75	7.1	453.9	
				9/15/75	6.4	454.6	
06S/08W-24H01 S	30		507.8	11/11/74	10.4	497.4	5102
				1/23/75	8.1	499.7	
				3/17/75	6.9	500.9	
				5/19/75	8.5	499.3	
				7/21/75	10.8	497.0	
				9/15/75	13.8	494.0	
06S/08W-26A01 S	30		440.0	11/11/74	9.8	430.2	5102
				1/23/75	8.5	431.5	
				3/17/75	4.3	435.7	
				5/19/75	7.0	433.0	
				7/21/75	8.3	431.7	
				9/15/75	8.9	431.1	
06S/08W-26B03 S	30		443.0	11/11/74	26.7	416.3	5102
				1/23/75	26.1	416.9	
				3/17/75	26.5	416.5	
				5/19/75	25.4	417.6	
				7/21/75	24.6	418.4	
				9/15/75	24.2	418.8	
06S/08W-26F03 S	30		421.9	11/11/74	19.1	402.8	5102
				1/23/75	20.6	401.3	
				3/17/75	16.1	405.8	
				5/19/75	16.2	405.7	
				7/21/75	16.2	405.7	
				9/15/75	20.5	401.4	
06S/08W-26F04 S	30		420.2	11/11/74	18.4	401.8	5102
				1/23/75	17.8	402.4	
				3/17/75	15.2	405.0	
				5/19/75	15.3	404.9	
				9/15/75	15.2	405.0	
06S/08W-26H03 S	30		414.0	11/11/74	DRY		5102
				1/23/75	NM-5		
				3/17/75	NM-5		
				5/19/75	23.2	390.8	
				7/21/75	24.9	389.1	
				9/15/75	DRY		
06S/08W-27J01 S	30		396.0	11/11/74	21.7	374.3	5102
				1/23/75	21.9	374.1	
				3/17/75	21.5	374.5	
				5/19/75	20.8	375.2	
				7/21/75	20.8	375.2	
				9/15/75	20.8	375.2	
06S/08W-27Q01 S	30		377.7	11/11/74	15.7	362.0	5102
				1/23/75	15.4	362.3	
				3/17/75	14.7	363.0	
				5/19/75	14.0	363.7	
				7/21/75	14.2	363.5	
06S/08W-27Q02 S	30		383.0	11/11/74	16.1	366.9	5102
				1/23/75	15.6	367.4	
				3/17/75	15.0	368.0	
				5/19/75	14.5	368.5	
				7/21/75	14.5	368.5	
06S/08W-34C02 S	30		365.8	11/11/74	13.9	351.9	5102
				1/23/75	13.6	352.2	
				3/17/75	13.4	352.4	
				5/19/75	13.1	352.7	
				9/21/75	14.1	351.7	
07S/08W-04G01 S	30		320.0	11/11/74	106.2	213.8	5102
				1/23/75	106.1	213.9	
				3/17/75	NM-7		
				5/28/75	97.2	222.8	
				7/21/75	NM-7		
07S/08W-05P01 S	30		500.0	11/11/74	103.0	397.0	5102
				1/23/75	91.3	408.7	
				3/17/75	NM-7		
				5/28/75	NM-1		
SAN JUAN HYDRO UNIT SAN JUAN HYDRO SUBUNIT						Z-01 Z-01.B	
07S/07W-32Q02 S	30		140.0	11/18/74	10.9	129.1	5102
				1/27/75	12.9	127.1	
				3/27/75	12.9	127.1	
				5/29/75	13.4	126.6	
				9/16/75	14.0	126.0	
07S/07W-33B01 S	30		200.0	11/18/74	13.9	186.1	5102
				1/27/75	12.9	187.1	
				3/27/75	12.7	187.3	
				5/29/75	NM-1		
				9/16/75	NM-1		
07S/07W-33M01 S	30		159.0	11/18/74	9.0	150.0	5102
				1/27/75	9.3	149.7	
				3/27/75	9.3	149.7	
				5/29/75	10.2	148.8	
				9/16/75	NM-2		
07S/08W-12N01 S	30		230.0	12/20/74	4.0	226.0	5102
				1/24/75	4.6	225.4	
				3/26/75	4.1	225.9	
				5/27/75	4.7	225.3	
				8/05/75	4.6	225.4	
				9/15/75	4.5	225.5	
07S/08W-25B02 S	30		239.5	11/18/74	51.9	187.6	5102
				1/24/75	54.4	185.1	
				3/26/75	51.2	188.3	
				5/27/75	40.4	199.1	
				8/05/75	43.9	195.6	
				9/15/75	44.3	195.2	
07S/08W-25B03 S	30		240.0	11/18/74	53.8	186.2	5102
				1/24/75	56.4	183.6	
				3/26/75	NM-6		
07S/08W-25K02 S	30		223.0	11/18/74	48.0	175.0	5102
				1/24/75	47.5	175.5	
				3/26/75	49.0	174.0	
				5/27/75	NM-1		
				8/05/75	51.7	171.3	
				9/15/75	NM-1		
07S/08W-25N01 S	30		203.5	11/18/74	42.6	160.9	5102
				1/24/75	42.8	160.7	
				3/26/75	39.1	164.4	
				5/27/75	37.5	166.0	
				8/05/75	41.9	161.6	
				9/15/75	41.7	161.8	
07S/08W-25N02 S	30		204.0	11/18/74	43.7	160.3	5102
				1/24/75	41.5	162.5	
				3/26/75	41.2	162.8	
				5/27/75	45.5	158.5	
				8/05/75	41.4	162.6	
				9/15/75	NM-1		
07S/08W-25P02 S	30		213.0	1/24/75	NM-1		5102
				3/26/75	NM-1		
				5/27/75	NM-1		
				8/05/75	50.9	162.1	
				9/16/75	NM-1		
07S/08W-36C03 S	30		200.4	11/18/74	NM-1		5102
				1/24/75	40.9	159.5	
				3/26/75	40.2	160.2	
				5/27/75	38.2	162.2	
				8/05/75	NM-1		
				9/16/75	NM-1		
07S/08W-36L01 S	30		171.3	11/18/74	29.2	142.1	5102
				1/24/75	28.1	143.2	
				3/26/75	27.5	143.8	
				5/27/75	26.2	145.1	
				8/05/75	28.7	142.6	
07S/08W-36L02 S	30		159.5	11/18/74	16.2	142.3	5102
				1/24/75	15.8	142.7	
				3/26/75	13.7	144.8	
				5/27/75	13.0	145.5	
				8/05/75	16.9	141.6	
07S/08W-36P02 S	30		145.0	11/18/74	10.0	135.0	5102
				1/24/75	11.8	133.2	
				3/26/75	8.6	136.4	
				5/27/75	8.8	136.2	
				8/05/75	12.4	132.6	
07S/08W-36P03 S	30		140.2	11/18/74	18.2	122.0	5102
				1/24/75	16.6	123.6	
				3/26/75	16.6	123.6	
				5/27/75	16.5	123.7	
				8/05/75	18.1	122.1	
				9/15/75	18.6	121.6	
08S/07W-05B01 S	30		130.0	11/20/74	5.4	124.6	5102
				1/24/75	5.5	124.5	
				3/26/75	5.3	124.7	
				5/29/75	5.6	124.4	
08S/07W-05C01 S	30		132.0	11/20/74	6.5	125.5	5102
				1/27/75	6.6	125.4	
				3/27/75	5.0	127.0	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SAN JUAN HYDRO UNIT						Z-01	
SAN JUAN HYDRO SUBUNIT						Z-01.A	
08S/07W-05C01 S (CONTINUED)	30		132.0	5/29/75	5.5	126.5	5102
				9/15/75	5.7	126.3	
08S/07W-05C02 S	30		128.0	11/18/74	4.0	124.0	5102
				1/27/75	4.1	123.9	
				3/27/75	5.3	122.7	
				5/29/75	4.3	123.7	
				9/16/75	10.2	117.8	
08S/07W-06H01 S	30		120.0	11/20/74	8.5	111.5	5102
				1/27/75	7.9	112.1	
				3/27/75	8.4	111.6	
				5/29/75	NM-6		
08S/07W-06H02 S	30		113.0	11/20/74	13.1	99.9	5102
				1/27/75	12.5	100.5	
				3/27/75	11.3	101.7	
				5/29/75	10.5	102.5	
08S/07W-06H03 S	30		110.0	11/20/74	8.0	102.0	5102
				1/27/75	9.2	100.8	
				3/27/75	6.8	103.2	
				5/29/75	8.1	101.9	
				9/16/75	NM-1		
08S/07W-06P02 S	30		88.0	11/20/74	7.8	80.2	5102
				1/27/75	6.4	81.6	
				3/27/75	6.1	81.9	
				5/29/75	8.6	79.4	
08S/07W-07C03 S	30		86.0	11/18/74	9.7	76.3	5102
				1/24/75	8.1	77.9	
				3/26/75	8.0	78.0	
				5/29/75	8.0	78.0	
				8/05/75	9.6	76.4	
				9/16/75	15.8	70.2	
08S/08W-01F01 S	30		137.0	11/18/74	25.4	111.6	5102
				1/04/75	NM-5		
				3/26/75	22.5	114.5	
				5/27/75	NM-9		
				8/05/75	28.9	108.1	
				9/15/75	29.5	107.5	
08S/08W-01K01 S	30		110.0	11/18/74	26.9	83.1	5102
				1/24/75	27.8	82.2	
				3/26/75	21.2	88.8	
				5/29/75	21.0	89.0	
				8/05/75	23.3	86.7	
				9/15/75	22.6	87.4	
08S/08W-01K02 S	30		105.0	11/18/74	17.0	88.0	5102
				1/24/75	8.3	96.7	
				3/26/75	8.2	96.8	
				5/29/75	10.0	95.0	
				8/05/75	11.2	93.8	
				9/15/75	11.0	94.0	
08S/08W-12P03 S	30		54.4	11/18/74	14.5	39.9	5102
				1/24/75	12.9	41.5	
				3/26/75	5.1	49.3	
				5/29/75	15.1	39.3	
				8/05/75	15.8	38.6	
08S/08W-12P05 S	30		48.0	11/18/74	4.4	43.6	5102
				1/24/75	3.1	44.9	
				3/26/75	1.4	46.6	
				5/29/75	4.1	43.9	
08S/08W-13D01 S	30		46.4	11/18/74	10.7	35.7	5102
				1/24/75	10.2	36.2	
				3/26/75	8.8	37.6	
				5/29/75	10.3	36.1	
				8/05/75	11.7	34.7	
				9/15/75	11.5	34.9	
08S/08W-23A04 S	30		24.5	11/18/74	19.6	4.9	5102
				1/24/75	20.9	3.6	
				3/26/75	17.8	6.7	
				5/29/75	18.8	5.7	
				8/05/75	18.4	6.1	
				9/15/75	18.8	5.7	
08S/08W-23A05 S	30		19.3	11/18/74	14.9	4.4	5102
				1/24/75	14.3	5.0	
				3/26/75	13.4	5.9	
				5/29/75	13.5	5.8	
				8/05/75	14.0	5.3	
				9/15/75	14.3	5.0	

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA MARGARITA HYDRO UNIT						Z-02	
MURRIETA HYDRO SUBUNIT						Z-02.C	
WILDOMAR HYDRO SUBAREA						Z-02.C1	
06S/04W-26M01 S	33		1350.0	10/24/74	82.8	1267.2	5103
				11/14/74	82.4(4)	1267.6	
				12/11/74	82.5(4)	1267.5	
				4/07/75	60.4	1289.6	
				6/02/75	NM-2		
06S/04W-27N02 S	33		1290.9	10/24/74	77.5	1213.4	5103
				4/07/75	75.4	1215.5	
06S/04W-33A04 S	33		1310.0	10/29/74	58.4	1251.6	5103
				4/11/75	59.3	1250.7	
06S/04W-35F02 S	33		1279.6	10/24/74	106.3	1173.3	5103
				11/14/74	109.5(3)	1170.1	
				12/11/74	NM-1		
				4/07/75	105.8	1173.8	
				6/02/75	106.0	1173.6	
				7/07/75	106.6	1173.0	
				8/07/75	108.5	1171.1	
				9/12/75	108.4	1171.2	
07S/04W-03B01 S	33		1284.0	10/24/74	64.6	1219.4	5103
				11/14/74	64.6	1219.4	
				12/11/74	64.7	1219.3	
				4/07/75	65.0	1219.0	
				6/02/75	65.1	1218.9	
MURRIETA HYDRO SUBAREA						Z-02.C2	
07S/03W-17P08 S	33		1093.8	10/24/74	NM-1		5103
				11/14/74	91.9	1001.9	
				12/11/74	91.8	1002.0	
				4/07/75	90.6	1003.2	
				6/02/75	89.7	1004.1	
				7/07/75	90.5	1003.3	
				8/07/75	90.8	1003.0	
				9/12/75	90.3	1003.5	
08S/03W-12M06 S	33		1019.7	10/24/74	26.2	993.5	5103
				11/14/74	26.0	993.7	
				12/11/74	25.6	994.1	
				4/07/75	25.2	994.5	
				6/02/75	24.1	995.6	
				7/07/75	25.2	994.5	
				8/07/75	25.2	994.5	
				9/12/75	24.9	994.8	
08S/03W-12P08 S	33		1002.5	10/24/74	NM-8		5103
				11/14/74	NM-8		
				12/11/74	20.8	981.7	
				4/07/75	20.0	982.5	
				6/02/75	NM-2		
08S/03W-13K02 S	33		992.0	10/24/74	15.7	976.3	5103
				11/14/74	15.4	976.6	
				12/11/74	15.2	976.8	
				4/07/75	14.9	977.1	
				6/02/75	14.9	977.1	
PECHANGA HYDRO SUBUNIT						Z-02.E	
PECHANGA HYDRO SUBAREA						Z-02.E2	
08S/02W-19J02 S	33		1030.8	1/29/75	22.0	1008.0	5000
				2/27/75	21.9	1008.1	
				3/27/75	21.7	1008.3	
				4/23/75	21.7	1008.3	
				5/23/75	22.1	1007.9	
				6/27/75	23.2	1006.8	
				7/25/75	24.9	1005.1	
				8/25/75	25.3	1004.7	
				9/24/75	25.4	1004.6	
08S/02W-20R01 S	33		1087.0	1/29/75	75.3	1011.7	5000
				2/27/75	75.7	1011.3	
				3/27/75	75.2	1011.8	
				4/23/75	75.1	1011.9	
				5/23/75	76.6	1010.4	
				6/27/75	107.6(1)	979.4	
				7/25/75	115.8(1)	971.2	
				8/25/75	83.9	1003.1	
				9/24/75	86.4	1000.6	
08S/02W-28M01 S	33		1126.0	3/04/75	65.1	1060.9	5000
				4/23/75	192.3(2)	933.7	
				5/23/75	208.9(2)	917.1	
				9/24/75	206.8(1)	919.2	
08S/02W-28P01 S	33		1150.0	1/29/75	26.9(4)	1123.1	5000
				2/27/75	25.7	1124.3	
				3/27/75	25.8	1124.2	
				4/23/75	26.0	1124.0	
				5/23/75	26.7	1123.3	
				6/27/75	27.3	1122.7	
				7/25/75	27.5	1122.5	
				8/25/75	28.3	1121.7	
				9/24/75	29.7	1120.3	
08S/02W-28Q02 S	33		1160.0	1/29/75	36.2	1123.8	5000
				2/27/75	36.0	1124.0	
				3/27/75	36.0	1124.0	
				4/23/75	36.0	1124.0	
				5/23/75	36.5	1123.5	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SANTA MARGARITA HYDRO UNIT						Z-02	
PECHANGA HYDRO SUBUNIT						Z-02.E	
PECHANGA HYDRO SUBAREA						Z-02.E2	
08S/02W-28H02 S (CONTINUED)	33		1160.0	6/27/75	42.2(1)	1117.8	5000
				7/25/75	37.6	1122.4	
				8/25/75	37.6	1122.4	
				9/24/75	39.8	1120.2	
08S/02W-28H03 S	33		1170.0	1/29/75	94.4(2)	1075.6	5000
				2/27/75	94.3	1075.7	
				3/27/75	94.4	1075.6	
				4/23/75	95.1	1074.9	
				5/23/75	94.4(2)	1075.6	
				6/27/75	94.5	1075.5	
				7/25/75	94.5	1075.5	
				8/25/75	94.5	1075.5	
				9/24/75	94.4	1075.6	
08S/02W-28R01 S	33		1190.0	1/29/75	81.8	1108.2	5000
				2/27/75	81.9	1108.1	
				3/27/75	82.0	1108.0	
				4/23/75	82.2	1107.8	
				5/23/75	82.4	1107.6	
				6/27/75	82.6	1107.4	
				7/25/75	82.8	1107.2	
				8/25/75	83.1	1106.9	
				9/24/75	83.1	1106.9	
08S/02W-29C01 S	33		1070.8	1/29/75	6.6	1064.2	5000
				2/27/75	6.7	1064.1	
				3/27/75	6.4	1064.4	
				4/23/75	10.3	1060.5	
				5/23/75	17.3	1053.5	
				6/27/75	17.7	1053.1	
				7/25/75	18.1	1052.7	
				8/25/75	18.3	1052.5	
				9/24/75	18.5	1052.3	
08S/02W-29G01 S	33		1091.1	1/29/75	46.3	1044.8	5000
				2/14/75	46.4	1044.7	
				3/27/75	46.6	1044.5	
				4/23/75	46.8	1044.3	
				5/23/75	47.0	1044.1	
				6/02/75	47.1	1044.0	
				7/25/75	47.5	1043.6	
				8/25/75	47.7	1043.4	
				9/24/75	47.9	1043.2	
08S/02W-29J02 S	33		1110.0	1/29/75	35.0	1075.0	5000
				2/27/75	NM-1		
				3/27/75	35.2	1074.8	
				4/23/75	36.4	1073.6	
				5/23/75	NM-1		
				8/25/75	39.3	1070.7	
				9/24/75	49.1(4)	1060.9	
ANZA HYDRO SUBUNIT						Z-02.G	
ANZA HYDRO SUBAREA						Z-02.G3	
07S/03E-28A01 S	33		3820.0	1/28/75	44.4(2)	3775.6	5000
				2/26/75	69.2(2)	3750.8	
				4/10/75	56.7(2)	3763.3	
				5/07/75	60.3	3759.7	
				6/02/75	76.5(2)	3743.5	
				7/24/75	78.1(2)	3741.9	
				8/28/75	78.2(2)	3741.8	
				9/29/75	49.3	3770.7	
07S/03E-31H01 S	33		3840.0	1/28/75	57.8	3782.2	5000
				2/26/75	47.9	3792.1	
				4/10/75	44.6	3795.4	
				5/07/75	43.5	3796.5	
				6/02/75	61.7(4)	3778.3	
				7/24/75	58.5(4)	3781.5	
				8/28/75	67.1(4)	3772.9	
				9/29/75	54.2(4)	3785.8	
07S/03E-34E01 S	33		3870.0	1/28/75	68.2	3801.6	5000
				2/24/75	70.4	3799.6	
				4/10/75	69.7	3800.3	
				5/07/75	69.9	3800.1	
				6/02/75	71.9(4)	3798.1	
				7/24/75	72.6(4)	3797.4	
				8/28/75	73.0	3797.0	
				9/29/75	70.5	3799.5	
SAN LUIS REY HYDRO UNIT						Z-03	
BONSALL HYDRO SUBUNIT						Z-03.A	
MISSION HYDRO SUBAREA						Z-03.A1	
11S/04W-09F01 S	37		64.6	10/07/74	11.9	52.7	5202
				11/04/74	12.3	52.3	
				12/04/74	12.6	52.0	
				1/06/75	10.6	54.0	
				2/03/75	10.2	54.4	
				3/03/75	8.8	55.8	
				4/07/75	8.3	56.3	
				5/05/75	8.3	56.3	
				6/02/75	9.3	55.3	
				7/07/75	8.9	55.7	
				8/04/75	10.1	54.5	
				9/08/75	10.2	54.4	
11S/04W-18C04 S	37		35.0	10/10/74	6.5	28.5	5205
				11/14/74	6.4	28.6	
				12/10/74	6.2	28.8	
				1/08/75	5.8	29.2	
				2/27/75	6.0	29.0	
				3/13/75	5.6	29.4	
				4/17/75	5.4	29.6	
				5/15/75	5.9	29.1	
				6/12/75	6.1	28.9	
				7/22/75	6.4	28.6	
				8/20/75	6.5	28.5	
				9/11/75	6.4	28.6	
11S/04W-18C05 S	37		36.0	10/10/74	5.4	30.6	5205
				11/14/74	5.2	30.8	
				12/10/74	5.1	30.9	
				1/08/75	5.0	31.0	
				2/27/75	4.9	31.1	
				3/13/75	4.5	31.5	
				4/17/75	4.3	31.7	
				5/15/75	4.8	31.2	
				6/12/75	5.0	31.0	
				7/22/75	5.2	30.8	
				8/20/75	5.3	30.7	
				9/11/75	5.3	30.7	
11S/04W-18C09 S	37		32.0	10/10/74	5.4	26.6	5205
				11/14/74	4.9	27.1	
				12/10/74	5.2	26.8	
				1/08/75	5.1	26.9	
				2/27/75	5.0	27.0	
				3/13/75	4.5	27.5	
				4/17/75	4.4	27.6	
				5/15/75	4.9	27.1	
				6/12/75	5.1	26.9	
				7/22/75	5.4	26.6	
				8/20/75	5.4	26.6	
				9/11/75	5.3	26.7	
11S/04W-18F01 S	37		30.0	10/10/74	3.7	26.3	5205
				11/14/74	3.6	26.4	
				12/10/74	3.5	26.5	
				1/08/75	3.4	26.6	
				2/27/75	2.3	27.7	
				3/13/75	2.9	27.1	
				4/17/75	2.8	27.2	
				5/15/75	2.4	27.6	
				6/12/75	3.4	26.6	
				7/22/75	3.9	26.1	
				8/20/75	3.7	26.3	
				9/11/75	3.6	26.4	
11S/04W-18G02 S	37		38.8	10/07/74	9.8	29.0	5202
				11/04/74	9.8	29.0	
				12/04/74	9.6	29.2	
				1/06/75	8.3	30.5	
				2/03/75	8.3	30.5	
				3/03/75	8.3	30.5	
				4/07/75	7.8	31.0	
				5/05/75	7.8	31.0	
				6/02/75	8.3	30.5	
				7/07/75	8.0	30.8	
				8/04/75	8.3	30.5	
				9/08/75	8.3	30.5	
11S/04W-18L03 S	37		38.0	10/07/74	9.6	28.4	5202
				11/04/74	9.4	28.6	
				12/04/74	9.3	28.7	
				1/06/75	9.2	28.8	
				2/03/75	9.2	28.8	
				3/03/75	9.0	29.0	
				4/07/75	8.7	29.3	
				5/05/75	9.7	28.3	
				6/02/75	9.8	28.2	
				7/07/75	9.8	28.2	
				8/04/75	9.3	28.7	
				9/08/75	9.6	28.4	
11S/04W-18L10 S	37		31.0	10/10/74	8.5	22.5	5205
				11/14/74	8.5	22.5	
				12/10/74	8.6	22.4	
				1/08/75	8.3	22.7	
				2/27/75	7.9	23.1	
				3/13/75	7.8	23.2	
				4/17/75	7.7	23.3	
				5/15/75	7.8	23.2	
				6/12/75	7.9	23.1	
				7/22/75	8.4	22.6	
				8/20/75	8.7	22.3	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SAN LUIS REY HYDRO UNIT						Z-03	
BONSALL HYDRO SUBUNIT						Z-03.A	
MISSION HYDRO SUBAREA						Z-03.A1	
11S/04W-18L19 S	37		31.0	9/11/75	8.5	22.5	5205
11S/05W-13N02 S	37		17.7	10/07/74	4.2	13.5	5202
				11/04/74	4.0	13.7	
				12/04/74	4.8	12.9	
				1/06/75	3.8	13.9	
				2/03/75	3.8	13.9	
				3/03/75	3.7	14.0	
				4/07/75	3.7	14.0	
				5/05/75	3.8	13.9	
				6/02/75	3.8	13.9	
				7/07/75	4.0	13.7	
				8/04/75	4.2	13.5	
				9/08/75	4.6	13.1	
11S/05W-13P02 S	37		21.5	10/07/74	6.3	15.2	5202
				11/04/74	5.8	15.7	
				12/04/74	5.7	15.8	
				1/06/75	5.7	15.8	
				2/03/75	5.5	16.0	
				3/03/75	5.5	16.0	
				4/07/75	5.0	16.5	
				5/05/75	5.2	16.3	
				6/02/75	5.6	15.9	
				7/07/75	5.8	15.7	
				8/04/75	5.9	15.6	
				9/08/75	6.2	15.3	
11S/05W-24R01 S	37		23.6	10/07/74	4.5	19.1	5202
				11/04/74	4.3	19.3	
				12/04/74	3.7	19.9	
				1/06/75	3.9	19.7	
				2/03/75	4.2	19.4	
				3/03/75	4.1	19.5	
				4/07/75	3.7	19.9	
				5/05/75	4.0	19.6	
				6/02/75	4.4	19.2	
				7/07/75	4.2	19.4	
				8/04/75	4.4	19.2	
				9/08/75	4.5	19.1	
MONSERATE HYDRO SUBUNIT						Z-03.B	
PALA HYDRO SUBAREA						Z-03.B1	
09S/02W-26P01 S	37		422.6	1/29/75	34.5	388.1	5000
				3/10/75	28.6	394.0	
				4/22/75	18.0	404.6	
				5/22/75	27.7	394.9	
				6/17/75	30.1	392.5	
				7/29/75	33.0	389.6	
				8/21/75	34.2	388.4	
				9/25/75	35.3	387.3	
09S/02W-28K01 S	37		357.0	5/30/75	NM-0		5000
09S/02W-32A01 S	37		330.0	1/29/75	8.4	321.6	5000
				3/10/75	7.9	322.1	
				4/22/75	7.8	322.2	
				5/22/75	8.9	321.1	
				6/16/75	8.0	322.0	
				7/29/75	8.5	321.5	
				8/26/75	9.2	320.8	
				9/26/75	9.6	320.4	
09S/02W-32L01 S	37		310.0	1/29/75	NM-1		5000
				3/10/75	NM-1		
				4/22/75	NM-1		
				5/22/75	NM-1		
				6/16/75	NM-1		
				7/29/75	NM-1		
10S/02W-06F02 S	37		282.7	1/29/75	9.8	272.9	5000
				3/10/75	8.4	274.3	
				4/22/75	7.7	275.0	
				5/22/75	7.8	274.9	
				6/16/75	NM-1		
				7/29/75	16.4(1)	266.3	
				8/26/75	11.3	271.4	
				9/26/75	11.8	270.9	
10S/02W-06G01 S	37		295.0	1/29/75	10.2	284.8	5000
				3/10/75	9.3	285.7	
				4/22/75	8.1	286.9	
				5/22/75	8.4	286.6	
				6/16/75	8.9	286.1	
				7/29/75	11.8(2)	283.2	
				8/26/75	11.1	283.9	
				9/26/75	11.7	283.3	
PAUMA HYDRO SUBAREA						Z-03.B2	
10S/01W-05M01 S	37		710.0	1/30/75	46.5	663.5	5000
				3/10/75	NM-1		
				4/22/75	21.5	688.5	
				5/22/75	41.2(2)	668.8	
				6/18/75	NM-1		
				7/29/75	NM-1		
				8/26/75	NM-1		
				9/25/75	NM-1		
10S/01W-08Q01 S	37		733.0	1/30/75	60.1	672.9	5000
				3/10/75	44.5	688.5	

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SAN LUIS REY HYDRO UNIT						Z-03	
MONSERATE HYDRO SUBUNIT						Z-03.B	
PAUMA HYDRO SUBAREA						Z-03.B2	
10S/01W-08Q01 S (CONTINUED)	37		733.0	4/22/75	37.0	696.0	5000
				5/22/75	60.9	672.1	
				6/18/75	82.9	650.1	
				7/29/75	94.6	638.4	
				8/26/75	94.6(2)	638.4	
				9/25/75	97.8	635.2	
10S/01W-16H01 S	37		885.0	1/30/75	NM-1		5000
				3/10/75	185.4	699.6	
				4/22/75	178.3	706.7	
				5/22/75	NM-1		
				6/18/75	NM-1		
				7/29/75	NM-1		
				8/26/75	NM-1		
				9/25/75	NM-1		
10S/01W-35C01 S	37		860.0	1/30/75	32.7	827.3	5000
				3/10/75	32.4	827.6	
				4/22/75	28.8	831.2	
				5/22/75	27.7	832.3	
				6/18/75	28.2	831.8	
				7/29/75	30.8	829.2	
				8/26/75	32.2	827.8	
				9/25/75	32.6	827.4	
WARNER HYDRO SUBUNIT						Z-03.C	
WARNER HYDRO SUBAREA						Z-03.C1	
10S/02E-24D01 S	37		2726.2	9/29/75	23.0	2703.2	4405
10S/02E-24J01 S	37		2770.0	10/29/74	49.0	2721.0	4405
				11/26/74	51.0	2719.0	
				12/28/74	50.0	2720.0	
				1/27/75	51.0	2719.0	
				2/25/75	52.0	2718.0	
				4/28/75	47.0	2723.0	
				5/28/75	48.0	2722.0	
				9/29/75	49.0	2721.0	
10S/02E-24Q01 S	37		2749.2	9/29/75	42.0	2707.2	4405
10S/02E-24R01 S	37		2763.6	10/29/74	38.8	2724.8	4405
				11/26/74	39.8	2723.8	
				12/28/74	38.8	2724.8	
				1/27/75	39.8	2723.8	
				2/25/75	39.8	2723.8	
				4/28/75	36.8	2726.8	
				5/28/75	36.8	2726.8	
				9/29/75	38.8	2724.8	
10S/02E-25A01 S	37		2741.2	10/29/74	31.4	2709.8	4405
				11/26/74	33.4	2707.8	
				12/28/74	32.4	2708.8	
				1/27/75	32.4	2708.8	
				2/25/75	34.4	2706.8	
				4/28/75	30.4	2710.8	
				5/28/75	30.4	2710.8	
				9/29/75	28.4	2712.8	
10S/02E-25C01 S	37		2733.6	10/29/74	28.0	2705.6	4405
				11/26/74	30.0	2703.6	
				12/28/74	30.0	2703.6	
				1/27/75	30.0	2703.6	
				2/25/75	31.0	2702.6	
				4/28/75	27.0	2706.6	
				5/28/75	27.0	2706.6	
				9/29/75	26.0	2707.6	
10S/02E-25E01 S	37		2730.0	10/29/74	17.0	2713.0	4405
				11/26/74	17.0	2713.0	
				12/28/74	19.0	2711.0	
				1/27/75	17.0	2713.0	
				2/25/75	19.0	2711.0	
				4/28/75	18.0	2712.0	
				5/28/75	17.0	2713.0	
				9/29/75	19.0	2711.0	
10S/02E-25G01 S	37		2732.0	10/29/74	21.0	2711.0	4405
				11/26/74	21.0	2711.0	
				12/28/74	20.0	2712.0	
				1/27/75	21.0	2711.0	
				2/25/75	21.0	2711.0	
				4/28/75	19.0	2713.0	
				5/28/75	19.0	2713.0	
				9/29/75	22.0	2710.0	
10S/02E-25H01 S	37		2755.0	10/29/74	56.0	2699.0	4405
				11/26/74	58.0	2697.0	
				12/28/74	59.0	2696.0	
				1/27/75	57.0	2698.0	
				2/25/75	54.0	2701.0	
				4/28/75	55.0	2700.0	
				5/28/75	54.0	2701.0	
				9/29/75	61.0	2694.0	
10S/03E-17H01 S	37		2920.0	10/29/74	65.0	2855.0	4405
				11/26/74	66.0	2854.0	
				12/28/74	66.0	2854.0	
				1/27/75	66.0	2854.0	
				2/25/75	66.0	2854.0	
				4/28/75	63.0	2857.0	
				5/28/75	64.0	2856.0	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SAN LUIS REY HYDRO UNIT WARNER HYDRO SUBUNIT WARNER HYDRO SUBAREA						Z-03 Z-03.C Z-03.C1	
10S/03E-17H01 S	37		2920.0	9/29/75	63.0	2857.0	4405
10S/03E-19N01 S	37		2769.9	10/29/74	47.6	2722.3	4405
				11/26/74	47.6	2722.3	
				12/28/74	47.6	2722.3	
				1/27/75	47.6	2722.3	
				2/25/75	48.6	2721.3	
				4/28/75	47.6	2722.3	
				5/28/75	47.6	2722.3	
				9/29/75	45.6	2724.3	
10S/03E-19P01 S	37		2777.7	10/29/74	48.2	2729.5	4405
				11/26/74	51.2	2726.5	
				12/28/74	51.2	2726.5	
				1/27/75	51.2	2726.5	
				2/25/75	49.2	2728.5	
				4/28/75	46.2	2731.5	
				5/28/75	46.2	2731.5	
				9/29/75	49.2	2728.5	
10S/03E-19Q01 S	37		2781.0	10/29/74	49.0	2732.0	4405
				11/26/74	50.0	2731.0	
				12/28/74	48.0	2733.0	
				1/27/75	50.0	2731.0	
				2/25/75	52.0	2729.0	
				4/28/75	47.0	2734.0	
				5/28/75	47.0	2734.0	
				9/29/75	49.0	2732.0	
10S/03E-20N01 S	37		2791.2	10/29/74	42.0	2749.2	4405
				11/26/74	44.0	2747.2	
				12/28/74	43.0	2748.2	
				1/27/75	43.0	2748.2	
				2/25/75	43.0	2748.2	
				4/28/75	40.0	2751.2	
				5/28/75	41.0	2750.2	
				9/29/75	41.0	2750.2	
10S/03E-20P01 S	37		2800.0	10/29/74	49.2	2750.8	4405
				11/26/74	52.2	2747.8	
				12/28/74	51.2	2748.8	
				1/27/75	52.2	2747.8	
				2/25/75	52.2	2747.8	
				4/28/75	46.2	2753.8	
				9/29/75	51.2	2748.8	
10S/03E-20Q01 S	37		2816.6	10/29/74	53.0	2763.6	4405
				11/26/74	54.0	2762.6	
				12/28/74	55.0	2761.6	
				1/27/75	54.0	2762.6	
				2/25/75	52.0	2764.6	
				4/28/75	50.0	2766.6	
				5/28/75	50.0	2766.6	
				9/29/75	54.0	2762.6	
10S/03E-28P01 S	37		2885.8	2/25/75	233.2	2652.6	4405
				4/28/75	203.2	2682.6	
10S/03E-29E01 S	37		2794.0	10/29/74	41.7	2752.3	4405
				11/26/74	42.7	2751.3	
				12/28/74	42.7	2751.3	
				1/27/75	42.7	2751.3	
				2/25/75	41.7	2752.3	
				4/28/75	40.7	2753.3	
				5/28/75	41.7	2752.3	
				9/29/75	39.7	2754.3	
10S/03E-29J01 S	37		2810.7	10/29/74	31.4	2779.3	4405
				11/26/74	33.4	2777.3	
				12/28/74	31.4	2779.3	
				1/27/75	32.4	2778.3	
				2/25/75	32.4	2778.3	
				4/28/75	29.4	2781.3	
				5/28/75	30.4	2780.3	
				9/29/75	30.4	2780.3	
10S/03E-29J02 S	37		2815.5	12/28/74	76.0	2739.5	4405
				1/27/75	75.0	2740.5	
				2/25/75	75.0	2740.5	
10S/03E-29L01 S	37		2798.5	11/26/74	47.0	2751.5	4405
				12/28/74	43.0	2755.5	
				1/27/75	47.0	2751.5	
				2/25/75	47.0	2751.5	
10S/03E-29M01 S	37		2766.0	10/29/74	44.0	2722.0	4405
				11/26/74	43.0	2723.0	
				12/28/74	41.0	2725.0	
				1/27/75	43.0	2723.0	
				2/25/75	40.0	2726.0	
				4/28/75	43.0	2723.0	
				5/28/75	44.0	2722.0	
				9/29/75	42.0	2724.0	
10S/03E-30A01 S	37		2779.7	10/29/74	42.1	2737.6	4405
				11/26/74	42.1	2737.6	
				12/28/74	43.1	2736.6	
				1/27/75	41.1	2738.6	
				2/25/75	41.1	2738.6	
				4/28/75	40.1	2739.6	
				5/28/75	40.1	2739.6	
				9/29/75	42.1	2737.6	
SAN LUIS REY HYDRO UNIT WARNER HYDRO SUBUNIT WARNER HYDRO SUBAREA						Z-03 Z-03.C Z-03.C1	
10S/03E-30B01 S	37		2775.0	10/29/74	46.0	2729.0	4405
				11/26/74	42.0	2733.0	
				12/28/74	40.0	2735.0	
				1/27/75	41.0	2734.0	
				2/25/75	43.0	2732.0	
				4/28/75	43.0	2732.0	
				5/28/75	42.0	2733.0	
				9/29/75	45.0	2730.0	
10S/03E-30C01 S	37		2750.0	10/29/74	42.0	2708.0	4405
				11/26/74	44.0	2706.0	
				12/28/74	44.0	2706.0	
				1/27/75	44.0	2706.0	
				2/25/75	44.0	2706.0	
				4/28/75	40.0	2710.0	
				5/28/75	40.0	2710.0	
				9/29/75	39.0	2711.0	
10S/03E-30H01 S	37		2779.6	10/29/74	29.0	2750.6	4405
				11/26/74	29.0	2750.6	
				12/28/74	29.0	2750.6	
				1/27/75	28.0	2751.6	
				2/25/75	28.0	2751.6	
				4/28/75	27.0	2752.6	
				5/28/75	27.0	2752.6	
				9/29/75	30.0	2749.6	
10S/03E-31C01 S	37		2760.0	10/29/74	132.0	2628.0	4405
				11/26/74	139.0	2621.0	
				12/28/74	138.0	2622.0	
				1/27/75	139.0	2621.0	
				2/25/75	140.0	2620.0	
				4/28/75	130.0	2630.0	
				5/28/75	130.0	2630.0	
				9/29/75	142.0	2618.0	
10S/03E-31C02 S	37		2760.0	10/29/74	45.0	2715.0	4405
				11/26/74	45.0	2715.0	
				1/27/75	45.0	2715.0	
				2/25/75	44.0	2716.0	
				4/28/75	43.0	2717.0	
				5/28/75	42.0	2718.0	
				9/29/75	43.0	2717.0	
10S/03E-31C05 S	37		2780.0	10/29/74	68.0	2712.0	4405
				11/26/74	63.0	2717.0	
				1/27/75	63.0	2717.0	
				2/25/75	63.0	2717.0	
				4/28/75	61.0	2719.0	
				5/28/75	61.0	2719.0	
				9/29/75	63.0	2717.0	
10S/03E-32C01 S	37		2784.6	10/29/74	36.0	2748.6	4405
				11/26/74	36.0	2748.6	
				12/28/74	35.0	2749.6	
				1/27/75	36.0	2748.6	
				2/25/75	34.0	2750.6	
				4/28/75	34.0	2750.6	
				5/28/75	34.0	2750.6	
				9/29/75	35.0	2749.6	
10S/03E-32H01 S	37		2810.7	11/26/74	71.0	2739.7	4405
				12/28/74	64.0	2746.7	
				1/27/75	71.0	2739.7	
				2/25/75	71.0	2739.7	
				4/28/75	49.0	2761.7	
				5/28/75	49.0	2761.7	
10S/03E-33B01 S	37		2927.4	10/29/74	199.3	2728.1	4405
				11/26/74	201.3	2726.1	
				12/28/74	202.3	2725.1	
				1/27/75	201.3	2726.1	
				2/25/75	203.3	2724.1	
				4/28/75	198.3	2729.1	
				9/29/75	199.3	2728.1	
10S/03E-33D01 S	37		2865.0	10/29/74	192.3	2672.7	4405
				11/26/74	194.3	2670.7	
				12/28/74	205.3	2659.7	
				1/27/75	194.3	2670.7	
				2/25/75	195.3	2669.7	
				4/28/75	189.3	2675.7	
				9/29/75	190.3	2674.7	
10S/03E-33D02 S	37		2848.3	10/29/74	180.6	2667.7	4405
				11/26/74	181.6	2666.7	
				12/28/74	181.6	2666.7	
				1/27/75	180.6	2667.7	
				2/25/75	179.6	2668.7	
				4/28/75	178.6	2669.7	
				9/29/75	185.6	2662.7	
10S/03E-33E01 S	37		2848.0	10/29/74	156.0	2692.0	4405
				11/26/74	173.0	2675.0	
				12/28/74	167.0	2681.0	
				1/27/75	173.0	2675.0	
				2/25/75	174.0	2674.0	
				4/28/75	152.0	2696.0	
				9/29/75	148.0	2700.0	
10S/03E-33F01 S	37		2883.4	10/29/74	194.7	2688.7	4405

See page 79 for key to terms a abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SAN LUIS REY HYDRO UNIT						Z-03	
WARNER HYDRO SUBUNIT						Z-03.C	
WARNER HYDRO SUBAREA						Z-03.C1	
10S/03E-33F01 S (CONTINUED)	37		2883.4	11/26/74	215.7	2667.7	4405
				12/28/74	216.7	2666.7	
				1/27/75	215.7	2667.7	
				2/25/75	217.7	2665.7	
				4/28/75	192.7	2690.7	
				9/29/75	186.7	2696.7	
10S/03E-33H01 S	37		2902.2	10/29/74	180.9	2721.3	4405
				11/26/74	181.9	2720.3	
				12/28/74	182.9	2719.3	
				1/27/75	181.9	2720.3	
				2/25/75	179.9	2722.3	
				4/28/75	178.9	2723.3	
				9/29/75	183.9	2718.3	
11S/03E-03J01 S	37		2970.0	11/26/74	127.0	2843.0	4405
				12/28/74	123.0	2847.0	
				1/27/75	127.0	2843.0	
				2/25/75	124.0	2846.0	
				4/28/75	110.0	2860.0	
11S/03E-04A01 S	37		2856.4	10/29/74	172.3	2684.1	4405
				11/26/74	180.3	2676.1	
				12/28/74	182.3	2674.1	
				1/27/75	180.3	2676.1	
				2/25/75	182.3	2674.1	
				4/28/75	170.3	2686.1	
				9/29/75	173.3	2683.1	
11S/03E-06001 S	37		2750.0	9/29/75	140.0	2610.0	4405
SAN DIEGUITO HYDRO UNIT						Z-05	
HODGES HYDRO SUBUNIT						Z-05.B	
HODGES HYDRO SUBAREA						Z-05.B1	
12S/02W-35K01 S	37		420.0	10/08/74	30.8(1)	389.2	5710
				11/08/74	27.3(1)	392.7	
				2/21/75	25.3(1)	394.7	
				6/11/75	28.8(1)	391.2	
				8/11/75	19.5	400.5	
				9/17/75	31.2(1)	388.8	
12S/02W-35P01 S	37		395.0	10/08/74	9.3	385.7	5710
				11/08/74	7.5	387.5	
				2/21/75	5.0	390.0	
				6/11/75	4.8	390.2	
				8/11/75	7.7	387.3	
				9/17/75	8.1	386.9	
12S/02W-35Q04 S	37		395.0	10/09/74	25.2(1)	369.8	5710
				11/08/74	24.2(1)	370.8	
				2/21/75	17.9(1)	377.1	
				6/11/75	6.9	388.1	
				8/11/75	8.0	387.0	
				9/17/75	12.2	382.8	
13S/01W-07F01 S	37		330.8	10/01/74	16.3	314.5	5229
				11/01/74	18.6(1)	312.2	
				12/01/74	20.9(1)	309.9	
				1/01/75	28.0(1)	302.8	
				2/01/75	17.8(1)	313.0	
				3/01/75	16.7(1)	314.1	
				4/01/75	8.8	322.0	
				5/01/75	12.4(1)	318.4	
				7/01/75	15.2(1)	315.6	
				8/01/75	13.9	316.9	
				9/01/75	12.7(1)	318.1	
13S/02W-02C02 S	37		374.0	10/09/74	12.3	361.7	5710
				11/08/74	10.9	363.1	
				2/21/75	5.2	368.8	
				6/11/75	8.7	365.3	
				7/17/75	10.7	363.3	
				8/11/75	8.6	365.4	
13S/02W-02C04 S	37		390.0	10/09/74	9.0	381.0	5710
				11/08/74	3.8	386.2	
				2/21/75	3.4	386.6	
				6/11/75	20.2	369.8	
				8/11/75	4.5	385.5	
				9/17/75	21.5(1)	368.5	
13S/02W-02D01 S	37		390.0	10/08/74	21.3	368.7	5710
				11/08/74	18.0	372.0	
				2/21/75	12.1(1)	377.9	
				6/11/75	25.0	365.0	
				8/11/75	27.8	362.2	
				9/12/75	19.7	370.3	
13S/02W-02D03 S	37		380.0	10/08/74	7.7	372.3	5710
				11/08/74	7.6	372.4	
				2/21/75	6.7	373.3	
				6/11/75	7.0	373.0	
				8/11/75	9.0	371.0	
				9/17/75	9.1	370.9	
13S/02W-02F01 S	37		375.0	10/09/74	17.2	357.8	5710
				11/08/74	16.8	358.2	
				2/21/75	10.4	364.6	
				6/11/75	14.9	360.1	
				8/11/75	15.0	360.0	
				9/17/75	16.1	358.9	
13S/02W-02F02 S	37		365.0	10/09/74	5.8	359.2	5710
				11/08/74	4.5	360.5	
				2/21/75	2.8	362.2	
				6/11/75	4.1	360.9	
				8/11/75	4.7	360.3	
				9/17/75	19.4(1)	345.6	
13S/02W-02L01 S	37		345.0	10/09/74	4.2	340.8	5710
				11/08/74	1.5	343.5	
				6/11/75	2.5	342.5	
				9/17/75	1.8	343.2	
13S/02W-02M01 S	37		358.4	10/09/74	14.3	344.1	5710
				11/08/74	12.0	346.4	
				2/21/75	6.5	351.9	
				6/11/75	7.9	350.5	
				8/11/75	53.2(1)	305.2	
				9/17/75	14.2	344.2	
13S/02W-11R01 S	37		315.6	10/01/74	16.8	298.8	5229
				11/01/74	15.4	300.2	
				12/01/74	15.4	300.2	
				1/01/75	15.4	300.2	
				2/01/75	15.2	300.4	
				3/01/75	14.2	301.4	
				4/01/75	13.3	302.3	
				5/01/75	13.1	302.5	
				6/01/75	14.6	301.0	
				7/01/75	15.4	300.2	
				8/01/75	18.0(1)	297.6	
				9/01/75	18.9(1)	296.7	
13S/02W-12G01 S	37		326.0	10/01/74	21.5	304.5	5229

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SAN DIEGUITO HYDRO UNIT						Z-05	
HODGES HYDRO SUBUNIT						Z-05.B	
HODGES HYDRO SUBAREA						Z-05.B1	
13S/02W-12G01 S (CONTINUED)	37		326.0	11/01/74	19.4	306.6	5229
				12/01/74	19.3	306.7	
				1/01/75	19.4	306.6	
				2/01/75	19.7	306.3	
				3/01/75	19.6	306.4	
				4/01/75	18.4	307.6	
				5/01/75	20.5	305.5	
				6/01/75	22.1	303.9	
				7/01/75	23.2	302.8	
				8/01/75	24.1	301.9	
				9/01/75	24.6	301.4	
13S/02W-12N01 S	37		315.6	10/01/74	15.3	300.3	5229
				11/01/74	14.8	300.8	
				12/01/74	14.7	300.9	
				1/01/75	13.7	301.9	
				2/01/75	14.2	301.4	
				3/01/75	13.5	302.1	
				4/01/75	12.6	303.0	
				5/01/75	12.6	303.0	
				6/01/75	14.0	301.6	
				7/01/75	15.5	300.1	
				8/01/75	16.4	299.2	
				9/01/75	16.9	298.7	
13S/02W-12N02 S	37		318.0	10/01/74	18.9(1)	299.1	5229
				11/01/74	17.0(1)	301.0	
				12/01/74	16.2	301.8	
				1/01/75	15.4	302.6	
				2/01/75	15.6(1)	302.4	
				3/01/75	13.9	304.1	
				4/01/75	14.4(1)	303.6	
				5/01/75	15.1(1)	302.9	
				7/01/75	20.8(1)	297.2	
				8/01/75	18.5(1)	299.5	
				9/01/75	19.3(1)	298.7	
13S/02W-13C01 S	37		331.6	10/01/74	13.0	318.6	5229
				11/01/74	14.2	317.4	
				12/01/74	15.0	316.6	
				1/01/75	16.1	315.5	
				2/01/75	16.0	315.6	
				3/01/75	16.8	314.8	
				4/01/75	13.0	318.6	
				5/01/75	12.4	319.2	
				6/01/75	12.7	318.9	
				7/01/75	13.0	318.6	
				8/01/75	12.8	318.8	
				9/01/75	12.7	318.9	
BEAR HYDRO SUBAREA						Z-05.B4	
12S/02W-24N02 S	37		639.0	11/12/74	17.0	622.0	5711
				12/22/74	17.0	622.0	
				1/10/75	15.0	624.0	
				2/24/75	11.0	628.0	
				4/03/75	10.0	629.0	
SAN PASQUAL HYDRO SUBUNIT						Z-05.C	
SAN PASQUAL HYDRO SUBAREA						Z-05.C2	
12S/01W-29P01 S	37		378.8	10/01/74	9.0	369.8	5229
				11/01/74	8.8	370.0	
				12/01/74	6.1	372.7	
				1/01/75	8.0	370.8	
				2/01/75	7.4	371.4	
				3/01/75	14.9	363.9	
				4/01/75	15.4	363.4	
				5/01/75	15.1	363.7	
				6/01/75	6.1	372.7	
				7/01/75	15.8	363.0	
				8/01/75	6.9	371.9	
				9/01/75	15.6(1)	363.2	
12S/01W-29N01 S	37		347.0	10/01/74	50.5(1)	296.5	5229
				11/01/74	48.5(1)	298.5	
				12/01/74	38.2	308.8	
				1/01/75	45.2	301.8	
				2/01/75	40.1	306.9	
				3/01/75	26.8	320.2	
				4/01/75	25.4	321.6	
				5/01/75	28.5(1)	318.5	
				6/01/75	30.7(1)	316.3	
				7/01/75	44.8(1)	302.2	
				8/01/75	44.5(1)	302.5	
				9/01/75	48.2(1)	298.8	
12S/01W-30A01 S	37		375.7	10/01/74	16.1(1)	359.6	5229
				11/01/74	17.6(1)	358.1	
				12/01/74	5.1	370.6	
				1/01/75	4.8	370.9	
				2/01/75	4.3	371.4	
				3/01/75	3.7	372.0	
				4/01/75	3.7	372.0	
				5/01/75	17.3(1)	358.4	
				6/01/75	17.2(1)	358.5	
				7/01/75	16.3(1)	359.4	
				8/01/75	16.9(1)	358.8	
				9/01/75	18.6(1)	357.1	
12S/01W-30A05 S	37		398.1	10/01/74	27.8(1)	370.3	5229
				11/01/74	30.3	367.8	
SAN DIEGUITO HYDRO UNIT						Z-05	
SAN PASQUAL HYDRO SUBUNIT						Z-05.C	
SAN PASQUAL HYDRO SUBAREA						Z-05.C2	
12S/01W-30A05 S (CONTINUED)	37		398.1	12/01/74	26.8	371.3	5229
				1/01/75	32.1(1)	366.0	
				2/01/75	32.0(1)	366.1	
				3/01/75	32.4(1)	365.7	
				4/01/75	29.0(1)	369.1	
				5/01/75	27.6(1)	370.5	
				6/01/75	37.2(1)	360.9	
				7/01/75	34.7(1)	363.4	
				8/01/75	34.7(1)	363.4	
				9/01/75	32.7(1)	365.4	
12S/01W-30J01 S	37		366.3	10/01/74	16.5	349.8	5229
				11/01/74	64.3	302.0	
				12/01/74	3.5	362.8	
				1/01/75	60.1	306.2	
				2/01/75	3.8	362.5	
				3/01/75	60.0	306.3	
				4/01/75	1.0	365.3	
				5/01/75	59.4	306.9	
				6/01/75	14.8(1)	351.5	
				7/01/75	9.3	357.0	
				8/01/75	71.1	295.2	
				9/01/75	3.2	363.1	
12S/01W-30R01 S	37		358.8	10/01/74	10.3	348.5	5229
				11/01/74	12.9	345.9	
				12/01/74	11.4	347.4	
				1/01/75	25.7(1)	333.1	
				2/01/75	23.3	335.5	
				3/01/75	3.4	355.4	
				4/01/75	3.0	355.8	
				5/01/75	4.9(1)	353.9	
				6/01/75	4.4	354.4	
				7/01/75	11.5(1)	347.3	
				9/01/75	12.7	346.1	
12S/01W-31L03 S	37		353.0	10/01/74	51.0	302.0	5229
				11/01/74	51.6	301.4	
				12/01/74	50.9	302.1	
12S/01W-32M03 S	37		357.0	10/01/74	58.0(1)	299.0	5229
				11/01/74	59.4(1)	297.6	
				12/01/74	53.1	303.9	
				1/01/75	50.1	306.9	
				2/01/75	50.7	306.3	
				3/01/75	49.3	307.7	
				4/01/75	19.0	338.0	
				5/01/75	46.8(1)	310.2	
				6/01/75	47.8(1)	309.2	
				7/01/75	57.1(1)	299.9	
				8/01/75	61.8(1)	295.2	
				9/01/75	65.4(1)	291.6	
12S/01W-32Q01 S	37		366.4	10/01/74	52.8(1)	313.6	5229
				11/01/74	54.8(1)	311.6	
				12/01/74	43.8(1)	322.6	
				1/01/75	46.1	320.3	
				2/01/75	45.1	321.3	
12S/01W-32Q02 S	37		367.0	10/01/74	48.0	319.0	5229
				11/01/74	49.2	317.8	
				12/01/74	40.3	326.7	
				1/01/75	50.9	316.1	
				2/01/75	50.4	316.6	
				3/01/75	51.0	316.0	
				4/01/75	49.3	317.7	
				5/01/75	50.7	316.3	
				6/01/75	51.4	315.6	
				7/01/75	52.4	314.6	
				8/01/75	53.9	313.1	
				9/01/75	55.5	311.5	
12S/01W-32Q03 S	37		367.0	10/01/74	56.6(1)	310.4	5229
				11/01/74	58.7(1)	308.3	
				12/01/74	45.3	321.7	
				1/01/75	50.2	316.8	
				2/01/75	49.0	318.0	
12S/01W-33N01 S	37		378.0	10/01/74	57.1(1)	320.9	5229
				11/01/74	45.2(1)	332.8	
				12/01/74	54.5	323.5	
				1/01/75	62.5(1)	315.5	
				2/01/75	60.9	317.1	
				3/01/75	51.6	326.4	
				4/01/75	50.2	327.8	
				5/01/75	52.4(1)	325.6	
				6/01/75	55.9(1)	322.1	
				8/01/75	63.0(1)	315.0	
				9/01/75	65.5(1)	312.5	
12S/01W-34J01 S	37		414.0	10/01/74	110.2	303.8	5229
				11/01/74	30.5	383.5	
				12/01/74	30.1	383.9	
				1/01/75	29.5	384.5	
				2/01/75	29.9	384.1	
				3/01/75	29.5	384.5	
				4/01/75	28.0	386.0	
				5/01/75	29.9	384.1	
				6/01/75	30.8	383.2	
				7/01/75	32.5	381.5	
				8/01/75	34.4	379.6	
				9/01/75	35.2	378.8	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

SAN DIEGUITO HYDRO UNIT — Z-05
SAN PASQUAL HYDRO SUBUNIT — Z-05.C
SAN PASQUAL HYDRO SUBAREA — Z-05.C2

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
12S/01W-34K02 S	37		408.8	10/01/74	41.0(1)	367.8	5229
				11/01/74	41.5(1)	367.3	
				12/01/74	35.3	373.5	
				1/01/75	33.9	374.9	
				2/01/75	39.1(1)	369.7	
				3/01/75	40.6(1)	368.2	
				4/01/75	39.8(1)	369.0	
				5/01/75	35.1(1)	373.7	
				7/01/75	41.6(1)	367.2	
				8/01/75	45.2(1)	363.6	
				9/01/75	44.5(1)	364.3	
12S/01W-34P07 S	37		400.3	10/01/74	33.1	367.2	5229
				11/01/74	33.3	367.0	
				12/01/74	33.3	367.0	
				1/01/75	33.3	367.0	
				2/01/75	33.5	366.8	
				3/01/75	33.5	366.8	
				4/01/75	33.5	366.8	
				5/01/75	33.8	366.5	
				6/01/75	34.1	366.2	
				7/01/75	34.9	365.4	
				8/01/75	35.4	364.9	
				9/01/75	36.0	364.3	
12S/01W-35A01 S	37		443.4	10/01/74	41.4	402.0	5229
				11/01/74	40.3	403.1	
				12/01/74	40.9	402.5	
				1/01/75	40.4	403.0	
				2/01/75	41.3	402.1	
				3/01/75	41.3	402.1	
				4/01/75	39.2	404.2	
				5/01/75	62.8(1)	380.6	
				6/01/75	40.0	403.4	
				7/01/75	62.4(1)	381.0	
				8/01/75	64.3(1)	379.1	
				9/01/75	46.8	396.6	
12S/01W-35B03 S	37		437.0	10/01/74	41.3	395.7	5229
				11/01/74	36.8	400.2	
				12/01/74	37.3	399.7	
				1/01/75	36.7	400.3	
				2/01/75	37.6	399.4	
				3/01/75	37.5	399.5	
				4/01/75	36.6	400.4	
				5/01/75	41.5(1)	395.5	
				6/01/75	37.0	400.0	
				7/01/75	42.6	394.4	
				8/01/75	42.1	394.9	
				9/01/75	41.1	395.9	
12S/01W-35C01 S	37		426.5	10/01/74	28.8	397.7	5229
				11/01/74	26.7	399.8	
				12/01/74	29.2	397.3	
				1/01/75	28.8	397.7	
				2/01/75	29.7	396.8	
				3/01/75	28.8	397.7	
				4/01/75	28.6	397.9	
				5/01/75	25.4	401.1	
				6/01/75	29.6	396.9	
				7/01/75	32.8	393.7	
				8/01/75	32.8	393.7	
				9/01/75	35.0	391.5	
12S/01W-35C05 S	37		429.0	10/01/74	28.2	400.8	5229
				11/01/74	29.0	400.0	
				12/01/74	29.4	399.6	
				1/01/75	28.2	400.8	
				2/01/75	29.2	399.8	
				3/01/75	30.0	399.0	
				4/01/75	29.1	399.9	
				5/01/75	29.1	399.9	
				6/01/75	29.6	399.4	
				7/01/75	30.6	398.4	
				8/01/75	31.7	397.3	
				9/01/75	33.0	396.0	
12S/01W-35C06 S	37		430.0	10/01/74	37.7(1)	392.3	5229
				11/01/74	33.2(1)	396.8	
				12/01/74	33.5	396.5	
				1/01/75	35.9	394.1	
				2/01/75	33.8	396.2	
				3/01/75	33.6	396.4	
				4/01/75	33.2	396.8	
				5/01/75	33.0	397.0	
				6/01/75	34.6(1)	395.4	
				7/01/75	36.5	393.5	
				8/01/75	37.7	392.3	
				9/01/75	37.7	392.3	
12S/01W-35D02 S	37		419.3	10/01/74	25.5	393.8	5229
				11/01/74	25.7	393.6	
				12/01/74	25.8	393.5	
				1/01/75	25.4	393.9	
				2/01/75	25.9	393.4	
				3/01/75	25.5	393.8	
				4/01/75	24.7	394.6	
				5/01/75	23.1	396.2	
				6/01/75	26.5	392.8	
				7/01/75	27.6	391.7	
				8/01/75	29.2	390.1	

SAN DIEGUITO HYDRO UNIT — Z-05
SAN PASQUAL HYDRO SUBUNIT — Z-05.C
SAN PASQUAL HYDRO SUBAREA — Z-05.C2

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
12S/01W-35D02 S	37		419.3	9/01/75	30.4	388.9	5229
12S/01W-35F01 S	37		429.4	10/01/74	33.2	396.4	5229
				11/01/74	35.0	394.6	
				12/01/74	34.4	395.2	
				1/01/75	33.4	396.2	
				2/01/75	33.2	396.4	
				3/01/75	33.1	396.5	
				4/01/75	32.5	397.1	
				5/01/75	32.9	396.7	
				9/01/75	44.2	385.4	
12S/01W-35F02 S	37		429.5	10/01/74	32.5	397.0	5229
				11/01/74	29.8	399.7	
				12/01/74	32.7	396.8	
				1/01/75	32.7	396.8	
				2/01/75	33.3	396.2	
				3/01/75	33.3	396.2	
				4/01/75	32.8	396.7	
				5/01/75	33.9	395.6	
				6/01/75	27.4	402.1	
				7/01/75	27.5	402.0	
				8/01/75	28.6	400.9	
				9/01/75	34.0	395.5	
12S/01W-35G02 S	37		434.7	10/01/74	33.4	401.3	5229
				11/01/74	33.5	401.2	
				12/01/74	33.9	400.8	
				1/01/75	33.7	401.0	
				2/01/75	34.4	400.3	
				3/01/75	34.6	400.1	
				4/01/75	34.2	400.5	
				5/01/75	34.6	400.1	
				6/01/75	34.7	400.0	
				7/01/75	35.6	399.1	
				8/01/75	66.4	368.3	
				9/01/75	67.5	367.2	
12S/01W-35H02 S	37		444.3	10/01/74	42.3	402.0	5229
				11/01/74	41.7	402.6	
				12/01/74	42.3	402.0	
				1/01/75	41.7	402.6	
				2/01/75	42.7	401.6	
				3/01/75	42.7	401.6	
				4/01/75	41.3	403.0	
				5/01/75	40.7	403.6	
				6/01/75	41.6	402.7	
				7/01/75	44.0	400.3	
				8/01/75	45.6	398.7	
				9/01/75	46.8	397.5	
12S/01W-35L04 S	37		430.0	10/01/74	38.1(1)	391.9	5229
				11/01/74	39.3(1)	390.7	
				12/01/74	39.5(1)	390.5	
				1/01/75	38.2(1)	391.8	
				2/01/75	39.1(1)	390.9	
				3/01/75	39.5(1)	390.5	
				4/01/75	38.9(1)	391.1	
				5/01/75	38.9	391.1	
				6/01/75	40.0	390.0	
				7/01/75	43.3	386.7	
				8/01/75	42.4	387.6	
				9/01/75	43.5(1)	386.5	
12S/01W-36D01 S	37		448.1	10/01/74	42.6	405.5	5229
				11/01/74	42.5	405.6	
				12/01/74	43.1	405.0	
				1/01/75	42.8	405.3	
				2/01/75	43.7	404.4	
				3/01/75	44.0	404.1	
				4/01/75	40.0	408.1	
				5/01/75	39.3	408.8	
				6/01/75	40.7	407.4	
				7/01/75	43.3	404.8	
				8/01/75	45.5	402.6	
				9/01/75	47.1	401.0	
12S/01W-36D03 S	37		444.5	10/01/74	41.0	403.5	5229
				11/01/74	40.4	404.1	
				12/01/74	40.8	403.7	
				1/01/75	45.7	398.8	
				2/01/75	40.3	404.2	
				3/01/75	41.3	403.2	
				4/01/75	39.1	405.4	
				5/01/75	39.0	405.5	
				6/01/75	39.8	404.7	
12S/01W-36F01 S	37		458.5	10/01/74	42.9	415.6	5229
				11/01/74	43.9	414.6	
				12/01/74	44.5	414.0	
				1/01/75	45.4	413.1	
				2/01/75	46.7	411.8	
				3/01/75	47.6	410.9	
				4/01/75	33.7	424.8	
				5/01/75	33.2	425.3	
				6/01/75	35.6	422.9	
				7/01/75	38.0	420.5	
				8/01/75	41.0	417.5	
				9/01/75	43.6	414.9	
12S/01W-36H01 S	37		467.1	10/01/74	42.0	425.1	5229
				11/01/74	44.8	422.3	

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SAN DIEGUITO HYDRO UNIT SAN PASQUAL HYDRO SUBUNIT SAN PASQUAL HYDRO SUBAREA						Z-05 Z-05.C Z-05.C2	
12S/01W-36H01 S (CONTINUED)	37		467.1	12/01/74	39.2	427.9	5229
				1/01/75	48.3(1)	418.8	
				2/01/75	49.5	417.6	
				3/01/75	53.0(1)	414.1	
				4/01/75	32.5	434.6	
				5/01/75	29.8	437.3	
				6/01/75	30.8	436.3	
				7/01/75	33.7	433.4	
				8/01/75	37.5	429.6	
				9/01/75	41.2	425.9	
13S/01W-03F01 S	37		399.2	10/01/74	38.9	360.3	5229
				11/01/74	38.7	360.5	
				12/01/74	39.5	359.7	
				1/01/75	39.7	359.5	
				2/01/75	40.2	359.0	
				3/01/75	40.4	358.8	
				4/01/75	38.9	360.3	
				5/01/75	34.8	364.4	
				6/01/75	41.5(1)	357.7	
				7/01/75	37.8	361.4	
				8/01/75	40.6	358.6	
				9/01/75	45.4(1)	353.8	
13S/01W-05A02 S	37		372.6	10/01/74	95.0(1)	277.6	5229
				11/01/74	79.6(1)	293.0	
				12/01/74	67.1	305.5	
				1/01/75	20.6(1)	352.0	
				2/01/75	69.5	303.1	
				3/01/75	60.1	312.5	
				4/01/75	56.9	315.7	
				5/01/75	61.5(1)	311.1	
				6/01/75	64.6(1)	308.0	
				7/01/75	70.7(1)	301.9	
				8/01/75	72.1(1)	300.5	
				9/01/75	80.5(1)	292.1	
13S/01W-06H01 S	37		334.3	10/01/74	38.1	296.2	5229
				11/01/74	34.7	299.6	
				12/01/74	33.8	300.5	
				1/01/75	31.9	302.4	
				2/01/75	30.7	303.6	
				3/01/75	30.0	304.3	
				4/01/75	30.3	304.0	
				5/01/75	35.2	299.1	
				6/01/75	31.3	303.0	
				7/01/75	31.7	302.6	
				8/01/75	34.5	299.8	
				9/01/75	35.8	298.5	
SANTA MARIA VALLEY HYDRO SUBUNIT RAMONA HYDRO SUBAREA						Z-05.D Z-05.D1	
13S/01E-10J01 S	37		1465.0	10/31/74	11.8	1453.2	4402
				11/30/74	11.6	1453.4	
				12/31/74	11.2	1453.8	
				1/31/75	10.8	1454.2	
				3/03/75	10.5	1454.5	
				4/02/75	9.6	1455.4	
				5/01/75	9.0	1456.0	
				6/30/75	9.6	1455.4	
				7/31/75	10.8	1454.2	
				9/30/75	11.1	1453.9	
13S/01E-10R01 S	37		1450.0	10/31/74	10.9	1439.1	4402
				11/30/74	10.6	1439.4	
				12/31/74	9.8	1440.2	
				1/31/75	9.5	1440.5	
				3/03/75	8.9	1441.1	
				4/02/75	7.8	1442.2	
				5/01/75	6.9	1443.1	
				6/30/75	8.3	1441.7	
				7/31/75	8.8	1441.2	
				9/30/75	9.3	1440.7	
13S/01E-11H01 S	37		1465.0	10/31/74	11.8	1453.2	4402
				11/30/74	11.6	1453.4	
				12/31/74	11.5	1453.5	
				1/31/75	11.3	1453.7	
				3/03/75	11.8	1453.2	
				4/02/75	11.2	1453.8	
				5/01/75	10.7	1454.3	
				6/30/75	10.6	1454.4	
				7/31/75	11.6	1453.4	
				9/30/75	11.8	1453.2	
13S/01E-11H02 S	37		1455.5	10/31/74	12.1	1443.4	4402
				11/30/74	11.7	1443.8	
				12/31/74	11.4	1444.1	
				1/31/75	11.2	1444.3	
				3/03/75	10.9	1444.6	
				4/02/75	10.3	1445.2	
				5/01/75	9.8	1445.7	
				6/30/75	10.3	1445.2	
				7/31/75	11.5	1444.0	
				9/30/75	11.7	1443.8	
13S/01E-11H03 S	37		1465.0	10/31/74	11.7	1453.3	4402
				11/30/74	11.5	1453.5	
				12/31/74	11.2	1453.8	
				1/31/75	11.1	1453.9	
				3/03/75	10.9	1454.1	
SAN DIEGUITO HYDRO UNIT SANTA MARIA VALLEY HYDRO SUBUNIT RAMONA HYDRO SUBAREA						Z-05 Z-05.D Z-05.D1	
13S/01E-11H03 S (CONTINUED)	37		1465.0	4/02/75	10.5	1454.5	4402
				5/01/75	10.1	1454.9	
				6/30/75	11.2	1453.8	
				7/31/75	11.6	1453.4	
				9/30/75	11.5	1453.5	
13S/01E-15D01 S	37		1425.0	10/31/74	12.5	1412.5	4402
				11/30/74	11.1	1413.9	
				12/31/74	9.8	1415.2	
				1/31/75	9.1	1415.9	
				3/03/75	8.6	1416.4	
				4/02/75	7.2	1417.8	
				5/01/75	6.3	1418.7	
				6/30/75	7.8	1417.2	
				7/31/75	9.4	1415.6	
				9/30/75	8.8	1416.2	
13S/01E-15R02 S	37		1435.0	10/31/74	9.8	1425.2	4402
				11/30/74	8.8	1426.2	
				12/31/74	7.8	1427.2	
				1/31/75	7.2	1427.8	
				3/03/75	6.8	1428.2	
				4/02/75	5.6	1429.4	
				5/01/75	4.7	1430.3	
				6/30/75	5.6	1429.4	
				7/31/75	6.8	1428.2	
				9/30/75	7.0	1428.0	
13S/01E-15H01 S	37		1410.0	10/31/74	6.6	1403.4	4402
				11/30/74	6.5	1403.5	
				12/31/74	6.7	1403.3	
				1/31/75	6.9	1403.1	
				3/03/75	7.0	1403.0	
				4/02/75	6.8	1403.2	
				5/01/75	6.5	1403.5	
				6/30/75	7.7	1402.3	
				7/31/75	8.1	1401.9	
				9/30/75	9.0	1401.0	

See page 79 for key to terms a abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SAN DIEGO HYDRO UNIT						Z-07	
LOWER SAN DIEGO HYDRO SUBUNIT						Z-07.A	
SANTEE HYDRO SUBAREA						Z-07.A2	
15S/01E-17R01 S	37		430.0	10/01/74	63.5	366.5	5400
				11/01/74	63.5	366.5	
				12/01/74	63.4	366.6	
				1/02/75	62.7	367.3	
				2/01/75	62.1	367.9	
				3/01/75	61.6	368.4	
				4/05/75	61.1	368.9	
				5/30/75	60.5	369.5	
				7/01/75	60.6	369.4	
				8/03/75	60.0	370.0	
				9/01/75	59.5	370.5	
15S/01E-17R02 S	37		425.0	10/01/74	60.6	364.4	5400
				11/01/74	60.3	364.7	
				12/01/74	60.1	364.9	
				1/02/75	59.0	366.0	
				2/01/75	58.1	366.9	
				3/01/75	58.2	366.8	
				4/05/75	57.6	367.4	
				5/30/75	57.0	368.0	
				7/01/75	55.9	369.1	
				8/03/75	56.5	368.5	
				9/01/75	56.2	368.8	
15S/01E-17H02 S	37		430.0	10/01/74	65.9	364.1	5400
				11/01/74	65.8	364.2	
				12/01/74	65.8	364.2	
				1/02/75	65.9	364.1	
				2/01/75	65.9	364.1	
				3/01/75	65.6	364.4	
				4/05/75	65.5	364.5	
				5/30/75	65.2	364.8	
				7/01/75	64.6	365.4	
				8/03/75	64.8	365.2	
				9/01/75	64.7	365.3	
15S/01E-17H07 S	37		435.0	10/01/74	64.7	370.3	5400
				11/01/74	64.8	370.2	
				12/01/74	64.7	370.3	
				1/02/75	64.7	370.3	
				2/01/75	64.6	370.4	
				3/01/75	64.2	370.8	
				4/05/75	64.0	371.0	
				5/30/75	63.5	371.5	
				7/01/75	63.3	371.7	
				8/03/75	63.1	371.9	
				9/01/75	62.8	372.2	
15S/01E-20H04 S	37		476.6	10/01/74	28.6	448.0	5400
				11/01/74	27.7	448.9	
				12/01/74	27.6	449.0	
				1/02/75	28.6	448.0	
				2/01/75	28.4	448.2	
				3/01/75	27.5	449.1	
				4/05/75	28.6	448.0	
				5/30/75	41.9	434.7	
				7/01/75	41.9	434.7	
				8/03/75	28.1	448.5	
				9/01/75	27.6	449.0	
EL MONTE HYDRO SUBAREA						Z-07.A5	
15S/01E-09P01 S	37		445.0	10/01/74	66.4	378.6	5400
				11/01/74	66.5	378.5	
				12/01/74	66.6	378.4	
				1/02/75	66.7	378.3	
				2/01/75	66.9	378.1	
				3/01/75	67.0	378.0	
				4/05/75	67.0	378.0	
				5/30/75	67.1	377.9	
				7/01/75	67.2	377.8	
				8/03/75	67.3	377.7	
				9/01/75	67.3	377.7	
15S/01E-09Q02 S	37		460.0	10/01/74	67.9	392.1	5400
				11/01/74	68.0	392.0	
				12/01/74	68.1	391.9	
				1/02/75	68.3	391.7	
				2/01/75	68.3	391.7	
				3/01/75	68.5	391.5	
				4/05/75	68.7	391.3	
				5/30/75	68.8	391.2	
				7/01/75	68.9	391.1	
				8/03/75	69.0	391.0	
				9/01/75	69.2	390.8	
15S/01E-09R01 S	37		450.0	10/01/74	64.6	385.4	5400
				11/01/74	64.8	385.2	
				12/01/74	64.9	385.1	
				1/02/75	65.0	385.0	
				2/01/75	65.0	385.0	
				3/01/75	65.2	384.8	
				4/05/75	65.4	384.6	
				5/30/75	65.4	384.6	
				7/01/75	65.7	384.3	
				8/03/75	65.8	384.2	
				9/01/75	66.2	383.8	
15S/01E-10N01 S	37		450.0	10/01/74	65.8	384.2	5400
				11/01/74	66.0	384.0	
				12/01/74	66.0	384.0	
				1/02/75	66.3	383.7	
SAN DIEGO HYDRO UNIT						Z-07	
LOWER SAN DIEGO HYDRO SUBUNIT						Z-07.A	
EL MONTE HYDRO SUBAREA						Z-07.A5	
15S/01E-10N01 S (CONTINUED)	37		450.0	2/01/75	66.3	383.7	5400
				3/01/75	66.4	383.6	
				4/05/75	66.4	383.6	
				5/30/75	66.5	383.5	
				7/01/75	66.7	383.3	
				8/03/75	66.9	383.1	
				9/01/75	67.1	382.9	
15S/01E-16R01 S	37		451.5	10/01/74	67.0	384.5	5400
				11/01/74	67.1	384.4	
				12/01/74	67.2	384.3	
				1/02/75	67.3	384.2	
				2/01/75	67.5	384.0	
				3/01/75	67.6	383.9	
				4/05/75	67.7	383.8	
				5/30/75	67.8	383.7	
				7/01/75	67.9	383.6	
				8/03/75	68.0	383.5	
				9/01/75	68.2	383.3	
15S/01E-16C02 S	37		440.0	10/01/74	61.8	378.2	5400
				11/01/74	61.9	378.1	
				12/01/74	61.9	378.1	
				1/02/75	62.0	378.0	
				2/01/75	62.1	377.9	
				3/01/75	62.1	377.9	
				4/05/75	62.1	377.9	
				5/30/75	62.1	377.9	
				7/01/75	62.1	377.9	
				8/03/75	62.1	377.9	
				9/01/75	62.1	377.9	
15S/01E-16C03 S	37		448.5	10/01/74	66.5	382.0	5400
				11/01/74	66.6	381.9	
				12/01/74	66.7	381.8	
				1/02/75	66.9	381.6	
				2/01/75	67.0	381.5	
				3/01/75	67.1	381.4	
				4/05/75	67.2	381.3	
				5/30/75	67.2	381.3	
				7/01/75	NM-7		
				8/03/75	NM-7		
				9/01/75	NM-7		
15S/01E-16C04 S	37		445.8	10/01/74	65.9	379.1	5400
				12/01/74	66.2	378.8	
				1/02/75	66.3	378.7	
				2/01/75	66.4	378.6	
				3/01/75	64.6	380.4	
				4/05/75	66.6	378.4	
				5/30/75	66.7	378.3	
				7/01/75	66.8	378.2	
				8/03/75	66.8	378.2	
				9/01/75	66.9	378.1	
15S/01E-16E01 S	37		435.0	10/01/74	63.2	371.8	5400
				11/01/74	63.3	371.7	
				12/01/74	63.3	371.7	
				1/02/75	63.4	371.6	
				2/01/75	63.5	371.5	
				3/01/75	63.4	371.6	
				4/05/75	63.3	371.7	
				5/30/75	63.2	371.8	
				7/01/75	63.0	372.0	
				8/03/75	62.9	372.1	
				9/01/75	62.8	372.2	
CUYAMACA HYDRO SUBUNIT						Z-07.D	
SPENCER HYDRO SUBAREA						Z-07.D2	
12S/04E-31R01 S	37		4265.0	12/18/74	240.0	4025.0	5727
13S/04E-05D01 S	37		4200.0	12/05/74	95.0	4105.0	5727
13S/04E-06A01 S	37		4220.0	12/16/74	210.0	4010.0	5727
13S/04E-06A02 S	37		4210.0	1/02/75	120.0	4090.0	5727

See page 79 for key to terms & abbreviations

TABLE C-1

GROUND WATER LEVELS AT WELLS

SOUTHERN CALIFORNIA

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
SWEETWATER HYDRO UNIT						Z-09	
LOWER SWEETWATER HYDRO SUBUNIT						Z-09.A	
SWEETWATER HYDRO SUBAREA						Z-09.A2	
17S/01W-19J01 S	37		96.4	10/04/74	14.4	82.0	5703
				1/15/75	14.4	82.0	
				5/05/75	10.8	85.6	
				6/06/75	11.0	85.4	
				7/01/75	11.3	85.1	
				8/15/75	11.8	84.6	
				9/12/75	13.0	83.4	
17S/01W-19K01 S	37		91.0	10/04/74	11.6	79.4	5703
				1/15/75	11.6	79.4	
				5/05/75	8.1	82.9	
				6/06/75	8.3	82.7	
				7/01/75	8.8	82.2	
				8/15/75	9.9	81.1	
				9/12/75	10.1	80.9	
17S/01W-30F01 S	37		71.6	10/04/74	5.4	66.2	5703
				1/15/75	3.7	67.9	
				5/05/75	2.6	69.0	
				6/06/75	3.1	68.5	
				7/01/75	3.6	68.0	
				8/15/75	4.6	67.0	
				9/12/75	5.0	66.6	
17S/01W-30F01 S	37		80.1	10/04/74	8.5	71.6	5703
				1/15/75	8.2	71.9	
				5/05/75	5.9	74.2	
				6/06/75	6.6	73.5	
				7/01/75	7.7	72.4	
				8/15/75	7.9	72.2	
				9/12/75	8.5	71.6	
17S/02W-25P04 S	37		55.0	5/05/75	5.0	50.0	5703
				6/06/75	4.9	50.1	
				7/01/75	5.3	49.7	
				8/15/75	5.9	49.1	
MIDDLE SWEETWATER HYDRO SUBUNIT						Z-09.B	
JAMACHA HYDRO SUBAREA						Z-09.B1	
16S/01E-31D03 S	37		325.8	10/04/74	10.5	315.3	5703
				1/15/75	10.9	314.9	
				4/18/75	8.5	317.3	
				5/05/75	8.5	317.3	
				6/06/75	8.5	317.3	
				7/01/75	8.8	317.0	
				8/15/75	9.6	316.2	
				9/12/75	10.2	315.6	

STATE WELL NUMBER	COUNTY	AQUIFER	GROUND SURFACE ELEVATION IN FEET	DATE	GROUND SURFACE TO WATER SURFACE IN FEET	WATER SURFACE ELEV. IN FEET	AGENCY SUPPLYING DATA
TIA JUANA HYDRO UNIT						Z-11	
TIA JUANA HYDRO SUBUNIT						Z-11.A	
TIA JUANA HYDRO SUBAREA						Z-11.A1	
19S/02W-01N02 S	37		50.2	1/03/75	36.6	13.6	5015
				2/07/75	36.3	13.9	
				3/07/75	36.2	14.0	
				4/01/75	36.1	14.1	
				5/01/75	35.6	14.6	
				6/03/75	36.2	14.0	
				7/03/75	36.5	13.7	
				8/05/75	36.3	13.9	
				9/05/75	36.5	13.7	
19S/02W-02K01 S	37		44.9	1/03/75	35.3	9.6	5015
				2/07/75	35.1	9.8	
				3/07/75	35.2	9.7	
				4/01/75	34.1	10.8	
				5/01/75	34.7	10.2	
				6/03/75	34.5	10.4	
				7/03/75	34.5	10.4	
				8/05/75	34.6	10.3	
				9/05/75	34.4	10.5	
19S/02W-02P07 S	37		38.0	1/03/75	28.3	9.7	5015
				2/07/75	27.7	10.3	
				3/07/75	27.7	10.3	
				4/01/75	27.5	10.5	
				5/01/75	27.3	10.7	
				6/03/75	26.7	11.3	
				7/03/75	26.3	11.7	
				8/05/75	26.0	12.0	
				9/05/75	26.0	12.0	
MONUMENT HYDRO SUBUNIT						Z-11.D	
PINE HYDRO SUBAREA						Z-11.D1	
15S/04E-25M01 S	37		3650.8	1/01/75	28.0	3622.8	5723
				2/01/75	28.0	3622.8	
				3/01/75	28.0	3622.8	
				4/01/75	27.5	3622.5	
				5/01/75	27.5	3622.5	
				6/01/75	26.8	3624.0	
				7/01/75	25.5	3624.5	
				8/01/75	24.8	3626.0	
				9/01/75	23.0	3627.0	
15S/04E-25N01 S	37		3640.0	1/01/75	8.0	3632.0	5723
				6/01/75	8.0	3632.0	
15S/04E-26J01 S	37		3851.0	1/01/75	47.0	3804.0	5723
				2/01/75	47.0	3804.0	
				3/01/75	47.0	3804.0	
				4/01/75	47.5	3803.5	
				5/01/75	47.5	3803.5	
				6/01/75	48.0	3803.0	
				7/01/75	48.5	3802.5	
				8/01/75	48.5	3802.5	
				9/01/75	49.0	3802.0	
15S/04E-26R01 S	37		3645.8	1/01/75	18.8	3627.0	5723
				2/01/75	18.0	3627.0	
				3/01/75	18.0	3627.0	
				4/01/75	18.0	3627.0	
				5/01/75	18.0	3627.0	
				6/01/75	17.5	3627.5	
				7/01/75	17.0	3628.0	
				8/01/75	16.5	3628.5	
				9/01/75	16.0	3629.0	
15S/04E-36F01 S	37		4000.0	1/01/75	28.0	3972.0	5723
				2/01/75	28.0	3972.0	
				3/01/75	28.0	3972.0	
				4/01/75	28.0	3972.0	
				5/01/75	26.5	3973.5	
				6/01/75	26.5	3973.5	
				7/01/75	26.5	3973.5	
				8/01/75	27.0	3973.0	
				9/01/75	27.5	3972.5	

See page 79 for key to terms & abbreviations

TABLE C-2

GROUND WATER REPLENISHMENT IN SOUTHERN CALIFORNIA

DURING THE 1974-75 WATER YEAR

Areal designation code number	Project	Agency* conducting spreading operation	Source of recharge water	Amount spread, in acre-feet												
				Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Total
U-03.A1	El Rio	UWCD	Local	0	0	385	3,079	4,941	6,495	5,041	1,230	0	0	0	0	21,171
U-03.A1	Saticoy	UWCD	Local	437	146	3,588	430	2,384	4,705	7,137	2,965	1,645	620	183	118	24,360
U-03.D1	Piru	UWCD	Local	427	0	0	0	0	0	659	2,147	1,888	424	0	0	5,545
U-05.A2	Dominguez	LACFCD	Local	19	6	513	0	242	271	82	0	0	0	0	0	1,130
U-05.A2	Dominguez Barrier	LACFCD	Imported	557	511	485	446	412	436	412	440	414	342	343	331	5,159
U-05.A2	Walteria	LACFCD	Local	16	0	218	0	124	127	72	0	0	0	0	0	577
U-05.A2	West Coast Basin Barrier	LACFCD	Imported	1,944	2,229	2,183	2,325	2,178	2,753	2,650	2,573	2,231	2,633	674	2,091	28,434
U-05.A5	Rio Hondo Combined System	LACFCD	Combined	4,870	5,070	7,362	5,293	3,969	8,259	4,430	4,169	6,747	2,049	913	919	57,055
U-05.A5	San Gabriel Spreading System	LACFCD	Combined	1,245	133	821	411	1,368	1,426	2,297	4,696	2,019	1,325	1,908	2,683	20,332
U-05.B1	Branford	LACFCD	Local	22	6	155	2	111	287	77	0	6	6	7	3	667
U-05.B1	Headworks, Los Angeles River	LADW&P	Local	381	262	123	474	94	68	405	541	660	753	461	48	4,070
U-05.B1	Big Tujunga	LADW&P	Local	0	0	0	0	0	0	0	0	0	0	0	0	0
			Imported	0	0	489	149	1,946	406	3,070	310	0	0	1,724	1,130	9,224
U-05.B1	Pacoima	LACFCD	Local	42	0	260	0	423	991	604	0	0	0	156	0	2,476
U-05.B3	Hansen	LACFCD	Local	1,731	0	0	0	0	1,333	2,359	0	0	0	0	0	5,423
U-05.B3	Lopez	LACFCD	Local	0	0	16	0	0	353	358	152	0	0	36	0	915
U-05.C1	Eaton Spreading Grounds	LACFCD	Local	0	0	0	0	0	257	68	12	0	0	0	0	337
U-05.C1	Arroyo Seco	LACFCD	Local	25	0	66	7	24	472	71	0	0	0	0	0	665
U-05.C3	Santa Anita	LACFCD	Local	0	0	0	0	0	3	0	0	0	56	0	0	59
U-05.C3	Sierra Madre	CSMWD	Imported	116	63	202	0	113	474	596	148	162	157	0	0	2,031
			Local	0	0	5	5	8	23	12	8	0	0	0	0	61
U-05.D1	Ben Lomond	LACFCD	Local	371	249	74	52	116	121	112	76	47	7	6	56	1,287
U-05.D1	Big Dalton	LACFCD	Local	0	0	0	0	0	0	237	0	0	0	0	0	237
U-05.D1	Buena Vista	LACFCD	Local	19	0	24	5	57	44	22	4	14	5	0	0	183
U-05.D1	Citrus	LACFCD	Local	0	0	0	0	0	0	0	0	0	0	0	0	0
U-05.D1	Eaton Spreading Basin	LACFCD	Local	0	0	252	0	110	138	27	0	0	0	0	0	527
U-05.D1	Irwindale	LACFCD	Local	92	0	201	0	216	520	171	109	0	0	0	0	1,309
U-05.D1	Little Dalton	LACFCD	Local	0	0	0	0	0	0	46	0	0	0	0	0	46
U-05.D1	Peck Road	LACFCD	Local	189	16	760	0	0	0	0	0	0	0	0	0	985
U-05.D1	Forbes	LACFCD	Local	0	0	18	19	81	305	39	24	290	0	0	0	686
U-05.D1	San Dimas Canyon	LACFCD	Local	55	0	0	0	120	362	34	21	194	0	0	0	786
U-05.D1	Santa Fe	LACFCD	Imported	0	2	527	35	286	1,136	787	9,045	5,036	0	325	684	17,853
			Local	0	0	100	0	0	42	4,009	0	0	0	0	0	4,151
U-05.D1	Sawpit	LACFCD	Local	72	0	93	76	124	116	171	84	0	71	0	0	809
U-05.D1	Walnut	LACFCD	Local	52	4	4	0	0	1	48	236	99	115	12	40	611
U-05.D3	Eastside Mouth Canyon Basin	SGRSC	Local	1,625	1,021	571	440	642	1,144	1,637	1,898	1,554	1,588	1,417	1,430	15,227
U-05.D3	San Gabriel River**	CAWC	Imported	841		848		716		1,159		1,594	747	755	725	7,385
U-05.E3	Live Oak	LACFCD	Local	0	0	0	0	0	0	13	0	0	0	0	0	13
U-05.E3	Thompson	LACFCD	Local	0	0	0	0	0	18	2	0	0	0	0	0	20
U-05.F1	Alamitos Barrier	LACFCD	Imported	476	473	450	413	350	385	316	340	296	257	348	356	4,442
U-05.F1	Alamitos Barrier	OCWD	Imported	70	79	70	60	60	42	62	45	55	53	62	60	718
U-05.F1	Carbon Creek System	OCFCD	Local	0	0	28	41	217	523	135	0	0	0	0	0	944
			Imported	586	0	522	0	0	0	0	0	0	0	0	0	1,108
U-05.F1	Anaheim Lake	OCWD	Imported	8,748	6,609	4,392	4,457	3,865	4,161	4,093	4,198	1,637	0	0	0	42,160
Y-01.A1	Santa Ana River	OCWD	Imported	0	0	0	0	0	0	0	14	272	213	0	0	499
Y-01.A1	Batavia-Fletcher	OCWD	Local	51	22	95	95	61	57	69	65	310	285	0	16	1,126
Y-01.A3	OC 39	OCWD	Imported	6,656	3,071	2,850	1,328	0	0	0	0	3,498	7,119	4,524	2,792	31,838
Y-01.B1	Day Canyon	EWC*	Local	59	30	10	6	20	22	140	105	23	51	31	25	522
Y-01.B1	Day Creek	SBCFCD	Local	No data available												
Y-01.B1	Eighth Street	SBCFCD	Local	0	0	0	0	0	0	0	0	0	0	0	0	0
Y-01.B1	Linden	SBCFCD	Local	0	0	0	0	35	81	14	0	0	0	0	0	130
Y-01.B1	Monclair	SBCFCD	Local	0	0	0	0	12	32	1	0	0	0	0	0	45
Y-01.B1	San Sevaine	SBCFCD	Local	No data available												
Y-01.B3	City of Pomona	CPWD	Local	20	0	14	0	17	136	55	16	0	0	3	2	263
Y-01.B4	Red Hill	SBCFCD	Local	2	0	63	0	19	124	0	0	0	0	0	0	208
Y-01.B4	19th Street and Cucamonga	SAWC	Local	62	124	325	179	290	610	628	449	128	47	37	49	2,921
Y-01.C1	Mayhew Wash	TWC	Local	0	0	18	0	12	106	0	0	0	0	0	0	136
Y-01.C4	Indian Creek	TWC	Local	0	0	0	0	27	60	0	0	0	0	0	0	87
Y-01.C4	Horsethief Creek	TWC	Local	0	0	0	0	32	0	0	0	0	0	0	0	32
Y-01.C4	Cow Creek	TWC	Local	0	0	0	0	6	0	0	0	0	0	0	0	6
Y-01.E2	City Creek	SBCFCD	Local	59	74	199	128	312	743	743	293	48	19	5	6	2,628
Y-01.E3	Devil Canyon	SBCFCD	Imported	0	90	0	0	0	0	0	0	0	0	0	0	90
			Local	56	74	136	108	185	329	257	179	138	95	66	58	1,660
Y-01.E2	Patton	SBCFCD	Local	No data available												
Y-01.E2	East Twin Creek	SBCFCD	Local	51	63	107	128	166	383	273	192	92	46	26	24	1,551
Y-01.E2	Waterman Canyon	SBCFCD	Imported	0	0	0	254	218	196	0	0	4	0	0	398	1,070
			Local	34	37	68	58	93	197	179	131	85	43	23	13	961
Y-01.E3	Santa Ana River	SBVWCD	Local	33	164	1,630	331	1,496	2,875	3,121	629	0	0	0	0	9,699
Y-01.E4	Mill Creek (Lower)	SBVWCD	Local	0	0	15	16	62	303	312	0	0	0	0	0	708
Y-01.E9	Lytle Creek	FUWC	Local	68	41	19	0	45	76	137	9	0	0	0	0	395
Y-01.F9	Little San Gorgonio	RCFC&WCD	Local	0	0	0	0	0	0	0	0	0	0	0	0	0
Y-02.B1	Bautista Creek	RCFC&WCD	Local	9	5	9	2	17	32	67	0	0	1	1	0	143
Y-01.B1	San Jacinto	EMWD	Local	0	0	0	0	0	233	560	33	0	0	0	0	826

* Abbreviation of agencies conducting spreading operations are presented in alphabetical order: CAWC, California-American Water Company; CPWD, City of Pomona Water Department; CSMWD, City of Sierra Madre Water Department; EMWD, Eastern Municipal Water District; EWC, Etiwanda Water Co.; FUWC, Fontana Union Water Co.; LACFCD, Los Angeles County Flood Control District; LADW&P, Los Angeles Department of Water and Power; OCFCD, Orange County Flood Control District; OCWD, Orange County Water District; RCFC&WCD, Riverside County Flood Control and Water Conservation District; SAWC, San Antonio Water Co.; SBCFCD, San Bernardino County Flood Control District; SBVWCD, San Bernardino Valley Water Conservation District; SGRSC, San Gabriel River Spreading Corporation; TWC, Temescal Water Company; UWCD, United Water Conservation District.

** Estimated amounts

83. Swanberg v. O'Mectia. 84 Daily Journal D.A.R. 2237, 203 Cal Rptr. 701, (D.C.A. 2, 1984)

have analyzed data that have this counseling process and, as far as none of the studies has attempted in- verify the "truth" of the clients' recollec- or to determine the legal implication of the clients' fac- al accounts.[12]

Because it was developed for an entirely different pur- se than, for example, the battered child syndrome, rape rau[illegible]ndrome represents a distinctly different concept han the battered child diagnosis described in Jackson. It oes not consist of a relatively narrow set of criteria or mptoms whose presence demonstrates that the client or atient has been raped; rather, as the counselor in this case estified, it is an "umbrella" concept, reflecting the broad ange of emotional trauma experienced by clients of rape ounselors. Although there are patterns that have been bserved, the ongoing studies reveal that a host of variables ontribute to the effect of rape on its victims; as one recent tudy concluded: "(c)learly, the concept of a typical rape ictim has no place within the context of post-rape adjust- ent." (McCahill et al., The Aftermath of Rape, supra, p. 5.)[13]

Given the history, purpose and nature of the rape auma syndrome concept, we conclude that expert estimony that a complaining witness suffers from rape auma syndrome is not admissible to prove that the witness as raped. We emphasize that our conclusion in this regard not intended to suggest that rape trauma syndrome is not enerally recognized or used in the general scientific com- unity from which it arose, but only that it is not relied on in at community for the purpose for which the prosecution ought to use it in this case, namely, to prove that a rape in act occurred. Because the literature does not even purport claim that the syndrome is a scientifically reliable means *proving that a rape occurred, we conclude that it may not* properly be used for that purpose in a criminal trial.

We hasten to add that nothing in this opinion is intended im[illegible] that evidence of the emotional and psychological auma that a complaining witness suffers after an alleged ape is inadmissible in a rape prosecution. As discussed in e statement of facts, in this case numerous witnesses, in addition to the rape counselor, described the severe emo- onal distress that Melanie exhibited both in the house im- ediately following the attack and in subsequent weeks. nd, as defendant implicitly concedes, there is no question t that such evidence was properly received. Lay jurors re, however, fully competent to consider such evidence in etermining whether a rape occurred, and "(p)ermitting a erson in the role of an expert to suggest that because the omplainant exhibits some of the symptoms of rape trauma ndrome, the victim was therefore raped, unfairly pre- udices the appelant by creating an aura of special reliabili- and trustworthiness.'" (State v. Saldana, supra, 324 W.2d at p. 230. See generally People v. Arguello (1966) 244 al.App.2d 413, 420-421.)[14]

Accordingly, we conclude that the trial court erred in mitting the rape counselor's testimony on rape trauma ndrome. The question remains wheter the error was pre- udicial. We conclude that it was not. The prosecution's case ainst defendant was very strong. On her return from fendant's residence, Melanie immediately told her iends that she had been sexually attacked; her numerous ruises and extreme emotional distress provided per- asive corroboration of her testimony that she had not con- nted to the sexual encounter. Although the defense was ble t[illegible]t doubt on some of Melanie's testimony, and the

JUDGE:
Robert R. Fitzgerald

HGP
EJ2

TORTS

Landowner Duty to Landscape Not Delegable to Tenant

Cite as 84 Daily Journal D.A.R. 2237

RON SWANBERG and PAULA SWANBERG,
Plaintiffs and Appellants,
v.
THOMAS O'MECTIN and PRISCILLA O'MECTIN,
Defendants and Respondents.
No. B002103
(LASC No. C-222118)
IN THE COURT OF APPEAL OF THE
STATE OF CALIFORNIA
SECOND APPELLATE DISTRICT
DIVISION FIVE
Filed June 19, 1984

On February 24, 1977, plaintiff Ron Swanberg was seriously injured when the motorcycle he was driving collided in an intersection with an automobile operated by defendant, Debbie Popovich. Plaintiff Swanberg, along with his wife, Paula, filed suit for their personal injuries and property damage on December 2, 1977.[1] Named as defendants were Popovich as well as Thomas and Priscilla O'Mectin. In their complaint, the Swanbergs alleged that their injuries were proximately caused by defendant Popvich's negligent operation or maintenance of her vehicle. In addition, the complaint alleged that the injury was due to the negligent maintenance of certain shrubs growing from the O'Mectins' land, which obscured defendant Popovich's view of vehicular traffic approaching the intersection.

The case went to trial by jury on November 16, 1982, at which time the court dismissed defendant Popovich from the complaint. In substance, plaintiffs proceeded against the remaining defendants on the theory that pursuant to statutory and common law, defendants, as landowners, were affirmatively obligated to maintain their premise in a reasonably safe condition so as not to endanger users of the adjacent public street.

The evidence adduced at trial established that defendants had not had actual possession of their property since 1966 or 1967, and that successive tenants of the property were responsible for the yard work in accordance with the terms of their leasehold agreements. The defendants themselves never cut any of the shrubbery and although they lived some 45 minutes from the property, they visited same only two or three times in the three years prior to the collision. Further, defendants never checked to see if the tenants were taking care of the shrubbery or for that matter whether the shrubs were growing out into the street and thus hindering traffic.

In determining the instructions which were to be asked of the jury, the court refused plaintiffs' request for BAJI instructions, No. 8.00 and No. 8.20. These instructions require a lessor to exercise reasonable care to inspect his property for a dangerous condition which may expose other persons to unreasonable risk of harm.[2] Instead, the court determined that the jury should be instructed that defendants could be held liable for a dangerous condition on their property causing injury to others outside the land, only if defendant

landowner had actual knowledge of that condition.[3]

Given the foregoing principles for guidance, the jury rendered a verdict in favor of defendants. Subsequent thereto, a motion by plaintiffs for a new trial was denied which was followed by this appeal.

DISCUSSION

Plaintiffs contend that the trial court erred in instructing the jury that a lessor must have actual knowledge of the dangerous condition of his property, as a prerequisite to finding the lessor liable for injuries to persons off the property caused by the dangerous condition. Thus, the preeminent issue is whether actual knowledge is essential for landowner/lessor — liability, given the above circumstances. Of secondary but equal concern, is whether a landowner can immunize himself from liability for a known or discoverable hazard on his property, by contracting away said obligation to his lessee or tenant.

In California, it has long been the law that a person may be liable for injuries resulting from his failure to use ordinary care in the management of his property. (Civ. Code, Sec. 1714; Lipson v. Superior Court (1982) 31 Cal.3d 362, 372.) It makes no difference whether the danger posed by said lack of care manifests itself in the form of a natural as opposed to an artificial condition on the property. (Sprecher v. Adamson Companies (1981) 30 Cal.3d 358.) Further, a landowner may face liability for injury to another, incurred outside of the former's property (on an adjacent street), if the injury is found to be caused by a traffic obstruction in the form of shrubbery growing from the property. Wisher v. Fowler (1970) 7 Cal.App.3d 225.)

Although liability might easily be found where the landowner has actual knowledge of the dangerous condition, "(t)he landowner's lack of knowledge of the dangerous condition is not a defense. He has an affirmative duty to exercise ordinary care to keep the premises in a reasonably safe condition, and therefore must inspect them or take other proper means to ascertain their condition. And if, by the exercise of reasonable care, he would have discovered the dangerous condition, he is liable." (4 Witkin, Summary of Cal. Law (8th ed. 1974) Torts, Sec. 592, p. 2860; emphasis in original.) Accordingly, it would appear that actual knowledge is not an absolute requirement for finding liability here.

Unfortunately, it is not clear whether the above authority applies merely to the owner of property under all circumstances, or solely to an owner in possession. In the matter sub judice, the trial court's disallowance of jury instructions embodying the above tenets of law, was undoubtedly grounded upon a belief that a landowner can exempt himself from said affirmative duty, by leasing his property and therein relinquishing his right to control same. Although we are in accord with the general principle that a party should not be held liable for conditions beyond his control, in this case the evidence strongly suggests that the landowner could have easily controlled his property, and further, that said duty to control is nondelegable.

The authority underlying the court's rejection of the proffered jury instructions is the case of Uccello v. Laudenslayer (1975) 44 Cal.App.3d 504. Uccello involved an action against a landlord brought by an invitee who received injuries from a vicious dog kept on the leased premises. The Uccello court emphasized that actual, as opposed to constructive, knowledge was a requisite for finding the landlord liable. The reason for the distinction being rooted to the historical doctrine that a landlord who leases his property, surrenders virtual control of his land to the lessee, absent an agreement to the contrary. (Uccello, supra, at pp. 510-511; see also com. (a) to Rest., Torts, Sec. 355.) Because said loss of control includes the right of a landlord to reenter the property without the lessee's permission, short of abridging the latter's right of quiet enjoyment, amongst other privacy law considerations, the landlord is in no position to reliably determine whether or not a tenant/lessee is harboring a dangerous animal.[4]

In contrast, this case does not involve a "transitory" and "easily-concealed" danger such as an animal with vicious propensities. On the contrary, it involves a portion of the property easily viewed from the outside of same. In fact, it was so easily viewed, as alleged, that it may have constituted a menace to persons off the land on the adjacent street. For this reason, we find Uccello v. Laudenslayer, supra, 44 Cal.App.3d 504 inapplicable to the instant case.

Aside from the inapplicability of Uccello, it would appear that the O'Mectins' duty to care for their property, so as to reasonably avoid injury to others, outside the perimeters of their land, was nondelegable.

At the outset, the parties pose a seeming incongruity in the law, as applied to the respective duties of a landlord and tenant, where maintenance of leasehold property is required by statute. On the one hand, it is said that "Since the property owner is initially under the duty to comply with all laws and orders, he, as lessor, remains subject to that duty unless it is assumed by the lessee." (Glenn R. Sewell Sheet Metal, Inc. v. Loverde (1969) 70 Cal.2d 666, 672; emphasis added.)[5] On the other hand, our Supreme Court has held that the owner of land who constructs a driveway adjacent to her property and who is thus duty bound by law to maintain same, ". . . could not relieve herself of such duty either by leasing the same . . . to her (tenant) or by contracting with him by the terms of said lease for the keeping of said premises and said driveway in a proper state of repair." (Granucci v. Claasen (1928) 204 Cal. 509, 512.)

The difference in the two holdings may be reconciled by characterizing the holding in Glenn R. Sewell Sheet Metal, Inc. v. Loverdi, supra, 70 Cal.2d 666 as the rule and the Granucci holding as the exception. As such, Granucci would appear to fall within one or two of the five exceptions delineated in Ucello v. Laudenslayer, supra, 44 Cal.App.3d at page 511. namely, ". . . where there is a nuisance existing on the property at the time the lease is made or renewed (citation), (or) when a safety law has been violated (citation), . . ."

Because we are unaware of any specific date upon which the subject shrubbery first became an alleged traffic hazard, we choose not to consider whether the hazard existed at the time defendants last rented their property, a point representing defendants' last "unequivocal" opportunity to carefully inspect same. (See Burroughs v. Ben's Auto Park, Inc. (1945) 27 Cal.2d 449, 453-454.) However, were it to be established that defendants should have anticipated that plant growth from their property could or would pose a potentially serious danger to travelers off the land, in violation of a municipal ordinance prohibiting said overgrowth (Los Angeles Municipal Code Sec. 62.200), the act of renting the premises and putting another party in possession does not relieve defendants of their duty nor would it immunize them from liability. (See Grant v. Hipsher (1967) 257 Cal.App.2d 375, 383; see also Stanford v. Bailey Incorporated (1955) 132 Cal.App.2d 725, 729-730.)[6] [7]

Given the error respecting the instructions that defendant landlords were required to have "actual knowledge" of the dangerous condition, it becomes highly probable that said instructions contributed to a defense verdict. Since evidence exists that defendants could and should very well have discovered the defect in a reasonable time prior to the time of collision, coupled with the fact that some evidence suggests that the overgrown flora substantially contributed to the collision injuring plaintiffs, it is difficult not to conclude that a different result would have been possible if said instructions were not given. Thus, the instructional error was prejudicial. As a result, the judgment is reversed. (Code Civ. Proc., Sec. 475.) Costs to be awarded to plaintiffs/appellants.

CERTIFIED FOR PUBLICATION.

STEPHENS, Acting P. J.

We concur:

ASHBY, J.

HASTINGS, J.

---

1. Paula Swanberg alleged a loss of consortium.

2. In relevant part, BAJI No. 8.00 (1977 Revision) states:

"'The (owner) (occupant) (lessor) of premises is under a duty to exercise ordinary care in the management of such premises in order to avoid exposing persons thereon to an unreasonable risk of harm. A failure to fulfill this duty would be negligence.'"

In relevant part, BAJI No. 8.20 (1977 Revision) states:

"'The (owner) (occupant) (lessor) of premises is not liable for an injury suffered by a person on his premises which resulted from a dangerous or defective condition of which the (owner) (occupant) (lessor) had no knowledge, unless the condition existed for such a length of time that if the (owner) (occupant) (lessor) had exercised reasonable care in inspecting the premises he would have discovered the condition in time to remedy it or to give warning before the injury occurred."

3. The actual instructions involving this issue, as settled upon by the court, read:

"In the absence of an agreement to the contrary, a lessor of real property surrenders both possession and control of the land to the lessee, retaining only a reversionary interest; and he has no right to enter without the permission of the lessee. Consequently, it is the general rule that the lessor is under no obligation to anyone to look after the premises or to keep them in repair, and is not responsible, either to persons injured on the land or to those outside of it for conditions which develop or are created by the tenant after possession has been transferred. Neither is he responsible, in general, for the activities which the tenant carries on upon the land after such transfer.

"A landlord is not held liable for injuries from conditions over which he has no control. However, if you find from the evidence that the lessor of the premises has actual knowledge that the tenant has created an unreasonable risk of harm, and if you further find from the evidence that the landlord has such a degree of control over the premises, it fairly may be concluded that he could obviate the unreasonable risk of harm, then the landlord is under a duty to exercise ordinary care to avoid exposing persons that a reasonably prudent person of the same or similar circumstances should have foreseen would be exposed to such risk of harm.

"The landlord is under no duty to inspect the premises for the purpose of discovering the existence of an unreasonable risk of harm created by the tenant and only when the landlord has actual knowledge of an unreasonable risk of harm created by the tenant coupled with the right to have it" removed from the premises, does the duty of care arise.

"A lessor of land, subject to a month to month tenancy, is not subject to liability in negligence for bodily harm to other outside the land caused by any dangerous condition upon the land which come into existence after his lessee takes possession unless:

"1. the lessor has actual knowledge of the condition, and;

"2. he realizes or should realize that the condition poses an unreasonable risk of bodily harm to persons outside the land, and;

"3. he possesses such knowledge at least thirty days prior to the date of the occurrence resulting in bodily harm to another."

The court also instructed the jury that a violation of Los Angeles Municipal Code section 62.200 (prohibiting the obstruction of visibility at a street intersection by shrubbery growing on adjacent property) could be the basis for negligence with the caveat: "You cannot find that any defendant violated this section unless you first find that such defendant had actual knowledge of the obstruction."

4. Plaintiff notes that ". . . even a careful inspection of the premises may not disclose the animal, which could be elsewhere at the time; or, if the animal is disclosed, it may not be obvious that the animal is dangerous."

5. That court suggested that a lessee might assume responsibility for compliance with laws and orders by virtue of the leasing arrangement itself. Thus, the lessee affirmatively undertakes to satisfy legally required activities ". . . that are truly minor in expense and inconvenience, that arise out of the ordinary course of the lessee's use of the premises, and that would in no event impose upon the lessee a burden greater than that imposed by the common law duty to prevent waste." (70 Cal.2d at p. 672, fn. 6.)

In addition, the court noted that accountability might be assumed by the lessee's changed use of the property causing it to fall within the realm of existent law not previously applicable. Recognizing under these circumstances that if the lessee were not held responsible, ". . . (the lessee) would have the lessor at his mercy." (Id., at p. 673.) However, the court was quick to note that it made no comment on this rule regarding situations where the lease restricts the use of the premises or where the lessor has a direct interest in the specific use to which the lessee puts the premises. (Id., at p. 673, fn. 8.)

6. We make no comment as to the viability of any claim for indemnification by lessor against lessee.

7. It bears noting that in these cases, the violation of a safety law was such that it might pose a danger to the general public. Here, a shrub obstructing a public thoroughfare unassailably achieves the same effect.

84. Tallard, Gilbert M., Slurry Trenches for Containing Hazardous Wastes, Civil Engineering, ASCE, February 1984

2646
2647
2648

Slurry trench technology has not advanced much during the past 10 years, says the author. He reviews today's state-of-the-art, laboratory testing practices, and describes future developments and alternative technologies.

GILBERT TALLARD

SLURRY TRENCHES FOR CONTAINING HAZARDOUS WASTES

Although slurry trench methods are becoming standard practice for protecting aquifers endangered by contamination, viewing this as a panacea would be an oversimplification that could have grave consequences. To date, no comprehensive studies have been carried out in the field in achieving a level of knowledge that would provide more performance assurance and guarantees to owners and authorities. This is due to the lack of cooperation between all the parties involved in a project and the exacerbated litigious climate prevailing in the environmental protection field.

TODAY'S STATE OF THE ART

Slurry trench technology has been developed primarily to prevent clean groundwater from seeping through impounding structures or into large excavations. One should distinguish, however, between two fundamentally different technologies for forming a slurry trench cutoff: the first excavates the trench with a pure bentonite slurry, and then backfills it with various materials all of which have a high proportion of aggregates; and the second excavates the trench by using a slurry which is a grout mixture that, after playing its role as a trenching fluid, sets in place and forms the barrier itself.

For the last 30 years, slurry trenches have been installed in the United States for controlling groundwater seepage, and for the past 10 years to prevent groundwater contamination from spreading. The state of the art evolved dramatically when hydraulic excavators became available. This allowed narrower trenches than was possible with draglines and much deeper trenches than was possible with cable backhoes. The increased rate of trenching forced the development of high capacity semi-automatic slurry mixing plants. As a result, the cost of trench excavation fell, which allowed more money to the elaboration of a quality backfill material and expanded the field of application.

SOIL BENTONITE TRENCHES

The most widely used method in the United States is the soil bentonite slurry trench. Permeability coefficients of 10^{-8} cm/sec are common, with the proper aggregate grain size distribution and adequate amount of fines passing the #200 sieve. With regard to pollution control, improvements are being made with this method in the chemistry of the bentonites used for slurrying and backfill preparation. Some manufacturers (American Colloid, Federal Bentonite, for example) are offering specially manufactured and treated bentonite products either as a multipurpose material (the Saline Seal of American Colloid) or engineered for specific conditions (the Ultra Seal X of Federal Bentonite). If these manufacturers are given the opportunity to test the leachates against their products, they will provide a guarantee for 20 to 40 years, which is a strong encouragement for the users, if not a legal hand rail.

Bentonite is not the only criterion in establishing quality, for the type of mixing method used in

0360-0556/84/0002-041/$01.00

soil bentonite backfill preparation will also have an impact on the quality of the mix. The author has experienced significantly higher densities with backfill prepared in a batching pugmill compared with the same mix prepared by blading on the ground by a bulldozer (Addicks Dam repair, Houston). Blading is the standard procedure when practical; it is also more economical.

There has been a debate over the additional benefit of the bentonite cakes that form on the walls of the trench during construction. The debate is academic—a cake forms against pervious soils during and after the excavation takes place and until the trench is more or less sealed. Numerous field observations have led the author to conclude that most of the cake is removed physically by the scraping action of the backfill talus moving along with the excavation. This does not mean that all the cake is gone, but one should not assume the cake is present when evaluating the future performance of the cutoff trench (which leaves the backfill material all the more important).

CEMENT BENTONITE TRENCHES

Cement bentonite trenches originated in Europe, and have been introduced in the U.S. during the last 10 years in direct competition with the soil bentonite trenches. The self-hardening slurry is more expensive than pure bentonite slurry but it eliminates all backfilling operations, which greatly simplifies construction. When the ground is unstable, a cement bentonite trench is preferred over a soil bentonite trench, since the open fluid trench is shorter. The cement bentonite slurry, generally also used for trenching, has poor filtrate loss characteristics. This means that the walls of the trench are not sealed as well as when pure bentonite is used and implies a continuous loss of water to the ground until setting takes place. The end-product ends up with a water/cement ratio substantially lower than that of the initial slurry. This factor is dependent on the soils characteristics and the groundwater table elevation, and it should be taken into account when writing specifications, preparing costs estimates and when performing the work.

During trenching, soil particles are carried in suspension and start segregating as soon as the slurry is left to rest. Similarly, the larger grains of cement will have a tendency to segregate and concentrate at the bottom. The end-product is a heterogeneous material of variable characteristics from top to bottom. One way to mitigate both this and the water loss to the ground, is to accelerate the self-hardening slurry, within practical limits, by using finer cement and additives, thus minimizing the filtration time and the segregation of cement. Viscosifiers and plugging agents can be added to achieve this, the decision being an economic one.

Cement bentonite trenches are performing very well in preventing groundwater contamination by hydrocarbons. Although much less sensitive than concrete to chemical aggression in the case of acid or alkaline solutions, prior evaluation is necessary before considering this type of material.

TESTING

All materials used for slurry trench cutoff construction are essentially tested on a permeability performance basis. These tests are generally performed on samples made in the laboratory—not at the design stage, but prior to construction. Most of these materials are weak and therefore very difficult to sample in situ for quality control. It is rare to find a specification that will specify the following modus operandi for permeability testing: sample dimensions; equipment; preconsolidation; percolation fluid; temperature; presaturation; gradient; duration; and chemical analysis of filtrate. It is therefore easy to understand why different testing procedures on the same material will yield different results and different materials tested differently can be made to meet a too simplistic specification.

The Clifton laboratory of Woodward Clyde Consultants and its director Richard Ladd have developed permeability procedures that should be accepted as a standard in this domain. Some of these are preconsolidation of the sample; complete saturation of the sample; high and low gradients; permeameter—triaxial cell with plastic membrane; and percolation distilled water and leachates. An ASTM committee on slurry trenches has been organized to come up with standards, but none has yet emerged.

Besides permeability testing—using the leachates as percolating fluids— there are no standards for evaluating the performance of cutoffs. Since their long term behaviour cannot yet be assessed in the laboratory, that leaves individual judgement. The substitute to this lack of scientific knowledge is the owner's quest for a lifetime guarantee on the performance of the cutoff.

The emphasis on permeability is a remnant of seepage control specifications. However, except perhaps for tailing dams, most slurry trench cutoffs are subject to a minimal gradient, if at all, when not a negative one. Hydraulic gradients will generally be from 1 to 5, up to 10, and gradients used for permeability testing generally vary between 20 and 50. Under most cases, a gravity flow through the cutoff may never occur. If this is so, then why are cutoff wall materials primarily tested for permeability when they are used for waste confinement? An interesting parameter to introduce in the testing of cutoff wall materials is the threshold of gradient at which percolation through a saturated sample will occur. This threshold could be called "percolation resistance," from which a safety coefficient with respect to filtration could be derived.

Another factor often overlooked is that lab test samples may be substantially different from the materials in situ. To compound this problem, cutoff wall materials generally being very weak, they are extremely difficult to sample in situ. Only large size sampling can result in reliable data. Further, as a general rule, the characteristics of the materials will vary with depth.

If one figures that—in many cases and probably in most hazardous waste situations—the cutoff is subjected to a negative gradient (in that the leachate piezometric level is kept below the general aquifer), the permeability characteristic is obviously not the

prevailing one anymore.

To illustrate: concrete is stronger and more impervious by 1 or 2 orders of magnitude than soil bentonite or cement bentonite; however, the absence of clay and a high concentration of pure cement leads to much faster chemical degradation in either an acidic or alkaline environment. One therefore questions why a concrete cutoff wall was specified for the Love Canal cleanup project, for example.

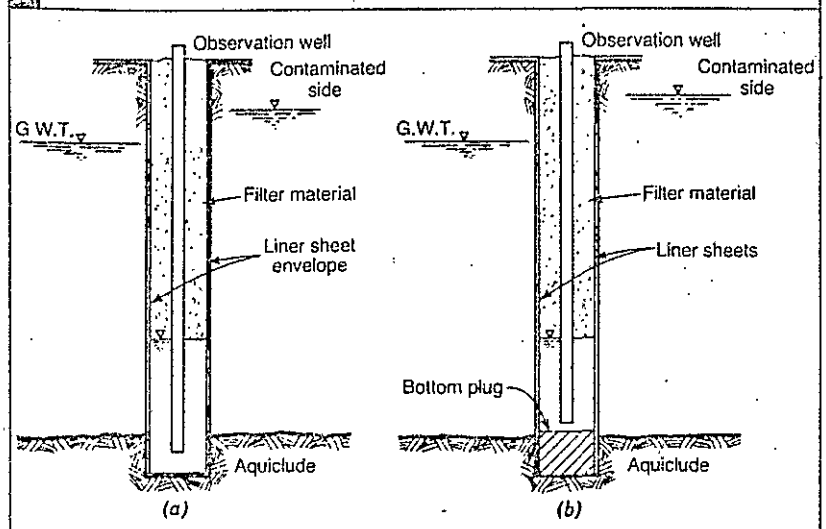
More important than Darcy's K, one should think of corrosion when contemplating any backfill material that has to withstand chemicals over a very long period of time.

Areas to investigate would include: migration by capillarity; electrical potentials; ion migration & exchange; surface reactions and neutralizations; permeability to gasses (dissolved in leachate); osmosis; and chemical corrosion. It appears that the chemical engineer and the physicist must work with civil, geotechnical and hydrological engineers to complete the full evaluation required for this very sensitive subject. The scope of studies I am alluding to can rarely fit in the time frame allocated for testing within the traditional contracting framework. But in a design-construct approach, teamwork allows you to simultaneously use all the necessary talent to achieve a higher level of sophistication. Also, formal research should be carried out in university laboratories to develop basic statistical knowledge and a refined understanding of the interactions between leachate and barrier materials.

I must stress here how unsophisticated cutoff wall material technology is today, greatly due to separating the role and responsibility of the design engineer—who is often unfamiliar with the technology or has an oversimplified view of it—and the construction engineer—who has neither the incentive nor the time to become inventive.

Another obstacle in designing an effective cutoff wall for hazardous waste is the frequent lack of adequate information. There is a natural reluctance for owners to know more about what they should, thus increasing their liability. In addition, sites can be of such dimensions that sampling becomes a hit-and-miss operation and substances may be left out of the inventory. In the case of manufacturing installations, where the manufacturing process is known, the substances disposed of are easily inventoried. But when generations of different industries have used the same site or when a variety of sources share waste disposal areas, the inventory of chemicals present at the site can only be done through extensive sampling. When analysing concentrations, keep in mind the hit-and-miss approach from which the data is issued.

FIGURE 1
SELF-CONTAINED MONITORING BARRIERS



Hazardous waste barrier with self-contained monitoring. (A) is an Enviro-Wall (Icos patent) double sheet envelope system. (B) is an equivalent system with two single sheets and a bottom plug.

BEYOND TODAY'S STATE OF THE ART—SOIL BENTONITE TRENCHES

Dressed bentonites were mentioned earlier as a recent advancement made in waste confinement technology. An area that has not been explored from a chemical view is the fines included in the aggregate. In a regular backfill mix, the bentonite solids represent 1 to 2% of the whole mass, gelled in 4 to 8% of void. Ten to 15% of the backfill mass are passing the #200 sieve and, when mixed with the bentonite slurry, form the paste filling the voids of the aggregate. These fines may be silts, clays or other soil properties, which should be analysed chemically, and the fines-bentonite paste should be tested for chemical resistance for specific site conditions. This approach may lead to consider the fines as filler (a third ingredient in the mix) that is separate from the aggregate. If clean aggregates are used, the filler can be designed to combine with the bentonite to achieve an optimum chemical resistance for a specific case.

Further, the common practice of sluicing hydrated bentonite slurry with the backfill aggregate should be reexamined. In terms of chemical resistance, bentonite is not at its best when fully hydrated. This is why "chemically resistant" bentonites require the shield of a polymer. Engineers eventually specify for the backfill mix additional dry bentonite (2 to 6% by weight). This practice is often criticized because of the additional material cost and of spreading with no appreciable benefit on a strict permeability testing basis, once the fine content (passing the #200 mesh sieve) is above 10% of solids by weight. However, on the basis of chemical resistance, it may well provide an improvement by introducing poorly hydrated bentonite. This allows the voids to be filled by more solids and enhances the backfill density. Further, it impedes the movement of liquids and resulting chemical interactions.

This leads to why bentonites or

other high swelling clays are used at all as a component of soil backfill mixes when chemical resistance is the prime consideration. So far, the distinction has not been made between the bentonite used for the trenching mud—which stabilizes the sides of the excavation—and the plastic clay filler that complements a well-graded aggregate for backfilling the trench and creating the impervious barrier. Again this derives from the traditional focus on permeability testing in the area of clean water, high gradient, seepage control situations.

The fine fraction of the backfill constitutes a paste that should be considered and analysed as a distinct material. My suggestion is that specific research be undertaken for determining which minerals, in a colloidal form, are more desirable from a chemical stability standpoint, then choosing the corresponding natural materials—which may belong to groups other than bentonites.

Because of potential costs, little research has been done on obtaining backfill mixes using a synthetic product as paste, giving the backfill mix a resistance to a specific site condition. Emulsions would be appropriate for mixing with concrete equipment. The only practices resemblying this idea were the hot asphalt and cold emulsions concretes used in slurry walls for seepage control in Europe and Australia in the 1960s. High costs forced it to be abandoned for clean water projects but it may be "re-opened" for waste containment.

C.B. TRENCHES

Since cement bentonite slurry is a liquid grout, it can be modified in many ways by adding additives. Such slurry can be retarded or accelerated and the rheology of the system can be modified to increase its rigidity at rest without increasing its dynamic viscosity by using special cements (Type V, for example). In environmental projects the strength of the material is immaterial. You should therefore minimize the cement content when it is economical to do so.

Contaminants in fly-ash?

As coal is being used again across the nation, fly-ash is available in many areas of the country. When used, it can substantially reduce the cement content and provide a beneficial flowing effect. A slurry with fly-ash will contain more solids than without it and be less permeable and more resistant to chemicals. If the problem is the permanence of the cement bentonite grout in either high or low pH solutions, the slurry can be boosted with slow-release salts to enhance a superficial neutralization that will protect the rest of the cutoff within the "percolation resistance" limits of the material.

Cement bentonite, self-hardening slurries are appealing because of the simplicity of the construction process. However, little research is being done to boost the resistance of the material to eventual chemical attack.

OTHER CUTOFFS

Two techniques that do not pertain to slurry trench technology but either claim or could claim to be a valid substitute to slurry trenches are the *thin diaphragm*(or beam injection) *system* and the *jet grouting panel wall*.

Over the last 10 years, there has been a rebirth in the U.S. of the thin diaphragm, which is a European technology using a soil bentonite grout as an end product. With the advent of modern slurry trenching equipment during the 1960s, the interest in this cutoff technology has diminished. Thin diaphragms are still being installed in Europe, often for the repair of levees in connection with flood control or for dewatering excavation—where clean water is the permeant, the use is often temporary, and the degree of efficiency is not required to be what is expected of hazardous waste barriers. Since the U.S. style soil bentonite slurry trench has never been introduced in Europe, the thin diaphragm can be more economical than the wider cement bentonite slurry cutoff.

In the U.S., polymerized asphalt emulsion compounds are providing a modern component to this old technique, opening some fields of application in pollution control. Quality control in terms of diaphragm integrity is difficult to establish since small collapses caused by local soil instability or the vibration itself can cause windows in the cutoff that cannot be detected during construction. Consequently, a responsible guarantee of long-term performance would be hard to come by. For shallow cutoffs and nonhazardous waste sites, the process provides a solution for seepage control that should be considered. However, be aware that in terms of price per vertical square foot of diaphragm, which may be cheaper than that of a slurry trench, it represents only 2 to 4 inches in thickness compared to 2 or 3 feet for the slurry trench. The method will always be more expensive based on a per cubic foot of cutoff.

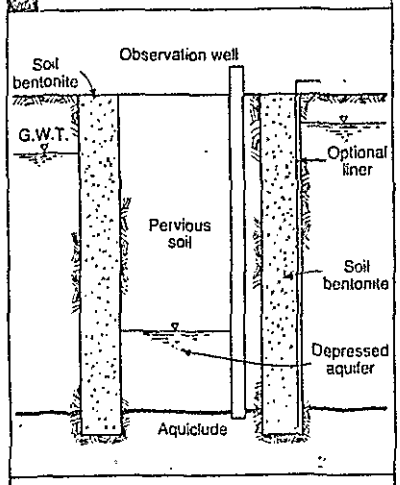
A promising technology for economical and reliable cutoff construction is the jet grouting panel wall construction method that was invented by the Japanese. The name is misleading in that the jetting action excavates with pressurized water and air, while the grout filling the excavation is being jetted at a lower level of energy. Although the Japanese had cement grouts for seepage control, a similar process for ground treatment does use chemical grouts. It is perfectly conceivable that synthetic grouts could be used at affordable prices. This technology, providing a cutoff of 4 to 8 inches and being subject to sophisticated quality control, is appealing for waste containment projects, especially on industrial sites where numerous obstacles and utilities are usually in the way of a vibrating beam or a slurry trench operation.

SYNTHETIC LINERS IN COMPOSITE SLURRY CUTOFFS

The concept of installing a synthetic liner in a slurry trench excavation is an old one but installation difficulties have seriously limited the development of this process. However, the seriousness of the hazardous waste situation and the marketing efforts of certain liner manufacturers in the United States have given an impetus to finding practical ways to overcome the difficulties of installation.

The major advantage of a synthetic liner is that its material can, to some extent, be custom made to resist specific site contaminents. With any cutoff, the condition of continuity is paramount, but seaming and site welding are prov-

FIGURE 2
DOUBLE SLURRY TRENCH



Double slurry trench with in between monitoring of pervious soil.

en techniques today.

If using a liner reduces the slurry trench backfill to a pure physical support role, its cost could then be minimized. However, in waste containment situations, more than anywhere else, the belt and suspender approach is justified and conventional soil bentonite or cement bentonite should be considered if economically viable.

Another attractive feature that liners can provide within the same trench: a double liner sheet envelope backfilled with pervious material that permits you to monitor, through observation wells, eventual contaminent ingress through the inside liner and that also allows repair inside the containment area with the protection of the outside liner. (How to repair remains to be invented!)

The water level in the filter material is lowered in order to create introvert gradients through the liner sheets. Regularly spaced risers allow automatic monitoring and sensing. Although a double sheet envelope has been installed at a test site by Icos Corp. of America, no such system has yet been installed industrially. (See Fig. 1.)

It is clear that for such an approach to be marketable, the economics must be in favor of digging one trench and placing the envelope in it instead of building two parallel trenches with or without liner on the contaminated side. If you can observe a failure of the inside trench without taking the risk of contaminating the outside one, you may question the additional cost of having to install a synthetic liner at all. (See Figure 2.)

The difficulties of installation mentioned above persist in the case of the Enviro-wall: weather permitting, liner sheets are welded on the ground, complex rigging is required to place the envelope into the trench, and Schlegel's excellent liner sheet has a major handicap—it floats—which requires ballasting. Practice will probably smooth out the problems and the viability of the process will be conditioned by its ability to install the envelope as fast as the trenching goes and by overall economics.

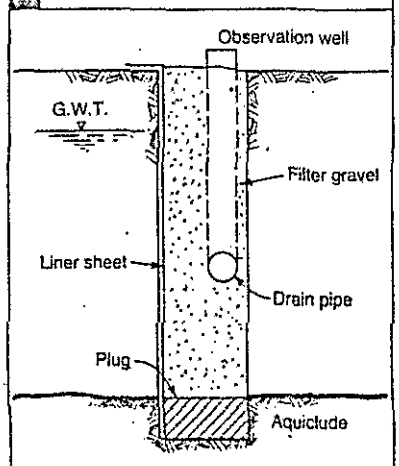
There are other ways of installing liners that should be looked at. One is having thin sheets unrolled from a container immersed in the trench (a folded sheet could provide the double sheet envelope but linear capacity would be reduced by half). Another is yet more promising: an in situ extruded liner sheet, where a resin compound is forced through the slit of the submerged extruder, producing the sheet on demand to match the speed of trench excavation. The labor saving device and the adaptability to match variable depth should provide both a technical and economical solution to the initial problem of installing a synthetic liner in a slurry trench.

Presently, leachate collection is through well systems or shallow trench drains. However, trenches in hazardous or toxic sites are undesirable because of labor safety and liability problems. The ability to construct a deep gravity drainage grid system, using the slurry trench method of excavation, with a biodegradable mud in which drain pipes and risers for monitoring and servicing are installed, allows for a safe and economical gravity system.

The combination of these upcoming processes is the juxtaposition of a synthetic liner and a drain in the same trench. A slurry trench is excavated using biodegradable mud. A single liner sheet is installed on the good aquifer side while the drain tubing and risers are positioned along the contaminated side with a slope for drainage. The trench is then backfilled with filter material. It is thus possible to install an impervious barrier that is chemically resistant, and a leachate collection system around a hazardous waste site, without putting any worker below ground level and at a fraction of the cost of conventional construction methods. (See Figure 3.)

In short, slurry trench technology is an evolving science. However, innovations are rare because of the isolation in which manufacturers, contractors, engineers and authorities are working in order to respect rigid contracting procedures and maintain clear-cut liability boundaries. Engineering schools should participate in research and sustained collective efforts should be able to bear fruit in the future.

FIGURE 3
AN IDEAL DESIGN



The future in hazardous waste vertical barriers.

Gilbert Tallard, M. ASCE, has worked for the past ten years as vice president, international for the Icos Corporation of America and as general manager at Soletanche and Rodio, Inc. Tallard has worked in Canada, the United States, Thailand, Mexico, and Chile on projects involving grouting, slurry walls, tunnelling, and heavy foundation construction. He is now a private consultant in Pelham, New York.

85. Todd, D. K. Groundwater Hydrology, Second Edition, John Wiley & Sons, New York, New York, 1980

Groundwater Hydrology

SECOND EDITION

David Keith Todd
UNIVERSITY OF CALIFORNIA, BERKELEY
and
DAVID KEITH TODD,
CONSULTING ENGINEERS, INC.

John Wiley & Sons
New York Chichester Brisbane Toronto

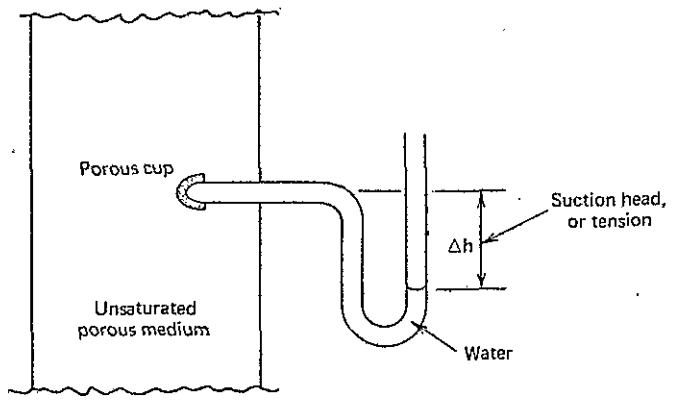


Fig. 2.9 Illustration of a tensiometer for measuring water tension in unsaturated porous media.

Available Water. Soils absorb and retain water, which may be withdrawn by plants during periods between rainfalls or irrigations. This water-holding capacity is defined by the *available water*, which is the range of plant-available water, the moist end being the field capacity and the dry end the wilting point. *Field capacity* can be defined as the amount of water held in a soil after wetting and after subsequent drainage has become negligibly small. The negligible drainage rate is often assumed after two days; however, different soils possess varying drainage rates so that quantitative values may not be comparable. The *wilting point* defines the water content of soils when plants growing in that soil are reduced to a permanent wilted condition. Because factors such as soil type and volume and plant type and age influence wilting point, this moisture content can also be variable.

Zone of Saturation

In the zone of saturation, groundwater fills all of the interstices; hence, the (effective) porosity provides a direct measure of the water contained per unit volume. A portion of the water can be removed from subsurface strata by drainage or by pumping of a well; however, molecular and surface tension forces hold the remainder of the water in place.

Specific Retention. The *specific retention* S_r of a soil or rock is the ratio of the volume of water it will retain after saturation against the force of gravity to its own volume. Thus,

$$S_r = w_r/V \tag{2.8}$$

where w_r is the volume occupied by retained water,* and V is the bulk volume of the soil or rock.

Specific Yield. The *specific yield* S_y of a soil or rock is the ratio of the volume of water that, after saturation, can be drained by gravity to its own volume.[13] Therefore,

$$S_y = w_y/V \tag{2.9}$$

where w_y is the volume of water drained. Values of S_r and S_y can also be expressed as percentages. Because w_r and w_u constitute the total water volume in a saturated material, it is apparent that

$$\alpha = w_r + w_y \tag{2.10}$$

where all pores are interconnecting.

Values of specific yield depend on grain size, shape and distribution of pores, compaction of the stratum, and time of drainage.[29] Representative specific yields for various geologic materials are listed in Table 2.5; individual values for a soil or rock can vary considerably from these values. It should be noted that fine-grained materials yield little water, whereas coarse-grained materials permit a substantial release of water—and hence serve as aquifers. In general, specific yields for thick unconsolidated formations tend to fall in the range of 7–15 percent, because of the mixture of grain sizes present in the various strata; furthermore, they normally decrease with depth due to compaction.

Specific yield can be measured by a variety of techniques involving laboratory, field, and estimating techniques.[3,18,19] Methods based on well-pumping tests, described in Chapter 4, generally give the most reliable results for field measurements.

Geologic Formations as Aquifers

A geologic formation that will yield significant quantities of water has been defined as an aquifer. Many types of formations serve as aquifers.[4,27] A key requirement is their ability to store water in the rock pores. Porosity may be derived from intergranular spaces or from fractures. Table 2.6 summarizes the geologic origin of aquifers in terms of type of porosity and rock type. The roles of various geologic formations as aquifers are briefly described in the following subsections.

*It should be noted that the terms *field capacity* and *retained water* refer to the same water content but differ by the zone in which they occur.

86. Underwriters Laboratories of Canada, 3615, 1977, "Standard for Reinforced Plastic Underground Storage Tanks for Petroleum Products" as cited in Criteria and Guidance for Underground Storage of Petroleum(Draft), New York State Department of Environmental Conservation, Albany, New York, August 1983, pp. 1-16

Stephen A. Fagundes 86

DEC
PUBLICATION

Criteria and Guidance for Underground Storage of Petroleum

DRAFT

NOTE

This report contains references to the "Bulk Storage Code." As of July 1983, New York State has a Bulk Storage Law, which manadates such a Code. **References to the Code are for discussion purposes only.** Formal enactment of this Code is about two years away.

August 1983

New York State/Department of Environmental Conservation

SW-P58 (8/83)

D. Design Recommendations - Fiberglass-Reinforced Plastic Tanks

Fiberglass-reinforced plastic (FRP) tanks are manufactured by a highly specialized industry. These tanks must be designed and fabricated by engineers with expertise in the strength of fiberglass materials, material compatibility, and underground tank installation. For this reason, only FRP tanks constructed by a reputable manufacturer should be used.

The following recommendations cover spherical or horizontal cylindrical atmospheric-type tanks of fiberglass-reinforced plastic construction which are intended for underground storage of petroleum.

1. FRP Tank Design

FRP tanks should be UL listed and designed in accordance with Underwriters' Laboratory Standard 1316, Standard for Glass-Fiber-Reinforced Plastic Underground Storage Tanks [3], or Underwriters' Laboratory of Canada, Standard ULC-S615-1977, Standard for Reinforced Plastic Underground Tanks for Petroleum Products [4]. These standards set forth requirements for structural strength, criteria for chemical compatibility of tank material with product stored, and surrounding soil, and test methods for quality control. Usually the wall thickness of an underground FRP tank is 0.22 inches, although a thicker wall may be necessary for large tanks or tanks storing products with a specific gravity greater than 1.5.

Some FRP tanks have incorporated reinforcing ribs in their design. These ribs provide the additional structural strength that is necessary for tank integrity in those cases. These ribs are designed to withstand both the internal stresses from the stored product, and the external backfill, hydrostatic and buoyancy forces. The ribs are also often designed to accept the hold down straps used to ballast the tank when flotation is a possibility.

An FRP tank should be equipped with lifting lugs that are attached to the tank or can be attached to a fitting on the tank. Tanks with a capacity of 1,000 gallons or less may be equipped with only one lifting lug. The precise method of handling and lifting the tank should be prescribed by the

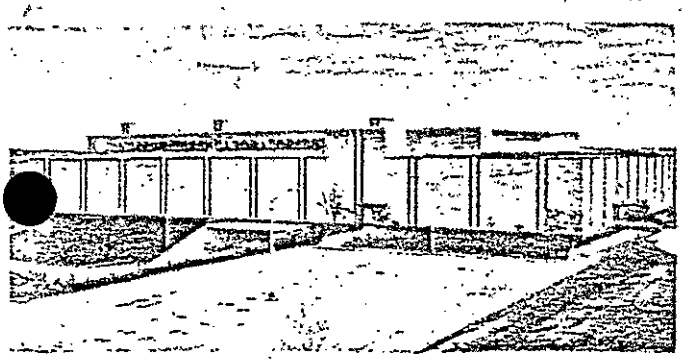
87. Underwriters Laboratories, Inc. Glass-Fiber-Reinforced Plastic Underground Storage Tanks for Petroleum Products, UL1316, 193

UL 1316

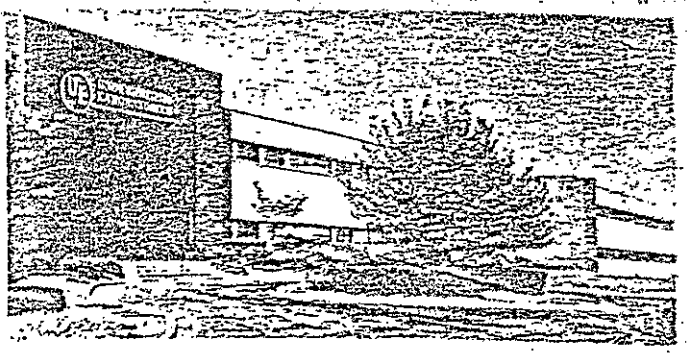
STANDARD for SAFETY

GLASS-FIBER-REINFORCED PLASTIC UNDERGROUND STORAGE TANKS FOR PETROLEUM PRODUCTS

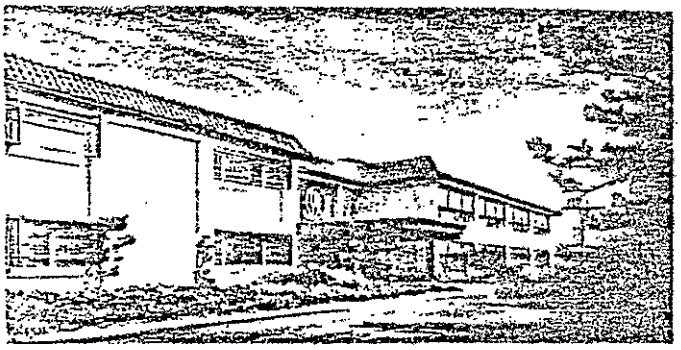
UNDERWRITERS LABORATORIES INC.



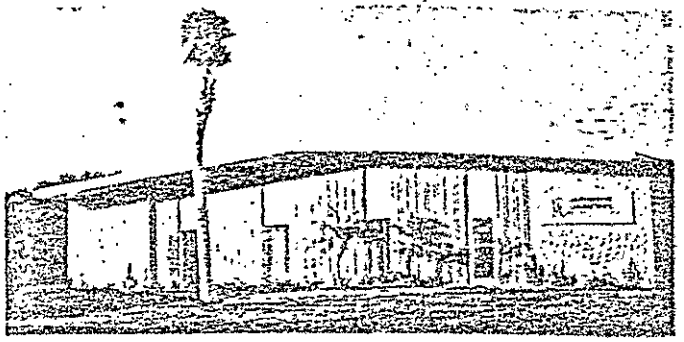
Northbrook, Illinois



Melville, New York



Santa Clara, California



Tampa, Florida

UNDERWRITERS LABORATORIES INC.

AN INDEPENDENT NOT-FOR-PROFIT ORGANIZATION
TESTING FOR PUBLIC SAFETY

Underwriters Laboratories Inc., founded in 1894, is chartered as a not-for-profit organization without capital stock, under the laws of the State of Delaware, to establish, maintain, and operate laboratories for the examination and testing of devices, systems and materials to determine their relation to hazards to life and property.

A complete description of the organization, purposes, and methods of Underwriters Laboratories Inc. is given in a separate pamphlet entitled "TESTING FOR PUBLIC SAFETY."

The names of manufacturers who have demonstrated an ability to produce products meeting UL requirements are published annually in the following Product Directories.

- Building Materials
- Fire Protection Equipment
- Fire Resistance
- Recognized Component
- Electrical Appliance and Utilization Equipment
- Electrical Construction Materials
- Hazardous Location Equipment
- General Information From Electrical Construction Materials Directory
- Marine Products
- Automotive, Burglary Protection, and Mechanical Equipment
- Gas and Oil Equipment
- Supplements to Directories

The price list for these publications and ordering information may be obtained upon request from UL, Publications Stock, 333 Pfingsten Road, Northbrook, Illinois 60062.

A Catalog of UL Standards for Safety with costs and ordering information is also available from this office.

UNDERWRITERS LABORATORIES INC.

an independent, not-for-profit organization testing for public safety

1285 Walt Whitman Road, Melville, L.I., N.Y. 11747
1655 Scott Boulevard, Santa Clara, Calif. 95050
2602 Tampa East Blvd., Tampa, Fla. 33619
333 Pfingsten Road, Northbrook, Ill. 60062

July 1, 1983

STANDARD FOR
GLASS-FIBER-REINFORCED PLASTIC UNDERGROUND STORAGE TANKS
FOR PETROLEUM PRODUCTS

UL 1316, FIRST EDITION

Accompanying this transmittal notice is a copy of the first edition of UL 1316.

THIS EDITION OF THE STANDARD IS NOW IN EFFECT EXCEPT FOR PARAGRAPHS 6.1, 18.5, AND 19.1, WHICH BECOME EFFECTIVE OCTOBER 19, 1983 AS INDICATED IN THE SMALL PRINT NOTE FOLLOWING THE AFFECTED ITEM.

New product submittals made prior to a specified future effective date will be judged under all of the requirements in this standard unless the applicant specifically requests that the product be judged under the current requirements. However, should the applicant elect this option, it should be noted that compliance with all the requirements in this standard will be required as a condition of continued Listing and Follow-Up Service after the effective date and understanding of this should be signified in writing.

The requirements in this standard are substantially in accordance with UL's bulletins on this subject dated January 27, 1982, and April 14, 1983.

Revised and/or additional pages may be issued from time-to-time.

UL 1316

STANDARD FOR GLASS-FIBER-REINFORCED PLASTIC UNDERGROUND STORAGE TANKS FOR PETROLEUM PRODUCTS

FIRST EDITION

First Impression ..... July 1, 1983

COPYRIGHT © 1983 UNDERWRITERS LABORATORIES INC.

UL's Standards for Safety are copyrighted to protect UL's publication rights, not to restrict their use in product design or evaluation. See paragraph E of the Foreword.

TABLE OF CONTENTS

Foreword 4
General 5
1. Scope 5
2. General 5
Construction 5
3. General 5
4. Pipe Connections 5
5. Manholes 6
6. Deflection Plates 6
Performance 6
7. General 6
8. Leakage Test 6
9. Strength of Pipe Fittings Tests 6
10. Strength of Lifting Fittings Tests 7
11. Water-Load Test 7
12. External Pressure Test 7
13. Internal Pressure Test 7
14. Physical Properties of Materials Tests 8
15. Earth-Load Test 9
Manufacturing and Production Tests 9
16. Leakage Test 9
17. Internal Vacuum Test 10
Marking 10
18. General 10
19. Installation Instructions 10

FOREWORD

A. This Standard contains basic requirements for products covered by Underwriters Laboratories Inc. (UL) under its Follow-Up Service for this category within the limitations given below and in the Scope section of this Standard. These requirements are based upon sound engineering principles, research, records of tests and field experience, and an appreciation of the problems of manufacture, installation, and use derived from consultation with and information obtained from manufacturers, users, inspection authorities, and others having specialized experience. They are subject to revision as further experience and investigation may show is necessary or desirable.

B. The observance of the requirements of this Standard by a manufacturer is one of the conditions of the continued coverage of the manufacturer's product.

C. A product which complies with the text of this Standard will not necessarily be judged to comply with the Standard if, when examined and tested, it is found to have other features which impair the level of safety contemplated by these requirements.

D. A product employing materials or having forms of construction differing from those detailed in the requirements of this Standard may be examined and tested according to the intent of the requirements and, if found to be substantially equivalent, may be judged to comply with the Standard.

E. UL, in performing its functions in accordance with its objectives, does not assume or undertake to discharge any responsibility of the manufacturer or any other party. The opinions and findings of UL represent its professional judgment given with due consideration to the necessary limitations of practical operation and state of the art at the time the Standard is processed. UL shall not be responsible to anyone for the use of or reliance upon this Standard by anyone. UL shall not incur any obligation or liability for damages, including consequential damages, arising out of or in connection with the use, interpretation of, or reliance upon this Standard.

F. Many tests required by the Standards of UL are inherently hazardous and adequate safeguards for personnel and property shall be employed in conducting such tests.

GENERAL

1. Scope

1.1 These requirements cover spherical or horizontal cylindrical, atmospheric-type tanks of glass-fiber-reinforced plastic (FRP) that are intended for the underground storage of petroleum-based flammable and combustible liquids.

1.2 These requirements do not cover tanks for use with alcohol or alcohol-blended fuels. Such tanks are covered by these and additional requirements.

1.3 These tanks are completely assembled and tested for leakage before shipment.

1.4 These tanks are intended for installation and use in accordance with the Standard for the Installation of Oil-Burning Equipment, ANSI/NFPA 31, the Flammable and Combustible Liquids Code, ANSI/NFPA 30; and the manufacturer's instructions.

1.5 These requirements do not cover optional accessories for these tanks, such as heating coils or hotwells; nor do they cover compartmented tanks.

2. General

2.1 If a value for measurement is followed by a value in other units in parentheses, the second unit may be only approximate. The first stated value is the requirement.

2.2 A component of a product covered by this standard shall comply with the requirements for that component and shall be used in accordance with its recognized rating and other limitations of use. A component need not comply with a specific requirement that:

A. Involves a feature or characteristic not needed in the application of the component in a product covered by this standard, or

B. Is superseded by a requirement in this standard.

CONSTRUCTION

3. General

3.1 A tank shall be provided with one or more lugs for lifting that are attached to the tank or can be attached to a fitting on the tank. Also, see Strength of Lifting Fittings Tests, Section 10.

3.2 A tank shall be capable of being anchored.

4. Pipe Connections

4.1 A fitting for pipe connection shall be a standard threaded pipe coupling (see the Standard for Welded and Seamless Wrought Steel Pipe, ANSI B36.10—1979), a threaded flange, a standard half pipe nipple, or a bolted and gasketed flanged connection. The connection shall be bonded directly to the tank.

4.2 All openings in a tank shall be located in the top. They shall be located on the longitudinal centerline of the top if the tank is cylindrical. If the tank is spherical, the openings shall be located on the vertical centerline of the tank.

Exception: If the application of a tank is such that openings in the top for pipe connection are required to be grouped, the openings may be located not more than 12 inches (305 mm) from the longitudinal centerline of the top of a cylindrical tank or the vertical centerline of a spherical tank, provided the upper end of each pipe coupling or other fitting for pipe connection terminates above the top of the shell.

4.3 An opening in a tank shall be closed with a wooden plug, metal cover, or the equivalent, to protect the threads and exclude foreign matter while the tank is in storage or in transit.

4.4 A tank shall have a fitting of a size not less than that specified in Table 4.1 for attachment of a vent pipe.

4.5 An opening for connection of a vent pipe shall not be located in a manhole cover.

Exception: In a spherical tank, all openings may be grouped together in a manhole cover.

TABLE 4.1
SIZE OF VENT-PIPE FITTING

Tank Capacity		Nominal Pipe Size, Inches[a]
U. S. Gallons	Liters	
0–500	0–1,893	1-1/4
501–3,000	1,896–11,356	1-1/2
3,001–10,000	11,360–37,854	2
10,001–20,000	37,858–75,708	2-1/2
20,001–35,000	75,712–132,489	3
35,001–50,000	132,493–189,270	4

[a] Nominal pipe size specifications are in accordance with the Standard for Welded and Seamless Wrought Steel Pipe, ANSI B36.10—1979.

5. Manholes

5.1 A manhole, if provided in a tank, shall be located above the highest normal liquid level and shall be of the bolted-cover type.

5.2 A manhole-cover joint shall be provided with a gasket at least 1/8 inch (3.2 mm) thick of material acceptable for use with the liquid to be stored.

6. Deflection Plates

6.1 A tank shall have a deflection plate of steel at least 0.053 inch (1.35 mm) thick or aluminum at least 1/8 inch (3.2 mm) thick. The deflector plate shall be at least 9 inches (229 mm) wide, and at least 1 square foot (0.009 m^2) in area under (1) each opening, or (2) one opening that is marked as specified in paragraph 18.5.

Paragraph 6.1 effective October 19, 1983

PERFORMANCE

7. General

7.1 One sample of a tank is to be subjected to each of the tests described in Sections 8–13. However, the same sample need not be subjected to all tests. If a manufacturer produces a line of cylindrical tanks that differ only in shell length, the longest tank may be tested as representative of the entire line. For a line of spherical tanks that differ only in diameter, only the largest diameter tank need be tested.

8. Leakage Test

8.1 A tank, including fittings, shall be tested as described in paragraph 8.2 and shall not leak.

8.2 The tank is to be pressurized for 5 minutes to the applicable value specified in Table 8.1, and the entire surface is to be brushed with a leak-detection fluid. Continuous formation of bubbles at any location on the tank surface is evidence of leakage.

TABLE 8.1
LEAKAGE-TEST PRESSURES

Maximum Diameter of Tank, Feet (m)	Applied Pressure, Psig (kPa)
10 (3.0) or less	5 (34)
More than 10	3 (21)

9. Strength of Pipe Fittings Tests

Torque

9.1 A length of pipe shall be threaded into a fitting for pipe connection and shall be tightened to the torque specified in Table 9.1. The fitting shall not crack or split and the threads shall not strip.

TABLE 9.1
TORQUES ON PIPE FITTINGS

Nominal Pipe Size, Inches[a]	Torque, Pound-Inches (N-m)
3/4	2000 (226)
1	2400 (271)
1-1/4	2900 (328)
1-1/2	3100 (350)
2	3300 (373)
2-1/2	3500 (395)
3	3600 (407)
3-1/2	3700 (418)
4	3800 (429)
6	4200 (475)
8	4600 (520)

[a] Nominal pipe size specifications are in accordance with the Standard for Welded and Seamless Wrought Steel Pipe, ANSI B36.10—1979.

Bending Moment

9.2 The bond between a fitting for pipe connection and the tank shall be subjected to a bending moment of 2000 pound-feet (2700 N·m) as described in paragraph 9.3. The bond shall not be damaged.

9.3 A 4-foot (1.2-m) length of Schedule 40 steel pipe is to be threaded into the fitting. A force is then to be applied to the top of the pipe. For a cylindrical tank, the force is first to be applied parallel to the longitudinal axis of the tank, and then transverse to the longitudinal axis of the tank. For a spherical tank, the force is first to be applied in any one direction and then perpendicular to the direction in which the force was first applied. The applied force is to be increased so that the bending moment is increased from zero to 2000 pound-feet (2712 N·m) in 250 pound-feet (339 N·m) increments. If the Schedule 40 pipe bends before the required bending moment is reached, the test is to be stopped and the fitting is to be examined for compliance with the requirements specified in paragraph 9.2.

Leakage

9.4 After each of the tests specified in paragraphs 9.1 and 9.2, the tank is to be subjected to the Leakage Test, Section 8.

10. Strength of Lifting Fittings Tests

10.1 A fitting intended to be used to lift and move a tank shall be subjected for 1 second to a load equal to twice that imposed by lifting the empty tank. If more than one fitting is provided on a tank, the load is to be divided between the fittings in proportion to the loads to which they are subjected by lifting the tank as intended. The fitting shall not be damaged or damage the tank.

10.2 Following the test described in paragraph 10.1, the tank is to be subjected to the Leakage Test, Section 8.

11. Water-Load Test

11.1 A tank shall be (1) placed in a sand bed so that approximately one-eighth of the tank diameter is buried, and (2) filled to capacity with water for 1 hour. The tank shall not be damaged.

12. External Pressure Test

General

12.1 A tank shall be tested either as described in paragraph 12.2 or, at the manufacturer's option, as described in paragraphs 12.3 and 12.4. The tank shall not implode or otherwise be damaged.

Method I

12.2 The empty tank is to be installed in a test pit using the recommended anchoring system and the specified backfill procedure. The pit is then to be filled with water to such a level that the tank is submerged to its maximum recommended burial depth. The tank is to remain submerged for 24 hours. While the tank is still submerged, it is to be subjected for 1 minute to a partial internal vacuum so that the internal pressure on the tank is 5.3 inches of mercury (17.9 kPa) less than the external pressure imposed by the hydrostatic head.

Method II

12.3 The tank is to be placed, at points simulating the use of hold-down straps, on saddles padded with 1/2-inch (12.7-mm) thick expansion-joint material. The tank is to be filled to capacity with water for 24 hours, and then is to be drained.

12.4 After the procedure described in paragraph 12.3, the tank is to be subjected for 24 hours to a partial internal vacuum so that the difference between the internal and external pressures on the tank is equal to that which would exist if the empty tank were submerged in water to its maximum recommended burial depth. The vacuum is then to be increased, for 1 minute, so that the internal pressure on the tank is 5.3 inches of mercury (17.9 kPa) less than the previous value.

13. Internal Pressure Test

13.1 A tank shall withstand without rupture for 1 minute an internal pressure as specified in Table 13.1.

TABLE 13.1
INTERNAL PRESSURE TEST

Maximum Diameter of Tank, Feet (m)	Applied Pressure, Psig (kPa)
10 (3.0) or less	25 (172)
More than 10	15 (103)

14. Physical Properties of Materials Tests

General

14.1 Samples cut directly from a tank are to be used for the tests described in paragraphs 14.2–14.12. At least 84 samples are to be used. The samples are to measure approximately 5 by 9 inches (127 by 229 mm) and are to be cut to minimize the amount of curvature, that is, so that the 5-inch dimension is parallel to the cylinder circumference.

Air-Oven Aging

14.2 Four as-received samples and 12 samples conditioned as described in paragraph 14.3 are to be subjected to the strength tests specified in paragraphs 14.4 and 14.5. The strength of the conditioned samples shall be at least 80 percent of the strength of the unconditioned samples.

14.3 Three groups of four samples are to be conditioned for 30, 90, and 180 days, respectively, in an air-circulating oven at a temperature of 70°C (158°F). Two of the samples from each group are then to be tested as specified in paragraph 14.4 and the remaining two are to be tested as specified in paragraph 14.5.

14.4 Samples are to be subjected to the flexural strength test described in Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials, ANSI/ASTM D790–81, using a cross-head speed of 0.1 inch per minute (2.5 mm/min) and with the inside surface facing down. Five specimens are to be cut from each sample, parallel to the longest dimension of the sample, and as described in ASTM D790–81.

14.5 Samples are to be subjected to the Izod impact-strength test described in Test Methods for Impact Resistance of Plastics and Electrical Insulating Materials, ASTM D256–81. Five specimens are to be cut from each sample, parallel to the longest dimension of the sample, and as described in ASTM D256–81.

Immersion

14.6 Four as-received samples and 56 samples conditioned as described in paragraphs 14.8–14.10 are to be subjected to the tests specified in paragraphs 14.4 and 14.5. The strength of each sample that has been immersed in a Type A liquid shall be at least 50 percent of the strength of an unconditioned sample. The strength of each sample that has been immersed for 180 days in a Type B liquid shall be at least 30 percent of the strength of an unconditioned sample.

14.7 An immersion test liquid is classed as either Type A or Type B according to the following:

A. Type A liquids represent either an actual product to be stored or an outside soil condition.

B. Type B liquids are more severe than expected conditions and are intended to indicate whether additional testing is required to determine the acceptability of the material.

14.8 Samples are to be immersed in each of the liquids specified in Table 14.1 for 30, 90, and 180 days. A separate group of 14 samples (total of 42 samples) is to be used for each immersion period for each of the test liquids.

14.9 The liquids are to be maintained at 38°C (100°F) during the tests. The edges of all samples for immersion are to be coated with the same resin the tank is made from to minimize edge effects during the immersion. For the tests specified in paragraphs 14.4 and 14.5, specimens are to be cut from the centers of the samples that have been subjected to the immersion conditioning.

TABLE 14.1
IMMERSION-TEST LIQUIDS[a]

Type A	Type B
Premium leaded gasoline	Toluene
Regular unleaded gasoline	Distilled water[b] or deionized water[c]
No. 2 fuel oil	Hydrochloric acid (5 percent)[d]
ASTM Reference Fuel C[e]	Nitric Acid (5 percent)[d]
Sulfuric acid (pH=3)	Sodium carbonate-sodium bicarbonate solution (pH=10)[f]
Saturated sodium chloride	Sodium hydroxide (pH=12)
No. 6 fuel oil[g]	Sodium hydroxide (5 percent)[d]

a Test parameters, such as temperature and concentrations of media, are increased in severity over those of normal operating conditions to obtain observable deterioration in a reasonable period of time. This accelerated test may not give any direct correlation with service performance. However, the method yields comparative data on which to base judgment as to expected service.

b Distilled water having a maximum total matter of 2.0 ppm and a maximum electrical conductivity of 5.0 micromhos/cm at 25°C (77°F), as described for Type IV grade reagent water in the Standard Specification for Reagent Water, ASTM D1193—77.

c Deionized water having a maximum electrical conductivity of 5.0 micromhos/cm at 25°C (77°F), as described for Type IV grade reagent water in ASTM D1193—77.

d Percentage by weight.

e As described in the Test Method for Rubber Property — Effect of Liquids, ASTM D471—79.

f A pH of 10 can be obtained by mixing 10.6 g/L of sodium carbonate and 8.4 g/L of sodium bicarbonate. A pH meter is to be used and the ratio of sodium carbonate to sodium bicarbonate adjusted as needed. The pH is to be checked several times during the test.

g Optional, to be used only at the request of and at the temperature specified by manufacturer.

14.10 After immersion, specimens cut from each of the samples from each immersion group are to be tested separately as specified in paragraphs 14.4 and 14.5. The results of the tests are to be evaluated according to paragraph 14.6 and, in addition, the results from immersion in each of the Type A liquids are to be extrapolated to obtain 270-day retention values. The extrapolated strength shall be not less than 50 percent of the strength of unconditioned samples. If the extrapolated value is less than 50 percent for a particular liquid, an additional group of 14 samples is to be immersed in that liquid for a total of 270 days as described in paragraph 14.9, and then tested as described in paragraphs 14.4 and 14.5. The strength of the samples shall be not less than 50 percent of that of an unconditioned sample.

Impact

14.11 A sample shall be tested as described in paragraph 14.12 and shall not crack or show rupture of the laminate. Crazing is acceptable.

14.12 Four samples are to be conditioned for 16 hours in a cold box maintained at minus 29°C (minus 20°F). These samples and four additional unconditioned samples are then to be clamped, one at a time, between two steel rings having an inside diameter of 4-1/4 inches (108 mm). A 1.18-pound (0.536-kg) steel ball is to be dropped once from a height of 6 feet (1.8 m) to strike the outside surface of each sample.

15. Earth-Load Test

15.1 A tank shall be subjected to the test specified in paragraphs 15.2 and 15.3 and shall not implode, leak, or otherwise be damaged.

15.2 An empty tank of each diameter is to be installed in a test pit or an apron is to be constructed around the four sides of the tank. Backfilling is to be done according to the manufacturer's installation instructions. The tank is to be covered so that it is 3 feet (0.9 m) below the surface of the fill. The tank is to remain buried for at least 1 hour.

15.3 The tank is then to be subjected to the Leakage Test, Section 8.

MANUFACTURING AND PRODUCTION TESTS

16. Leakage Test

16.1 Each tank shall be tested, as a routine production-line test, for leakage as described in paragraph 8.2. If leakage is noted, the tank shall be repaired and retested.

17. Internal Vacuum Test

17.1 Each tank shall withstand, without rupture, internal partial vacuum according to the equation:

$$V = (1/2\ D + h) \times 0.88 \text{ inches Hg/ft}$$

in which:

V is the vacuum in inches Hg,
D is the tank diameter in feet, and
h is the maximum recommended burial depth in feet, but not less than 3 feet.

Exception: A lower internal vacuum may be used if it can be shown that the lower value, applied to the tank above ground, is representative of the specified value applied to the buried tank.

MARKING

18. General

18.1 All required markings shall be permanent, such as paint or paper labels imbedded in clear resin on the outside surface of the tank.

18.2 Each tank shall be legibly marked with the name of the manufacturer or a distinctive marking by which it may be identified as the product of a particular manufacturer.

18.3 If a manufacturer produces tanks at more than one factory, each tank shall have a distinctive marking to identify it as the product of a particular factory.

18.4 Each tank shall be marked with information that is deemed necessary by the manufacturer. This marking shall include at least the following:

A. "Maximum test pressure X psig" or the equivalent, in which X is 5 for tanks 10 feet (3 m) in diameter or less and 3 for tanks larger than 10 feet in diameter.

B. "Keep tank vented," or the equivalent.

C. "Follow installation instructions," or the equivalent.

D. The word "CAUTION" and the following or the equivalent: "To reduce the risk of damage to the tank, do not fill tank prior to backfilling."

E. "Do not roll or drop tank," or the equivalent.

18.5 If a tank has a steel deflection plate under only one opening as covered in item (2) of paragraph 6.1, the opening shall be marked to indicate that dipstick measurements shall be made only at that location.

Paragraph 18.5 effective October 19, 1983

19. Installation Instructions

19.1 Two copies of the manufacturer's installation instructions shall be provided with each tank, one of which shall be embedded in clear resin on the outside surface of the tank.

Paragraph 19.1 effective October 19, 1983

19.2 The installation instructions shall include (1) the method of intended lifting, including the intended distribution of the load between the fittings if more than one fitting is provided, and (2) indication that the backfill to be used shall be either pea gravel or compacted, clean dry sand, as specified by the manufacturer.

UL Standards for Safety are developed under a procedure which provides for participation and comment from the affected public as well as industry. The procedure takes into consideration a survey of known existing standards, and the needs and opinions of a wide variety of interests concerned with the subject matter of the Standard. Thus manufacturers, consumers, individuals associated with consumer-oriented organizations, academicians, government officials, industrial and commercial users, inspection authorities, insurance interests and others provide input to UL in the formulating of UL Standards for Safety, and keeping them consonant with social and technological advances.

AN INDEPENDENT LABORATORY · UL · TESTING FOR PUBLIC SAFETY

UNDERWRITERS LABORATORIES INC.

88. Underwriters Laboratories, Inc. "Lining of Underground Storage Tanks," UL Subjects 58, 1316, April 1984

UNDERWRITERS LABORATORIES INC.
NORTHBROOK, IL · HELVILLE, NY · SANTA CLARA, CA · TAMPA, FL
an independent, not-for-profit organization testing for public safety

CALIFORNIA RE
25
CONTROL BOARD

333 Pfingsten Road
Northbrook, Illinois 60062

Subjects 58, 1316

April 23, 1984

TO: Manufacturer's of Steel Tanks, Composite Tanks, and Nonmetallic Tanks for Underground Storage of Flammable Liquids and/or Petroleum Products

SUBJECT: Lining of Underground Storage Tanks

UL provides two options for the investigation of tank linings: (1) Listing by Report for the complete lining process including an evaluation of the actual lining materials and (2) Component Recognition of the lining materials only. This Component Recognition would assist any applicators that wish to submit their lining process to UL for Listing by Report, in that it would not be necessary to repeat the evaluation of the lining materials.

Details of these two options are discussed below.

A. Listing by Report - UL's investigation is limited to the materials and application of the lining. The acceptability of the tank intended to be lined and the lining process will be under the jurisdiction of the inspection authority.

   UL's investigation consists of two basic elements: (1) exposure testing of coupons of the lining only and (2) physical testing of a lined tank. The tests involved are outlined in the Appendices A and B.

   Upon satisfactory completion of all the tests and examinations specified, a report is then prepared and sent to UL's Casualty and Fire Councils for comments. Listing is promulgated by means of a Listing Report.

B. Component Recognition - UL's investigation is limited to an evaluation of the coating material's resistance to the corrosive effects of stored flammable liquids as well as the material's resistance to permeation. The test program for Component Recognition is outlined in Appendix A; it does not include the tests outlined in Appendix B.

If you would like to submit drawings for review, please address your request to Mr. S. C. Slowik, Associate Project Engineer at UL's Northbrook office.

UNDERWRITERS LABORATORIES INC.

JOHN J. HAWLEY
Engineering Group Leader
Casualty and Chemical Hazards
Department

REVIEWED BY:

ROBERT G. HARRIS
Executive Staff Engineer
Manager
Casualty and Chemical Hazards
Department

SR:JES

312-772-8800

A P P E N D I X A

TEST PROGRAM FOR EVALUATING TANK-LINING SYSTEMS

PHYSICAL TESTS OF LAMINATE:

METHOD

Five by nine inch (127 by 229 mm) lining samples are to be immersed in the solutions specified below and maintained at a temperature of 100°F (38°C). Specimens are also to be exposed in an air-circulating oven maintained at a temperature of 158°F (70°C). After 30, 90, 180 and, if necessary, 270 days, selected samples are to be removed from the solution and tested for flexural strength and Izod impact.

The specimens subjected to the flexural strength test are to be tested in accordance with the Test Method for Tensile Properties of Plastics Using Microtensile Specimens, ASTM D1708-79, using a cross head speed of 0.01 inch/minute (0.25 mm/minute).

The specimens to be subjected to the Izod impact test are to be tested in accordance with the Test Method for Impact Resistance of Plastics and Electrical Insulating Materials, ASTM D256-81.

SOLUTIONS OR IMMERSION

The following solutions are to be used for immersion of the samples:

1. Premium leaded gasoline
2. Regular unleaded gasoline
3. No. 2 fuel oil
4. ASTM Reference Fuel C.
5. Toluene
6. No. 6 fuel oil
7. 100-percent methanol
8. 200-percent ethanol
9. 50-percent ethanol, 50-percent ASTM Reference Fuel C

10. 50-percent ethanol, 50-percent ASTM Reference Fuel C

11. 85-percent Reference Fuel C, 15-percent methanol

12. 85-percent ASTM Reference Fuel C, 15-percent ethanol

13. 70-percent ASTM Reference Fuel C, 30-percent ethanol

14. Distilled water

PERMEANCE - COATING DISSOLUTION EVALUATION:

METHOD

Coupon samples of the lining only are to be bonded to glass dishes containing the immersion solutions. Before the samples are attached to the dishes, the thickness is to be measured in the center of each quadrant and these values are to be recorded for later use. The assemblies are to be weighed on an analytical balance. The assemblies are then to be inverted and placed in a 100°F (38°C) ambient chamber so that the solution will contact the test specimen.

To determine the rate or percent of transmission of the solution through the test specimen, the assemblies are to be reweighed after 30, 90, 180 and, if necessary, 270 days. At the conclusion of the test, the thickness of each sample is to be remeasured and any loss or swelling is to be recorded.

RESULTS

No permeance or dissolution of the liner material is to occur.

BONDING TO SURFACE:

METHOD

Steel coupons coated with the minimum thickness of liner material are to be bonded to glass cups filled with each of the immersion solutions and the assemblies are to be inverted so the solution contacts the surface. Before bonding the coupons to the cup, the hardness of the liner material is to be determined. Following each exposure period, the exposed liner material is to be visually examined and the hardness determined.

RESULTS

There shall not be any softening blistering or uplift of the liner material.

COLD IMPACT:

METHOD

Six by six inch (152 by 152 mm) sheets of the liner are to be conditioned for 16 hours in a cold box maintained at minus 20°F (minus 29°C). Each conditioned specimen, and additional unconditioned specimens, are to be clamped between two steel rings having an inside diameter of 4.25 inch (108 mm) and impacted once by dropping a 1.18 pound (535 g) steel sphere from a height of 6 feet (1.83 m) onto the surface of the specimen.

RESULTS

The samples shall not crack or show rupture of the liner.

A P P E N D I X B

TEST PROGRAM FOR EVALUATING THE STRUCTURAL SUITABILITY OF TANK-LINING SYSTEMS

PHYSICAL TESTS OF TANK:

METHOD

Using a tank selected by the manufacturer and judged by UL to meet the criteria outlined in the manufacturer's instructions, the following test and examination are to be conducted.

Note: The tank selected will become the basis for judging the acceptability of future tanks for the lining process.

1. The tank is to be inspected by a representative of UL's engineering staff and a detailed description of the tank's physical condition recorded.

2. The tank is then to be prepared by the manufacturers personnel and lined in accordance with the lining instructions.

3. A 5-psig (34.5-kPa) leakage and 5.3-inch (135-mm) Hg vacuum test are then to be performed, exactly as they are conducted during an actual lining procedure.

4. The tank is then to be tested for voids and holidays.

5. After the buried tank has been lined, the thank is to be excavated and placed at ground level for visual examination of the exterior.

6. The excavation is to be prepared for anchoring the tank as required.

7. The tank is to be repositioned in the excavation and anchored (tied down) to prevent float-out.

8. The tied-down tank is to be recovered with back fill material to grade and the entire excavation flooded for a 24 hours.

9. At the end of the 24-hour flooded condition, a vacuum of 5.3 inch (135 mm) Hg is to be applied for 1 minute to simulate an additional external pressure equivalent of 6-feet (1.83-m) of water.

10. Unless a metal deflector plate is provided to protect the area under the fittings from a dipstick, an impact test is to be conducted on the interior of the tank. A 2-pound (901-g) steel sphere is to be dropped from a height equal to the tank diameter so as to impact the area under the fitting opening.

RESULTS

As a result of the tests, there shall be no damage to the tank as evidence by cracking, buckling, or deformation. The tank is again to be tested for voids or holidays. In addition, there shall be no cracking of the lining material.

89. Underwriters Laboratories, Inc. Standard for Steel Underground Tanks for Flammable and Combustible Liquids, UL58, 1981

Stephen A. Fugimura

UL 58

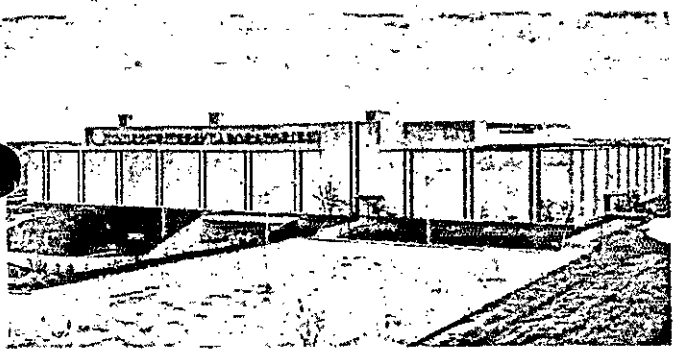
STANDARD & SAFETY

STEEL UNDERGROUND TANKS

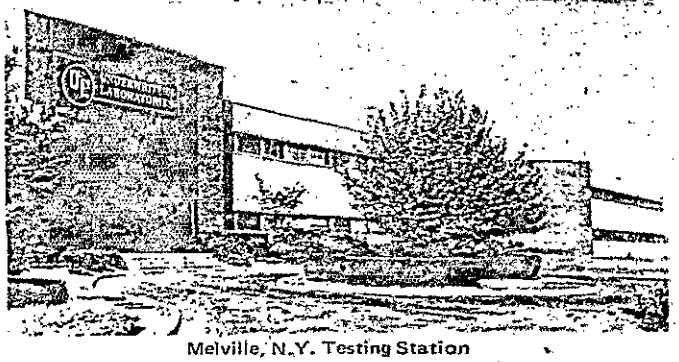
FOR FLAMMABLE AND COMBUSTIBLE LIQUIDS

AN INDEPENDENT LABORATORY · UL · TESTING FOR PUBLIC SAFETY

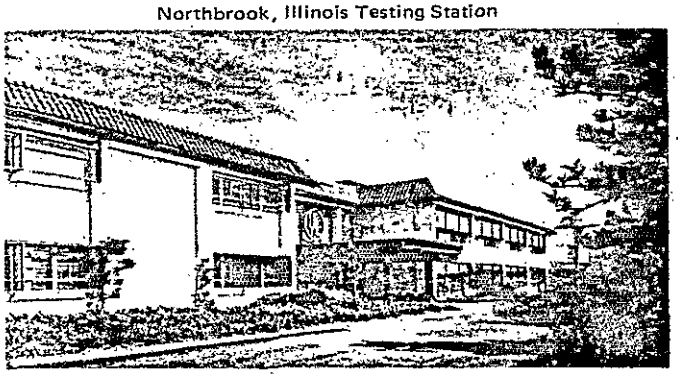
UNDERWRITERS LABORATORIES INC.



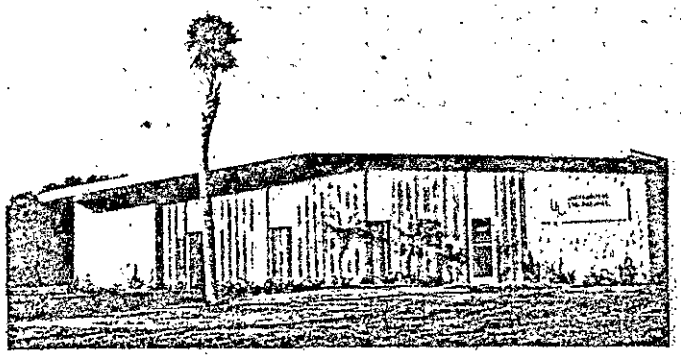
Northbrook, Illinois Testing Station



Melville, N.Y. Testing Station



Santa Clara, Calif. Testing Station



Tampa, Florida Testing Station

UNDERWRITERS LABORATORIES INC.

AN INDEPENDENT NOT-FOR-PROFIT ORGANIZATION
TESTING FOR PUBLIC SAFETY

Underwriters Laboratories Inc., founded in 1894, is chartered as a not-for-profit organization without capital stock, under the laws of the State of Delaware, to establish, maintain, and operate laboratories for the examination and testing of devices, systems and materials to determine their relation to hazards to life and property.

A complete description of the organization, purposes, and methods of Underwriters Laboratories Inc. is given in a separate pamphlet entitled "TESTING FOR PUBLIC SAFETY."

The names of manufacturers who have demonstrated an ability to produce products meeting UL requirements are published annually in the following Product Directories.

- Building Materials
- Fire Protection Equipment
- Fire Resistance
- Recognized Component
- Electrical Appliance and Utilization Equipment
- Electrical Construction Materials
- Hazardous Location Equipment
- General Information From Electrical Construction Materials and Hazardous Location Equipment
- Marine Products
- Automotive, Burglary Protection, and Mechanical Equipment
- Gas and Oil Equipment
- Supplements to Directories

The price list for these publications and ordering information may be obtained upon request from UL, Publications Stock, 333 Pfingsten Road, Northbrook, Illinois 60062.

A Catalog of UL Standards for Safety with costs and ordering information is also available from this office.

UNDERWRITERS LABORATORIES INC.

an independent, not-for-profit organization testing for public safety

1285 Walt Whitman Road, Melville, L.I., N.Y. 11747
1655 Scott Boulevard, Santa Clara, Calif. 95050
2602 Tampa East Blvd., Tampa, Fla. 33619
333 Pfingsten Road, Northbrook, Ill. 60062

April 10, 1981

STANDARD FOR
STEEL UNDERGROUND TANKS FOR FLAMMABLE AND COMBUSTIBLE LIQUIDS

UL 58, SEVENTH EDITION

Accompanying this sheet is a copy of the second impression of the seventh edition of UL 58.

A CHANGE IN REQUIREMENTS AS INCLUDED IN REVISED PAGES DATED NOVEMBER 28, 1977 IS INDICATED BY A VERTICAL MARGINAL RULE ON THE AFFECTED PAGE. EDITORIAL CHANGES ARE NOT SO MARKED.

THIS EDITION OF THE STANDARD IS NOW IN EFFECT.

With the inclusion of the acoompanying material, the standard consists of pages dated as shown in the following check list:

Page	Date
1	April 10, 1981
2	—
3	October 29, 1976
4	November 28, 1977
5	October 29, 1976
6	November 28, 1977
7–16	October 29, 1976

Revised and/or additional pages may be issued from time to time.

Transmittal only — not a permanent part of the standard

UL 58

STANDARD FOR STEEL UNDERGROUND TANKS FOR FLAMMABLE AND COMBUSTIBLE LIQUIDS

First Edition – October, 1925
Second Edition – September, 1929
Third Edition – February, 1937
Fourth Edition – April, 1949
Fifth Edition – December, 1961
Sixth Edition – December, 1971

(The fifth and previous editions were originally titled "Underground Tanks for Flammable Liquids")

SEVENTH EDITION

First Impression ..... October 29, 1976
Second Impression (as revised to January 6, 1978) ..... April 10, 1981

Approval as an American National Standard covers the numbered paragraphs on pages dated October 29, 1976. These pages should not be discarded when revised or additional pages are issued if it is desired to retain the approved text. Revisions of this standard will be made by issuing revised or additional pages bearing their dates of issue.

Approved as ANSI B137.1–1971, July 27, 1971
Approved as ANSI B137.1–1976, July 23, 1976

Replaces page 1 dated October 29, 1976

COPYRIGHT © 1976 UNDERWRITERS LABORATORIES INC.

UL's Standards for Safety are copyrighted to protect UL's publication rights, not to restrict their use in product design or evaluation. See paragraph E of the Foreword.

TABLE OF CONTENTS

Foreword 4
General 5
1. Scope 5
2. General 5
3. Capacities, Dimensions, and Metal Thicknesses 5
4. Materials 5
5. Shell Seams 6
6. Heads and Head Joints 7
7. Compartment Tanks 10
8. Pipe Connections 12
9. Manholes 14
10. Heating Coils and Hot Wells 15
Manufacturing and Production Tests 15
11. General 15
Marking 15
12. General 15

FIGURES

Shell Seams (Figure 5.1) 6
Heads and Head Joints for all Diameter Tanks (Figure 6.1) 7
Bracing for Unflanged and Flanged Flat Heads and Bulkheads (Figure 6.2) 8
Bulkheads for Compartment Tanks (Figure 7.1) 11
Pipe Connections (Figure 8.1) 12
Conventional Manholes (Figure 9.1) 14

TABLES

Thickness of Steel (Table 3.1) 5
Nominal and Minimum Thickness for Uncoated Sheet and Plate Steel (Table 4.1) 6
Nominal and Minimum Thickness for Galvanized Sheet Steel (Table 4.2) 6
Dished Heads — Minimum Height (Table 6.1) 8
Strut Bracing for Unflanged Flat Heads and Bulkheads (Table 6.2) 9
Surface Bracing for Unflanged Flat Heads and Bulkheads (Table 6.3) 9
Surface Bracing for Flanged Flat Bulkheads (Table 6.4) 10
Pipe Connections (Table 8.1) 13
Size of Vent-Pipe Fitting (Table 8.2) 13
Gallon Capacity per Foot of Length Appendix A, Table I 16
Liter Capacity per Meter of Length Appendix A, Table II 16

FOREWORD

A. This Standard contains basic requirements for products covered by Underwriters Laboratories Inc. (UL) under its Follow-Up Service for this category within the limitations given below and in the Scope section of this Standard. These requirements are based upon sound engineering principles, research, records of tests and field experience, and an appreciation of the problems of manufacture, installation, and use derived from consultation with and information obtained from manufacturers, users, inspection authorities, and others having specialized experience. They are subject to revision as further experience and investigation may show is necessary or desirable.

B. The observance of the requirements of this Standard by a manufacturer is one of the conditions of the continued coverage of the manufacturer's product.

C. A product which complies with the text of this Standard will not necessarily be judged to comply with the Standard if, when examined and tested, it is found to have other features which impair the level of safety contemplated by these requirements.

D. A product employing materials or having forms of construction differing from those detailed in the requirements of this Standard may be examined and tested according to the intent of the requirements and, if found to be substantially equivalent, may be judged to comply with the Standard.

E. UL, in performing its functions in accordance with its objectives, does not assume or undertake to discharge any responsibility of the manufacturer or any other party. The opinions and findings of UL represent its professional judgment given with due consideration to the necessary limitations of practical operation and state of the art at the time the Standard is processed. UL shall not be responsible to anyone for the use of or reliance upon this Standard by anyone. UL shall not incur any obligation or liability for damages, including consequential damages, arising out of or in connection with the use, interpretation of, or reliance upon this Standard.

F. Many tests required by the Standards of UL are inherently hazardous and adequate safeguards for personnel and property shall be employed in conducting such tests.

GENERAL

1. Scope

1.1 These requirements cover horizontal atmospheric-type steel tanks intended for the storage underground of flammable and combustible liquids.

1.2 These tanks are intended for installation and use in accordance with the Standard for the Installation of Oil-Burning Equipment, NFPA No. 31, and the Flammable and Combustible Liquids Code, NFPA No. 30, of the National Fire Protection Association.

1.3 Tanks covered by these requirements are cylindrical tanks which are fabricated, inspected, and tested for leakage before shipment from the factory as completely assembled vessels.

2. General

2.1 Capacities, dimensions, and construction details shall conform to the applicable requirements of this Standard.

2.2 Gallon capacities per foot of length of cylindrical shells having diameters of 24 to 144 inches, inclusive, are given in Appendix A, Table I. Capacities in liters (dm^3) per meter of length of cylindrical shells having diameters of 600 to 3800 mm, inclusive, are given in Appendix A, Table II. (Add one-third the height of conical heads to shell lengths to obtain total capacity.)

2.3 If a value for measurement as given in these requirements is followed by an equivalent value in other units, the first stated value is to be regarded as the requirement. A given equivalent value may be only approximate.

3. Capacities, Dimensions, and Metal Thicknesses

3.1 The overall length of a tank shall be not greater than six times its diameter.

3.2 Neither the capacity nor the diameter for the corresponding gage or thickness of metal shall exceed that specified in Table 3.1.

3.3 To provide for manufacturing variations, a plus tolerance of 10 percent in maximum capacity and a plus tolerance of 5 percent in either the maximum diameter or the maximum length will be permitted for tanks constructed of No. 7 gage (0.167 inch minimum) (4.24 mm minimum) or heavier steel. This does not mean that a tank is to be designed intentionally to have a capacity, diameter, or length greater than the maximum designated above. There is no limit on the minus tolerances for capacity, diameter, or length.

4. Materials

4.1 A tank shall be constructed of commercial quality uncoated or galvanized steel of good welding quality. Only new material shall be used.

4.2 The thickness of steel, as measured in accordance with paragraph 4.3 shall be not less than the appropriate minimum value given in Table 4.1 or 4.2.

4.3 The thickness of steel is to be determined by five micrometer readings equally spaced along the edge of the full piece as rolled. Thickness is to be determined on the sheet not less than 3/8 inch (9.5 mm) from a cut edge and not less than 3/4 inch (19 mm) from a mill edge.

TABLE 3.1
THICKNESS OF STEEL

TP-8

Capacity		Maximum Diameter		Manufacturers' Standard or Galvanized Sheet	Nominal Thickness			
					Uncoated		Galvanized	
U.S. Gallons	dm^3	Inches	m	Gage No.	Inches	mm	Inches	mm
Up to 285	Up to 1078	42	1.07	14	0.075	1.91	0.079	2.01
286 to 560	1082 to 2120	48	1.22	12	0.105	2.67	0.108	2.74
561 to 1100	2124 to 4164	64	1.63	10	0.135	3.43	0.138	3.51
1101 to 4000	4168 to 15142	84	2.13	7	0.179	4.55		
4001 to 12,000	15145 to 45425	126	3.20	1/4 inch	0.250	6.35		
12,001 to 20,000	45429 to 75708	144	3.66	5/16 inch	0.312	7.92		
20,001 to 50,000	75712 to 189270	144	3.66	3/8 inch	0.375	9.53		

TABLE 4.1
NOMINAL AND MINIMUM THICKNESS
FOR UNCOATED SHEET AND PLATE STEEL

Manufacturers' Standard Gage No.	Nominal Thickness		Minimum Thickness	
	Inches	mm	Inches	mm
3/8 inch	0.375	9.53	0.365	9.27
5/16 inch	0.312	7.92	0.302	7.67
1/4 inch	0.250	6.35	0.240	6.10
7	0.179	4.55	0.167	4.24
9	0.150	3.81	0.138	3.51
10	0.135	3.43	0.123	3.12
12	0.105	2.67	0.093	2.36
14	0.075	1.91	0.067	1.70

TABLE 4.2
TP-10 NOMINAL AND MINIMUM THICKNESS FOR
GALVANIZED SHEET STEEL

Galvanized Sheet Gage No.	Nominal Thickness		Minimum Thickness	
	Inches	mm	Inches	mm
10	0.138	3.51	0.126	3.20
12	0.108	2.74	0.097	2.46
14	0.079	2.01	0.070	1.78

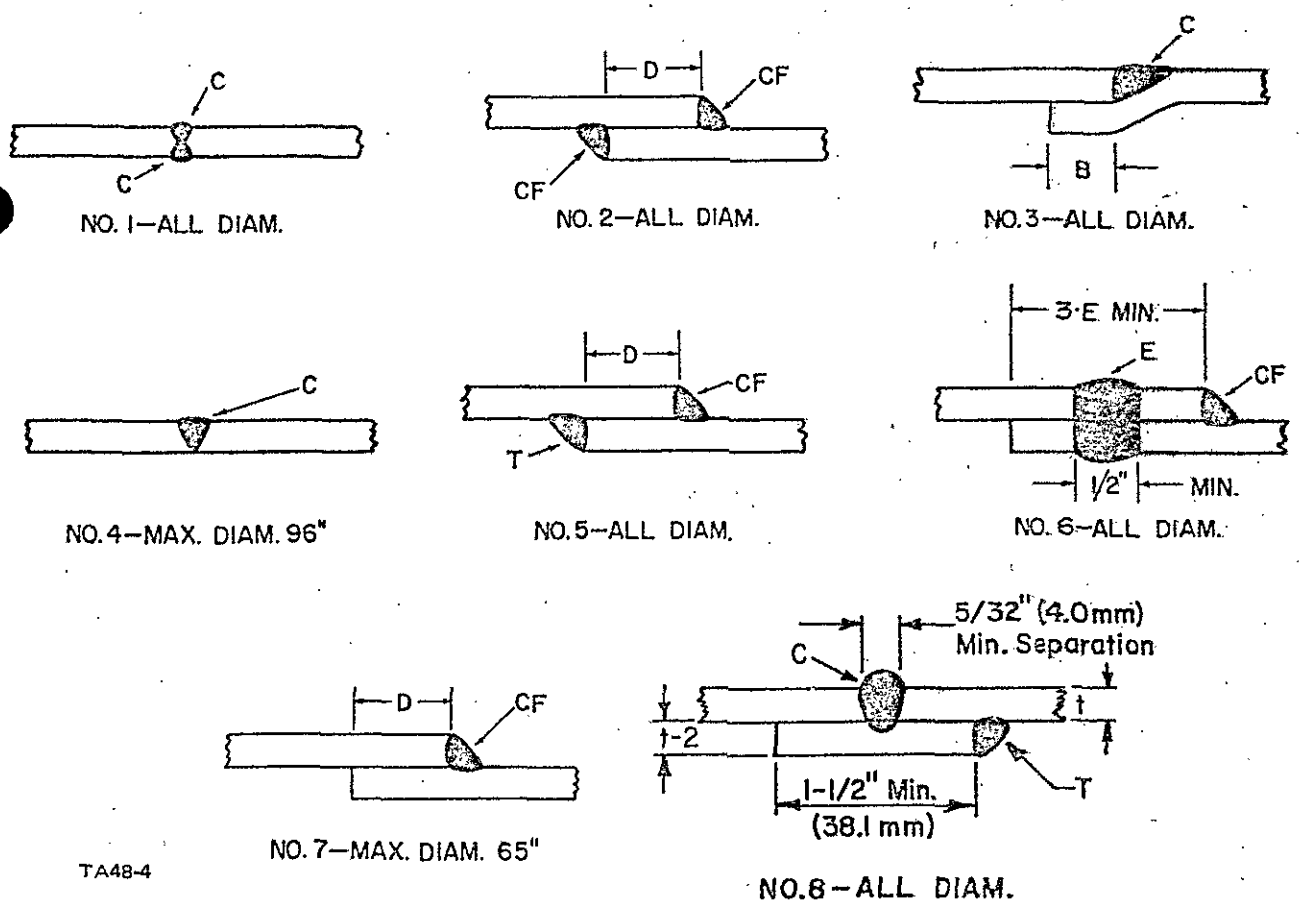
5. Shell Seams

5.1 A shell seam of a tank shall be one of the forms shown by Figure 5.1.

5.2 Shell seam No. 4 shall not be used on tanks larger than 96 inches (2.44 m) in diameter.

5.3 Shell seam No. 7 shall not be used on tanks larger than 65 inches (1.65 m) in diameter.

FIGURE 5.1
SHELL SEAMS



TA48-4

B — Overlap — 1/2 inch (12.7 mm) minimum.

C — Continuous welds.

CF — All lap welds shall be continuous full fillet welds.

D — Overlap — 1/2 inch (12.7 mm) minimum for diameters 48 inches (1.2 m) or less; 3/4 inch (19.1 mm) minimum for diameters over 48 inches (1.2 m).

E — 1/2 inch (12.7 mm) minimum diameter lock weld, not over 12 inches (305 mm) apart.

T — Tack weld 1 inch (25 mm) spots, not over 12 inches (305 mm) apart.

t — Thickness of backup bar to be same as shell thickness.

Figure 5.1 revised November 28, 1977

*Replaces page 6 dated October 29, 1976

COPYRIGHT © 1976, 1977 UNDERWRITERS LABORATORIES INC.

6. Heads and Head Joints

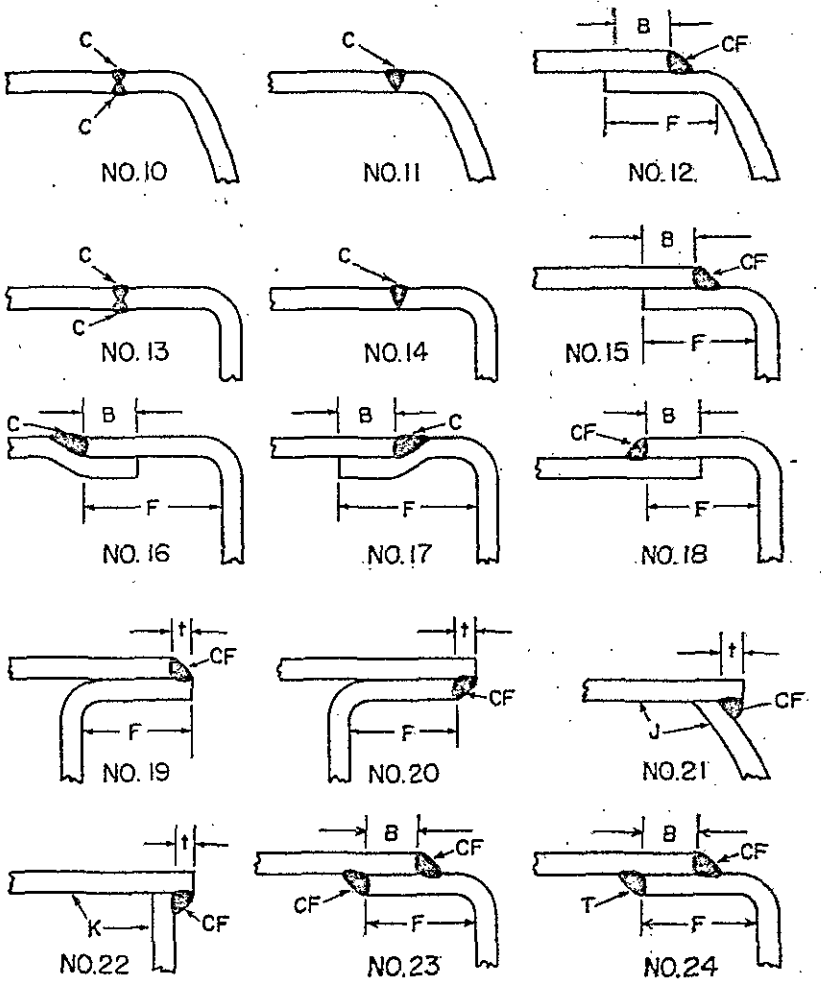
6.1 A head of a tank shall be fabricated of not more than two pieces for diameters of 48 inches (1.22 m) or less; three pieces for diameters of from 49 to 96 inches (1.24 to 2.44 m); and four pieces for diameters of from 97 to 144 inches (2.46 to 3.66 m). When two or more pieces are used, seams shall be one of the forms shown by Figure 5.1, observing the diameter limits as noted.

6.2 A head of a tank may be flat, dished, or conical.

6.3 A head of a tank shall be attached to the shell by one of the joints shown by Figure 6.1.

6.4 An unflanged flathead of a tank shall be braced in accordance with Figure 6.2, No. 1 or 2, and the head and shell shall be made of not less than No. 7 gage (see Table 4.1) material.

FIGURE 6.1
HEADS AND HEAD JOINTS FOR ALL DIAMETER TANKS



B — Overlap — 1/2 inch (12.7 mm) minimum.

C — Continuous welds.

CF — Shall be continuous full fillet welds.

F — Not less than five times head thickness — minimum 1/2 inch (12.7 mm).

J — Joint No. 21 — Minimum Gage No. 7, (0.179 inch) (4.55 mm) nominal.

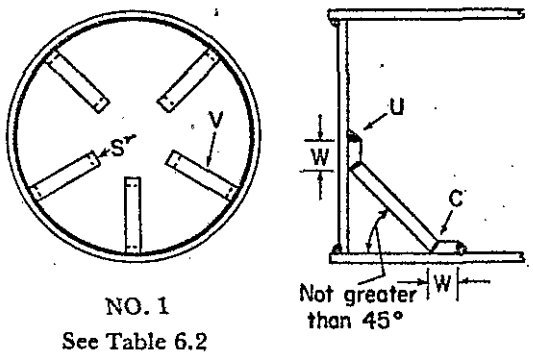
K — Joint No. 22 — Heads require bracing (see No. 1 and 2 of Figure 6.2). Minimum Gage No. 7, (0.179 inch) (4.55 mm) nominal.

T — Tack weld 1 inch (25 mm) spots, not over 12 inches (305 mm) apart.

t — Minimum, 1 X shell thickness.

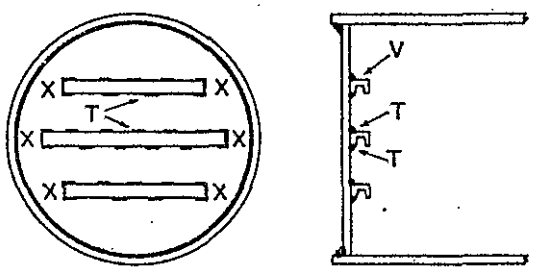
Heads may be flat, dished, or cone.
Height of cone heads — not less than one-twelfth diameter.
Height of dished heads shall conform to Table 6.1.

FIGURE 6.2
BRACING FOR UNFLANGED FLAT HEADS AND BULKHEADS



C–Weld.
S–From center, approximately ¼ of diameter.
U–Weld three sides each foot.
V–Bracing.
W–Minimum length of foot.

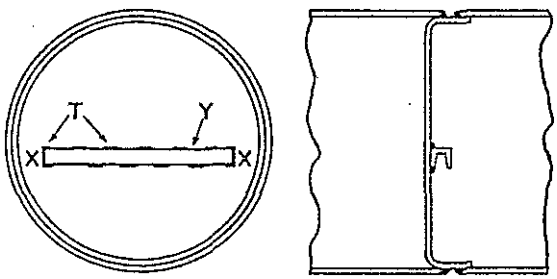
NO. 1
See Table 6.2



T–Tack welds, not over 12 inches (305 mm) apart.
V–Bracing.
X–Not over 2 inches (51 mm) from shell.

NO. 2
See Table 6.3

BRACING FOR FLANGED FLAT BULKHEADS



T–Tack welds, not over 12 inches (305 mm) apart.
X–Not over 2 inches (51 mm) from shell.
Y–Bracing (locate 6 inches (150 mm) below center of head).

NO. 3
See Table 6.4

TA 44-1

TABLE 6.1
DISHED HEADS – MINIMUM HEIGHT

TP-5

Diameter		Minimum Dish		Diameter		Minimum Dish	
Inches	m	Inches	mm	Inches	m	Inches	mm
Up to 60	Up to 1.52	1-1/2	38	97–108	2.46–2.74	4-1/2	114
61–72	1.55–1.83	2	51	109–120	2.77–3.05	5-1/2	140
73–84	1.85–2.13	2-1/2	64	121–132	3.07–3.35	7	178
85–96	2.16–2.44	3-1/2	89	133–144	3.38–3.66	8	203

NOTE — The use of standard S.I. (metric) sizes and weights of angles, channels, and I-beams as substitutes for the U.S.A. structural units specified in Tables 6.2, 6.3, and 6.4 shall be based on those sizes and weights having an equal or greater section modulus (S).

TABLE 6.2
STRUT BRACING FOR UNFLANGED FLAT HEADS AND BULKHEADS[a]

TP-2

Diameter Head		Channels		Angles		W[a]	
Inches	m	Size, Inches	Section Modulus(s) In.^{3}	Size, Inches	Section Modulus(s) In.^{3}	Inches	mm
Up to — 60	Up to 1.52	1 by 3/8 by 1/8	0.048[b]	1 by 1 by 1/8	0.031	1	25.0
61—72	1.55—1.83	1 by 3/8 by 1/8	0.048[b]	1-1/4 by 1-1/4 by 1/8	0.049	1-1/4	32.0
73—84	1.85—2.13	1 by 1/2 by 1/8	0.063[b]	1-1/2 by 1-1/2 by 1/8	0.072	1-1/2	38.0
85—96	2.16—2.44	1 by 1/2 by 1/8	0.063[b]	1-3/4 by 1-3/4 by 3/16	0.140	1-3/4	44.0
97—108	2.46—2.74	1-1/2 by 3/4 by 1/8	0.147[b]	2 by 2 by 3/16	0.190	2	51.0
109—120	2.77—3.05	3 inches — 4.1 pounds	1.1[b]	2 by 2 by 1/4	0.250	2	51.0
121—132	3.07—3.35	3 inches — 4.1 pounds	1.1[b]	2-1/2 by 2-1/2 by 5/16	0.480	2-1/2	64.0
133—144	3.38—3.66	3 inches — 4.1 pounds	1.1[b]	2-1/2 by 2-1/2 by 5/16	0.480	2-1/2	64.0

[a] See Figure 6.2, No. 1.

[b] Flange of channel welded to head or bulkhead and shell.

TABLE 6.3
SURFACE BRACING FOR UNFLANGED FLAT HEADS AND BULKHEADS[a]

TP-3

Diameter Head		Channels		Angles	
Inches	m	Size	Section Modulus(s) In.^{3}	Sizes, Inches	Min. Section Modulus(s) In.^{3}
Up to — 60	Up to 1.52	3 inches — 4.1 pounds	1.1[b]	2 by 2 by 3/8 or 2-1/2 by 2-1/2 by 1/4	0.35
61—72	1.55—1.83	3 inches — 4.1 pounds	1.1[b]	3 by 3 by 7/16 or 3-1/2 by 3-1/2 by 5/16	0.95
73—84	1.85—2.13	4 inches — 5.4 pounds	1.9[b]	3-1/2 by 3-1/2 by 1/2 or 4 by 4 by 3/8	1.50
85—96	2.16—2.44	5 inches — 6.7 pounds	3.0[b]	4 by 4 by 1/2 or 5 by 3-1/2 by 3/8	2.00[b]
97—108	2.46—2.74	5 inches — 6.7 pounds	3.0[b]	4 by 4 by 3/4 or 6 by 4 by 3/8	2.80[b]
109—120	2.77—3.05	6 inches — 8.2 pounds	4.3[b]	5 by 5 by 5/8 or 6 by 4 by 1/2	3.90[b]
121—132	3.07—3.35	7 inches — 9.8 pounds	6.0[b]	5 by 5 by 3/4 or 6 by 4 by 9/16	4.50[b]
133—144	3.38—3.66	7 inches — 9.8 pounds	6.0[b]	5 by 5 by 3/4 or 6 by 4 by 9/16	4.50[b]

[a] See Figure 6.2, No. 2.

[b] Short leg of angle or flange of channel welded to head or bulkhead.

TABLE 6.4
SURFACE BRACING FOR FLANGED FLAT BULKHEADS[a]

TP-4

Diameter Head		I-Beams		Channels	
Inches	m	Size	Section Modulus(s) In.^{3}	Size	Section Modulus(s) In.^{3}
72–84	1.83–2.13	3 inches — 5.7 pounds	1.7[b]	3 inches — 4.1 pounds	1.1[b]
85–96	2.16–2.44	3 inches — 5.7 pounds	1.7[b]	4 inches — 5.4 pounds	1.9[b]
97–108	2.46–2.74	4 inches — 7.7 pounds	3.0[b]	5 inches — 6.7 pounds	3.0[b]
109–120	2.77–3.05	5 inches — 10 pounds	4.8[b]	5 inches — 6.7 pounds	3.0[b]
121–132	3.07–3.35	5 inches — 10 pounds	4.8[b]	6 inches — 8.2 pounds	4.3[b]
133–144	3.38–3.66	5 inches — 10 pounds	4.8[b]	6 inches — 8.2 pounds	4.3[b]

[a] See Figure 6.2, No. 3.

[b] Flange of I-beam or channel welded to bulkhead.

6.5 A flanged flathead of a tank is not required to be braced.

6.6 A conical head of a tank shall have a height of not less than one-twelfth the diameter of the tank.

6.7 A dished head shall have a dish height of not less than that specified in Table 6.1.

7. Compartment Tanks

7.1 Bulkheads of compartment tanks shall be of such construction that any leakage through joints will be directed to the outside of the tank rather than from one compartment to another. See Figure 7.1 for acceptable bulkhead constructions.

7.2 A single bulkhead of a compartment tank, shown by Nos. 101 and 102, Figure 7.1, shall be fabricated of one piece of material and may be flat or dished. The height of a dished bulkhead shall be not less than that specified in Table 6.1.

7.3 A bulkhead of a double bulkhead tank, shown by No. 100, Figure 7.1, shall be fabricated of not more than two pieces for diameters of 48 inches (1.22 m) or less; three pieces for diameters of from 49 to 96 inches (1.24 to 2.44 m); and four pieces for diameters of from 97 to 144 inches (2.46 to 3.66 m). When two or more pieces are used, seams shall be one of the forms shown by Figure 5.1, observing the diameter limits as noted.

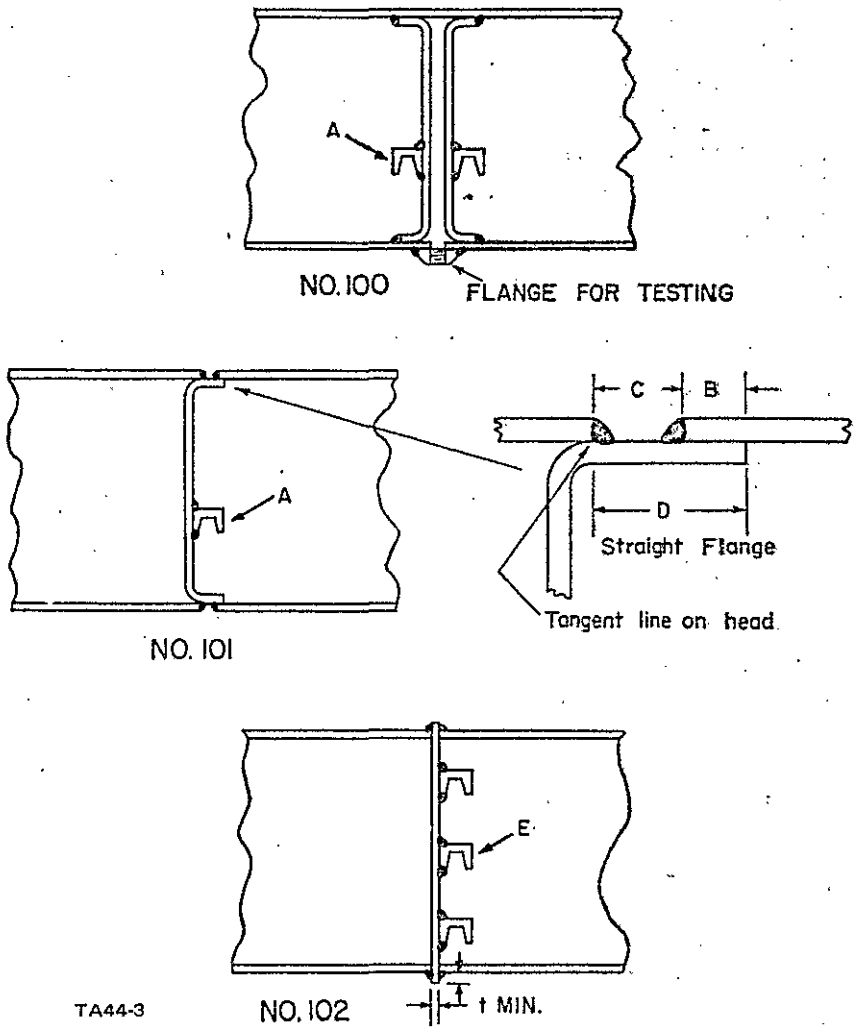
7.4 The thickness of metal employed for a bulkhead depends upon its diameter and shall be not less than that specified in Table 3.1.

7.5 An unflanged flat bulkhead of a compartment tank shall be braced in accordance with Figure 6.2, No. 1 or 2, and shall be made of not less than No. 7 gage (see Table 4.1) material.

7.6 A flanged flat bulkhead of a compartment tank more than 72 inches (1.83 m) in diameter shall be made of not less than 5/16-inch (see Table 4.1) thick material or it shall be braced in accordance with Figure 6.2, No. 3.

7.7 A flanged flat bulkhead 72 inches (1.83 m) or less in diameter does not require bracing.

FIGURE 7.1
BULKHEADS FOR COMPARTMENT TANKS



A — Bracing as per Table 6.4 if diameter exceeds 72 inches (1.8 m)

B — 1/2 inch (12.7 mm)

C — 3/4 inch (19.1 mm)

D — 1-1/4 inch (31.8 mm)

E — Bracing as per Table 6.2 or 6.3

8. Pipe Connections

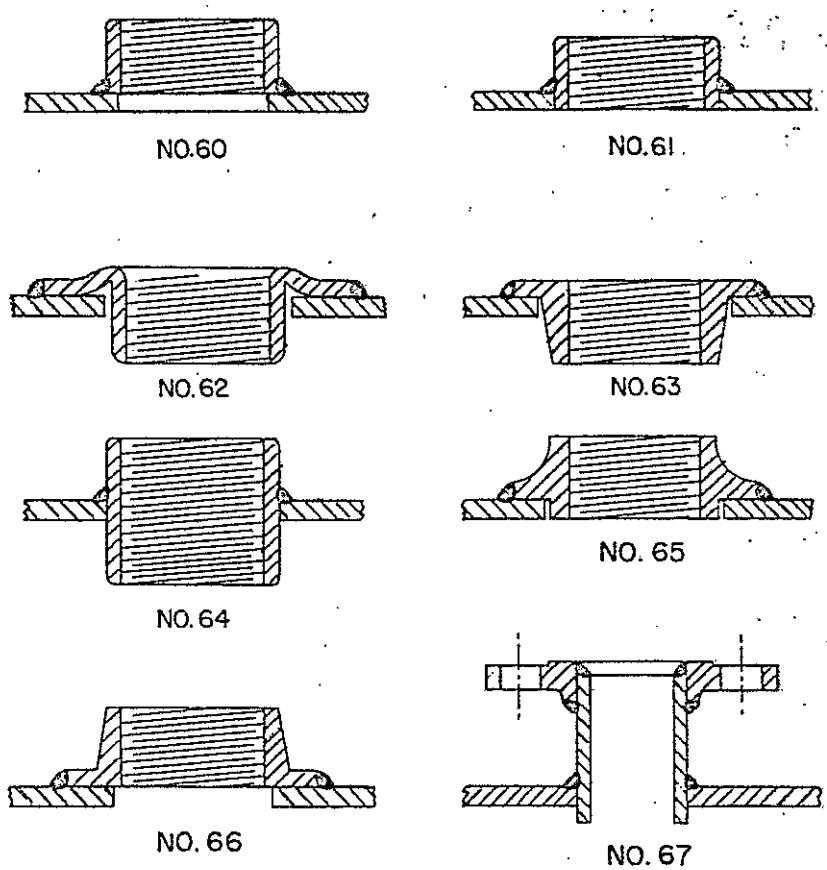
8.1 Pipe connections shall be supplied by welding to the tank, standard threaded pipe couplings, substantial threaded flanges, standard half pipe nipples, or by bolted and gasketed flanged connections welded to pipe nipples which, in turn, are welded to the tank.

8.2 Conventional types of pipe connections are illustrated by Figure 8.1.

8.3 Pipe-connecting fittings shall be of steel of a good welding quality. The minimum length of thread shall conform to the values specified by Table 8.1.

8.4 Pressed-steel pipe-connecting fittings shall be installed with the hub section on the inside of the tank only and of the form shown by No. 62, Figure 8.1. The thickness of the flange section shall be as specified in Table 8.1 with tolerances as permitted by Table 4.1.

FIGURE 8.1
PIPE CONNECTIONS



TA45-1 All welds shall be full fillet welds.

No. 60 – Half pipe coupling.
No. 61 – Half pipe coupling.
No. 62 – Pressed steel, hub inside tank only.
No. 63 – Forged steel, hub inside tank.
No. 64 – Full pipe coupling.
No. 65 – Forged steel, with pilot.
No. 66 – Forged steel, without pilot.
No. 67 – Standard pipe nipple and welding flange.

TABLE 8.1
PIPE CONNECTIONS

TP-6

Pipe Size[a] Nominal	Minimum Length of Thread		Thickness of Flange Section of Pressed-Steel Fittings		
Inches	Inches	mm	Gage No.	Nominal, Inches	mm
1/8	1/4	6.4			
1/4	3/8	9.5			
3/8	3/8	9.5			
1/2	1/2	12.7			
3/4	5/8	15.9	10	0.135	3.4
1	5/8	15.9	9	0.150	3.8
1-1/4	11/16	17.5	9	0.150	3.8
1-1/2	3/4	19.1	9	0.150	3.8
2	3/4	19.1	9	0.150	3.8
2-1/2	1	25.4	7	0.179	4.6
3	1	25.4	7	0.179	4.6
3-1/2	1	25.4	7	0.179	4.6
4	1-1/8	28.6	7	0.179	4.6
5	1-3/16	30.2			
6	1-1/4	31.7			
8	1-3/8	34.9			

[a] American Standard, ANSI B36.10.

8.5 Half pipe nipples shall be welded to the tank as shown by No. 67, Figure 8.1.

8.6 Except as indicated in paragraphs 8.7 and 8.8, all openings in a tank shall be located in the top, parallel with the longitudinal axis of the tank.

8.7 If the application of a tank is such that pipe-connecting openings in the top are required to be grouped, the openings may be located off center of the longitudinal axis under the conditions specified in paragraph 8.8.

8.8 No opening in the shell of a tank shall be located more than 12 inches (305 mm) from the longitudinal center line of the top, and the upper end of the pipe coupling or other pipe-connecting fitting welded to the tank shall terminate above the top of the shell.

8.9 All openings in a tank shall be closed with wooden plugs, metal covers, or their equivalent, to protect the threads and exclude foreign matter while in storage or in transit.

8.10 Each tank shall have a pipe connection of a size not less than that specified in Table 8.2 for attachment of a vent pipe.

8.11 An opening for connection of a vent pipe shall not be located in a manhole cover.

TABLE 8.2
SIZE OF VENT-PIPE FITTING

TP-7

Capacity of Tank, U.S. Gallons	dm^3	Pipe Size[a] Nominal Inches
0 to 500	Up to 1,895	1-1/4
501 to 3,000	1,900 to 11,355	1-1/2
3,001 to 10,000	11,360 to 37,855	2
10,001 to 20,000	37,860 to 75,710	2-1/2
20,001 to 35,000	75,715 to 132,490	3
35,001 to 50,000	132,495 to 189,270	4

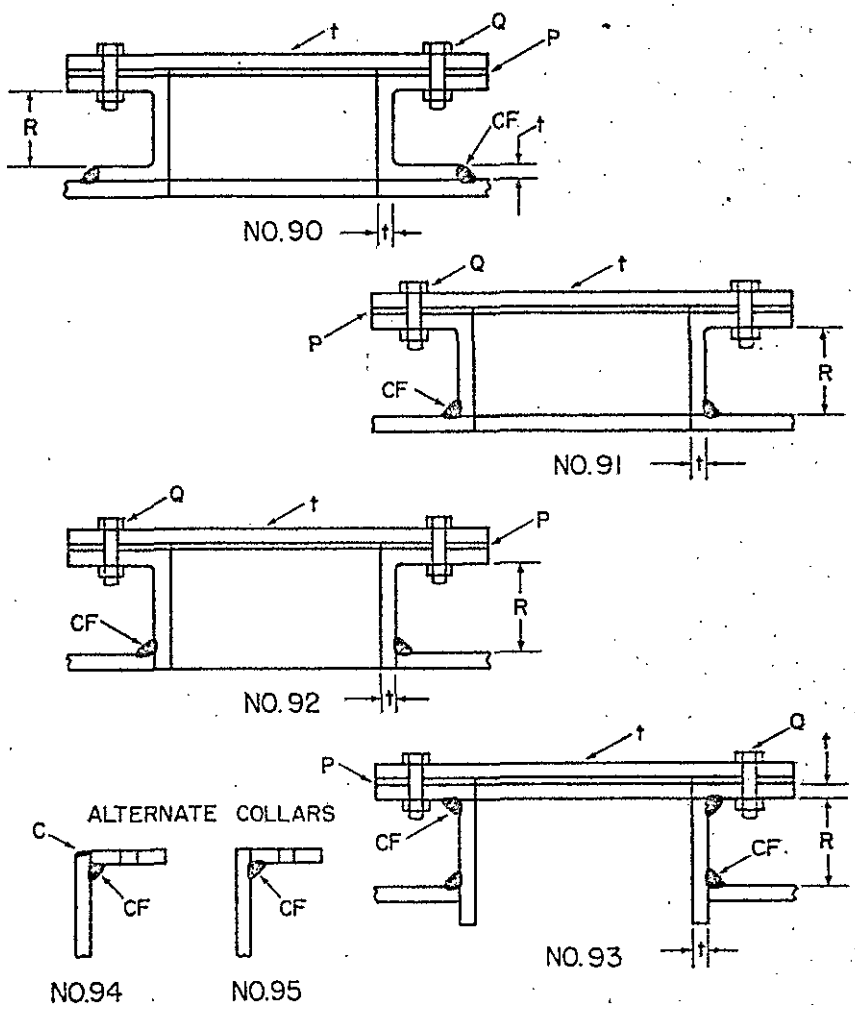
[a] American Standard, ANSI B36.10.

9. Manholes

9.1 A manhole, if provided in a tank, shall be located above the highest normal liquid level and shall be of the bolted-cover type as shown by Figure 9.1.

9.2 A manhole-cover joint shall be provided with a gasket of material determined to be suitable for the liquid to be stored and shall have a thickness of not less than 1/8 inch (3.2 mm).

FIGURE 9.1
CONVENTIONAL MANHOLES



TA48-3

CF — Continuous full fillet weld.

P — Gasket material, 1/8 inch (3.2 mm) thick minimum — ring or face gasket.

Q — Minimum, 1/2 inch (12.7 mm) bolts spaced 4 inch (102 mm) centers maximum.

R — Minimum, 2 inches (51 mm) for tanks 6 feet (1.8 m) in diameter or larger.

t — Not less than No. 7 gage (0.179 inch) (4.55 mm) nominal.

10. Heating Coils and Hot Wells

10.1 A heating coil or hot well, if provided as a part of a tank assembly and if handling a fluid other than that stored in the tank, such as steam or hot water, shall have no joints in that portion located within the tank unless such joints are continuously welded or brazed.

10.2 Inlet and outlet connections of a heating coil or a hot well shall be located above the highest normal liquid level. A continuous weld shall be made where a connection pierces the shell of the tank or a manhole cover.

MANUFACTURING AND PRODUCTION TESTS

11. General

11.1 Each tank, before painting, shall be tested by the manufacturer and proved tight against leakage in accordance with one of the following methods:

A. By applying internal air pressure and using soapsuds, linseed oil, or equivalent material for the detection of leaks. The test pressure is to be not less than 5 nor more than 7 pounds per square inch gauge (psig) (34.5–48.3 kPa).

B. By completely filling the tank with water and applying an additional 5 psig (34.5 kPa) pressure. When using this method, the tank is to be placed in the position in which it will be installed.

11.2 If leaks are noted during the test, the tank shall be made tight by welding and retested. Defects in welds shall be repaired by chipping or melting out from one or both sides of the joint, as required, and rewelding.

11.3 Each compartment of compartment tanks shall be separately tested for leakage.

MARKING

12. General

12.1 Each tank shall be marked with the name of the manufacturer or a distinctive marking, which may be in code, by which it may be identified as the product of a particular manufacturer.

12.2 If a manufacturer produces tanks at more than one factory, each tank shall have a distinctive marking to identify it as the product of a particular factory.

APPENDIX A

TD-3

TABLE I
GALLON CAPACITY PER FOOT OF LENGTH

Diameter in Inches	U. S. Gallons 1-Foot Length	Diameter in Inches	U. S. Gallons 1-Foot Length	Diameter in Inches	U. S. Gallons 1-Foot Length
24	23.50	65	172.38	105	449.82
25	25.50	66	177.72	106	458.30
26	27.58	67	183.15	107	467.70
27	29.74	68	188.66	108	475.89
28	31.99	69	194.25	109	485.00
29	34.31	70	199.92	110	493.70
30	36.72	71	205.67	111	502.70
31	39.21	72	211.51	112	511.90
32	41.78	73	217.42	113	521.40
33	44.43	74	223.42	114	530.24
34	47.16	75	229.50	115	540.00
35	49.98	76	235.66	116	549.50
36	52.88	77	241.90	117	558.51
37	55.86	78	248.23	118	568.00
38	58.92	79	254.63	119	577.80
39	62.06	80	261.12	120	587.52
40	65.28	81	267.69	121	597.70
41	68.58	82	274.34	122	607.27
42	71.97	83	281.07	123	617.26
43	75.44	84	287.88	124	627.00
44	78.99	85	294.78	125	638.20
45	82.62	86	301.76	126	647.74
46	86.33	87	308.81	127	658.60
47	90.13	88	315.95	128	668.47
48	94.00	89	323.18	129	678.95
49	97.96	90	330.48	130	690.30
50	102.00	91	337.86	131	700.17
51	106.12	92	345.33	132	710.90
52	110.32	93	352.88	133	721.71
53	114.61	94	360.51	134	732.60
54	118.97	95	368.22	135	743.58
55	123.42	96	376.01	136	754.64
56	127.95	97	383.89	137	765.78
57	132.56	98	391.84	138	776.99
58	137.25	99	399.88	139	788.30
59	142.02	100	408.00	140	799.68
60	146.88	101	416.00	141	811.14
61	151.82	102	424.48	142	822.69
62	156.83	103	433.10	143	834.32
63	161.93	104	441.80	144	846.03
64	167.12				

TD-4

TABLE II
LITER CAPACITY PER METER OF LENGTH

Diameter in mm	Liters (dm^3) 1-meter Length
600	282.7
700	384.8
800	502.7
900	636.2
1000	785.4
1100	958.2
1200	1131.0
1300	1327.3
1400	1539.4
1500	1767.2
1600	2010.6
1700	2269.8
1800	2544.7
1900	2835.3
2000	3141.6
2100	3463.6
2200	3801.3
2300	4154.8
2400	4523.9
2500	4908.8
2600	5309.3
2700	5725.6
2800	6157.5
2900	6605.2
3000	7068.6
3100	7547.7
3200	8042.5
3300	8553.0
3400	9079.2
3500	9621.2
3600	10178.8
3700	10752.1
3800	11341.2

90. Uniform Fire Code. "Interior Lining of Existing Steel Underground Storage Tanks" Standard No. 79-6, Chapter 1-6 (draft)

UNIFORM FIRE CODE
STANDARD No. 79-6

INTERIOR LINING OF EXISTING STEEL UNDERGROUND STORAGE TANKS

CHAPTER 1

GENERAL PROVISIONS

SCOPE:

Sec. 79.601 This standard sets forth the minimum requirements for the interior lining of existing steel underground tanks utilized for the storage of flammable and combustible liquids. Included under the scope of this standard is the repair of leaking tanks and protection of tanks from corrosion through the application of a lining material and cathodic protection. The lining itself is not intended to replace the structural strength provided by the steel tank shell or prevent future external corrosion. This standard addresses only those issues directly related to fire prevention and control. It is the intent of this standard to recognize that all applicable safety and health laws, regulations and ordinances shall be complied with in conjunction with the provisions set forth in this standard and that the contractor is knowledgeable of its content as well as the referenced material listed herein.

DEFINITIONS:

Sec. 79.602

APPROVED - SEE U.F.C.

CLASS I, DIVISION I, GROUP D - SEE ELECTRICAL CODE

COMBUSTIBLE LIQUID - SEE U.F.C.

FLAMMABLE LIQUID - SEE U.F.C.

LABELED - SEE U.F.C.

LISTED - SEE U.F.C.

LOWER FLAMMABLE LIMITS - The minimum concentration of vapor to air below which propagation of a flame will not occur in the presence of an ignition source.

NATIONALLY RECOGNIZED TESTING LABORATORY - A testing laboratory, inspection agency, or other organization concerned with product evaluation that maintains periodic inspection of production of labeled equipment or materials and by whose labeling is indicated compliance with

nationally recognized standards or tests to determine suitable usage in a specific manner.

STATIC ELECTRICITY - The electrification of materials through physical contact and separation, and the various effects that result from the positive and negative charges so formed - particularly where they constitute a fire or explosion hazard.

SELF CONTAINED BREATHING APPARATUS - A portable respiratory protective device designed to protect the wearer from oxygen-deficient or a hazardous atmosphere that has its own air or oxygen supply and is approved by NIOSH (National Institute of Occupational Safety and Health).

VAPOR AREA - SEE U.F.C.

PERMITS & PLANS:

Sec. 79.603 (a) Prior to engaging in any activities relating to the alteration or repair of tanks or equipment in connection with the storage, handling, use or sale of flammable or combustible liquids regulated by the Uniform Fire Code, a permit shall be applied for from the Chief. No on-site work shall be initiated until a permit has been issued. (See Article 4, U.F.C.)

(b) At the time a permit is applied for, the applicant shall submit all certificates, specifications, licenses, certificates of insurance and such other documents required by this standard and the Chief.

MATERIALS:

Sec. 79.604 (a) Materials used for the interior lining of steel underground tanks shall be approved by the Chief.

(b) Guidelines for approval may include the following:

1) Materials listed by a nationally recognized testing laboratory for the intended use.

2) Acceptable materials shall satisfy the following requirements certified by the manufacturer and in accordance with nationally recognized and accepted standards, principles and tests.

a. Adhesion

Coatings, when applied to properly-prepared steel surfaces must maintain adhesion (bond) to the tank while in its designated service.

b. Immersion Tests

Representative coating samples shall be tested to determine compatibility of the lining material with stored products. Samples shall be immersed in the liquids listed below at either 38° C (100° F) for periods of one, three and six months, or 23° C (74° F) for periods of one, three, six and twelve months. The 23° C (74° F) exposure is more realistic and is preferred.

LIQUIDS FOR IMMERSION TESTING:

ASTM Reference Fuel C
Unleaded Gasoline
Leaded Gasoline
No. 2 Fuel Oil or Diesel Oil
Toluene
Xylene
Gasohol (50% ethanol)
Gasohol (50% methanol)
Distilled Water

Upon completion of each immersion period, samples shall be tested in accordance with the following:

TEST	PURPOSE
ANSI-N5.12-1983	Bonding Strength
ASTM D790-81	Flexural Strength
ASTM D2794-69	Impact Resistance
ASTM D2583-81 (Model 934-1)	Barcol Hardness
or	
Barber Coleman GYZJ (Model 935)	
ASTM D543-67 Procedure 1	Weight and Dimension Changes

Properties after the final immersion period shall be a minimum of 30% of the original properties before immersion in toluene, xylene, and distilled water; and 50% for immersion in all other listed liquids, with a stable trend indicating no further long-term deterioration.

NOTE: Before storage is permitted of liquids other than those listed, test results demonstrating the liner will meet the above requirements in those liquids must be submitted by the manufacturer.

CHAPTER 2

GENERAL SAFETY REQUIREMENTS

Sec. 79.605 (a) Site Preparation. Prior to excavation, the site shall be safeguarded from all sources of ignition for an area of 25 feet in all directions until vapor free. All open flame and spark producing equipment within the area shall be shut down. Barricades and warning signs reading "Flammable - No Smoking" shall be provided in accordance with the directions of the Chief.

(b) Clearance. A clearance from the Chief shall be obtained prior to proceeding with any work that may generate or produce flammable or combustible vapors.

(c) Fire Extinguishers. Two portable A:B:C type fire extinguishers each having a rating not less than 80B:C shall be provided on the site in accordance with U.F.C. Standard No. 10-1 for extra (high) hazard.

(d) Emergency Communications. A dependable method, approved by the Chief, of notifying the fire department shall be maintained.

(e) Static Electricity Control. Adequate precautions shall be taken to prevent the accumulation and discharge of static electricity.

(f) Class I, Division I Electrical Equipment. All electrical equipment used in the area must be explosion-proof (Class I, Group D, Division I) or approved for the service.

PREPARATION FOR OPENING THE TANK:

Sec. 79.606. Tank Isolation. Before any work on the exterior surface of the tank begins, tanks must be inspected to determine how the tank is to be isolated. If a tank is equipped with a manifold vent or fill line or syphon assembly, necessary measures must be taken to isolate each tank(s). All product and vapor recovery piping shall be disconnected and blanked off and the bungs of the tank plugged. The vent for the tank being lined should be isolated from vents for other tanks which may still be in service. This may require a temporary separate vent for the tank being lined. All electrical switches supplying electrical current to submerged pumps and/or other equipment connected to the tank shall be disconnected and locked.

Sec. 79.607. Removal of Liquid Product. As much product, water and sediment as possible shall be removed using explosion-proof or air driven pumps. Pum motors and suction hoses must be bonded to the tank to prevent electrostatic ignition hazards. A small quantity of water can be pumped into the tank to float the product from a low spot where it can be pumped from the tank. Als where possible, fill (drop) tubes shall be removed to allow for maximum removal of all liquid and to provide for adequate air ventilation.

Sec. 79.608 Removal of Flammable Vapors (Gas Freeing) (a) The tank shall be thoroughly purged only with air to remove flammable vapors of residue capable of producing flammable vapors. The concentration of flammable vapors in a tank may go through the flammable range before a safe atmosphere is obtained. It therefore is necessary that precautions are taken to eliminate the possibility of the discharge of static electricity during gas freeing procedures.

Air pressure in the tank must not exceed 5 psig. To prevent excess air pressure the vent line must be checked to make certain it is free from obstruction and traps.

Ventilation of the tank can be accomplished by one of two methods which are listed below.

(1) An eductor-type air mover (see Appendix C, Figure 1) usually driven by compressed air, shall be properly bonded to prevent the possibility of static electricity generation and discharge. When using this method, the fill (drop) tube should remain in place to ensure ventilation at the bottom of the tank. Tanks equipped with fill (drop) tubes which are not removable shall be purged by this method. An extension shall be used to discharge vapors a minimum of twelve (12) feet above grade.

(2) Diffused blown-air is illustrated in Appendix C, Figure 2. When using this purging method it is imperative that the air-diffusing pipe is properly bonded to prevent the discharge of a spark. Fill (drop) tubes must be removed to allow proper diffusion of the air in the tank. Air supply shall be from a compressor, which has been checked to ensure a clean air supply, free from volatile vapors. Air pressure in the tank must not exceed 5 psig.

Sec. 79.609. Testing Flammable Vapor Concentrations. An important phase of the operation is the testing for flammability of the vapor in the excavated area and in the tank. Such tests are to be made with a combustible gas indicator which is properly calibrated on hexane in air and thoroughly checked and maintained in accordance with manufacturer's instructions. Persons responsible for testing must be completely trained and familiar with the use of the instrument and the interpretation of the instrument's readings.

The tank vapor space is to be tested by placing the combustible gas indicator probe into the fill opening with the fill (drop) tube removed. Readings shall be taken at the bottom, middle and upper portions of the tank and the instrument shall be purged with fresh air after each reading. If the tank is equipped with a non-removable fill tube, readings shall be taken through another opening. Liquid product must not enter the probe. The vapors shall be tested at the vent riser or eductor while the air mover is in operation and purging is in progress, and also in the tank itself with purge air shut off. Readings of 10 percent or less of the lower flammable limit (LFL), as indicated in the tank and at the vent riser or

eductor, must be obtained before the tank is considered safe for opening.

79.610. Opening the Tank. If no manway exists, or if an existing manway is less than 24 inches in diameter, an opening with the minimum dimension of 24" X 24" shall be cut in the top. The tank section to be removed should be marked square with chalk and a hole drilled with an explosion-proof (such as air-driven) drill at one corner of the section. After the hole is drilled, the tank vapors must again be tested by inserting the meter probe into the hole to verify that the vapor concentration does not exceed 10 percent LFL.

NOTE: It is important that the purging, air ventilation and testing continue throughout the entire lining operation. During the tank cutting operation minimal air pressure shall be maintained to prevent a blow out.

The tank shall be cut using an explosion-proof (such as air-driven) saber saw or snipper using lubricating oil to reduce friction, heat and possible sparks. Prior to the final cut, the plate shall be supported to prevent its falling into the tank.

Sec. 79.611. Tank Entry. Before entering tanks, the procedures described in API Publications 2015, "Cleaning Petroleum Storage Tanks", and 2015A, A Guide for Controlling the Lead Hazard Associated with Tank Entry and Cleaning", should be followed. This includes checking the oxygen content inside the tank with a properly calibrated oxygen monitor. At all times, personnel entering the tank shall be equipped with positive pressure air supplied equipment with full face enclosure and safety harness connected to a safety line held by an attendant outside the tank. A self-contained breathing apparatus shall be available to the attendant for rescue operations or other emergencies.

Oil and water-resistant rubber or neoprene boots and gloves shall be worn. Clothing shall cover the arms, legs, torso and head of tank entry personnel. Disposable clothing, impervious to product, is preferred. Clothing saturated with product shall be removed immediately. All personnel working inside the tank should be familiar with ANSI Z117.1, "Confined Spaces Safety".

Tests with the combustible gas indicator and oxygen monitor should be performed periodically in the tank to ascertain that the tank vapors and oxygen content are in the safe range. It should be recognized that if the tank is perforated, product or vapors which have leaked into the soil may re-enter the tank through a perforation. The vent line shall remain clear and unobstructed to allow continuous ventilation. All other lines and openings shall be plugged or capped off to insure no liquids or vapors may enter the tank during the lining operation.

79.612. Sludge Removal. Sludge accumulation on the bottom of the tank must be removed and placed in tightly sealed containers. It must be disposed of as soon as practical in accordance with local, State and Federal regulations, which may require mandatory documentation as well as safe disposal.

NOTE: Tank sludge and scale are potentially hazardous as they may contain tetraethyl lead vapors which can be inhaled, or toxic liquid tetraethyl lead which may be absorbed through the skin. If the dry internal surface of the tank is scraped, the resulting atmosphere may contain dangerous quantities of lead. The quantity of lead in the tank atmosphere should be checked using a lead-in-air analyzer.

CHAPTER 3

TANK INSPECTION AND STRUCTURAL CERTIFICATION

INTERIOR SURFACE PREPARATION FOR INSPECTION:

Sec. 79.613. Surface Preparation. All abrasive blasting personnel should be familiar with the hazards described in API Publication 2027, "Ignition Hazards Involved in Abrasive Blasting of Tanks in Service". All perforations shall be plugged with boiler plugs or hydraulic cement as necessary to permit abrasive blasting; seams may be plugged with hydraulic cement.

CAUTION: BEFORE ABRASIVE BLASTING, THE TANK SHOULD BE CHECKED AGAIN WITH THE COMBUSTIBLE GAS INDICATOR TO ENSURE THAT NO FLAMMABLE VAPORS HAVE ENTERED THE TANK.

BLAST CLEANING OPERATIONS SHALL NOT BE CONDUCTED ON SURFACES THAT WILL BE WET AFTER BLASTING AND BEFORE APPLICATION OR WHEN THE SURFACE IS LESS THAN 5° F ABOVE DEW POINT, OR WHEN THE RELATIVE HUMIDITY OF THE AIR IS GREATER THAN 85%.

The entire internal tank surface shall be abrasive blasted completely free of scale, rust and foreign matter. Abrasive blast operators shall wear approved helmets connected to sources of clean air. Bonding should be provided between the blasting nozzle and the work surface, or else the blasting nozzle should be effectively grounded to provide equivalent protection from static charges.

Sec. 79.614. Tank Inspection. During inspection, the entire surface of the tank shall be inspected using a light fixture approved for Class I, Division I, Group D hazardous locations. The structural integrity of the tank shall be determined by an approved non-destructive thickness measuring device. The entire tank interior shall be inspected using the approved wall thickness measuring device on a two foot grid pattern and also a visual inspection. All questionable tank wall areas (less than 1/8" wall thickness) will be tap tested with a ballpeenhammer to determine extent of metal loss. A lined tank's structural integrity is dependent on the steel tank shell; therefore a repairable tank will be identified by the following guidelines:

1. A tank having a single open seam or split no longer than three (3) inches in areas other than within six (6) inches of head to shell seam; or

2. A tank having a single perforation no larger than one and one-half (1-1/2) inch in diameter except under the gauging opening where the perforation may be no larger than two and one-half (2-1/2) inches in diameter; or

3. A tank with less than five (5) perforations (none larger than one-half inch in diameter) in any one square foot area; or

f. A tank with less than twenty (20) perforations (none larger than one-half inch in diameter) in a five hundred (500) square foot area.

To determine adherence to these guidelines, perforations and seams shall be less ballpeen hammered (before and after abrasive blasting) to remove thin metal and obtain structurally sound edges. Perforations and seam splits shall be reamed until the edges of the hole or split are a minimum of 1/8" thick. Tanks that exceed any one of the above shall not be interior lined. Tanks having a leak in a toggle or lap joint shall not be repaired. The structural integrity of the tank shall be certified by a registered engineer unless waived by the Chief.

CHAPTER 4

APPLICATION OF LINING AND TANK CLOSING

Sec. 79.615. Application of Lining. Prior to the application of lining material, boiler plugs and hydraulic cement plugs shall be covered with epoxy or polyester then covered with fiberglass cloth (minimum 1½ oz./yd^2, silane treated) which overlaps all sides of the plug with a minimum of two (2) inches. If a perforation in a seam is present, the perforation shall be sealed with hydraulic cement then covered with glass cloth and resin, overlapping the perforation by six (6) inches. A 1/4" steel reinforcing plate rolled to the contour of the tank and with minimum dimensions of 8" by 8" shall be installed under the fill (drop) tube and gauging tube. This plate shall be covered with fiberglass cloth imbedded in resin. The blast-cleaned surface should be coated within eight hours after blasting and before any visible rusting occurs. Only those lining materials meeting the specifications in Section 79.604 shall be used. Manufacturer's instructions are to be followed on handling and/or preparation of the lining materials and these materials shall be applied to the entire interior surface of the tank by the manufacturer or his designated distributor following the specified method of application, to the designated thickness and at the recommended application temperature. If a heater is used to accelerate the curing process, all other work which might release flammable vapors must be halted and the heating unit must be attended whenever it is in operation. The coating shall be cured thoroughly to the manufacturer's specifications and checked for air pockets, and pinholes using an approved Holiday Detector. If any exceptions are found they shall be repaired to manufacturer's specifications. Contractor shall protect the coated surfaces from contamination by foreign matter. The coating thickness shall be checked with an Elcometer Thickness Gauge or equivalent and tested for hardness using a Barcol Hardness Tester or equivalent to ensure compliance with manufacturer's specifications.

Sec. 79.616. Tank Closing. If an opening has been cut, the tank shall be sealed as follows:

(a) A 1/4" minimum thick steel cover plate, but not less than the original size plate, rolled to the contour of the tank, shall be made to overlap the hole at least two inches on each side.

(b) The cover shall be used as a template to locate 3/4" diameter holes not exceeding five inch centers, one inch from the edge of the cover and tank opening.

(c) The cover plate shall be abrasive blasted to white metal on both sides, and also shall include the outside of the opening under tank cover, and the entire inside cover surface shall be coated with coating material to act as a gasket.

(d) Before the coating on the cover cures, the cover shall be fastened to the tank using 1/2" (minimum) diameter bolts. The bolt shafts are to be placed through the holes from the inside of the tank and held in place by spring clips, then fastened with lock washers and nuts as illustrated in Figure 3.

(e) All bare surfaces shall be coated on the interior and exterior with the coating material.

(f) After being bolted to the tank, the cover plate and surrounding tank surface shall be abrasive-blasted to white metal, coated with coating material and allowed to cure before backfilling the hole.

CHAPTER 5

TESTING

Sec. 79.617. Pressure Testing. Before backfilling, the tank shall be tightness tested in accordance with U.F.C. Sec. 79.605 (b). Particular attention should be paid to the cover plate and all exposed fittings.

Sec. 79.618. Vacuum Testing. Before backfilling, the tank shall be tightness tested at a vacuum equivalent to the burial depth of the tank times 1.05.

CHAPTER 6

EXTERNAL CORROSION PROTECTION

Sec. 79.619. Cathodic Protection. Interior lined underground tanks shall be cathodically protected in accordance with U.F.C. Sec. 79.603.

APPENDIX A

REFERENCE MATERIALS

ANSI Z117.1	Confined Spaces Safety
A.P.I. PUBLICATION 2015	Cleaning Petroleum Storage Tanks
A.P.I. PUBLICATION 2015A	A Guide for Controlling the Lead Hazard Associated with Tank Entry and Cleaning
A.P.I. R.P. 2003	Protection Against Ignitions Arising Out Of Static, Lightning and Stray Currents
A.P.I. R.P. 2027	Ignition Hazards Involved In Abrasive Blasting of Tanks In Service
N.F.P.A. Standard 77	Static Electricity
N.F.P.A. Standard 327	Cleaning Small Tanks and Containers

91. U.S. Environmental Protection Agency. A Guide to the Selection of Materials for Monitoring Well Construction and Ground-Water Sampling, EPA-600/2- 84-024, January 1984

2648

Eagle

A GUIDE TO THE SELECTION OF MATERIALS FOR MONITORING WELL CONSTRUCTION AND GROUND-WATER SAMPLING

by MICHAEL J. BARCELONA, JAMES P. GIBB, and ROBIN A. MILLER

ILLINOIS STATE WATER SURVEY
Champaign, Illinois
1983
ISWS Contract Report 327

A Guide to the Selection of Materials for Monitoring Well Construction and Ground-Water Sampling

by

Michael J. Barcelona
James P. Gibb
Robin A. Miller

Prepared in cooperation with

Robert S. Kerr Environmental Research Laboratory, Ada, Oklahoma
and the
Environmental Monitoring Systems Laboratory, Las Vegas, Nevada
U.S. Environmental Protection Agency
Contract No. EPA CR-809966-01

Illinois State Water Survey
Department of Energy and Natural Resources
Champaign, Illinois

August 1983

SWS Contract Report 327

FOREWORD

The subsurface environment of ground water presents many challenges to effective monitoring efforts. Physical, microbiological and geochemical forces interact over variable time frames as the evolution of ground-water solution characteristics proceeds. Monitoring data should be collected with minimum disturbance of the subsurface. This goal implies careful attention to the details of sound drilling, well construction, and sampling methodologies.

The complex nature of ground-water monitoring further demands that cost-effective choices of materials, target chemical constituents, and procedures are made prior to implementation of the network design. Attempts to cut costs for the sake of short-term 'savings' can result in substantial added expense. This may occur when the goals of the monitoring effort are expanded and information needs require increased analytical detail. There are few merits to penny-wise, pound-foolish approaches to ground-water monitoring.

CONTENTS

	Page
Foreword	iii
Figures	vi
Tables	vii
Acknowledgements	viii
Section 1. Introduction	1
Need for and Importance of Monitoring	2
Section 2. Objectives	4
Section 3. Ground-Water Monitoring Requirements	5
Resource Conservation and Recovery Act (RCRA)	5
The Comprehensive Environmental Response, Compensation and Liability Act (CERCLA)	5
State Requirements for Ground-Water Monitoring	6
Section 4. Background	7
Previous Studies	7
Monitoring in General	7
Monitoring Well Design and Construction	8
Ground-Water Sampling	9
Materials Used in Monitoring Efforts	10
Current Research Efforts	11
Section 5. Monitoring Wells and Sampling Apparatus	13
Monitoring Well Components	13
Well Location	14
Well Diameter	14
Well Depth	15
Well Design and Construction Materials	15
Drilling Methods	17
Well Development	20
Sampling Apparatus	22
Section 6. Sampling Strategy	26
Effects of Subsurface Conditions on Ground-Water Quality and Sampling	26
Effects of Hydrologic Conditions on Sampling Strategy	27
Section 7. Evaluation of Materials	31
Overview of Subsurface Conditions	31
Chemical Properties of Water and Their Effects on Various Materials	31
Candidate Test Solutions for Materials' Evaluation	33
Preliminary Ranking of Well Construction/Sampling Materials	34
Evaluation of Selected Materials	37
Teflon® Well Casing	38
Stainless Steel Well Casing	38
PVC Well Casing	39
PVC product formulations and applicable standards	39
Practical considerations and potential for analytical bias due to the use of PVC well casing	41

representative of the water contained in the ground. However, there is considerable controversy among laboratories, agency policies, and researchers concerning proper well construction and sampling techniques and appropriate procedures for preserving the original chemical character of the samples. If monitoring wells and water samples are to provide the performance yardstick for disposal facilities' design and operation, the significance of various monitoring well construction and sampling procedures and preservation techniques must be determined.

Need for and Importance of Monitoring

Ground-water monitoring is essential to determine the quality of the nation's ground-water resources and the effectiveness of ground-water pollution control regulations. Only through the collection of accurate data can we ascertain the chemical nature of our ground-water resources. Ground-water monitoring can be divided into four types: *ambient* monitoring, *source* monitoring, *case preparation* monitoring, and *research* monitoring.

Ambient ground-water quality monitoring establishes an understanding of characteristic regional water quality variations and changes over time. This type of monitoring is normally accomplished through routine sampling of wells on an areal or regional basis. The wells sampled are often public water supply, industrial or domestic wells as opposed to specially constructed monitoring wells. The sample collection techniques also are often quite different from those for monitoring wells. Therefore, data obtained from ambient monitoring programs may not be comparable to that obtained by more rigorous well construction and sampling procedures. However, the data are invaluable in detecting significant changes in water quality and protecting public health.

Source monitoring is the type normally conducted at a potential pollution source. *Source* monitoring detects and quantifies the migration of pollutants from potential pollution sources. Most regulatory programs have monitoring guidelines that detail minimum standards for source monitoring. In an effort to minimize cost to the regulated community, a two-step approach to source monitoring has been used by most states.

The first step is a minimum-requirement approach based on the principle of detecting leakage of pollutants from disposal or storage facilities. It is understood that data collected from a detective monitoring scheme will not define the extent or seriousness of a developing problem. Therefore, once the detective monitoring system has sounded the alarm, most states require a more definitive monitoring program to provide interpretive information concerning the extent and seriousness of the problem.

The second step is interpretive monitoring which normally requires expanded information needs and the installation of additional wells. The purpose of interpretive monitoring is to define the limits and concentrations within the plume of pollutants moving from the presumed source. The addition of wells areally, and vertically nested well sets often is required to adequately define plume geometry and concentration gradients.

Case-preparation or *enforcement* monitoring is undertaken by the regulatory community to collect evidence for prosecution of ground-water pollution cases. This type

of monitoring usually is developed in response to the language in the appropriate laws intended to be used in the prosecution of the case. The detailed information resulting from this type of monitoring generally is more specific with respect to concentrations and changes in concentrations at the legal points of regulation. Further definition of plume geometry or concentrations normally is not required for successful litigation.

Research monitoring often results in a level of data collection far beyond that required for other types of monitoring activities. Added information is required to help understand and document the mechanisms controlling solute transport of pollutants. The collection of this type of monitoring data is very rigorous and demanding although limited to specific research goals.

Selection of the types and levels of monitoring to be used in any situation should be made with care and judgment. The goals of a proposed monitoring program should be clearly stated and understood before consideration is given to what types of wells should be constructed, where they should be located, how deep they should be, what materials should be used, what chemical constituents should be analyzed, and how samples should be collected. Successful and cost-effective monitoring at all levels can be accomplished only after the goals or purposes of the monitoring program are thoroughly understood.

Considerable effort at EMSL-Las Vegas is directed toward monitoring ground-water quality using non-drilling or remote-sensing techniques, especially at hazardous waste sites. One project is investigating the feasibility of sampling by cone penetrometer in lieu of conventional drilled wells. Other projects involve using geophysical methods such as complex resistivity for tracking leachates from hazardous waste sites.

Research at MERL-Cincinnati does not specifically address ground-water monitoring. The emphasis there is on providing technical support to RCRA and Superfund activities of the Agency. Most research is related to remedial action activities at waste disposal sites and/or the evaluation of the effectiveness of these activities. Ground-water monitoring is necessarily a part of such evaluations, but development of new monitoring techniques is generally not a part of MERL's research efforts.

SECTION 5
MONITORING WELLS AND SAMPLING APPARATUS

The success of a ground-water monitoring program depends, in part, on the selection of the proper type of well.

Production or traditional wells often are used to obtain samples in ambient ground-water monitoring programs. Designed to yield large quantities of turbidity-free water for potable or irrigation supplies, these wells generally tap the more permeable portions of an aquifer. Chemical data obtained from these wells depict the quality of water being delivered to the user community. Because water pumped from these wells is a composite of water from different horizontal and vertical strata in the aquifer systems, the presence of relatively narrow or small plumes of polluted water can be masked by dilution with water obtained from unaffected portions of the aquifer.

Production or traditional wells should not be used for the more detailed source, case-preparation, and research types of monitoring. Such detailed monitoring efforts call for wells designed to determine the ground-water quality at a given location and depth within the geologic materials being monitored. All available geologic and hydrologic information for the site of interest should be reviewed prior to selecting preliminary locations and depths for monitoring wells. The potential paths of pollutant movement from the site should be estimated and wells should be placed so that they can effectively and quickly detect releases. Information gained during the drilling process should be used to modify the monitoring plan to make it more effective.

Monitoring Well Components

The principal reason for constructing monitoring wells is to collect ground-water samples which, upon analysis, enable describing a contaminant plume and tracking movement of specific chemical or biological constituents. Obviously, the location of monitoring wells spatially and vertically is important. Of equal importance is the design and construction of monitoring wells to provide easily obtainable samples that will yield reliable, meaningful information. In general, monitoring well design and construction follow production well design and construction techniques. However, emphasis is placed on the effect these practices may have on the chemistry of the water samples being collected rather than on maximizing well efficiency.

From this emphasis, it follows that an understanding of the chemistry of the suspected pollutants and the geologic setting in which the monitoring wells are constructed plays a major role in the drilling technique and materials used. There are several components to be considered in the design of a monitoring well, including location, diameter, depth, casing, screen, sealing material, and well development. As these components are discussed in detail, it may be helpful to refer to Figure 5-1, which portrays two typical well installations: one for water supply and the other for ground-water quality monitoring.

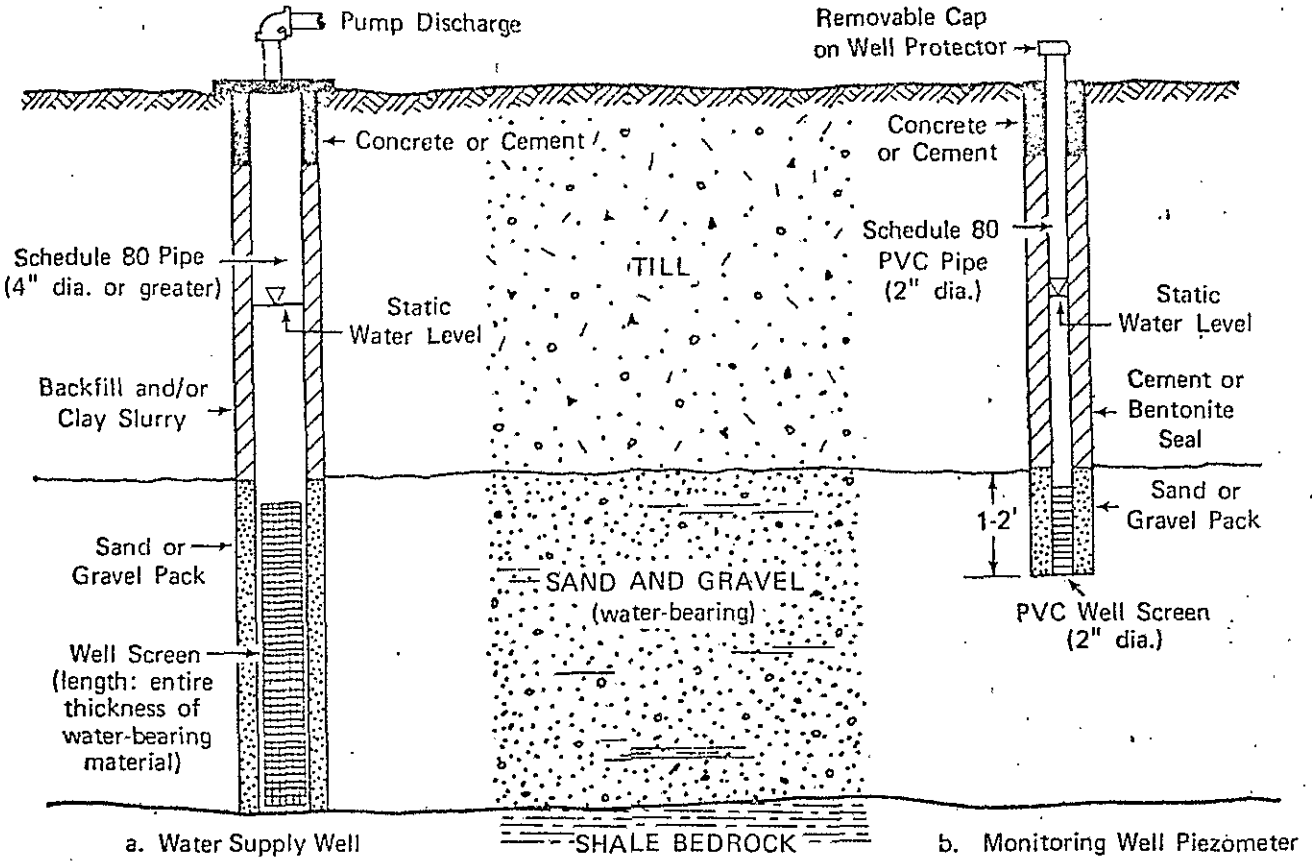


Figure 5-1. Schematic diagrams of typical water supply (a) and monitoring (b) well installations

Well Location

The location of a monitoring well should be selected on the basis of the purpose of the program. This purpose may be to verify predictions of contaminant migration; to detect contaminants in drinking water supplies and thus protect public health; to activate a contingency plan such as a program for leachate collection; to protect the operator; or to reassure the public by demonstrating that their water quality is being monitored. Each of these purposes will require a somewhat specialized array of monitoring points and a somewhat different sampling program. The monitoring system must be designed to suit the purpose(s) in mind.

The positioning of a monitoring point in a contaminant flow path for an "interpretive" monitoring effort must be determined on the basis of reliable preliminary data. To do this, the contaminant flow path must be clearly defined in three dimensions during the "detective" phase. Only then can the optimum location for proposed monitoring wells be effectively determined.

Well Diameter

A domestic water supply well is commonly 4 inches in diameter to accommodate a submersible pump capable of delivering 5-10 gallons per minute. Municipal and

industrial supply wells have greater diameters to handle larger pumps and to increase the available screened open area so the well can produce water more efficiently. Like that of a water supply well, the diameter of a monitoring well is determined by the size of the sampling device or pump. This strategy works well in very permeable formations, but unlike most water supply wells, monitoring wells are quite often completed in very marginal water-producing zones. Pumping one or more well volumes of water from a monitoring well built in such zones may present a serious problem if the well has a large diameter. Large quantities of water must be disposed of, and it may take several hours or even days for enough water to return to the well for successful collection of a representative sample. With the advent of several commercially available small-diameter pumps (less than 2 inches outside diameter) capable of lifting water from several hundred feet, it is rarely necessary to construct monitoring wells larger than 2 inches in diameter. Additionally, the smaller the diameter, the less it will cost for drilling and construction. A thorough discussion of advantages and disadvantages of monitoring well diameter has recently been published (55).

Well Depth

The depth of each monitoring well normally is determined by the geohydrologic conditions at the site being monitored. Most "detective" monitoring wells are completed in the first relatively permeable water-bearing zone encountered, since potential pollution sources requiring the installation of monitoring wells are frequently at ground surface. Locating the monitoring well in the first relatively permeable zone therefore yields an early warning of the migration of pollutants in most situations. However, care must be taken to assure the well is completed at a depth sufficient to allow for seasonal water table fluctuations. Under confined or semi-confined (leaky) conditions the water level will rise above the top of the water-bearing zone. In this instance, the well should be finished in the water-bearing zone and not above it.

If the water-bearing zone is thick (greater than 10 feet) or contamination is known or suspected in deeper formations, multiple wells completed at different depths should be used. For sampling at various depths, some engineers have nested several wells in a single borehole. This requires drilling a large diameter hole and exercising special care to ensure that the vertical integrity of the sampling points is maintained. It is important that monitoring wells be constructed so that they are depth-discrete, that is, so that they sample from one specific formation or zone without interconnection to others. To assure that this requirement is met, provisions for placing cement grout above and, if necessary, below the intake portion of the well, must be made in the design of the well.

Well Design and Construction Materials

The type of material used for monitoring well casing can have a distinct effect on the quality of the water samples collected. Galvanized casing will impart iron, manganese, zinc and cadmium to many waters. Steel casing may impart iron and manganese to the water samples. PVC pipe has been shown to release and adsorb trace amounts of various organic constituents to water after prolonged exposure. PVC solvent cements used to attach sections of PVC pipe also have been shown to release significant quantities of organic compounds. Teflon® and glass are among the most inert materials

that have been considered for monitoring well construction. Glass, however, is very difficult and expensive to use under most field conditions. Stainless steel also has been found to work satisfactorily. A detailed discussion of materials is presented in later portions of the text.

In many situations, it may be possible to compromise accuracy or precision for initial cost. For example, if the contaminants of interest are already defined and they do not include substances which might bleed from, sorb or interfere with other analytical methods, it might be reasonable to use wells cased with a less expensive material. Wells constructed of less-than-optimum materials might be used for sampling if identically constructed wells are available in both uncontaminated and contaminated parts of the aquifer to provide ground-water samples for use as "blanks." Obviously, such "blanks" may not address adequately problems of adsorption on or leaching from the casing material induced by contaminants in the ground water. Careful consideration is required in each individual case, and the analytical laboratory should be fully aware of construction materials used.

Care must be given to the preparation of the casing and well screen materials prior to installation. As a minimum, both should be washed with detergent and rinsed thoroughly with clean water. Care also should be taken to ensure that these and other sampling materials are protected from contamination by using some type of ground cover such as plastic sheeting for temporary storage in the work area.

All wells should allow free entry of water. They also should produce clear, silt-free water. For drinking water supplies, the reason is obvious: sediment in the raw water can create additional pumping and treatment costs and lead to the general unsuitability of the finished water. With monitoring wells, sediment-laden water can greatly lengthen filtering times and create chemical interferences with the collected samples.

Commercially manufactured well screens generally work best provided the proper slot size is chosen. In formations where fine sand, silt, and clay predominate, sawed or torch cut slots will not retain the material, and the well may clog. It may be helpful to have well screens of several slot-sizes on site so that the correct manufactured screen can be placed in the hole after the water-bearing materials have been inspected. Gravel-packing materials compatible with the selected screen size will further help retain fine materials and also allow freer entry of water into the well by creating a zone of higher permeability around the well.

Well screen length is an important consideration. When monitoring a potable-water-supply aquifer, the entire thickness of the water-bearing formation should be screened. This provides an integrated water sample similar to what would be found in the drinking water supply. A monitoring program to describe contaminant plume geometry requires sampling discrete intervals of the water-bearing formation. In this situation, screen lengths of no more than 5 feet (1.5 m) should be used. Thick aquifers would require completion of several wells at different depth intervals. In some situations, only the first water-bearing zone encountered will require monitoring. Here the "aquifer" may be only 6 inches to a few feet (0.2-2 m) thick, and the screen length should be limited to 1 or 2 feet (<1 m). Monitoring for low density organic solvents or hydrocarbons which may float on the water surface creates a special problem. In

such a case, the screen must be long enough to extend above the water level in the formations so these lighter substances can enter the well.

It is critical that the screened portion of each monitoring well access ground water from a specific depth interval. Vertical movement of water in the vicinity of the intake and around the casing must be prevented to obtain samples representative of that in the formation of interest. Specifically, rainwater can infiltrate backfill materials and dilute or contaminate samples collected from the screened portion of the well. Vertical seepage of leachate or contaminated water from adjacent formations along the well casing also may produce unrepresentative samples for the depth interval being sampled. More serious indeed is the creation of a conduit in the annulus of a monitoring well which could contribute to or hasten the spread of contamination.

Monitoring wells usually are sealed with neat cement grout, dried bentonite, or bentonite slurry. While a neat cement grout often is recommended, shrinkage and cracking of the cement upon curing can create an improper seal. The use of bentonite traditionally has been considered more effective than neat cement grout. However, recent studies have shown that some organic compounds migrate through bentonite layers with little or no attenuation (56). Therefore, expanding cement appears to offer the greatest potential for the effective sealing of wells. There are several commercial formulations of this type of cement which generally is more chemical resistant than clays. The seal should extend from just above the well intake to a level above the highest known seasonal water level. Backfill cuttings then may be used to fill the annulus in the unsaturated zone provided that they are free of contamination, and a mounded, expanded cement collar can be placed around the well casing to divert surface drainage from the immediate area of the well casing. This collar should extend well below the frostline and should be checked periodically for cracks or fissures.

When sealing materials must be placed below the water table (or where water has risen in the borehole), it is recommended that they be pumped down the annulus through a tremie pipe and filled from the bottom upward.

Drilling Methods

The selection of a drilling method best suited for a particular installation is based on the following factors, listed in order of importance:

1) Hydrologic information
   a. types of formations
   b. depth of drilling
   c. depth of desired screen setting below water table
2) Types of pollutants expected
3) Location of drilling site, e.g., dry lands or inside a lagoon
4) Design of monitoring well desired
5) Availability of drilling equipment

The principles of operation and the advantages and disadvantages of the more common types of drilling techniques suitable for constructing ground-water monitoring wells are discussed by Scalf (1). The following is a brief summary of material presented in that publication.

Auger drilling frequently is accomplished by rotating a solid-stem, continuous-flight auger into the soil. As the augers are "screwed" into the soil, the cuttings are brought to the surface on the rotating flights. Auger bits are essentially of two types: fish tail or drag bits for use in unconsolidated materials, or claw or finger bits for use in consolidated or cemented soils. Once the desired depth is reached, the augers are allowed to rotate to clean out the borehole. The augers then are removed from the borehole and the well screen and casing installed. This method is best applied when installing monitoring wells in shallow unconsolidated formations that will maintain an open borehole long enough to permit emplacement of the well, piezometer, or sampling device.

Hollow-stem, continuous-flight auger drilling differs from the solid-stem augers in that the stem is hollow. Upon reaching the desired depth, a small-diameter casing and screen can be set inside the hollow stem. The augers then are pulled out as the casing is held in place. If the borehole stands open after withdrawing the augers, an artificial gravel pack is placed opposite the screened portion of the well. If the material collapses around the screened portion of the well, those materials are ultimately removed or altered in grain size by the development procedures employed after well construction.

Auger drilling rigs generally are mobile, fast, and inexpensive to operate in unconsolidated formations. Because no drilling fluid is required, contamination problems are minimized. However, these types of rigs cannot be used in hard-rock drilling. Depth limitations vary with the equipment and types of soils, but usually are a maximum of 150 feet. Collection of formation samples is not expedited by the use of solid-stem, continuous-flight augers. However, conventional soil sampling techniques (split spoon and Shelby tube sampling) can be accomplished effectively during the drilling procedure through the hollow-stem, continuous-flight augers. Formation sampling has been covered in detail by Scalf et al. (1).

Straight rotary drilling is accomplished by pumping a drilling mud down the inside of a rotating drill pipe and allowing it to return to the surface through the annulus. The drilling mud cools the drill bit, carries the cuttings to the surface, prevents excess fluid loss into the formation and prevents the formation from caving. The rotating drill pipe turns the bit, which cuts the formation, allowing the cuttings to be flushed out. The drilling fluid (or mud) may be clear water, water mixed with bentonite, or water mixed with various synthetic or natural drilling aids. Rotary rigs generally are available throughout the United States. They are capable of drilling in all types of formations to almost any depth desired for monitoring and are fairly reliable in most formations. Casing is not required during the drilling and logging of formations.

The use of drilling fluids or muds during construction can bias the results of samples collected from wells. The introduction of clear water has a tendency to allow water to migrate into permeable formations which may be of interest. This water must be effectively removed before the quality of "native ground water" can be determined. Drilling muds also present a problem during the well development and have the ability to affect the transport of certain pollutants as water moves toward the well. Organic-based muds add significant quantities of foreign organic material into the aquifer system (57,58,59). Studies concerning the effects of these types of muds on the analytical results of collected samples and the biodegradability of the muds have not been conclusive.

Air rotary rigs operate in the same manner as the mud rotary rig except that air is circulated down the drill pipe and returns with the cuttings up the annulus. Some rotary rigs are equipped to operate with either mud or air. Air rotary rigs are available throughout much of the United States and are well suited for many drilling applicatons.

Air rotary rigs operate best in hard rock formations. Formation water is blown out of the hole along with the cuttings, so it is possible to determine when the first water-bearing zone is encountered. After filtering of water blown from the hole, collection and field analyses may provide preliminary information regarding changes in water quality for some parameters. Formation sampling ranges from excellent in hard, dry formations to nonexistent when circulation is lost in cavernous limestones and other formations with cavities.

Casing is required to keep the borehole open when drilling in soft, caving formations below the water table. When more than one water-bearing zone is encountered and where the hydrostatic pressures are different, flow between zones will occur between the time when the drilling is done and the time when the hole can be properly cased and one zone grouted off. Commonly, no synthetic drilling aids are used in air rotary drilling. If the air is filtered to capture compressor lubricants, contamination can be minimized relative to other methods. The use of air rotary drilling in badly contaminated subsurface situations must be approached carefully to minimize the exposure of drilling personnel to potentially hazardous materials.

A cable tool rig uses a heavy, solid-steel chisel-type drill bit suspended on a steel cable which, when raised and dropped, chisels or pounds a hole through the soils and rock. When drilling through the unsaturated zone, some water must be added to the hole. Cuttings are suspended in the water and periodically bailed. After enough water enters the borehole to replace the water removed by bailing, no additional water needs to be added. When soft, caving formations are encountered, it is necessary to drive casing as the hole is advanced to prevent collapse of the hole. Often the drilling can be advanced only a few feet below the bottom of the casing. Because the drill bit is lowered through the casing, the hole created by the bit is smaller than the casing. Therefore, the casing (with a sharp, hardened casing shoe on the bottom) must be driven into the hole. The shoe, in fact, cuts a slightly larger hole than does the drill bit. This tight-fitting drive shoe cannot be relied upon to form a seal when overlying water-bearing zones are encountered.

Formation samples can be excellent when a skilled driller uses a sand-pump bailer. Information regarding water-bearing zones is readily available during drilling. Relative permeabilities and some water-quality data also can be obtained from different zones penetrated if a skilled operator is available. Cable tool rigs can operate satisfactorily in all formations, but they are best suited for large, caving, gravel-type formations or formations with large cavities above the water table.

Cable tool drilling is slow compared with rotary drilling. The necessity of driving the casing along with drilling in unconsolidated formations requires that the casing be pulled back to expose selected water-bearing zones. This process complicates the well completion process and often increases cost. Relatively large diameter casing is required (minimum 4-inch casing) which increases the costs compared with rotary drilled wells with plastic casing. The use of cable tool rigs for small-diameter (2-inch) wells is not recommended.

Reverse circulation drilling is accomplished by allowing water or mud to circulate down the annulus and up the inside of the drill pipe (reverse flow direction from direct rotary mud drilling). This type of drilling is used for construction of high-capacity production wells and is not suited for small, water-quality sampling wells. Custom drilling techniques may be necessary for specialized investigations (60).

Well Development

Development is a facet of monitoring-well construction that is often overlooked. During the drilling process, fines are forced into the open borehole, forming a mud cake that reduces the hydraulic conductivity of the materials opposite the screened portion of the well. To allow free entry of water into the monitoring well and to maximize well yields (a particularly important factor for low-yield geologic materials), this mud cake must be broken down and the fines removed from the well.

Additionally, monitoring wells must be developed to provide water free of suspended solids for sampling. When sampling for metal ions and other inorganic constituents, water samples must be filtered and preserved at the well site at the time of sample collection. Improperly developed monitoring wells will produce samples containing suspended sediments that will both bias the chemical analysis of the collected samples and frequently cause clogging of the field filtering mechanisms (61).

The development procedures used for monitoring wells are similar to those used for production wells. The basic principles include creating alternately high and low velocities of water flow in the well to break down the mud pack or loosen fines, followed by pumping to remove the fines from the well and the immediate area outside the well screen.

Successful development methods for relatively productive wells include the use of a surge block, bailing, and surging by pumping. A surge block is a plunger device that fits loosely inside the well casing. It is moved forcibly up and down, causing water to surge in and out of the well screen. After surging, the well must be pumped to remove the fines carried into the well screen and casing. The use of surge blocks for monitoring well development has not been widely attempted. The potential for damaging a relatively fragile, 2-inch-diameter PVC well with a tight-fitting surge block has generally overruled the potential benefits that would be gained from this type of development.

A bailer sufficiently heavy to fall quickly through the water can be raised and lowered rapidly through the screened portion of the well. This action will create the same alternating surging action as the surge block. The use of bailers for developing wells is more common than the use of the surge block.

Another method for developing wells in relatively productive geologic materials is to surge either with a pump or by air. When using a pump, the well is alternately pumped and left idle to simulate the surging action desired to loosen the fines and remove them from the well. However, in most applications, no outward movement of water from the well is experienced, and bridging of fines moving toward the well limits the effectiveness of this technique.

When pumping with air, the effectiveness of the procedure depends on the geometry of the device injecting air into the well. Figure 5-2 illustrates a simple device

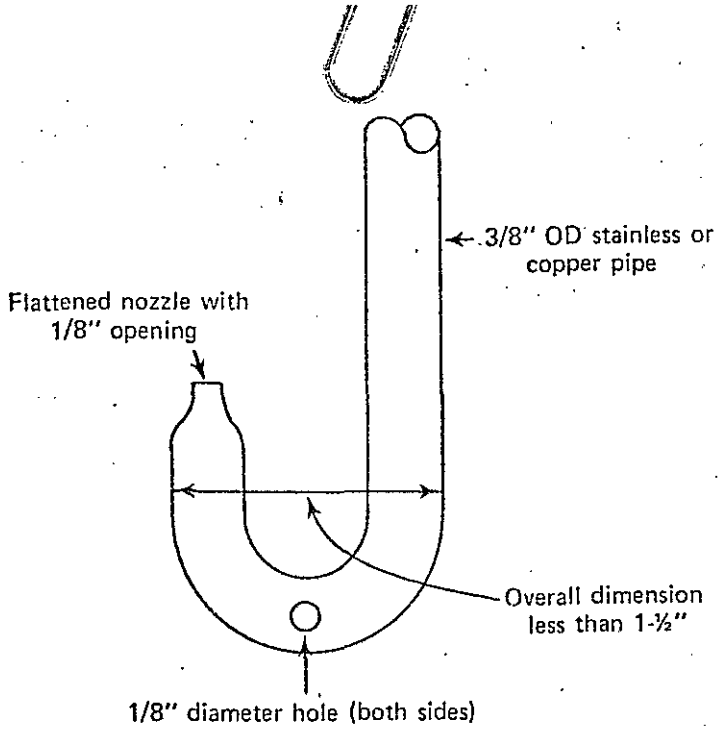


Figure 5-2. Schematic diagram of an air driven well development device

that diverts air through the well screen to loosen the fines and forces air, water and fines up the well casing and out of the well. These devices are particularly effective for developing monitoring wells in relatively productive geologic materials. Air development techniques also may cause the exposure of drilling personnel to hazardous materials when badly contaminated ground water is present. Careful precautions must be taken to minimize personnel exposure.

Development procedures for monitoring wells in relatively unproductive geologic materials is somewhat limited. Due to the low hydraulic conductivity of the materials, surging of water in and out of the well casing is extremely difficult. Also, when the well is pumped, the entry rate of water is inadequate to effectively remove fines from the well bore and the gravel pack material outside the well screen.

In this type of geologic setting, clean water can be circulated down the well casing, out through the screen and gravel pack, and up the open borehole prior to placement of the sealant in the annulus. Relatively high water velocities can be maintained and the mud cake from the borehole wall can be broken down effectively and removed. (Because of the low hydraulic conductivity of geologic materials outside the well, a negligible amount of water will penetrate the formation being monitored.) Immediately following this procedure, the well sealant should be installed and the well pumped.

In summary, all monitoring wells should be developed. The additional time and money spent for this important procedure will expedite sample filtration and result in samples more representative of water contained in the formation being monitored. The time saved in filtration alone will more than offset the cost of development.

SECTION 6
SAMPLING STRATEGY

The importance of proper sampling of monitoring wells cannot be overemphasized. Even when the wells are correctly located, constructed and developed, special precautions must be taken to ensure that the sample collected is representative of the ground water at that location. Care also is needed to ensure that the sample is neither altered nor contaminated by the sampling and handling procedures.

To select proper sampling procedures for monitoring wells, several basic questions must be reviewed. First, the purpose of the monitoring program and collection of samples must be reevaluated. Monitoring commonly is undertaken to comply with state or federal regulations that set forth a list of chemical constituents to be monitored. They also usually stipulate the concentrations of various chemical constituents that must be analyzed and reported. Sampling procedures for defining plume geometry and migration may require different procedures than those for routine regulatory monitoring. Sampling procedures for research projects may be particularly specialized and more demanding. In all instances, it is essential to develop a complete list of chemical parameters to be measured and the sensitivity at which they will be measured. Secondly, the physical limitations of the well and the well site must be considered. The diameter of the well, depth to water, length and location of the well screen, and accessibility of the well site all bear on the practical application of various sampling procedures.

Prior to discussing the effects of well flushing and pumping mechanisms on ground-water quality, it would be instructive to review briefly the factors controlling ground-water quality. An understanding of these factors enables one to better plan sampling efforts and minimize the effects of reactions that may occur due to sample handling.

Effects of Subsurface Conditions on Ground-Water Quality and Sampling

The subsurface is a condensed, geologic, and geochemical environment which also serves as a habitat for microorganisms (62,63). It is difficult to describe the entire range of subsurface conditions since local effects can drastically alter regional properties of temperature, pressure, oxidation-reduction potential, mineral solubility, solution chemistry, and biological activity. The relevance of average conditions must be evaluated on a case-by-case basis in order to account for the changes in ground-water chemistry which may occur during sample collection and retrieval. Temperature and pressure are major physical influences in this regard.

Temperature fluctuations in the upper 10 m (33 ft) of the subsurface occur in response to seasonal air temperature variations. In the United States, average ground-water temperatures range from 3°C to 25°C (37°F to 77°F) to a depth of 20 m (66 ft) (64). Local effects can be quite marked, however, since increases from 7°C to 16°C

(42°F to 60°F) above background have been observed in contaminated aquifers near landfills (65). Pressure gradients in the subsurface may be approximated as those due to the hydrostatic pressure of a column of water equivalent to the depth of interest. The strength of the pressure gradient may vary, though it is generally about 0.1 atm $\cdot$ m^{-1} (0.4-0.5 psi $\cdot$ ft^{-1}). Summarizing average physical conditions in the subsurface, one can expect that from the screened portion of a shallow monitoring well 10-20 m (33-66 ft) deep to the surface, temperature and pressure differentials may range from 10-30°C (45-83°F) and from 2-3 atm, respectively. Regardless of the choice of well construction methods or materials which contact the sample, the impact of temporal and spatial physical changes must be minimized to provide the most representative ground-water sample possible.

Chemical and biological indicators of subsurface conditions vary greatly in response to small changes in the above-mentioned physical factors. Considerations of sample handling procedures and the compatibility of materials with the ground-water system are subtle. In general, the subsurface environment is not in equilibrium with ambient surface conditions. This is particularly true of the atmospheric gases oxygen and carbon dioxide, which exert control over the oxidation-reduction potential, pH, buffer capacity, and chemical speciation of dissolved substances. Several reference works on aquatic and ground-water chemistry provide background information on the range of potential conditions to which samples, well casing, and sampling devices may be subjected (66,67,68,69).

Within an aquifer, there are six major processes which affect subsurface geochemistry. These are: 1) complex formation; 2) acid-base reactions; 3) oxidation-reduction processes; 4) precipitation-dissolution reactions; 5) sorptive interactions; and 6) microbiological processes.

All of these processes can be affected by sample collection procedures. Shifts in solution chemistry caused by rapid changes in temperature, pressure, or gas content may result in nonrepresentative samples. This is particularly true of the carbonate buffer system since ground water is normally oversaturated with carbon dioxide (CO_2). The system is sensitive to temperature and pressure changes since gaseous, dissolved, and solid chemical constituents participate in equilibrium reactions. For example, the loss of dissolved CO_2 on simultaneous temperature increase and sample depressurization will cause an increase in the pH. The pH changes in turn affect mineral solubility, the kinetics of iron and manganese oxidation, and hydrolysis reactions. Products of these reactions in turn may shift the chemical speciation of nutrients and metals and either stimulate or inhibit microbial activity.

Many potential changes can take place in a ground-water sample while being collected or before it is preserved (22,70). The previous discussion described general subsurface conditions and examples of solution chemical changes in inorganic constituents if samples are improperly collected. The impacts on volatile organic compound concentrations also can be quite marked. Samples collected from sites exhibiting unusual chemical properties may respond differently.

Effects of Hydrologic Conditions on Sampling Strategy

Hydrologic factors can exert controlling effects on the collection of representative samples. The yield potential of a monitoring well will determine the length of time

systems have been determined, chemical constituents for routine sampling can be selected.

4) Based on the sensitivity of the selected chemical parameters, a choice of pumps for routine sampling can be made.

5) The monitoring wells should be pumped at a constant rate for a period of time that will result in delivery of at least 95 percent aquifer water. The rate and time of pumping should be determined on the basis of the transmissivity of the aquifer, the well diameter, and the results of the sampling experiment.

6) Measurements of pH, Eh, temperature, and specific conductance also should be made at the time of sample collection. Field determinations of alkalinity together with a mineral analysis, the foregoing measurements and total dissolved solids permit mass and charge balance calculations to be made which are valuable analytical quality control checks.

The steps outlined above are designed for collecting representative samples for inorganic analysis. The same procedures likely will produce representative samples for nonvolatile organic analysis. The use of a syringe sampler (75) in conjunction with pumping or a bottom-draw bailer is desirable for collecting samples for volatile organic constituents.

Special care must be taken to prevent cross-contamination when carrying sampling apparatus from one well to another. The sampling devices must be cleaned thoroughly to ensure that contaminants from one well are not carried to the other. Cleaning procedures should be tailored to the analytes of interest. The use of detergents, dilute hydrochloric acid, hexane, and deionized rinse water often is necessary. In addition, cleaning of sampling devices, all delivery tubes, and tether cables also must be performed thoroughly. The effects of cross-contamination also can be minimized by sampling the least contaminated wells first and progressing to the more contaminated ones. Dedicated sampling devices for each well also may be desirable in certain cases where the potential for cross contamination is high.

In the case of monitoring wells that will not yield water at a rate adequate to be effectively flushed, different procedures must be followed. There are divergent points of view on how flushing should be performed in these situations. The principal difference in the arguments concerns the degree to which such wells should be evacuated. One suggested procedure includes the removal of water to the top of the screened interval to prevent the exposure of the gravel pack or formation to atmospheric conditions (5). Then the sample is taken at a rate which would not cause rapid drawdown. On the other hand, the wells may be pumped dry and allowed to recover. The samples should be collected as soon as a volume of water sufficient for the intended analytical scheme re-enters the well. Exposure of water entering the well for periods longer than 2 or 3 hours may render samples unsuitable and unrepresentative of water contained within the aquifer system. Finally, in these cases, it may be desirable to collect small volumes of water over a period of time, each time pumping the well dry and allowing it to recover. At present there is very little reliable data on which to choose one sampling method over another in "tight" formations.

SECTION 7
EVALUATION OF MATERIALS

The selection of materials used for well construction and sample collection, handling, and storage is a critical consideration in planning the well-conceived monitoring program. The materials of choice should retain their structural integrity for the duration of the monitoring program under actual subsurface conditions. They should neither adsorb nor leach chemical constituents which would bias the collection of representative samples. The material combinations also must be compatible with each other and the goals of the program. For example, in a detective monitoring situation where the presumed inorganic contaminant source (e.g., brine or pickling liquor) is held in a surface impoundment, material selection should be made so as to ensure the reliability of analytical determinations of chemical constituents of the waste in groundwater. These parameters may include pH, specific conductance (Ω^{-1}), alkalinity, hardness, total dissolved solids (TDS), chloride, and trace metals. In this hypothetical situation, the "background" ground water is relatively high in ionic solids, and the goals of a long-term (e.g., 30-year) monitoring program would be most closely met by a properly constructed network of non-metallic or corrosion-resistant monitoring wells. Sampling gear and sample handling precautions also should be chosen carefully to ensure that the samples are neither contaminated nor biased by the effects of materials.

Overview of Subsurface Conditions

The structural requirements for well casings to withstand normal subsurface pressures are met by most common piping materials: steel, polyvinyl chloride, and iron for depths up to ~30 m. In deeper monitoring situations, the use of corrosion-resistant metallic casing of large diameter (>10 cm or 4 inches) may be required to provide necessary structural integrity. Local water well construction practices should serve as a guide.

Metallic corrosion problems may be encountered under either oxidizing or reducing conditions and are aggravated by high dissolved-solids content. Other materials (thermoplastics) may deteriorate under the influence of dissolved chemical substances or direct contact with wastes. Whether the well construction or sampling materials retain their integrity or not, there are also potential problems due to microbial attachment and growth and the sorptive capacity of the exposed materials for the chemical species of interest. Representative sampling depends on the proper choice of materials which can retain their integrity over the entire length of a well casing, from the aerobic, unsaturated surface zone to the unique conditions in the saturated zone.

Chemical Properties of Water and Their Effects on Various Materials

To achieve the goals of a detective monitoring program in a cost-effective manner, one must carefully design and construct the sampling network after consideration of

organic bases (aniline, nitroaniline); aromatic hydrocarbons (benzene, toluene, xylene, substituted benzenes); and chlorinated aliphatic hydrocarbons (dichloroethane, trichloroethane, trichloroethylene, tetrachloroethylene). The presence of these slightly water-soluble compounds in ground water would be expected to affect sorptive or leaching characteristics of the subsurface environment, particularly toward thermoplastic or elastomeric materials.

On the other hand, the low-organic group showed mineral acidity and low pH values. It also was associated with TDS levels five to ten times ambient background. Several metallic elements (Zn, Cd, Cr) normally present in trace amounts were observed at concentrations exceeding background ground-water levels by factors of 10 to 1,000. These low pH, high TDS solutions would be expected to be quite aggressive toward metallic casing materials after extended exposure periods.

It is clear that a reasoned strategy for ground-water monitoring must consider the effects of contaminated water on well construction materials. Unfortunately, there is very little published information on the performance of specific materials in varied hydrogeologic situations. The monitoring strategy must be tailored to fit unique situations, and strict guidelines are currently unavailable.

In the preceding discussion, four categories of subsurface solution conditions were identified. These categories range from carbonate-buffered water to leachate-impacted ground water. The categories are outlined in Table 7-2 with the principal chemical species identified.

The range of chemical exposures represented by these four categories of solution composition should provide general test cases for consideration of compatible well construction materials.

Table 7-2. Solution Composition for a Range of Ground-Water Conditions

General category	*pH*	*Solids content ($mg \cdot L^{-1}$)*	*Principal soluble species present*
Buffered Weak Acid	5	100-200	Na^+, HCO_3^-, H^+, H_2CO_3 (aq.)
Weak Acid	5	5,000	$RCOO^-$, RCOOH, H^+
Mineral Acid/ High Dissolved Solids	3	1,000-13,000	H^+, Cl^-, $SO_4^=$, Na^+, Ca^{++}, Mg^{++}, transition series and heavy metals
Aqueous Organic Mixture	7	1,000-2,000	Cl^-, $SO_4^=$, HCO_3^-, Na^+, Ca^{++}, Mg^{++} and synthetic organic compounds

R – denotes an organic functional group

Preliminary Ranking of Well Construction/Sampling Materials

A preliminary ranking of commonly used materials was performed on the basis of chemical compatibility and manufacturers' recommendations. Chemical exposures were grouped in one of the related solution categories presented in Table 7-2. A listing of these chemical substances in each category is provided in Table 7-3. Compatibility was judged from the point of view of potential deterioration of each material. No

Table 7-3. Chemical Exposures Grouped in General Solution Categories

Buffered weak acid	*Weak acid*	*Mineral acid/ high dissolved solids*	*Aqueous organic mixtures*
Ammonium Carbonate	Acetic Acid	Acid Mine Waters	Aniline
Ammonium Chloride	Benzoic Acid	Brine Acid	Beer
Calcium Carbonate	Citric Acid	Hydrochloric Acid	Benzene
Aqueous Carbon Dioxide	Glycolic Acid	Metallic Chlorides	Butyl Alcohol
Distilled Water	Fatty Acids	Metallic Sulfates	Carbon Tetrachloride
Potassium Bicarbonate	Formic Acid	Mixed Acids	Chlorobenzene
Sodium Acetate	Gallic Acid	Plating Solutions	Cresol
Sodium Benzoate	Hydrogen Sulfide (aq.)	Seawater	Methyl Alcohol
Sodium Bicarbonate	Lactic Acid	Sulfuric Acid	Methylene Chloride
Sodium Carbonate	Oxalic Acid		Naphtha
Sodium Phosphate	Tannic Acid		Phenol
Sodium Sulfide	Tartaric Acid		Toluene
Sulfite Solutions			Trichloroethylene
			Wine
			Xylene

second-order effects such as adsorption, absorption or leaching were considered. Compatibility ratings were as follows: (3 points) no significant deterioration, embrittlement, or corrosion in general use; (2 points) the potential exists for deterioration, etc., and this material is recommended only after testing; (1 point) the possibility of deterioration, etc., clearly exists and is likely after extended use. Rigid materials used for well casings or sampling gear, as well as semi-rigid or elastomeric materials for tubing and other apparatus, were treated in the same fashion. The compatibility of each material was ranked after the total rating in each category was converted to a percentage of the maximum possible score. The percent ratings in each category served to rank the materials in order, and the sum of the ratings for each material in all four categories provides an overall ranking scheme.

There are limitations in this approach which stem from the lack of detailed information on testing conditions, the subjective nature or varied sources of judgment of "significant" deterioration, and the tenuous relationship of exposures to pure chemicals or dilute aqueous solutions to actual subsurface conditions. However, this preliminary ranking is a starting point for in-depth consideration of materials performance under actual site conditions. Generally recommended materials for monitoring applications are noted by Pettyjohn et al. (17).

The following rigid well-casing materials were considered: PVC I (unplasticized polyvinyl chloride), galvanized steel, carbon steel, Lo-Carbon Steel, Stainless Steels 304 and 316, and Teflon®. Flexible (or semi-rigid) materials commonly used for pump parts, sample transfer lines, in-line devices or storage vessels were rated, including flexible PVC (plasticized), polypropylene, polyethylene (conventional), polyethylene (linear), polymethylmethacrylate (Lucite or Plexiglas), Viton®, silicone, and neoprene. Glass was not considered among the rigid materials due to the unavailability of well screening and hazards associated with its use for casings. Rating results in each category and overall are shown in Tables 7-4 and 7-5 for the rigid and flexible or semi-rigid materials, respectively. Sources for the exposure ratings (83-91) are included in the references.

into water from static or flowing tests have been shown to be a function of exposed surface area and actual levels of RVCM in the product (42,112,113). These laboratory results on samples that meet NSF Standard 14 specifications (80) show that leached VCM levels are in the <1 to 2 microgram · L^{-1} range. Though these levels are below those of toxicological concern (111) the potential exists for organic analytical interferences in monitoring situations where prolonged exposure to aggressive aqueous organic mixtures may occur.

Rigid PVC materials used for pipe and well casing with NSF-listing are essentially free of plasticizers. Although plasticizers are unnecessary for rigid pipe applications, a small number of sources of well casing may include plasticizers which are added along with the thermal stabilizer component. Plasticizer levels in such pipe samples would not be expected to exceed 0.01%. These levels are far lower than those in flexible PVC formulations for tubing or sheet materials which can contain up to 30-50 percent by weight of plasticizer. Rigid PVC contains several types of other additives at levels approaching 5 percent by weight, which may pose a source of bias or analytical interferences in ground-water monitoring programs (113). These additives include pigments, antioxidants, thermal stabilizers, and inorganic fillers (114,115). Some representative chemical classes of additives which have been used in rigid PVC manufacture are contained in Table 7-6. There are clearly many possible combinations of substances which may be included in PVC formulations. The potential for their release into aqueous solutions or ground waters may be determined by the individual formulation, rigor of exposure, manufacturing techniques, and the chemical state of a particular component in the finished product. Here again, NSF-listed products for well casing and potable water applications are continually checked and tested. Products that are found to exceed the maximum contaminant levels set by the *National Interim Primary Drinking Water Standards* in leach tests (Table 7-7) do not qualify to carry the NSF logo. Their use should be avoided in monitoring well construction since many manufacturers include compounding ingredients that are not permitted by the specifications.

Table 7-6. Representative Classes of Additives in Rigid PVC Materials Used for Pipe or Well Casing

(Concentration in wt. %)

Heat stabilizers (0.2-1.0%)

Dibutyltin diesters of lauric and maleic acids
Dibutyltin bis (laurylmercaptide)
Dibutyltin-β-mercaptopropionate
di-n-octyltin maleate
di-n-octyltin-S,S'-bis isoctyl mercaptoacetate
di-n-octyltin-β-mercaptopropionate
Various other alkyltin compounds
Various proprietary antimony compounds

Fillers (1-5%)

$CaCO_3$
diatomaceous earth
clays

Pigments

TiO_2
carbon black
iron and other metallic oxides

Lubricants (1-5%)

stearic acid
calcium stearate
glycerol monostearate
montan wax
polyethylene wax

(Reference 115)

Table 7-7. Chemical Parameters Covered by NSF Standard 14 for Finished Products* and in Standard Leach Tests

Parameter	*Maximum contaminant level (mg·L⁻¹)*
Antimony (Sb)	0.05†
Arsenic (As)	0.05
Barium (Ba)	1.0
Cadmium (Cd)	0.01
Chromium (Cr)	0.05
Lead (Pb)	0.05
Mercury (Hg)	0.002
Phenolic substances	0.05†
Residual vinyl chloride monomer* (RVCM)	10†
Selenium (Se)	0.01†
Tin (Sn)	0.05

† Not covered under National Interim Primary Drinking Water Regulations.
* Total residual after complete dissolution of polymer matrix.

Tabulated values are the maximum levels permissible in NSF-listed products after standardized leach testing in weakly acidic aqueous solution. [Carbonic acid solution with 100 $mg \cdot L^{-1}$ hardness as $CaCO_3$ with 0.5 $mg \cdot L^{-1}$ chlorine; pH 5.0 to 0.2; and surface to solution ratio of 6.5 $cm^2 \cdot mL^{-1}$]

Source: National Sanitation Foundation

Practical considerations and potential for analytical bias due to use of PVC well casing

The use of NSF-listed well casings provides us with a minimum standard material that can be judged for suitability in specific monitoring situations. All types of well casings should be cleaned with detergent and rinsed with water prior to well construction to remove processing lubricants and release agents. This is particularly true of PVC well casing, which may be coated with natural or synthetic waxes, fatty acids, or fatty acid esters.

Threaded joints are the preferred means of connecting sections of PVC well casing. In this way, problems associated with use of solvent primers and cements can be avoided. Threaded joints on PVC well casing (or pipe) can be provided in three ways: solvent cementing a molded thread adaptor to the end of the pipe, molded flush-threaded joints built into each pipe section, and cutting tapered threads on the pipe with National Pipe Thread sized dies. The latter method is only recommended by the industry for schedule 80 PVC well casing or pipe. Numerous studies have pointed out analytical interferences and direct sources of bias caused by the migration of the components of solvent mixtures into water samples (79,41,116,117). The mixtures frequently contain two or more of the following solvents: methyl-ethylketone (2-butanone), methyl-butylketones, cyclohexanone, tetrahydrofuran, and dimethylformamide. Some of these substances may not be among the analytes of interest; however, their presence in a water sample can cause severe problems in the determination of priority pollutants (41). In the experience of the Illinois State Water Survey, even minimal solvent-cement application is sufficient to supply consistent levels of cement/primer components above 100 ppb in actual ground-water samples despite proper well development and flushing prior to sampling. This problem may persist for months after well construction even after repeated attempts to develop the wells. Prolonged exposure to aggressive aqueous mixtures is probably the single most important factor

Seals, grouts, and cements

Seals, grouts, and cements are the primary safeguards against the migration of water from the surface and from overlying or adjacent formations into monitoring wells. Surface seals also must be completed with concern for the security at the well-head by including casing sheaths and locking caps. Most seals between the formation of interest and regions above or below are made by the addition of clay materials or cement. Bentonite clay can swell from 10-15 times in volume after wetting with deionized water. Variations in the composition of the contacting solution can severely reduce the swelling of clay seals. Swelling volumes of 25-50 percent of the maximum values are not uncommon. The organic content of the solution in contact with the clay can have a dramatic effect on the integrity of the seal. Organic compounds can cause significant disruption of normal shrinking, swelling, or dehydration of the clay lattice during alternate wetting and drying cycles (139). Alcohols, ketones, and other polar organic solvents have a significant potential for these changes. On the microscopic level, these phenomena can materially increase the permeability of the clay seal. This is presently an active area of research which has wide application in well construction, landfill liners, and slurry or grout cutoff walls (56,140). Macroscopic changes in the permeability of clay or cement seals can occur due to solution channeling by aggressive solvents, compaction or subsidence, and freezing and thawing processes at the surface.

Chemical-resistant and expanding cement formulations effectively minimize these problems. Faulty seals or grouts can seriously bias the analytical results on water samples from the formation of interest, particularly if water quality conditions vary or surface soils are badly contaminated. The impact of leaking seals may go far beyond the realm of analytical interferences or non-representative samples. A leaky well bore may act as a conduit to permit rapid contaminant migration which otherwise would not have occurred. This is one aspect of a ground-water monitoring program which should not be left to an unsupervised drilling crew or last-minute substitutions for preferred materials.

Evaluation of Sample Collection Materials

The choices of sample collection devices, procedures, and all materials which ultimately contact water samples are probably the most critical considerations in a ground-water monitoring program. The materials' related problems which may be encountered in well construction are secondary to those involved in sample handling. The careful monitoring program planner must evaluate the potential of collection mechanisms and all materials which contact the samples to introduce interference or bias into the final analytical result. For example, a collection mechanism that creates turbulent transfer of the sample and the opportunity for gas exchange (e.g., air-lift pumping mechanisms) is clearly inappropriate in sampling for volatile organic compounds and pH- or redox-sensitive chemical species. The act of sampling alone would alter solution composition, introducing bias into subsequent analytical determinations as well as matrix effects which may not be totally accounted for by spiked field samples.

Desirable attributes for sample collection materials include:

1) Durability, reliability, and ease of repair
2) A minimum number of moving parts or combinations of materials

3) Capability of being cleaned and sterilized effectively to prevent cross-contamination between sampling points
4) Capacity for being checked for deterioration or malfunctions such as stuck check valves, clogging, and breakage
5) Verified low potential for introducing contamination, bias, or interferences into the analytical results

Each of these attributes plays an important role in the overall performance of monitoring efforts and bears directly on the successful retrieval of respresentative water samples. The difficulties involved in the evaluation of materials for sample collection apparatus stem mainly from the variety of combinations of components in pumps (or other samplers) and the properties of polymeric and elastomeric materials for tubing or transfer lines.

Sampling devices

Apart from the actual mechanisms employed by sampling devices, the consideration of materials is of prime importance in the choice of a suitable sampler. Fortunately, most types of devices are constructed in several models which may be chosen for specific monitoring situations. For example, bailers are presently fabricated by commercial suppliers in Teflon®, stainless/Teflon®, stainless/PVC 1, and totally PVC 1. These materials satisfy the major critical materials' specifications. Problems arise in materials selection with samplers employing non-rigid components. Even those devices which incorporate a single pair of 0-rings may be limited in their application by the material employed.

The preliminary ranking of materials in Tables 7-4 and 7-5 serves as a general guide for materials selection for sampling devices. Teflon® again incorporates most of the characteristics for an ideal material in sampling applications. However, it is a difficult material to machine and threaded components are very easily damaged. For chemical resistance and durability, several materials other than stainless steel may be expected to perform satisfactorily in low-organic environments. These materials include polypropylene, linear polyethylene, plasticized PVC, Viton®, and conventional polyethylene. Viton® is a preferred material for elastomeric parts, since it may be expected to give improved chemical resistance over silicone and neoprene.

One may expect that the least desirable material in a given sampler design will eventually cause monitoring problems. For example, significant differences have been observed in the organic contamination potential of impeller pumps as a function of impeller material (3). In this instance, consistently high PCB (polychlorinated biphenyl) values due to cross-contamination were observed in samples obtained by a plastic impeller pump relative to those obtained from a device with a stainless steel impeller. Similarly, solvent cements used in the construction of rigid-PVC bailers can result in gross analytical errors for volatile organic compounds (41) in samples collected shortly after bailer fabrication.

Flexible materials in collection devices can be particularly problematic since they owe their flexibility and resiliency to plasticizers as well as a range of compounding ingredients no less diverse than those contained in Table 7-6 for polyvinyl chloride. Here, a considerable overlap between materials selection for samplers and tubing or transfer lines arises. Careful consideration should be given to flexible components of

92. U.S. Environmental Protection Agency. Monitoring Groundwater Quality: Monitoring Methodology, EPA-600/4-76-026, June 1976

2647

EPA-600/4-76-026
June 1976

Environmental Monitoring Series

MONITORING GROUNDWATER QUALITY: MONITORING METHODOLOGY

Environmental Monitoring and Support Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Las Vegas, Nevada 89114

Rank in Terms of Total Groundwater Use	Type of Industry
1	Oil Refining
2	Paper Manufacturing
3	Metal Working
4	Chemical Manufacturing
5	Building, Air Conditioning and Refrigerating
6	Distilling
7	Ice Manufacturing and Cold Storage
8	Food Processing
9	Rubber Manufacturing
10	Meat Packing
11	Brewing
12	Railroad Yards
13	Gas and Electricity
14	Dairying
15	Electric Equipment Manufacturing

If no local summary of industrial use of self-supplied groundwater is available from appropriate public agencies, pertinent industries will have to be identified. Industrial areas can be located from aerial photographs or zoning maps; industries which do not receive municipal water can then be contacted to obtain their annual groundwater pumpage data. Often these are not directly available and must be estimated from the type of industry, number of workers, units of production, or other factors.

AGRICULTURAL USE. In the Western United States groundwater is used mostly in irrigated agriculture; however, data on such usage are also generally difficult to obtain. Accurate records of pumpage are rarely kept by farmers, and, in fact, most irrigation wells are not equipped with flow meters. Pumpage estimates can be made by either of two methods. One is to determine cropping patterns of areas irrigated by wells, using aerial photographs and crop surveys. By knowing the consumptive use of the crops and representative irrigation efficiencies (from local farm advisors) and mean annual growing season rainfall (from U.S. National Weather Service records), the total applied water for irrigation purposes can be computed. In areas where both surface water and groundwater are used, the portion of applied water supplied by groundwater can usually be determined from irrigation district records. A second approach is to obtain records of power consumption for representative pumps and of pump discharges per unit of power use from electric utility companies. These data enable the quantities of water pumped to be calculated. Where such data are available for only a fraction of the irrigated area, extrapolation to the gross area can be made; however, results can be subject to error if significant differences in pumping levels exist.

RURAL USE. Data will rarely be available on pumpage from individual domestic water supply wells in rural areas. Estimates of pumpage can be made, however, by multiplying rural population figures by typical per capita water use. In general, these pumpage rates are so scattered over agricultural areas that they do not influence the groundwater flow. However, the existence of the rural use should be recognized, particularly in the event of a localized pollution problem.

In summary, the total of the four above groundwater uses provides the usage data for a monitoring area. Locations of major pumping centers, such as well fields of municipalities and large industries, should be identified. Average pumpage rates over uniform subareas, such as irrigated lands, should be defined from irrigation well pumping rates and well densities. Great precision in determining groundwater pumpage is not as important as a comprehensive coverage of all significant pumpage within an area.

Step 5 — Define Hydrogeologic Situation

To understand where and how groundwater pollution occurs and moves within a monitoring area, the hydrogeologic framework must be understood. This information will aid in the design of an effective as well as an efficient groundwater quality monitoring system.

Because some subsurface data are available in most areas of groundwater development, initial hydrogeologic work will consist of gathering, organizing, and analyzing existing information. On other occasions, geologic or hydrologic investigations requiring field work will be necessary. Specific materials needed for the monitoring program, as well as how they are obtained, include:

- Aquifer locations, depths, and areal extents — from geologic data
- Transmissivities of aquifers — from well pumping tests and geologic data
- Map of groundwater levels — from observations of well levels
- Map of depths to groundwater — from water level and topographic data
- Areas and magnitudes of natural groundwater recharge — from precipitation, evapotranspiration, soils, land use, and water level data
- Areas and magnitudes of artificial groundwater recharge — from irrigation and recharge data
- Areas and magnitudes of natural groundwater discharge — from streamflow and water level data

- Directions and velocities of groundwater flows — from water level and transmissivity data.

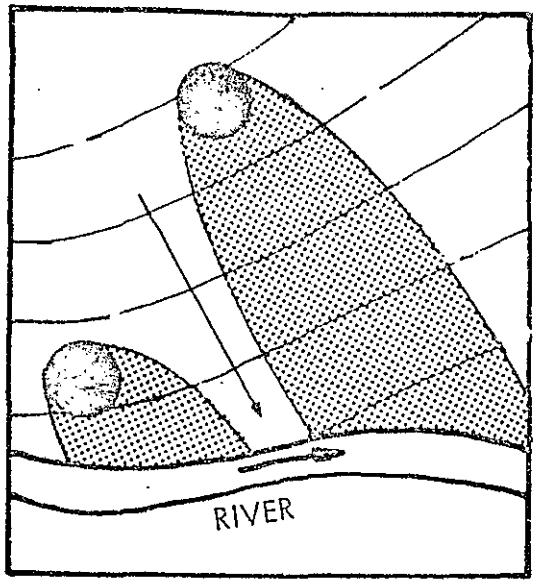
Information sources for preparation of the above items should normally include State geologic and water agencies, local water agencies, the U. S. Geological Survey, and the U. S. National Weather Service.

In preparing the above materials it should be kept in mind that these serve as tools for monitoring; consequently, the hydrogeologic effort should not become an obstacle to the completion of the monitoring program. All hydrogeologic data are incomplete in a relative sense. What is needed is an overall picture of the hydrogeologic situation in the monitoring area. Initially, refinement is less important than comprehensive coverage, no matter how preliminary or approximate. Categories indicating ranges rather than specific values, such as for transmissivity or dissolved solids, are often sufficient. Also, it should be recognized that with time and with increasing amounts of groundwater data, knowledge of the hydrogeologic situation will gradually improve.

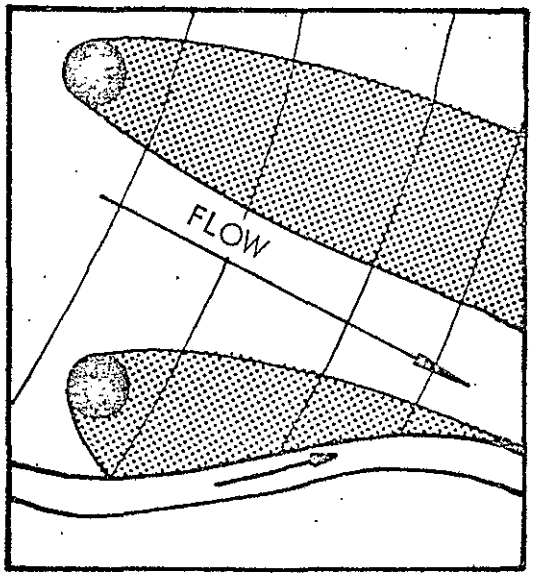
EXAMPLE 1 — POLLUTION PLUME GEOMETRY. Figure 2 shows examples of the configurations of pollution plumes resulting from a pollution source, such as a landfill, located near a river. In Figure 2(A) the angle between the groundwater flow direction and the river is relatively large. This limits the extent of the plume; furthermore, where the source is located close to the river, the plume is smaller. In Figure 2(B) the angle between the groundwater flow direction and the river is relatively small; this creates elongated plumes, particularly where the source is some distance from the stream.

EXAMPLE 2 — GROUNDWATER FLOW SYSTEM. Figure 3 depicts schematically a groundwater flow system under idealized homogeneous aquifer conditions. Groundwater travels along flow paths which extend from areas of groundwater recharge to areas of groundwater discharge. Horizontal and vertical gradients are indicated by equipotential lines; potential, or total head, is simply the elevation to which water will rise in a cased well from a point source below the water table. Groundwater moves in the direction of decreasing total head. In recharge and discharge areas, movement may have an appreciable vertical component; between these end areas, flow is predominantly horizontal. Any pollution will travel along the flow line where it occurs.

EXAMPLE 3 — COMPLEX PLUME GEOMETRIES. Figure 4 presents an idealized vertical aquifer cross-section, somewhat similar to Figure 3, together with the pollution plumes for various locations of pollution sources. Note that Sources A-1 and A-2 create short plumes because they are close to streams, while B and C are longer because they are more distant. Source F, located in a discharge area, has no effect on groundwater quality.



A



B

Figure 2. Relation of groundwater pollution plume size and orientation for a pollution source near a river with different groundwater flow directions (Palmquist and Sendlein, 1975).

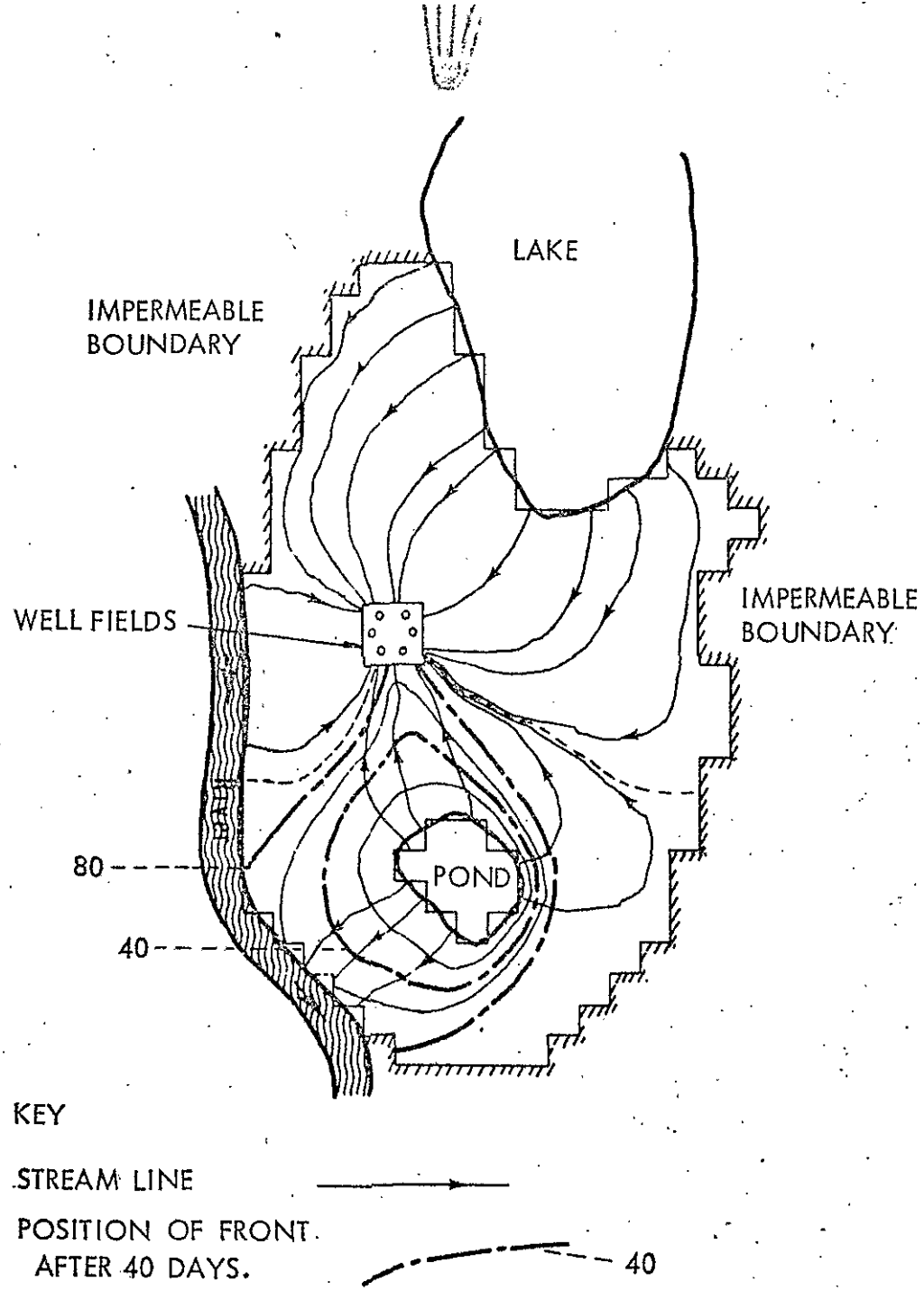


Figure 5. Flow lines for steady-state conditions in an aquifer and positions of a pollution front advancing from a percolation pond (Cole, 1975).

Step 6 — Study Existing Groundwater Quality

In order to define the groundwater quality problems within a monitoring area, an assessment needs to be made of the background quality situation. To do this, recent groundwater quality data need to be collected and reviewed. Attention should be focused first on the natural groundwater

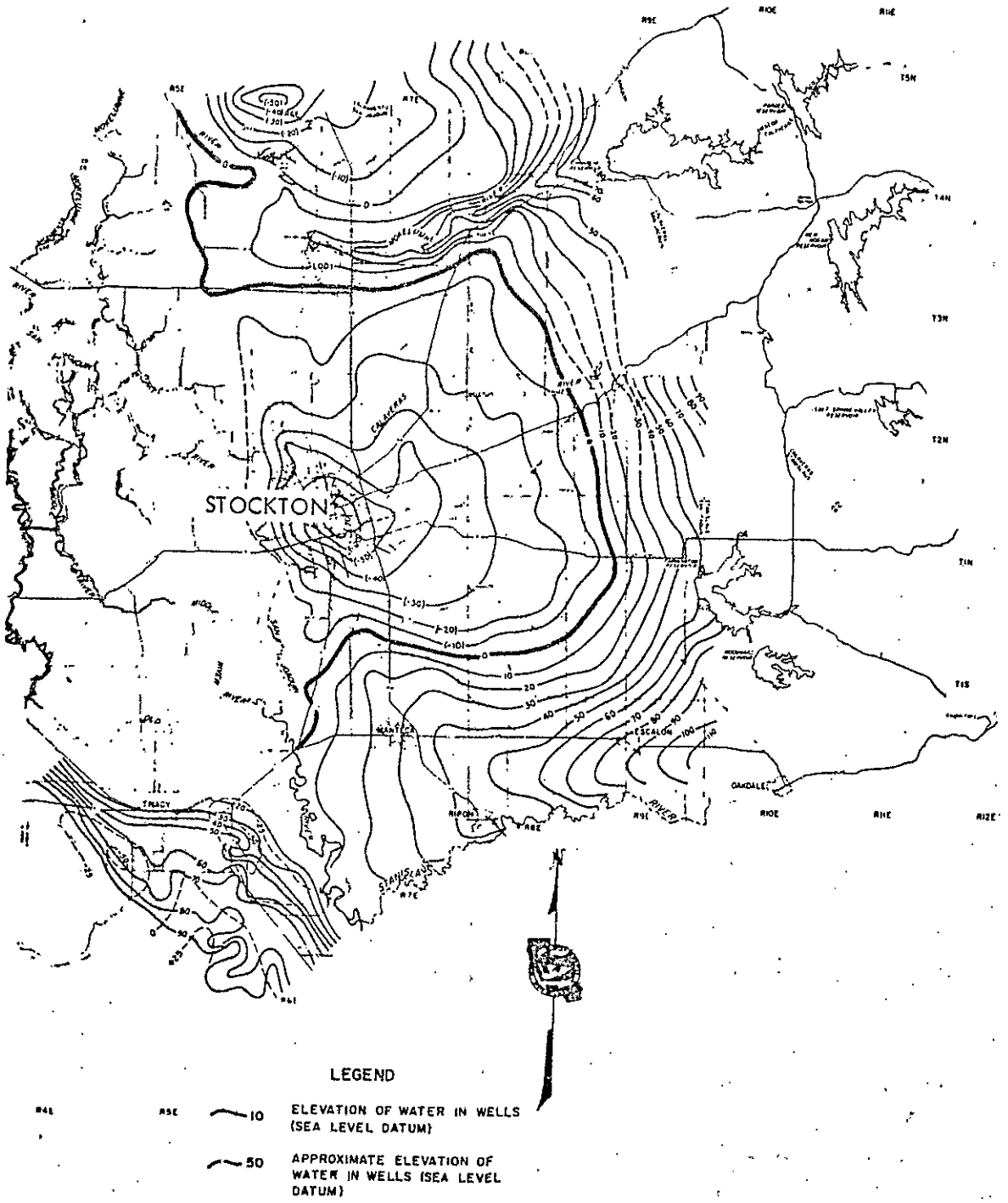


Figure 6. Water table contours in the vicinity of Stockton, California, Fall 1964 (California Department of Water Resources, 1967).

at manholes, and infiltration causing sewage to flow into abandoned sewer laterals (Meyer, 1973).

Sewer leakage releases raw sewage into the ground, often close to groundwater. This can introduce high concentrations of BOD, COD, chlorides, unstable organics, and bacteria into groundwater. On the other hand suspended solids tend to clog sewer cracks, and the surrounding soils tend to become clogged due to anaerobic conditions; therefore, the actual effect of sewer leakage may be less than the theoretical potential.

TANK AND PIPELINE LEAKAGE. Underground storage and transmission of a wide variety of fuels and chemicals is a common practice for commercial, industrial, and individual uses. These tanks and pipelines are subject to structural failures from several causes, and the subsequent leakage becomes a source of groundwater pollution.

Petroleum and petroleum products, because of their large usage, are responsible for most of the pollution. Thus, 90 percent of the interstate liquid pipeline accidents reported in 1971 involved crude oil, gasoline, liquefied propane gas, or fuel oil (Meyer, 1973). Major causes of these pipeline leaks were corrosion, equipment rupturing the pipelines, defective pipe seams, or incorrect operations by handling personnel.

Leakage is particularly frequent from small installations such as home fuel oil tanks and gasoline stations, where installation, inspection, and maintenance standards may be low. In Maryland some 60 instances of groundwater pollution were reported in a single year from gasoline stations; and in northern Europe, where most homes are heated by oil stored in subsurface tanks, oil pollution has become the major threat to groundwater quality (Meyer, 1973).

Liquid radioactive wastes are sometimes stored in underground tanks. Leakage has been reported from an installation at Hanford, Washington.

Leakage of an immiscible liquid such as oil into the ground will cause the oil to move downward in relatively permeable soils or, if the leak is from a pipeline in relatively impermeable soil, the oil will tend to remain in the trench and move in the down-slope direction. Oil coats soil particles as it advances; therefore, if the quantity of leaked liquid is sufficiently small, the total flow may become immobilized. Subsequent infiltrating water will tend to transport the pollutant from the soil particles downward to the water table. Once oil reaches a water table it spreads to form a thin layer on top of the water table and then to migrate laterally with the groundwater body.

DISPOSAL WELLS. Many thousands of wells throughout the United States are used for disposal of pollutants into freshwater aquifers. Examples include electronic industries disposing of metal-plating wastes in

Arizona; domestic sewage disposal from individual homes in Florida and Texas; low-level radioactive wastes at one location in Idaho; and heated water from cooling systems in New York, California, and several midwestern States (Meyer, 1973).

In recent years considerable attention has been given to the possibility of injecting treated municipal sewage into wells penetrating freshwater aquifers. Several of the proposed schemes not only would solve a sewage-disposal problem but also would help to recharge freshwater aquifers or to establish hydraulic barriers against saltwater encroachment in freshwater aquifers. Advanced pilot plant experiments are being conducted in Long Island and in California (Meyer, 1973). Sewage must be given at least secondary treatment and preferably tertiary treatment to prevent clogging of the disposal wells and to reduce or prevent significant chemical and bacteriological pollution of the aquifer.

Modification of the quality of groundwater caused by subsurface disposal of wastes through wells depends on a variety of factors, including the composition of the native water, the amount and composition of the injected waste fluid, the rate of injection, the permeability of the aquifer, the type of well construction, and the kinds of biological and chemical degradation that may occur. Most wells used for disposal of polluted liquids are, for economic reasons, located in the shallowest available aquifer.

INJECTION WELLS. Deep injection wells are employed for disposal of industrial wastes and oilfield brines. At present there are fewer than 300 industrial disposal wells in the United States (Meyer, 1973), but there are more than 70,000 brine disposal wells.

It has been common practice in the past to use abandoned oil production wells for brine disposal. Because the wells were not designed, cased, or cemented for brine injection, there have been numerous instances of injection wells with undetected ruptures beneath the surface where injected brines have seeped into freshwater aquifers for many years before being discovered. Some State regulatory agencies have alleviated this problem by requiring an injection tubing inside a casing. The space between the tubing and casing is filled with a fluid which is monitored to detect ruptures.

Currently, most oilfield brines are returned to subsurface formations either for secondary recovery in an oil-producing formation or just as a disposal method. However, even with properly designed and constructed injection wells, brine disposal presents pollution problems because of the numerous oil, gas, injection, and test holes, which for many years were simply abandoned without proper plugging. Unplugged wells provide vertical pathways for injected brines to rise into overlying freshwater aquifers.

Because of the limited number of industrial waste injection wells and the careful attention given to their siting, design, and operation by State

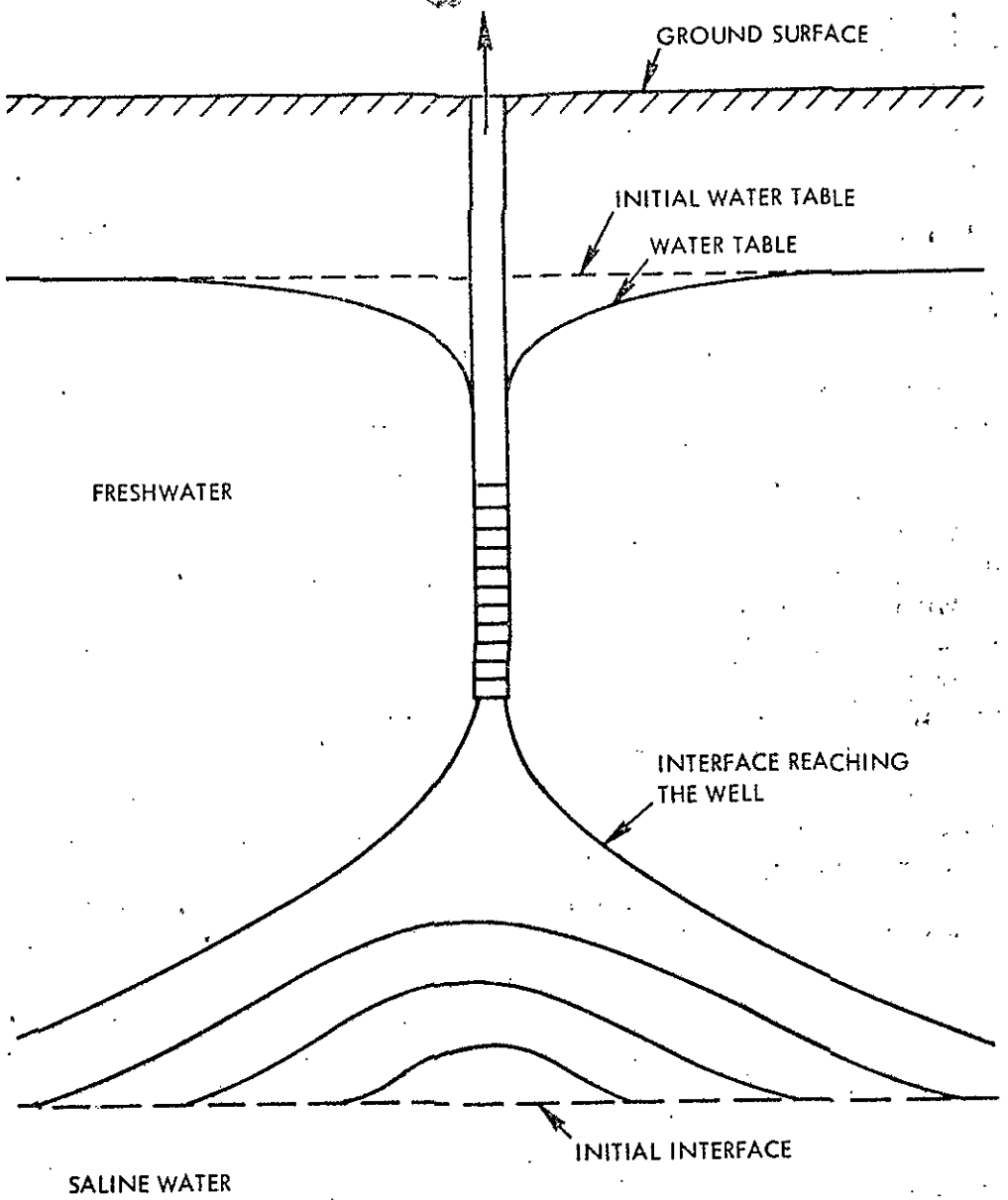


Figure 51. Schematic diagram of upconing of underlying saline water to a pumping well.

In addition, if provisions are not made to divert surface water away from a well, it can drain downward into a well. Most public water supply wells are properly sealed, inspected, and maintained, but surveys by health authorities have revealed that private wells serving individual residences often are not protected against pollution from overland runoff containing septic fluids, barnyard wastes, or storm waters.

In most States today, regulations exist requiring plugging of abandoned wells. But there are many thousands of abandoned wells which remain unplugged either because they cannot be located or because changes in property ownership with time make the responsibility for plugging indeterminate. The problem is particularly serious in oil and gas areas where numerous

exploration and production wells have been abandoned (Scalf et al., 1973). These holes serve as avenues for brine from injection wells to rise into overlying freshwater aquifers.

Miscellaneous

SPILLS AND SURFACE DISCHARGES. Groundwater pollution can result from hazardous and nonhazardous liquids that are discharged onto the ground surface in an uncontrolled manner and then seep into the underlying soils. If the volume of the fluid is sufficiently large, the pollutant can migrate down to the water table and degrade the groundwater quality. Any of a variety of activities can lead to spills and surface discharges that may serve as pollution sources.

Poor housekeeping at large industrial plants and airports is a contributory pollution cause. At industrial sites, causal activities may include boilovers and blowoffs, overpumping during transfer of liquids to or from storage and carriers, leaks from faulty pipes and valves in product distribution systems, and poor control over waste discharges and storm-water runoff. At airports the washing of planes with solvents and spills of fuel can form an extensive body of hydrocarbons floating on the water table (Miller, 1974).

Pollution of groundwater also occurs from the intermittent dumping of fluids on the ground, especially at gasoline stations and other types of small commercial establishments. Automotive waste oil is disposed of on the ground by car owners, by commercial garages and gasoline stations, and at construction sites; the total of these many small contributions runs to millions of gallons of oil annually (Miller, 1974). Small industries often dispose of lubricating, hydraulic, and cutting oils by local dumping. It is not uncommon to find small commercial facilities discharging liquid wastes onto undeveloped land, the reasoning being that it is uneconomic to store and to haul the wastes to municipal treatment plants or landfills and that the liquids may be harmful to local septic tanks or cesspools.

Finally, accidents involving aboveground pipes and tanks, railroad cars, and trucks can cause the release of large quantities of a pollutant at a particular site. The use of water to flush spilled fluids, as from a highway, may actually aid in transporting the pollutant down to the water table.

SEPTIC TANKS AND CESSPOOLS. Of all the sources and causes of groundwater pollution, the most numerous and widely distributed is that of septic tanks and cesspools. It is estimated that approximately 40 million persons, or nearly 20 percent of the total population, are served by individual household waste water treatment systems. This means that some 2.5 billion gallons of partially treated sewage is discharged from residences directly into the underground every day. In addition, stores, laundries, small office buildings, hospitals, and industries employ septic tanks in

93. U.S. Environmental Protection Agency. NEIC Manual for Groundwater/Subsurface Investigations at Hazardous Waste Sites, EPA-300/9-81-002, July 1981

2645
2646
2647
2648

Bud Fagan

PB82-103755

NEIC Manual for Groundwater/Subsurface Investigations at Hazardous Waste Sites

(U.S.) National Enforcement Investigations Center, Denver, CO

Jul 81

U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
NTIS

PB82-103755

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

EPA-330/9-81-002

NEIC MANUAL FOR GROUNDWATER/SUBSURFACE INVESTIGATIONS AT HAZARDOUS WASTE SITES

July 1981

Steven W. Sisk

NATIONAL ENFORCEMENT INVESTIGATIONS CENTER
Denver, Colorado

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

1. Land use in the area
2. Site use prior to waste disposal
3. Site preparation prior to waste disposal; identifying predisposal engineering or geological studies and records of soil tests
4. Types and volumes of wastes disposed of
5. Sources of waste
6. Chronology and location of waste disposal
7. Total active life of site
8. Approximate volume of waste present (total area and thickness)
9. Site ownership and relationship of owner(s) to waste source(s)
10. Permits and site approval correspondence
    a. Past and pending legal problems
    b. Citizen complaints
11. Established monitoring points and historical data
12. Records of catastrophic events (fires, explosions, floods, etc.)
13. Reported health problems attributed to the site
14. Location of buried utilities passing through site
15. Other potential sources of pollutants
16. Groundwater use in the area
17. Information on how the site was closed (if not active)

HYDROGEOLOGIC SETTING

To assess groundwater impacts from an HWS, there must be an understanding of how the waste deposit interacts with the surface and subsurface environments (hydrogeologic setting) in both space and time. The substance of the study is to assemble data for this assessment including site geology, hydrology, and climate.

The following discussion presents types of information that are gathered about the hydrogeologic setting. Information sources include published and unpublished literature, maps, computer data bases, personal contacts, and aerial photography [Appendix A].

Geology

Relevant geologic information includes regional and site specific data pertaining to both consolidated (bedrock) and unconsolidated formations. Those factors that affect water movement and quality are most important. If nothing is known about the geologic setting of the site, research stratigraphy first [Table 1]. If other geologic factors are of concern, stratigraphic information is likely to provide clues as to which are important. For example, if stratigraphy is complex due to faults and folds, "structural features" would be an appropriate subject to research. If certain formations are found to contain abundant lead-bearing minerals, then "mineral resources" should be researched. Judgment is exercised to determine the extent of information gathering in any subject area.

Site geology is often expressed in the surface topography as land forms because geologic structure is a dominant control factor in their evolution.[76] After identifying geologic features, plot them on the topographic map so the geologic setting can be related to observable land forms [Figure 1]. These land forms will be evaluated during the site visit regarding their potential to direct surface and/or subsurface water toward the disposal site [Figure 2].

Primary sources of geologic information are the U.S. and state Geological Surveys [Appendix A, Parts 2 and 6]. Much of the published literature is available from the USGS library in Golden, Colorado and from various USGS offices at the Denver Federal Center [Appendix A, Part 2].

Hydrology

Water transports pollutants from disposal sites into the surrounding environment [Figure 2]. Pertinent hydrologic information relates to transport water sources (i.e., rainfall and upgradient groundwater flow) and downgradient movement on the land surface or in the subsurface through permeable media. No single factor prevails at all sites; therefore, several characteristics of local hydrology must be assessed for their relative

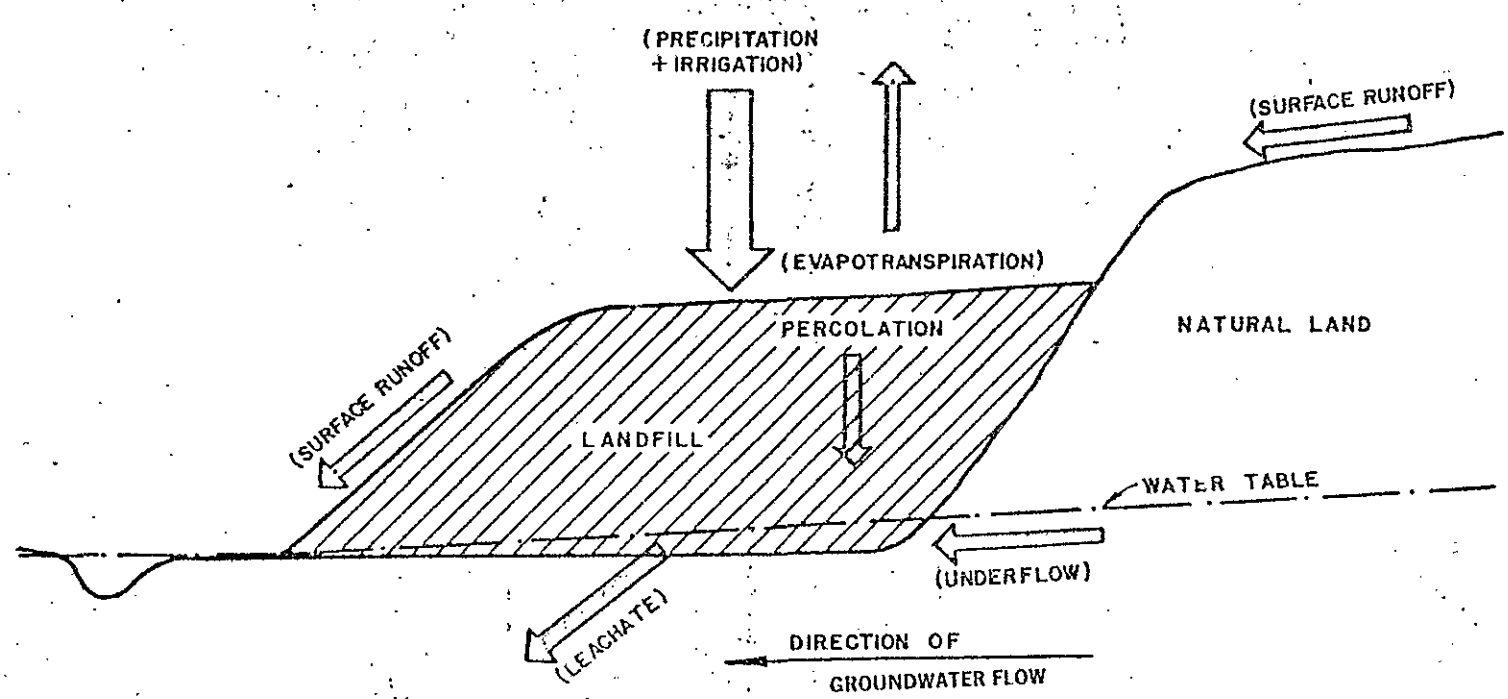


Figure 2. Simplified Landfill Water Balance

(From Reference 23, Figure 55)

importance [Table 2]. During an investigation, all topics presented in Table 2 should be addressed. Again, the investigator's judgment is required to determine the extent of data gathering on a particular subject.

Understanding groundwater hydrology involves creating a three-dimensional image of the site. As hydrogeologic data are gathered, draw vertical cross-sectional diagrams for visualizing subsurface conditions and identifying data deficiencies. Delineate waste deposits, geologic formations, aquifers, structures, and water tables or confined aquifer pressure surfaces (piezometric surfaces) [Figure 3].

Evaluating hydrologic data usually requires more specialized knowledge and experience than the geologic data because more judgment is needed. A basic understanding of the natural paths and rates of groundwater movement is important in evaluating groundwater pollution problems. A section on the fundamentals of groundwater hydrology, excerpted from a Princeton University training course manual, is presented in Appendix C. A more basic discussion on rocks and their water-bearing properties is presented in a publication by O. C. Meinzer.[47]

Climate

Climatic data, such as precipitation, temperature, wind movement, and evaporation potential, are essential background information. Precipitation records need to be complete enough to delineate seasonal trends which suggest periods of groundwater recharge. Temperature and wind data aid in evaluating airborne pollutant movement. Evaporation potentials enable calculation of subsurface water loss from waste liquid impoundments. Both pan and lake evaporation data have been compiled for most of the country. Recent climatic data can be obtained from the NEIC Technical Information staff and reference 6. Historical data are summarized in references 27 and 78 available at the USGS library in Golden [Appendix A, Part 2].

Surficial Materials

Groundwater recharge from infiltrating precipitation depends on the permeability of surficial materials and rainfall intensity. General soils information is found in USDA County Soils Maps [Appendix A, Part 5]. Examine surficial materials at several representative locations and classify them by grain size and degree of sorting, as a minimum. A shallow hole excavated by shovel or hand auger is desirable to obtain suitable samples for examination. Use the following table as a guide for describing grain sizes.

Table 3
GRAIN SIZE CLASSIFICATION

Classification	Grain Size (mm)	Grain Size (in.)	Common Reference
Gravel	>2	>0.08	1/10 in. or larger
Very coarse sand	1 to 2	0.04 to 0.08	
Coarse sand	1/2 to 1	0.02 to 0.04	Sand grains visible
Medium sand	1/4 to 1/2	0.01 to 0.02	to unaided eye
Fine sand	1/8 to 1/4	0.005 to 0.01	
Very fine sand	1/16 to 1/8	0.002 to 0.005	
Silt	1/256 to 1/16	0.00015 to less than 0.002	Grains not visible to unaided eye
Clay	<1/256	<0.00015	

Distinguish silts and clays using a 10x hand lens; if fine grains are visible, the material is probably silt. Describe grain size mixtures by using subordinate fraction names as modifiers for the dominant fraction (i.e., silty sand). Denote the range in grain sizes by descriptors ranging from "poorly" to "well" sorted, depending on the degree of uniformity. Describe other features such as color, plasticity, organic content, and dessication cracks. Determine colors through comparison with standard soil color charts.*

---

* *Munsell Soil Color Charts, MacBeth Division, 2441 North Calvent Street, Baltimore, Md. 21218*

Bedrock Outcrops

Locate bedrock outcrops on the site map, record the physical dimensions, and identify the rock type. Also measure major joint trends and formational strike and dip (if discernible) with a pocket transit. Methods for making these measurements are presented in reference 12. If rock identification is not possible, collect samples of each rock type, label properly, and photograph the outcrop. Proper labeling involves recording the vertical position in the section in a project logbook and keying the information to a sample tag affixed to the specimen and/or sample bag. Handle the sample under normal chain-of-custody procedures.[54]

Onsite Wells and Depth to Groundwater

Onsite or nearby wells are potential groundwater monitoring points. To the extent possible, collect construction information about any well identified during the site inspection.

Some minimal detail that should be collected includes data on screened or open intervals, construction and plumbing materials, total well depth, and water level. The screened or open interval is obtained from drilling records; direct methods are normally impractical. Complete construction details are necessary for any well used in a permanent monitoring network.*

Total well depth is also taken from drilling records; check by actual field measurements, if practical. Well depths from drilling records often exceed actual depths due to aquifer invasion through the screen or open-hole sloughing below the casing. Because of the potential for equipment contamination, sound the well with a reusable weight attached to a disposable line. Slowly lower the weight into the well until the bottom is detected. With the line taut, mark the top of casing level on the line with waterproof ink. Recover the line and weight from the well and accurately measure the length of line below the mark. Discard the line and

---

* *Some data may be useful for estimating pollutant travel distances and the other interpretation without being used as evidence.*

Good engineering practice for cover, dike, and liner installations is to conduct preliminary soil exploration work. If available, review exploration records for relevant details.

Buildings and Structures

As with dike and liner installations, major building and structure construction is normally preceded by soil exploration work, which could also yield pertinent subsurface information. If soil exploration work was conducted, obtain boring logs, location maps, and any results of soil testing.

Check foundations for settling cracks and basement seepage that might yield information about subsurface conditions such as areas of subsidence or shallow groundwater conditions.

IV. SITE MONITORING

PURPOSE

The objective of monitoring at an HWS is to identify or define the groundwater pollution problem. To achieve this objective, NEIC procedure is to conduct a multimedia study which often includes sampling pollutant source areas, groundwater, surface water, sediment, and air. Subjects and procedures discussed here deal specifically with direct and indirect indicators of both site hydrogeology and pollutant movement in the subsurface. Information on "above ground" monitoring procedures are available in the literature.[53]

GENERAL SAMPLING CONSIDERATIONS

Selecting chemical parameters for sample analysis is based on background research findings, the site evaluation, and discussions with laboratory personnel.* For sites where waste mixtures of unknown composition have been disposed, chemical analysis typically comprises a general organics scan, with emphasis on priority pollutants, other pesticides, metals, and anions. Mutagenicity testing and bioassays, with water fleas and fish, may be conducted to determine potential adverse effects on the living community. Table 4 (from reference 29) indicates major types of pollutants from various industrial and municipal sources that should be considered for monitoring.

Chemicals known to be in the disposed waste with demonstrated high mobilities can potentially be used as leachate plume tracers or indicators. Analyze for these parameters at all sampling points. Organic wastes tend to produce strongly reducing conditions that increase the solubility of the "non-mobile" chemicals until soil attenuation or oxidizing conditions remove them from solution. Therefore, plan waste source and close-in groundwater

---

* *Any samples collected during an HWS investigation must be in accord with established chain-of-custody and document control procedures.*[54]

CONSTITUENTS IN INDUSTRIAL AND MUNICIPAL WASTEWATER HAVING SIGNIFICANT POTENTIAL FOR GROUNDWATER CONTAMINATION

MINING (SIC 10, 11, and 12)

Metal and Coal Mining Industry (SIC 10, 11, and 12)

pH	Zinc	Magnesium
Sulfate	Tin	Silver
Nitrate	Vanadium	Manganese
Chloride	Radium	Calcium
Total Dissolved Solids	Phenol	Potassium
Phosphate	Selenium	Sodium
Copper	Iron	Aluminum
Nickel	Chromium	Gold
Lead	Cadmium	Fluoride
	Uranium	Cyanide

PAPER AND ALLIED PRODUCTS (SIC 26)

Pulp and Paper Industry (SIC 261 and 262)

COD/BOD	Phenols	Nitrogen
TOC	Sulfite	Phosphorus
pH	Color	Total Diss. Solids
Heavy metals	Biocides	

CHEMICALS AND ALLIED PRODUCTS (SIC 28)

Organic Chemicals Industry (SIC 286)

COD/BOD	Alkalinity	Phenols
pH	TOC	Cyanide
Total Dissolved Solids	Total phosphorus	Total nitrogen
Heavy metals		

Inorganic Chemicals, Alkalies, and Chlorine Industry (SIC 281)

Acidity/alkalinity	Chlorinated benzenoids and polynuclear aromatics	Chromium
Total dissolved solids	Phenols	Lead
Chloride	*Fluoride*	Titanium
Sulfate	Total phosphorus	*Iron*
COD/BOD	Cyanide	Aluminum
TOC	Arsenic	Boron
Mercury		

CHEMICALS AND ALLIED PRODUCTS

Plastic Materials and Synthetics Industry (SIC 282)

COD/BOD	Phosphorus	Ammonia
pH	Nitrate	Cyanide
Phenols	Organic nitrogen	Zinc
Total dissolved solids	Chlorinated benzenoids and polynuclear aromatics	Mercaptans
Sulfate		

Nitrogen Fertilizer Industry (SIC 2873)

Ammonia	Sulfate	COD
Chloride	*Organic nitrogen compounds*	Iron, total

Nitrogen Fertilizer Industry (SIC 2873) (Cont.)

Chromium	Zinc	pH
Total dissolved solids	Calcium	Phosphate
Nitrate	Sodium	

Phosphate Fertilizer Industry (SIC 2874)

Calcium	Acidity	Mercury
Dissolved solids	Aluminum	Nitrogen
Fluoride	Arsenic	Sulfate
pH	Iron	Uranium
Phosphorus	Cadmium	Vanadium
		Radium

PETROLEUM AND COAL PRODUCTS (SIC 29)

Petroleum Refining Industry (SIC 291)

Ammonia	Chloride	Nitrogen
Chromium	Color	Odor
COD/BOD	Copper	Total phosphorus
pH	Cyanide	Sulfate
Phenols	Iron	TOC
Sulfide	Lead	Turbidity
Total dissolved solids	Mercaptans	Zinc

PRIMARY METALS (SIC 33)

Steel Industry (SIC 331)

pH	Cyanide	Tin
Chloride	Phenols	Chromium
Sulfate	Iron	Zinc
Ammonia	Nickel	

ELECTRIC, GAS, AND SANITARY SERVICES (SIC 49)

Power Generation Industry (SIC 491)

COD/BOD	Copper	Phosphorus
Polychlorinated biphenyls	Zinc	Organic biocides
Total dissolved solids	Chromium	Sulfur dioxide
Oil and grease	Other corrosion inhibitors	Heat

Municipal Sewage Treatment (SIC 495)

pH	Nitrate	Sulfate
COD/BOD	Ammonia	Copper
Alkalinity	Chloride	Tin
Detergents	Sodium	Zinc
Total dissolved solids	Potassium	Various Organics

sampling to be more comprehensive than elsewhere. By studying where cer tain pollutants are likely to be detected, and planning the study accord ingly, the laboratory load can be decreased and data turnaround times ca be improved without sacrificing thoroughness.

The potential fate of pollutants in surface water and sediment is als addressed when selecting analytical parameters. When groundwater dischar into flowing surface streams, the oxidizing environment will cause some pollutants to precipitate out of solution into the bottom sediments. In impoundments, they may be concentrated in stagnant stratified layers or bottom sediment.

Several references in the Literature Sources list can provide a start ing point for mobility research.[2,8,13,14,24,29,36,42,46,61,69,80] Data base searches by the NEIC Technical Information staff can also supply per tinent information.

For many pollutants, ambient concentrations are very low, yet their presence in any measurable concentration may be significant. Procedures employed or materials contacting the sample should not cause pollutants to be gained or lost. Consequently, sampling equipment and sample containers are fabricated from inert materials and thoroughly cleaned before use. Thorough cleaning extends to drilling rigs, tools, and ancillary equipment which has a potential of imparting contaminants to the sample. Materials recommended for equipment contacting samples to be analyzed for organic compounds in order of preference, are as follows:

1. Glass
2. Teflon®
3. Stainless steel
4. High grade carbon steel
5. Polypropylene
6. Polyethylene

A common and proven effective cleaning procedure is to thoroughly wash the equipment with a laboratory-grade detergent followed by clean water, solvent, and distilled water rinses. Acetone is generally the recommended solvent. Sufficient time should be allowed for the solvent to evaporate before the final rinse as sample contamination problems have arisen from solvent/rinse water not drying completely before equipment use. Cleaned equipment surfaces may be protected with new aluminum foil if there is a potential for contamination between cleaning and use.

GROUNDWATER MONITORING

Accessible sampling stations, such as seeps, springs, and existing wells, are normally the first choices for groundwater monitoring. The paucity or absence of these points may require installing shallow-driven well points in some cases, depending on the water table depth and materials to be penetrated.*

During preliminary monitoring, choose points close to the disposal site to increase the chance of detecting leachate in groundwater. If appropriate, select points near property lines to document probable or actual offsite pollutant movement. Locate sampling stations both up- and downgradient from the site to determine the extent of groundwater degradation.

Seeps and Springs

In the simplest cases, fill the sample containers either directly from the discharge or an adjacent downstream pool. Excavation, with thoroughly cleaned tools, may be required to form a pool of sufficient size. If excavation is required, allow solids stirred into suspension to settle or flush out before sampling.

---

* *Comprehensive monitoring well networks are discussed in Section V.*

The following are suggested field measurements and observations:

1. Flow, if possible
2. Temperature
3. Conductivity
4. pH
5. Color
6. Odor
7. Explosivity of atmosphere above flow (explosivity meter
8. Volatile gas release (HNU® meter)

These determinations will also enable the investigator to decide whether the samples are "hazardous" or "environmental" for shipping purpos

Existing Wells

As previously noted, up- and down-gradient monitoring stations are important to the hydrogeologic investigation. Because more data points are required for plume definition, sampling emphasis is on down-gradient wells. Ideally, these wells would be relatively close to the site because groundwater typically moves slowly. Sampling wells without benefit of minimal construction information [Chapter III] should be avoided. However, do not be overselective for initial sampling if the well is likely to tap an aquifer of concern.

Well sampling involves two steps (not necessarily with the same equipment):

1. Presample purge
2. Sample collection

The primary consideration is to obtain a representative sample of the groundwater body by guarding against mixing the sample with stagnant (standing) water in the well casing. In a nonpumped well, there will be little or no vertical mixing of the water, and stratification may occur. Water

in the screened section will mix with the groundwater due to normal flow patterns, but the well water above the screened section will remain isolated and become stagnant. Stagnant water may contain foreign material inadvertently or deliberately introduced from the surface, resulting in unrepresentative data and misleading interpretations.

Considerations for presample purging include proper disposal of pumped liquid and calculation of adequate volumes. Because of the potential for further environmental contamination, planning for purge water disposal is a necessary part of well monitoring. Alternatives range from dumping it on the ground (not back down the well) to full containment, treatment, and disposal. If the well is believed to be contaminated, the best practice is to contain the purge water and store it until the water samples have been analyzed.* Once the contaminants are identified, appropriate treatment requirements can be determined.

Required purging, suggested by available literature, ranges from one to five casing volumes** with judgment input being a critical factor to ensure that pumping is not excessive. Leachate stratification in groundwater may occur, and excessive pumping can result in flow entering the well from outside the zone of interest. Purging, necessary before obtaining predominantly "fresh" groundwater, depends on:

1. the pump intake level
2. water-yielding ability (specific capacity) of the aquifer
3. well "openness" to the aquifer (well efficiency)[40]

Pumping is required to determine the latter two factors; therefore, during initial sampling, "rules of thumb" are followed while well performance information is gathered for future sampling.

---

* *See "Containing and Disposing of Contaminated Materials" in Chapter V.*

** *The volume of water contained in the casing before pumping.*

Common well situations, initial purging, and sampling procedures are presented in Examples 1, 2, and 3. In each example, three casing volumes are pumped through the screen before sampling except when a pump/packer assembly is used. Procedures discussed may be modifed for specific analytical parameters, well designs, and pumping systems. Volatile organics, for example, may require special sampling techniques, sealed wells may prohibit depth and water level measurements, and ideal purging may be impractical. Investigators must exercise judgment when collecting samples and fully document the procedures used.

Driven Well Points

When existing groundwater sampling points are either inadequate or nonexistent, driven well points can sometimes be installed. In some instances, shallow augering equipment can be rented from a contractor's supply firm to enable deeper well point installations.

Generally, well points are installed in medium- to coarse-grained, unconsolidated sandy materials in shallow water table areas. They are usually placed near the disposal site or zones of groundwater discharge, such as along streams. For this method, a 1.25 in. diameter well point with a 60-gauze or 10-slot screen is recommended. The well point is attached to the same diameter pipe and driven to completion depth with a drive weight or sledge hammer [Figure 8]. Normally, the well point can be driven to about 10 ft, however, 30 ft depths have been reported. Advantages of this method are: (1) low cost, (2) installed by hand without need for drilling contractor, and (3) good seal between casing and aquifer can be expected with little or no leakage. The well points can be recovered, but reuse is not recommended due to cleaning problems. Example 4 presents the procedure suggested for driven well point installations.

A small continuous-flight power auger [Figure 9] can be used to bore down to the desired completion depth before the well point is driven. In loose, sandy soils, well point penetration is much easier and installation depths are increased. For more cohesive materials (i.e., sifts and clays),

Generally, there are two types of sediment samplers: (1) bottom scrapers, such as scoops and dredges; and (2) bottom penetrators such as solid core tubes and split-spoon samplers. The nature of bottom materials and/or the survey purpose usually dictate the sample type. The bottom scraping samplers collect disturbed (relatively recently deposited) sediment while the coring devices collect relatively undisturbed samples representing longer periods of deposition.

AIR MONITORING

Air monitoring can sometimes be useful as a safety precaution during drilling and in determining the presence of volatile organics in boreholes and wells that could migrate in the subsurface. During drilling operations, use the HNU meter to monitor the borehole and cuttings for potentially dangerous gases to minimize the amount of protective gear worn by the drilling crew and others close to the rig [Appendix G].

Screening of the head space (air above the water level) in boreholes and wells can also be accomplished with the HNU meter. If vapors are detected, air samples should be collected. Sampling equipment often consists of a calibrated personnel monitor (vacuum source) connected, via an intake line, to a glass tube packed with Tenax®, a porous polymer resin [Appendix E].

Generally, there are two types of sediment samplers: (1) bottom scrapers, such as scoops and dredges; and (2) bottom penetrators such as solid core tubes and split-spoon samplers. The nature of bottom materials and/or the survey purpose usually dictate the sample type. The bottom scraping samplers collect disturbed (relatively recently deposited) sediment while the coring devices collect relatively undisturbed samples representing longer periods of deposition.

AIR MONITORING

Air monitoring can sometimes be useful as a safety precaution during drilling and in determining the presence of volatile organics in boreholes and wells that could migrate in the subsurface. During drilling operations, use the HNU meter to monitor the borehole and cuttings for potentially dangerous gases to minimize the amount of protective gear worn by the drilling crew and others close to the rig [Appendix G].

Screening of the head space (air above the water level) in boreholes and wells can also be accomplished with the HNU meter. If vapors are detected, air samples should be collected. Sampling equipment often consists of a calibrated personnel monitor (vacuum source) connected, via an intake line, to a glass tube packed with Tenax®, a porous polymer resin [Appendix E].

V. INSTALLING MONITORING WELLS

PURPOSE

Every groundwater pollution investigation poses unique physical problems for designing and installing a monitoring well network, even in a framework of typical objectives. There are common factors for designing, installing, and using a groundwater monitoring system. This chapter addresses briefly some major considerations for either designing a network or evaluating one. In most cases, the situations discussed represent ideal conditions that may or may not apply to a particular project.

PURPOSE OF MONITORING WELLS

The usual purpose of a monitoring well network is to define groundwater quality and movement and to accomplish specific study objectives such as:

- To define the vertical and areal extent of the leachate plume
- To monitor pollutant concentrations
- To provide the means for detecting the leachate plume front, unexpected changes in size, or direction of flow
- To determine the extent of interaquifer movement of pollutants
- To determine aquifer characteristics (permeability, head distribution, transmissivity, etc.)
- To estimate rate of leachate plume movement
- To develop a data base for designing remedial measures
- To determine effects of remedial measures
- To assist in performing remedial work (leachate recovery)
- To provide data base for groundwater modelling

The objectives must be clearly defined and integrated at the outset since they will dictate fundamental design, such as whether monitoring stations

will comprise a single well or a well nest.* They will also define where in the plume (top, middle, bottom, or outside) the wells must be located.

The evaluator must be able to recognize the ability of a particular network or plan to achieve the stated purposes or objectives. The key points to look for in study plans are specificity and reasonableness; the plan should fully explain how the objectives are to be met by the network, exactly how the wells will be installed, and the flexibility given to the field supervisor. For example, the plan should detail procedures for containing and disposing of contaminated cuttings. Disposal of the contaminated cuttings in a nearby stream is unreasonable. Errors, oversights, and misunderstandings can be reduced by following these two guidelines which must be used for writing plans as well as reviewing them.

PLANNING THE MONITORING NETWORK

Early in the planning phase, factors such as external requirements, data requisites, and well placement are considered to avoid shortcomings during the well design and installation phases. These three topics are presented here in a recommended order of consideration for a "typical" planning exercise. When evaluating plans, check to see that the variables indicated have been addressed.

External Requirements

External requirements or conditions are those that can affect well design and locations, over which the planner has no control. Three types of requirements and conditions normally researched include: 1) pertinent state, local, or other regulations; 2) permission to construct wells on private property; and 3) location of buried and above-ground utilities that might pose safety hazards to the drillers. Some of this information may have been gathered during earlier investigation activities as outlined in previous chapters of this manual. If not, begin gathering this information when the design process is initiated.

---

* *Two or more wells, finished to different depths, usually installed in close proximity.*

Contact state and local governments* to determine if special per licenses, construction practices, or borehole closure procedures are quired. Appendix B presents a summary of water well industry codes licensing requirements for water well drillers. Also included is a l state agencies and officials responsible for industry codes in 1976. geological surveys [Appendix A, Part 6] and local drillers may also be to supply appropriate information.

When drilling on private property, obtain easements from the owne their authorized representatives. Any easement developed must be cle through appropriate legal channels. Examples of easements (also calle cense agreements) which have been used by EPA are presented in Appendi Generally, the easements should:

1. protect the property owner,
2. protect the government or company,
3. be fair to both parties, and
4. be executed in good faith.

Locating buried utilities is normally done by contacting local ele tric, telephone, gas, water, and pipeline companies, and requesting appr priate information or service. To aid in making the proper contacts, t American Public Works Association periodically publishes a "One-Call Sy tems Directory" that lists contacts and telephone numbers to locate bur utilities in many geographical areas of the United States.**

---

* *The Corps of Engineers regulates drilling and dredging activities along major water courses.*

** *The directory is available from the Utility Location and Coordination Council, 1313 East 60th Street, Chicago, Illinois 60637, 312 947-2520*

Data Requisites

The first four chapters discuss various activities for obtaining hydrogeologic information during a hazardous waste site investigation. This same information is used for planning, designing and installing a monitoring well network. As a minimum, assemble data for requisites presented in Table 6 from the file information. If critical information on these requisites has not been obtained, either estimates must be made or more data will have to be gathered. Installing monitoring wells and analyzing water samples are expensive, thus a concerted attempt must be made to gather real data whenever possible.

Well Placement

Determining the number and map location of groundwater monitoring sites are the first major tasks in the network design process. The next step is determining the vertical position of the well screens. During the planning process, attention must always be focused on the network purpose and objectives. Rather than stating specific procedures, several factors and concepts are considered for planning or evaluating a monitoring network.

In an ideal situation with one potential leachate source, a generally known groundwater flow direction, and an objective of identifying if problem exists, only two properly placed wells (one upgradient and one downgradient) would be needed [Figure 10a]. Even with a single leachate source and a simple objective, flow directions and proper locations are normally difficult to accurately determine. Consequently, more than two wells are usually installed to increase the probability of intercepting the plume [Figure 10b], collect adequate data, and be economical. Ultimately, the number of wells will depend on problem seriousness, hydrogeologic complexity, and available funds.

Table 6

DATA REQUISITES AND USES FOR PLANNING MONITORING WELL NETWORKS

Requisite	Use
Probable groundwater flow direction and expected seasonal changes	Use this information to locate areas for ground (upgradient) wells and select the where intercepting the leachate plume is
Location of other potential pollutant sources	In conjunction with information on groun flow directions, determine if and where p ants from other sources might be detected the study area.
Probable groundwater contaminants	Consider the chemical effects of the cont nated groundwater on potential casing mat (corrosion, adsorption, etc.), grout, and tonite seals. Also determine if well desi must accommodate special sampling procedur equipment for these pollutants.
Expected range in depths to groundwater	Use these data to ensure proper well depth for year-round sampling. For water depths low about 20 ft, determine if well design accommodate submersible pumps or other larg down-the-hole equipment.
Types of materials to be drilled	Identify whether consolidated (rock), uncon- solidated, or both types of formations will have to be penetrated so that the drilling alternatives can be determined. If unconsol dated formations are the only concern, find out if cobbles or boulders are common.
Probable geologic and hydrologic characteristics of the target formation and overlying materials	Use these data for selecting screen slot siz determining if a gravel pack is necessary, l ting where the borehole should be sealed with grout or bentonite, and/or whether or not a s face casing should be set.
Available drilling equipment	Contact local drillers and identify the gener availability of hollow-stem auger, hydraulic and air rotary, and cable tool drilling rigs i the area for establishing alternatives. Inqu about borehole diameter, depth capabilities, costs.

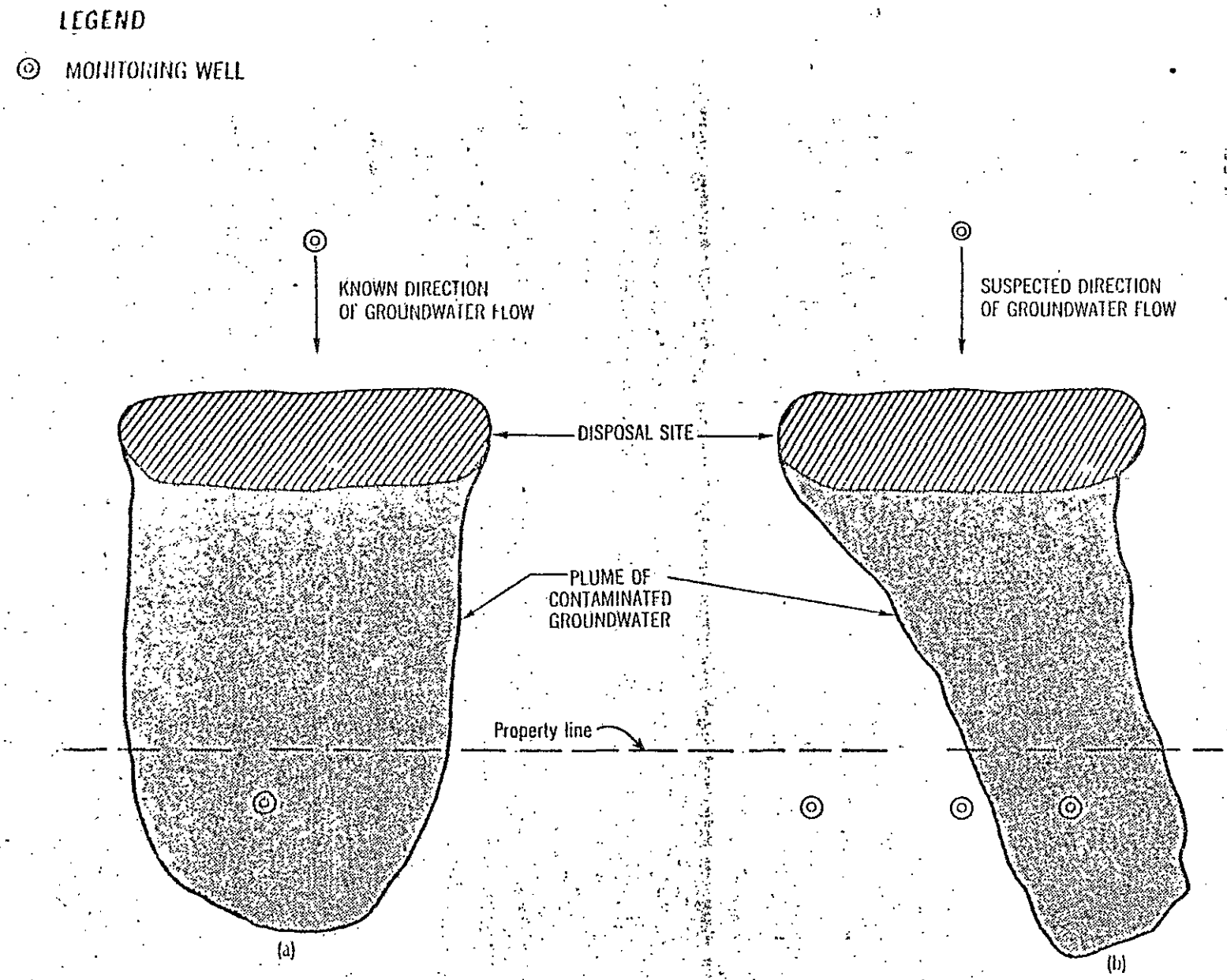


Figure 10. Well Locations for Problem Identification with Known and Suspected Groundwater Flow Directions in Plan View

(From Reference 23, Figure 6)

Wells should generally not be installed through fill materials until alternate methods of obtaining the desired information have been exhausted, for the following reasons:

1. Reactive materials could be united in the well bore to produce toxic gases, explosions, fires, or other potential hazards.

2. The borehole may create a conduit through which pollutants could move easily into the underlying aquifer.

3. Density stratification of leachate could produce nonrepresentative samples.

The purpose of such wells is usually to identify the waste composition, fill thickness, and nature of underlying materials. In many cases, however, waste deposit composition can be learned from background information and samples collected from shallow, hand-augered, or dug holes. The nature of underlying materials can be identified from perimeter borings.

Upgradient wells are critical for understanding leachate effects on water quality. Judgment is required in placing these wells for monitoring background conditions. They should be close to the fill or waste disposal area, yet out of the influence of the water table/leachate mound that often forms around HWSs. Not only will the mound affect "upgradient" water quality, but water table elevations in the mound will also be unrepresentative of ambient conditions. If multiple aquifers are of concern, there should be a background well for each.

Most monitoring sites will be downgradient from the waste deposit because more data points are required to define the leachate plume than to monitor background water quality. The recommended approach is to track the leachate plume outward from its source into the environment. Continuing success in tracking and locating the plume is more probable with this method.

Earth resistivity and shallow seismic surveys are frequently suggested for preliminary site studies aimed at locating leachate plumes and determining bedrock depths. In each method, the key to success is a high contrast between features of interest (e.g., conductivities of plume and background water and elastic properties of bedrock and overlying material).

If the contrast is minimal or clouded by complex geology and man-induced interferences (buried metal objects), then the techniques may not be applicable. Although these methods are valid and sometimes helpful, their use should be thoroughly justified. Results should always be confirmed with a representative amount of boring data; without adequate confirmation, the results are considered suspect.

In a typical groundwater pollution investigation setting, where the waste is underlain by unconsolidated alluvial materials with a free water table above bedrock, locate downgradient wells in an array that parallels the fill boundary. The first line of monitoring locations might be within 100 to 300 ft of the fill [Figure 11]. The second line is located by moving outward from the fill either on rays from the waste center through the first line of borings or where permeable or contaminated areas are suspected. Monitoring locations in areas near property lines is preferred for documenting offsite pollutant movement.

Grid-structured monitoring locations are generally not recommended because they are usually not cost effective and do not apply the planner's ability to interpret site hydrogeology.

Since leachate plumes are three dimensional, the vertical placement of the well screen is a major part of the planning process. Knowing the vertical position of the plume is important. Complexity is introduced by the fact that the plume may move vertically in response to seasonal or artificial (e.g., pumping) changes of one type or another. For these reasons, nested wells are commonly installed to locate the plume and detect vertical movement over time.

Well nests are state-of-the-art for monitoring networks because of the information they can yield. In addition to locating the vertical and areal extent of the plume, head distributions and flow directions can be determined. Generally, the nests should define the bottom of the plume, especially if important aquifers are below the site. This depth may sometimes be inferred from known hydrogeologic data or determined from preliminary borings with water sampling at progressive depths.

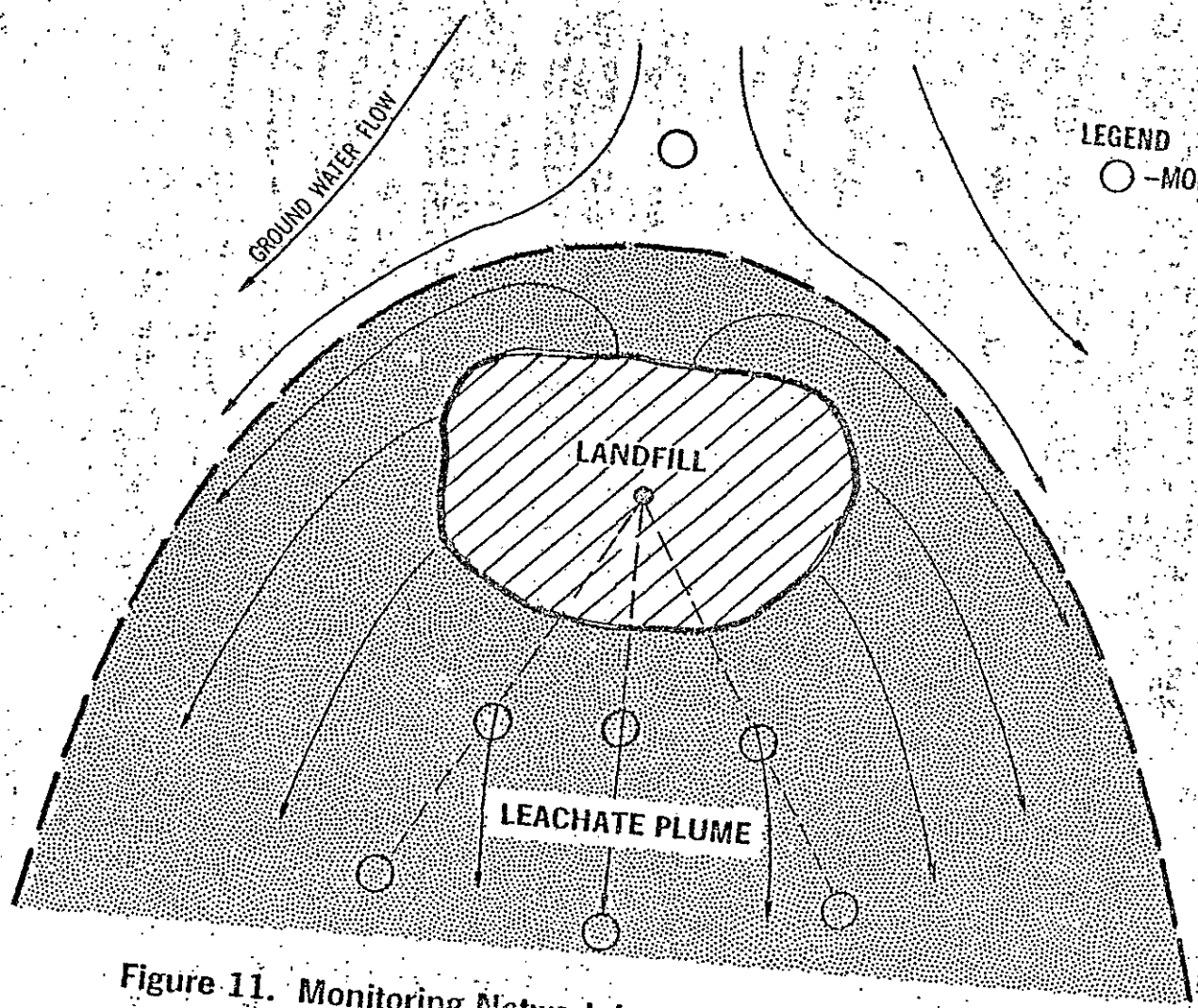


Figure 11. Monitoring Network in an Unconsolidated Aquifer

From progressive-depth groundwater sampling, a "snapshot" of the plume's vertical location can be determined. Two of the many procedures for this method in unconsolidated materials include: 1) driving a well point through a hollow-stem auger with sampling at 5 or 10 ft intervals; and 2) collecting aliquots of the air/water/cuttings mixture from a dual-tube reverse-air rotary drilling rig [Appendix D]. Sample analysis is usually limited to several parameters that are indicative of the waste, mobile in the subsurface, and relatively inexpensive to detect (e.g., chloride, sulfate, arsenic, etc.). Based on this initial sampling, the depths of permanent wells are selected so that specific horizons or zones of the plume will be monitored.

DESIGNING THE WELLS

A generally accepted all-inclusive design for monitoring wells is not available; however, many factors are basic to most wells. These common factors make a degree of standardization possible. Many of the engineering design particulars, such as casing and screen material strengths, standard dimensions, weights, and resistance to acid corrosion are covered in considerable detail in other publications and will not be presented here.[4,7,18,40,62] Design factors discussed here are:

- Well use
- Formation hydraulic characteristics
- Screen slot size and length
- Casing and screen diameter
- Casing and screen materials
- Drilling methods [Appendix D]

Although individually discussed, sound practice requires that these factors be considered together. Regardless of individual design, all wells should be fitted with a secure or locking cap to prevent tampering and minimize vandalism.

Well Use

The most fundamental factor in any design is the projected use of well. If probable uses can be successfully defined and accounted for the design, the need for costly additional wells may be reduced or eli "Observation wells" are constructed for collecting water samples to loc and track the leachate plume and/or for measuring water levels for dete ing groundwater flow paths and pressure gradients. "Production-type we can also be used for these purposes, but they are designed primarily f conducting tests to estimate aquifer characteristics* and perform remed measures through injecting purge water or recovering leachate.

In most situations, a well that substantially penetrates an aquife and is open throughout the saturated thickness is neither required nor d sirable. This applies to observation wells installed for monitoring wat quality and head levels in certain zones and to production-type wells us for aquifer testing or remedial measures. Consequently, the well screen bore is designed to be isolated so that only a specific zone is monitore Sealing materials, such as cement grout and bentonite, are used above th open part of the well to prevent vertical migration of fluids in the annu lus between the casing and hole wall. A well with a seal above the moni- tored zone is called a piezometer.

As a practical matter, in rock wells and those penetrating cohesive, fine-grained, unconsolidated materials, the seal is critical to assure screen or bore isolations. In loose unconsolidated materials where heaving sands are common and/or the borehole collapses immediately upon auger re- moval, the need for seals below the zone of natural collapse is question- able. Much time, motion, and expense can be wasted in installing seals where they are not reasonably needed.

---

* *Wells installed for pump tests generally should not be placed where they would discharge contaminated groundwater because that water would have to be properly disposed of.*

Formation Hydraulic Characteristics

For production-type wells, characteristics such as depth-to-water, permeability, storage coefficients, and the primary way in which water is transmitted (through fractures or around grains) can influence design.

Some networks may be planned so that the formation characteristics are determined during a preliminary drilling phase or initial well set. Formational sampling while drilling should be part of the comprehensive installation plan.

Screen Slot Size and Length

Ideally, for naturally developed wells (those without a gravel pack) screen slot sizes are selected from sieve analysis data for the target horizon or zone in the formation. A plot of grain size vs cumulative percent retained on the sieves is made for study.

For production-type wells, samples for grain-size analysis are normally collected. The samples represent the depth interval to be occupied by the screen. The slot size selected should retain 40% or more of the zone material. In conventional water well design, the percentage range is 40 to 50.[4,40] However, when larger slot sizes are used, more formation material will move into the well during development. If all water removed from the well is to be treated, considerable solids may accumulate in the collection vessel or treatment system, which must also be handled and disposed. In situations where production or injection rates do not require optimum yield, design for the smaller screen openings.

If the required slot size is less than 0.010 in. (10 slot or 60 gauze), a gravel pack should be considered.[40] In gravel-packed wells, the space between the screen and borehole is filled with material coarser than the formation. The principal functions are to:

1. stabilize the formation and minimize pumping of fines,
2. permit use of the largest possible screen slot, and
3. increase the effective well diameter.

Screens should not pass more than 5% of the pack material.[4]

Experience indicates that observation wells are seldom designed benefit of grain-size analyses from the zone of interest. The usual recommended procedure is to use a 10-slot screen with or without gra pack. For most fine-grained unconsolidated formations, such as loess, cial till, lacustrine, and backwater deposits, the gravel pack is a m In medium-to-coarse sand or larger materials and in bedrock, a pack is mally not required. For the wide gray area in between, plan to instal gravel pack, but allow flexibility for field evaluation and determinat of actual need and practicality.

The process of selecting screen lengths for either a production observation well is largely subjective. The primary variables are proj ted well use and purpose and the designer's experience. In most situa tions, wells will be installed as piezometers to monitor a specific zone horizon. In these instances, screen lengths rarely exceed 20 ft and ar more often 5 to 10 ft. Shorter screens installed in well nests are reco mended because they yield more specific information about water quality, head distribution, and flow in the formation. Also, commonly used stain less steel screens become very expensive in longer lengths (more than $30 for a 10 ft x 2 in. screen).

Casing and Screen Diameter

Probably the most important factor in selecting an appropriate well diameter is the size of equipment (pumps, packers, sondes, etc.) the well will have to accommodate. When the depth of water exceeds 25 ft, using electric submersible pumps is desirable for purging and sampling. The smallest commercially available electric submersible pump requires a 3 in. well casing. Submersible pneumatic diaphragm pumps require a 2 in. diameter casing. If the casing is too large, purge volumes (and costs) can be excessive, especially if the purge water must be treated or contained.

Consequently, the 2 and 4 in. diameter casings are the most common for observation and small production wells. As a general rule, if the pumped water level is not expected to fall below 20 ft, 2 in. wells will probably be adequate. For expected pumping levels below 20 ft, use 4 in. or larger casing. The screen and casing diameter are usually the same. Consult references 4 and 40 for more specific information about casing strengths, collapse pressures, etc.

Hybrid well designs with multiple sampling ports or screens have been presented in recent literature due to current interest in groundwater monitoring. Inherent problems with many of these designs include assuring a good seal between the sampling zones (both internal and external), obtaining a sufficient sample in a reasonable length of time, and the relative seriousness of even minor screen plugging (suggested total screen area in one design is less than 0.2 in.^{2}). The relative costs of well design, sample collection, analytical work on water samples and their bearing on remedial measures are ample economic reasons for not cutting too many corners on monitoring wells. Certain situations may clearly justify (either economically or hydrogeologically) installing hybrid wells. However, the recommended approach for most sites is one well/screen per hole, using nests of wells if multiple depth sampling is desirable.

Casing and Screen Materials

Steel and PVC plastic are the most widely used casing and screen materials for monitoring wells at HWSs. Presently, the use of PVC pipe in groundwater contaminated by organic wastes is controversial. The major advantages of PVC pipe are its relatively low cost, light weight, and durability in harsh chemical environments. Opponents claim that the pipe can either absorb/adsorb compounds from the water and render them undetectable or contribute compounds to the water, resulting in an unclear picture of groundwater quality in either case.

Proponents reply that if wells are purged adequately for normal s collection (3 to 5 casing volumes) and the sample is drawn opposite screen, any potential interferences would be negligible. Also, if po tant concentrations are high enough to be of concern, they are unlike be substantially removed by sorption to the PVC casing.

Chemical deterioration of PVC casing is possible when either keto aromatics, alkyl sulfides, or specific chlorinated hydrocarbons are pre Currently, there is a dearth of information regarding critical concent tions of these solvents where deterioration of the PVC is significan enough to affect sample quality.

If the particular compounds of interest in the groundwater are al components of PVC pipe, its use should definitely be avoided. In contra if metals are the pollutants of concern or the groundwater is very acid basic, or reactive, steel pipe may not be appropriate and PVC may be th prudent choice; data on contaminants detected which are potentially attr butable to the pipe may be of questionable value.

Drilling Methods

Drilling equipment selected for installing monitoring wells must b compatible with the well design and capable of penetrating the geologic materials above the estimated well depth. In general, there are three typ of wells based on the installation method:

1. Driven wells
2. Augered wells
3. Drilled wells

Figure 12 shows where these wells types are often installed. Appendix D presents a discussion of well drilling methods and limitations. Dry drilling methods are preferred to avoid introducing extraneous fluids/ muds, required in some methods for removing cuttings from the borehole. If drilling fluids are required, the recommended approach is to try

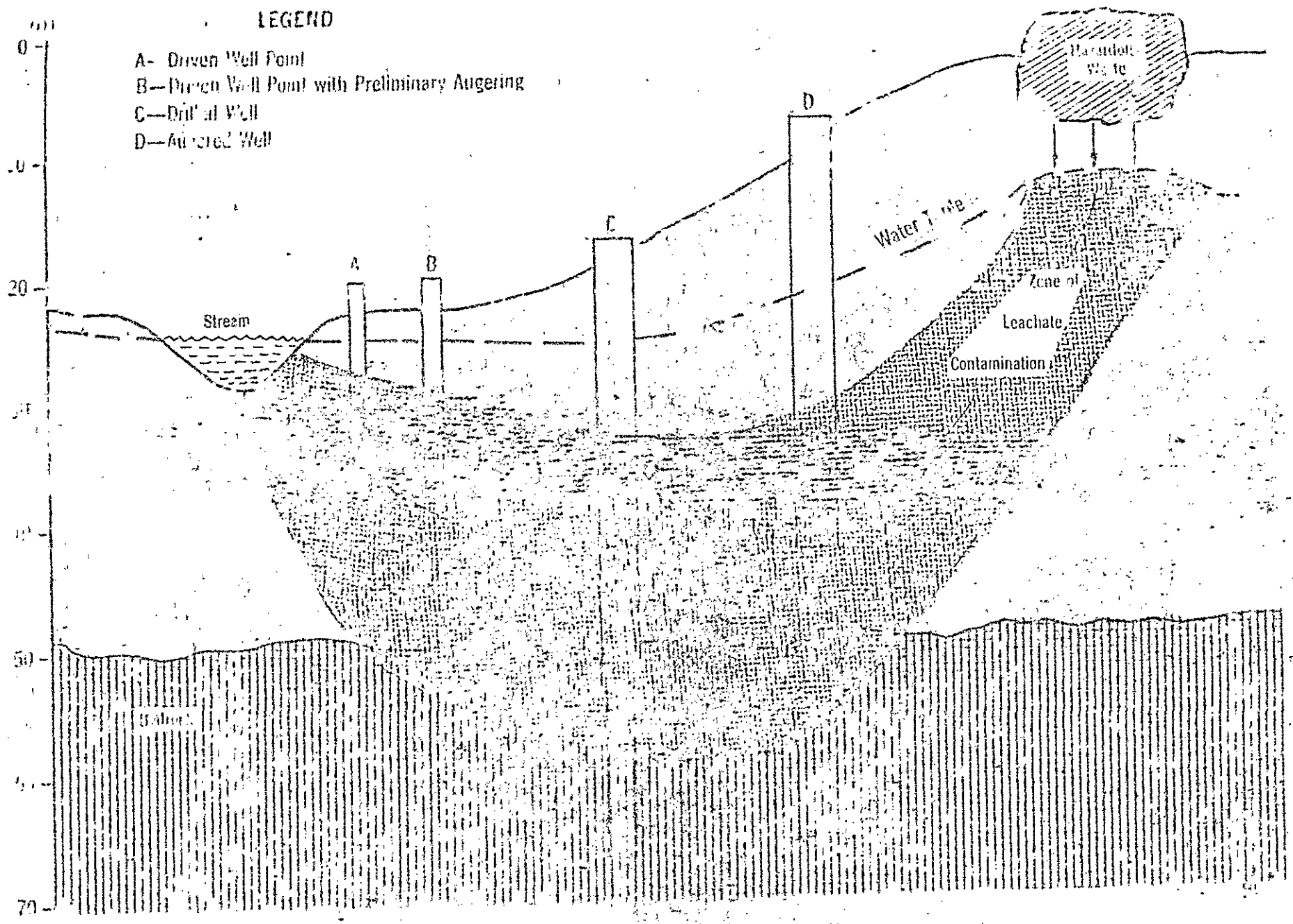


Figure 2. Cross Section of Various Well Types

that the identity, quantity, and concentration of pollutants in these materials are unknown.

If contamination is suspected and the material cannot appropriately returned to the borehole or applied to the waste fill, the following procedure is recommended. Contain all materials in 55 gal. drums or tanks a store them until samples from the well or boring are chemically analyzed On the drums, indicate the material contained and borehole number; do no mix wastes from different boreholes as some uncontaminated wastes may en up requiring expensive disposal. When the samples are analyzed, determin proper disposal methods. Slow turnaround times in the laboratory may (and probably will) create storage needs. If onsite storage is not practical, transport the waste to a secure location.*

Sampling During Drilling

Installing monitoring wells should be planned as an intermediate stage in data gathering. A complete drilling program that includes formation sampling, during or preceding well installation, provides a cost effective means of obtaining definitive site specific data on geology and groundwater quality; wells need not be installed at all boring sites.

Both formation and water samples should be collected at progressive depths when searching out a leachate plume. The formation samples are used to define stratigraphy, hydraulic characteristics, and engineering properties (for design of remedial measures). Chemical analyses of formation samples might be performed to study attenuation capabilities, but plume location is better done with water samples because they are easier to analyze and pollutant detection limits are much lower. Also, water is the primary pollutant transport medium.

---

* *In instances of severe contamination, appropriate Department of Transportation (DOT) packaging and vehicle placarding may be necessary.*

In bedrock formations, stratigraphy can be defined from either cuttings or core samples and geophysical methods. Core samples, rather than cuttings, are usually required for hydraulic testing.* Commonly, rock cores are collected using a hydraulic rotary rig [Appendix D] and either a conventional or wireline diamond core drill. Wireline coring is usually the preferred method, if available. Water samples can be collected from various horizons in a rock hole using a pump and packer assembly.

For unconsolidated formations, core samples should be used to log stratigraphy and can be used to conduct hydraulic testing. Two general types of core samples can be collected from unconsolidated formations, disturbed and undisturbed. As a practical matter, both core types are disturbed to a greater and lesser extent. The distinction is made here for both the collection method and the types of tests that are properly conducted on each. All disturbed core tests can be run on undisturbed samples [Table 7].

Table 7

APPROPRIATE ANALYSES FOR DISTURBED AND UNDISTURBED CORE SAMPLES[15]

Analysis	Undisturbed	Analysis	Disturbed
Permeability	X	Grain size	X
Unit weight	X	Chemical analysis	X
Consolidation	X	Specific gravity	X
Triaxial compression	X	Water content	X
Unconfined compression	X	Atterberg limits	X
Direct shear	X	Shrinkage limits	X
		Standard compaction	X
		Vibrated density	X

Disturbed samples are usually collected with a thick-walled split-barreled core tube called a split spoon. Although the sample is compressed and somewhat deformed during entry into the core tube, the stratigraphy is

* *If fractures are the primary avenues of groundwater movement in bedrock, hydraulic testing on core samples may provide meaningless data.*

easily discernable. Information on relative soil strength, which may be necessary for designing remedial measures, can be obtained during disturbed core collection by the standard penetration test. The test comprises driving a standard 2.0 in. diameter split spoon with a 140 lb hammer freely dropping 30 in.; blow counts are recorded for every 6 in. of penetration. The more blows required, the more resistant the soil is.

Undisturbed samples are usually collected with a thin-walled core tube (Shelby Tube) with or without a check valve in the upper assembly to improve core retention. Undisturbed core samplers are pushed into the formation with the hydraulic drill head on the rig rather than being driven. Care must be taken during transport to ensure sample integrity. Ideally, the soils laboratory employed would be near the HWS.

There are many variations in soil sampling and analysis techniques. The methods to be employed should be described in the project plan, before drilling begins, and evaluated by a qualified geologist or soil scientist. Detailed information about both disturbed and undisturbed core sampling is contained in references 15 and 82. Sampling programs should also include procedures for cleaning equipment after each sample is collected.

Progressive depth water sampling in unconsolidated materials is addressed in the "Well Placement" section of this chapter and in Appendix D.

Surveying Well Elevations

After the wells are completed each well-head elevation should be established, to third order standards, with respect to a fixed point, the local datum or, preferably, mean sea level.[22] These elevations are as important as water quality to the hydrogeologist because they enable him to determine flow rates and directions, and they can yield much information about designing remedial measures.

94. U.S. Environmental Protection Agency. Monitoring Groundwater Quality: Methods and Costs, EPA-600/4-76-023, May 1977

Eagle
2648

EPA-600/4-76-023
May 1976

Environmental Monitoring Series

MONITORING GROUNDWATER QUALITY: METHODS AND COSTS

Environmental Monitoring and Support Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Las Vegas, Nevada 89114

useful when relatively rapid water-level fluctuations occur, such as in observation wells during pump tests. These recorders cost about $375. If a digital system rather than a chart is desired, the unit can cost about $675. Most recorders come with about 20 feet of line and an extra charge of $0.25 per foot is charged for additional line.

Garber and Koopman (1968) summarized methods of measuring water levels in deep wells. Accurate measurement of water levels deeper than 1000 feet in wells requires special equipment. Correction for stretch and thermal expansion of measuring tapes must be considered.

Water Sampling

Most of the physical factors which promote mixing in surface waters are absent or much less effective in groundwater systems. A well can be considered as a sampling point in a large body of slowly moving water, which differs in chemical composition vertically as well as areally. Unfortunately, most techniques for well sampling at discrete depths are usable only in unfinished or nonoperating wells. A more reliable means of evaluating the quality of water tapped by a well is an analysis of a pumped sample.

The volume of water that is generally collected for chemical analysis from individual widely scattered monitoring wells is relatively insignificant volumetrically. Therefore, either many more monitoring wells must be sunk or a smaller number of existing wells must be pumped at higher rates or more frequently to obtain representative values. Most wells are integrators of complex systems of surface water, soil water, and groundwater. In some cases the integrated sample is of most importance because it represents the water used, or likely to be used in the future. In other cases, an integrated sample is not of interest, but rather a sample from a specific depth zone. This requires either careful selection from existing wells or construction of special monitoring wells.

Well Hydraulics

The composition of water obtained from a well is likely to be influenced by well construction, well development, and pump operation, and these should be considered in the sampling program. Well construction can determine the depth of zones from which the water is coming and influence the local groundwater flow pattern. Perforations above the water table can permit cascading water, or direct movement of groundwater from shallow perched layers above the water table, to flow down the inside of the well to the water table. Drilling mud remaining from well construction can contain contaminants, as can well casing, seals, and pump parts.

Well hydraulics can cause chemical changes in the composition of a pumped sample. For example, pressure changes associated with velocity

changes at the well inlet can cause changes in oxidation state, pH, and temperature which, in turn, affect certain chemical constituents. Thus, a sample from the well discharge may differ significantly in quality from groundwater in the aquifer. Also, in cases where chemicals are added at the discharge pipe, care must be taken to ensure the chemical composition of the sample is not altered.

Time Changes in Quality

Quality changes in groundwater are usually much slower than those in surface water. The composition of well samples from a large, relatively homogeneous aquifer usually will not change much over long periods of time. Therefore, changes in groundwater quality can be described satisfactorily by monthly, seasonal, or annual sampling schedules. However, exceptions usually occur in cases of groundwater pollution.

Just as water levels in a well change drastically soon after a pump is turned on, so can the quality of pumped water. This is particularly true where there is vertical stratification of groundwater quality. These short-term changes in some cases may be linear with pumping time, whereas in other cases they may be exponential. In the case of high-yielding wells (greater than 500 gpm), several days or weeks of pumping may be necessary to purge the well of atypical water due to local conditions. These local conditions could include poor quality, shallow water cascading down the well casing and accumulating in or near the well during nonpumping periods or vertical leakage down a gravel pack to a deeper producing zone. Often, field measurements of water temperature and electrical conductivity at the well discharge as the well is pumped can yield useful information on short-term changes in water quality. For short-term testing, consideration should be given to a logarithmic frequency of sample collection, analogous to the procedure for water-level measurements during a pump test. Short-term trends should be evaluated before adequate data are collected to determine long-term time trends in groundwater quality.

In the early days of water-level measurement programs, weekly or monthly measurements were made to discover seasonal fluctuations; elsewhere, semiannual measurements, related to high and low water levels for a year, were instituted. In some areas significant seasonal fluctuations occur in the quality of groundwater. In these areas seasonal trends must be established in the first stages of the development of monitoring programs. Specific locations where seasonal changes are likely to occur include:

1. Near large-volume point or line sources of recharge or pollution
2. Near disposal sites for highly concentrated wastes

95. United States Testing Company, Inc, Engineering Services Division. Report of Test, letter to Client: Bridgeport Chemical Corporation, "Resistance to Reagents of an Epoxy Coating," May 28, 1980

United States Testing Company, Inc.
Engineering Services Division
1415 PARK AVENUE • HOBOKEN, NEW JERSEY 07030 • 201-792-2400

JUN 2

REPORT OF TEST

78557
NUMBER

CLIENT: Bridgeport Chemical Corporation
2610 N.E. 5th Avenue
Pompano Beach, Fla. 33064

May 28, 1980

SUBJECT: Resistance to Reagents of an Epoxy Coating

REFERENCE:

Bridgeport Chemical Corporation letters of authorization dated August 29, 1989 and May 27, 1980 by Mr. Paul I. Meli, Jr.

SAMPLE IDENTIFICATION:

One (1) sample (15 panels) of steel coated with epoxy were submitted and identified by the Client as: GA27P epoxy coating.

TEST PERFORMED:

The submitted panels were immersed in various reagents for a period of seven (7) months at 75°F. Upon completion of the immersion period the panels were examined for visual affects.

Testing Supervised by:

Frank Razzuoli

SIGNED FOR THE COMPANY
BY Frank Pepe
Assistant Vice President,
Engineering Division

mg

Laboratories in: New York • Chicago • Los Angeles • Houston • Tulsa • Memphis • Reading • Richland

THIS REPORT APPLIES ONLY TO THE STANDARDS OR PROCEDURES IDENTIFIED AND TO THE SAMPLE(S) TESTED. THE TEST RESULTS ARE NOT NECESSARILY INDICATIVE OR REPRESENTATIVE OF THE QUALITIES OF THE LOT FROM WHICH THE SAMPLE WAS TAKEN OR OF APPARENTLY IDENTICAL OR SIMILAR PRODUCTS. NOTHING CONTAINED IN THIS REPORT SHALL MEAN THAT UNITED STATES TESTING COMPANY, INC. CONDUCTS ANY QUALITY CONTROL PROGRAM FOR THE CLIENT TO WHOM THIS TEST REPORT IS ISSUED UNLESS SPECIFICALLY SPECIFIED. OUR REPORTS AND LETTERS ARE FOR THE EXCLUSIVE USE OF THE CLIENT TO WHOM THEY ARE ADDRESSED AND THEY AND THE NAME OF THE UNITED STATES TESTING COMPANY, INC. OR ITS SEALS OR INSIGNIA ARE NOT TO BE USED UNDER ANY CIRCUMSTANCES IN ADVERTISING TO THE GENERAL PUBLIC AND MAY NOT BE USED IN ANY OTHER MANNER WITHOUT OUR PRIOR WRITTEN APPROVAL. SAMPLES NOT DESTROYED IN TESTING WILL BE RETAINED A MAXIMUM OF THIRTY DAYS.

United States Testing Company, Inc.

CLIENT: Bridgeport Chemical Corporation

78557
Number

May 28, 1980

TEST RESULTS:

Reagent	Visual Affects
1. Deionized Water	No Affect
2. 10% Sulfuric Acid	No Affect
3. 10% Phospheric Acid	No Affect
4. 10% Lactic Acid	No Affect
5. 10% Sodium Hydroxide	No Affect
6. 30% Sodium Hydroxide	No Affect
7. 5% Sodium Chloride	No Affect
8. Mineral Spirits	No Affect
9. Benzene	No Affect
10. Toluene	No Affect
11. Xylene	No Affect
12. Unleaded Gasoline	No Affect
13. Gasohol	No Affect
14. JP-4	No Affect
15. Sky-Drol	Slight surface dulling

2610 N.E. 5th Avenue
Pompano Beach, Florida 33064
(305) 781-3720

SAFETY DATA SHEET

The information and recommendations contained herein are based upon date believed to be correct. However, no guarantee or warranty of any kind expressed or implied is made with respect to the information contained herein.

SECTION I

TRADE NAME GA 27P HARDENER	PRODUCT TYPE Formulated amine hardener
CHEMICAL FAMILY Amines	

SECTION II. HAZARDOUS INGREDIENTS

INGREDIENT	%	TLV (UNITS)	INGREDIENTS	%	TLV (UNITS)
4,4' Diaminodiphenyl Methane	5%	0.1	(0.1 ppm) estimated		
Phenol	1½	5	(ppm) estimated		
Xylene	2	100	(ppm) estimated		

SECTION III. PHYSICAL DATA

BOILING POINT (°F)		SOLUBILITY IN WATER	
MELTING POINT (°F)		SPECIFIC GRAVITY (H2O=1)	
VAPOR PRESSURE (mmHg)		PERCENT VOLATILE BY VOLUME (%)	
VAPOR DENSITY (AIR=1)		EVAPORATION RATE (=1)	
APPEARANCE AND ODOR : White Thixatropi liquid			

SECTION IV. FIRE AND EXPLOSION HAZARD DATA

FLASH POINT (°F) (METHOD USED) 100 closed cup	FLAMMABLE LIMITS IN AIR	LEL	UEL
EXTINGUISHING MEDIA Carbon Dioxide, dry chemical, foam			

SPECIAL FIRE FIGHTING PROCEDURES :
Use self contained breathing apparatus

UNUSUAL FIRE AND EXPLOSION HAZARDS :
No unusual hazards-This product should be handled as a combustible material

SECTION V. REACTIVITY DATA

STABILITY	UNSTABLE		CONDITIONS TO AVOID
	STABLE	X	

INCOMPATIBILITY (materials to avoid) Strong oxidizing agents

HAZARDOUS DECOMPOSITION PRODUCTS Carbon monoxide, carbon dioxide, nitrogen oxides

HAZARDOUS POLYMERIZATION	MAY OCCUR		CONDITIONS TO AVOID : Masses of 1 lb. or more plus an epoxy resin causes irreversable polymerization with considerable heat build up.
	WILL NOT OCCUR	X	

SECTION VI. HEALTH HAZARDOUS DATA

ORAL:

DERMAL:

IRRITATION: SKIN (rabbit) Mild

EYE (rabbit) Moderate

SENSITIZATION: Moderate sensitize

THRESHOLD LIMIT VALUE: None established

RESPIRATORY: May cause sensitization

EFFECTS OF OVEREXPOSURE: Primary irritation & sensitizes, headache, vertigo nausea, vomiting, fever, temporary jaundice, liver toxin

EMERGENCY & FIRST AID PROCEDURES: Call a physician

INHALATION: Remove to fresh air, oxygen and artifical respiration, if necessary

INGESTION: If conscious, give water or milk, induce vomiting

SKIN: Remove contaminated clothing. Wash with soap and water.

EYES Flush with water for at least 15 minutes

OTHER

SECTION VII. SPILL OR LEAK PROCEDURES

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED

Remove all sources of ignition. Absorb on combustible material for proper disposal. Flush comtaminated areas with water.

WASTE DISPOSAL METHOD

Incineration in accordance with Federal, State and local regulation

SECTION VIII. SPECIAL PROTECTION INFORMATION

RESPIRATORY PROTECTION (SPECIFY TYPE) NIOSH approved respiratory protection equipment as required to prevent vapor over exposure

PROTECTIVE CLOTHING

Impervious gloves, elbow length to prevent skin contact

EYE PROTECTION

Splash proof goggles to protect eyes

VENTILATION

General mechanical ventilation and local exhaust

SECTION IX. SPECIAL PRECAUTIONS

PRECAUTIONS TO BE TAKEN IN HANDLING, STORING ETC.

DATE: _____ SIGNATURE: _____

2810 N.E. 5th AVENUE • POMPANO BEACH, FLORIDA 33064 • (305) 781-3700

SIX MONTH DATA GENERATED ON GA 27P IN VARIOUS TESTS FUELS

Tests Fuels:

a) Basic unleaded

b) 4.58V% Methanol + 4.58V% TBA gasoline

c) 3.3V% Methanol + 7.65V% TBA gasoline blend

d) Water/alc/hydrocarbon bottoms mixture 50V% V Methanol, 20V% Aromatics, 20V% TBA, 10% water

The sample coupons have been continuously immersed in separate containers of the individual test fuels at 75°F.

Percent weigh gain and barcol hardeners were determined after 6 months immersion.

These tests indicate that GA 27P is an acceptable coating for the lining of underground service station tanks containing gasoline oxygenate blends containing Methanol for the test fuels above.

COMPANY - BRIDGEPORT CHEMICAL

MATERIAL - GA-27P

SIX MONTH DATA

	Base Unleaded	Oxinol 50	Oxinol 30	H2O Btms
Coupon # 1				
Initial wt (g)	145.2010	139.2474	142.2200	144.5352
@ Six Months (g)	145.1851	139.6418	142.3185	145.1181
Weight Change (g)	-0.0159	+0.3944	+0.0985	+0.5829
% Change	0.01	0.28	0.07	0.40
Coupon #2				
Initial Wt (g)	141.7097	140.3515	142.7688	144.3092
@ Six Months (g)	141.7260	140.5731	142.8748	144.8791
Weight Change (g)	+0.0163	+0.2216	+0.1060	+0.5699
% Change	0.01	0.16	0.07	0.39
Coupon # 1				
Initial Thickness (in)	0.273	0.259	0.272	0.271
@ Six Months (in)	0.272	0.259	0.272	0.273
Thickness Change (in)	-.001	0.000	0.000	+.002
% Change	0.30	0.00	0.00	0.74
Coupon # 2				
Initial Thickness (in)	0.274	0.267	0.271	0.273
@ Six Months (in)	0.274	0.268	0.272	0.272
Thickness change (in)	0.000	+.001	+.001	-.001
% Change	0.00	0.30	0.30	0.30
Coupon # 1				
Initial Width (in)	2.084	2.116	2.033	2.047
@ Six Months (in)	2.084	2.110	2.035	2.049
Width Change (in)	0.000	-.006	+.002	+.002
% Change	0.00	0.28	0.10	0.10
Coupon # 2				
Initial Width (in)	2.084	2.036	2.030	2.026
@ Six Months (in)	2.084	2.038	2.030	2.028
Width Change (in)	0.000	-.002	0.000	+.002
% Change	0.00	0.00	0.00	0.00

COMPANY - BRIDGEPORT CHEMICAL

MATERIAL - GA-27P
SIX MONTH DATA

	Base Unleaded	Oxinol 50	Oxinol 30	H2O Btms
Coupon # 1				
Initial Length (in)	4.066	4.004	4.012	4.096
@ Six Months (in)	4.066	4.004	4.010	4.099
Length Change (in)	0.000	0.000	-.002	+.003
% Change	0.00	0.00	0.00	0.00
Coupon # 2				
Initial Length (in)	4.040	4.051	4.010	4.079
@ Six Months (in)	4.040	4.051	4.012	4.080
Length Change (in)	0.000	0.000	+.002	+.001
% Change	0.00	0.00	0.00	0.00
Coupon # 1 934				
Initial Barcol Hardness	41	41	39	39
@ Six Months	41	26	35	12
Hardness Change	0	-15	-4	-27
% Change	0.00	36.6	10.3	69.2
Coupon # 2 934				
Initial Barcol Hardness	41	40	38	40
@ Six Months	41	25	36	13
Hardness Change	0	-15	-2	-27
% Change	0.00	37.5	5.3	67.5
Coupon # 1 935 Barcol Hardness				
@ One Month	83	83	83	83
@ Six Months	83	80	83	74
Hardness Change	0	-3	0	-9
% Change	0.0	3.6	0.0	10.8
Coupon # 2 935 Barcol Hardness				
@ One Month	83	83	83	83
@ Six Months	83	81	83	74
Hardness Change	0	-2	0	-9
% Change	0.0	2.4	0.0	10.8

96. Voytek J.E.
"Considerations in the Design and Installation of Monitoring Wells", Ground Water Monitoring Review, Winter 1983, pp. 70-71

2648

CONSIDERATIONS IN THE DESIGN AND INSTALLATION OF MONITORING WELLS

An overview of this process, including a discussion of how monitoring wells operate and their design efficiencies.

by John E. Voytek, Jr.

Introduction

A monitoring well is not simply a hole in the ground with a pipe stuck in it. Rather, it is a series of events and ideas that result in a system that allows reliable water samples to be retrieved for the purpose of monitoring or investigating the chemical quality of ground water. Analysis of water samples will show any degradation of water quality that may occur over time, whether from coal mining activities or refuse landfilling. A monitoring well that fails to meet any of these tests is just a hole in the ground. If a comprehensive total monitoring "game plan" is not completely thought out beforehand, many more wells may be installed than are actually needed.

This paper provides insight into the importance of planning in the design and operation of a monitoring well. Space does not permit a detailed discussion of any one phase of well design; rather, this paper is an overview of the entire process, a discussion of how monitoring wells operate and how they are typically designed for maximum efficiency.

Why are ground-water monitoring systems installed? Besides the obvious governmental influences, the object of a monitoring well is to:

- Provide access to ground water
- Determine which pollutants are present and in what concentrations
- Determine the distribution of pollutants both areally and vertically.

A series of events should precede the actual well-drilling process. Some of the aspects that must be considered beforehand are:

- Well design
- Well installation methodology
- Well development
- What kind of samples will be taken
- How samples will be taken
- How samples will be analyzed
- How to plan a system for maximum benefit from each dollar spent.

This discussion will be limited to those individual wells which are completed in unconsolidated sand and gravel aquifers. Wells of this type generally fall into two categories:

1. Those that are naturally developed
2. Those that are sand-packed with a very specific pre-designed filter media adjacent to the well intake.

When a well is designed, four integral parts of the well must be planned so the well meets present and future needs efficiently and economically. For example, it is useless and wasteful to design an all stainless steel well when the data required from the well are pH and iron. If future needs are to monitor for chromium content, the stainless steel well may become a problem due to potential leaching of chromium out of the stainless steel. However, because of its resistance to corrosion, stainless steel may be considered under other specific conditions, such as monitoring for organic constituents.

The four parts of the well to consider in well design are:

1. Diameter,
2. Total depth,
3. The type of intake structure (i.e., screen or perforated casing) that will be used, and
4. The type of casing material that is needed.

In determining well diameter, the following parameters must be considered:

- Design for minimal water volume
- Installation method
- The types of sampling devices to be used.

Installing a larger casing than is necessary results in larger water storage volume within the well which may lead to:

- Difficulty in construction
- Higher construction costs
- Double drilling—one to gather detached soil information and one to install the well
- Longer pumping times before the sample can be taken
- Dilution effects.

From the beginning, the monitoring industry has been geared to the Tokyo phenomenon: "small is better." A number of individuals have come up with a variety of equipment and the know-how to get monitoring done efficiently with small diameter wells.

On the other hand, a 2-inch diameter well is almost useless if aquifer characteristics, such as transmissivity or storativity, are desired from the well. Well diameter must fit both present and future needs.

The second factor in well design

pth. Factors to consider
ermining well depth are:

- the well to be depth-discrete—
r will it have a depth range?
- Are specific layers with a soil horizon to be monitored?
- Are the contaminants miscible a less dense than water or are t more dense than water?

A well-designed monitoring well includes a good intake device. The well intake must have sufficient open area:

- To allow for water production and formation access
- To allow for good hydraulic conductivity with the aquifer
- To be developed properly to allow water to enter the well without also carrying sand into the well.

The latter may be a combination of intake device design, sand pack design and well development. Sand packs are specially-designed products for a particular aquifer; if designed properly and installed correctly, they will result in sand-free and silt-free water at maximum yields.

The type of casing that will be used in the well can be chosen by the following:

- The material (steel, stainless steel, PVC, Teflon, etc.)
- The type of field joints that will be used (threaded and coupled, n-joint threads, glued or welded)
- The drilling method
- The casing preparation.

In addition to the aforementioned factors, the best drilling method for the design must also be determined. The criteria to include are:

- The type of formation
- The depth of drilling
- The depth of the screen below the water
- The location of the site
- The well design
- Availability.

This planning should occur before installation begins. Development of the well is the final step in completing the well. There is no one method that is best-suited for all situations. Commonly, air surging and the use of a surge block are employed. The purpose of development is to move water in and out of the intake openings so that particles of finer aquifer material can be removed from the well. An intake with a high open area facilitates the development process by allowing more ifer contact.

The surge block is a tool that fits tightly into the casing of the well. When moved up and down it creates a small pressure and vacuum build-up in the well. Water is then forced out of the screen, carrying with it smaller sand- or silt-sized particles.

Air surging is simply a method of pumping the well with using compressed air. To be effective, air surging needs at least 30 percent submergence plus a well that yields a significant volume of water so that recovery times are minimal.

Development is extremely important. It creates a zone of high permeability around the well, stabilizes the formation and cleans the fine particles out of the well. A well that does not yield much water, cannot be effectively developed, even if the well has a large diameter.

Summary

It is clear from the preceding discussion that a properly designed and effective monitoring well is a complex structure which requires a great deal of planning. Some wells silt up over time, others leak or connect two different aquifers and many don't yield enough water to be useful in the sampling process. Many of these problems can be overcome by using good design techniques and quality equipment. Water well technology has been around for many years and has proven very successful in obtaining water from aquifers. Monitoring well technology is not new, but rather an extension and modification of knowledge that already exists. Each well is different and each site presents new challenges.

Biographical Sketch

John Voytek is the Johnson representative for the greater Ohio River Valley. He received his B.S. degree in geology from Bowling Green State University. After graduation, Voytek worked with the Ohio EPA as a district geologist helping to solve many groundwater related problems.

Voytek started with Johnson Division in 1978. He has been a guest speaker at the annual short course sponsored by the University of Alberta and the Alberta Research Council. He is a member of NWWA and the American Institute of Professional Geologists and is a certified Class I water treatment plant operator.

97. Warrick A., et al. "Areal Predictions of Water and Solute Flux in the Unsaturated Zone," Project Summary EPA, 1981

United States
Environmental Protection
Agency

Robert S. Kerr Environmental Research
Laboratory
Ada OK 74820

2645

Research and Development

EPA-600/S2-81-058 June 1981

Project Summary

Areal Predictions of Water and Solute Flux in the Unsaturated Zone

Arthur W. Warrick and Azizolah Amoozegar-Fard

This investigation was undertaken to develop procedures for evaluating distribution of water and salt fluxes over land areas. Relevant applications include numerical simulations and sampling in fields of large areal extent. The primary focus is on irrigated lands including effects of salinization and crops on the ground and surface waters. The study was in three parts: 1) observations of distributions for a variety of soil physical parameters and inference on sampling; 2) simulations of water and salt fluxes for nondeterministic systems; and 3) a sensitivity analysis for drainage. The major emphasis was placed on Part 2.

Simulations of water and salt fluxes were made using the "crude" Monte Carlo technique. For infiltration, "Philip's" equation was utilized in a scaled form by solving one time. Individual simulations were made algebraically without repeating the laborious steps of resolving the unsaturated moisture flow equation each time. Similarly, results for the nonlinear drainage case were solved based on only one finite difference determination. The Monte Carlo simulation was carried out by simple interpolation from the one nonlinear solution. Unfortunately, no great short-cut was found for cyclic or seasonal irrigation regimes, although some interesting results based on linearized solutions were found for high frequency water applications.

Salt distributions were calculated for cases of equal irrigation amounts over time but with intake rate varying over space. Deterministic calculations based on the mean velocity and apparent diffusion coefficient gave erroneous results compared to the "average" values over the field for both salt profiles or fluxes. The true "average" by depth for a given time is much more dispersed, with more salts reaching very deep depths and also with more salts remaining close to the surface when pulses of salt are added. Similarly, the mass emission of salts averaged over a field for a given depth appear earlier in time and taper off more gradually for a pulse input than deterministic calculations based on mean velocities would indicate.

This Project Summary was developed by EPA's Robert S. Kerr Environmental Research Laboratory, Ada, OK, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

This two-year study dealt with areal predictions of water and solute fluxes within the soil profile. The project was designed to develop methods to account quantitatively for the inherent variability of soils over a region — such as an irrigated field or larger. Two very important observations should be made in terms of trends of current research and awareness since the inception of this project: (1) there has been a tremendous

increase of interest in variability of soil properties; and (2) there has been an equally impressive increase of interest among hydrologists and soil scientists with regard to geostatistical techniques which were largely ignored until recently.

Soil scientists (and farmers) have always recognized that soils are heterogeneous. The approach to the problem has necessarily been almost universally deterministic in nature. The procedure has generally been to sample, average the samples, and use the results to make calculations. For example, if a mass flux of salts is needed, the land area is multiplied by the "average" profile results to get total emissions. That such an approach may not give the right answer is stated in elementary works on stochastic processes (e.g. Hammersly and Handscomb, 1964, p. 13) and is demonstrated in the case of mean water flux by Warrick et al. (1977b) and in results from this project. In some cases, a choice other than the arithmetic mean may be appropriate; in other cases, no "average" value may be satisfactory to obtain an overall response or integrated estimate. Efforts to adequately assess confidence of results have been generally lacking.

The techniques within this project are somewhat intermediate between the deterministic and the geostatistical methods. Ramifications of spatial variability are pursued in terms of water and salt fluxes, primarily by Monte Carlo simulations. It is hoped that sampling and confidence intervals can be obtained more efficiently in the future, by taking advantage of what is known of the spatial structure and by using geostatistical techniques (Journel and Huijbregts, 1978).

These problems of area distribution and predictions encompass all aspects of earth sciences. An immediate and obvious connection between soil physical properties and soil maps exists and suggests mutual benefits for close cooperation between classifiers and the soil physicists. Not only is this true for soil physical measurement, but also for other soil properties, e.g., fertility level, chemical activity and distributions of biomass and microbes.

Conclusions

Observed variations of soil parameters in the literature were reasonably consistent when more than one source was found. Generally these parameters can be grouped into three classes:

1. Low variability — (Coefficient of variation less than 20%)
   - Bulk density
   - Water content at a zero tension
2. Medium variability — (Coefficient of variation 20-75%)
   - Textures (sand, silt or clay)
   - Field water content
   - Water content at specified tension between 0.1-15 bars
3. High variability — (Coefficient of variation greater than 100%)
   - Saturated hydraulic conductivity
   - Unsaturated hydraulic conductivity
   - Apparent diffusion coefficient
   - Pore water velocity
   - Electrical conductivity of extract
   - Scaling coefficients.

Sample numbers may be estimated assuming independence and that the central limit theorem applies, by

$$N = t_\alpha^2 s^2/d^2$$

where N is the number of samples, t_α is the "Student's t" with n-1 degrees of freedom at a probability level of α, s is the standard deviation of the mean, and d is a specified limit. Table 1 shows an analysis of the number of samples required to estimate the mean values of selected soil properties within 10 percent at the 0.05 significance level.

Scaling techniques offer distinct advantages in terms of economy of calculation and in synthesizing large volumes of data. Figure 1 demonstrates the results of scaling the hydraulic head values for 840 data points. The scaling (based on the assumption that the internal geometry for similar media differs only by the characteristics size) process coalesces the data points into a curvilinear function as shown in Figure 1, A & B. In this particular data set the sum of squares of the scaled data was reduced by 80 percent over the same form of equation for the non-scaled data.

Solute movement is a function of soil water flux and apparent diffusion coefficient. Use of the deterministic value of these parameters can result in erroneous estimates of solute concentration and movement when the pore-water velocity and apparent diffusion are highly variable. Figures 2A and 2B show the solute concentrations with depth after five days using a deterministic approach compared to the mean values for step

Table 1. Summary of Approximate Number of Samples Required to Estimate Mean Values Within 10% at 0.05 Significant Level (After GUMAA, 1978)

Parameters	Field	Soil Depth, cm 30	60	90	120	150
Low Variation						
Bulk density	1	1	1	1	1	1
	2	1	1	1	1	1
	3	1	1	1	1	1
Medium Variation						
In situ field capacity	1	10	28	24	47	2
	2	12	23	61	49	75
	3	10	9	15	10	24
In situ available water capacity	1	21	43	35	55	45
	2	55	36	110	78	116
	3	47	31	33	30	45
15 bars	1	20	55	33	57	47
	2	25	78	68	57	125
	3	23	19	31	35	30
% clay	1	25	49	33	51	47
	2	28	91	104	36	110
	3	20	18	24	36	36
% silt	1	20	57	66	122	71
	2	16	61	88	83	104
	3	8	20	47	28	40
% sand	1	15	28	13	27	43
	2	19	16	21	23	47
	3	1	1	3	2	3
High Variation						
K_{sat}	1	110	150	362	635	155
	2	119	49	155	102	560

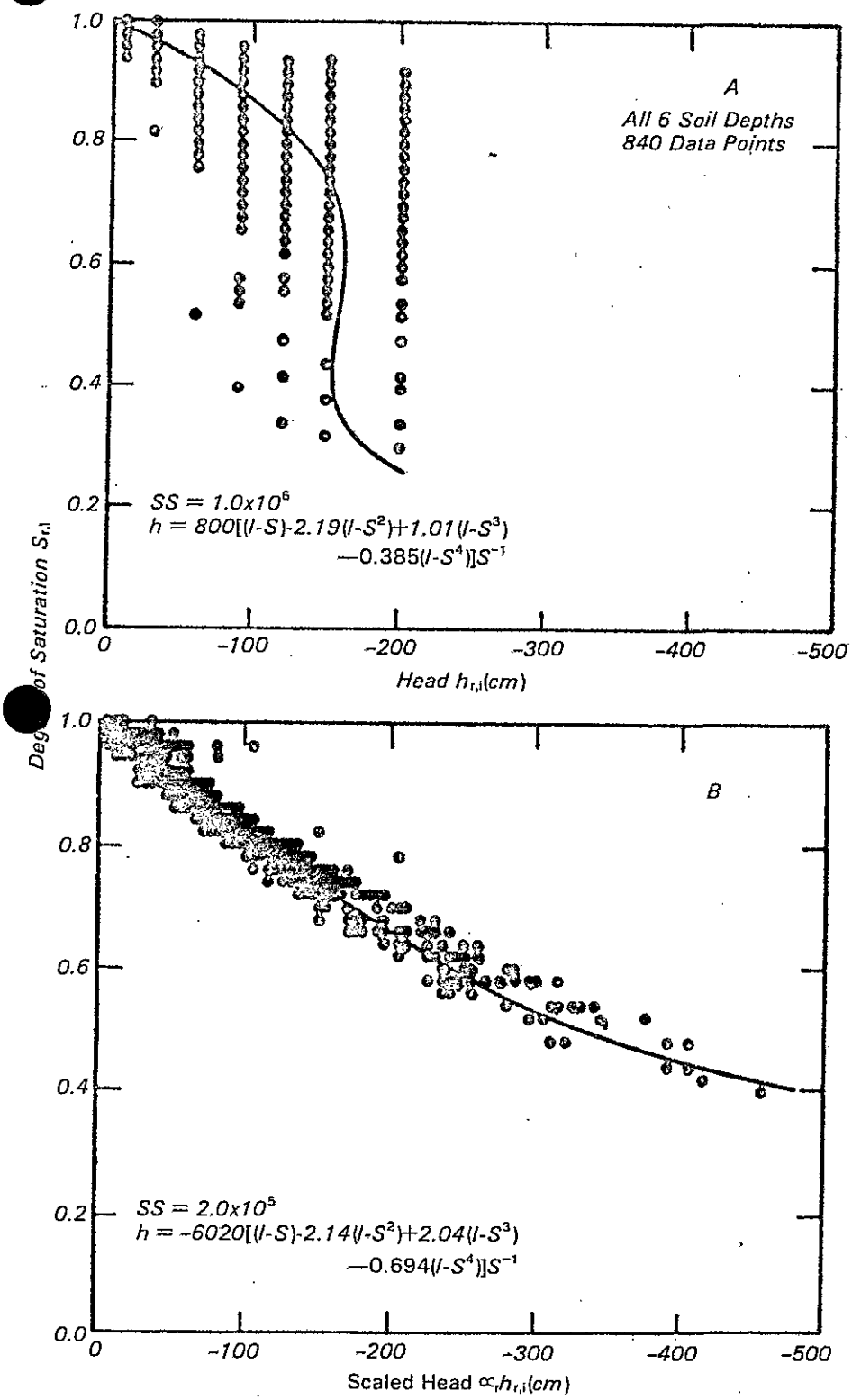


Figure 1. Soil water characteristics data for six depths of Panoche soil: (A) unscaled and (B) scaled.

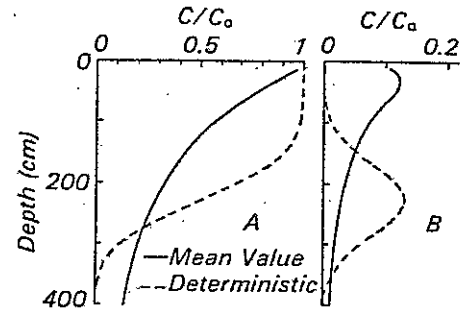


Figure 2. Salt concentration with depth for a "step input" (A) and a "pulse input" (B) after 5 days.

and pulse inputs. The true means were evaluated using the Monte Carlo simulations in which an average of 2000 salt profiles is calculated for each case. For both step and pulse inputs, the solute concentration at larger depth is greater for the mean values than the deterministic solution. The depth at which $c/c_o = 0.5$ is about 220 cm for the deterministic and 110 cm for the mean value for step input, a consequence of averaging in some of the high velocity sites. For the pulse input, the maximum concentration for the mean value is closer to the soil surface although it is less than the deterministic value. In fact, there is no single value of pore-water velocity that could give the shape of the true mean for this example.

Recommendations

The variability in data of soil parameters should always be included in addition to mean values when reporting environmental data. Information regarding the frequency distribution and/or the spatial distributions of the data should be included.

Sensitivity analysis should be conducted to evaluate the behavior of dependent variables in relation to changes in the independent variable. Relative sensitivity is more meaningful when the range of variability is masked by the numerical magnitude of the parameter.

Techniques such as geostatistics should be examined in soil science to provide basic descriptions of soil physical properties and for integrating over large land areas.

References

Gumaa, G.S. 1978. Spatial Variability of *In situ* Available Water. Ph.D. Dissertation, University of Arizona.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1981-757-012/7148

140 pages. (No. 78-24, 365, Xerox University Microfilms, Ann Arbor, MI 48106).

Hammersly, J.M. and D.C. Handscomb. 1964. Monte Carlo Methods. Metheum and Co., London.

Journel, A.G. and C.J. Huijbregts. 1978. Mining Geostatistics. Academic Press, New York. 600 pages.

Warrick, A.W., G.J. Mullen, and D.R. Nielsen. 1977b. Predictions of the Soil Water Flux Based Upon Field-Measured Soil-Water Properties. Soil Sci. Soc. Amer. J. 41:14-19.

Arthur W. Warrick and Azizolah Amoozegar-Fard are with the Department of Soils, Water, and Engineering, University of Arizona, Tucson, AZ.

***Arthur Hornsby** is the EPA Project Officer (see below).*

The complete report, entitled "Areal Predictions of Water and Solute Flux in the Unsaturated Zone," (Order No. PB 81-191 124; Cost: $9.50, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650

The EPA Project Officer can be contacted at:

Robert S. Kerr Environmental Research Laboratory
U.S. Environmental Protection Agency
P. O. Box 1198
Ada, OK 74820

United States
Environmental Protection
Agency

Center for Environmental Research
Information
Cincinnati OH 45268

Postage and
Fees Paid
Environmental
Protection
Agency
EPA 335

Official Business
Penalty for Private Use $300

98. Wilson, L.G. Monitoring in the Vadose Zone: A Review of Technical Elements and Methods, GE79TMP-55, General Electric Company, Tempo

7496 Eagle

TEMPO

MONITORING IN THE VADOSE ZONE: A REVIEW OF TECHNICAL ELEMENTS AND METHODS

GE79TMP-55

TEMPO

GENERAL ELECTRIC COMPANY - TEMPO
CENTER FOR ADVANCED STUDIES
SANTA BARBARA, CALIFORNIA
WASHINGTON, D.C.

MONITORING IN THE VADOSE ZONE:
A Review of Technical Elements and Methods

By

L.G. Wilson
General Electric Company—TEMPO
Center for Advanced Studies
Santa Barbara, California 93102

Contract No. V-0591-NALX

Project Officer

Leslie G. McMillion
Environmental Monitoring Systems Laboratory
Las Vegas, Nevada 89114

ENVIRONMENTAL MONITORING SYSTEMS LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
LAS VEGAS, NEVADA 89114

RECEIVED

JUN 1 9 1982

DIVISION OF
TECHNICAL SERVICES

DISCLAIMER

This report has been reviewed by the Environmental Monitoring Systems Laboratory, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

source-specific monitoring programs was proposed by Todd et al. (1976). This approach includes an evaluation of potential pollutants at each source location, considers the mobility of pollutants in the site-specific hydrologic regimen, and examines the potential impact of pollutants on current groundwater uses. Everett et al. (1976) presented a review of specific techniques and costs for establishing comprehensive monitoring networks. Similarly, Fenn et al. (1977) prepared a procedures manual to aid in designing monitoring systems at solid waste disposal facilities.

IMPORTANCE OF SOURCE MONITORING AND MONITORING IN THE VADOSE ZONE: WHEN SHOULD VADOSE ZONE MONITORING BE DISCOUNTED?

Figure 1 shows the hypothetical flow paths of a pollutant beneath a waste disposal site. It is well known that when groundwater underlying such a disposal site begins to manifest pollution by quality changes in pumped water, the aquifer may have already become badly contaminated. Monitoring the quality of wastes entering and within a disposal site (i.e., source monitoring), coupled with monitoring in the vadose zone, offers an "early warning" or groundwater pollution. Remedial measures may be implemented prior to the onset of severe pollution and the associated renovation costs will be eliminated or reduced. As an example, Wilson and Schmidt (1979) presented a case study entailing the monitoring of cascading water in an abandoned irrigation well near a field irrigated with sewage effluent. Groundwater from a nearby pumping well was also monitored. Analysis of cascading water samples showed that water of very poor quality was in transit through the vadose zone. Furthermore, the quality of cascading water was markedly poorer than that of pumped groundwater. The important feature of this case study is that if only pumped groundwater had been used to monitor return flow, it would have been erroneously concluded that no pollution was occurring.

In addition to providing an early warning of pollutant movement in groundwater, vadose zone monitoring may reduce the need for and costs of groundwater monitoring. In other words, if a vadose zone monitoring program fails to detect the movement of pollutants, the requirements for groundwater monitoring may be reduced or largely precluded. The savings in costs for constructing monitoring wells could be significant.

It is not our intention to proclaim vadose zone monitoring as a panacea for all hydrogeological conditions and for all waste disposal operations. The need for and extent of such monitoring should be tailored to site-specific conditions. For example, if the water table at a given site is relatively shallow, say within 10 feet of the land surface, vadose zone monitoring may be minimal. Similarly, if the vadose zone consists of fractured media, flow occurs primarily in channels and the ameliorating interactions of the vadose zone and water-borne pollutants may be minimal. Monitoring activities for these two cases could be restricted to source monitoring and groundwater monitoring. Installation of in-source monitoring facilities, including vadose zone units, may not be recommended for certain sources, such as landfills. The rationale was presented in the proposed guidelines for landfill disposal of solid waste (U.S. EPA, 1979b): "In no case should groundwater or leachate monitoring wells be installed through the bottom of the landfill proper since such installation could result in creation of a conduit for the direct passage

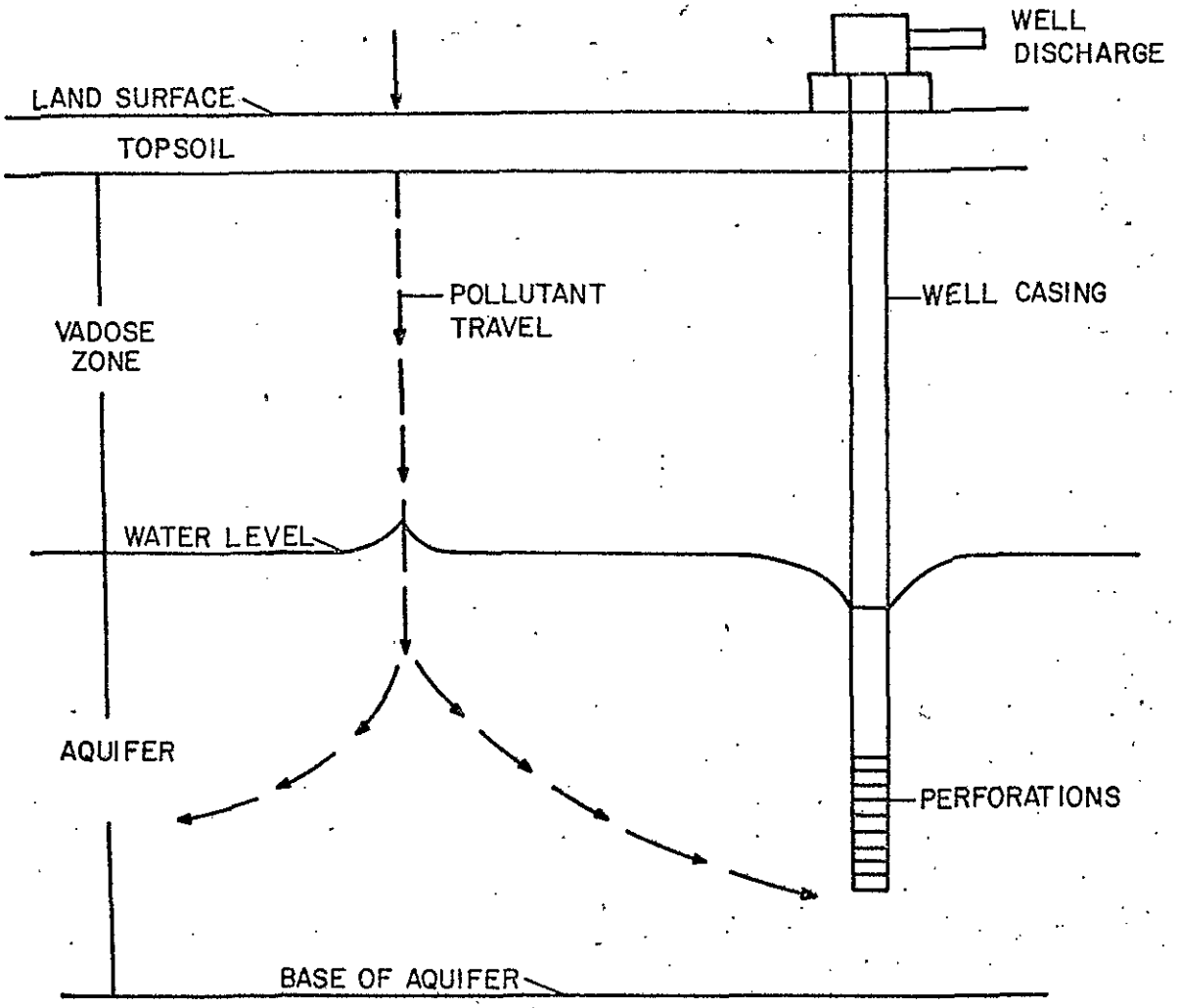


Figure 1. Schematic representation of the flow paths of a pollutant from a surface source (after Schmidt, 1977).

of landfill leachate into underlying groundwater." Thus, it would be necessary to either install monitoring facilities around the periphery of the landfills or use angle-drilling methods to install such facilities below the base of the lowermost cells.

OBJECTIVE OF MONITORING IN THE VADOSE ZONE

The basic objective of a monitoring program in the vadose zone is to characterize three properties: (1) storage properties, (2) flow rates, and (3) spatial and temporal changes in pollutants. Storage properties are important in that pollutants are placed in temporary storage within the void space of the vadose zone prior to movement into groundwater. In some cases, such as in western valleys, the storage space may be sufficient to preclude movement into productive aquifers. In fact, Winograd (1974) suggested using the vadose zone for the storage of low-grade radioactive wastes. Mann (1976) recommended using the storage space of the vadose zone in arid regions to augment the above-ground storage of tailings ponds. Wilson, Osborne, and

Percious (1968) showed that by locating a disposal pond for blowdown effluent near an ephemeral stream, periodic recharge events diluted the effluent stored in the vadose zone.

Information on the flux of water (flux refers to the quantity of water flowing through a unit area per unit time) may indicate the macroscopic velocity of water in the vadose zone. Thus, if a piston flow model is assumed, the arrival time of pollutants at the water table may be determined from estimates of flux and the thickness of the vadose zone. (As will be shown later, a more realistic estimate of particle velocity is the average linear velocity, which accounts for variations in the cross-sectional areas of the flow path and degree of saturation.)

Pollutants may not necessarily travel at the same rate as water because of attenuation in the vadose zone. Consequently, the travel time of water represents an upper limit on the mobility of pollutants. (A few pollutants may move at a higher rate than water because of physical and chemical properties. For example, based on differences in viscosity, the velocity of gasoline should be about 1.5 times that of water (Schwille, 1967).) In considering rate, it is important to quantify both the infiltration rate at the ground surface and the percolation rate through the vadose zone. "Recharge" refers to the movement of water and pollutants across the water table.

Information on the third element, changes in pollutants during transit within the vadose zone, is needed to quantify the mobility and spatial distribution of specific pollutants. The vadose zone may attenuate certain pollutants to the point that they could be excluded as pollution sources. For example, Runnells (1976) demonstrated that soil from Sulfur Spring, New Mexico, has an enormous capacity to remove copper from mill water. The additional observation that copper removal was irreversible indicated that thousands of years would be required before groundwater (located at about 100 feet*) at the site would be affected.

PURPOSE OF THE REPORT

Present day monitoring in the vadose zone entails using a mix of methods developed by soil scientists and hydrogeologists. As a consequence, vadose zone monitoring requires an interdisciplinary approach. Unfortunately, many of those charged with designing, implementing, and regulating monitoring operations lack the necessary multidisciplinary skills and, in fact, may not even be aware that an interdisciplinary approach is required.

The purpose of this report is to provide an introduction to the principles and techniques of vadose zone monitoring. In the next section, a review

---

*See Appendix A for conversion to metric units. English units are used in this report because of their currently common usage in industry and hydrology-related sciences. In cases where metric units are more appropriate (e.g., laboratory analyses), the English units are included parenthetically.

of general features of the vadose zone is presented to set the stage for subsequent chapters. The third section reviews preliminary approaches to a vadose zone monitoring program. Subsequent sections review the technical elements and state of the art in present monitoring techniques in each of the three categories: storage properties in the vadose zone, flow properties in the vadose zone, and pollutant mobility in the vadose zone. The technical review in each of these sections is intended to provide the reader with a basic introduction to the theories governing the selection of specific methods and to review associated laboratory procedures. The reader who is not interested in such background information should pass directly to the review of field methods.

To facilitate comparison of the alternative techniques available for specific functions, advantages and disadvantages have been presented whenever possible. Regarding costs, the present rate of inflation precludes quoting precise values for the techniques described in this report. Instead, the reader is referred to a report by Everett et al. (1976) which reviews procedures for estimating the costs for many of the techniques under a range of hydrogeological conditions.

SECTION 2

GENERAL FEATURES OF VADOSE ZONES

The geological profile extending from ground surface to the upper surface of the principal water-bearing formation is called the vadose zone. As pointed out by Bouwer (1978), the term "vadose zone" is preferable to the often-used term "unsaturated zone" because saturated regions are frequently present in some vadose zones. The term "zone of aeration" is also often used as a synonym for vadose zone.

Davis and deWiest (1966) subdivided the vadose zone into three regions, designated as the soil zone, the intermediate vadose zone, and the capillary fringe. The surface soil zone is generally recognized as that region which manifests the effects of weathering of native geological material, together with the processes of elluviation and illuviation of colloidal materials, to develop more or less well-developed profiles (Simonson, 1957). The movement of water in the soil zone occurs mainly in the unsaturated state, i.e., that state in which the soil water exists under pressures less than atmospheric. The principal transport mechanisms associated with unsaturated flow are infiltration, percolation, redistribution, and evaporation (Klute, 1969). In some soils, primarily those containing horizons of low permeability, saturated regions may develop during surface flooding, creating shallow perched water tables.

The physics of unsaturated soil-water movement has been intensively studied by soil physicists, agricultural engineers, and microclimatologists. In fact, a copious amount of literature is available on the subject in periodicals (Journal of the Soil Science Society of America, Soil Science) and books (Childs, 1969; Kirkham and Powers, 1972; Hillel, 1971). Similarly, a number of published references are available on the theory of flow in perched water tables (Luthin, 1957; van Schilfgaarde, 1970). Soil chemists and soil microbiologists have also attempted to quantify chemical-microbiological transformations during soil-water movement (Bohn, McNeal, and O'Connor, 1979; Rhoades and Bernstein, 1971; Dunlap and McNabb, 1973).

Weathered materials of the soil zone may gradually merge with underlying deposits, which are generally unweathered, comprising the intermediate vadose zone. In some regions, this zone may be practically nonexistent, the soil zone merging directly with bed rock. In alluvial deposits of western valleys, however, this zone may be hundreds of feet thick. Figure 2 shows a geologic cross section through a vadose zone in an alluvial basin in California. By the nature of the processes by which such alluvium is laid down, this zone is unlikely to be uniform throughout, but may contain micro- or macrolenses of

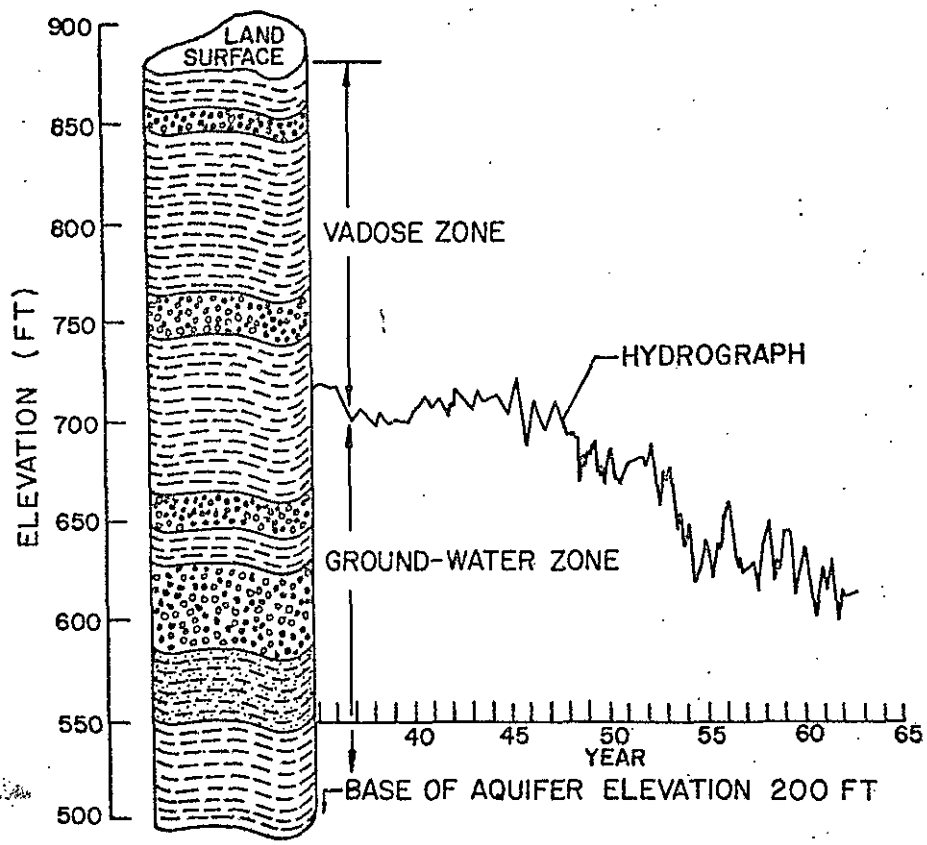


Figure 2. Cross section through the vadose zone and groundwater zone (after Ayers and Branson, 1973).

silts and clays interbedding with gravels and clays. Water in the intermediate vadose zone may exist primarily in the unsaturated state, and in those regions receiving little inflow from above, flow velocities may be negligible. However, perched groundwater may develop in the interfacial deposits of regions containing varying textures. Such perching layers may be hydraulically connected to ephemeral or perennial stream channels so that, respectively, temporary or permanent perched water tables may develop. Alternatively, saturated conditions may develop as a result of deep percolation of water from the soil zone during prolonged surface application of water. Studies by McWhorter and Brookman (1972) and Wilson (1971) have shown that perching layers that intercept downward-moving water may transmit the water laterally at substantial rates. Thus, these layers serve as underground spreading regions transmitting water laterally away from the overlying source area. Eventually, water leaks downward from these layers and may intercept a substantial area of the water table. Because of dilution and mixing below the water table, the effects of recharge may not be noticeable until a large volume of the aquifer has been affected.

In contrast to the large number of theoretical studies on water movement in the soil zone, parallel studies in the intermediate zone have been minimal. In fact, Meinzer (1942) coined the term "no-man's land of hydrology" to describe the limited knowledge of this zone. Reasoning from Darcy's equation,

Hall (1955) developed a number of equations to characterize mound (perched groundwater) development in the intermediate zone. Hall also discussed the hydraulic energy relationships during lateral flow in perched groundwater. More recently, Freeze (1969) attempted to describe the continuum of flow between the soil surface and underlying saturated water bodies.

The base of the vadose zone, the capillary fringe, merges with underlying saturated deposits of the principal water-bearing formation. This zone is not characterized as much by the nature of geological materials as by the presence of water under conditions of saturation or near-saturation. Studies by Luthin and Day (1955) and Kraijenhoff van deLeur (1962) have shown that both the hydraulic conductivity and flux may remain high for some vertical distance in the capillary fringe, depending on the nature of the materials. In general, the thickness of the capillary fringe is greater in fine materials than in coarse deposits. Apparently, few studies have been conducted on flow and chemical transformations in this zone. Taylor and Luthin (1969) reported on a computer model to characterize transient flow in this zone and compared results with data from a sand tank model. Freeze and Cherry (1979) indicated that oil reaching the water table following leakage from a surface source flows in a lateral direction within the capillary fringe in close proximity to the water table. Because oil and water are immiscible, oil does not penetrate below the water table, although some dissolution may occur.

The overall thickness of the vadose zone will not necessarily be constant. For example, as a result of recharge at a water table during a waste disposal operation, a mound may develop throughout the capillary fringe extending into the intermediate zone. Such mounds have been observed during recharge studies (e.g., Wilson, 1971) and efforts have been made to quantify their growth and dissipation (Hantush, 1967; Bouwer, 1978). Pumping in the groundwater zone also modifies the overall thickness of the zone of aeration, as apparent on Figure 2.

As already indicated, the state of knowledge of water movement and chemical-microbiological transformations is greater in the soil zone than elsewhere in the vadose zone. Fortunately, renovation of an applied wastewater occurs primarily in the soil zone. This observation is borne out by the results of the well-known studies of McMichael and McKee (1966), Parizek et al. (1967), and Sopper and Kardos (1973). These studies indicate that the soil is essentially a "living filter" effectively reducing certain microbiological, physical, and chemical constituents to safe levels after passage through a relatively short distance (e.g., Miller, 1973; Thomas, 1973). As a result of such favorable observations, a certain complacency may have developed with respect to the need to monitor only in the soil zone. However, in one reported instance at a disposal operation for cannery wastes, an apparent breakdown of the living filter occurred because of excessive soil loading with the sugars, sucrose, and fructose (Meyer, personal communication, 1979). There is growing concern, moreover, that certain toxic substances, such as chlorinated hydrocarbons, other refractory organics, and microorganisms, may escape the soil zone, eventually passing into underlying groundwater (Walker, 1973; Ongerth et al., 1973; Shuval and Gruener, 1973; Robertson, Toussaint, and Jorque, 1974). For example, when soils are thin and underlain in the intermediate zone by fractured rocks, short circuiting of these materials may

occur directly into groundwater. Thomas and Phillips (1979) have shown that for well-structured soils, rapid water movement occurs in macropores between soil peds. Consequently, entrained pollutants may not have the opportunity to interact with the bulk of the soil matrix.

Dunlap and McNabb (1973) also pointed out that microbial activity may be significant in the regions underlying the soil. They recommended that investigations be conducted to quantify the extent that such activity modifies the nature of pollutants travelling through the intermediate zone.

The foregoing discussion again emphasizes the need to monitor water movement and water quality throughout the vadose zone. For the soil zone, a large number of techniques were compiled into a two-volume series entitled "Methods of Soil Analyses" compiled by Black (1965). Monitoring in the intermediate zone and capillary fringe will require the extension of technology developed in both the soil zone and in the groundwater zone. Examples are already available where this approach has been used. For example, Apgar and Langmuir (1971) successfully used suction cups developed for in-situ sampling of the soil solution to sample at depths up to 50 feet below a sanitary landfill. Meyer, in a personal communication (1979), reported that suction cups were used to sample from depths greater than 100 feet below land surface at cannery and rock phosphate disposal sites in California.

In addition to the use of available techniques, new methods will undoubtedly be developed as additional insight is gained into the complexity of flow in the vadose zone.

SECTION 3

PRELIMINARY CHARACTERIZATION OF THE VADOSE ZONE

Prior to initiating a vadose zone monitoring program, an assessment should be made of existing monitoring efforts and relevant background information should be collected. Such a "nonsampling" approach will aid in the selection of methods to offset monitoring gaps and will generally increase the chances of designing an effective system. Assessing the existing monitoring includes determining sample collection methods for the source, defining the network of existing monitoring wells, including the locations and types of wells, and determining methods for sampling groundwater. Background information should be obtained on the following items: (1) nature of pollutants, (2) pollutant source loading, (3) existing groundwater usage and quality, and (4) a description of the hydrogeologic framework, including infiltration potential and hydraulic/geochemical properties of the vadose zone and groundwater zone.

The existing source monitoring program could be evaluated by comparing the ongoing sampling techniques with recommended approaches described in recent published guidelines, such as the report of Huibregtse and Moser (1976). Similarly, the groundwater monitoring program could be compared with approaches recommended by Mooij and Rovers (1976), and by Everett et al. (1976). Approaches for collecting background quality information on a source and existing groundwater usage and quality have been described in detail by Todd et al. (1976) and by Fenn et al. (1977). The quality data should be examined for completeness; for example, there may be gaps in existing analyses. Specific pollutants should be delineated and ranked.

As a first step in characterizing the hydrogeological framework with particular emphasis on the vadose zone, all relevant data should be collected. For example, comprehensive soil survey data may be available through state agricultural experiment stations, the Soil Conservation Service, or other agencies. Such surveys generally include information on depths of soil horizons, presence of hardpan, clay pan, color, porosity, structure, texture, organic matter content, soil pH, and infiltration rates.

For deeper horizons in the lower vadose zone, data may be available from drillers' well logs, Water Supply Papers of the U.S. Geological Survey, University theses, dissertations, and special reports. In general, well logs by drilling companies mainly describe conditions below the water table. However, they should be consulted for possible clues on stratification. In some areas, the U.S. Geological Survey collects drill cuttings from drilling sites. These samples are evaluated in the laboratory for particle-size distribution, color,

and source of origin. Some universities also collect samples as part of their hydrology or agricultural engineering programs. Again, the purpose of these sampling programs is to characterize the saturated zone, but valuable clues on the vadose zone may also be included (Matlock, Morin, and Posedly, 1976). Historic trends in groundwater levels should be determined by examining existing water level contour maps.

In addition to collecting available data, wells in the area of a monitoring site should be used to the fullest extent. For example, static water levels in a network of wells can be plotted to give the water table configuration and thus an approximate idea of the thickness of the vadose zone. Also, the presence of cascading water in wells will indicate the possible presence of perching layers. Finally, abandoned wells, or wells in which the pumps have been removed for servicing, may be used with borehole geophysical methods (described later) to provide further clues on the vadose zone.

After exhausting all existing sources for clues on the nature of the vadose zone at a site, a test drilling program may be considered necessary to provide more detailed information. The extent and thoroughness of the program will depend on the availability of funds. At any rate, care should be exercised in setting up the program to ensure the maximum value of the data. For example, a careful grid should be laid out for the project area. Also, the test wells should be established based on the possibility that they may eventually be used as observation wells, piezometers, or access wells during an actual monitoring program.

In general, samples from the soil zone are obtained to: (1) characterize the average soil texture, water content, or chemistry in increments (say 6-inch increments); (2) observe the precise depth-distribution of soil texture; or (3) determine the bulk density or water-release curves of soil increments. For the first purpose, samples obtained using post-hole augers, screw or sleeve-type augers, or power-driven augers are useful. For the second purpose, cores are obtained by driving small-diameter tubes into the soil to the desired depth. For the third purpose, larger-diameter core samplers are used. These may be hand-driven or forced into the soil by power-driven hydraulic soil coring equipment. With these methods, cores of a specific volume are obtained. More information on coring is presented by Blake (1965).

To sample throughout the vadose zone, it may be necessary to construct deep wells, using standard drilling techniques. Such techniques include jetting, rotary, cable-tool, augering, and air drilling. Of these methods, perhaps augering, using continuous flights, and air drilling provide the most usable samples. Problems develop in characterizing the distribution of indigenous salt and water content with cable-tool and rotary methods because of water additions during the drilling process.

One air drilling technique involves driving a double-wall drive tube by a pile hammer and, concurrently, forcing air under pressure down the annulus of the pipe. Air and entrained material cut by the bit return to the surface through the inside pipe. The sample, available continuously, is diverted into a cyclone sampler where it is bagged for laboratory analyses. According to the manufacturer, formation changes can be determined within a few

centimeters. Furthermore, water seams can be determined immediately. This feature is advantageous in locating the depth and thickness of perching layers. Whichever technique is used, samples should be taken in increments throughout the vadose zone.

Drill cuttings could be examined in the laboratory for particle-size distribution and other geologic parameters. Knowing the vertical distribution of grain size in the hole, the location of potential perching zones may be delineated. The collected samples could also be used to estimate storage and transmissive properties of the vadose zone.

Following construction of a test well or wells, geophysical logging should be initiated. First, the test hole(s) should be logged. The results of logging in the test well should be correlated with drill cutting analyses to delineate stratigraphy. Subsequent logs from other wells could thus be interpreted and the lateral and vertical extent of various layers (e.g., those favoring perching) defined.

Among the common borehole logging techniques are the spontaneous potential method, resistance logging, acoustic logging, and nuclear logging. The spontaneous potential method and resistance logging require an uncased water-filled well. Acoustic logging is conducted in a fluid-filled cavity and is not applicable to the vadose zone. Only nuclear logging methods are suitable for logging in either uncased or cased wells above the water table.

Common nuclear logging techniques include natural gamma logging, gamma-gamma logging, and neutron logging. The principles of and procedures in applying these techniques in groundwater investigations are discussed thoroughly by Keys and MacCary (1971). Briefly, natural gamma logging comprises the detection of natural gamma activity of rocks. Keys and MacCary (1971) list the following sequence of sedimentary rocks in ascending order of natural gamma activity: anhydrite, coal, salt, dolomite, sandstone, sandy shale, shale, organic marine shale, and potash beds. Natural gamma logs are particularly advantageous in characterizing the vertical extent of sediments and tracing them laterally from well to well (Keys and MacCary, 1971; Norris, 1972).

Gamma-gamma logs provide a record of the intensity of radiation from a source in a down-hole probe after it has backscattered and attenuated in the well and surrounding media (Keys and MacCary, 1971). The down-hole probe contains a source of gamma photons, such as cobalt-60 or cesium-137, and sodium iodide detector. The principal uses of gamma-gamma logs are to identify the lithology and to estimate bulk density and porosity of rocks (Keys and MacCary, 1971).

Neutron logging comprises lowering into a well a down-hole probe containing a source of high-energy neutrons and a detector of thermalized neutrons. Neutron loggers provide information on the hydrogen content, and consequently water content, of sediments within the vadose zone and the porosity of sediments below the water table. Neutron logs are useful in detecting the presence of perched groundwater. For example, Keys (1967) used a combination of gamma logs and neutron logs to delineate a clay perching bed at the National

Reactor Testing Station in Idaho. Neutron logging between wells may indicate the lateral extent of perched groundwater bodies.

SECTION 4

MONITORING STORAGE PROPERTIES OF THE VADOSE ZONE

TECHNICAL CONSIDERATIONS

Physical properties of the vadose zone associated with storage of water include the following: (1) total thickness, (2) porosity, (3) bulk density, (4) water content, (5) soil-water characteristics, (6) field capacity (specific retention), (7) specific yield, and (8) fillable porosity. Greater technical information on each of these items may be found in reference works by Childs (1969); Hillel (1971); Davis and deWiest (1966); Cooley, Harsh, and Lewis (1972); Freeze and Cherry (1979); Bouwer (1978); and Brakensiek, Osborn, and Rawls (1979).

The relationships of each of these properties to storage are reviewed in this section. Laboratory methods for quantifying the magnitudes of the first six properties are also presented.

Thickness

The storage capacity of a vadose zone is obviously related to the overall thickness, i.e., depth from ground surface to the water table. As shown on Figure 2 , the thickness is not constant but changes in response to pumping or recharge. The theoretical depth of water that could be stored in a vadose zone assuming 100-percent saturation is expressed by the following relationship:

$$d_w = \frac{\Delta P_w}{100} \frac{D_b}{D_w} d_{vz} \qquad (1)$$

where d_w = depth of water applied during surface flooding

D_b = bulk density of soil

D_w = density of water

d_{vz} = depth of vadose zone to be wetted

ΔP_w = difference in the percentage of water on a mass basis at saturation and after oven drying (105°C for 24 hours).

SECTION 6

MONITORING QUALITY CHANGES IN THE VADOSE ZONE

So far in our discussion on monitoring in the vadose zone, we have concentrated on the storage and movement of water, the vehicle for transmitting pollutants. In a quality monitoring program, the major emphasis will be to monitor the spatial and temporal variations of specific water-borne pollutants. In the ensuing discussion, such pollutants are categorized as follows: major inorganic chemical constituents, trace chemical constituents, organic chemical constituents, microbial constituents, and radionuclides. Physical constituents, such as temperature and suspended sediment, will not be considered.

Particular constituents within each of these categories which should be monitored in the vadose zone will obviously be site-specific, i.e., depend upon the waste disposal operation. For example, when monitoring agricultural return flows, specific pollutants may include the nitrogen series, particularly NO_3-N, phosphate, total dissolved salts (TDS), and pesticides. For land treatment sites, monitoring may emphasize bacteria, virus, heavy metals, NO_3-N, and phosphate, TDS, total organic carbon (TOC), biochemical oxygen demand (BOD), and chemical oxygen demand (COD). For sanitary landfills, a range of pollutants in all four categories should be monitored in leachate, with particular emphasis on heavy metals. Finally, for hazardous waste disposal operations, great emphasis should be placed on monitoring the fate of specific organic toxins during flow in the vadose zone.

In the following discussion, reactions affecting the movement of pollutants in the vadose zone are briefly discussed and current methods for vadose zone monitoring are reviewed.

TECHNICAL REVIEW

As with water movement, the present state of knowledge on pollutant movement in the vadose zone is derived from the efforts of specialists working in soils and deeper geological regions. For example, soil chemists and soil microbiologists have examined chemical and microbiological interactions, respectively, in soils. Similarly, geochemists have studied low-temperature chemical reactions in groundwater. Among the references which the interested reader may wish to consult for greater detail on soils/geochemistry relative to pollutant movement are the following: (1) Bohn, McNeal, and O'Connor (1979), a review of the modern concepts of soils chemistry; (2) Alexander (1961), a text on soil microbiology; (3) Hem (1970), a detailed review of water chemistry, including a discussion of chemical constituents in groundwater;

and (4) texts by Davis and deWiest (1966), Bouwer (1978), and Freeze and Cherry (1979) containing chapters on water quality.

Several review papers have also been published in recent years dealing with interactions between water, pollutants, and vadose zone materials. Such papers include those of Ellis (1973), Rhoades and Bernstein (1971), Murrmann and Koutz (1972), McNeal (1974), Pratt et al. (1978), and Chang and Page (1979). In his review paper, Runnells (1976) itemized 11 physical-chemical processes that may operate in the subsurface to purify liquid wastes. The specific processes are: dilution, buffering of pH, precipitation by reaction of wastes with indigenous water or solids, precipitation due to hydrolysis, removal due to oxidation and reduction, mechanical filtration volatilization and loss as a gas, biological assimilation or degradation, radioactive decay, membrane filtration and sorption. Runnells (1976) briefly discussed each of these factors, and the interested reader should consult his paper for details. Fuller (1977) also presented a review article dealing with the movement of selected heavy metals in soils. Among the factors which Fuller (1977) examined relative to the movement of these metals were: soil pH, oxidation-reduction (eH), surface area of soils, pore-size distribution, organic matter, concentration of ions or salts, and presence of hydrous oxides. Pratt et al. (1978) discussed the removal of biological and chemical contaminants by soil systems. The removal process included filtration, adsorption, decomposition, ion exchange, oxidation-reduction, chemical complex formation, chemical precipitation, and other chemical reactions.

In recent years, a number of soil column experiments have been conducted in the laboratory to identify the factors influencing the mobility of pollutants. The column studies of Fuller (1978) and his associates at the University of Arizona on the mobility of trace contaminants from landfill leachate are an example of such laboratory studies. Based on statistical analyses of these laboratory studies, Korte et al. (1976) found that the following factors were dominant in affecting the movement of trace contaminants in soils: soil texture and surface area, percentage of free oxides, and pH.

Field studies have also been conducted to determine the factors affecting the movement of pollutants in vadose zones. Apgar and Langmuir (1971) obtained water samples to a depth of about 55 feet from the vadose zone beneath a landfill in Pennsylvania. (The technique used to obtain these samples was suction cup lysimeters, described later in this report.) Based on their field observations, Apgar and Langmuir (1971) concluded that the following factors were important in attenuating pollutants: dilution and dispersion, oxidation, chemical precipitation, cation exchange, and anion exchange. During field studies to determine chemical changes in water during artificial recharge at a site in Texas, Wood and Signor (1975) examined the following mechanisms: cation exchange, anion exchange, mineral solution, adsorption, desorption, and sulfate reduction. They concluded that at their site, ion exchange and desorption were the major mechanisms affecting water quality in the vadose zone.

soils except possibly as an impurity in phosphorus compounds formed over a long period of time."

The complex chemistry of selenium is described by Fuller. The behavior of selenium is closely related to that of sulfur in acid formation and other properties. Based on experimental studies at the University of Arizona, Fuller concluded that other factors being equal, selenium is less mobile in acidic than in neutral or alkaline soils.

Regarding the mobility of zinc, Fuller (1977) indicated that Zn^{2+} forms slowly soluble precipitates with carbonate, sulfides, silicate, and phosphate ions. Sulfide values may increase in leachate if waterlogging occurs, promoting precipitation of zinc (and other cationic heavy metals). Zinc is also strongly sorbed on the exchange complex of soil.

Unlike other members of the halogen group, flouride compounds tend to be rather insoluble (Hem, 1970). The mobility of flouride in leachate may be limited by the formation of flourite (CaF_2) with a solubility product of $10^{-10.57}$ (Hem, 1970). High concentrations of calcium in leachate would tend to favor flourite formation in spite of common ion effects.

Reactions of strontium in water are similar to those of calcium. Strontianite, formed by the reaction of strontium and bicarbonate, is slightly less soluble than calcite (Hem, 1970). In addition, relatively insoluble strontium sulfate may be formed in sulfate rich waters (Davis and deWiest, 1966). Both reactions may occur, limiting the mobility of strontium.

Copper appears to be strongly complexed to organic matter (Fuller, 1977); consequently, copper-organic chelates may form in leachate which may be soluble and mobile. The formation of hydrous oxides of Mn and Fe provides the main control in the immobilization of copper. Hem (1970) reported that copper solubility is generally lower in reducing systems than in oxidizing systems, particularly if reduced sulfur species are present. Reducing or anaerobic conditions could exist if saturation develops. Reduction of sulfate, present in leachate, would then lead to precipitation of copper (as well as iron, zinc, cadmium, lead, and mercury (Fuller, 1977)).

Both nickel and cobalt are strongly adsorbed by iron and manganese oxides (Hem, 1970). The low solubility of $CaCO_3$ may be an important factor in limiting cobalt concentrations in solutions in which HCO_3^- concentrations are high. According to Hem (1970), there are no effective solubility controls over molybdenum concentrations in water. Consequently, the mobility of the anionic form, molybdate, will probably be high.

Jurinak and Santillan-Medrano (1974) examined the transport of lead and cadmium in soils. Processes considered to be important in governing cadmium and lead movement in soils included the following: precipitation and dissolution, ion-pair formation, pH flux, cation exchange, and adsorption. Jurinak and Santillan-Medrano (1974) concluded that the principal mechanism regulating Pb solubility in noncalcareous soils was precipitation of the forms: $Pb(OH)_2$ and $Pb_5(PO_4)_3OH$. In calcareous soils, $PbCO_3$ also precipitates. "Calcareous soils appear to be an excellent sink for Pb^{2+} ions."

Jurinak and Santillan-Medrano found that the solubility of cadmium in soils is about 100 times greater than lead in the pH range 5 to 9. "The data suggest that particularly at low concentrations, the adsorption of Cd by the soils is a more important mechanism in retention than in the case of Pb where precipitation of slightly soluble compounds regulates solubility."

Pratt et al. (1978) indicated that in solution, mercury exists in inorganic form as a monovalent or divalent ion and as complex ions or ion pairs. Regarding mobility of mercury, these authors stated, "The concentrations of Hg in soil solutions are governed by ionic adsorption by organic and inorganic materials and by the low solubilities of Hg as phosphate, carbonate, and sulfide."

Alesii (1976) studied the mobility of simple and complex forms of cyanide in soil columns. He observed, "Cyanide as $Fe(CN)_6^{3-}$ and CN^- in water were both found to be very mobile in soils. Soil properties, such as low pH, percentage free iron oxide and Kaolin, chloride, and gibbsite type clay (high positive charges) tended to increase the attenuation of cyanide. High pH, presence of free $CaCO_3$ (high negative charge), low clay content, and montmorillonite clay tended to increase the mobility of the cyanide forms." When an abundant energy source is available, microorganisms volatilize cyanide into less harmful forms of nitrogen. However, as noted by Fuller (1977), anaerobic conditions inhibit the microbial degradation of a cyanide. In a survey of municipal wastewaters in California, Pratt et al. (1978) found that the maximum cyanide level was 0.16 mg/l. They concluded that during recharge, cyanide levels would be reduced well below the recommended limit of 0.2 mg/l.

Organic Constituents--

A problem in specifying the mobility of specific organic pollutants is that quantitative studies have only recently been reported. One problem is that analytical procedures to identify organic constituents are still being developed. "Methods of sampling and analyzing for most organics are in their relative infancy compared to those used for other pollutants" (U.S. EPA, 1979a).

Two alternative methods which may have applicability in characterizing organic pollutants during flow in the vadose zone have been proposed by the U.S. EPA (1979a). One method is quantitative, employing GC/MS (gas chromatography/mass spectrometry). The other method provides for "screening" to detect the presence or absence of organic toxins by GC/MS, followed by extra GC or LC (liquid chromatography) quantification of identified pollutants.

Recently, Leenheer and Huffman (1976) described the development of the dissolved organic carbon (DOC) technique for fractionating organics into hydrophobic and hydrophilic components using macroreticular resins. The technique was applied to several natural waters. This technique has advantages over other methods for concentrating organics, such as activated carbon. For example, Robertson, Toussaint, and Jorque (1974) reported that only 10 percent of organics present in groundwater beneath a landfill in Oklahoma were identified using carbon adsorption followed by carbon chloroform and carbon alcohol extraction.

The principal mechanisms for attenuating organic pollutants are adsorption and decomposition (Pratt et al., 1978). As an example of the importance of adsorption, Robertson, Toussaint, and Jorque (1974) observed that polychlorinated biphenyls (PCBs) tend to be strongly adsorbed in soils. Leenheer and Huffman (1976) indicated that both hydrophobic and hydrophilic organics may be sorbed by sediment. Chang and Page (1979) discussed adsorption of organic substances on soils in some detail:

> The adsorption of dissolved organic substances usually is complicated by the chemical characteristics (i.e., molecular weight, structure and the presence of various functional groups) of each organic compound.... Since many organic substances tend to form negatively charged colloids in aqueous solution, the most likely sites for adsorption to take place would be the positively charged edges of clay minerals. These organic substances also form organometallic complexes which may be adsorbed as neutral or positively charged molecules.

Biodegradable organics are decomposed by microorganisms rendering potentially harmful constituents into gases. Davis (1956) reported that microbiologists have observed the utilization of hydrocarbons by certain bacteria, actinomycetes, filamentous fungi, and yeasts. In general, however, hydrocarbons are not as readily decomposed as carbohydrates, proteins, or fats. Furthermore, the cyclic hydrocarbons are less susceptible to microbial decomposition than are the aliphatic hydrocarbons. Chlorination of wastewaters prior to recharge may destroy both pathogenic organisms and microorganisms responsible for decomposition (Pratt et al., 1978).

The pH may also be a factor in the mobility of organics. For example, Leenheer and Huffman (1976) noted the formation of an organic precipitate upon acidification of a groundwater sample from an oil shale area near Rock Springs, Wyoming. Raising the pH dissolved the precipitate. The pH of leachate during aerobic decomposition within a sanitary landfill may be low enough to cause the flocculation of certain organics. In the underlying media, flocs would then be filtered out. However, in alkaline soils, the pH would eventually elevate to a point in the flow system at which organic flocs would dissolve.

In studies on leaching of spent oil shale, Schmidt-Collerus (1974) noted that the solubilization of polycondensed organic matter was enhanced by the presence of seepage water high in TDS. Possibly, the flux of organics in wastewater would be accelerated in a similar fashion if the initial TDS were high.

Microorganisms--

According to Gilbert et al. (1976), bacteria are removed at the soil surface by filtration, sedimentation, and adsorption. Virus removal occurs mainly by adsorption, which increases with decreasing pH. Other factors listed by Gilbert et al. as important in attenuating bacteria and virus are: salt concentration, pH, organic matter, soil composition, infiltration rates, and climatic conditions. Survival and movement of microorganisms within a

soil relate to soil moisture content, temperature, pH, nutrient availability, and antagonisms. The presence of excessive salt levels in wastewater, coupled with the presence of high levels of toxic substances (e.g., trace contaminants, pesticides), may limit the migration of bacteria and virus to a small segment of the vadose zone beneath a landfill.

Specific factors affecting the movement of virus in soils are summarized in Table 4. Chang and Page (1979) cautioned that immobilization of viruses by soil should not be equated with virus inactivation. "Many adsorbed virus particles have been demonstrated to be infectious for significant periods of time. Viruses immobilized by soil adsorption may also become desorbed when the chemical composition of the percolating wastewater is changed."

Pesticides--

Factors influencing the fate and behavior of pesticides in soil systems include: (1) chemical decomposition, (2) photochemical decomposition, (3) microbial decomposition, (4) volatilization, (5) plant or organism uptake, and (6) adsorption-desorption (Bailey and White, 1970). The last item, adsorption-desorption, directly or indirectly influences the magnitude of the other five factors and is considered to be the prime factor governing the interactions between pesticides and soil colloids. Leonard, Bailey, and Swank (1976) classified organic pesticides as ionic or nonionic. In turn, ionic pesticides are subclassified as cationic (paraquat, disquat), basic (s-triazones), and acidic (benzoic acids, phenols, picolinic acid). Nonionic pesticides include chlorinated hydrocarbons and organophosphates. Cationic pesticides are retained tenaciously on the exchange complex. Changes in soil pH have a profound but complex effect on pesticide forms. For example, a decrease in pH increases the molecular form of an acidic pesticide but increases the conjugate acid form of the base (Leonard, Bailey, and Swank, 1976). These changes will modify adsorption-desorption characteristics and the mobility of pesticides. Leonard, Bailey, and Swank also reviewed the effect of clay on sorption-desorption properties and pointed out that organic matter greatly increases the sorptive tendency of soils.

Temperature effects adsorption-desorption of pesticides. For example, an increase in temperature decreases adsorption and promotes desorption (Leonard, Bailey, and Swank, 1976). Temperature also affects sorption through effects on solubility and vapor pressure.

Regarding soil moisture effects, Leonard, Bailey, and Swank indicated, "A decrease in soil moisture (a) causes an increase in concentration per unit volume, ... and may increase surface acidity, and, thus increases adsorption; and (b) causes a decrease in competition with water for adsorption sites, which should increase adsorption." Furthermore, when the pesticide concentrates to the solubility product, crystallization will result.

Pesticide degradation will occur in soils. Photodecomposition will reduce pesticide levels near the soil surface but may be inconsequential with depth. Chemical degradation is a complex phenomena, related to pH, redox potential, and surface acidity.

Solids Sampling in the Vadose Zone

An important aspect of a monitoring program for the vadose zone underlying a waste disposal operation is to obtain samples of the solid materials throughout this region. Solids are defined as soils and underlying geologic materials. The rationale for solids sampling in the vadose zone was stated by Dunlap et al. (1977):

> Only by analysis of earth solids from the unsaturated zone underlying pollutant-releasing activities can those pollutants which are moving very slowly toward the water table because of sorption and/or physical impediment be detected and their rates of movement and degradation measured. Such pollutants, which probably include a major proportion of organics and microorganisms, are not likely to be detected in groundwater until the activities releasing them have been in operation for protracted periods. Because of their potential for long-term pollution of groundwater, it is imperative that the behavior of these pollutants in the subsurface be established at the earliest practicable time.

Dunlap et al. (1977) also listed reasons for sampling from the groundwater zone ("zone of saturation"). These reasons apply equally well for sampling from perched groundwater:

> Analyses of organic pollutants in solid samples from the zone of saturation are needed for a realistic evaluation of the total extent and probable longevity of organic pollution in an aquifer. Such analyses provide a measure of the quantity of pollutants which are sorbed on aquifer solids and which are in equilibrium with, and in essence serve as a reservoir for, pollutants in solution in the adjacent groundwater.
>
> Microbial populations which may be involved in the biological alteration of pollutants in subsurface formations are likely to be in such close association with subsurface solids that they will not be present in well waters in numbers which are quantitatively indicative of their presence in the formations; hence, analyses of subsurface solids are needed for accurate evaluation of such populations.
>
> Even when the best well construction and groundwater sampling procedures are used, it is difficult to completely eliminate the possibility that contaminating surface microbes may be present in groundwater samples. Solids taken from the interior of cores carefully obtained from the zone of saturation probably provide the most authentic samples of aquifer microorganisms that can be obtained.

In this section, the following items are discussed: (1) soils sampling methods for inorganic chemicals, organic constituents, and microorganisms; (2) sampling of solids in the lower vadose zone; (3) field analyses; (4) field and

laboratory handling of samples; and (5) advantages and disadvantages of solids sampling methods.

Soils Sampling--

Soil sampling methods used by soil scientists and irrigation and drainage engineers to evaluate the physical properties of soils are also suitable for sampling to determine inorganic chemical constituents. Particular methods which have been used include the following types of hand augers: screw-type augers, post-hole augers, barrel augers, and dutch augers (Donnan, 1957). Another common type of sampler is the split-spoon sampler, which is a barrel-type auger, one side of which pivots on a hinge. Tube-type samplers have been used extensively to obtain soil cores. The Veihmeyer sampler is an example of such a unit. The end of the sampler is bevelled and sharpened to facilitate insertion into the soil. A drive hammer is used to force the tube to the desired depth. An intact core is removed from the tube. Such a core may show the distinct breaks in soil layering.

A problem associated with using augers and tube-type samplers is that if the soil is very dry, the sample tends to fall out of the unit when it is being withdrawn. "Core catchers" could be used to overcome this problem (Thomas, personal communication, 1979). Another problem is that if the soil is wet, some chemical interactions may occur between the soil water and the metal parts of the sampler. Thus, trace metals could be introduced into the sample.

The problem of contamination between a soil sample and sampling device is of particular importance when sampling for organic chemicals and microorganisms. Bordner, Winter, and Scarpino (1978) recommended the following procedure for obtaining soil samples for microbial analysis:

> ... scrape the top one inch of soil from a square foot area using a sterile scoop or spoon. If a subsurface sample is desired, use a sterile scoop or spatula to remove the top surface of one inch or more from a one-foot square area. Use a second scoop or spoon to take the sample. Place samplings in a sterile one quart screw-cap bottle until it is full. Depending on the amount of moisture, a one-quart bottle holds 300-800 grams of soil. Label and tag the bottle carefully and store at 4°C until analyzed.

Techniques for sampling organic and microbial constituents have been examined by The Groundwater Research Branch of the Robert S. Kerr Environmental Research Laboratory, as reported by Dunlap et al. (1977). One method used with success comprises an auger and dry-tube coring procedure. The method entails augering a hole to the top of the desired sampling depth and forcing a "dry-tube" core sampler into the sampling region. The core sampler used by Dunlap et al. (1977) was a steel tube about 18 inches long and 3 inches in diameter. The core barrel is fitted with a steel drive shoe which is of slightly smaller inside diameter than the diameter of the barrel. This arrangement facilitates removing the core. As pointed out by Dunlap et al. (1977), contamination problems are minimized by the auger/dry-tube coring

99. Wilson, L.G. "Monitoring in the Vadose Zone Part I: Storage Changes," Ground Water Monitoring Review, Fall 1981, pp. 32-41

MONITORING IN THE VADOSE ZONE PART I: STORAGE CHANGES

The author begins a three-part series with a description of the vadose zone and an outline of why and how to monitor it. The first article discusses the neutron moisture logging method of determining storage and storage changes, and offers a catalog of alternative methods.

By L. G. Wilson

Introduction

The geological profile extending from the ground surface to the upper surface of a principal water-bearing formation is called the vadose zone. As pointed out by Bouwer (1978), the term "vadose zone" is preferable to the often-used term "unsaturated zone" because saturated regions are frequently present in some vadose zones. The term "zone of aeration" is also often used as a synonym for vadose zone. In some regions the vadose zone may be only a few feet in thickness. Elsewhere, the vadose zone may be tens or hundreds of feet thick. Changes in the thickness of the vadose zone at a given site reflect the response of a water table to either recharge or discharge. Figure 1 is a cross-section through the vadose zone of an alluvial basin in the west.

Monitoring within the vadose zone underlying a surface pollution source affords an "early warning" of potential ground-water pollution. If remedial measures are implemented prior to the onset of pollution, the associated renovation costs will be eliminated or reduced. Concomitantly, vadose zone monitoring may reduce the need for extensive ground-water monitoring. In other words, if a vadose zone monitoring program fails to detect the movement of pollutants, the requirements for ground-water monitoring may be reduced or largely precluded. The savings in costs for constructing ground-water monitoring wells could be significant, particularly in western regions where water tables are often hundreds of feet deep.

Vadose zone monitoring is appropriate for a number of potential pollution sources including sanitary landfills, land treatment facilities, spoil piles, septic tank areas, pits, ponds, lagoons, dry channels used for effluent disposal, and irrigated fields. The "Hazardous Waste and Consolidated Permit Regulations" issued by the Environmental Protection Agency (1980) require that areas used for land treatment of hazardous wastes shall install a vadose zone monitoring system, in addition to ground-water monitoring wells. However, vadose zone monitoring was not recommended for hazardous waste landfills and surface impoundments due to the problem of installing sampling units, such as suction cup samplers, beneath existing facilities. Because of the importance of obtaining an early warning of pollutant travel from impoundments and landfills, however, alternative possibilities should be considered. For example, sampling units could be installed during construction of new facilities. Similarly, sampling and nonsampling units could be installed on the perimeter of existing disposal facilities without disturbing the waste deposits. Sampling units are defined as those providing liquid or solid samples for analysis. Nonsampling units provide inferential evidence of liquid/pollutant movement.

Basically, a monitoring program for the vadose zone comprises a premonitoring phase followed by an active monitoring phase. Implementation of both phases will draw upon an array of sampling and nonsampling techniques for characterizing three properties: (1) storage (and storage changes), (2) fluid transmission and (3) pollutant mobility. Information on storage properties is important in that liquid wastes are placed in temporary storage within the void space of the vadose zone prior to movement into ground water. In some cases, such as in western valleys, the storage space may actually be sufficient to preclude movement into productive aquifers. In fact, Winograd (1974) suggested using the vadose zone for the storage of low-grade radioactive wastes. Mann (1976) recommended using the storage space of the vadose zone in arid regions to augment the above-ground storage capacity of tailings ponds. In addition to an interest in storage, *per se*, information on storage changes is of prime importance in a monitoring program. For instance, a change in the liquid content of the vadose zone at a given depth beneath a disposal facility suggests that liquid-borne wastes have reached that depth.

The transmission of liquid wastes in the vadose zone is expressed in terms of flux and rate of flow. "Flux" (actually, the term "darcian flux" is more accurate—see Freeze and Cherry, 1979) represents the quantity of liquid crossing a unit cross-sectional area per unit time. Information on the flux of liquid wastes can be used to estimate the amount of liquid-borne pollutants entering a ground-water system. Similarly, estimating the velocity (or "average linear velocity"—see Freeze and Cherry, 1979) of liquid wastes in the vadose zone is useful for establishing a lower limit on the arrival time of pollutants at the water table. This provides a conservative estimate of when pollution might begin. The actual travel time of specific pollutants may be longer because of attenuation. Unfortunately, very few field measurements have been obtained on either the flux or velocity of liquid wastes in representative vadose zones. Evans, Sammis and Warrick (1976),

ported deep percolation rates for irrigated field in the Salt River lley, Arizona. Estimates of the rclan flux ranged from 9 to 38 /yr (4 to 15 in/yr). Corresponding timates of the average linear y ranged from 57 to 130 cm/yr to 51 in/yr).

Specific pollutants may not cessarily travel at the same rate the fluid in which they are trained. Actually, the vadose zone ay attenuate certain pollutants to e point that they could be excluded pollution sources. Runnells 976) demonstrated that soil from lfur Spring, New Mexico, has an ormous capacity to remove copper m copper mill wastewater. The ditional observation that copper moval was irreversible indicated at thousands of years would be quired before ground water pproximately 100 feet deep) at the te would be affected. Thus the purse of a sampling program in the dose zone is to determine the obility of particular pollutants, as oderated by attenuation meanisms.

The present array of tools for onitoring in the vadose zone consts of existing techniques from lated disciplines such as groundr hydrology, soil science and geics. For example, approaches veloped by soil specialists for charterizing the storage and flow of il water and solutes in the root ne of crops have been extended to deeper reaches of the vadose one. Similarly, techniques nployed by hydrogeologists for onitoring ground water are used r monitoring perched groundater regions of the vadose zone. nless an interdisciplinary pproach is undertaken, the task of esigning a vadose zone monitoring rogram for a pollution source may e assigned to a specialist in a parcular discipline. Such an indiidual may be unfamiliar with the road array of alternative methods.

The purpose of the three articles this series is to provide a primer n techniques for vadose zone monoring. This article deals with methds for determining storage and storge changes; the second will discuss ethods for characterizing the ansmission of liquid wastes; and e third will cover techniques for acterizing pollutant mobility. In article an elementary technical eview will be presented, followed by detailed examination of a popular ethod. Finally, a catalog of comon, alternative methods will be cluded. This catalog summarizes the principles of operation, together with major advantages and disadvantages of each method. Appropriate literature citations are included for those readers seeking additional information on each method. The third article will demonstrate how the individual methods could be grouped in a premonitoring/monitoring program.

Unless specified, the carrier fluid associated with waste transmission is assumed to be water.

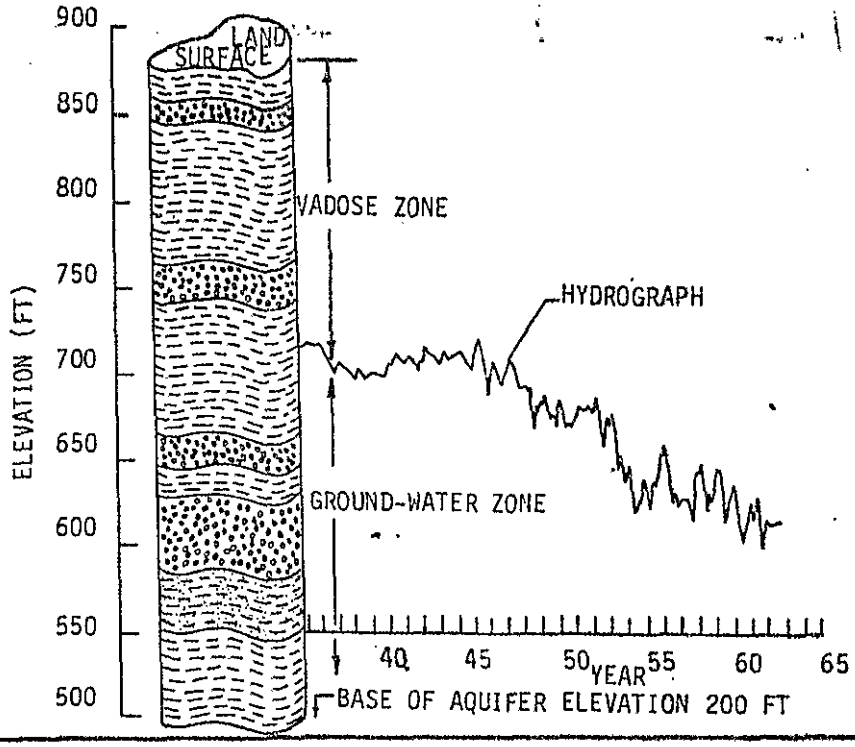


Figure 1. Cross-section through a vadose zone in an alluvial valley of the western U.S. Note that the thickness of the vadose zone changes in response to pumping or recharge (after Ayers and Branson, 1973.)

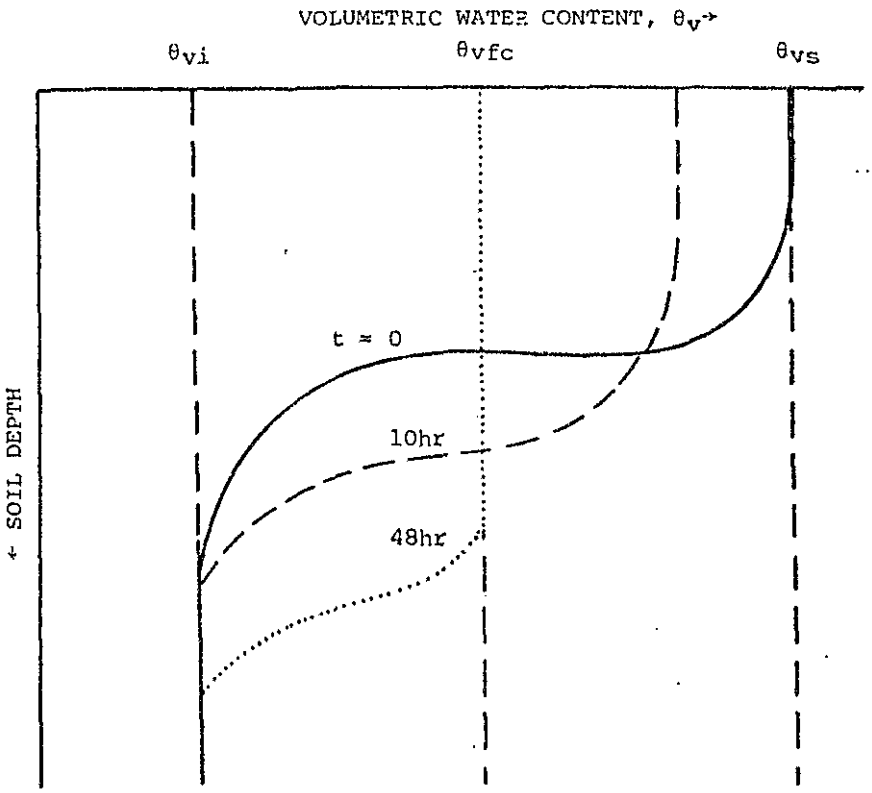


Figure 2. Idealized water content profiles in a soil for three different times. The curve for t = 0 represents the profile at the instant surface application of water is stopped. Redistribution of infiltrated water occurs as shown until the profile approaches field capacity (t = 48 hr) (from Hanks and Ashcroft, 1980).

Storage Changes

The total storage capacity of the vadose zone at a given site is a function of the total thickness of the zone and the porosity of the associated media. As shown on Figure 1, the thickness of the vadose zone, and consequently the overall storage capacity, can change in response to recharge or discharge conditions. In addition, the available storage capacity cannot be equated to an overall or representative porosity value because residual water generally occupies some of the storage space. Residual water may constitute water present in the pore space during deposition of vadose zone materials; water remaining following recession of the water table; or water arriving by deep percolation from the land surface. The effect of the presence of residual water is to diminish the total available storage capacity of the vadose zone for liquid wastes.

Infiltration of ponded water at the land surface increases the volume of water stored in the uppermost horizons of the vadose zone. A "snapshot" of a water content vs. depth profile in a homogeneous medium during infiltration, such as depicted on Figure 2, shows that water content values approach saturation for some distance in the profile but diminish rapidly to initial values near the wetting front. If infiltration is eliminated or greatly reduced (such as by clogging of surface pores) water becomes "redistributed" throughout the profile as water continues to move downward by gravity (see Figure 2). The amount of fluid stored above the gradually deepening wetting front approaches values that are greater than the residual value, and less than or equal to those corresponding to "field capacity."

By appropriate equipment (e.g., neutron moisture logger), the magnitude of the volumetric change in storage, $\Delta\theta$, can be determined. The same equipment can be used to estimate the depth, D, of the wetting front. Knowing these values, the depth, d, of fluid crossing the surface can be calculated by the following equation:

$$d = \frac{\Delta\theta}{100} D$$

For example, if the depth of penetration of a liquid waste is 100 feet, and the measured change in water content is five percent by volume, the depth of applied fluid would be 5 feet.

Other physical properties relating to the storage of liquid wastes in the vadose zone are: (1) the relationship between water pressure and water content, (2) field capacity and (3) fillable porosity. In an unsaturated medium, water is held by various forces within the pore space (or fractures) at water pressures less than atmospheric. Hanks and Ashcroft (1980) reviewed such forces and related potentials in detail. The potential related to the adsorptive forces in a soil matrix is called the "matric" potential (Hanks and Ashcroft, 1980). The relationship between water content and matric potential for a given material is depicted by a "water characteristic curve." Such curves are prepared in the laboratory from analyses of core samples or disturbed solids samples using a pressure plate apparatus (see Richards, 1965) and in the field using a neutron moisture logger (see Bouwer, 1978). Figure 3 includes water characteristic curves for various soils. Water characteristic curves show that as the material becomes unsaturated—for example through drainage—water content values steadily decrease and corresponding pressure values increase negatively. As seen on Figure 3, materials of different texture have different curves. For example, the curve for a clay is displaced to the right of that for a sand because water is held more tightly in finer textured material. Also, different curves will be obtained for the same material depending on whether it is being wetted or drained.

Field capacity (specific retention) may be defined in a general sense as the volume of water which a unit volume of soil will retain against the force of gravity during drainage. The concept of field capacity was developed many years ago by agriculturists concerned with quantifying the amount of water to apply to irrigated fields. The original premise was that field capacity is a fixed value representing the amount of water stored in a soil a certain time after drainage has "essentially ceased." By the same token, it is usually assumed that during recharge (wetting), water movement will not occur until the medium has been wetted to field capacity. Although these concepts of field capacity are useful in an applied sense, one should be aware of certain technical limitations (Hillel, 1971).

One limitation is that the simplistic concept of field capacity fails to account for the dynamic nature of soil-water movement. In particular, drainage does not really cease at field capacity but may continue at a slower rate for a prolonged period of time (Hillel, 1971). The modern view

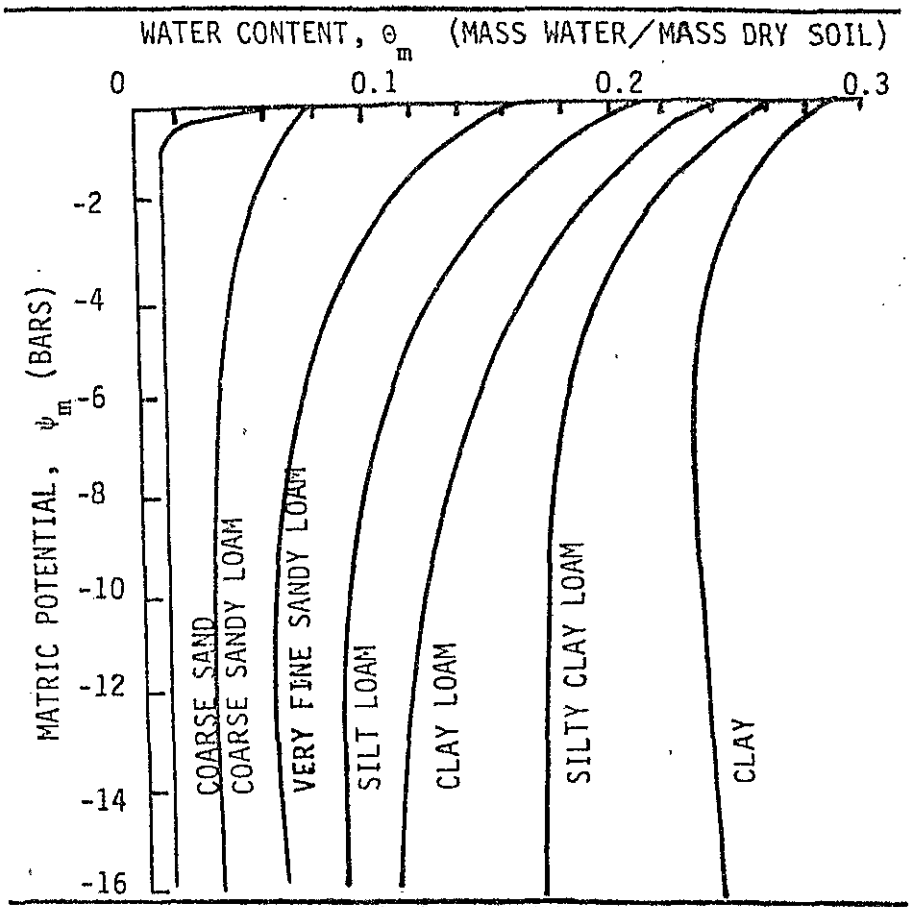


Figure 3. Soil water characteristics for soils of different texture (from Hanks and Ashcroft, 1980).

of field capacity is that it is not a unique soil property; instead, a range of values is possible.

The volume of water that an unconfined aquifer stores during a unit rise in water table per unit surface area is called the fillable porosity (Bouwer, 1978). The amount of water placed into storage (fillable porosity) during the rise of a water table is less than the corresponding amount released during drainage (specific yield). The difference in storage reflects hysteresis caused by air entrapped in pore sequences during the rise of the water table.

Methods for Monitoring Water Storage and Storage Changes in the Vadose Zone

Determining the overall thickness of the vadose zone at a site requires measuring the depth to ground water (for water table conditions) or determining the depth to the base of a confining layer for artesian conditions. Techniques for measuring depths to water include electric sounders, tapes, bubbler techniques and neutron moisture logging. Changes in water levels are monitored using automatic water stage recorders. Drillers logs or geological logs may also be useful in determining the depth to confined ground water.

Methods for monitoring water storage and storage changes in the vadose zone include a direct method, designated the gravimetric method, and indirect methods such as neutron moisture logging, gamma ray transmission, gamma ray scattering, tensiometers, electrical resistance blocks, and thermocouple psychrometers. The principles, advantages and disadvantages of each of these methods, as well as other methods such as remote sensing, were extensively reviewed by Schmugge, Jackson and McKim (1980). The catalog of methods, presented in the latter part of this paper, also summarizes alternative methods. Only the neutron moisture logging method will be discussed in detail in this section.

Neutron Moisture Logging

Agriculturists have employed the principle of neutron moderation or thermalization for many years to measure the volumetric water content of soils to assist in scheduling irrigations. The technique has also been used in water resources investigations to estimate the specific yield of unconfined aquifers; to locate ground-water tables; to determine the porosity of water-bearing formations; and to develop water content profiles in the vadose zone (Keys and MacCary, 1971). Keys (1967) used the neutron logging method in conjunction with natural gamma logging to delineate perched ground water above a clay bed at a site on the National Reactor Testing Station in Idaho. Wilson and DeCook (1968) examined neutron logs in a transect of access wells perpendicular to the Santa Cruz River, Arizona, to estimate lateral flow rates in a perching layer during recharge from ephemeral flow events in the river.

The neutron thermalization method is based on the principle that high energy neutrons are slowed down (thermalized) in their trajectories primarily by collisions with light atomic nuclei, especially those in hydrogen atoms. Hydrogen atoms are mainly present in water molecules within the vadose zone pore space. The density and radius of the cloud of thermalized neutrons will thus be a function of the water content of the media and the strength of the fast neutron source (Brakensiek, Osborn and Rawls, 1979). The principle of operation of a neutron moisture logger is depicted in Figure 4. Readers interested in technical details on the principles of the method should consult references such as Schmugge, Jackson and McKim (1980), Brakensiek, Osborn and Rawls (1979), Gardner (1965), and van Bavel (1963).

Instrumentation used to measure water content by neutron thermalization requires three principal components: (1) a source of fast neutrons, (2) a detector of slow neutrons and (3) an instrument to determine the count rate from the detection equipment. These components are mounted within a cylindrical probe, such as that shown on Figure 4, which can be lowered into a cased or uncased borehole or an access tube. A common source of fast neutrons is americium-beryllium. Smaller units used by agriculturists contain sources in the millicurie range (e.g., 50, 100, 150 millicuries), requiring

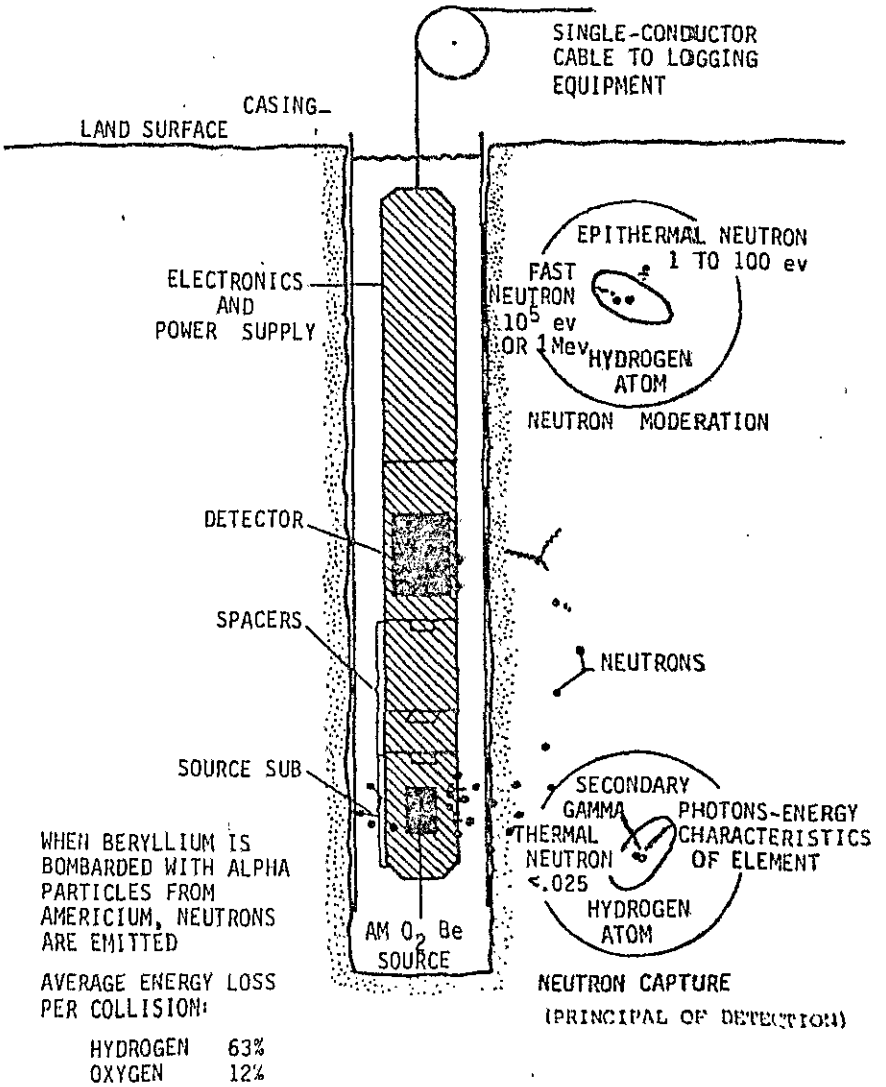


Figure 4. Equipment and principles of neutron moisture logging (from Keys and MacCary, 1971).

only small-diameter (e.g., 2 inch) access wells. Larger units with multicurie sources are used to log wells with larger casing. The most common detector of slow neutrons is lithium-enriched BF_3. The relative positions of source and detector in the down-hole tool are critical (see van Bavel, 1963). The pulse emitted during capture is amplified by a preamplifier within the down-hole tool and sent through the cable to an above-ground meter for counting (see Figure 4), or recording the output.

Access tubes for neutron moisture logging are usually constructed of seamless steel or aluminum tubes. Wells cased with plastic (PVC, ABS, etc.) may cause difficulty in that hydrogen or chlorine atoms present in the casing may moderate the thermal neutrons, interfering with soil moisture evaluation. Aluminum-cased wells may deteriorate in saline soils.

The inside diameter of wells should be as close as possible to the outside diameter of the probe. Work by Ralston (1967) showed that for a 100-mc Am-Be source in a 1.5-inch O.D. tool, water content could not be accurately evaluated in wells greater than 4 inches. Brakensiek, Osborn and Rawls (1979) recommend that the radial air gap should not exceed 0.02 inch. Thus, for large-diameter casing it is advisable to use loggers with sources in the multicurie range.

Careful installation of wells is of critical importance in ensuring the accuracy of the method. As pointed out by McGowan and Williams (1980), a neutron probe has a large sphere of influence but readings are particularly sensitive within a narrow region of soil, perhaps only a few millimeters in thickness, immediately surrounding the well. Unfortunately, this region is most susceptible to damage during construction. Unless the well is tightly installed, cavities may promote the preferential flow of water along the casing wall, leading to erroneous results.

As with all indirect methods, the neutron attenuation method requires the preparation of calibration curves relating water content to the output signal of surface components (e.g., count rate). Generally a curve is supplied with each unit, but for the sake of accuracy, curves should be prepared for on-site materials. Vaidlingam and Tandy (1972), and Brakensiek, Osborn and Rawls (1979) discussed calibration techniques in detail. Briefly, in laboratory calibration the sample must be of homogeneous water content, structure, and density, and of large enough volume to encompass the sphere of influence of the source. A series of samples with distinct water contents must be prepared. The samples and a central access tube are placed in a suitable container. Logs are obtained for each sample. Output values of the neutron logger are then plotted against water content values. Inasmuch as disturbed samples are used, the calibration curve may or may not represent field conditions.

One approach for field calibration is to collect solids samples during installation of access wells and determine water contents gravimetrically. Immediately after installing each well, neutron moisture logs are obtained. The logger output values for each depth are plotted against the corresponding water content values.

Advantages and disadvantages of the neutron method are discussed in detail in the catalog of methods at the end of this article. One advantage which must be emphasized is that neutron logs may show the presence of perched ground water in the vadose zone, thus assisting in positioning monitoring wells for sampling water in transit through the vadose zone. Another advantage relative to vadose zone monitoring near ponds, lagoons, and landfills is that access wells can be installed on the periphery of such facilities. Moisture logs from such wells may detect the horizontal spread of waste water. The sequence of logs shown on Figure 5, obtained in an access well near a recharge pit, exemplify perched ground-water development. This example shows that neutron moisture logging in peripheral access wells could be used as an alter-

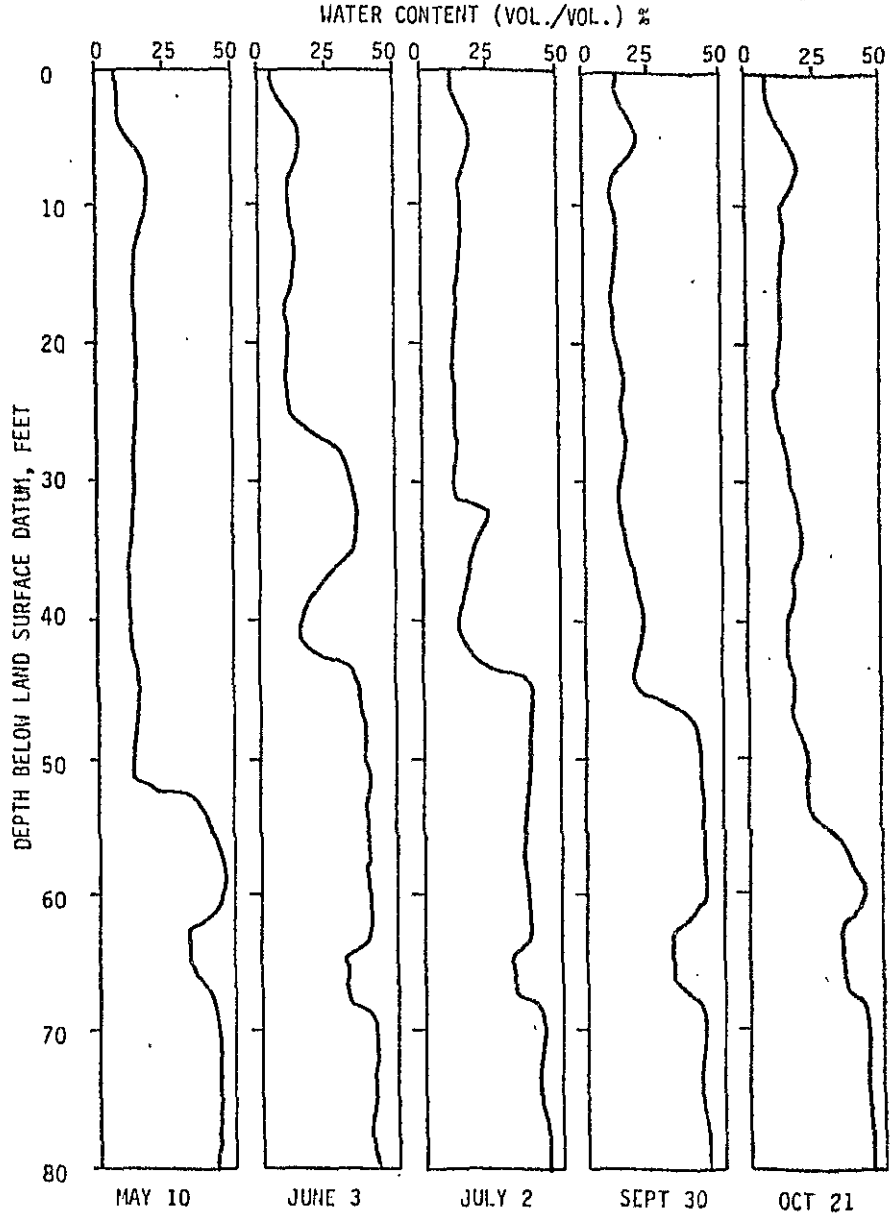


Figure 5. Sequence of water content profiles obtained in the vadose zone during pit recharge studies near Tucson, Arizona.

ive monitoring technique for ›oundments in lieu of sampling thods excluded by the Hazardous ste and Consolidated Permit ;ulations. An important disad- ıtage of neutron moisture logging water may move through a subsurface horizon without ısing a change in storage (Hillel, 30). In this case, a neutron log ıld not manifest water movement.

talog of Methods for ›nitoring Water Content in › Vadose Zone

Table 1 constitutes a catalog of nmon methods which have been could be used for monitoring ıer content in the vadose zone. e emphasis is on methods pos- ly useful in deeper regions. Re- ›te sensing approaches are luded because their focus is on ullow regions. For an excellent lew of remote sensing methods d others, including those in ble 1, the reader should consult hmugge, Jackson and McKim)80).

›graphical Sketch

G. Wilson received his B.S. in riculture from the University of itish Columbia in 1951, and his *in irrigation science and in soil physics from the Uni- rsity of California in 1957 and 62 respectively. From 1956 to 60 he served as assistant spe- alist in irrigation at the Univer- ty of California. Since 1962, he ıs been employed as a hydrolo- st at the Water Resources Re- arch Center, University of izona, Tucson, Arizona. Wilson ıs written journal articles and chnical articles on vadose zone onitoring, most notably an EPA- onsored report entitled "Moni- ring in the Vadose Zone: A view of Technical Elements and ethods" (1980). He has also been volved in a number of studies on ıdose zone and saturated zone onitoring, and has designed mon- ›ring networks for recharge pits, idation ponds, landfills, irriga- ›n return-flow systems, and both ›al strip mining and oil shale ocessing operations.*

rences

ıs, R.S., and R.L. Branson, editors. 1973. Nitrates in the Upper Santa Ana River Basin in relation to ground-water pollution. California Agricultural Experiment Station Bulletin 861.

Bianchi, W.C. 1967. Measuring soil moisture tension changes. Agricultural Engineering, v. 43, no. 7, pp. 398, 399, 404.

Bouwer, H. 1978. Ground Water Hydrology, McGraw-Hill Book Co., New York, N.Y.

Bouwer, H., and R.D. Jackson. 1974. Determining soil properties. In: Drainage for Agriculture. J. van Schilfgaarde, editor. Agronomy, no. 17, published by the American Society of Agronomy, Madison, Wis.

Brakensiek, D.L., H.B. Osborn, and W.J. Rawls. 1979. Field manual for research in agricultural hydrology. Agricultural Handbook, no. 224, published by the U.S. Department of Agriculture, Science and Education Administration.

Briscoe, R. 1979. Effective use of thermocouple psychrometers in the measurement of water. Paper presented at the annual meeting of the Agronomy Society of America, Fort Collins, Colo., August 3, 1979.

Campbell, E.C., G.S. Campbell, and W.K. Barlow. 1973. A dewpoint hygrometer for water potential measurement. Agricultural Meteorology, v. 12, pp. 113-121.

Enfield, C.G., J.J.C. Hsieh, and A.W. Warrick. 1973. Evaluation of water flux above a deep water table using thermocouple psychrometers. Soil Science Society of America Proceedings, v. 37, no. 6, pp. 968-970.

Evans, D.D., T.W. Sammis, and A.W. Warrick. 1976. Transient movement of water and solutes in unsaturated soil systems. Project completion report, Department of Hydrology and Water Resources, The University of Arizona, Tucson.

Freeze, R.A., and J.A. Cherry. 1979. Ground Water, published by Prentice-Hall Inc., Englewood Cliffs, N.J.

Gairon, S. and S. Hadas. 1973. Measurement of the water status in soils. In Arid Zone Irrigation, Yaron B., E. Dantois and Y. Vaadia, editors. Published by Springer-Verlag, New York, N.Y., pp. 215-266.

Gardner, W.H. 1965. Water content. In Methods of Soil Analyses, Black, C.A., ed., Agronomy, no. 9, published by the American Society of Agronomy, Madison, Wis.

Hanks, R.J., and G.L. Ashcroft. 1980. Applied soil physics. Published by Springer-Verlag, Berlin, Heidelburg, New York.

Hillel, D. 1971. Soil and water, physical principles and processes. Published by Academic Press, New York, N.Y.

Hillel, D. 1980. Applications of soil physics. Published by the Academic Press, New York, London, Toronto, Sydney, San Francisco.

Holmes, J.W., S.A. Taylor, and S.J. Richards. 1967. In Irrigation of Agricultural Lands, Hagan, R.M., H.R. Haise, and T.W. Edminster, editors, Agronomy, no. 9, American Society of Agronomy, Madison, Wis., pp. 275-298.

Keys, W.S. 1967. The application of radiation logs to ground-water hydrology. In Symposium on Use of Isotopes in Hydrology. International Atomic Energy Agency, pp. 477-488.

Keys, W.S., and L.M. MacCary. 1971. Application of borehole geophysics to water resources investigations. In Techniques of Water Resources Investigations of The United States Geological Survey, Chapter E1, Book 2, Collection of Environmental Data.

McGowan, M., and J.B. Williams. 1980. The water balance of an agricultural catchment. I: Estimation of evaporation from soil water records. Journal of Soil Science, v. 31, pp. 217-230.

Mann, J.F. 1976. Wastewaters in the vadose zone of arid regions. Ground Water, v. 14, no. 6, pp. 367-372.

Merrill, S.D. and S.C. Rawlins. 1972. Field measurement of soil water potential with thermocouple psychrometers. Soil Science, v. 113, no. 2, pp. 102-109.

Oaksford, E.T. 1978. Water-manometer tensiometers installed and read from the land surface. Geotechnical Testing Journal, v. 1, no. 4, pp. 199-202.

Paetzold, R.F. 1979. Measurement of soil physical properties. In Infiltration Research Planning Workshop. Part 1. State of The Art Reports. Science and Education Administration, ARM-NC-4, U.S. Department of Agriculture.

Phene, C.J., G.J. Hoffman, and S.J. Rawlins. 1971a. Measuring soil matric potential in-situ by sensing heat dissipation within a porous body. I: Theory and sensor construction. Soil Science Society of America Proceedings, v. 35, pp. 27-33.

Phene, C.J., S.J. Rawlins, and G.J. Hoffman. 1971b. Measuring soil matric potential in-situ by sensing heat dissipation within a porous body. I: Experimental

results. Soil Science Society of America Proceedings, v. 35, pp. 225-229.

Ralston, D.R. 1967. Influence of water well design on neutron logging. Unpublished M.S. Thesis, The University of Arizona.

Rawlins, S.L., and F.W. Dalton. 1967. Psychrometric measurement of soil water potential without precise temperature control. Soil Science Society of America Proceedings, v. 31, pp. 297-301.

Reginato, R.J., and R.D. Jackson. 1971. Field measurement of soil water content by gamma-ray transmission compensated for temperature fluctuations. Soil Science Society of America Proceedings, v. 35, pp. 529-533.

Reginato, R.S., and C.H.M. van Bavel. 1964. Soil water measurement with gamma attenuation. Soil Science Society of America Proceedings, v. 28, pp. 721-724.

Reynolds, S.G. 1970a. The gravimetric method of soil moisture determination. I: A study of equipment and methodological problems. Journal of Hydrology, v. 11, no. 3, pp. 258-273.

Reynolds, S.G. 1970b. The gravimetric method of soil moisture determination. II: Typical required sample sizes and methods of reducing variability. Journal of Hydrology, v. 11, no. 3, pp. 274-287.

Richards, L.A. 1965. Physical condition of water in soils. In: Methods of Soil Analysis, C.A. Black, editor, Agronomy, no. 9, published by the American Society of Agronomy, pp. 128-152.

Runnells, D.D. 1976. Wastewaters in the vadose zone of arid regions: geochemical interactions. Ground Water, v. 14, no. 6, pp. 374-385.

Schmugge, T.J., T.J. Jackson, and H.L. McKim. 1980. Survey of methods for soil moisture determination. Water Resources Research, v. 16, No. 6, pp. 961-979.

U.S. Environmental Protection Agency. 1980. Hazardous waste and consolidated permit regulations. Federal Register, v. 45, no. 98, book 2, pp. 33063-33588.

van Bavel, C.H.M. 1963. Neutron scattering of soil moisture: development and current status. Proceedings International Symposium Humidity and Moisture, Washington, D.C., pp. 171-184.

Visvalingam, M., and J.D. Tandy. 1972. The neutron method for measuring soil moisture content. Journal of Soil Science, v. 23, no. 4, pp. 499-510.

Watson, K.K. 1967. A recording field tensiometer with rapid response characteristics. Journal of Hydrology, v. 5, pp. 33-39.

Wilson, L.G. 1980. Monitoring in the vadose zone: a review of technical elements and methods. U.S. Environmental Protection Agency, EPA-600/7-80-134. 168 pp.

Wilson, L.G., and K.J. DeCook. 1968. Field observations on changes in the subsurface water regime during influent seepage in the Santa Cruz River. Water Resources Research, v. 4, no. 6, pp. 1219-1234.

Winograd, I.J. 1974. Radioactive waste storage in the arid zone. EOS, Transactions American Geophysical Union, v. 55, no. 10, pp. 884-894.

Table 1. Catalog of Methods for Monitoring Water Content in the Vadose Zone

Method	Principle	Advantages	Disadvantages	References
1. Gravimetric a. Oven drying	Core samples are obtained from the vadose zone using tube samplers for shallow depths and hollow stem auger plus core sampling for greater depths. A core sample is weighed, oven dried at 105°C for 24 hours, and reweighed. The water content is determined by difference in weight. Results expressed on a dry weight or volume basis. The difference in water content values of successive samples represents change in storage.	1. A direct method. 2. The most accurate of available methods. 3. Simple.	1. A large number of replicate samples are required for each depth increment (necessitating several holes) to account for spatial variability of water holding properties. 2. Expensive if large numbers of samples are required. 3. A destructive method—i.e., additional measurements cannot be obtained at the same sites.	Gardner (1965), Hillel (1971), Schmugge, Jackson and McKim (1980), Reynolds (1970a, 1970b), Brakensiek, Osborn and Rawls (1979).
b. Carbide method	A field method. Solids samples are placed in a container with calcium carbide. The calcium carbide reacts with water, releasing a gas. The gas pressure, registered on a gage, is converted into water content on a dry weight basis.	1. More rapid than oven drying. 2. Initial capital investment is lower than for oven drying.	1. May not be as accurate as oven drying 2. Other disadvantages are the same as for oven drying.	

Method	Principle	Advantages	Disadvantages	References
Neutron moisture logging (neutron scatter method)	A source of high energy neutrons (e.g., amerecium-beryllium) in a down-hole tool is lowered into an access well. Water in the vadose zone slows down the fast neutrons, which are captured by a detector in the tool. Counts are measured by a surface scaler, ratemeter, or recorder. Counts are converted into volumetric water content by an appropriate calibration relationship. Successive readings show temporal changes in water storage at successive depths.	1. Rapid. 2. An in-situ method. 3. Can be conducted in cased or uncased holes (for safety in unstable material should install casing). 4. Can be interfaced with portable data collection system. 5. Successive readings are obtained in the same profile at the same field location. 6. Can be used to locate perched ground-water zones, i.e., valuable for positioning monitoring wells for sampling perched ground water.	1. Expensive, requiring the purchase or lease of equipment. 2. Water content is measured in a sphere. Cannot relate results exactly to a specific depth. 3. Fast neutrons are moderated by other constituents besides hydrogen in water, e.g., chlorine or boron. Accuracy may be affected. 4. During installing of access wells, cracks or cavities may be formed causing leakage along the casing wall. 5. An indirect method requiring calibration. Calibration is a difficult procedure. 6. Accurate readings are not possible within 6 in. of soil surface. 7. Cannot be used to infer water movement in regions where storage changes do not occur.	Holmes, Taylor and Richards (1967), van Bavel (1963), Keys and MacCary (1971), McGowan and Williams (1980), Schmugge, Jackson and McKim (1980), Wilson (1980), Hillel (1971), Brakensiek, Osborn and Rawls (1979), Visvalingum and Tandy (1972).
Gamma ray attenuation. a. Transmission method.	Two parallel wells installed at precise distances apart are required. A probe with a gamma photon source (e.g. cesium 137) is lowered in one well. A second probe with a detector (e.g. sodium iodide scintillation crystal) is lowered at the same rate in the second well. Accessories include a high-voltage supply, amplifier, scaler, timer, spectrum analyzer, pulse height analyzer and photomultiplier tube. The degree to which a beam of monoenergetic gamma rays is attenuated depends on the bulk density and water content. Assuming that the bulk density remains constant, changes between readings reflects changes in water content.	1. A rapid, in-situ method. 2. Water content is obtained in a narrow beam—depth-wise measurement can be obtained as close as one inch apart. 3. Measurements can be obtained within one inch of surface. 4. Nondestructive and successive measurements are obtained at same locations. 5. Can be interfaced with portable data collection system.	1. Limited to shallow depths because of difficulties in installing precisely parallel wells, particularly in rocky material. 2. Instabilities in count rate may occur. 3. Expensive. 4. Changes in bulk density in shrinking-swelling material affects accuracy of water content readings. 5. Variations in water content and bulk density occur in stratified soils. 6. Care must be taken in handling radioactive source.	Brakensiek, Osborn and Rawls (1979), Gardner (1965), Bouwer and Jackson (1974), Reginato and van Bavel (1964), Reginato and Jackson (1971), Schmugge, Jackson and McKim (1980).
b. Scattering method.	A single probe is used, containing a gamma source and a detector, separated by a lead shield. Gamma rays beamed into the surrounding media are absorbed by the solid media and water. Back-scattered rays are detected and measured. Knowing the dry bulk density of the media, the water content can be calculated. Requires empirical calibration curves.	1. Rapid. 2. Nondestructive, with successive measurements obtained at same depth. 3. In contrast to the transmission method only one access well is required. Readings can be obtained at great depth in vadose zone.	1. Requires a source of higher strength than transmission method. 2. Not as accurate as transmission method because water content measured in sphere and not a beam. 3. Expensive. 4. Changes in bulk density in shrinking, swelling material changes calibrations.	Keys and MacCary (1971), Brakensiek, Osborn and Rawls (1979), Paetzold (1979).

Method	Principle	Advantages	Disadvantages	References
4. Tensiometers	A tensiometer consists of a porous ceramic cup cemented to rigid plastic tube, containing small diameter tubing leading to a surface reservoir of mercury. Alternate version uses strain gage transducer in lieu of mercury manometer. The body tubing is filled with water. Pores in cup form continuum with pores in exterior medium. Water moves into or out of body tube until equilibrium is reached. Measured water pressure reflects corresponding water pressure in medium. By using appropriate soil water characteristic curve, pressure can be related to water content.	1. Provide continuous, in place measurements of water content. 2. Successive measurements are obtained. 3. Inexpensive and simple. 4. Transducer units respond fairly rapidly to water content changes.	1. Units fail at the air entry value of the ceramic cup, generally about -0.8 atmospheres. 2. Results are subject to hysteresis, that is, different results are obtained for wetting vs. drying media. 3. If proper contact is not made between cup and media units will not operate properly. 4. Sensitive to temperature changes. 5. Difficult to install at great depth in vadose zone.	Brakensiek, Osborn and Rawls (1979), Holmes, Taylor and Richards (1967), Bianchi (1967), Gairon and Hadas (1973), Schmugge, Jackson and McKim (1980), Wilson (1980), Oaksford (1978).
5. Electrical resistance blocks	Blocks consist of electrodes embedded in porous material (plaster of paris, nylon, cloth, fiberglass). Water content of blocks change with water content of soil. Electrical properties of blocks change with changing water content. Electrical properties are measured using a meter. Calibration curves must be obtained.	1. Can be interfaced with portable data collection system. 2. Can be used at soil water pressures less than -0.8 atmospheres. 3. Gypsum blocks are inexpensive. 4. Precision is good.	1. Subject to hysteresis. 2. May be difficult to install at great depth in vadose zone and maintain good contact. 3. Requires calibration for each textural type in profile. 4. Lack of insensitivity in wet range. 5. Sensitivity to soil salinity (except gypsum blocks). 6. Gypsum blocks deteriorate badly in certain media. 7. Calibration curves of some units shift with time. 8. Time lag in response.	Brakensiek, Osborn and Rawls (1979), Holmes, Taylor and Richards (1967), Phene, Hoffman and Rawlins (1971), Schmugge, Jackson and McKim (1980), Gairon and Hadas (1973).
6. Thermocouple psychrometers/ hygrometers	A psychrometer unit consists of a porous bulb with a chamber in which the relative humidity of the exterior media is sampled; a sensitive thermocouple, a heat sink, reference electrode, and electrical circuitry. The unit operates on the principle that a relationship exists between soil water potential and relative humidity. Two types are available, the wet bulb type and the dew point type. Both types rely on cooling of the thermocouple junction by the Peltier effect. In the wet bulb type, when the temperature of the junction is reduced below the dew point, cooling is discontinued. As condensed water evaporates, the temperature increases to ambient. Signal from the junction at the temperature plateau is proportional to relative humidity. In the dew point type, the temperature at junction is held constant at dew point. The thermocouple signal corresponds to dew point depression.	1. In-situ pressure measurements are possible down to -50 atmospheres, permitting the determination of water contents in the very dry range. 2. Permits continuous recording of pressures (and water contents) at the same depth. 3. Can be interfaced with portable or remote data collection systems. 4. Some units have been installed to great depth (down to 300 feet).	1. Results are subject to hysteresis. 2. Good contact between bulb and surrounding media may be difficult to obtain. 3. Provide point measurements only. 4. May be difficult to obtain accurate calibration curves for deep regions of the vadose zone. 5. Fragile, requiring great care in installation.	Rawlins and Dalton (1967), Merrill and Rawlins (1972), Enfield, Hsieh and Warrick (1973), Schmugge, Jackson and McKim (1980), Hanks and Ashcroft (1980), Briscoe (1979), Campbell, Campbell and Barlow (1973).

	and thus to the relative humidity. Different methods are required for the two types.The dew point method is more accurate. Calibration curves relating relative humidity to water potential are required. Water potential and water content are related through a characteristic curve for each material.			
Heat dissipation sensor	Heat dissipation sensors operate on the principle that the temperature gradient to dissipate a given amount of heat in a porous medium of low conductivity is related to water content. In practice, the water content of a soil can be measured by applying a heat source at a central point within the sensor and measuring the temperature rise at that point. Calibration curves of matric potential vs. temperature difference are obtained using a pressure plate apparatus with soils from the site. The matric potential is related to water content by preparing a water characteristic curve. Commercial sensors consist of a miniature heater, temperature sensors and circuitry, embedded in a cylindrical porous ceramic block within a small-diameter PVC tube, and a lead cable.	1. Simple. 2. May be interfaced with a data acquisition system for remote collection of data. 3. Measurements are independent of salt content of soil. 4. Calibration appears to remain constant. 5. Can be used to measure soil temperature as well as matric potential. 6. Useful for measuring water contents in the dry range.	1. Subject to hysteresis in the water characteristic. 2. Calibration is required for each change in texture. 3. May be difficult to install at depth in the vadose zone and maintain good contact between the sensor and medium.	Phene, Hoffman and Rawlins (1971a). Phene, Rawlins and Hoffman (1971b). Schmugge, Jackson and McKim (1980).

100. Wilson, L.G. "Monitoring in the Vadose Zone: Part II," Ground Water Monitoring Review, Winter 1982, pp. 31-42

MONITORING IN THE VADOSE ZONE: PART II

2646

In this section of a three-part article, the author discusses methods for characterizing the transmission of liquid wastes in the vadose zone.

L. G. Wilson

Monitoring within unsaturated/ .urated regions in the vadose zone ove a principal aquifer affords an ırly warning" of subsurface pol- ant movement from waste dis- sal sites. Included among the sites concern are liquid impound- :nts, spoil piles, sanitary landfills, igated fields and land treatment :as. A vadose zone monitoring ɔgram for a waste disposal site nerally includes pre-monitoring d active monitoring phases. In neral, the monitoring methods sociated with these phases are ed to characterize the following ree properties during wastewater ɔvement in the vadose zone: stor- and changes in storage, the ınsmission of liquid wastes and nobility of pollutants.

e array of present monitoring thods includes techniques devel- ed for related disciplines such as ıl science, hydrogeology and geo- ysics. Individuals responsible for dose zone monitoring at waste sposal sites may be familiar with e techniques in their own disci- ne but perhaps not with those in ated disciplines. The three papers this series constitute an elemen- ry exposition of methods for dose zone monitoring. The first ticle in this series (Fall 1981 VMR, vo. 1, no. 3) relates to ethods for monitoring storage and ɔrage changes during liquid move- nt; this, the second, deals with thods for characterizing the trans- ission of liquid wastes. A third ticle will present methods for mon- ring the movements of pollutants.

ansmission of Liquid astes in the Vadose Zone

The rationale for monitoring flow the vadose zone is to characterize e flux and velocity of wastewater g transit to a water table. Flux stewater is defined as the antity of fluid crossing a unit ea per unit time. Velocity is the te of transit of wastewater. In- rmation on flux is useful in pre- cting the quantity of wastewater intercepting the water table. Estimates of velocity can be used to calculate travel time of wastes through the vadose zone. For an active or abandoned site, estimates of velocity and travel time will indicate whether or not pollutants have already reached the water table. Estimates of travel time obtained at a new or proposed site will establish bounds on the available time for initiating remedial measures in case of failure of liners or other protective measures.

The three stages of liquid transmission in the vadose zone are infiltration, percolation and recharge. Defined generally, infiltration is the process of water movement across the land surface into the underlying soil. Infiltration losses in canals and impoundments are generally described as "seepage" losses. Percolation (often referred to as "deep percolation") refers to the movement of water through flow conducting channels (e.g., pores, fractures and solution cavities) in the vadose zone. Finally, recharge consists of liquid movement into the ground-water zone. Recharge rates equal deep percolation rates in the vicinity of the water table. Consequently, this article will focus on the first two processes, infiltration and percolation.

Only a brief review of the technical elements of the infiltration and deep percolation processes is included in this article. For additional information the interested reader is referred to recent texts by Hanks and Ashcroft (1980), Hillel (1980a), and Hillel (1980b).

Infiltration

Hillel (1980b) prefers the term "infiltrability" to infiltration capacity" to describe the infiltration flux when water is applied continuously in a thin film at the soil surface. If water is ponded above the soil surface such that the pressure at the water-soil interface is greater than atmospheric, the infiltration rate exceeds the infiltrability (Hillel, 1980b). In contrast if water is applied slowly at the surface, the infiltration rate will be less than the infiltrability.

When infiltration occurs into a dry soil the intake rate is initially governed by strong suction forces within the soil profile. Later, as the profile becomes wetted to greater and greater depths, the suction gradients diminish and gravity becomes the predominant force in promoting downward flow. Eventually, the rate approaches a steady-state value, approximately equal to the saturated hydraulic conductivity, if the profile is homogeneous (Hillel, 1980b). Factors affecting the infiltrability of a soil (and thus the potential amount of pollutants entering the vadose zone) include soil texture, soil structure, initial water content, presence of shallow impeding layers or water tables, water temperatures, entrapped and confined air, biological activity, entrained sediment and salinity of applied water. Each of these factors is worthy of an extensive discussion, which is not possible here. One factor which should be singled out, however, is soil structure. In particular, a soil with large cracks between soil blocks will have higher intake rates than expected on the basis of soil texture alone. A problem with a well-structured soil is that pollutants pass quickly into the vadose zone without the ameliorative effects of soil filtration. The reader should consult Hillel (1980b) for details on the other factors.

Percolation

Technically, percolation of wastewater beneath a surface disposal facility can be subdivided into two interrelated stages: (1) percolation in a profile during the initial stages of the infiltration process, when the infiltration rate approaches the "steady-state" infiltrability and (2) percolation in the profile when either the infiltration process has ceased or has been affected by the clogging of surface pores. In the first stage the profile may be more or less at saturation above the wetting front. The infiltration and percolation rates approximately equal the saturated hydraulic conductivity. In the second stage drainage occurs from

upper regions of the profile through or into the lower regions and the percolation rate diminishes.

Hillel (1980b) differentiated between drainage from a profile wetted throughout and overlying a shallow water table, and drainage for a wetted profile overlying a deep, mainly unsaturated vadose zone. In the first case, drainage occurs throughout the entire profile. In the second case the upper part of the profile drains while the initially dry underlying material becomes wetted. That is, water becomes redistributed in the profile. A succession of water content profiles obtained during redistribution would show the gradual vertical displacement and "smearing out" of a water content bulge. The process of redistribution is effected by two principal mechanisms: suction gradients between wet and dry material and gravitational gradients.

Two important factors affecting percolation rates of liquid waste beneath a surface disposal facility are permeability of vadose sediments and the presence of flow impeding layers. The permeability of granular vadose-zone layers is related to the grain-size distribution and to the degree of sorting of associated sediments. In general, permeabilities are greater in well-sorted material than in poorly-sorted material, particularly when the predominant grain size is coarse.

The horizontal permeability of vadose zone sediments is generally greater than the vertical permeability. Consequently, the presence of flow-impeding layers in the vadose zone, such as clay lenses, causes water to flow preferentially in the horizontal direction within the material above the impeding layer. Vertical percolation rates are decreased commensurately. The resultant saturated water body is called perched ground water. If the impeding layer is shallow, perched ground water may merge with surface water causing a reduction in infiltration rates.

(1979) and by Moss, Davidson and Tollner (1979). The interested reader should consult these publications for details. Of the algebraic/empirical equations for describing infiltration, Brakensiek (1979) recommended the Green and Ampt (1911) equation and the Philip (1969) two-parameter equation.

As presented by Bouwer (1978) the Green and Ampt equation is written:

$$V_i = K\frac{H_w + L_f - h_{cr}}{L_f} \qquad (1)$$

where V_i = infiltration rate
K = hydraulic conductivity of wetted zone
H_w = depth of water above soil
h_{cr} = critical pressure head of soil for wetting
L_f = depth of wetting front

Brakensiek (1979) itemized parameter estimation procedures for the Green and Ampt equation.

The fundamental relationships describing percolation in the vadose zone are Darcy's equation and the equation of continuity. Groundwater hydrologists are familiar with the following form of Darcy's equation describing one-dimensional, saturated flow:

$$J = -K\frac{dH}{dz} \qquad (2)$$

where J = flux
K = hydraulic conductivity
H = total hydraulic head [sum of pressure head (positive) and positional head]
z = vertical distance downward

For unsaturated flow in the vadose zone, Darcy's equation is expressed (using the symbols of Hanks and Ashcroft, 1980):

$$J = K(\psi_m)\frac{d\psi_h}{dz} \qquad (3a)$$

where J = flux
$K(\psi_m)$ = hydraulic conductivity as a function of water content θ
ψ_h = hydraulic potential $= \psi_m + \psi_z$
ψ_m = matric potential
ψ_z = gravitational potential

Note that in this expression the hydraulic conductivity is a function of matric potential. Laboratory techniques are available for obtaining a $K(\theta)$ vs. ψ_m calibration curve using core samples. Such curves show that as the matric potential increases negatively the hydraulic conductivity diminishes. Different curves will be obtained for different textured media, as depicted on

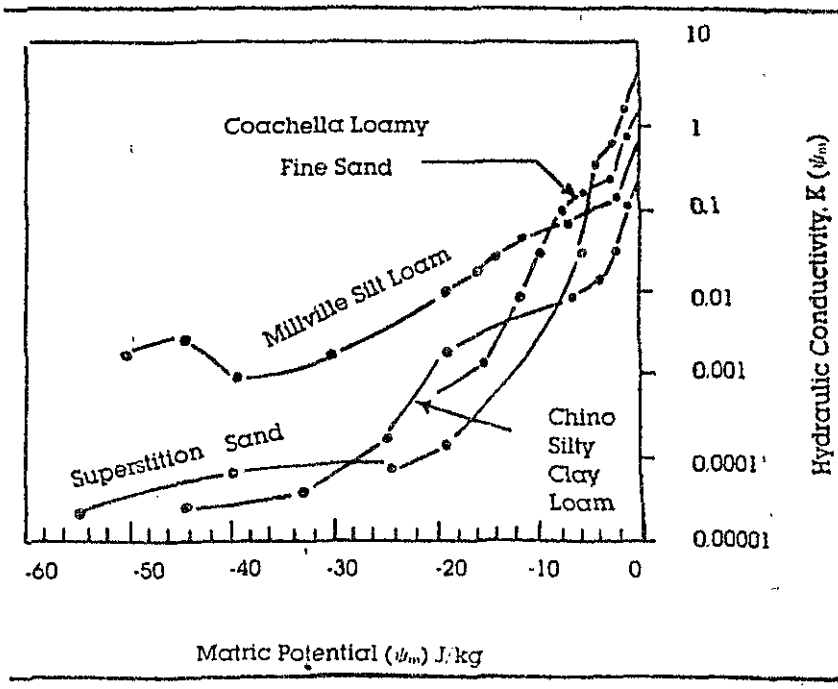


Figure 1. Curves showing the relationship between hydraulic conductivity $K(\psi_m)$, and matric potential, (ψ_m), for four soils [after U.S. Environmental Protection Agency et al (1977)].

ure 1. Because the water content ependent on the matric pressure the media, the hydraulic con- tivity is also a function of water tent. Thus equation (3a) can be ritten as follows:

$$K(\theta) \quad \frac{d\psi_h}{dz} \qquad (3b)$$

A consequence of the $K(\theta)$ vs. θ tionship is that a certain amount ercolating water may need to be led to storage before flow rates ome significant. As described by ns and Warrick (1970), "...for an ially dry soil, the water content of soil must first be increased to a l to accommodate the input rate ore any water reaches the water le."

As expressed in equation 3, J is Darcian velocity. J is a macro- pic quantity because the cross tional area of flow includes both ds and voids. A more representa- depiction of velocity would ex- de solids from the flow path and ount for the water content of the J spaces. Consequently, an al- native form of Darcy's equation unsaturated media is:

$$J = \frac{K(\theta)}{\theta} \frac{d\psi_h}{dz} \qquad (4)$$

ere $\bar{v}$ is the average linear velocity eeze and Cherry, 1979). The aver- linear velocity is also a macro- pic quantity and the actual flow ocity in the tortuous intertwining ore sequences is of greater mag- ude.

For vertical percolation, the equa- n of continuity is written as ows (Hanks and Ashcroft, 1980):

$$= \frac{\partial J}{\partial z} \qquad (5)$$

$$= \frac{\partial}{\partial z}\left(K(\theta) \frac{\partial \psi_h}{\partial z} \right) \qquad (6)$$

Equation (6) is frequently called Richard's equation.

Modeling techniques are avail- le for predicting seepage and deep rcolation. The results of a mod- ng effort often provide an insight ubsurface flow patterns at the al site, and facilitate predict- g the arrival times of wastes at the ter table. The effect of alternative undary conditions, such as liner ickness and permeability, on flow tterns and velocity can be studied.

Generally, however, flow models require good definition of such vadose zone properties as textural layering; $\psi_m - \theta$, $K - \theta$, and $K - \psi_m$ relationships; porosity and grain-size distribution. Information on the physical and hydraulic properties of liners and surface impeding layers are also required.

King and Lambert (1976) developed a model for predicting percolation beneath agricultural fields. Two linked computer programs are used. The root zone model uses rainfall (or irrigation) and temperature data to determine the amount of water leaving the root zone. The deep seepage model simulates deep percolation movement through the vadose zone.

More complex models are required to characterize seepage and deep percolation from canals and impoundments because the subsurface flow system is two- or three-dimensional. Bouwer (1978) and Kraatz (1977) summarized existing models describing steady state and transient seepage losses from lined and unlined canals. Stephens and Siegel (1981) presented an excellent review of current techniques for modeling seepage and vadose zone flow from lined impoundments. Among the methods reviewed by Stephens and Siegel (1981) is that of McWhorter and Nelson (1978, 1979 and 1980), who developed a simple numerical technique for characterizing seepage histories in lined ponds which initially overlay unsaturated vadose zones.

Field Methods for Determining the Rate of Water Movement in the Vadose Zone

Infiltration

A review of alternative methods for determining intake rates of liquid wastes in impoundments and land-spreading operations is included in the catalog of methods. Infiltrometers and test basins, two common techniques for measuring long-term infiltration rates at landspreading sites, are described in more detail in this section.

Infiltrometers may be either the single-ring or double-ring type (Figure 2). In the double-ring infiltro-

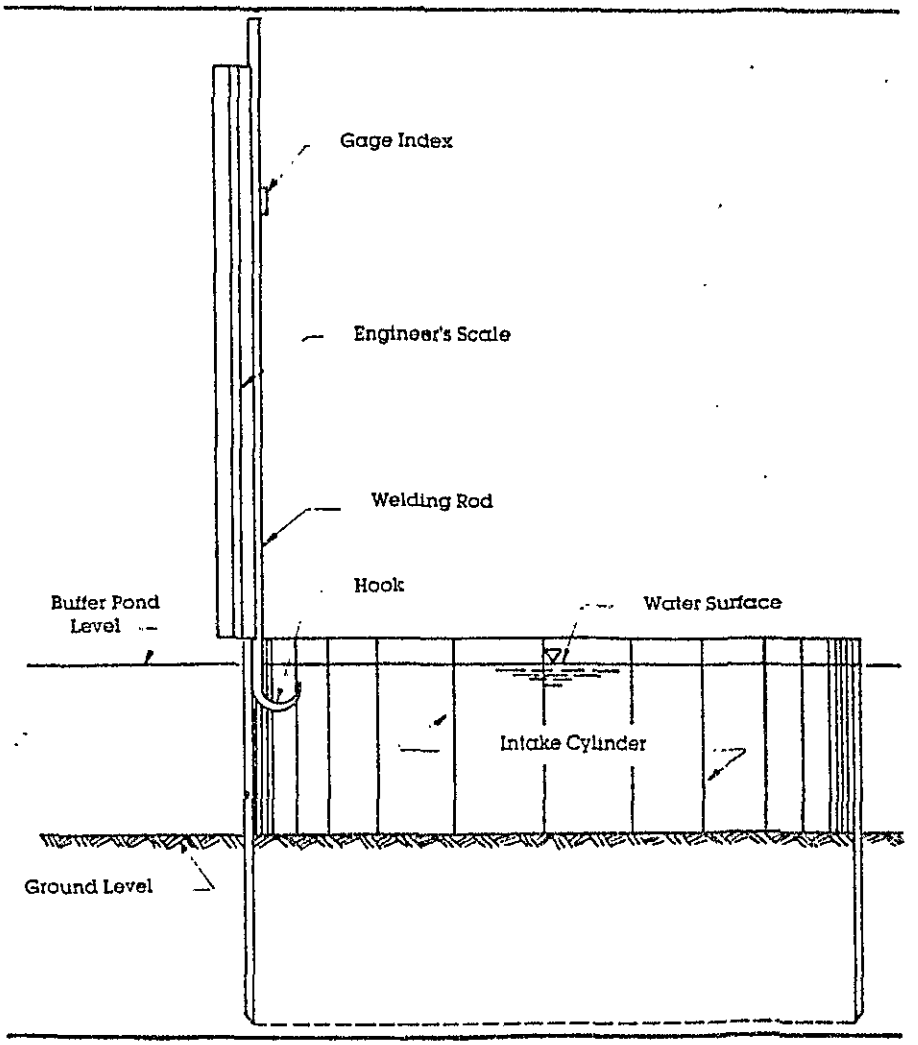


Figure 2. Intake cylinder and appurtenances of a double ring infiltrometer, during use [after U.S. Environmental Protection Agency et al. (1977)].

meter method, a metal cylinder from 6 to 14 inches in diameter is driven to a depth of 6 inches into the soil at the test site. A larger ring, ranging from 16 to 30 inches in diameter, is placed concentrically around the smaller ring. The areas within inner and outer rings are flooded and the rate of recession of water level in the inner ring is measured via a hook or point gage.

By keeping the outer region flooded, flow in the inner region is restricted mainly to the vertical direction. Wastewater to be used during the full-scale disposal operation should be used during infiltrometer tests. Because of the spatial variability of soil properties, an inordinate number of ring tests may be required to ensure that results are within a certain percentage of "true" mean values. Even with care, however, experience has shown that double-ring infiltrometers tend to overestimate the true infiltration rate because of the divergence of flow due to shallow impeding layers and unsaturated flow (Bouwer, 1978). Bouwer recommended using a single large cylinder, in lieu of a double-ring infiltrometer, to offset the problem of divergence from unsaturated flow.

A superior alternative to infiltrometers is to install a number of small test basins at a disposal site. Test basins should be large enough to permit installation of the desired accessory facilities. Basins may be constructed by digging a narrow trench around the desired rectangular area to such a depth that lateral flow will be minimized. Side boards, possibly covered with plastic sheeting, are placed in the trench, ensuring that good contact is made with the soil within the plot and also at the corners. Sufficient free-board should be allowed to permit a range of flooding heads. During tests, water is metered into the plot at a discharge rate such that a constant head is maintained. The discharge rate to maintain this head is the application rate. The infiltration rates at selected times are calculated by dividing the application rate by the surface area.

Alternatively, the head may be allowed to fall a short distance by shutting down the inflow, and the volume which infiltrates per unit area over a measured period of time may be converted to infiltration rates.

As with infiltrometers, the same water source to be used during the actual operation should be applied during the tests. The effect of such effluent on surface intake rates (e.g., by clogging) may be readily examined. Similarly, the effect of unfavorable exchangeable sodium percentages and electrolyte concentrations on the hydraulic conductivity can be quantified.

Because of the spatial variability of soil properties, even on supposedly homogeneous areas, it is recommended that a number of test basins be located on the proposed waste disposal site. Another problem with test basins is that shallow impeding layers may promote lateral movement of water in preference to truly vertical flow. Lateral flow rates generally exceed vertical rates. Hence, measured intake rates tend to overestimate the intake rates of a larger disposal area.

If the technique for applying wastewater to the disposal site is sprinkler irrigation, it is recommended that infiltration tests be conducted using rainfall simulators. Such units are described by Bertrand (1965), Sidle (1979) and Harmon (1979).

In conducting infiltration trials, a record should be kept of the intake rate as a function to time. Plotting of the results will produce an exponential relationship between intake and time. The resultant curve will asymptotically approach a final value, specifically that of the saturated hydraulic conductivity.

Deep Percolation

Alternative methods of estimating deep percolation of liquid wastes in the vadose zone are summarized in the catalog of methods. Except for flowmeters, the methods listed in the catalog are based either on the equation of continuity or on Darcy's flux equation. Thus, the water budget methods are essentially applications of the equation of continuity. The methods based on Darcy's equation provide information for solving the flux equation, such as values of in-situ hydraulic gradients and hydraulic conductivity. However, some methods use simplifying assumptions for solving the flux equation, for example, assuming that hydraulic gradients are unity. The largest group of methods are aimed at estimating values for the hydraulic conductivity, and several methods estimate saturated k values, even though the flow is basically unsaturated. The premise is that overestimation of flux and velocity provides a margin of error for avoiding ground-water pollution. Several of the methods assume that flow is entirely unidirectional, specifically vertically downward, when in reality capillarity effects and layering in the vadose zone may promote a great deal of lateral flow (Stephens and Siegel, 1980).

Two methods for estimating deep percolation will be discussed in more detail than in the catalog of methods, namely a draining profile method and a simple method using infiltration data. The basis of the draining profile method is the equation of continuity, expressed as follows:

$$J = -\int_{o}^{z} \frac{\partial \theta}{\partial t}\, dz \qquad (7)$$

This expression can be regarded as the area between successive water content profiles ($d\theta dz$) above a depth z; during a period of drainage, dt. The method is best suited for determining flux during profile drainage at disposal sites operated intermittently, such as some land treatment areas. To use equation (7), evaporation must either be prevented or assumed to be negligible. During drainage, water content profiles are obtained using methods described in the first paper of this series. Examples of such methods include neutron moisture logging, tensiometers and moisture blocks.

The draining profile method is exemplified by the hypothetical profiles shown on Figure 3. The area between the two curves (shown by cross-hatching) in the region from land surface to a depth of 135 cm (about 53 inches) is 2 cm (0.79 inches). Thus the flux is 2 cm/16 hrs. or 0.125 cm/hr. Assuming that the average water content in the cross-hatched area is 0.23, the average velocity would be 0.54 cm/hr.

An alternative, simple approach for estimating deep percolation from large spreading areas and extensive impoundments is to apply Darcy's equation based on the following assumptions: (1) seepage has proceeded for a sufficiently long time so that deep percolation is at steady state, (2) the vadose zone is unlayered, isotropic and very deep, (3) flow is vertically downward and (4) hydraulic gradients are equal to unity. For this case, equation (4) reduces to:

$$\bar{v} = \frac{J}{\theta} = \frac{K(\theta)}{\theta} \qquad (8)$$

Several of the field techniques described in the catalog of methods could be used to estimate hydraulic conductivity values, which are needed to solve for the numerator in

'uation (8). It should be noted, wever, that these methods gen- ally provide values for the satur- 'd hydraulic conductivity, result- g in an overestimation of the sponding J and v values. In on, because unsaturated hy- ulic conductivity [K(θ)] values log-normally distributed, a large mber of measurements are re- ired to obtain reliable estimates mean values (Warrick and Niel- 1980). In contrast, water con- nt (θ) values are normally distri- ted and fewer measurements are uired to ensure accuracy. Sim- rly, long-term surface intake rates, 'an be obtained with reasonably od accuracy. Consequently, rather an attempting to measure hy- aulic conductivity values, Warrick 'rsonal communication, 1981) commended substituting I for J in uation (8) so that:

$$= \frac{I}{\theta} \qquad (9)$$

Both terms on the right hand side can be measured with reasonably good accuracy. Again, for this relationship to hold, seepage must have approached steady state.

To exemplify the use of this equation, suppose that the long-term intake rate of a pond is one foot per day, and that the prevailing water content of the vadose zone is 20 percent. Therefore the average velocity would be 5 feet per day. If the water table is 200 feet below ground surface, the travel time of fluids would be 40 days.

Catalog of Methods

A catalog of methods for estimating flow rates of wastewater in the vadose zone is included as Table 1. For convenience, the catalog is divided into three sections, respectively describing methods for estimating infiltration at the land surface, flux in the vadose zone and velocity in the vadose zone. The principle of the alternative methods is briefly described, followed by a list of important advantages and disadvantages. A list of references is included for the reader interested in an in-depth discussion of each method.

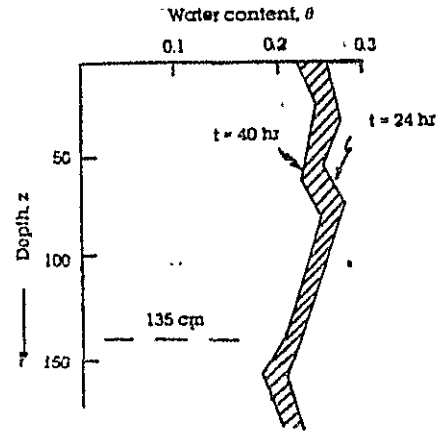


Figure 3. Hypothetical water content profiles obtained during the draining profile method.

able 1. Catalog of Methods for Monitoring or Estimating Flux of Wastewater in the Vadose Zone

Method	Principles	Advantages	Disadvantages	References
Infiltration at land surface				
a. Impoundments				
(i) Water budget method	Entails solving for the seepage component of the water budget equation. That is: Inflow − Outflow = ± ΔS. $S_L = (I + P) - (D + E) \pm \Delta S$. Where S_L = seepage loss; I = inflow from all sources; P = precipitation; D = discharge; E = evaporation; S = storage. Measurements of I, P, D, E, ΔS are required; requiring flumes, raingages, evaporation pan, and staff gages or water stage recorders. Calibration curve or table of head vs. surface area is required.	1. Averages intake rate for the entire surface area of the pond (sides and bottom). 2. Measurements do not interfere with normal pit operation.	1. Time consuming and expensive. 2. Errors in measurements of auxiliary parameters affect accuracy in estimating seepage.	Bouwer (1978).
(ii) Instantaneous rate method	By shutting down all inflows to a pond and all discharges from a pond, the water level will recede primarily as a result of infiltration. That is, all the components of the water budget equation are set equal to zero except for infiltration, evaporation and change in storage. Measuring ΔS for a short time provides a value for infiltration rate (neglecting evaporation).	1. Simple and inexpensive. 2. Errors in measuring auxiliary components do not enter into calculations. 3. Estimates average intake rate for entire surface area of pond.	1. May cause inconvenience to pond operator. 2. The measured instantaneous rate does not account for rate fluctuations caused by fluctuations in inflow and outflow components.	

Method	Principles	Advantages	Disadvantages	References
(iii) Seepage meters	Seepage meters are cylinders, capped at one end and open at the other end. The open end of the cylinder is forced into the pond surface and seepage is equated to the outflow from the cylinder when pressure heads inside and outside the cylinder are equal. Types include: the SCS seepage meter, the USBR seepage meter and the Bouwer-Rice seepage meter.	1. Inexpensive. 2. Simple to operate. 3. Uses only one piece of equipment, i.e., reduces the overall error compared to using several measuring devices as with water budget.	1. Measures seepage at discrete points and a large number of measurements are required to obtain "average" intake rates (including both sides and bottom points). 2. Operator will need to swim underwater to install units in bottom of pond.	Bouwer (1978), Bouwer and Rice (1963), Kraatz (1977).
b. Land treatment areas and irrigated fields				
(i) Water budget method	See impoundments: Water budget method. Inflow and outflow from fields are measured by flumes, weirs, etc. Evaporation equated to that from a free surface.	See impoundments: water budget method.	See impoundments: water budget method.	
(ii) Infiltrometers	An infiltrometer is an open ended cylinder driven into the ground. The amount of water added to maintain a constant head in the cylinder is equated to infiltration rate. Types include single-ring and double-ring infiltrometers. In double-ring type both the outer and inner annular areas are flooded, ostensibly to minimize divergence in flow from inner area. Intake measurements are taken in the inner area.	1. Simple 2. Inexpensive 3. Portable	1. Provides point measurements only. 2. Because of spatial variability in soil properties a large number of readings required to estimate "average" infiltration. 3. Shallow, flow impeding layers affect results. 4. Divergence in subsurface flow occurs because of unsaturated flow (Bouwer recommends using single, large cylinder to minimize this problem). 5. Leakage along side walls may cause anomalously high rates.	Bouwer (1978), Dunne and Leopold (1978), Burgey and Luthin (1956), U.S. Environmental Protection Agency, U.S. Army Corps of Engineers and U.S. Department of Agriculture (1977).
(iii) Test basins	Large basins (e.g. 20 feet by 20 feet) are constructed at several locations in a field. The basins are flooded and intake rates are measured. Results are related to "average" intake rate for the field. (The water source to be used for field-sized operations should be used during testing.)	1. Provides more representative intake rates than infiltrometers-results can be used to design full-scale projects. 2. Simple.	1. Expensive. 2. Time consuming. 3. May be difficult to transport water to sites. 4. Shallow lenses of fine material will affect results by causing divergence of flow. 5. Spatial variability in soil properties affects results.	U.S. Environmental Protection Agency, U.S. Corps of Engineers, and U.S. Department of Agriculture (1977).
2. Flux in the vadose zone.				
a. Water budget with soil moisture accounting.	The water budget method of Thornthwaite and Mather (1957) is applied to a given soil depth (e.g. root zone of an irrigated field; final soil cover on a landfill). Inflow components include rainfall and irrigation. Outflow components include runoff, evapotranspiration, drainage, and deep percolation (flux). Change in storage	1. Estimates flux for entire area and not only points. 2. Computer programs are available to simplify calculations (e.g. WATBUG, Willmott, 1977).	1. Errors in measurement or estimation of components accumulate in estimates of flux.	Thornthwaite and Mather (1957), Willmott (1977), Mather and Rodriquez (1978), Fenn, Hanley and DeGeare (1975), Jensen (1973).

Method	Principles	Advantages	Disadvantages	References
	equals water content change in depth of interest. Flux equated to known inflow and outflow components and ΔS. Evapotranspiration may be most difficult component to measure (see Jensen, 1973 for alternative methods).			
b. Methods relying on water content measurements (e.g., draining profile methods).	Flux is related to water content changes in a given depth of the vadose zone. The relationship between flux and water content is expressed as follows: $J = -\int_0^z \frac{\partial \theta}{\partial t} dz$ Where J = flux, θ = water content, z = depth, and t = time. (This method is actually a profile-specific water budget with all terms except flux and storage change set equal to zero). Water content changes are measured by neutron logging, tensiometers, resistance blocks and psychrometers.	1. Simple. 2. Compared to methods relying on data for hydraulic gradients, a large number of measurements can be obtained with minimal cost and labor needs. 3. A large number of measurements using simple methods is more amenable to statistical analyses.	1. Errors in measuring devices affect results. 2. Spatial variability in soil hydraulic properties requires that a large number of measurements be obtained to obtain an "average" value. 3. Costly. 4. May not be suitable for measuring flux below impoundments of landfills because of difficulties in installing measuring units.	Libardi et al. (1980), Nielsen, Biggar and Erh (1973), Warrick and Amoozegar-Fard (1980), Bouwer and Jackson (1974), Wilson (1980).
c. Method requiring measurements of hydraulic gradients.	The method is based on solving Darcy's equation for unsaturated flow. $J = K(\theta)\, i$ where $K(\theta)$ designates that hydraulic conductivity is a function of water content θ; i = hydraulic gradient. Hydraulic gradients are measured by installing tensiometers, blocks or psychrometers. Calibration curves are required to relate negative pressure measurements to water content, and water content to unsaturated hydraulic conductivity. Separate curves are required for each textural change.	1. A very precise method.	1. More complex than methods using water content values. 2. Results are subject to hysteresis in the calibration curves. 3. Expensive to install the requisite number of units for statistical analyses. 4. May not be suitable for ponds or landfills. 5. Generally restricted to shallow depths in the vadose zone.	LaRue, Nielsen and Hagan (1968), Bouwer and Jackson (1974), Wilson (1980).
d. Method based on assumption that hydraulic gradients are unity.	Same as above except that unit hydraulic gradient is assumed so that $J = K(\theta)$. Only one pressure measuring unit is required at each depth of interest to permit estimating θ from a pressure vs. water content curve. $K(\theta)$ is estimated from a separate curve. (For a more complex version of this method see Nielsen, Biggar and Erh, 1973.) An alternative approach is to use the relationship $J = K(\psi_m)$, which requires a curve showing the changes in hydraulic conductivity with matric potential (ψ_m). Bouma, Baker and Veneman (1974) described the so-called "crust test" for preparing a $K(\theta)$ vs. ψ_m curve. This field procedure is carried out on cylindrical columns	1. Simpler and less expensive than methods requiring gradients.	1. Assumption of unit hydraulic gradients may fail, particularly in layered media. 2. Results are subject to hysteresis in calibration curves. 3. May not be suitable for ponds or landfills. 4. More complex than methods requiring soil moisture evaluation. 5. Large number of units required to offset spatial variability in soil properties.	Nielsen, Biggar and Erh (1973), Bouwer and Jackson (1974), Warrick and Amoozegar-Fard (1980), and Bouma, Baker and Venneman (1974).

Method	Principles	Advantages	Disadvantages	References
	constructed in a test pit. Each column is instrumented with a tensiometer, a ring infiltrometer, and gypsum-sand crusts. A series of crusts are used during different runs to impose varying resistances to flow. During each run, infiltration rates and tensiometer values are monitored.			
e. Flowmeters	Flux is measured directly using flowmeters. Principles of two available types are as follows: (1) direct flow measurement using a sensitive flow transducer, and (2) flow is related to movement of a heat pulse in water moving in a porous cup buried in the soil. Calibration curves are required for second type.	1. Do not require information on hydraulic conductivity or hydraulic gradients.	1. Disturbance of soil during installation may affect results. 2. Convergence/divergence problems arise in the flow field. 3. Limited range of soil types and fluxes. 4. Calibration procedures are tedious. 5. Applicability to deeper regions of the vadose zone is questionable.	Cary (1973), Dirksen (1974a), Dirksen (1974b).
f. Methods based on *estimating or* measuring hydraulic conductivity, K. (i) Laboratory methods.	The premise of these *methods is that if K values* are available the flux can be estimated by assuming hydraulic gradients are unity, and that Darcy's law is valid.			
(aa) Permeameters	Cylindrical cores of vadose zone sediments are placed in tight fitting metal or plastic cylinders. Water is applied to the cores and outflow is metered. The head of water applied to cores may be either constant head or falling. Appropriate equations are solved to determine K, knowing head values, application rates and dimensions of the container. Primarily for saturated K.	1. Simple 2. May be used to determine variations in K values because of stratifications.	1. Expensive if a large number of samples are required. 2. Accuracy of method is questionable because of wall effects. 3. Not an in-situ method—results will be affected by spatial variability of hydraulic properties in vadose zone.	Bouwer (1978), Freeze and Cherry (1979).
(bb) Relationships between hydraulic conductivity and grain-size.	*Grain-size distribution* curves are obtained for samples of vadose zone material. The hydraulic conductivity is calculated from equations which account for a representative grain-size diameter or from the spread in the gradation curve. Primarily for saturated K.	1. A "*first cut*" *method* if other data are unavailable. 2. May be used to estimate relative variations in K because of stratification.	1. Accuracy is questionable. 2. A disturbed method—results may not be representative of in-situ values. 3. Expensive if grain-size values are unavailable. 4. Requires trained personnel.	Freeze and Cherry (1979) and references therein.
(cc) Catalog of hydraulic properties.	A catalog of hydraulic properties of soils, prepared by Mualem (1976) is consulted for soil types similar to vadose zone sediments. Both saturated and unsaturated K values are reported.	1. Simple. 2. A quick method. 3. May be used to estimate relative variations in K because of stratification. 4. Inexpensive—provided that grain-size data are available.	1. Problems arise because of hysteresis in unsaturated K. 2. Because of errors in measuring K (θ), values for a particular soil type may not be transferable to similar types. To obtain a closer estimate K(θ) must be evaluated *for each soil* (Evans and Warrick, 1970).	Mualem (1976).

Method	Principles	Advantages	Disadvantages	References
(ii) Field methods.				
(aa) Shallow methods.				
(aa1) Methods for measuring saturated K in the absence of a water table.	A portion of the soil zone is brought to saturation and saturated K is estimated for the flow system thus created. Appropriate measurements and equations are used to solve for K. Alternative methods include: (1) pump-in method, (2) air-entry permeameters, (3) infiltration gradient method, and (4) double tube method.	1. Each method has its own advantages—see Bouwer and Jackson (1974).	1. Each method has its own disadvantages—see Bouwer and Jackson (1974). 2. Because of air entrapment during tests complete saturation is not possible. Measured K values may be 1/2 actual values (Bouwer, 1978). 3. Several of the methods are based on the assumption that flow is entirely vertical—a false premise.	Bouwer and Jackson (1974).
(aa2) Instantaneous profile method.	The basis of this method is the Richards equation, rewritten as follows: $K(\theta) = \frac{\partial\theta/\partial t}{\partial\psi_h/\partial z} z$ In practice, a soil plot in the region of interest is instrumented with a battery of tensiometers, with individual units terminating at depths of interest, for measuring water pressures; and with an access tube for moisture logging. The soil is wetted to saturation throughout the study depth. Wetting is stopped and the surface is covered to prevent evaporation. Water pressure and water content measurements are obtained during drainage. Curves of ψ_h vs. z and θ vs. t are prepared. Slopes of the curves at the depths of interest are used to solve for $K(\theta)$. Values of $K(\theta)$ at varying times can be used to prepare $K(\theta)$ vs. θ and $K(\psi_m)$ vs. ψ_m curves; (for a detailed description of the method, including step by step procedures, see Bauma, Baker and Veneman, 1974).	1. Method can be used in stratified soils. 2. Simple. 3. Reasonably accurate, at least at each measuring site.	1. Provides hydraulic conductivity values only for draining profiles. Because of hysteresis, these values are not representative of the hydraulic conductivity during wetting cycles. 2. Because of spatial variabilities in soil hydraulic properties, a large number of sites must be used to obtain mean values of hydraulic conductivity. 3. Time consuming and relatively expensive.	Bouma, Baker and Veneman (1974).
(bb) Deeper methods.				
(bb1) USBR single well method.	Water is pumped into a borehole at a steady rate such that a uniform water level is maintained in a basal test section. Saturated K is estimated from appropriate curves and equations, knowing dimensions of the hole and inlet pipes, length in contact with formation, height of water above base of borehole, depth to water table, and intake rate at steady state. Two types of tests: (1) open-end casing tests, in which water flows only out of the end of the casing, and (2) open-hole tests, in which water flows out of sides and bottom.	1. May be used to estimate K at great depths in vadose zone. 2. A profile of K values may be obtained.	1. Solution methods are based on assumption that flow region is entirely saturated (free surface theory)—this is not true. 2. As a consequence of 1, K is underestimated. 3. Expensive and time consuming. 4. Requires skilled personnel to conduct tests.	U.S. Bureau of Reclamation (1977).

Method	Principles	Advantages	Disadvantages	References
(bb2) USBR multiple well method.	Used to estimate K in vicinity of widespread lenses of slowly permeable material. An intake well and series of piezometers are installed. Water is pumped into well at a steady rate and water levels are measured in piezometers. Appropriate curves and equations are used to determine K.	1. Results can be used to estimate lateral flow rates in perched ground-water regions.	1. Expensive and time consuming. 2. Requires trained personnel.	U.S. Bureau of Reclamation (1977).
(bb3) Stephens-Neuman single well method.	Stephens and Neuman (1980) developed an empirical formula based on numerical simulations using the unsaturated characteristics of four soils. That is, this approach accounts for unsaturated flow.	1. The formula can be used to estimate the saturated hydraulic conductivity of an unsaturated soil with improved accuracy. 2. No need to wait for steady state conditions—the final flow rate can be estimated from data during transient stage.	1. Needs field testing.	Stephens and Neuman (1980).
(bb4) Air permeability method.	Air pressure changes are measured in specially constructed piezometers during barometric changes at the land surface. Pressure response data are coupled with information on air-filled porosity to solve equations leading to air permeability. If the Klinkenberg effect is small, air permeability is converted to hydraulic conductivity.	1. Can be used to estimate hydraulic conductivity values of layered materials in the vadose zone.	1. An indirect method. 2. Presence of excessive water limits the utility of the method. 3. Expensive. 4. Time consuming. 5. Complex—requires trained personnel.	Weeks (1978).
3. Velocity in the vadose zone. a. Tracers	A suitable tracer (e.g. tritium, iodide, bromide, fluorocarbons) is introduced into the liquid souce. (Alternatively, a tracer such as chloride, already present in the source could be used.) Samples are obtained from suction cups at successive depths and tracer break-through curves are prepared.	1. A direct method. 2. Simple. 3. *Accounts for flow in* actual pores—a closer measure of the true velocity. 4. More accurate than methods requiring knowledge of components of Darcy's equation.	1. Analyses of tracers may be expensive. 2. *Operation of suction* samplers may affect natural flow field, leading to incorrect values. 3. In structured media the actual velocity may be higher than measured because of flow in cracks. 4. If velocities are slow, excessively long time periods will be required for tests.	Freeze and Cherry (1979). Frissel, et al. (1974).
b. Calculation using flux values.	Flux values obtained by methods described above are used, together with estimated or measured water content values, in the following relationship: $v = \frac{J}{\theta}$ where v = velocity, J = flux, and θ = water content. Assumes that (1) hydraulic gradients are unity, (2) an average water content can be determined, (3) flow is vertical, and (4) homogeneous media.	1. Inexpensive when coupled with other methods. 2. Simple. 3. A "quick and dirty" method for estimating the travel time of pollutants in the vadose zone.	1. Velocity will be higher in structured media than that calculated. 2. Method assumes vertical flow only—perching layers cause lateral flow. 3. For multilayered media an average θ and v value may be difficult to obtain.	Bouwer (1980). Wilson (1980).

Method	Principles	Advantages	Disadvantages	References
c. Calculation using long-term infiltration data. $v = \frac{I}{\theta} = \frac{J}{\theta}$	The long-term infiltration rate, I, of the facility is assumed to equal the steady state flux J in the vadose zone. Consequently, Also assumes the (1) hydraulic gradients are unity, (2) average water content = θ, (3) flow is vertical, and (4) homogeneous media.	1. Simple. 2. Probably satisfactory as first estimate of velocity. 3. Inexpensive.	1. Velocity will be higher in structured media than calculated. 2. Method assumes vertical flow only. Perching layers cause lateral flow. 3. For multilayered media an average θ and v may be difficult to obtain.	Bouwer (1980), Warrick (1981).

References

Bertrand, A.R. 1965. Rate of water intake in the field. In: Methods of Soil Analysis, C.A. Black, Editor. Agronomy No. 9, American Society of Agronomy, Madison, Wisconsin.

Bouma, J., F.G. Baker and P.L.M. Veneman. 1974. Measurement of water movement in soil pedons above the water table. University of Wisconsin-Extension, Geological and Natural History Survey, Information Circular No. 27.

Bouwer, H. 1978. Ground-Water Hydrology, McGraw-Hill Book Co., New York, N.Y.

Bouwer, H. 1980. Deep percolation and ground-water management. In: Proceedings of the Deep Percolation Symposium. Arizona Department of Water Resources Report No. 1, pp. 13-19.

Bouwer, H. and R.D. Jackson, 1974. Determining soil properties. In: Drainage for Agriculture. J. van Schilfgaard, Editor. Agronomy No. 17. Published by the American Society of Agronomy, Madison, Wisconsin.

Bouwer, H. and R.C. Rice. 1963. Seepage meters in recharge and seepage studies. Journal Irrigation and Drainage Division, American Society of Civil Engineers, v. 89, no. IR1, pp. 17-42.

Brakensiek, D.L. 1979. Empirical and simplified models of the infiltration process. In: Infiltration Research Planning Workshop. Part 1. State of the Art Reports. Science and Education Administration, ARM-NC-4, U.S. Department of Agriculture.

Burgy, R.H., and J.N. Luthin. 1956. A test of single- and double-ring types of infiltrometers. Transactions American Geophysical Union, v. 37, pp. 189-191.

Cary, J.W. 1973. Soil water flowmeters with thermocouple outputs. Soil Science Society of America Proceedings, v. 37, pp. 176-181.

Dirksen, C. 1974a. Water flux measurements in unsaturated soils. In: Flow—Its Measurement and Control in Science and Industry, Instrument Society of America, v. 1, pp. 479-486.

Dirksen, T., and L.B. Leopold. 1978. Water in Environmental Planning, W.H. Freeman and Company, San Francisco.

Evans, D.D., and A.W. Warrick. 1970. Time of transit of water moving vertically for ground water recharge. Symposium on Saline Water. Contribution No. 13. Committee on Desert and Arid Zone Research. Southwest and Rocky Mountain Division American Academy for the Advancement of Science, pp. 87-97.

Fenn, D.C., K.J. Hanley and T.V. DeGeare. 1975. Use of the water balance method for predicting leachate generation from solid waste disposal sites. U.S. Environmental Protection Agency, EPA/530/SW-168.

Freeze, R.A. and J.A. Cherry. 1979. Ground Water. Published by Prentice-Hall Inc., Englewood Cliffs, New Jersey.

Frissel, M.J., P. Peolstra, K. Harmsen, and G.H. Bolt. 1974. Tracing soil-moisture migration with $^{36}C1$, ^{60}Co and tritium. In: Isotope and Radiation Techniques in Soil Physics and Irrigation Studies, 1973. International Atomic Energy Agency, Vienna.

Green, W.H. and G.A. Ampt. 1911. Studies on soil physics: I. Flow of air and water through soils. Journal of Agricultural Research, v. 4, pp. 1-24.

Hamon, W.R. 1979. Infiltrometer using simulated rainfall for infiltration research. In: Infiltration Research Planning Workshop. Part 1. State of the Art Reports. Science and Education Administration, The U.S. Department of Agriculture, ARM-NC-4.

Hanks, R.J. and G.L. Ashcroft. 1980. Applied Soil Physics. Published by Springer-Verlay, Berlin, Heidelburg, New York.

Hillel, D. 1980a. Fundamentals of Soil Physics. Published by The Academic Press, New York, N.Y.

Hillel, D. 1980b. Applications of Soil Physics. Published by The Academic Press, New York, London, Toronto, Sydney, San Francisco.

Jensen, M.E., Editor. 1973. Consumptive Use of Water and Irrigation Water Requirements, American Society of Civil Engineers, New York.

King, T.G. and J.R. Lambert. 1976. Simulation of deep seepage to a water table. Transactions American Society of Agricultural Engineers, v. 10, pp. 50-54.

Kraatz, D.B. 1977. Irrigation canal lining. FAO Land and Water Development Series, No. 1. Food and Agriculture Organization of the United Nations.

LaRue, M.E., D.R. Nielsen and R.M. Hagan. 1968. Soil water flux below a ryegrass root zone. Agronomy Journal, v. 60, pp. 625-629.

Libardi, P.L., K. Reichardt, D.R. Nielsen, and J.W. Biggar. 1980. Simple field methods for estimating soil hydraulic conductivity. Journal Soil Science Society of America, v. 44, pp. 3-7.

Mather, J.R. and P.A. Rodriguez. 1978. The use of the water budget in evaluating leaching

through solid waste landfills. University of Delaware Water Resources Center, Contribution No. 25.

McWhorter, D. B. and J.D. Nelson. 1978. Drainage of earthen lined tailings ponds. In: Symposium on Uranium Mill Tailings Management. Fort Collins, Colorado, 1978. Colorado State University, pp. 31-49.

McWhorter, D.B. and J.D. Nelson. 1979. Unsaturated flow beneath tailings impoundments. Journal of the Geotechnical Engineering Division, Proceedings of the American Society of Civil Engineers, v. 105, no. GT11, pp. 1317-1334.

McWhorter, D.B. and J.D. Nelson. 1980. Seepage in the partially saturated zone beneath tailings impoundments. Mining Engineering, v. 32, no. 4, pp. 432-439.

Molz, F.J., J.M. Davidson, and E.W. Tollner. 1979. Unsaturated-zone water. Reviews of Geophysics and Space Physics, v. 17, no. 6, pp. 1221-1239.

Mualem, Y. 1976. A catalog of the hydraulic properties of unsaturated soils. Technion, Israel Institute of Technology, Report on Research Project 442.

ielsen, D.R., J.W. Biggar, and K.T. Erh. 1973. Spatial variability of field measured soil-water properties. Hilgardia, v. 43, no. 7, pp. 215-260.

Philip, J.R. 1969. Theory of infiltration. In: Advances in Hydroscience. Van Te Chow, Editor. Volume 5. Academic Press, N.Y., pp. 215-296.

Science and Education Administration. 1979. Infiltration Research Planning Workshop, Part 1. State of the Art Reports. U.S. Department of Agriculture, ARM-NC-4.

Sidle, R.C. 1979. Infiltration measurements and soil hydraulic characteristics. In: Infiltration Research Planning Workshop, Part 1. State of the Art Reports. Science and Education Administration, The U.S. Department of Agriculture, ARM-NC-4.

Stephens, D.B., and S.P. Neuman. 1980. Analysis of borehole infiltration tests above the water table. Technical Report No. 35, Department of Hydrology and Water Resources, The University of Arizona.

Stephens, D.B., and J. Siegel. 1981. Fluid-waste movement through the vadose zone. In: Environmental Geology and Hydrology in New Mexico. S.G. Wells and W. Lambert, Editors. New Mexico Geological Society, Special Publication no. 10, pp. 103-110.

Thornthwaite, C.W., and J.R. Mather. 1957. Instructions and tables for computing potential evapotranspiration and water balance. Drexel Institute of Technology, Laboratory of Climatology, v. X, no. 3.

U.S. Bureau of Reclamation. 1977. Ground Water Manual. U.S. Department of the Interior.

U.S. Environmental Protection Agency, U.S. Army Corps of Engineers, and the U.S. Department of Agriculture. 1977. Process design manual for land treatment of municipal wastewater, EPA625/1-77-008 (COE EM-1110-1-501).

Warrick, A.W., and A. Amoozegar-Fard. 1980. Area prediction of water and solute flux in the unsaturated zone. Final report on grant No. R-804-751-010, U.S. Environmental Protection Agency (in press).

Warrick, A.W. and D.R. Nielsen. 1980. Spatial variability of soil physical properties in the field. In: Applications of Soil Physics. Academic Press, N.Y., pp. 319-344.

Warrick, A. W. 1981. Personal communication.

Weeks, E.P. 1978. Field determination of vertical permeability to air in the unsaturated zone. U.S. Geological Survey Professional Paper No. 1051.

Willmott, C.J. 1977. WATBUG: A FORTRAN IV algorithm for calculating the climatic water budget. University of Delaware Water Resources Center, Contribution No. 23.

Wilson, L.G. 1980. Monitoring in the vadose zone: a review of technical elements and methods. U.S. Environmental Protection Agency, EPA-600/7-80-134, 168 pp.

Acknowledgments

The following agencies provided financial assistance in the preparation of material in this paper: The University of Arizona, State of Arizona; General Electric TEMPO (now Kaman TEMPO); and the U.S. Environmental Protection Agency. The author also expresses gratitude to Nancy Svacha for typing the manuscript and to Leigh Wood for drafting the figures.

101. Woods, Paul H., et al. "Underground Storage Tanks: Problems, Technology, and Trends," Pollution Engineering, July 1984

Underground Storage Tanks: Problems, Technology, and Trends

2645
2646
2647

Paul H Woods, Jr and Dale E Webster

During the 1950s and 60s, the construction of many chemical manufacturing and processing facilities, gasoline stations, and other facilities storing hazardous (toxic, flammable, etc.) materials in bulk led to the installation of thousands of underground and aboveground storage tanks nationwide. In the case of underground tanks, the majority of the tanks installed were made of carbon steel. Many of these tanks have exceeded or are currently close to their useful lives, and are now or will soon be leaking.

With the present national emphasis on preventing the contamination of groundwater supplies, leaks from underground storage tanks are becoming a major area of concern, as emphasized by the examples listed in Table 1. This article presents an overview of the underground storage issue. The following sections of the article focus on the problems associated with underground storage, the technology currently available to prevent and detect these problems, and current regulatory trends in this area.

The problem

The basic problems associated with underground storage systems are leaks from those systems, and the costs, dangers, and potential liabilities associated with those leaks. Product leaks represent losses which can lead to increased costs for owners and consumers. Leaks of volatile and flammable materials can result in fire or explosion hazards in the basements of nearby homes or buildings. Leaks can result in contamination of nearby product or water pipelines, and in the contamination of groundwater.

There are three primary causes of leaks from underground storage systems: (1) corrosion; (2) poor installation; and (3) poor operating practices.

Table 1.
Examples of Cases Involving Underground Leaks

- In the Silicon Valley area of northern California, groundwater contamination from underground storage tanks storing trichloroethylene has led to the preparation of a model underground storage ordinance which requires overfill protection equipment, secondary containment, and leak monitoring systems for all new facilities.
- In a recently publicized case in Rhode Island, the owners of two neighboring gas stations were found liable for the cost of cleaning up the local groundwater supply and supplying potable water to area residents because of contamination from leaking underground storage tanks.
- In Massachusetts, a leak from an underground storage tank contaminated a town's drinking water supply, and left the station owner liable for cleaning the groundwater.
- On Long Island, leaks from underground storage tanks contaminated the basements of neighboring homes. As a result, the station owner was forced to purchase 25 homes in the area.

Corrosion

Corrosion Mechanisms. The corrosion of tanks and piping systems is a complex phenomenon that may take one or more forms. Corrosion results from interactions between the tanks and piping and their surroundings, both internal and external. The deterioration of plastics and other non-metallic materials, which are susceptible to softening, cracking, swelling, etc., is essentially chemical in nature. The corrosion of non-metallic storage system components can be controlled and essentially eliminated through proper selection and careful handling of tank and piping materials.

Corrosion of metals is primarily an electrical process; it may take the form of either galvanic or electrolytic corrosion. Electrolytic corrosion is a result of direct current from outside sources entering and then leaving a particular metal structure by way of the electrolyte. The surrounding material serves as the electrolyte, with soil fulfilling that role for underground structures. The structure is usually unaffected or is provided with some degree of protection at the point the current enters (the cathodic area). Corrosion occurs where the current leaves the structure (the anodic area).

Galvanic corrosion is a self-generated activity resulting from differences in electrical potential that develop when metal is placed in an electrolyte. These differences in electrical potential can result from the direct coupling of dissimilar metals, or they can result from variations in conditions which exist at the surface of a single metal. When two dissimilar metals are connected electrically and immersed in an electrolyte, current will be generated and galvanic corrosion will occur in one of the metals. Current from the corroding metal will flow into the electrolyte, over to the non-corroding metal, and then back through the connection between the two metals. The corroding metal (the one from which current leaves to enter the electrolyte) is known as the anode; the metal which receives current is known as the cathode.

Forms of Corrosion. The deterioration of tank or piping

Table 2. Common Forms of Localized Corrosion

Type	Description
Pitting Corrosion	Formation of shallow depressions or deep pits (cavities of small diameter).
Stress Corrosion Cracking	Corrosion accelerated by residual stresses resulting from fabrication operations or unequal heating and cooling of the structure.
Contact or Crevice Corrosion	Occurs at the point of contact or crevice between a metal and non-metal, or between two metals.
Intergranular Corrosion	Selective corrosion at the grain boundaries (microscopic) of a metal or alloy.

material may appear as either general or localized corrosion. If viewed without magnification, general corrosion appears as a relatively uniform loss of surface material. Localized corrosion results in a non-uniform loss of material from the corroded structure. Types of localized corrosion are described briefly in Table 2.

Factors Influencing Corrosion. There are numerous factors that can influence the presence and rates of internal and external corrosion in both aboveground and underground storage tanks and piping systems. The more prominent of these factors are listed in Table 3 and highlighted in Figures 1 through 5.

Poor Installation

Poor installation of underground storage system components is also a common cause of leaks. Structural damage to tanks or piping during handling and installation can lead to leak problems after the material is in place. For example, scratches on the surface of a coated steel tank can result in accelerated localized corrosion after the tank is placed in the ground.

Improper bedding, backfilling, or anchoring can also lead to leak problems. For example, Figure 6 shows several fiberglass-reinforced plastic (FRP) tanks which cracked or ruptured because they were not properly supported by their backfill. Figure 7 shows a steel tank which was not properly anchored in an area where the groundwater table was close to the surface. As a result, when the tank was empty or near empty, it was floated to the surface by the groundwater.

Improper connection of storage system components can also lead to leak problems. Piping joints which fail over time because of improper connection, and fittings which loosen over time because they were improperly installed, are good examples.

Poor Operating Practices

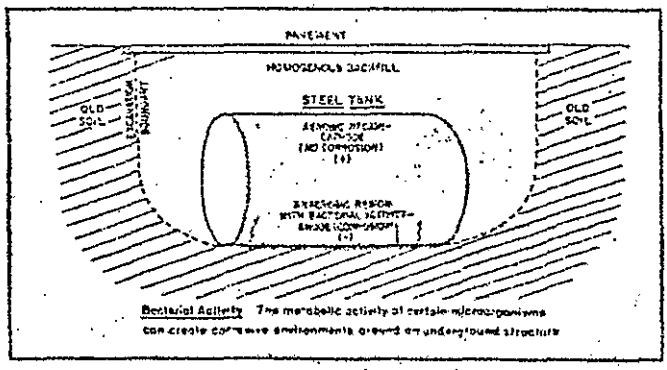
Poor operating practices can also lead to leak or spill problems. The best examples of such practices are overfilling of tanks during liquid transfer operations, and puncturing of tanks with dipsticks during inventory measurements.

The technology

As understanding of the causes of leaks from underground storage systems has evolved in recent years, so has the technology for addressing and coping with these problems. The following discussion of available and developing technology is broken down into two areas: leak prevention and leak detection. Leak prevention in-

FIGURE 1

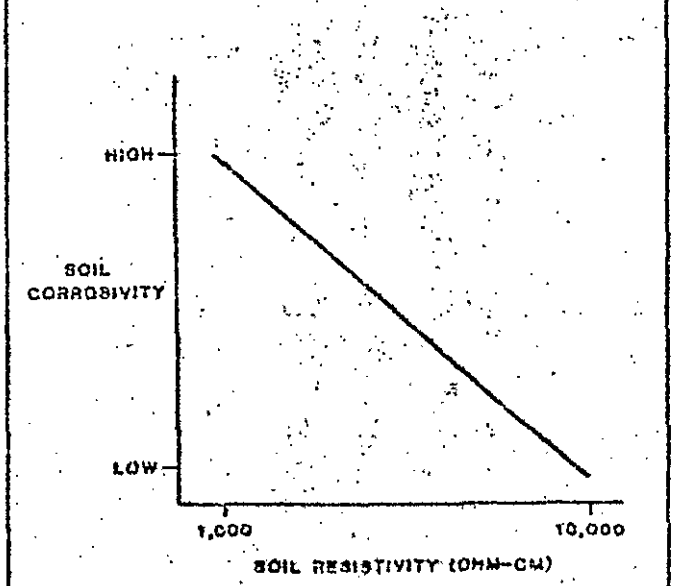
CORROSION MECHANISMS



SOURCE: FRED C. HART ASSOCIATES, INC.

FIGURE 2

SOIL RESISTIVITY VS. SOIL CORROSIVITY



SOURCE: FRED C. HART ASSOCIATES, INC.

Table 3. Factors Influencing Corrosion

Electrolyte Acidity. The acidity of the soil with which the material is in contact could have a substantial effect on the rate of corrosion. Acidic (low pH) soils are, as a general rule, more corrosive than neutral (pH 7) or alkaline (high pH soils in the case of ordinary iron and steel. However, for the amphoteric metals, such as aluminum and zinc, highly alkaline soils may be more corrosive than acidic soils.

Temperature. The rate of corrosion tends to increase with rising temperature.

Surface Films. Once corrosion has started, its progress is often controlled by the nature of the film that forms on the corroding metal. Some corrosion products may be insoluble and completely impervious to the corroding solution and, therefore, completely protective; or they may be very permeable and thus allow localized or general corrosion to proceed unhindered. In addition, discontinuous or non-uniform films may induce localized corrosion in particular areas.

Bacterial Action. The metabolic activity of certain microorganisms can either directly or indirectly affect the corrosion of metals. Such activity can:

- Produce a corrosive environment.
- Create electrolytic concentration cells, leading to crevice corrosion.
- Alter the resistance of surface films.
- Alter the composition of the metal's environment.
- Influence the rate of anodic or cathodic reaction.

Soil Resistivity. Soil resistivity is a measure of the resistance of soil to the flow of electric current, and is a very important factor in determining the potential rate of corrosion of underground pipes and tanks. The lower the resistivity of the soil, the greater the probability of corrosion.

Moisture Level. The presence of water can also promote corrosion of metals. The presence of moisture in soils acts to reduce soil resistivity, thereby increasing the probability of corrosion. Water accumulation inside tanks is also a major cause of internal corrosion.

Soil Variations. Corrosion of underground tanks and pipes can be influenced by variations in soil conditions along the surfaces of those tanks and pipes.

Adjacent Underground Metal Structurs. Corrosion of Underground tanks and piping can also result in the case of new structures which are installed near other tanks or other underground metal structures. Because the older structures may have rusted they could become cathodic to the newer tanks or pipes, thereby accelerating corrosion in the new structures.

Stray Electrical Currents. Stray underground currents from nearby electrical facilities using DC current, such as electrified railway or transit systems, factories, or shops, can induce electrolytic corrosion in underground tanks and pipes.

cludes the categories of equipment selection, installation practices, and operating practices. Leak detection includes leak and spill monitoring, tightness testing, and secondary containment.

Leak Prevention

Equipment Selection. The selection of the appropriate type of equipment for a particular application is an essential first step in the prevention of leaks. Equipment needs include the tank, piping and fittings, overfill prevention devices, and transfer spill prevention equipment.

Types of Storage Tanks. In the past, underground storage concerns centered on chemical compatibility with the stored product, structural strength of the storage system components, and foundation (support) requirements. As a result, bare carbon steel was widely used for underground storage tanks. These steel tanks were structurally strong, required little in the way of foundation support other than uniform backfill, and were compatible with a wide range of liquids. However, carbon steel is particularly susceptible to corrosion, especially when installed in environments that are highly conducive to corrosion, such as moist or highly acidic soils.

Recent developments in tank design have emphasized corrosion resistance to improve the performance of underground storage systems. The methods currently available to protect against corrosion include cathodic protection, protection coatings, electrical isolation, or some combination of these. The use of corrosion-resistant materials of construction has also become more widespread.

- Coatings and Linings. Coatings and linings applied to the walls of tanks and piping can serve to protect these structures from contact with the environment, thereby inhibiting corrosion. Examples of common coating and lining materials are rubber, epoxies, silicones, and fiberglass reinforced plastic.
- Cathodic Protection. Cathodic protection works by reversing the electrochemical action of corrosion. Instead of allowing electrons to flow away from the structure (thereby permitting corrosion to occur) an electron flow toward the structure is induced, thereby protecting the structure. There are two basic types of cathodic protection. These are the sacrificial anode (or galvanic) cathodic protection method and the impressed current (or electromotive force) method. The galvanic cathodic protection method employs a sacrificial anode, such as magnesium or zinc, in electrical contact with the metal structure to be protected. The impressed current cathodic protection method employs direct current provided by an external source. Figures 8 and 9 show these types of cathodic protection systems.
- Electrical Isolation. As the name implies, electrical isolation involves the use of non-conductive dielectric fittings, bushings, connections, etc. to electrically isolate metal components in a storage system; this minimizes the potential for the generation of electrical currents between dissimilar metals.
- Corrosion-Resistant Materials of Construction. Corrosion can also be controlled through the use of cor-

corrosion-resistant materials of construction. Examples of these include special alloys, fiberglass reinforced plastic, and fiberglass reinforced plastic coatings.

Much of the tank equipment currently available incorporates one or more of these corrosion protection methods while remaining compatible with chemical and structural strength requirements. Examples include preengineered cathodically protected steel tanks, fiberglass-reinforced plastic (FRP) tanks, FRP-clad steel tanks, and double walled tanks.

Cathodically Protected Tanks—The pre-engineered tanks are basically standard steel tanks provided with three levels of corrosion protection: cathodic protection, a protective coating, and electrical isolation.

Fiberglass-Reinforced Plastic Tanks—FRP tanks are constructed of a plastic resin which provides chemical resistance, and a fiberglass material that gives the tank its structural strength. Insuring compatibility of the tank with the stored product is an important consideration since numerous resins and glass materials can be used in the fabrication of FRP tanks. For example, an FRP tank suitable for gasoline storage may not be suitable for storage of another substance.

FRP-Clad Steel Tanks— These tanks combine the corrosion resistance of fiberglass-reinforced plastic and the strength of steel. They are constructed of an outer layer of FRP fused to an inner layer of carbon steel via a polyester resin bond. The steel inner structure of an FRP/steel tank provides structural support and serves to keep stresses evenly spread.

Double-Walled Tanks—These tanks are essentially a tank within a tank with a vacuum or pressurized space between the inner wall and outer wall. Leaks due to internal or external corrosion can be detected by loss of pressure or vacuum. Common materials of construction include coated steel and fiberglass.

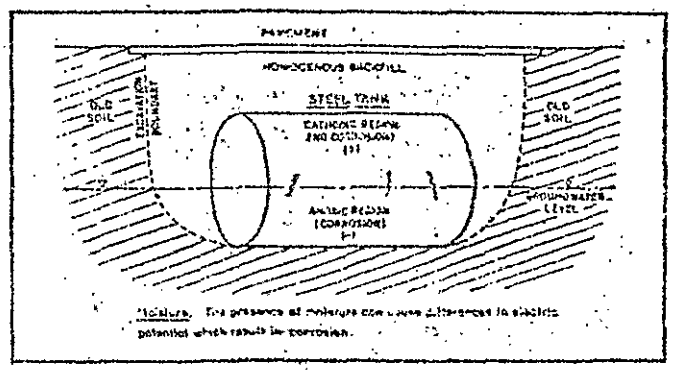
Piping Design. With the focus of concern on the prevention of leaks, there have also been improvements in piping and piping system design. For example, fiberglass-reinforced plastic pipe is now widely used in underground piping systems handling hydrocarbon products because of its inherent flexibility and its corrosion resistance. Expansion joints are more widely used to prevent or reduce pipeline stresses due to thermal expansion and contraction; eliminate vibration and noise in pipelines; compensate for piping misalignment which could otherwise result in problems; and reduce the likelihood of flange breakage due to piping movement. Swing joints are also becoming more widely used to provide rotational flexibility to pipelines. And double-walled pipes are also now increasing in popularity for handling very hazardous or toxic liquids.

Overfill Prevention. Overfill prevention is accomplished by measuring and controlling the liquid level in a tank. An unsophisticated system may include only a gauge which indicates liquid height in the tank. A sophisticated system could include an automatic shutoff system and a backup audible high level alarm to warn the operator of emergency conditions. The elements of a comprehensive overfill prevention system are highlighted in Table 4.

There are a variety of level sensing devices that have been designed to detect liquid levels in bulk storage

FIGURE 3

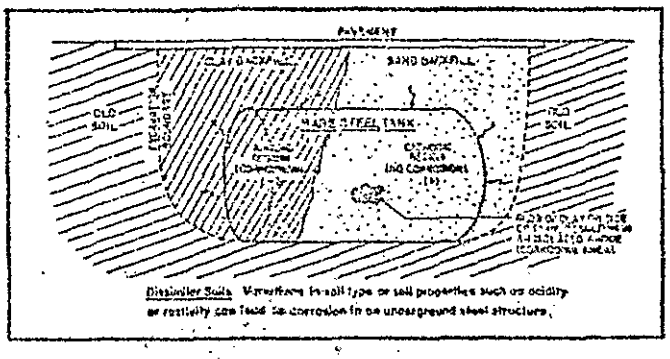
CORROSION MECHANISMS



SOURCE: FRED C. HART ASSOCIATES, INC.

FIGURE 4

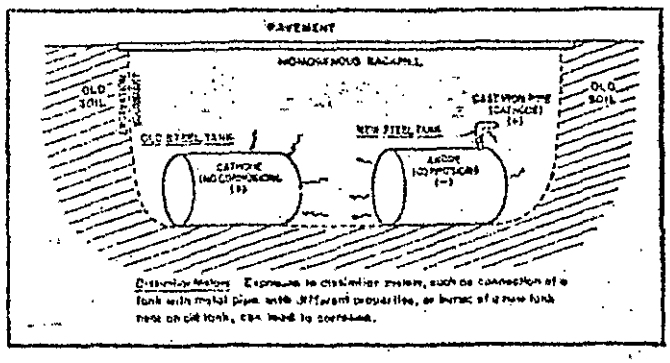
CORROSION MECHANISMS



SOURCE: FRED C. HART ASSOCIATES, INC.

FIGURE 5

CORROSION MECHANISMS



SOURCE: FRED C. HART ASSOCIATES, INC.

Table 4. Elements of a Comprehensive Overfill Prevention System

1. Level sensing device.
2. Level indicating device.
3. High level alarm.
4. Automatic shutoff control system.
5. Interlocking of the unloading process and the overfill prevention system so that loading cannot take place if the overfill prevention system in inoperative.
6. Bypass prevention so that the overfill prevention system cannot be overridden by the operator.

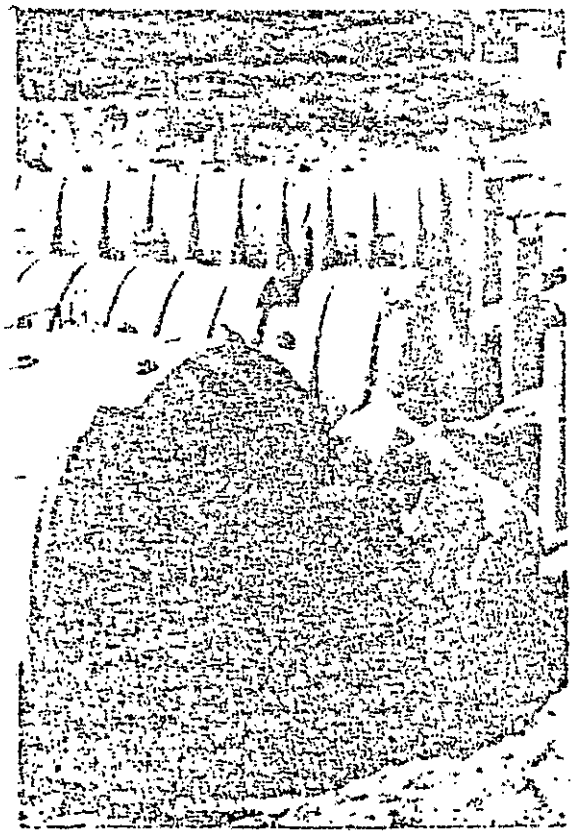


Figure 6. FRP tank failure of the type typically resulting from improper installation. *Source:* New York State Dept of Environmental Conservation.

tanks. These devices typically sense liquid characteristics, such as capacitance or thermal conductivity, or operate based on such common principles as buoyancy, differential pressure, and hydrostatic head. There are also sensing devices available which operate on the propagation and reflection of light waves or sound waves to detect liquid levels in a tank. Devices which operate these principles are generally independent of product flow rate, pressure, and temperature.

Transfer Spill Prevention. Spill prevention during transfer operations can be aided by using couplings equipped with spring loaded valves which automatically block flow when the hoses are disconnected. These include quick-disconnect couplings equipped with ball valves and dry-disconnect couplings. Emergency shutoff valves may also be provided in the product transfer line to stop flow in case of fire.

Installation Practices. As stated earlier, many leaks are traced to mishandling of storage tanks and equipment prior to installation, and to poor installation practices. The major areas of concern in underground storage installation practices are:

- Proper planning and design of the storage facility
- Care in handling of all equipment
- Proper selection of bedding and backfill material
- Proper anchoring of equipment.

Proper Planning and Design. Many storage problems occur as a result of poor site selection, or improper site layout and design. There are a number of planning and design concerns associated with underground storage installations. Table 5 summarizes the more important of these concerns.

Care in Handling. This is also an important consideration in prolonging the life of an underground storage facility. For example, although storage tanks are designed to withstand normal handling, and to provide secure product storage, they must not be dropped, handled with sharp objects, dragged, or rolled prior to and during installation.

Proper Bedding and Backfill. This is particularly critical in the case of FRP tanks, which receive as much as 90 percent of their structural support from the backfill and bedding used. Although steel structures are less dependent on backfill material for structural support, the use of good materials and adherence to sound engineering practices are essential for proper steel tank installation. Consistency in backfill and bedding material properties is also of utmost importance in the case of steel tanks. As mentioned earlier, soil variations can act to promote corrosion in steel structures.

Proper Anchoring of Equipment. To prevent flotation of tanks due to buoyant forces, weighting or anchoring of underground tanks is necessary under circumstances where the ground may become saturated with water, such as in floodplains or areas with high groundwater tables. Weighting the tank is accomplished by burying the tank deeper and/or adding a thicker surface (cover) slab. Anchoring involves strapping the tank to a reinforced concrete anchor pad buried beneath 12 in. or more of bedding, or strapping it to reinforced concrete deadmen layed along each side and parallel to the tank.

Operating Practices. Certain operating practices are recommended to prevent overfilling of tanks and to limit the likelihood of transfer spills, both of which may result in leakage into the groundwater. The more important of these are highlighted in Table 6.

Leak detection

The area of leak detection encompasses leak and spill monitoring, tightness testing, and secondary containment. Current technology and recommended practices in these areas are discussed below.

Leak and Spill Monitoring. Leak and spill monitoring can be accomplished through the use of either early warning leak detection systems that provide continuous surveillance for leaks or spills, or area-wide surveillance methods that may be used to investigate or pinpoint the source of a known or suspected spill or leak.

Early Warning Systems. Early warning leak detection systems typically provide continuous surveillance for the presence of a leak or spill. The types of early warning monitoring systems most widely used are the following:

1. Inventory monitoring (also called inventory control).
2. Interstitial monitors in double-walled tanks.
3. Systems that monitor the storage tank excavation. These types of systems include observation wells, U-tubes, and wire grids. The types of leak sensors used include:
   - thermal conductivity sensors;
   - electric resistance sensors; and
   - vapor detectors.

Inventory Control—Early detection of leaks may be achieved by regular reconciliation of tank inventory and book inventory, regular inspections of the visible parts of the product handling system, and prompt recognition of the conditions that indicate leaks in underground tanks and piping. Inventory monitoring is a technique that is widely applicable to any stored or transported product.

The accuracy of inventory control as a leak detection method is limited by several factors. These include the following:

1. Product thermal expansion.
2. Errors associated with faulty reading of dip stick measurements.
3. Errors associated with resolution in meter readings.

Given these limitations in accuracy, even a carefully conducted inventory monitoring program can only detect leaks that accumulate to an appreciable fraction (typically 0.5 to 1%) of the tank throughput.

Automatic inventory monitoring systems that take into consideration thermal expansion, and produce periodic readouts of product level have been developed recently by a number of manufacturers.

Interstitial Monitoring in Double-Walled Tanks—An early warning monitoring technique characteristic of double walled tanks involves monitoring the space between the inner and outer walls of the tank, using either fluid sensors or pressure sensors to detect the presence of liquid or change in pressure respectively to indicate a leak.

Table 5.
Planning and Design Considerations for Installing Underground Storage Facilities

SITE CONDITIONS

Soil Characteristics. Clays, wet soils, cinders and acid soils are highly corrosive and can significantly affect the rate of corrosion of metal tanks and piping.

Depth to Groundwater. Tanks installed in areas of high groundwater or in floodways must be properly anchored. Tanks placed in water-filled excavations require ballasting and special installation.

Land Use at the Site. Sites which contain abandoned pipes and tanks, agricultural drainage tiles, or landfill materials pose special installation problems. New metal parts may become anodic to old tanks and pipes. Fill may be highly corrosive. Agricultural drainage tiles or old storm drains may breach secondary containment barriers. Old buried tanks which were not properly filled when they were abandoned may collapse and cause foundation problems for newly installed tanks and pipes. In addition, stray electric currents from nearby underground power lines or from improperly constructed electric systems may cause problems of accelerated corrosion.

LAYOUT

Tank Fill Openings. Tank fill openings should be located to minimize maneuvering during truck deliveries and so that delivery trucks are not blocking driveways or located on public right-of-ways.

Maps of Facilities. As-built drawings should be prepared so that underground electrical circuits, pipes and tanks can be readily located.

DESIGN CONSIDERATIONS

Bimetallic and Galvanic Cells. Dissimilar metals in proximity to each other can cause problems with corrosion.

Initial Costs vs. Operating Costs. Frequently a higher initial capital outlay can mean lower operating costs over the long run.

Selection of Materials/Equipment. The choice of tank, whether steel or fiberglass, the dimensions of the tank, and the type of pump system may be determined by such factors as rock conditions, pumping lift requirements, or other site conditions described above.

Traffic. The type and amount of traffic above tanks and pipe galleries affect the physical loads on underground facilities and therefore must be considered in the design.

Venting. Each tank should be vented to prevent the buildup of excessive pressure or the blowback of vapor or liquid at the fill opening when the tank is being filled.

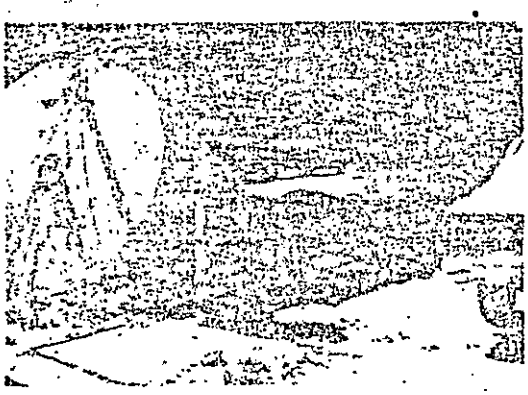
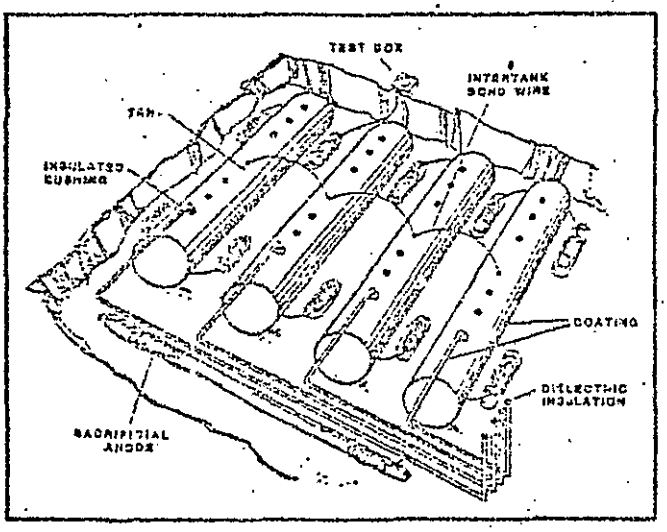


Figure 7. Steel tanks which floated to the surface because they were not properly anchored in an area of high groundwater. Source: New York State Dept of Environmental Conservation.

FIGURE 6

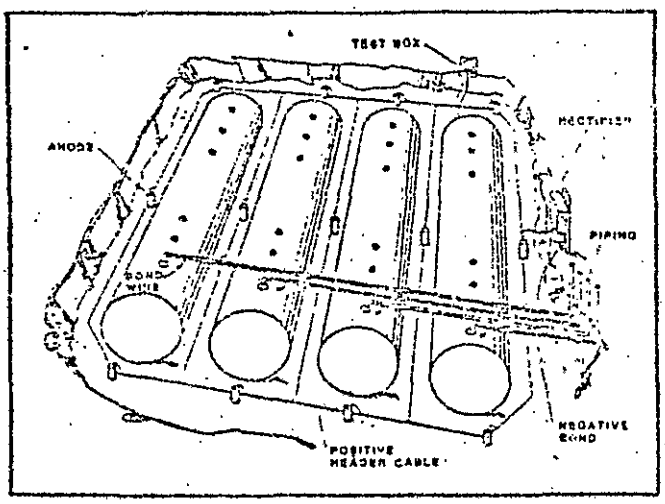
A GALVANIC CATHODIC PROTECTION SYSTEM CONFIGURATION



SOURCE: Suggested Ways to Meet Corrosion Protection Codes for Underground Tanks and Piping; The Hinchman Company, Detroit, MI.

FIGURE 8

AN IMPRESSED CURRENT CATHODIC PROTECTION SYSTEM CONFIGURATION



SOURCE: Suggested Ways to Meet Corrosion Protection Codes for Underground Tanks and Piping; The Hinchman Company, Detroit, MI.

Tank Excavation Monitoring Systems—There are several types of leak monitoring systems which may be employed using the leak sensors or detection techniques described above to detect leaks in or around underground tank storage areas. The types of systems include the following:

1. Wire grids.
2. Observation wells.
3. U-tubes.

Wire grid systems employ electrical resistivity sensors in a wire grid located either within or just outside the containment region (e.g. just inside or outside the secondary containment liner).

Observation wells are most commonly used in areas of high groundwater, where the underground tank is likely to be anchored in the groundwater during normal operation. An example of an observation well installation is shown in Figure 10.

A typical U-tube installation is shown in Figure 11. U-tube monitoring systems are most effective in areas of low groundwater, where exposure to groundwater is unlikely during normal operation.

Area-wide Surveillance Methods. Area-wide surveillance methods include the use of monitoring wells and the use of dyes or tracers. These methods are relied upon to investigate or pinpoint the source of a known leak or spill.

Dyes and Tracers—Dyes and tracers may be used as investigative tools to track down a source of groundwater contamination. The technique consists of injecting a strong dye or tracing material into a storage tank suspected of being the source of the contamination and monitoring the point where the contamination was first discovered for the appearance of the dye or tracer.

Monitoring Wells—There are two basic types or categories of monitoring that can be conducted using monitoring wells. These are:

1. Detective monitoring, which establishes the presence or absence of contaminants and the need for further monitoring.
2. Interpretive monitoring, which determines the extent of contamination.

Detective monitoring can be conducted using contaminant sensing devices such as those described earlier. Interpretive monitoring, on the other hand, typically requires sample collection and analysis.

Testing of Storage Systems

Tightness Testing of Tanks. The National Fire Protection Association (NFPA) has established the standard for accuracy of tank tightness tests in their definition of the Precision Test, as highlighted in Table 7. There are several tank testing techniques currently available. These include:

1. The Heath Petro-Tite (formerly Kent-Moore) Test.
2. The Hunter (formerly Sunmark) Leak Lokator.
3. The Horner Ezy Check Test.
4. The J-tube manometer test.
5. The ARCO HTC test.
6. Pneumatic (air or pressure) testing.

The first two tests in this list, the Heath Petro-Tite test and the Leak Lokator are currently the only widely available tank testing techniques that meet the NFPA

criteria of a Precision Test.

Petro-Tite Test—The Petro-Tite test, as shown in Figure 12, is essentially a hydrostatic test that compensates for temperature, pressure and viscosity variations. This test is conducted by exerting a pressure head on the tank by means of a standpipe filled with the same liquid stored in the tank. A pump is used to circulate the liquid in order to produce a uniform temperature throughout the tank. Using a thermal sensor, the temperature changes are precisely measured to account for expansion and contraction of the liquid. The volumetric measurements taken in the standpipe are then correspondingly adjusted for the changes in temperature.

Leak Lokator Test—The basic equipment of the Leak Lokator, as shown in Figure 13, consists of a sensor, an analytical balance, and two chart recorders. To conduct the test, the sensor is suspended from the analytical balance and partially submerged in the tank liquid. As the liquid level in the tank changes, the buoyancy of the sensor also changes. This change of mass displacement measured by the analytical balance is an indication of volume changes within the tank. One chart recorder provides a permanent graphical representation of volume change versus time. The Leak Lokator test compensates for temperature variations by means of a sensor lowered to the center of the tank that measures temperature continuously during the test, and records this on the second chart recorder.

Pressure Testing—Pressure testing, with air or other gases, of tanks or piping containing flammable or combustible liquids is not recommended, should not be required by regulations or ordinances, and should be discouraged in practice. Such tests are not likely to detect a leak that is below the liquid level in the tank, there is severe danger of causing a tank rupture, or expulsion of contained liquid through normal openings.

Piping Tightness Tests. The applicability of pipeline testing techniques depends, in part, upon whether the piping system in question involves the use of remote (typically submerged) pumps or suction pumps to deliver the tank contents.

If the pump is aboveground, the product delivery pipe operates under a suction head, and certain pumping characteristics can indicate the presence of a piping leak. These indications are presented in Table 8. In the case of a submerged pump system, a pipeline leak detector can be used to indicate the presence of a leak in the product delivery line. This device is mounted on the discharge line above the tank and operates as described in Table 9. Product lines can also be tested hydrostatically to detect leaks.

Secondary Containment Technology. The control technology used to contain underground spills and leaks consists of establishing a barrier around the storage tank so that any leaked liquid does not have a free path to escape from the storage area.

Types of Liners. The barrier materials that can potentially be used for containment include the following:

1. Soil liners with low permeability (e.g., clay).
2. Synthetic membrane liners.
3. Soil sealants, such as soil cement or bentonites.
4. Concrete vaults.
5. Double-walled tanks.

Table 6.
Operating Practices to Prevent Overfilling and other Spills

1. Loading and unloading of vehicles should be done only in approved locations.
2. The driver, operator, or attendant of any delivery vehicle should not leave the vehicle unattended during the loading or unloading process. The delivery hose, when attached to the vehicle, should be considered to be a part of that vehicle.
3. When transferring flammable liquids, motors of delivery vehicles and motors of auxiliary or portable pumps should be shut off during the making or breaking of hose connections. If loading or unloading does not require the use of the delivery vehicle's motor, the motor should be shut off throughout the liquid transfer operation.
4. Labels, markings, or color codes should be used on all couplings and hoses to prevent accidental mixing of incompatible liquids.
5. All transfer hoses should be inspected periodically for leaks.
6. Any operator of a loading or unloading operation should be properly trained and should be aware of all potential problems.

Table 7. Precision Test

Precision Test, as defined by NFPA, means any test that takes into consideration the temperature coefficient of expansion of the product being tested as related to any temperature change during the test, and is capable of detecting a loss of 0.05 gal (190 ml) per hour.

The key factors that must be accounted for in a Precision Test Are:

- Temperature changes
- Evaporation losses
- The presence of vapor pockets
- Tank and piping characteristics
- Water table
- Tank end deflection

Table 8. Suction Line Testing

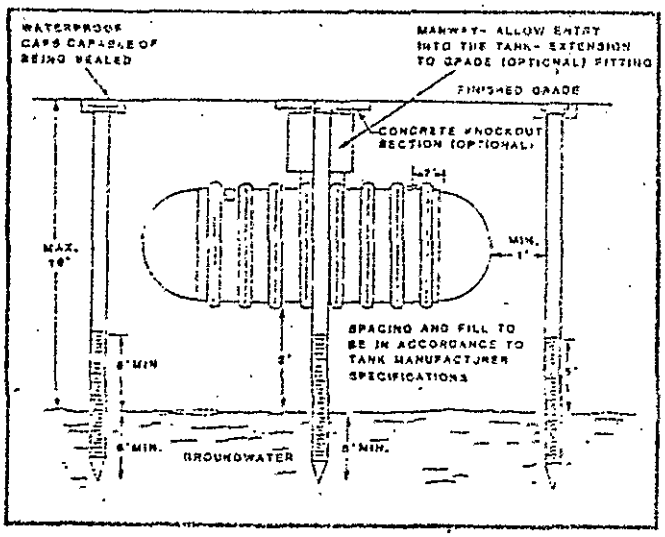
Air will enter the piping system if a leak exists.

Signs of leaks include:

- Skipping or jumping of the display wheels at the meter.
- The pump is running but not pumping liquid.
- The pump seems to overspeed when first turned on and then slows down as it begins to pump liquid.
- A rattling sound in the pump and erratic liquid flow indicates air and liquid are mixed.

EXAMPLES OF OBSERVATION WELLS

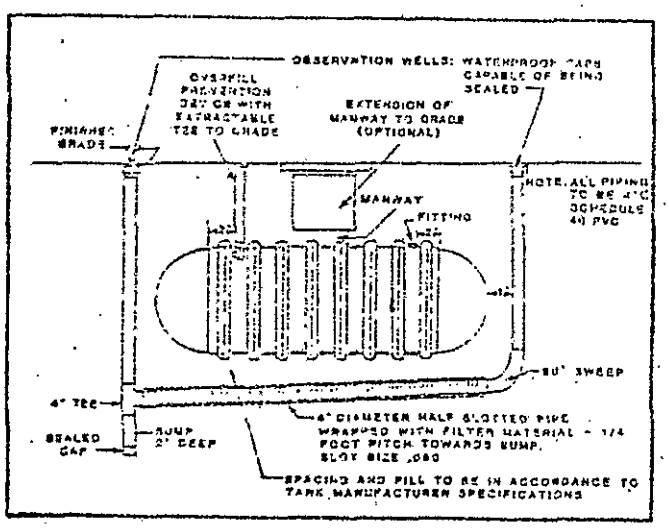
EACH WELL CONSISTS OF 4" PERFORATED PVC PIPE, DRIVEN AT LEAST 2 FEET BELOW THE BOTTOM OF THE TANK AND AT LEAST 5 FEET INTO THE GROUNDWATER



SOURCE: SUFFOLK COUNTY, N.Y. DEPARTMENT OF HEALTH SERVICES

FIGURE 11

EXAMPLE OF A U-TUBE INSTALLATION



SOURCE: SUFFOLK COUNTY, N.Y. DEPARTMENT OF HEALTH SERVICES

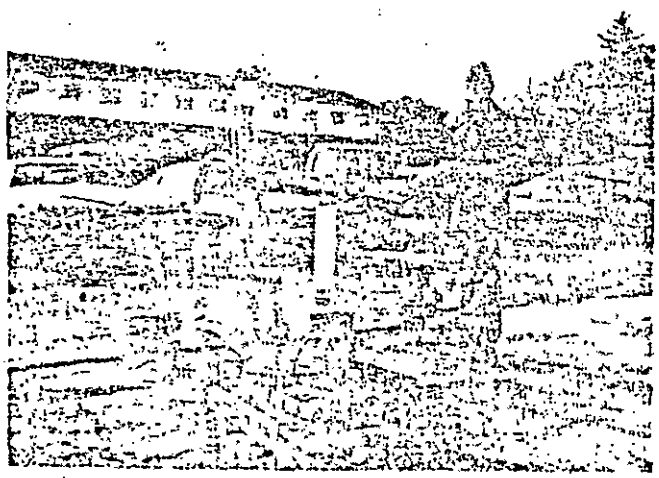


Figure 12. The Petro-Tite tank testing system in use.
Source: American Petroleum Institute.

Selection Considerations. Selection of the proper containment material and configuration for a particular application depends upon several factors including:

1. The type of material being stored.
2. Local environmental conditions.
3. Legislative requirements.

Type of Material Being Stored—Consideration of compatibility with the stored liquid is important: the liner material must be able to maintain its integrity and impermeability when exposed to the stored product.

Local Environmental Conditions—The sensitivity of the environment in the vicinity of the storage facility can largely affect the level of environmental protection and hence the type of containment liner required. For example, in areas where the storage facility is located near or above an aquifer, greater care may be required in the selection and installation of the containment liner. The level of the groundwater table in the area is also a major concern. Figures 14 and 15 give examples of groundwater level considerations in secondary containment system configuration.

Legislative Requirements—Local governments may be highly prescriptive and specific in terms of the type of containment barrier required.

Regulatory trends

Until recently, bulk storage regulations at the federal, state and local levels have focused on the hazards of aboveground storage. Spill Prevention, Control, and Countermeasures (SPCC) plans and OSHA safety requirements are common examples of the degree to which aboveground bulk storage controls have progressed. However, with the recent increased awareness of the dangers and potential costs of groundwater contamination, regulators have recognized the need to control underground storage as well. Programs regulating underground storage practices have been implemented in many localities, and the federal government and several states are beginning to develop comprehensive regulations in this area.

State and Local Regulations

The approaches being taken at the state and local level to address the underground storage issue have varied widely in response to local concerns, such as the number of underground storage systems in use, or the general depth to potable groundwater in the region. Table 10 presents information showing the items which are regulated in selected states, including the areas of equipment specifications, secondary containment requirements, inventory control requirements, and monitoring requirements.

As an example of equipment specifications, Florida's regulations limit acceptable designs for new tanks to cathodically protected steel, glass fiber reinforced plastic (FRP), steel clad with FRP, doubled-walled steel or FRP, or other equivalent approved designs. These regulations also require that new tanks have strike plates.

As an example of secondary containment requirements, the state of Kansas requires that the excavation bottom (base) of a storage facility consist of an impervious material approved by the Department of Health.

and Environment, and that this base be sloped to a collection basin.

As an example of inventory control requirements, Maryland requires the following:

- Daily measurements of liquid level for comparison with pump meter readings and receipts each day. These records shall be retained for one year.
- Loss of product above normal evaporation (proposed definition: 0.5% of pump meter readings) shall be reported immediately.

As an example of monitoring requirements, Florida's regulations require that new facilities have one of the following:

a. A continuous leak detection system in between the walls of a double-walled tank.
b. A single monitoring well or detector located in an impervious secondary containment.
c. A continuously operating leak detection system placed around a tank in an excavation or secondary containment in accordance with the manufacturer's requirements.
d. A network of at least four monitoring wells placed around a tank or tanks.
e. A groundwater monitoring plan submitted to and approved by the department for the pollutant storage facility.
f. An approved Spill Prevention Control and Cleanup plan for the pollutant storage facility submitted to the department.
g. Another alternative approved by the state.

In addition to the state programs, there are currently over 65 local (county or town) programs either proposed or in place with provisions that address underground product storage. Of these local ordinances, several have received extensive attention due to their scope or particular requirements. The four most prominent programs of this type are those of Santa Clara County, CA, Suffolk and Nassau Counties in New York, and Dade County, FL. Other notable programs include those of Dallas/Ft. Worth, Austin, and Houston, TX, and the model ordinance developed by the Cape Cod Planning and Economic Development Commission, which has been adopted by several communities on the Cape.

Federal Activity

The federal government is also actively analyzing and debating the underground storage issue. At the moment, EPA is considering the use of the Toxic Substances Control Act (TSCA) to regulate leaking underground storage tanks, and in the process created the acronym *LUST*. Two initiatives are currently under way at the agency. Once is the issuance of a chemical advisory warning owners and operators about the issue. The second is a careful statistical study of a national sample of tanks designed to provide a definitive assessment of the size, scope, and nature of the leaking underground storage tank problem.

Congress has also recently introduced several bills which address various aspects of the issue. For example, one bill would amend the Resource Conservation and Recovery Act (RCRA) to require EPA to develop final regulations on underground hazardous waste

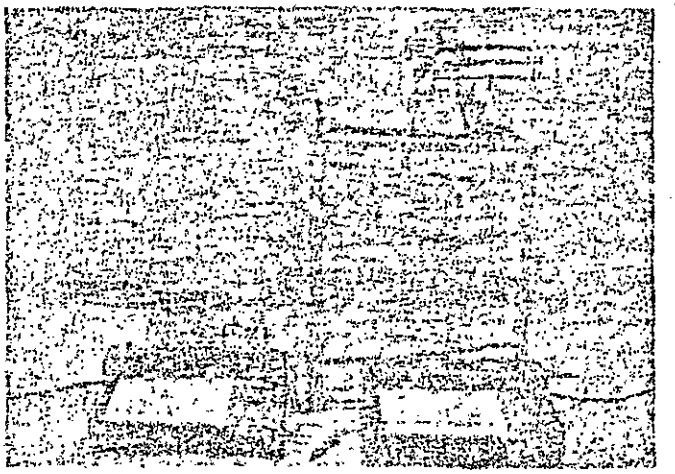
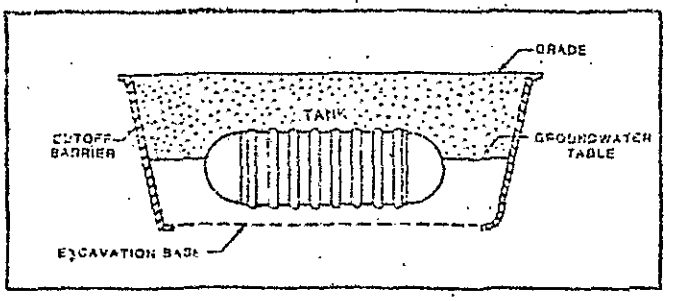


Figure 13. The basic equipment of the Leak Lokator Test. *Source:* Hunter Environmental Services.

FIGURE 14

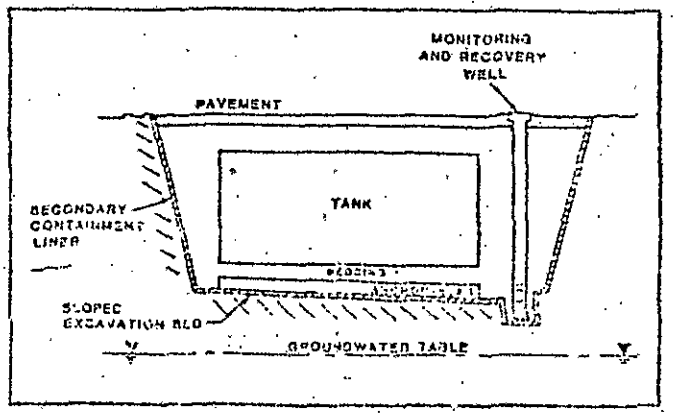
SCHEMATIC OF A CUTOFF BARRIER USED FOR SECONDARY CONTAINMENT IN AN AREA OF HIGH GROUNDWATER (STORING LIGHTER-THAN-WATER LIQUIDS)



SOURCE: FRED C. HART ASSOCIATES, INC

FIGURE 15

AN EXCAVATION LINER USED FOR SECONDARY CONTAINMENT IN AN AREA OF LOW GROUNDWATER (DRY INSTALLATION)



SOURCE: FRED C. HART ASSOCIATES, INC

Under Regulation in Selected States

	CT	MD	FL	KS	MI	OH	WI	IL	CA
Permits	●	●	●	●	●	●	●	●	●
Equipment Specifications	●	●	●		●			●	
Installation			●	●	●		●		
Secondary Containment			●	●				●	●
Replacement	●	●	●		●				●
Inventory Control	●	●	●	●	●	●	●	●	●
Tightness Testing	●	●	●	●	●	●	●		●
Monitoring & Leak Detection		●	●	●	●		●		●
Closure			●		●		●	●	●
Recordkeeping	●	●	●	●	●	●	●		●
Penalties							●	●	●

Table 9. Pipeline Leak Detector

- The pipeline detector is a pressure sensing valve installed on the discharge line of submersible pumps.
- It is designed to indicate a leak between the pump and the dispenser.
- It can be easily installed on virtually all types of pumps.
- When the pump is turned on, the detector allows only three (3) gal per hour to flow.
- If a leak is present, pressure does not build up in the piping system
  1. Once the dispenser nozzle is opened, if pressure is low, the detector moves to restrict flow to 3 GPM.
  2. This is the indication of a leak.
- If there are no leaks, pressure builds up in the system, which opens the leak detector to full flow position.

tanks. Another bill would amend the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) to allow money from that law's cleanup fund to be spent on cleaning up leaks from underground gasoline storage tanks.

Conclusion

The prevention of environmental nightmares caused by leaking underground tanks has recently received increased attention from regulators and the regulated community, and may become one of the most significant environmental issues of the decade. The good news to the owners of underground tanks is that the causes of leaks are known and the technology to prevent and detect them is reasonably well developed. The bad news is that the installation of equipment to prevent damage will be expensive, and the implementation of programs to comply with regulations may result in extensive procedural modifications. However, a soundly designed, properly maintained underground storage system can pay for itself by minimizing product losses and reducing liabilities. By using the information in this article, owners of underground storage systems can develop an awareness of potential problems, their causes, and available technologies to comply with regulations as they are developed. PE

Paul H. Woods, Jr. is the Manager of the Bulk Storage Group in the New York office of Fred C. Hart Associates. Mr. Woods has extensive experience with underground and aboveground bulk storage of hazardous liquids. He has completed a technology manual for the New York State Department of Environmental Conservation (DEC) which describes the state of the art in: tank and piping system design; installation practices; secondary containment systems; leak detection and leak monitoring systems; tank tightness testing procedures; transfer spill and overfill prevention systems and procedures; and temporary and permanent closure of storage facilities. He has also prepared a manual of recommended practices and guidelines for underground storage which will be used by DEC to support its underground bulk storage regulations. Mr. Woods has a Master's Degree in Civil Engineering and a Bachelor's Degree in Mechanical Engineering, both from the Massachusetts Institute of Technology.

Dale E. Webster is an Environmental Engineer with Fred C. Hart Associates. His experience with bulk storage systems includes the nationwide review of existing state programs for underground storage, and the analysis of alternative regulatory strategies for state agencies. He has also presented recommended design modifications to industries for compliance with underground storage regulations, and has written numerous permit applications for hazardous waste bulk storage and treatment-in-tanks facilities. He has a Master's Degree in Environmental Engineering from Duke University, and a Bachelor's Degree in Agricultural Engineering/Environmental Technology from Cornell University.

Bibliography

American Petroleum Institute, *Installation of Underground Petroleum Storage Systems*. API Publication 1615, Washington, DC, 1979.

American Petroleum Institute, *Recommended Practice for Bulk Liquid Stock Control at Retail Outlets*. APE Publication 1621, Washington DC 1977.

Clemmer Industries, Ltd., *Double-Walled Storage Tanks*. Waterloo, Ontario, August, 1981.

Dover Corp., *OPW Swivel Joints: Ball Bearing Joints for Flexible Piping Systems*, Catalog SJ, Cincinnati, OH, February, 1980.

Fred C. Hart Associates, Inc., *Criteria and Guidance for Underground Storage of Petroleum*, prepared for New York State Department of Environmental Conservation, Albany, NY, 1984.

Fred C. Hart Associates, Inc, *Technology for the Storage of Hazardous Liquids: A State-of-the-Art Review*, prepared for New York State Department of Environmental Conservation, Albany, NY, 1983.

Hasse Tank GmbH & Co., KG, Hasse: *The Double-Wall, Self Monitored Tank*, Betco Associates, Closter, NJ.

Heath Consultants, Inc., *Procedure Manual For The Operation of the Petro Tite Tank Tester*, Form #582 HPN 5124, Stoughton, MA.

102. 16A American Jurisprudence, (2d ed.), Sections 360-374

AMERICAN JURISPRUDENCE

SECOND EDITION

A MODERN COMPREHENSIVE TEXT STATEMENT
OF AMERICAN LAW

STATE AND FEDERAL

COMPLETELY REVISED AND REWRITTEN
IN THE LIGHT OF MODERN AUTHORITIES AND DEVELOPMENTS
BY THE EDITORIAL STAFF OF THE PUBLISHERS

VOLUME 16A

CONSTITUTIONAL LAW §§ 360–869

1979

THE LAWYERS CO-OPERATIVE PUBLISHING CO.
Rochester, New York 14694

BANCROFT-WHITNEY CO.
San Francisco, California 94107

4. Particular Constitutional Provisions as Imposing Limitations

§ 402. Fourteenth Amendment, generally
§ 403. Due process
§ 404. Equal protection
§ 405. Obligation of contracts
§ 406. —Public contracts restricting police power
§ 407. —Emergency legislation
§ 408. Reasonable compensation for appropriation of private property
§ 409. Freedoms of speech, press, religion, assembly
§ 410. Privileges and immunities provisions
§ 411. Other provisions

C. Exercise of Power

1. In General

§ 412. Generally
§ 413. Subjects of power
§ 414. General scope of power
§ 415. Necessity that public benefit be commensurate with private detriment

2. Purposes for Exercise of Power, Generally

§ 416. General welfare
§ 417. Physical welfare; public health and safety
§ 418. Public morals
§ 419. Public peace, good order, and comfort
§ 420. Public convenience and general prosperity; economic or financial welfare
§ 421. Protection of environment or ecology
§ 422. Conservation of natural resources
§ 423. Prevention of fraud

3. Regulation and Prohibition of Occupations and Businesses

a. Occupations and Businesses Subject to Control

§ 424. Generally
§ 425. Lawful pursuits
§ 426. —Professions
§ 427. Businesses affected with a public interest
§ 428. —Meaning of "affected with a public interest"
§ 429. —Legislative and judicial functions in determining businesses included

b. Mode of Regulation

§ 430. Generally
§ 431. Businesses affected with a public interest
§ 432. Prohibitions
§ 433. Fixing terms, conditions, and restrictions
§ 434. —Restrictions to qualified persons
§ 435. —Restrictions as to place

§ 436. —Restrictic
§ 437. —Restrictic
§ 438. Imposing li

X. FUNDA

A. In Ge

§ 439. Constitutio
§ 440. —"Bills of
§ 441. Rights as in
§ 442. —"Natural"
§ 443. Entitlement
§ 444. Enforcemen
§ 445. Equality of
§ 446. Limitations

B. Feder

§ 447. First ten am
§ 448. —Resume o
§ 449. —As protec
§ 450. —Applicabil
§ 451. Later amen
§ 452. Fourteenth
§ 453. —Complete
§ 454. —Specific p
§ 455. —To whom

C. Speci

1. Fir

a. I

§ 456. Generally
§ 457. To whom A
§ 458. Validity of l
§ 459. Vagueness c
§ 460. Overbreadth
§ 461. —Procedura
§ 462. —Substantiv
§ 463. —Specific fi

b. F

§ 464. Generally
§ 465. Nature of ri
§ 466. "Establishm
§ 467. —Incidental
§ 468. —Requirem
§ 469. —Excessive
§ 470. —Use by rel

§ 436. —Restrictions as to time
§ 437. —Restrictions as to price
§ 438. Imposing liabilities

X. FUNDAMENTAL RIGHTS AND PRIVILEGES

A. In General

§ 439. Constitutional guaranties, generally
§ 440. —"Bills of Rights"
§ 441. Rights as independent of constitutions
§ 442. —"Natural" rights
§ 443. Entitlement to rights
§ 444. Enforcement of rights; against whom enforceable
§ 445. Equality of rights; effect of conflict
§ 446. Limitations on rights

B. Federal Constitutional Guaranties, Generally

§ 447. First ten amendments
§ 448. —Resume of provisions
§ 449. —As protecting unspecified fundamental rights; "penumbra" doctrine
§ 450. —Applicability to state and federal governments
§ 451. Later amendments
§ 452. Fourteenth Amendment and effect thereof; generally
§ 453. —Complete or "selective" incorporation of Bill of Rights
§ 454. —Specific provisions of Bill of rights as applicable to states
§ 455. —To whom Fourteenth Amendment applicable

C. Specific Fundamental Rights

1. First Amendment Rights

a. In General

§ 456. Generally
§ 457. To whom Amendment applies
§ 458. Validity of legislation, in general
§ 459. Vagueness of legislation
§ 460. Overbreadth of legislation; generally
§ 461. —Procedural aspects of doctrine
§ 462. —Substantive aspects of doctrine
§ 463. —Specific fields of legislation

b. Religious Freedom

§ 464. Generally
§ 465. Nature of right, generally; definition of "religion"
§ 466. "Establishment of religion," generally; separation of church and state
§ 467. —Incidental benefit rule
§ 468. —Requirement of governmental neutrality
§ 469. —Excessive entanglement rule
§ 470. —Use by religious organizations of civil courts

§ 471. "Free exercise" of religion; generally
§ 472. —Incidental detriment rule
§ 473. —Permissible governmental regulation of religious activities
§ 474. —Protection of children
§ 475. —Religious beliefs as defense to crimes
§ 476. Standing to challenge legislation or activities
§ 477. State constitutions
§ 478. Particular applications
§ 479. —Aid to churches, generally
§ 480. —Aid to hospitals or other charitable institutions operated by religious groups
§ 481. —Education
§ 482. —Use of public places or property, generally
§ 483. —Distribution of religious tracts or pamphlets
§ 484. —Health matters; medical treatment
§ 485. —Judicial proceedings
§ 486. —Licenses and permits, generally
§ 487. —Marriage, divorce, and other domestic relations
§ 488. —Military service or instruction; conscientious objection
§ 489. —Prison inmates
§ 490. —Private employment or labor
§ 491. —Property matters; zoning; condemnation
§ 492. —Public office or employment
§ 493. —Sabbath observance; Sunday closing or "blue" laws
§ 494. —Taxation; exemptions
§ 495. —Other applications

c. Freedom of Speech and Press

§ 496. Generally; constitutional protection
§ 497. Nature, purpose, and scope of constitutional guaranties; in general
§ 498. —Freedom from prior restraint; censorship
§ 499. —Guaranties as protecting publication, distribution, and receipt of material
§ 500. —Broad or liberal construction, generally
§ 501. —Who is protected
§ 502. —Who is bound
§ 503. —Conflict with right of privacy
§ 504. —Interference with newsgathering function; access to information
§ 505. —Regulation of press as business; "commercial speech"
§ 506. General limitations
§ 507. Limitation by legislation, generally
§ 508. —"Clear and present danger"
§ 509. —Rule as to advocacy of unlawful acts
§ 510. Subject, scope and manner of speech; generally
§ 511. —Unprotected utterances, generally
§ 512. —Obscene matter
§ 513. —Incitement to crime; breach of peace
§ 514. —Seditious, subversive, or treasonous activities or utterances

§ 515. —Obstructio
§ 516. —Disrespect
§ 517. Medium, pla
§ 518. —Regulation
§ 519. —Regulation
tion
§ 520. —Regulation
§ 521. Manner of re
§ 522. —Licensing
§ 523. —Taxation
§ 524. Protection as
§ 525. Freedom of l

d. R

§ 526. Generally
§ 527. Nature and e
§ 528. Application o
§ 529. Application o
§ 530. Limitation an
§ 531. —Requiremer
§ 532. —Restrictions

e. Fr

(1.

§ 533. Generally; ori
§ 534. Aspects of rig
§ 535. Assertion of r

(2.

§ 536. Generally; pro
§ 537. Relationship b
or goals
§ 538. Right to anon
§ 539. Guilt by assoc
§ 540. Forced and pr

(3.)

§ 541. Attorneys; con
§ 542. —Inhibited as
§ 543. Labor unions
§ 544. Minority grou
§ 545. Political partie
§ 546. —Communist
§ 547. Social clubs
§ 548. Student organi
§ 549. Tenants; assoc
§ 550. Prison inmates
§ 551. Other associati

§ 515. —Obstruction of war measures
§ 516. —Disrespect of flag; displaying red flag
§ 517. Medium, place, or time of utterance; generally
§ 518. —Regulation or limitation, in general
§ 519. —Regulation of particular means or forms of utterance or dissemination
§ 520. —Regulation of use of particular places
§ 521. Manner of regulation or infringement of rights; generally
§ 522. —Licensing
§ 523. —Taxation
§ 524. Protection as extending to silence; compelled expression
§ 525. Freedom of legislative debate; parliamentary freedom

d. Right to Assemble Peaceably and to Petition Government

§ 526. Generally
§ 527. Nature and extent of right
§ 528. Application of rights in civil actions
§ 529. Application of rights in criminal actions
§ 530. Limitation and regulation; generally
§ 531. —Requirement of license or permit
§ 532. —Restrictions as to place or time

e. Freedom of Association

(1.) General Considerations

§ 533. Generally; origin and nature of right
§ 534. Aspects of right
§ 535. Assertion of right

(2.) Governmental Regulation

§ 536. Generally; protection against infringement of right by state regulation
§ 537. Relationship between state regulation and legality of association's aims or goals
§ 538. Right to anonymity or associational privacy
§ 539. Guilt by association
§ 540. Forced and prohibited associations

(3.) Particular Associations

§ 541. Attorneys; compelled association with bar groups
§ 542. —Inhibited associations
§ 543. Labor unions
§ 544. Minority group organizations
§ 545. Political parties and organizations; generally
§ 546. —Communist or other subversive organizations
§ 547. Social clubs
§ 548. Student organizations and activities
§ 549. Tenants; association in housing
§ 550. Prison inmates
§ 551. Other associations

§ 849. Right to confront and cross-examine witnesses
§ 850. Prescribing rules of evidence
§ 851. Presumptions and burden of proof; generally
§ 852. —Creation of statutory presumptions

3. THE TRIBUNAL

§ 853. Generally
§ 854. Necessity of judicial tribunal
§ 855. Requirements of fairness and impartiality
§ 856. —Pecuniary interest of judicial officer
§ 857. —Protection against arbitrary rulings

4. REVIEW OF DETERMINATION

§ 858. Generally; rehearing or new trial
§ 859. Appeal or similar review

XVI. FULL FAITH AND CREDIT

§ 860. Constitutional provision, generally
§ 861. History of provision
§ 862. Interpretation of provision
§ 863. Operation and effect of provision, generally
§ 864. Statutes and constitutions as "public acts"
§ 865. Application of provision to federal statutes
§ 866. Exceptions to provision
§ 867. —Policy of forum
§ 868. Application of provision to particular public acts and statutes
§ 869. When federal question arises under provision

IX. POLICE POWER

A. IN GENERAL

1. SOURCE; DEFINITIONS

§ 360. Generally.

The police power is an indispensable,[57] essential[58] and vital[59] attribute of

57. Miller v Board of Public Works, 195 Cal 477, 234 P 381, 38 ALR 1479, error dismd 273 US 781, 71 L Ed 889, 47 S Ct 460.

58. McInerney v Ervin (Fla) 46 So 2d 458; State ex rel. Zugravu v O'Brien, 130 Ohio St 23, 3 Ohio Ops 74, 196 NE 664; State v Langley, 53 Wyo 332, 84 P2d 767.

59. Cincinnati v Public Utilities Com., 98 Ohio St 320, 3 Ohio L Abs 19, 121 NE 688, 3 ALR 705 (ovrld on other grounds United Fuel Gas Co. v Ironton 107 Ohio St 173, 1 Ohio L Abs 881, 140 NE 884, 29 ALR 342) and (ovrld on other grounds New Boston v Public Utilities Com. 108 Ohio St 352, 1 Ohio L Abs 882, 140 NE 607).

sovereignty;[60] indeed, some courts have viewed it as of higher status than an attribute of sovereignty,[61] describing the power as constituting sovereignty,[62] or as synonymous with sovereign power.[63] In any case, it is clear that the power is a necessary attribute of every civilized government.[64]

60. Kindleberger v Lincoln Nat. Bank, 81 App DC 101, 155 F2d 281, 167 ALR 1011, cert den 329 US 803, 91 L Ed 686, 67 S Ct 495; Marrs v Oxford (CA8 Kan) 32 F2d 134, 67 ALR 1336, cert den 280 US 573, 74 L Ed 625, 50 S Ct 29; Miller v Board of Public Works, 195 Cal 477, 234 P 381, 38 ALR 1479, error dismd 273 US 781, 71 L Ed 889, 47 S Ct 460; Ingram v Colgan, 106 Cal 120, 38 P 315, subsequent op on reh 106 Cal 113, 39 P 437; People v Hupp, 53 Colo 80, 123 P 651; Van Winkle v State (Sup) 27 Del 578, 91 A 385; Everglades Sugar & Land Co. v Bryan, 81 Fla 75, 87 So 68, error dismd 257 US 667, 66 L Ed 425, 42 S Ct 183; People v Linde, 341 Ill 269, 173 NE 361, 72 ALR 997; Chicago v Washingtonian Home of Chicago, 289 Ill 206, 124 NE 416, 6 ALR 1584; People v Johnson, 288 Ill 442, 123 NE 543, 4 ALR 1535; State ex rel. Duensing v Roby, 142 Ind 168, 41 NE 145; Henry v Parrish, 307 Ky 559, 211 SW2d 418; Byrne v Maryland Realty Co., 129 Md 202, 98 A 547; State v Hyman, 98 Md 596, 57 A 6; Cape Girardeau v St. Louis S. F. R. Co., 305 Mo 590, 267 SW 601, 36 ALR 1488; Ex parte Taft, 284 Mo 531, 225 SW 457; State v Safeway Stores, Inc., 106 Mont 182, 76 P2d 81; Ives v South B. R. Co., 201 NY 271, 94 NE 431 (ovrld on other grounds Montgomery v Daniels 38 NY2d 41, 378 NYS2d 1, 340 NE2d 444); People v Budd, 117 NY 1, 22 NE 670, affd 143 US 517, 36 L Ed 247, 12 S Ct 468; Brewer v Valk, 204 NC 186, 167 SE 638, 87 ALR 237; State v Lockey, 198 NC 551, 152 SE 693; Skinner v Thomas, 171 NC 98, 87 SE 976; Board of Com'rs v Public Utilities Com., 107 Ohio St 442, 1 Ohio L Abs 389, 140 NE 87, 30 ALR 429; Cincinnati v Harth, 101 Ohio St 344, 128 NE 263, 13 ALR 308; Cincinnati v Public Utilities Com., 98 Ohio St 320, 3 Ohio L Abs 19, 121 NE 688, 3 ALR 705 (ovrld on another point United Fuel Gas Co. v Ironton 107 Ohio St 173, 1 Ohio L Abs 881, 140 NE 884, 29 ALR 342) and (ovrld on other grounds New Boston v Public Utilities Com. 108 Ohio St 352, 1 Ohio L Abs 882, 140 NE 607); National Bank of Tulsa Bldg. v Goldsmith, 204 Okla 45, 228 P2d 916; State ex rel. Short v Riedell, 109 Okla 35, 233 P 684, 42 ALR 765; Ex parte Fowler, 85 Okla Crim 64, 184 P2d 814; Appeal of White, 287 Pa 259, 134 A 409, 53 ALR 1215; Commonwealth v Vrooman, 164 Pa 306, 30 A 217; Shealy v Southern R. Co., 127 SC 15, 120 SE 561; Aetna Fire Ins. Co. v Jones, 78 SC 445, 59 SE 148; Motlow v State, 125 Tenn 547, 145 SW 177, error dismd 239 US 653, 60 L Ed 487, 36 S Ct 161; Williams v State, 146 Tex Crim 430, 176 SW2d 177; Beaumont Petroleum Syndicate v Broussard (Tex Civ App) 64 SW2d 993, app dismd 123 Tex 408, 73 SW2d 92, ans conformed to (Tex Civ App) 73 SW2d 1047; Bohn v Salt Lake City, 79 Utah 121, 8 P2d 591, 81 ALR 215; Sowma v Parker, 112 Vt 241, 22 A2d 513; Re Guerra, 94 Vt 1, 110 A 224, 10 ALR 1560; Sabre v Rutland R. Co., 86 Vt 347, 85 A 693; Virginia-Western Power Co. v Commonwealth, 125 Va 469, 99 SE 723, 9 ALR 1148, cert den 251 US 557, 64 L Ed 413, 40 S Ct 179 and (disapproved on other grounds Victoria v Victoria Ice Light & Power Co. 134 Va 134, 114 SE 92, 28 ALR 562) and (disapproved on other grounds Richmond v Virginia R. & P. Co. 141 Va 69, 126 SE 353); State ex rel. Webster v Superior Court of King County, 67 Wash 37, 120 P 861; Prager v W. H. Chapman & Sons Co., 122 W Va 428, 9 SE2d 880, 129 ALR 1114; State v Langley, 53 Wyo 332, 84 P2d 767.

61. The police power of the state is more than an attribute of sovereignty. It, like the power of taxation, is an essential element of government. State ex rel. Webster v Superior Court of King County, 67 Wash 37, 120 P 861.

62. The police power might be deemed sovereignty rather than a mere attribute of sovereignty. Re Guerra, 94 Vt 1, 110 A 224, 10 ALR 1560; Sabre v Rutland R. Co., 86 Vt 347, 85 A 693. And see Cady v Detroit, 289 Mich 499, 286 NW 805, app dismd 309 US 620, 84 L Ed 984, 60 S Ct 470.

63. Clifton Hills Realty Co. v Cincinnati, 60 Ohio App 443, 12 Ohio Ops 418, 27 Ohio L Abs 321, 21 NE2d 993.

64. Geurin v Little Rock, 203 Ark 103, 155 SW2d 719, 135 ALR 1305; McInerney v Ervin (Fla) 46 So 2d 458; East Side Levee & Sanitary Dist. v East St. Louis & C. R. Co., 279 Ill 123, 116 NE 720; Watertown v Mayo, 109 Mass 315; People v Brazee, 183 Mich 259, 149 NW 1053, affd 241 US 340, 60 L Ed 1034, 36 S Ct 561; Ex parte Taft, 284 Mo 531, 225 SW 457; Ives v South B. R. Co., 201 NY 271, 94 NE 431 (ovrld on other grounds Montgomery v Daniels 38 NY2d 41, 378 NYS2d 1, 340 NE2d 444); People v Budd, 117 NY 1, 22 NE 670, affd 143 US 517, 36 L Ed 247, 12 S Ct 468; Barker v Palmer, 217 NC 519, 8 SE2d 610; Calcutt v McGeachy, 213 NC 1, 195 SE 49; Brewer v Valk, 204 NC 186, 167 SE 638, 87 ALR 237; Cincinnati v Correll, 141 Ohio St 535, 26 Ohio Ops 116, 49 NE2d 412; Colletti v State, 12 Ohio App 104, motion overr; C. C. Julian Oil & Royalties Co. v Capshaw, 145 Okla 237, 292 P 841; State ex rel. Short v Riedell, 109 Okla 35, 233 P 684, 42 ALR 765; Ex parte Tindall, 102 Okla 192, 229 P 125;

The police
The states ex
possessed the
Moreover, it h
existence of th
fact.[66]

§ 361. Source.

"Police pow
particular right
it is an inhere
sovereign.[69]

Appeal of White,
ALR 1215; Shealy
15, 120 SE 561;
State Board of Pha
686, app dismd 34
S Ct 871; State e
Court of King Cou
Quesenberry v Este
832; Huntington v
Va 786, 73 SE2d 8

65. New York v M
Geurin v Little Roc
719, 135 ALR 130
46 So 2d 458; Peop
NE 870; Quesenber
95 SE2d 832; Hunt
137 W Va 786, 73 S

66. Geurin v Litt
SW2d 719, 135 AL
Co. v Illinois Com
158 NE 376, 55 AL
State Board of Educ
655, 67 ALR 1133;
NY 268, 25 NE 4
Gronna, 79 ND 67
berry v Estep, 142
Huntington v State
786, 73 SE2d 833.

67. Nebbia v New
940, 54 S Ct 505, 8
M. S. R. Co. v Sm
858, 19 S Ct 565
Pennsylvania R. Co
Ed 117, 38 S Ct
113, 24 L Ed 77; T
US 504, 12 L Ed 2
Leisy v Hardin 135
Ct 681); Alabama S
McAdory, 246 Ala 1
325 US 450, 89 L
Birmingham v Ho
233 Ala 352, 172 S
on other grounds D
99, 36 So 2d 673);
Corp. v White River
275 SW2d 455; Ge

The police power is as old as the civilized governments which exercise it. The states existed before the Constitution of the United States, and they possessed the police power before the adoption of that organic document.[65] Moreover, it has been held many times that the Constitution supposes the pre-existence of the police power, and must be construed with reference to that fact.[66]

§ 361. Source.

"Police power" is often said to be a general term used to express the particular right of a government which is inherent in every sovereignty.[67] Thus, it is an inherent power of the states,[68] possessed by every one of them as sovereign.[69]

Appeal of White, 287 Pa 259, 134 A 409, 53 ALR 1215; Shealy v Southern R. Co., 127 SC 15, 120 SE 561; Cavalier Vending Corp. v State Board of Pharmacy, 195 Va 626, 79 SE2d 636, app dismd 347 US 995, 98 L Ed 1127, 74 S Ct 871; State ex rel. Webster v Superior Court of King County, 67 Wash 37, 120 P 861; Quesenberry v Estep, 142 W Va 426, 95 SE2d 832; Huntington v State Water Com., 137 W Va 786, 73 SE2d 833.

65. New York v Miln, 36 US 102, 9 L Ed 648; Geurin v Little Rock, 203 Ark 103, 155 SW2d 719, 135 ALR 1305; McInerney v Ervin (Fla) 46 So 2d 458; People v Weiner, 271 Ill 74, 110 NE 870; Quesenberry v Estep, 142 W Va 426, 95 SE2d 832; Huntington v State Water Com., 137 W Va 786, 73 SE2d 833.

66. Geurin v Little Rock, 203 Ark 103, 155 SW2d 719, 135 ALR 1305; Chicago & N. W. R. Co. v Illinois Commerce Com., 326 Ill 625, 158 NE 376, 55 ALR 654; Borden v Louisiana State Board of Education, 168 La 1005, 123 So 655, 67 ALR 1183; Carthage v Frederick, 122 NY 268, 25 NE 480; State ex rel. Minot v Gronna, 79 ND 673, 59 NW2d 514; Quesenberry v Estep, 142 W Va 426, 95 SE2d 832; Huntington v State Water Com., 137 W Va 786, 73 SE2d 833.

67. Nebbia v New York, 291 US 502, 78 L Ed 940, 54 S Ct 505, 89 ALR 1469; Lake Shore & M. S. R. Co. v Smith, 173 US 684, 43 L Ed 858, 19 S Ct 565 (ovrld on other grounds Pennsylvania R. Co. v Towers 245 US 6, 62 L Ed 117, 38 S Ct 2); Munn v Illinois, 94 US 113, 24 L Ed 77; Thurlow v Massachusetts, 46 US 504, 12 L Ed 256 (ovrld on other grounds Leisy v Hardin 135 US 100, 34 L Ed 128, 10 S Ct 681); Alabama State Federation of Labor v McAdory, 246 Ala 1, 18 So 2d 810, cert dismd 325 US 450, 89 L Ed 1725, 65 S Ct 1384; Birmingham v Hood-McPherson Realty Co., 233 Ala 352, 172 So 114, 108 ALR 1140 (ovrld on other grounds Decatur v Robinson 251 Ala 99, 36 So 2d 673); Union Carbide & Carbon Corp. v White River Distributors, 224 Ark 558, 275 SW2d 455; Geurin v Little Rock, 203 Ark 103, 155 SW2d 719, 135 ALR 1305; Denver v Denver & R. G. R. Co., 63 Colo 574, 167 P 969, affd 250 US 241, 63 L Ed 958, 39 S Ct 450; State v Bassett, 100 Conn 430, 123 A 842, 37 ALR 131; Van Winkle v State (Sup) 27 Del 578, 91 A 385; Eccles v Stone, 134 Fla 113, 183 So 628; Fernandez v Alford, 203 La 111, 13 So 2d 483; Cochran v Preston, 108 Md 220, 70 A 113; Williams v Evans, 139 Minn 32, 165 NW 495, reh den 139 Minn 45, 166 NW 504; Kansas City v Holmes, 274 Mo 159, 202 SW 392; State v Safeway Stores, Inc., 106 Mont 182, 76 P2d 81; Boyd v Allen, 246 NC 150, 97 SE2d 864; State ex rel. Linde v Taylor, 33 ND 76, 156 NW 561, error dismd 245 US 627, 62 L Ed 518, 38 S Ct 60; Board of Com'rs v Public Utilities Com., 107 Ohio St 442, 1 Ohio L Abs 389, 140 NE 87, 30 ALR 429; State v Boone, 84 Ohio St 346, 95 NE 924, adhered to 85 Ohio St 513, 97 NE 975; State ex rel. Short v Riedell, 109 Okla 35, 233 P 684, 42 ALR 765; Ex parte Strauch, 80 Okla Crim 89, 157 P2d 201; State v Central Lumber Co., 24 SD 136, 123 NW 504, affd 226 US 157, 57 L Ed 164, 33 S Ct 66; Nance v O. K. Houck Piano Co., 128 Tenn 1, 155 SW 1172; Motlow v State, 125 Tenn 547, 145 SW 177; error dismd 239 US 653, 60 L Ed 487, 36 S Ct 161; Sabre v Rutland R. Co., 86 Vt 347, 85 A 693; Carty's Adm'r v Winooski, 78 Vt 104, 62 A 45; Hopkins v Richmond, 117 Va 692, 86 SE 139 (ovrld on other grounds Irvine v Clifton Forge 124 Va 781, 97 SE 310); State v Rossman, 93 Wash 530, 161 P 349; Quesenberry v Estep, 142 W Va 426, 95 SE2d 832; Huntington v State Water Com., 137 W Va 786, 73 SE2d 833; State ex rel. Morris v West Virginia Racing Com., 133 W Va 179, 55 SE2d 263; State ex rel. Carter v Harper, 182 Wis 148, 196 NW 451, 33 ALR 269.

68. Peirce v New Hampshire, 46 US 554, 12 L Ed 279; Atkinson, Kier Bros., Spicer Co. v Industrial Com. of Arizona, 35 Ariz 48, 274 P 634; Peavy-Wilson Lumber Co. v Brevard County, 159 Fla 311, 31 So 2d 483, 172 ALR 168; Railroad Com of Georgia v Louisville & N. R. Co., 140 Ga 817, 80 SE 327; East Side

From what has been said, it follows, as a matter of logic, that the police power is not a grant derived from or under any written constitution,[70] or from

Levee & Sanitary Dist. v East St. Louis & C. R. Co., 279 Ill 123, 116 NE 720; People v Weiner, 271 Ill 74, 110 NE 870; Chicago v Bowman Dairy Co., 234 Ill 294, 84 NE 913; Chicago, T. H. & S. R. Co. v Anderson, 182 Ind 140, 105 NE 49, affd 242 US 283, 61 L Ed 302, 37 S Ct 124; Eastman v State, 109 Ind 278, 10 NE 97; State v Gurry, 121 Md 534, 88 A 546; Singer v State, 72 Md 464, 19 A 1044; Williams v Evans, 139 Minn 32, 165 NW 495, reh den 139 Minn 45, 166 NW 504; Ex parte Taft, 284 Mo 531, 225 SW 457; Hadden v Aitken, 156 Neb 215, 55 NW2d 620, 35 ALR2d 1003 (ovrld on other grounds Stauffer v Weedlun 188 Neb 105, 195 NW2d 218, app dismd 409 US 972, 34 L Ed 2d 236, 93 S Ct 307); State v Drayton, 82 Neb 254, 117 NW 768; Wenham v State, 65 Neb 394, 91 NW 421; Re Boyce, 27 Nev 299, 75 P 1; State v Brooken, 19 NM 404, 143 P 479; People v Budd, 117 NY 1, 22 NE 670, affd 143 US 517, 36 L Ed 247, 12 S Ct 468; Brewer v Valk, 204 NC 186, 167 SE 638, 87 ALR 237; State v Lockey, 198 NC 551, 152 SE 693; State v Yarboro, 194 NC 498, 140 SE 216; State ex rel. Zugravu v O'Brien, 130 Ohio St 23, 3 Ohio Ops 74, 196 NE 664; State v Boone, 84 Ohio St 346, 95 NE 924, adhered to 85 Ohio St 313, 97 NE 975; Colletti v State, 12 Ohio App 104, motion overr; C. C. Julian Oil & Royalties Co. v Capshaw, 145 Okla 237, 292 P 841; Ex parte Tindall, 102 Okla 192, 229 P 125; Stettler v O'Hara, 69 Or 519, 139 P 743, affd 243 US 629, 61 L Ed 937, 37 S Ct 475; Shealy v Southern R. Co., 127 SC 15, 120 SE 561; Streich v Board of Education, 34 SD 169, 147 NW 779; Nance v O. K. Houck Piano Co., 128 Tenn 1, 155 SW 1172; Ex parte Townsend, 64 Tex Crim 350, 144 SW 628; Beaumont Petroleum Syndicate v Broussard (Tex Civ App) 64 SW2d 993, app dismd 123 Tex 408, 73 SW2d 92, ans conformed to (Tex Civ App) 73 SW2d 1047; Bohn v Salt Lake City, 79 Utah 121, 8 P2d 591, 81 ALR 215; Sowma v Parker, 112 Vt 241, 22 A2d 513; Re Guerra, 94 Vt 1, 110 A 224, 10 ALR 1560; Virginia-Western Power Co. v Commonwealth, 125 Va 469, 99 SE 723, 9 ALR 1148, cert den 251 US 557, 64 L Ed 413, 40 S Ct 179 and (disapproved on other grounds Victoria v Victoria Ice Light & Power Co. 134 Va 134, 114 SE 92, 28 ALR 562) and (disapproved on other grounds Richmond v Virginia R. & P. Co. 141 Va 69, 126 SE 353); Laughney v Maybury, 145 Wash 146, 259 P 17, 54 ALR 393; State ex rel. Davis-Smith Co. v Clausen, 65 Wash 156, 117 P 1101; Sutherland v Miller, 79 W Va 796, 91 SE 993; Peel Splint Coal Co. v State, 36 W Va 802, 15 SE 1000; State ex rel. La Follette v Kohler, 200 Wis 518, 228 NW 895, 69 ALR 348 (ovrld on other grounds Re Kading 70 Wis 2d 508, 235 NW2d 409, reh den 70 Wis 2d 543B, 238 NW2d 63 and supp op 70 Wis 2d 543F, 239 NW2d 297).

As to exercise of power by states, see §§ 375 et seq., infra.

69. East Side Levee & Sanitary Dist. v East St. Louis & C. R. Co., 279 Ill 123, 116 NE 720; Ex parte Taft, 284 Mo 531, 225 SW 457; Re Application of Jacobs, 98 NY 98; Brewer v Valk, 204 NC 186, 167 SE 638, 87 ALR 237; State v Lockey, 198 NC 551, 152 SE 693; Skinner v Thomas, 171 NC 98, 87 SE 976; Colletti v State, 12 Ohio App 104, motion overr; C. C. Julian Oil & Royalties Co. v Capshaw, 145 Okla 237, 292 P 841; Ex parte Tindall, 102 Okla 192, 229 P 125; Shealy v Southern R. Co., 127 SC 15, 120 SE 561.

The police power is an element of sovereignty reserved by the states to enable them to cope with any malignancy that threatens the body politic. Southern Bell Tel. & Tel. Co. v Nineteen Hundred One Collins Corp. (Fla) 83 So 2d 865.

70. Atkinson, Kier Bros., Spicer Co. v Industrial Com. of Arizona, 35 Ariz 48, 274 P 634; Geurin v Little Rock, 203 Ark 103, 155 SW2d 719, 135 ALR 1305; State v Crowe, 130 Ark 272, 197 SW 4 (ovrld on other grounds State v Fairfield Communities Land Co. 260 Ark 277, 538 SW2d 698, cert den 429 US 1004, 50 L Ed 2d 617, 97 S Ct 538); People v Hupp, 53 Colo 80, 123 P 651; McInerney v Ervin (Fla) 46 So 2d 458; People v Johnson, 288 Ill 442, 123 NE 543, 4 ALR 1535; East Side Levee & Sanitary Dist. v East St. Louis & C. R. Co., 279 Ill 123, 116 NE 720; People v Weiner, 271 Ill 74, 110 NE 870; Blue v Beach, 155 Ind 121, 56 NE 89; State v Gerhardt, 145 Ind 439, 44 NE 469; Jordan v Gaines, 136 Me 291, 8 A2d 585; State v Old Tavern Farm, Inc., 133 Me 468, 180 A 473, 101 ALR 810; Ex parte Taft, 284 Mo 531, 225 SW 457; State v Drayton, 82 Neb 254, 117 NW 768; Wenham v State, 65 Neb 394, 91 NW 421; Brewer v Valk, 204 NC 186, 167 SE 638, 87 ALR 237; State v Lockey, 198 NC 551, 152 SE 693; State v Yarboro, 194 NC 498, 140 SE 216; State ex rel. Minot v Gronna, 79 ND 673, 59 NW2d 514; State ex rel. Zugravu v O'Brien, 130 Ohio St 23, 3 Ohio Ops 74, 196 NE 664; Board of Com'rs v Public Utilities Com., 107 Ohio St 442, 1 Ohio L Abs 389, 140 NE 87, 30 ALR 429; C. C. Julian Oil & Royalties Co. v Capshaw, 145 Okla 237, 292 P 841; State ex rel. Short v Riedell, 109 Okla 35, 233 P 684, 42 ALR 765; Ex parte Tindall, 102 Okla 192, 229 P 125; Shealy v Southern R. Co., 127 SC 15, 120 SE 561; State ex rel. George v City Council of Aiken, 42 SC 222, 20 SE 221; Beaumont Petroleum Syndicate v Broussard (Tex Civ App) 64 SW2d 993, app dismd 123 Tex 408, 73 SW2d 92, ans conformed to (Tex Civ App) 73 SW2d 1047; Ex parte Townsend, 64 Tex Crim 350, 144 SW 628; Re Guerra, 94

the legislature.[71]
the Federal Cons
with this principl
is a grant from t
affirmed, howeve
legislature to exe
provision of the
our institutions;[74]
the same source,
tion.[75]

The police po
reserved, power,[71]

§ 362. Definition,

The term "pol

Vt 1, 110 A 224, 10
ing Corp. v State Bo
626, 79 SE2d 636, ap
L Ed 1127, 74 S C
County, 116 Wash 27
State ex rel. Webster
County, 67 Wash 37,
v Estep, 142 W Va
ington v State Water
SE2d 833; State ex
200 Wis 518, 228 NW
on other grounds Re
235 NW2d 409, reh
NW2d 63 and supp
NW2d 297).

The police power o
from the Constitution
is a power existing in
Armour & Co. v City
Ga 178, 67 SE 417.

Although the ter
sometimes cover acti
mental in nature, tha
exercise of governm
tribute of, and always
control of which is
independent of const
v West Virginia Liqu
Va 51, 53 SE2d 609.

71. Board of Com'
107 Ohio St 442, 1
87, 30 ALR 429.

72. Columbus v F
Ohio St 79, 133 NE
Ohio App 159, 21
Abs 636, 36 NE2d 16

73. Geurin v Little
SW2d 719, 135 ALR
Tex 350, 235 SW 5
Vending Corp. v Sta
Va 626, 79 SE2d 63
98 L Ed 1127, 74
Estep, 142 W Va 4

the legislature.[71] The term is not found in the Declaration of Independence, the Federal Constitution, or even in most state constitutions.[72] In connection with this principle, the point of view has been expressed that the police power is a grant from the people to their governmental agents.[73] It has also been affirmed, however, in discussing the source of the power, that the right of the legislature to exercise the police power is not only not referable to any single provision of the Constitution, but inheres in, and springs from, the nature of our institutions;[74] hence the limitations upon it are those which spring from the same source, as well as those which are expressly stated in the Constitution.[75]

The police power is very generally regarded not as a delegated, but a reserved, power,[76] although in some aspects it resembles a granted power.[77]

§ 362. Definition, generally; difficulty of definition.

The term "police power," although generally understood and universally

Vt 1, 110 A 224, 10 ALR 1560; Cavalier Vending Corp. v State Board of Pharmacy, 195 Va 626, 79 SE2d 636, app dismd 347 US 995, 98 L Ed 1127, 74 S Ct 871; Conger v Pierce County, 116 Wash 27, 198 P 377, 18 ALR 393; State ex rel. Webster v Superior Court of King County, 67 Wash 37, 120 P 861; Quesenberry v Estep, 142 W Va 426, 95 SE2d 832; Huntington v State Water Com., 137 W Va 786, 73 SE2d 833; State ex rel. La Follette v Kohler, 200 Wis 518, 228 NW 895, 69 ALR 348 (ovrld on other grounds Re Kading 70 Wis 2d 508, 235 NW2d 409, reh den 70 Wis 2d 543B, 238 NW2d 63 and supp op 70 Wis 2d 543F, 239 NW2d 297).

The police power of the states is not derived from the Constitution of the United States, but is a power existing in them as sovereign states Armour & Co. v City Council of Augusta, 134 Ga 178, 67 SE 417.

Although the term "police power" may sometimes cover activities not entirely governmental in nature, that power is essential to the exercise of governmental power and is an attribute of, and always exercised by, sovereignty, control of which is vested in the legislature independent of constitution or statute. Schippa v West Virginia Liquor Control Com., 132 W Va 51, 53 SE2d 609, 9 ALR2d 1284.

71. Board of Com'rs v Public Utilities Com., 107 Ohio St 442, 1 Ohio L Abs 389, 140 NE 87, 30 ALR 429.

72. Columbus v Public Utilities Com., 103 Ohio St 79, 133 NE 800; Myers v Defiance, 67 Ohio App 159, 21 Ohio Ops 165, 31 Ohio L Abs 636, 36 NE2d 162.

73. Geurin v Little Rock, 203 Ark 103, 155 SW2d 719, 135 ALR 1305; Spann v Dallas, 111 Tex 350, 235 SW 513, 19 ALR 1337; Cavalier Vending Corp. v State Board of Pharmacy, 195 Va 626, 79 SE2d 636, app dismd 347 US 995, 98 L Ed 1127, 74 S Ct 871; Quesenberry v Estep, 142 W Va 426, 95 SE2d 832; Huntington v State Water Com., 137 W Va 786, 73 SE2d 833.

74. The police power springs from the obligation of the state to protect its citizens and provide for the safety and good order of society, and permits reasonable regulation of rights of property in particulars essential to the preservation of the community from injury. Panhandle Eastern Pipe Line Co. v State Highway Com., 294 US 613, 79 L Ed 1090, 55 S Ct 563, reh den 295 US 768, 79 L Ed 1709, 55 S Ct 652; People v Johnson, 288 Ill 442, 123 NE 543, 4 ALR 1535.

75. Geurin v Little Rock, 203 Ark 103, 155 SW2d 719, 135 ALR 1305; Mitchell v Consolidated School Dist., 17 Wash 2d 61, 135 P2d 79, 146 ALR 612; Quesenberry v Estep, 142 W Va 426, 95 SE2d 832; Huntington v State Water Com., 137 W Va 786, 73 SE2d 833; State ex rel. La Follette v Kohler, 200 Wis 518, 228 NW 895, 69 ALR 348 (ovrld on other grounds Re Kading 70 Wis 2d 508, 235 NW2d 409, reh den 70 Wis 2d 543B, 238 NW2d 63 and supp op 70 Wis 2d 543F, 239 NW2d 297).

As to constitutional limitations, see §§ 391 et seq., infra.

76. Geurin v Little Rock, 203 Ark 103, 155 SW2d 719, 135 ALR 1305; Van Winkle v State (Sup) 27 Del 578, 91 A 385; State v Old Tavern Farm, Inc., 133 Me 468, 180 A 473, 101 ALR 810; Raymond Lumber Co. v Raymond Light & Water Co., 92 Wash 330, 159 P 133; Quesenberry v Estep, 142 W Va 426, 95 SE2d 832; Huntington v State Water Com., 137 W Va 786, 73 SE2d 833; State v Langley, 53 Wyo 332, 84 P2d 767.

77. The general police power vested in, although not expressly conferred on, the legislature under written constitutions is, like a power expressly granted, interpreted in connection with the maxims of Magna Charta and the common law. Re Morgan, 26 Colo 415, 58 P 1071.

recognized, is somewhat hazy and ambiguous.[78] While there have been many attempts to define the police power,[79] it has not received a full and complete definition.[80] The difficulty has been the subject of frequent judicial comment.[81] In fact it has been said that the police power is from its nature incapable of any satisfactory[82] or exact definition or limitation.[83] It is not susceptible of

78. Cincinnati v Correll, 141 Ohio St 535, 26 Ohio Ops 116, 49 NE2d 412.

79. Stone v Mississippi, 101 US 814, 25 L Ed 1079; State v Schlenker, 112 Iowa 642, 84 NW 698; York Harbor Village Corp. v Libby, 126 Me 537, 140 A 382.

As to particular judicially stated definitions, see § 363, infra.

80. Wolf v Smith, 149 Ala 457, 42 So 824; State ex rel. Duensing v Roby, 142 Ind 168, 41 NE 145; Champer v Greencastle, 138 Ind 339, 35 NE 14; State v Gurry, 121 Md 534, 88 A 546; Colletti v State, 12 Ohio App 104, motion overr; State v Theriault, 70 Vt 617, 41 A 1030; Etheredge v Norfolk, 148 Va 795, 139 SE 508, 55 ALR 781; Hopkins v Richmond, 117 Va 692, 86 SE 139 (ovrld on other grounds Irvine v Clifton Forge 124 Va 781, 97 SE 310); State v Walter Bowen & Co., 86 Wash 23, 149 P 330; Ex parte Hudgins, 86 W Va 526, 103 SE 327, 9 ALR 1361.

81. Thomas Cusack Co. v Chicago, 242 US 526, 61 L Ed 472, 37 S Ct 190; Coppage v Kansas, 236 US 1, 59 L Ed 441, 35 S Ct 240 (ovrld on other grounds Phelps Dodge Corp. v NLRB 313 US 177, 85 L Ed 1271, 61 S Ct 845, 133 ALR 1217); Lochner v New York, 198 US 45, 49 L Ed 937, 25 S Ct 539 (ovrld on other grounds Day-Brite Lighting, Inc. v Missouri 342 US 421, 96 L Ed 469, 72 S Ct 405, reh den 343 US 921, 96 L Ed 1334, 72 S Ct 674) and (ovrld on other grounds Ferguson v Skrupa 372 US 726, 10 L Ed 2d 93, 83 S Ct 1028, 95 ALR2d 1347); Western Union Tel. Co. v James, 162 US 650, 40 L Ed 1105, 16 S Ct 934; Patterson v Kentucky, 97 US 501, 24 L Ed 1115; Pacific Tel. & Tel. Co. v Eshleman, 166 Cal 640, 137 P 1119; Durgin v Minot, 203 Mass 26, 89 NE 144; Davock v Moore, 105 Mich 120, 63 NW 424; Donnell v State, 48 Miss 661; People v Lochner, 177 NY 145, 69 NE 373, revd on other grounds 198 US 45, 49 L Ed 937, 25 S Ct 539 (ovrld on other grounds Day-Brite Lighting, Inc. v Missouri 342 US 421, 96 L Ed 469, 72 S Ct 405, reh den 343 US 921, 96 L Ed 1334, 72 S Ct 674) and (ovrld on other grounds Ferguson v Skrupa 372 US 726, 10 L Ed 2d 93, 83 S Ct 1028, 95 ALR2d 1347); People v Ewer, 141 NY 129, 36 NE 4, writ dism (2d Dept) 32 App Div 2d 844, 302 NYS2d 990; Colletti v State, 12 Ohio App 104, motion overr; State ex rel. Short v Riedell, 109 Okla 35, 233 P 684, 42 ALR 765; State v Central Lumber Co., 24 SD 136, 123 NW 504, affd 226 US 157, 57 L Ed 164, 33 S Ct 66; Longmire v State, 75 Tex Crim 616, 171 SW 1165; Ex parte Townsend, 64 Tex Crim 350, 144 SW 628; Frach v Schoettler, 46 Wash 2d 281, 280 P2d 1038, cert den 350 US 838, 100 L Ed 747, 76 S Ct 75; Conger v Pierce County, 116 Wash 27, 198 P 377, 18 ALR 393; Re O'Neill, 41 Wash 174, 83 P 104; Quesenberry v Estep, 142 W Va 426, 95 SE2d 832.

In Alma Coal Co. v Cozad, 79 Ohio St 348, 87 NE 172, the court said: "Again the vain longing for conceptual definition of the police power is intensified."

82. McInerney v Ervin (Fla) 46 So 2d 458.

83. Pearsall v Great N. R. Co., 161 US 646, 40 L Ed 838, 16 S Ct 705; New Orleans Gas Co. v Louisiana Light Co., 115 US 650, 29 L Ed 516, 6 S Ct 252; Slaughter-House Cases, 83 US 36, 21 L Ed 394; Birmingham v Hood-McPherson Realty Co., 233 Ala 352, 172 So 114, 108 ALR 1140 (ovrld on other grounds Decatur v Robinson 251 Ala 99, 36 So 2d 673); State v Kartus, 230 Ala 352, 162 So 533, 101 ALR 1336, ans conformed to 26 Ala App 446, 162 So 538; Hunter v Green, 142 Fla 104, 194 So 379; Gundling v Chicago, 176 Ill 340, 52 NE 44, affd 177 US 183, 44 L Ed 725, 20 S Ct 633; Bruck v State, 228 Ind 189, 91 NE2d 349; Rehmann v Des Moines, 200 Iowa 286, 204 NW 267, 40 ALR 922; Aetna Ins. Co. v Chicago G. W. R. Co., 190 Iowa 487, 180 NW 649, 16 ALR 249; Meffert v State Board of Medical Registration & Examination, 66 Kan 710, 72 P 247, affd 195 US 625, 49 L Ed 350, 25 S Ct 790; Dunn v Commonwealth, 105 Ky 834, 49 SW 813; State v Canal & C. R. Co., 50 La Ann 1189, 24 So 265, error dismd (US) 44 L Ed 1221, 20 S Ct 1027; York Harbor Village Corp. v Libby, 126 Me 537, 140 A 382; State v Gurry, 121 Md 534, 88 A 546; Smith v New England Aircraft Co., 270 Mass 511, 170 NE 385, 69 ALR 300; Bowerman v Sheehan, 242 Mich 95, 219 NW 69, 61 ALR 859; Blaisdell v Home Bldg. & Loan Ass'n, 189 Minn 422, 249 NW 334, 86 ALR 1507, affd 290 US 398, 78 L Ed 413, 54 S Ct 231, 88 ALR 1481 and later app 189 Minn 448, 249 NW 893; State ex rel. Beery v Houghton, 164 Minn 146, 204 NW 569, 54 ALR 1012, affd 273 US 671, 71 L Ed 832, 47 S Ct 474; Sundeen v Rogers, 83 NH 253, 141 A 142, 57 ALR 950; Jensen v Southern Pac. Co., 215 NY 514, 109 NE 600, revd on other grounds 244 US 205, 61 L Ed 1086, 37 S Ct 524; People v Budd, 117 NY 1, 22 NE 670, affd 143 US 517, 36 L Ed 247, 12 S Ct 468; People v King, 110 NY 418, 18 NE 245; Brewer v Valk, 204 NC 186, 167 SE 638, 87 ALR 237; State ex rel. Cleveringa v Klein, 63

description with
description can
exercise.[85] More
ble to give the
its own facts.[86]
the power is ess
the purposes c
capable of com
standard of "rea
announcing any

§ 363. —Particu

While it is g
impossible to g
have been made
definitions are c
this power.

ND 514, 249 NW 1
ban R. & T. Co. v
Ohio St 287, 120 NE
v Cincinnati, 81 Ohio
v Marble, 72 Ohio
Butte Horse & Catt
Or 171, 289 P 503
Portland, 124 Or 67
Commonwealth v Vr
217; State v Kofines
Harrington v Board
38 A 1; Beaumont
Broussard (Tex Civ
dismd 123 Tex 408
formed to (Tex Civ
parte Meckel, 87 Te
State v Mountain Ti
135 P 645, affd 243
Ct 260; State ex rel.
237, 84 P 851 (ovrld
v Fox 158 Wash 32
Peier, 22 Wash 419,
gins, 86 W Va 526,

84. Eubank v Richm
156, 33 S Ct 76;
Ohio St 21, 116 NE

Its boundaries are
definable. Mirick v
NE 880; Colletti v
motion overr.

85. Columbus v P
Ohio St 79, 133 NE

86. Des Moines v
Iowa 1096, 184 NW
op, reh overr 193 Io
ALR 1337; Aetna In
Co., 190 Iowa 487,
Randall v Patch, 118
65; Bowerman v Sh
NW 69, 61 ALR 859
Ohio St 21, 116 N

description with precision,[84] because of its great dimensions[85] and because no description can foresee the ever-changing conditions which may call for its exercise.[86] Moreover, it has been held that these conditions render it inadvisable to give the power a limited definition.[87] Each individual case must turn on its own facts.[88] The United States Supreme Court has said that a definition of the power is essentially the product of legislative determinations "addressed to the purposes of government, purposes neither abstractly nor historically capable of complete definition."[89] Except for the substitution of the familiar standard of "reasonableness," the Supreme Court has generally refrained from announcing any specific criteria.[90]

§ 363. —Particular judicially stated definitions.

While it is generally recognized that it is very difficult and practically impossible to give an exact definition of the police power,[91] many attempts have been made. There is no consensus in favor of any of them, but these definitions are of considerable value as indicating the breadth and scope of this power.

ND 514, 249 NW 118, 86 ALR 1523; Interurban R. & T. Co. v Public Utilities Com., 98 Ohio St 287, 120 NE 831, 3 ALR 696; Sanning v Cincinnati, 81 Ohio St 142, 90 NE 125; State v Marble, 72 Ohio St 21, 73 NE 1063; Big Butte Horse & Cattle Ass'n v Anderson, 133 Or 171, 289 P 503, 70 ALR 399; Daniels v Portland, 124 Or 677, 265 P 790, 59 ALR 512; Commonwealth v Vrooman, 164 Pa 306, 30 A 217; State v Kofines, 33 RI 211, 80 A 432; Harrington v Board of Aldermen, 20 RI 233, 38 A 1; Beaumont Petroleum Syndicate v Broussard (Tex Civ App) 64 SW2d 993, app dismd 123 Tex 408, 73 SW2d 92, ans conformed to (Tex Civ App) 73 SW2d 1047; Ex parte Meckel, 87 Tex Crim 120, 220 SW 81; State v Mountain Timber Co., 75 Wash 581, 135 P 645, affd 243 US 219, 61 L Ed 685, 37 S Ct 260; State ex rel. Richey v Smith, 42 Wash 237, 84 P 851 (ovrld on other grounds Tacoma v Fox 158 Wash 325, 290 P 1010); Karasek v Peier, 22 Wash 419, 61 P 33; Ex parte Hudgins, 86 W Va 526, 103 SE 327, 9 ALR 1361.

84. Eubank v Richmond, 226 US 137, 57 L Ed 156, 33 S Ct 76; Wessell v Timberlake, 95 Ohio St 21, 116 NE 43.

Its boundaries are necessarily vague and indefinable. Mirick v Gims, 79 Ohio St 174, 86 NE 880; Colletti v State, 12 Ohio App 104, motion overr.

85. Columbus v Public Utilities Com., 103 Ohio St 79, 133 NE 800.

86. Des Moines v Manhattan Oil Co., 193 Iowa 1096, 184 NW 823, 23 ALR 1322, supp op, reh overr 193 Iowa 1117, 188 NW 921, 23 ALR 1337; Aetna Ins. Co. v Chicago G. W. R. Co., 190 Iowa 487, 180 NW 649, 16 ALR 249; Randall v Patch, 118 Me 303, 108 A 97, 8 ALR 65; Bowerman v Sheehan, 242 Mich 95, 219 NW 69, 61 ALR 859; Wessell v Timberlake, 95 Ohio St 21, 116 NE 43; Colletti v State, 12 Ohio App 104, motion overr; Daniels v Portland, 124 Or 677, 265 P 790, 59 ALR 512; State v Bunting, 71 Or 259, 139 P 731, affd 243 US 426, 61 L Ed 830, 37 S Ct 435; State v Kofines, 33 RI 211, 80 A 432; Re Ten-Hour Law, 24 RI 603, 54 A 602; Ex parte Meckel, 87 Tex Crim 120, 220 SW 81.

The line which separates the legitimate from the illegitimate assumption of the police power is not capable of precise delimitation. It varies with circumstances and conditions. Euclid v Ambler Realty Co., 272 US 365, 71 L Ed 303, 47 S Ct 114, 4 Ohio L Abs 816, 54 ALR 1016.

87. State v Hutchinson Ice Cream Co., 168 Iowa 1, 147 NW 195, affd 242 US 153, 61 L Ed 217, 37 S Ct 28.

Definitions of police power which give its boundaries with precision have not been attempted by any courts. It is wise that it is so, because this, like many of the subject matters of the law, is constantly in the process of evolution and development, and must be adapted to the social, industrial, and commercial conditions of the times. Wessel v Timberlake, 95 Ohio St 21, 116 NE 43.

As to flexibility of police power under changing conditions, see § 373, infra.

88. Berman v Parker, 348 US 26, 99 L Ed 27, 75 S Ct 98; Olds v Klotz, 131 Ohio St 447, 6 Ohio Ops 129, 3 NE2d 371.

89. Berman v Parker, 348 US 26, 99 L Ed 27, 75 S Ct 98.

90. Goldblatt v Hempstead, 369 US 590, 8 L Ed 2d 130, 82 S Ct 987.

As to requirement of reasonableness, generally, see §§ 384 et seq., infra.

91. § 362, supra.

The expression "police power," although capable of use, and sometimes used, in a restricted sense,[92] is frequently used very broadly to include all legislation and almost every function of civil government.[93] Thus, it has been stated that the police power in effect sums up the whole power of government, and that all other powers are only incidental and ancillary to the execution of the police power; it is that full, final power involved in the administration of law as the means to the attainment of practical justice.[94] And it has been said that the power is only another name for that authority which resides in every sovereignty to pass all laws for the internal regulation and government of the state,[95] that it is the vast residual power of the state,[96] and that it comprises that portion of the sovereignty of the state which is not surrendered by the terms of the Federal Constitution to the federal government.[97]

92. Dakota Cent. Tel. Co. v South Dakota, 250 US 163, 63 L Ed 910, 39 S Ct 507, 4 ALR 1623; Washington v Atlantic C. L. R. Co., 136 Ga 638, 71 SE 1066.

93. Dakota Cent. Tel. Co. v South Dakota, 250 US 163, 63 L Ed 910, 39 S Ct 507, 4 ALR 1623; Sligh v Kirkwood, 237 US 52, 59 L Ed 835, 35 S Ct 501; New Orleans Gas Co. v Louisiana Light Co., 115 US 650, 29 L Ed 516, 6 S Ct 252; Barbier v Connolly, 113 US 27, 28 L Ed 923, 5 S Ct 357; Hunter v Green, 142 Fla 104, 194 So 379; Washington v Atlantic C. L. R. Co., 136 Ga 638, 71 SE 1066; People v Chicago, M. & S. P. R. Co., 306 Ill 486, 138 NE 155, 28 ALR 610; Blaisdell v Home Bldg. & Loan Ass'n, 189 Minn 422, 249 NW 334, 86 ALR 1507, affd 290 US 398, 78 L Ed 413, 54 S Ct 231, 88 ALR 1481 and later app 189 Minn 448, 249 NW 893; State ex rel. Cleveringa v Klein, 63 ND 514, 249 NW 118, 86 ALR 1523; Wessell v Timberlake, 95 Ohio St 21, 116 NE 43; Camas Stage Co. v Kozer, 104 Or 600, 209 P 95, 25 ALR 27.

94. Ruona v Billings, 136 Mont 554, 323 P2d 29; Colvill v Fox, 51 Mont 72, 149 P 496; Wessell v Timberlake, 95 Ohio St 21, 116 NE 43; Quesenberry v Estep, 142 W Va 426, 95 SE2d 832; Huntington v State Water Com., 137 W Va 786, 73 SE2d 833.

The police power is nothing more or less than the powers of government inherent in every sovereignty to the extent of its dominions. AFL v American Sash & Door Co., 67 Ariz 20, 189 P2d 912, affd 335 US 538, 93 L Ed 222, 69 S Ct 258, 6 ALR2d 481.

The police power is the power to govern; it is the inherent, reserved power of the state to subject individual rights to reasonable regulation in the interests of the general welfare. The state has the sovereign right to protect its citizens and has wide discretion when it exercises its police power for this purpose. The existence of the police power imposes on the state the duty to take adequate steps to protect the lives of its residents. Re Quinn (5th Dist) 35 Cal App 3d 473, 110 Cal Rptr 881 (disapproved on other grounds State v San Luis Obispo Sportsman's Asso. 22 Cal 3d 440, 149 Cal Rptr 482, 584 P2d 1083).

The term "police power" has never been circumscribed. It means at the same time a power and function of government, a system of rules, and an administrative organization and force. State ex rel. Yaple v Creamer, 85 Ohio St 349, 97 NE 602.

95. Mutual Loan Co. v Martell, 222 US 225, 56 L Ed 175, 32 S Ct 74; Appeal of Allyn, 81 Conn 534, 71 A 794; Rodemacher v Milwaukee & St. P. Ry. Co., 41 Iowa 297; Union Ice & Coal Co. v Ruston, 135 La 898, 66 So 262; People v Dehn, 190 Mich 122, 155 NW 744; People v Budd, 117 NY 1, 22 NE 670, affd 143 US 517, 36 L Ed 247, 12 S Ct 468; State v Yarboro, 194 NC 498, 140 SE 216; Stettler v O'Hara, 69 Or 519, 139 P 743, affd 243 US 629, 61 L Ed 937, 37 S Ct 475; Shealy v Southern R. Co., 127 SC 15, 120 SE 561; Sabre v Rutland R. Co., 86 Vt 347, 85 A 693; Peel Splint Coal Co. v State, 36 W Va 802, 15 SE 1000.

The police power is the inherent and plenary power of the state which enables it to prohibit all things hurtful to the comfort and welfare of society. Ingram v Colgan, 106 Cal 120, 38 P 315, subsequent op on reh 106 Cal 113, 39 P 437.

Exercisable "police power," in the collective sense, is the sovereign authority exercisable directly, where not expressly or inferentially prohibited, to pass laws regulating, reasonably, all those things which pertain to the public welfare. Mehlos v Milwaukee, 156 Wis 591, 146 NW 882.

96. Powers neither judicial, legislative, nor executive, in the sense in which these terms are employed in discussions of constitutional law, belong to that great residuum of governmental authority, the police power, to be made effective through administrative agencies. Woods v State, 130 Tenn 100, 169 SW 558.

97. Slaughter-House Cases, 83 US 36, 21 L Ed 394; Bent Bros., Inc. v Campbell, 101 Cal App 156, 281 P 717; McGuire v Chicago, B. &

Blackstone's definition of police power as "the due regulation and domestic order of the kingdom, whereby the individuals of the state, like members of a well-governed family, are bound to conform their general behavior to the rules of propriety, good neighborhood, and good manners, and to be decent, industrious, and inoffensive in their respective stations," finds support in judicial decisions.[98] Some cases define it as "the power vested in the legislature by the Constitution to make, ordain, and establish all manner of wholesome and reasonable laws, statutes, and ordinances, either with penalties or without, not repugnant to the Constitution, as they shall judge to be for the good and welfare of the commonwealth, and of the subjects of the same."[99]

There is considerable authority which speaks of the police power as the power inherent in the state to prescribe, within the limits of the state and federal constitutions, reasonable regulations necessary to preserve the public order, health, safety, and morals.[1] And many cases which do not use this language state definitions of essentially similar import.[2] And it has been said

Q. R. Co., 131 Iowa 340, 108 NW 902, later app 138 Iowa 664, 116 NW 801, affd 219 US 549, 55 L Ed 328, 31 S Ct 259; People v Dehn, 190 Mich 122, 155 NW 744; Shealy v Southern R. Co., 127 SC 15, 120 SE 561.

98. Hunter v Green, 142 Fla 104, 194 So 379; Dunn v Commonwealth, 105 Ky 834, 49 SW 813; State v Bott, 31 La Ann 663 (ovrld on another point State v Baum 33 La Ann 981); Watertown v Mayo, 109 Mass 315; State v Mountain Timber Co., 75 Wash 581, 135 P 645, affd 243 US 219, 61 L Ed 685, 37 S Ct 260; State v Buchanan, 29 Wash 602, 70 P 52.

The police power is that power in government which restrains individuals from transgressing the rights of others, and restrains them in their conduct so far as is necessary to protect the rights of all. State v Dolan, 13 Idaho 693, 92 P 995.

Police power is the power to impose restrictions upon the personal or property rights of private persons. Cleveland Tel. Co. v Cleveland, 98 Ohio St 358, 121 NE 701.

99. Sweet v Rechel, 159 US 380, 40 L Ed 188, 16 S Ct 43; Hunter v Green, 142 Fla 104, 194 So 379; Rodemacher v Milwaukee & St. P. Ry. Co., 41 Iowa 297; Sanders v Commonwealth, 117 Ky 1, 77 SW 358; State v Bott, 31 La Ann 663 (ovrld on another point State v Baum 33 La Ann 981); State v Robb, 100 Me 180, 60 A 874; State v Gurry, 121 Md 534, 88 A 546; Commonwealth v Bearse, 132 Mass 542; Hart v State, 87 Miss 171, 39 So 523; Hadden v Auken, 156 Neb 215, 55 NW2d 620, 35 ALR2d 1003 (ovrld on other grounds Stauffer v Weedlun 138 Neb 105, 195 NW2d 218, app dismd 409 US 972; 34 L Ed 2d 236, 93 S Ct 307); State v Griffin, 69 NH 1, 39 A 260; State v Powell, 58 Ohio St 324, 50 NE 900; State ex rel. Whetsel v Wood, 207 Okla 193, 248 P2d 612, 34 ALR2d 1321; Daniels v Portland, 124 Or 677, 265 P 790, 59 ALR 512; State v Kofines, 33 RI 211, 80 A 432; Harrington v Board of Aldermen, 20 RI 233, 38 A 1; State v Central Lumber Co., 24 SD 136, 123 NW 504, affd 226 US 157, 57 L Ed 164, 33 S Ct 66; State v Theriault, 70 Vt 617, 41 A 1030; State v Harrington, 68 Vt 622, 35 A 515; Wisconsin Keeley Institute Co. v Milwaukee County, 95 Wis 153, 70 NW 68.

1. Re Application of Rameriz, 193 Cal 633, 226 P 914, 34 ALR 51; People v Chicago, M. & S. P. R. Co., 306 Ill 486, 138 NE 155, 28 ALR 610; Bruck v State, 228 Ind 189, 91 NE2d 349; Tighe v Osborne, 150 Md 452, 133 A 465, 46 ALR 80, former app 149 Md 349, 131 A 801, 43 ALR 819; State ex rel. Minot v Gronna, 79 ND 673, 59 NW2d 514; Lindsay v Cincinnati, 172 Ohio St 137, 15 Ohio Ops 2d 278, 174 NE2d 96; Camas Stage Co. v Kozer, 104 Or 600, 209 P 95, 25 ALR 27; Vermont Salvage Corp. v St. Johnsbury, 113 Vt 341, 34 A2d 188; Conger v Pierce County, 116 Wash 27, 198 P 377, 18 ALR 393.

2. Police power is simply the power to subject individuals to reasonable regulations so as to achieve such governmental objectives as the public safety, health, morals, and welfare. Doyle v Board of Barber Examiners (3d Dist) 219 Cal App 2d 504, 33 Cal Rptr 349.

The police power is the sovereign right of the state to enact laws for the protection of lives, health, morals, comfort, and general welfare. Burnsed v Seaboard C. R. Co. (Fla) 290 So 2d 13; State ex rel. Municipal Bond & Invest. Co. v Knott, 114 Fla 120, 154 So 143.

The term "police power" comprehends the power to make and enforce all wholesome and reasonable laws and regulations necessary to maintain the public health, comfort, safety, and welfare. Frazer v Shelton, 320 Ill 253, 150 NE 696, 43 ALR 1086; Culver v Streator, 130 Ill 238, 22 NE 840.

The "police power" is that inherent and plenary power in the state which enables it to

prohibit all things hurtful to the comfort, safety, and welfare of society. People v Weiner, 271 Ill 74, 110 NE 870.

"The police power is the name given to that inherent sovereignty which it is the right and duty of the government to exercise, whenever public policy in a broad sense demands, for the benefit of society at large, regulations to guard its morals, safety, health, order, or to insure, in any respect, such economic conditions as an advancing complex civilization requires." Chicago, T. H. & S. R. Co. v Anderson, 182 Ind 140, 105 NE 49, affd 242 US 283, 61 L Ed 302, 37 S Ct 124; State v Brooken, 19 NM 404, 143 P 479; Stettler v O'Hara, 69 Or 519, 139 P 743, affd 243 US 629, 61 L Ed 937, 37 S Ct 475; Ex parte Townsend, 64 Tex Crim 350, 144 SW 628; Hopkins v Richmond, 117 Va 692, 86 SE 139 (ovrld on other grounds Irvine v Clifton Forge 124 Va 781, 97 SE 310); Sutherland v Miller, 79 W Va 796, 91 SE 993.

The "police power," as that term is commonly employed, may be paraphrased as society's natural right of self-defense, and its definitions and limitations vary with the circumstances calling for its exercise; it comprehends all those general laws and internal regulations necessary to secure the peace, good order, health, and prosperity of the people, and the regulation and protection of property and property rights. McGuire v Chicago, B. & Q. R. Co., 131 Iowa 340, 108 NW 902, later app 138 Iowa 664, 116 NW 801, affd 219 US 549, 55 L Ed 328, 31 S Ct 259.

The police power is the taproot of government, out of which grow internal regulations necessary to preserve the public order, health, safety, and morals. Henry v Parrish, 307 Ky 559, 211 SW2d 418.

The police power is the power to protect the public health and the public safety, to preserve good order and the public morals, to protect the lives and property of citizens, and to govern men and things by any legislation appropriate to that end. Barker v Palmer, 217 NC 519, 8 SE2d 610; Calcutt v McGeachy, 213 NC 1, 195 SE 49.

The police power of the state is the power inherent in every sovereignty to govern men and things, under which power the legislature may, within constitutional limits, not only prohibit all things hurtful to the comfort, safety, and welfare of society, but may prescribe regulations to promote the public health, morals, and safety, and add to the general public convenience, prosperity, and welfare. State ex rel. Cleveringa v Klein, 63 ND 514, 249 NW 118, 86 ALR 1523; State ex rel. Linde v Taylor, 33 ND 76, 156 NW 561, error dismd 245 US 627, 62 L Ed 518, 38 S Ct 60.

Police power may be defined as the power "by which persons and property are subjected to all kinds of restraints and burdens in order to secure the general comfort, health, and prosperity of the state". Marmet v State, 45 Ohio St 63, 12 NE 463.

The police power of a state is the broad, inherent power of the General Assembly to prescribe regulations which promote the education, health, safety, peace, morals and general welfare of the community. State v Stouffer, 28 Ohio App 2d 229, 57 Ohio Ops 2d 342, 276 NE2d 651.

The police power of the state is the power of government inherent in every sovereignty to enact laws, within constitutional limits, to promote the general welfare of its citizens. Jack Lincoln Shops, Inc. v State Dry Cleaners' Board, 192 Okla 251, 135 P2d 332; Huntington v State Water Com., 137 W Va 786, 73 SE2d 833.

The police powers are nothing more nor less than the powers of government inherent in every sovereignty to govern men and things. Under these powers the government regulates the conduct of its citizens, one toward another, and the manner in which each shall use his own property, when such regulation becomes necessary for the public good. State v Rossman, 93 Wash 530, 161 P 349.

The police power of a state "embraces its whole system of internal regulation, by which the state seeks not only to preserve the public order and to prevent offenses against the state, but also to establish for the intercourse of citizens with citizens those rules of good manners and good neighborhood which are calculated to prevent a conflict of rights, and to insure to each the uninterrupted enjoyment of his own so far as is reasonably consistent with a like enjoyment of rights by others." Hunter v Green, 142 Fla 104, 194 So 379; Sifers v Johnson, 7 Idaho 798, 65 P 709; Meadowcroft v People, 163 Ill 56, 45 NE 991; Western Union Tel. Co. v Pendleton, 95 Ind 12, revd on other grounds 122 US 347, 30 L Ed 1187, 7 S Ct 1126; Dunn v Commonwealth, 105 Ky 834, 49 SW 813; Shreveport v Dantes, 118 La 113, 42 So 716; People v Dehn, 190 Mich 122, 155 NW 744; Donnell v State, 48 Miss 661; Colvill v Fox, 51 Mont 72, 149 P 496; Ives v South B. R. Co., 201 NY 271, 94 NE 431 (ovrld on other grounds Montgomery v Daniels 38 NY2d 41, 378 NYS2d 1, 340 NE2d 444); Hathorn v Natural Carbonic Gas Co., 194 NY 326, 87 NE 504; People ex rel. New York Electric Lines Co. v Squire, 107 NY 593, 14 NE 820, affd 145 US 175, 36 L Ed 666, 12 S Ct 880; Gibbons v Missouri, K. & T. R. Co., 142 Okla 146, 285 P 1040; State v Bunting, 71 Or 259, 139 P 731, affd 243 US 426, 61 L Ed 830, 37 S Ct 435; State v Kofines, 33 RI 211, 80 A 432; State v Scougal, 3 SD 55, 51 NW 858 (ovrld on other grounds Wall v Fenner 76 SD 252, 76 NW2d 722); State v Buchanan, 29 Wash 602, 70 P 52; Peel Splint Coal Co. v

that by means of this power the legislature exercises a supervision over matters involving the common welfare and enforces the observance, by each individual member of society, of the duties which he owes to others and to the community at large.[3]

2. Nature

a. In General

§ 364. Generally; importance of power.

The police power, which it has been said is not a rule but an evolution,[4] is, perhaps, the most important of governmental powers.[5] It has been called a principal pillar of government,[6] and has been described as the most essential, at the times the most insistent, and always one of the least limitable of the powers of government.[7] Moreover, it has been said that the very existence of government,[8] as well as the security of the social order, the life and health of

State. 36 W Va 802, 15 SE 1000; Wisconsin Keeley Institute Co. v Milwaukee County, 95 Wis 153, 70 NW 68.

3. Western Indem. Co. v Pillsbury, 170 Cal 686, 151 P 398; Hunter v Green, 142 Fla 104, 194 So 379; People v Dehn, 190 Mich 122, 155 NW 744; People v King, 110 NY 418, 18 NE 245, State v Yarboro, 194 NC 498, 140 SE 216.

4. State ex rel. Hughes v Cleveland, 47 NM 230, 141 P2d 192.

5. The police power is a great power. Without it the purpose of civil government could not be attained. It has more to do with the well-being of society than any other power. Properly exercised, it is a crowning influence. Improperly exercised, it would make of sovereign will a destructive despot, superseding and rendering innocuous some of the most cherished principles of constitutional freedom. Mehlos v Milwaukee, 156 Wis 591, 146 NW 882.

6. Ruona v Billings, 136 Mont 554, 323 P2d 29, Quesenberry v Estep, 142 W Va 426, 95 SE2d 832; Huntington v State Water Com., 137 W Va 786, 73 SE2d 833.

7. Queenside Hills Realty Co. v Saxl, 328 US 80, 90 L Ed 1096, 66 S Ct 850; McDonald v Mabee, 243 US 90, 61 L Ed 608, 37 S Ct 343; Hall v Geiger-Jones Co., 242 US 539, 61 L Ed 480, 37 S Ct 217; Hadacheck v Sebastian, 239 US 394, 60 L Ed 348, 36 S Ct 143; Sligh v Kirkwood, 237 US 52, 59 L Ed 835, 35 S Ct 501; Eubank v Richmond, 226 US 137, 57 L Ed 156, 33 S Ct 76, revg 110 Va 749, 67 SE 376, Miller v Board of Public Works, 195 Cal 477, 234 P 381, 38 ALR 1479, error dismd 273 US 781, 71 L Ed 889, 47 S Ct 460; State v Gerry, 121 Md 534, 88 A 546; Poole & Creber Market Co. v Breshears, 343 Mo 1133, 125 SW2d 23; Ex parte Taft, 284 Mo 531, 225 SW 457; A. E. Nettleton Co. v Diamond, 27 NY2d 182, 315 NYS2d 625, 264 NE2d 118, 44 ALR3d 994, reh den 28 NY2d 539, 319 NYS2d 440, 268 NE2d 122 and app dismd 401 US 969, 28 L Ed 2d 319, 91 S Ct 1201; Engelsher v Jacobs, 5 NY2d 370, 184 NYS2d 640, 157 NE2d 626, cert den 360 US 902, 3 L Ed 2d 1255, 79 S Ct 1286; People v Perretta, 253 NY 305, 171 NE 72, 84 ALR 636; Brewer v Valk, 204 NC 186, 167 SE 638, 87 ALR 237; State v Lockey, 198 NC 551, 152 SE 693; Wessell v Timberlake, 95 Ohio St 21, 116 NE 43; Colletti v State, 12 Ohio App 104, motion overr; C. C. Julian Oil & Royalties Co. v Capshaw, 145 Okla 237, 292 P 841; Commonwealth v Widovich, 295 Pa 311, 145 A 295, cert den 280 US 518, 74 L Ed 588, 50 S Ct 66; Shealy v Southern R. Co., 127 SC 15, 120 SE 561; State v Wood, 51 SD 485, 215 NW 487, 54 ALR 719; State v McKay, 137 Tenn 280, 193 SW 99.

8. Birmingham M. R. Co. v Parsons, 100 Ala 662, 13 So 602; American Union Tel. Co. v Western Union Tel. Co., 67 Ala 26; McInerney v Ervin (Fla) 46 So 2d 458; East Side Levee & Sanitary Dist. v East St. Louis & C. R. Co., 279 Ill 123, 116 NE 720; Ex parte Taft, 284 Mo 531, 225 SW 457; Brewer v Valk, 204 NC 186, 167 SE 638, 87 ALR 237; State v Lockey, 198 NC 551, 152 SE 693; Colletti v State, 12 Ohio App 104, motion overr; C. C. Julian Oil & Royalties Co. v Capshaw, 145 Okla 237, 292 P 841; Commonwealth v Widovich, 295 Pa 311, 145 A 295, cert den 280 US 518, 74 L Ed 588, 50 S Ct 66; Shealy v Southern R. Co., 127 SC 15, 120 SE 561; State ex rel. George v City Council of Aiken, 42 SC 222, 20 SE 221; Beaumont Petroleum Syndicate v Broussard (Tex Civ App) 64 SW2d 993, app dismd 123 Tex 408, 73 SW2d 92, ans conformed to (Tex Civ App) 73 SW2d 1047.

the citizen, the enjoyment of private and social life, and the beneficial use of property[9] are dependent upon this power.

§ 365. Distinctions between police and other governmental powers; eminent domain.

The boundary line which divides the police power of the state from the other functions of government is often difficult to discern,[10] but it is distinguishable from taxation,[11] and, although its exercise and the exercise of eminent domain have much in common,[12] the police and eminent domain powers are also essentially distinct.[13] Thus, under the police power, many restrictions may be imposed without compensation being given, whereas under the power of eminent domain compensation is required.[14] A further and more

9. Pearsall v Great N. R. Co., 161 US 646, 40 L Ed 838, 16 S Ct 705; Slaughter-House Cases, 83 US 36, 21 L Ed 394; AFL v Watson (DC Fla) 60 F Supp 1010, revd on other grounds 327 US 582, 90 L Ed 873, 66 S Ct 761; Geurin v Little Rock, 203 Ark 103, 155 SW2d 719, 135 ALR 1305; Idaho Power & Light Co. v Blomquist, 26 Idaho 222, 141 P 1083; East Side Levee & Sanitary Dist. v East St. Louis & C. R. Co., 279 Ill 123, 116 NE 720; State ex rel. Mavity v Tyndall, 225 Ind 360, 74 NE2d 914, app dismd 333 US 834, 92 L Ed 1118, 68 S Ct 609, reh den 333 US 858, 92 L Ed 1138, 68 S Ct 732; State v Gurry, 121 Md 534, 88 A 546; Ex parte Taft, 284 Mo 531, 225 SW 457; Ruona v Billings, 136 Mont 554, 323 P2d 29; Calcutt v McGeachy, 213 NC 1, 195 SE 49; Brewer v Valk, 204 NC 186, 167 SE 638, 87 ALR 237; State v Lockey, 198 NC 551, 152 SE 693; Colletti v State, 12 Ohio App 104, motion overr; C. C. Julian Oil & Royalties Co. v Capshaw, 145 Okla 237, 292 P 841; Harrington v Board of Aldermen, 20 RI 233, 38 A 1; Shealy v Southern R. Co., 127 SC 15, 120 SE 561; Beaumont Petroleum Syndicate v Broussard (Tex Civ App) 64 SW2d 993, app dismd 123 Tex 408, 73 SW2d 92, ans conformed to (Tex Civ App) 73 SW2d 1047; Quesenberry v Estep, 142 W Va 426, 95 SE2d 832; Huntington v State Water Com., 137 W Va 786, 73 SE2d 833.

10. Smiley v MacDonald, 42 Neb 5, 60 NW 355; Colletti v State, 12 Ohio App 104, motion overr.

11. § 366, infra.

12. State ex rel. Twin City Bldg. & Inv. Co. v Houghton, 144 Minn 13, 176 NW 159, 8 ALR 585; New York City Housing Authority v Muller, 270 NY 333, 1 NE2d 153, 105 ALR 905; People ex rel. Durham Realty Corp. v La Fetra, 230 NY 429, 130 NE 601, 16 ALR 152, error dismd 257 US 665, 66 L Ed 424, 42 S Ct 47.

There is a considerable resemblance between the police power and eminent domain in that each power recognizes the superior right of the community against the selfishness of an individual, the one preventing his use of his own property in his own way as against the general comfort and protection of the public, and the other depriving him of the right to obstruct the public necessity and convenience by obstinately refusing to part with his property when needed for the public use. People ex rel. Detroit & H. R. Co. v Township Board of Salem, 20 Mich 452 (ovrld on other grounds Burdick v Harbor Springs Lumber Co. 167 Mich 673, 133 NW 822) and (ovrld on other grounds Re Petition of Carson 362 Mich 409, 107 NW2d 902) as stated in Re Advisory Opinion 401 Mich 686, 259 NW2d 129.

13. Adams v Housing Authority of Daytona Beach (Fla) 60 So 2d 663 (ovrld on other grounds Baycol, Inc. v Downtown Development Authority (Fla) 315 So 2d 451).

11 Cal L Rev 188 (determining where eminent domain begins and police power ends); 50 Cal L Rev 549 (conflict between police power and power of eminent domain in restriction of new construction in urban renewal area).

14. Pacific Tel. & Tel. Co. v Eshleman, 166 Cal 640, 137 P 1119; Schaake v Dolley, 85 Kan 598, 118 P 80; Commonwealth v Bearse, 132 Mass 542; Watertown v Mayo, 109 Mass 315; Rothwell v Linzell, 163 Ohio St 517, 56 O Ops 431, 127 NE2d 524, app dismd 350 US 1012, 100 L Ed 872, 76 S Ct 658; Gibbons v Missouri, K. & T. R. Co., 142 Okla 146, 285 P 1040; Appeal of White, 287 Pa 259, 134 A 409, 53 ALR 1215; State v Kofines, 33 RI 211, 80 A 432.

Whether the state or its subdivisions may take or damage private property under the police power without compensation is a matter of the degree of necessity in the particular case. If not prompted by a sufficient necessity, a taking without compensation is not justified. Archer v Los Angeles, 19 Cal 2d 19, 119 P2d 1.

When in the exercise of the police power the state through its agents destroys diseased cattle, unwholesome meats, decayed fruits or fish, infected clothing, obscene books or pictures, or

important distinct
right in property is
be enjoyed by it a
and often does, ta
paid for, this is not
the property or ir
domain for a pu
enjoyment, or, if it
public use, but to
the public.[15] The es

buildings in the path
constitutional requirem
tion does not compel
the owner whose prop
property is incapable o
ever, a legislative provi
in such cases may be r
level the legislature m
where the payment of
requisite, the legislatur
maximum compensation
Board v Smith (Fla) 110

As to compensation
by exercise of the police

44 So Cal L Rev 1 (c
when compensation is c
for economic loss resul
regulation).

15. Rose v State, 19 Ca
(police power operates
except possibly in some
Pacific Tel. & Tel. Co.
640, 137 P 1119 (notin
passes beyond proper re
a taking of the property
then referable not to th
the power of eminent d
Q. R. Co. v Public Utiliti
193 P 726 (holding that
across a railroad right o
cise of the police power
v Board of Com'rs, 104
635, 23 ALR 866; Illinoi
135 Tenn 446, 186 SW

Property is taken by e
use of the public. The
the use of property or
property because the
rights is detrimental to p
v Whitney, 95 Conn 35
669.

The distinction betw
and eminent domain de
thing is destroyed or
public use. People ex re
v La Fetra, 230 NY 429
152, error dismd 257 US
S Ct 47.

In the exercise of the
main private property

important distinction lies in the fact that in eminent domain, property or a right in property is taken from the owner and transferred to a public agency to be enjoyed by it as its own, whereas under the police power, although it may, and often does, take property in the constitutional sense so that it must be paid for, this is not accomplished by a transfer of ownership, but by destroying the property or impairing its value.[15] Private property is taken by eminent domain for a public use, while the police power regulates its use and enjoyment, or, if it takes or damages it, it is not a taking or damaging for the public use, but to conserve the safety, morals, health, and general welfare of the public.[16] The essence of the police power, as differentiated from the power

buildings in the path of a conflagration, the constitutional requirement of just compensation does not compel the state to reimburse the owner whose property is destroyed. Such property is incapable of any lawful use. However, a legislative provision for compensation in such cases may be made as a bounty at a level the legislature may desire. But in cases where the payment of just compensation is a requisite, the legislature may not specify the maximum compensation to be paid. State Plant Board v Smith (Fla) 110 So 2d 401.

As to compensation for injuries occasioned by exercise of the police power, § 408, infra.

44 So Cal L Rev 1 (criteria for determining when compensation is constitutionally required for economic loss resulting from government regulation).

15. Rose v State, 19 Cal 2d 713, 123 P2d 505 (police power operates in field of regulation, except possibly in some cases of emergency); Pacific Tel. & Tel. Co. v Eshleman, 166 Cal 640, 137 P 1119 (noting that when an order passes beyond proper regulation it amounts to a taking of the property, and that the order is then referable not to the police power but to the power of eminent domain); Chicago, B. & Q. R. Co. v Public Utilities Com., 69 Colo 275, 193 P 726 (holding that the opening of a street across a railroad right of way was not an exercise of the police power); Pontiac Improv. Co. v Board of Com'rs, 104 Ohio St 447, 135 NE 635, 23 ALR 866; Illinois C. R. Co. v Moriarity, 135 Tenn 446, 186 SW 1053.

Property is taken by eminent domain for the use of the public. The police power regulates the use of property or impairs the rights in property because the free exercise of these rights is detrimental to public interest. Windsor v Whitney, 95 Conn 357, 111 A 354, 12 ALR 669.

The distinction between the police power and eminent domain depends on whether the thing is destroyed or is taken over for the public use. People ex rel Durham Realty Corp. v La Fetra, 230 NY 429, 130 NE 601, 16 ALR 152, error dismd 257 US 665, 66 L Ed 424, 42 S Ct 47.

In the exercise of the right of eminent domain private property may be taken or damaged to serve a public use, but not without just compensation. On the other hand, the police power is usually exerted merely to regulate the use and enjoyment of property by the owner, or, if he is deprived of his property outright, it is not taken for public use, but rather destroyed in order to promote the general welfare of the public, and in neither case is the owner entitled to any compensation for any injury he may sustain in consequence thereof, for the law considers that either the injury is damnum absque injuria or the owner is sufficiently compensated by sharing in the general benefits resulting from the exercise of the police power. The absence of compensation, of course, makes the police power much more harsh in operation than the power of eminent domain and, hence, subject to stricter limitations. State ex rel. Austin v Thomas, 96 W Va 628, 123 SE 590, 38 ALR 1490.

16. Adams v Housing Authority of Daytona Beach (Fla) 60 So 2d 663 (ovrld on other grounds Baycol, Inc. v Downtown Development Authority (Fla) 315 So 2d 451); Conger v Pierce County, 116 Wash 27, 198 P 377, 18 ALR 393.

There is a very clear distinction between an appropriation of private property to a public use in the exercise of the power of eminent domain, and the regulation of the use of property and its destruction, if necessary, in the exercise of the police power. Under the power of eminent domain the sovereign may make a compulsory purchase of the property of the citizen when such property is to be appropriated to a public purpose or use, but such appropriation cannot be made even by the sovereign, without just compensation. Differently stated, in the exercise of the power of eminent domain the sovereign compels the dedication of the property or some interest therein, to a public use or, if already dedicated to one public use, then to another. On the other hand, the police power is exercised by the sovereign to promote the health, morals and safety of the community. It rests upon the fundamental principle that everyone shall so use his own property as not to wrong or injure another. Thus to destroy property because it is a public nuisance is not to appropriate it to a

of eminent domain, is that deprivation of individual rights and property cannot prevent its operation, once it is shown that its exercise is proper and that the method of its operation is reasonably within the meaning of due process of law.[17]

Despite the above-stated distinctions, there still remains an area where the courts, in a case-by-case approach, must determine whether a particular governmental interference is an exercise of the power of eminent domain, subject to the duty to compensate the private owner,[18] or an exercise of the police power, free from such duty to indemnify the person whose property is affected.[19]

§ 366. —Taxation.[20]

Although it has been said that taxation for the purpose of regulation rather than to raise revenue is an exercise of the police power,[21] and the public purposes for which a state may raise funds by taxation embrace expenditures for the general welfare,[22] there is no doubt that a real distinction exists between the two powers:[23] they are both distinct, coexistent powers in the state.[24] Broadly speaking, the distinction is that the taxing power is exercised for the purpose of raising revenue and is subject to certain designated constitutional limitations, while the police power is exercised for the promotion of the public welfare by means of the regulation of dangerous or

public use, but to prevent any use of it by its owner and to put an end to its existence. State Plant Board v Smith (Fla) 110 So 2d 401.

Police power controls the use of property by the owner, for the public good, its use otherwise being harmful, while "eminent domain" and taxation take property for public use. Appeal of White, 287 Pa 259, 134 A 409, 53 ALR 1215.

17. Consolidated Rock Products Co. v Los Angeles, 57 Cal 2d 515, 20 Cal Rptr 638, 370 P2d 342, app dismd 371 US 36, 9 L Ed 2d 112, 83 S Ct 145; Beverly Oil Co. v Los Angeles, 40 Cal 2d 552, 254 P2d 865.

18. Albers v County of Los Angeles, 62 Cal 2d 250, 42 Cal Rptr 89, 398 P2d 129; Pacific Tel. & Tel. Co. v Eshleman, 166 Cal 640, 137 P 1119; People ex rel. Ricks Water Co. v Elk River Mill & Lumber Co., 107 Cal 221, 40 P 531.

19. San Mateo v Railroad Com. of California, 9 Cal 2d 1, 68 P2d 713; Southern Pacific Co. v Los Angeles (2d Dist) 242 Cal App 2d 38, 51 Cal Rptr 197, app dismd 385 US 647, 17 L Ed 2d 669, 87 S Ct 767.

In distinguishing the power of eminent domain from the police power, the test frequently mentioned—that one may recover if he has suffered a damage peculiar to himself and different in kind, as differentiated from degree, from that suffered by the public generally—is of no assistance in solution of the problem. Bacich v Board of Control, 23 Cal 2d 343, 144 P2d 818.

20. Discussed at this point are general principles relating to the distinction between the police power and the power of taxation. As to examples of specific legislation held to represent an exercise of one or the other of the powers, see 71 Am Jur 2d, STATE AND LOCAL TAXATION § 69.

21. Carthage v Rhoads, 101 Mo 175, 14 SW 181; Litchville v Hanson, 19 ND 672, 124 NW 1119.

22. See 71 Am Jur 2d, STATE AND LOCAL TAXATION § 47.

23. State v Anderson, 144 Tenn 564, 234 SW 768, 19 ALR 180; Robinson v Norfolk, 108 Va 14, 60 SE 762.

The police and taxing powers of the legislature, although coexistent, are distinct powers; hence, the exercise of the former is not restrained by the existence of the latter. Holst v Roe, 39 Ohio St 340.

24. Carthage v Rhoads, 101 Mo 175, 14 SW 181; Litchville v Hanson, 19 ND 672, 124 NW 1119; Holst v Roe, 39 Ohio St 340; State v Anderson, 144 Tenn 564, 234 SW 768, 19 ALR 180.

Power to tax for the purpose of creating revenue is not included within the police power of the state even though part of the fund so raised is devoted to the enforcement of police regulations. Iowa Motor Vehicle Ass'n v Board of Railroad Com'rs, 207 Iowa 461, 221 NW 364, 75 ALR 1, aff'd 280 US 529, 74 L Ed 595, 50 S Ct 151.

potentially dangerous businesses, occupations, or activities, and is not subject to the constitutional restrictions applicable to the taxing power.[25] It may consequently be said that if the primary purpose of a statute or ordinance exacting an imposition of some kind is to raise revenue, it represents an exercise of the taxing power,[26] while if the primary purpose of such an enactment is the regulation of some particular occupation, calling, or activity, it is an exercise of the police power, even if it incidentally produces revenue.[27]

An exaction which is invalid as an exercise of the taxing power may not be upheld as an exercise of the police power where it is clear that the legislative body imposing it did not intend it as such,[28] but, on the other hand, an exaction which would be invalid as an exercise of the taxing power may be upheld as a regulatory measure where the primary purpose of the legislature in imposing it was the regulation of some calling or activity which is potentially inimical.[29]

An exercise of the police power of the state may be sustained where the particular purpose is not such a public use as would sustain the validity of a

25. State ex rel. Pierce v Cowdy, 62 Mont 119, 203 P 1115; State v Anderson, 144 Tenn 564, 234 SW 768, 19 ALR 180; Robinson v Norfolk, 108 Va 14, 60 SE 762. See also McGlone v Womack, 129 Ky 274, 111 SW 688, holding that a tax imposed upon dogs for the purpose of raising a common fund for repairing or mitigating such losses as may be inflicted by them through killing or injuring sheep is a valid exercise of the police power, and is not within the requirement that taxes shall be imposed only for public purposes.

A constitutional provision requiring all property to be taxed in proportion to its value is not a limitation on the police power, but upon the taxing power, of the state. McGlone v Womack, 129 Ky 274, 111 SW 688; Carthage v Rhoads, 101 Mo 175, 14 SW 181.

In the exercise of the police power the legislature is not hampered by any limitation placed by the constitution on the exercise of the taxing power. State v Anderson, 144 Tenn 564, 234 SW 768, 19 ALR 180.

26. Lemont v Jenks, 197 Ill 363, 64 NE 362; State v McFall, 112 Or 183, 229 P 79; Reser v Umatilla County, 48 Or 326, 86 P 595; State v Anderson, 144 Tenn 564, 234 SW 768, 19 ALR 180.

The police power is chiefly regulative, and although, as an incident to regulative policy, a small fee may be imposed thereunder, usually supposed to cover the expense of the law's supervision of the business or matter to which it applies, the power may not be resorted to as a taxing power, and whenever, from the context of the statute by which the power is exercised or from the amount of the sum demanded therein, the court can see that the purpose of the regulation and fee imposed is primarily revenue, it will refer it to the taxing power and measure the act by its standards and requirements. Lemont v Jenks, 197 Ill 363, 64 NE 362.

27. Lemont v Jenks, 197 Ill 363, 64 NE 362; Holst v Roe, 39 Ohio St 340; Reser v Umatilla County, 48 Or 326, 86 P 595; State v Anderson, 144 Tenn 564, 234 SW 768, 19 ALR 180; Unemployment Compensation Com. v Renner, 59 Wyo 437, 143 P2d 181.

It is a well-established rule of law that notwithstanding revenue may result from the exercise of the police power, this alone does not strip the law of its police character and make of it an exercise of the taxing power. State v McFall, 112 Or 183, 229 P 79.

The fact that a considerable revenue is raised by a particular enactment and paid into the public treasury does not itself indicate that the act was passed as a revenue measure, nor destroy its character as a regulatory act passed in the exercise of the police power, where the object is to control, regulate, and restrict a particular activity. State v Packer Corp., 77 Utah 500, 297 P 1013.

28. Lemont v Jenks, 197 Ill 363, 64 NE 362; Littlefield v State, 42 Neb 223, 60 NW 724; Reser v Umatilla County, 48 Or 326, 86 P 595.

29. Lowell v Boston, 111 Mass 454; People v Van Horn, 46 Mich 183, 9 NW 246; Carthage v Rhoads, 101 Mo 175, 14 SW 181; Holst v Roe, 39 Ohio St 340; Donnelly v Decker, 58 Wis 461, 17 NW 389.

Although the term "tax" has never been thought to connote the expropriation of money from one group for the benefit of another, the latter sort of imposition is constitutional when imposed to effectuate regulation of a matter in which both groups are interested and in respect of which there is a power of regulation. United States v Butler, 297 US 1, 80 L Ed 477, 56 S Ct 312, 4 Ohio Ops 401, 102 ALR 914.

tax statute,[30] unless, of course, the legislature, in imposing such an exaction, acts in an arbitrary and unreasonable manner.[31]

Where the Federal Congress, which has no true police power,[32] has no power to regulate a particular subject matter directly, it cannot do so under the guise of taxation.[33]

There is no reason why a single statute or ordinance should not include the exercise of both the power of taxation and the police power,[34] and where this is the case, the only material inquiry with respect to its validity is whether or not the legislature could legally enact it in the exercise of either of said powers.[35] It has been held that when the purpose of the tax is a mixed one, it must conform to the limitations upon the taxing power, except so far as a departure is necessary to make it regulative or prohibitory.[36]

§ 367. Similarity to war power.

The war powers of Congress are not unlike what in the states is called police power, but it is the police power raised to the highest degree.[37] Both are well-known functions of government, and both are rules of necessity, impliedly or expressly existing in every form of government, the one to preserve sovereignty, and the other to preserve the health and morals of the community.[38] But both powers are subject to applicable constitutional limitations.[39]

The state's power to effect extraordinary regulations in emergencies, being

30. Lindsley v Natural Carbonic Gas Co., 220 US 61, 55 L Ed 369, 31 S Ct 337; Noble State Bank v Haskell, 219 US 104, 55 L Ed 112, 31 S Ct 186, amd on other grounds 219 US 575, 55 L Ed 341, 31 S Ct 299; Bacon v Walker, 204 US 311, 51 L Ed 499, 27 S Ct 289; Ohio Oil Co. v Indiana, 177 US 190, 44 L Ed 729, 20 S Ct 576.

31. Mirick v Gims, 79 Ohio St 174, 86 NE 880.

32. § 381, infra.

33. State Tonnage Tax Cases, 79 US 204, 20 L Ed 370.

34. State v Kartus, 230 Ala 352, 162 So 533, 101 ALR 1336, ans conformed to 26 Ala App 446, 162 So 538 (holding that the police power, as well as the sovereign power to tax for the purpose of raising revenue, is involved in a statutory provision imposing a license tax of $100 upon those selling or engaged in the business of selling goods at certain kinds of sales, as those advertised as bankrupt, insolvent, wholesale, fire, or closing-out sales); *Phoenix Assur. Co v Fire Dept. of Montgomery*, 117 Ala 631, 23 So 843; Re Application of Kalana, 22 Hawaii 96; Youngblood v Sexton, 32 Mich 406 (declaring that a statute which imposed a tax upon dealers in intoxicating liquors, although having revenue for one object, had the police of the state for another); State v Preston, 103 Or 631, 206 P 304, 23 ALR 414; Fahey v State, 27 Tex App 146, 11 SW 1081 rejecting the contention that because a statute imposing a tax on the occupation of dealing in intoxicating liquors involved the exercise of both the police power and the taxing power, it was violative of a constitutional provision forbidding any bill to contain more than one subject).

And see 51 Am Jur 2d, LICENSES AND PERMITS § 89; 60 Am Jur 2d, PEDDLERS, SOLICITORS, AND TRANSIENT DEALERS §§ 16–20.

35. Re Application of Kalana, 22 Hawaii 96.

That a statute combines a police regulation and an exercise of the taxing power does not render it invalid, if it operates uniformly throughout the state. State v Preston, 103 Or 631, 206 P 304, 23 ALR 414.

36. San Francisco v Liverpool & London & Globe Ins. Co., 74 Cal 113, 15 P 380.

37. Public Service Com. v New York C. R. Co., 230 NY 149, 129 NE 455, 14 ALR 449.

38. *Guttag v Shatzkin*, 230 NY 647, 130 NE 929.

39. As to constitutional limitations on the war power of the United States, see 78 Am Jur 2d, WAR § 20.

As to constitutional limitations on the police power, see §§ 391 et seq., infra.

limited to the polic
federal government

§ 368. Sic utere tuc

The police powe
alienum non laeda
another). The polic
maxim is enforced.
that degree of restr
ble enjoyment of a
of each citizen to u
due regard to the p
and most importan
involves restriction
principle does not

40. Re Blaney, 30 Cal
As to emergency polic
see § 371, infra.

41. Crowley v Christer
Ed 620, 11 S Ct 13;
Park, 97 US 659, 24
Illinois, 94 US 113, 2
House Cases, 83 US 36
Smith, 149 Ala 457,
Denver & R. G. R. Co.
969, affd 250 US 241,
450; People v Hupp, 5
Denver v Fruenuff, 39
McInerney v Ervin (Fla
County v Chicago, 311 I
ALR 442; Durand v D
NE 143; Chicago v Gu
628, 73 NE 1035; Pittsb
Co. v Chappell, 183 Ind
Moines v Manhattan Oi
184 NW 823, 23 ALR 1
193 Iowa 1117, 188 N
McGuire v Chicago, B.
340, 108 NW 902, later
NW 801, affd 219 US 5
Ct 259; Union Ice & C
La 898, 66 So 262; Gol
Md 282, 128 A 50, 3
Maryland Realty Co., 1
Watertown v Mayo, 109
v Holmes, 274 Mo 159,
rel. Star Pub. Co. v As
410, 60 SW 91; Colvill v
P 496; State v Griffin,
Eccles v Ditto, 23 NM
South B. R. Co., 201
(ovrld on other grounds
38 NY2d 41, 378 NYS2
Petition for Increase of
NC 151, 101 SE 619;
NC 329, 91 SE 1028; S
492, 80 SE 69; State ex

limited to the police power itself, is less extensive than the war power of the federal government.[40]

b. CONCEPTS EMBODIED IN POWER

§ 368. Sic utere tuo ut alienum non laedas.

The police power to a large extent rests on the maxim "sic utere tuo ut alienum non laedas"[41] (so use your own that you do not injure that of another). The police power is the function of the government by which this maxim is enforced.[42] Not only is it one of the objects of government to impose that degree of restraint on individual action which is required for the reasonable enjoyment of all in their respective rights,[43] but furthermore it is the duty of each citizen to use his property and exercise his rights and privileges with due regard to the personal and property rights of others. This duty is the first and most important obligation entering into the social compact, although it involves restrictions upon the so-called natural rights of individuals.[44] This principle does not conflict with[45] the express constitutional right that all

40. Re Blaney, 30 Cal 2d 643, 184 P2d 892.

As to emergency police legislation, generally, see § 371, infra.

41. Crowley v Christensen, 137 US 86, 34 L Ed 620, 11 S Ct 13; Fertilizing Co. v Hyde Park, 97 US 659, 24 L Ed 1036; Munn v Illinois, 94 US 113, 24 L Ed 77; Slaughter-House Cases, 83 US 36, 21 L Ed 394; Wolf v Smith, 149 Ala 457, 42 So 824; Denver v Denver & R. G. R. Co., 63 Colo 574, 167 P 969, affd 250 US 241, 63 L Ed 958, 39 S Ct 450; People v Hupp, 53 Colo 80, 123 P 651; Denver v Frueauff, 39 Colo 20, 88 P 389; McInerney v Ervin (Fla) 46 So 2d 458; Cook County v Chicago, 311 Ill 234, 142 NE 512, 31 ALR 442; Durand v Dyson, 271 Ill 382, 111 NE 143; Chicago v Gunning System, 214 Ill 628, 73 NE 1035; Pittsburgh, C., C. & S. L. R. Co. v Chappell, 183 Ind 141, 108 NE 403; Des Moines v Manhattan Oil Co., 193 Iowa 1096, 184 NW 823, 23 ALR 1322, supp op. reh overr 193 Iowa 1117, 188 NW 921, 23 ALR 1337; McGuire v Chicago, B. & Q. R. Co., 131 Iowa 349, 108 NW 902, later app 138 Iowa 664, 116 NW 801, affd 219 US 549, 55 L Ed 328, 31 S Ct 259; Union Ice & Coal Co. v Ruston, 135 La 898, 66 So 262; Goldman v Crowther, 147 Md 232, 128 A 50, 38 ALR 1455; Byrne v Maryland Realty Co., 129 Md 202, 98 A 547; Watertown v Mayo, 109 Mass 315; Kansas City v Holmes, 274 Mo 159, 202 SW 392; State ex rel. Star Pub. Co. v Associated Press, 159 Mo 410, 60 SW 91; Colvill v Fox, 51 Mont 72, 149 P 496; State v Griffin, 69 NH 1, 39 A 260; Eccles v Ditto, 23 NM 235, 167 P 726; Ives v South B. R. Co., 201 NY 271, 94 NE 431 (orrld on other grounds Montgomery v Daniels 38 NY2d 41, 378 NYS2d 1, 340 NE2d 444); Re Petition for Increase of Street Car Fares, 179 NC 151, 101 SE 619; Thomas v Sandlin, 173 NC 329, 91 SE 1028; State v Lawing, 164 NC 492, 80 SE 69; State ex rel Roth v Waterfield, 167 Okla 209, 29 P2d 24; Gant v Oklahoma City, 150 Okla 86, 6 P2d 1065, 86 ALR 794, app dismd 284 US 594, 76 L Ed 512, 52 S Ct 203 and later app 160 Okla 62, 15 P2d 833, affd 289 US 98, 77 L Ed 1058, 53 S Ct 530; C. C. Julian Oil & Royalties Co. v Capshaw, 145 Okla 237, 292 P 841; Big Butte Horse & Cattle Ass'n v Anderson, 133 Or 171, 289 P 503, 70 ALR 399; State v Kofines, 33 RI 211, 80 A 432; Shealy v Southern R. Co., 127 SC 15, 120 SE 561; Ex parte McCloskey, 82 Tex Crim 531, 199 SW 1101, affd 252 US 107, 64 L Ed 481, 40 S Ct 306; Block v Schwartz, 27 Utah 387, 76 P 22; Bowman v Virginia State Entomologist, 128 Va 351, 105 SE 141, 12 ALR 1121; Karasek v Peier, 22 Wash 419, 61 P 33; Peel Splint Coal Co. v State, 36 W Va 802, 15 SE 1000; State ex rel. Sampson v Sheridan, 25 Wyo 347, 170 P 1, 1 ALR 955.

Sic utere tuo ut alienum non laedas: A basis of the state police power, 21 Cornell LQ 276.

42. Re Morgan, 26 Colo 415, 58 P 1071; Union Ice & Coal Co. v Ruston, 135 La 898, 66 So 262; Daugherty v Thomas, 174 Mich 371, 140 NW 615; Re Application of Jacobs, 98 NY 98; C. C. Julian Oil & Royalties Co. v Capshaw, 145 Okla 237, 292 P 841; Shealy v Southern R. Co., 127 SC 15, 120 SE 561.

43. Re Morgan, 26 Colo 415, 58 P 1071; York Harbor Village Corp. v Libby, 126 Me 537, 140 A 382; C. C. Julian Oil & Royalties Co. v Capshaw, 145 Okla 237, 292 P 841; Shealy v Southern R. Co., 127 SC 15, 120 SE 561.

44. Des Moines v Manhattan Oil Co., 193 Iowa 1096, 184 NW 823, 23 ALR 1322, supp op, reh overr 193 Iowa 1117, 188 NW 921, 23 ALR 1337.

45. State ex rel. Hosack v Yocum, 136 Fla 246, 186 So 448, 121 ALR 270.

persons have of acquiring, possessing, and protecting property.[46]

It has been said that nearly every problem involved in the police power finds its solution in the application of the principle embodied in the maxim that everyone must so use his own property as not to injure the rights of others,[47] and that this principle should therefore be observed in the exercise of the police power.[48]

§ 369. Salus populi suprema lex est.

Another principle involved in the police power is expressed by the well-known maxim, "salus populi suprema lex est"[49] (the welfare of the people is the highest law). It has been said that this maxim is the foundation principle of all civil government[50] and that for ages it has been a ruling principle of jurisprudence.[51] It is the polestar of police power legislation.[52] All private rights enjoyed by individuals as members of the public are subject to the paramount right of the state to modify them to conserve the public welfare under this maxim.[53]

§ 370. The law of necessity, generally.

The police power has been described as the law of necessity[54] and as being

46. See §§ 580 et seq., infra.

47. Coca-Cola Bottling Co. v Mosby, 289 Mo 462, 233 SW 446; C. C. Julian Oil & Royalties Co. v Capshaw, 145 Okla 237, 292 P 841; Shealy v Southern R. Co., 127 SC 15, 120 SE 561; Karasek v Peier, 22 Wash 419, 61 P 33.

48. Sings v Joliet, 237 Ill 300, 86 NE 663; C. C. Julian Oil & Royalties Co. v Capshaw, 145 Okla 237, 292 P 841; Shealy v Southern R. Co., 127 SC 15, 120 SE 561.

49. St. Louis & S. F. R. Co v Mathews, 165 US 1, 41 L Ed 611, 17 S Ct 243, affg 121 Mo 298, 24 SW 591; Butchers' Union, etc., Co. v Crescent City, etc., Co., 111 US 746, 28 L Ed 585, 4 S Ct 652; Beer Co. v Massachusetts, 97 US 25, 24 L Ed 989; McKay Jewelers, Inc. v Bowron, 19 Cal 2d 595, 122 P2d 543, 139 ALR 1188; People v Hupp, 53 Colo 80, 123 P 651; Bland v People, 32 Colo 319, 76 P 359; McInerney v Ervin (Fla) 46 So 2d 458; People v Linde, 341 Ill 269, 173 NE 361, 72 ALR 997; Cook County v Chicago, 311 Ill 234, 142 NE 512, 31 ALR 442; Durand v Dyson, 271 Ill 382, 111 NE 143; State ex rel. Mavity v Tyndall, 225 Ind 360, 74 NE2d 914, app dismd 333 US 834, 92 L Ed 1118, 68 S Ct 609, reh den 333 US 858, 92 L Ed 1138, 68 S Ct 732; Jones Hollow Ware Co. v Crane, 134 Md 103, 106 A 274, 3 ALR 1658; Byrne v Maryland Realty Co., 129 Md 202, 98 A 547; State v Gurry, 121 Md 534, 88 A 546; Daugherty v Thomas, 174 Mich 371, 140 NW 615; Davock v Moore, 105 Mich 120, 63 NW 424; Ruona v Billings, 136 Mont 554, 323 P2d 29; Re Boyce, 27 Nev 299, 75 P 1; Wallace v Mayor, etc., of Reno, 27 Nev 71, 73 P 528; State ex rel. Hughes v Cleveland, 47 NM 230, 141 P2d 192; State v Boone, 84 Ohio St 346, 95 NE 924, adhered to on reh 85 Ohio St 313, 97 NE 975; Big Butte Horse & Cattle Ass'n v Anderson, 133 Or 171, 289 P 503, 70 ALR 399; Lingo Lumber Co. v Hayes (Tex Civ App) 64 SW2d 835; State v Rossman, 93 Wash 530, 161 P 349; State v Mountain Timber Co., 75 Wash 581, 135 P 645, affd 243 US 219, 61 L Ed 685, 37 S Ct 260.

The lives, health, and safety of the citizens of a state belong to the class of objects which demand the application of the maxim, "salus populi suprema lex." People ex rel. Doscher v Sisson, 180 App Div 464, 167 NYS 801, affd 222 NY 387, 118 NE 789.

50. State v Hay, 126 NC 999, 35 SE 459.

The maxim "salus populi suprema lex est" is more than a mere sentiment. It has become one of the props of the police power and is an elastic mantle whose ample folds cover much municipal legislation which finds no other justification. Cutsinger v Atlanta, 142 Ga 555, 83 SE 263; Byrne v Maryland Realty Co., 129 Md 202, 98 A 547.

51. Jentink v County of Lake, 244 Ill App 370; Eastman v State, 109 Ind 278, 10 NE 97; Ruona v Billings, 136 Mont 554, 323 P2d 29.

52. State ex rel. Ach v Braden, 125 Ohio St 307, 181 NE 138.

53. Neisel v Moran, 80 Fla 98, 85 So 346.

54. State ex rel. Wilkinson v Murphy, 237 Ala 332, 186 So 487, 121 ALR 283; Re Yun Quong, 159 Cal 508, 114 P 835; Ingram v Colgan, 106 Cal 120, 38 P 315, subsequent op on reh 106 Cal 113, 39 P 437; People v Linde, 341 Ill 269, 173 NE 361, 72 ALR 997; Cook

coextensive with
interest.[55] In a ge
needs and may be
the prevailing mor
immediately neces

County v Chicago, 311
ALR 442; Chicago v
Chicago, 289 Ill 206
1584; Randall v Patch.
8 ALR 65; State v St
431; State ex rel. Olso
457, 219 NW 770, 58
Westminster Presbyteri
108 Neb 859, 189 NW
v Vanhook, 182 NC 8
Public Utilities Com.,
Ohio Ops 39, 78 NE2
ham, 139 Or 592,
Portland, 124 Or 677,
Streich v Board of Ed
NW 779; Lingo Lumb
App) 64 SW2d 835; L
Crim 616, 171 SW 11
148 Va 795, 139 SE 5
low Amusement Co. v
269 P 1043, 60 ALR
County, 116 Wash 27,
State v Buchanan, 29
v Redmon, 134 Wis 8
rel. Sampson v Sherida
1 ALR 955.

55. Tanner v Little, 2
36 S Ct 379; Sligh v
L Ed 835, 35 S Ct
States, 167 US 518, 4
State v Kartus, 230 A
ALR 1336, ans confor
162 So 538; Draffen v
SW2d 362; Blaisdell
Ass'n, 189 Minn 422
1507, affd 290 US 39
231, 88 ALR 1481 and
249 NW 893; Hodge
Cincinnati, 123 Ohio
283, 175 NE 196, 77
335; 76 L Ed 323,
Timberlake, 95 Ohio
ex rel. Short v Riede
684, 42 ALR 765; Da
677, 265 P 790, 59 AL

The extent of the e
the police power of t
a consideration of the
any invocation of that
and as applied to exist
ably necessary to pr
safety, morals, or gen
of the community. M
Works, 195 Cal 477,
error dismd 273 US 7
460.

The exercise of po

coextensive with the necessities of the case and the safeguards of public interest.[55] In a general way the police power extends to all the great public needs and may be put forth in aid of what is sanctioned by usage or held by the prevailing morality or strong and preponderant opinion to be greatly and immediately necessary to the public welfare.[56] This general doctrine may be

County v Chicago, 311 Ill 234, 142 NE 512, 31 ALR 442; Chicago v Washingtonian Home of Chicago, 289 Ill 206, 124 NE 416, 6 ALR 1584; Randall v Patch, 118 Me 303, 108 A 97, 5 ALR 65; State v Starkey, 112 Me 8, 90 A 431; State ex rel. Olson v Guilford, 174 Minn 457, 219 NW 770, 58 ALR 607; State ex rel. Westminster Presbyterian Church v Edgecomb, 106 Neb 859, 189 NW 617, 27 ALR 437; State v Vanhook, 182 NC 831, 109 SE 65; Akron v Public Utilities Com., 149 Ohio St 347, 37 Ohio Ops 39, 78 NE2d 890; Mendiola v Graham, 139 Or 592, 10 P2d 911; Daniels v Portland, 124 Or 677, 265 P 790, 59 ALR 512; Streich v Board of Education, 34 SD 169, 147 NW 779; Lingo Lumber Co. v Hayes (Tex Civ App) 64 SW2d 835; Longmire v State, 75 Tex Crim 616, 171 SW 1165; Etheredge v Norfolk, 148 Va 795, 139 SE 508, 55 ALR 781; Bungalow Amusement Co. v Seattle, 148 Wash 485, 269 P 1043, 60 ALR 166; Conger v Pierce County, 116 Wash 27, 198 P 377, 18 ALR 393; State v Buchanan, 29 Wash 602, 70 P 52; State v Redmon, 134 Wis 89, 114 NW 137; State ex rel. Sampson v Sheridan, 25 Wyo 347, 170 P 1, 1 ALR 955.

55. Tanner v Little, 240 US 369, 60 L Ed 691, 36 S Ct 379; Sligh v Kirkwood, 237 US 52, 59 L Ed 835, 35 S Ct 501; Camfield v United States, 167 US 518, 42 L Ed 260, 17 S Ct 864; State v Kartus, 230 Ala 352, 162 So 533, 101 ALR 1336, ans conformed to 26 Ala App 446, 162 So 538, Draffen v Black, 302 Ky 775, 196 SW2d 362; Blaisdell v Home Bldg. & Loan Ass'n, 189 Minn 422, 249 NW 334, 86 ALR 1507, affd 290 US 398, 78 L Ed 413, 54 S Ct 231, 88 ALR 1481 and later app 189 Minn 448, 249 NW 893; Hodge Drive-It-Yourself Co. v Cincinnati, 123 Ohio St 284, 9 Ohio L Abs 283, 175 NE 198, 77 ALR 889, affd 284 US 335, 76 L Ed 323, 52 S Ct 144; Wessell v Timberlake, 95 Ohio St 21, 116 NE 43; State ex rel. Short v Riedell, 109 Okla 35, 233 P 684, 42 ALR 765; Daniels v Portland, 121 Or 677, 265 P 790, 59 ALR 512.

The extent of the exercise and application of the police power of the state is determined by a consideration of the question whether or not any invocation of that power in any given case, and as applied to existing conditions, is reasonably necessary to promote the public health, safety, morals, or general welfare of the people of the community. Miller v Board of Public Works, 195 Cal 477, 234 P 381, 38 ALR 1479, error dismd 273 US 781, 71 L Ed 889, 47 S Ct 460.

The exercise of power to regulate uses of property or courses of conduct must find basis in the doctrine of overruling necessity or bear some substantial relation to the public good. Chicago Park Dist. v Canfield, 370 Ill 447, 19 NE2d 376, 121 ALR 557.

The police power will be, and should be, put forth as an expression of the popular conception of the necessities of social and economic conditions. Under it may be done and should be done that which will best secure the peace, morals, health, and safety of the community. Bloomfield v State, 86 Ohio St 253, 99 NE 309.

The police power of a state or a municipality extends to the making of such laws and ordinances as are necessary to secure the safety, health, good order, peace, comfort, protection, and convenience of the state or municipality. Porter v Paris, 184 Tenn 555, 201 SW2d 688.

56. Day-Brite Lighting, Inc. v Missouri, 342 US 421, 96 L Ed 469, 72 S Ct 405, reh den 343 US 921, 96 L Ed 1334, 72 S Ct 674; California State Auto. Asso. Inter-Insurance Bureau v Maloney, 341 US 105, 95 L Ed 788, 71 S Ct 601; Noble State Bank v Haskell, 219 US 104, 55 L Ed 112, 31 S Ct 186, and on other grounds 219 US 575, 55 L Ed 341, 31 S Ct 299; District of Columbia v Brooke, 214 US 138, 53 L Ed 941, 29 S Ct 560; Alabama State Federation of Labor v McAdory, 246 Ala 1, 18 So 2d 810, cert dismd 325 US 450, 89 L Ed 1725, 65 S Ct 1384; Southern Express Co. v Whittle, 194 Ala 406, 69 So 652; Miller v Board of Public Works, 195 Cal 477, 234 P 381, 38 ALR 1479, error dismd 273 US 781, 71 L Ed 889, 47 S Ct 460; People v Hupp, 53 Colo 80, 123 P 651; Joseph Triner Corp. v McNeil, 363 Ill 559, 2 NE2d 929, 104 ALR 1435, affd 299 US 183, 81 L Ed 109, 57 S Ct 139, 7 Ohio Ops 146, 106 ALR 1476; Storen v Sexton, 209 Ind 589, 200 NE 251, 104 ALR 1359; Illinois C. R. Co. v Commonwealth, 305 Ky 632, 204 SW2d 973, cert den 334 US 843, 92 L Ed 1767, 68 S Ct 1511; State v Gurry, 121 Md 534, 88 A 546; State ex rel. Olson v Guilford, 174 Minn 457, 219 NW 770, 58 ALR 607; Williams v Evans, 139 Minn 32, 165 NW 495, reh den 139 Minn 45, 166 NW 504; United States Fidelity & Guaranty Co. v Parsons, 147 Miss 335, 112 So 469, 53 ALR 88, later app 154 Miss 587, 122 So 544; Colvill v Fox, 51 Mont 72, 149 P 496; People v Nebbia, 262 NY 259, 186 NE 694, affd 291 US 502, 78 L Ed 940, 54 S Ct 505, 89 ALR 1469; People v Perretta, 253 NY 305, 171 NE 72, 84 ALR 636; Durham v Eno Cotton Mills, 141 NC 615, 54

said to furnish the key to what is included within the boundaries of police power—not that a police regulation to be legitimate must be an absolute essential to the public welfare, but that the exigency to be met must so concern such welfare as to suggest, reasonably, necessity for the legislative remedy.[57] It is not essential that a present necessity should exist before the legislature moves under the police power; it may act to prevent apprehended dangers as well as to control those already existing.[58]

The police power is the power of self-protection on the part of the community,[59] and bears the same relation to the community that the principle of self-defense bears to the individual.[60]

SE 453, later app 144 NC 705, 57 SE 465; State ex rel. Linde v Taylor, 33 ND 76, 156 NW 561, error dismd 245 US 627, 62 L Ed 518, 38 S Ct 60; *MacNab v Board of Park Com'rs*, 108 Ohio St 497, 1 Ohio L Abs 780, 141 NE 332; Daniels v Portland, 124 Or 677, 265 P 790, 59 ALR 512; Appeal of White, 287 Pa 259, 134 A 409, 53 ALR 1215; Hopkins v Richmond, 117 Va 692, 86 SE 139 (ovrld on other grounds Irvine v Clifton Forge 124 Va 781, 97 SE 310); Laughney v Maybury, 145 Wash 146, 259 P 17, 54 ALR 393; State ex rel. Carter v Harper, 182 Wis 148, 196 NW 451, 33 ALR 269; State v Langley, 53 Wyo 332, 84 P2d 767.

57. State v Henry, 37 NM 536, 25 P2d 204, 90 ALR 805; People by Van Schaick v Title & Mortg. Guaranty Co., 264 NY 69, 190 NE 153, 96 ALR 297; Mendiola v Graham, 139 Or 592, 10 P2d 911; McCoy v York, 193 SC 390, 8 SE2d 905; Gasque, Inc. v Nates, 191 SC 271, 2 SE2d 36; *Etheredge v Norfolk*, 148 Va 795, 139 SE 508, 55 ALR 781; State v Redmon, 134 Wis 89, 114 NW 137.

The exercise of the police power is not limited to cases of absolute necessity, but may be put forth in aid of what is sanctioned by usage, or held by the prevailing morality or stronger and preponderant opinion to be greatly and immediately necessary to the public welfare. Miller v Board of Public Works, 195 Cal 477, 234 P 381, 38 ALR 1479, error dismd 273 US 781, 71 L Ed 889, 47 S Ct 460.

To be a legitimate exercise of the police power, a statute must be reasonably necessary to promote the accomplishment of a public good or to prevent the infliction of a public harm. State v Ballance, 229 NC 764, 51 SE2d 731, 7 ALR2d 407.

State legislation requiring collection and computer storage of data concerning prescription of certain drugs for which there was both a lawful and an unlawful market was a reasonable exercise of the state's police power. A lower court's finding that the necessity for such legislation had not been proved was not a sufficient reason for holding the statute unconstitutional. Whalen v Roe, 429 US 589, 51 L Ed 2d 64, 97 S Ct 869.

58. State ex rel. Hughes v Cleveland, 47 NM 230, 141 P2d 192.

The legislature may look to the future in making such regulations as may reasonably be expected to be necessary to promote and preserve the public health and welfare. Re Jones, 56 Cal App 2d 658, 133 P2d 418.

Existence of actual necessity for exercise of the police power is not a condition of the right to exercise it. Gutierrez v Middle Rio Grande Conservancy Dist. 34 NM 346, 282 P 1, 70 ALR 1261, cert den 280 US 610, 74 L Ed 653, 50 S Ct 158.

The state cannot reasonably be required to defer the adoption of measures for its own peace and safety until revolutionary utterance and acts lead to actual disturbance of the public peace or imminent and immediate danger of its own destruction; the state may, in the exercise of its judgment, seek to prevent evil in its incipiency. People ex rel. Fish v Sandstrom, 279 NY 523, 18 NE2d 840, 120 ALR 646.

It is not necessary to an exercise of such power that there be an immediate present danger: It includes anything which is reasonable and necessary to the best interests of the public. Kraus v Cleveland (CP) 55 Ohio Ops 6, 66 Ohio L Abs 417, 116 NE2d 779, affd (App) 55 Ohio Ops 36, 76 Ohio L Abs 214, 121 NE2d 311, affd 163 Ohio St 559, 57 Ohio Ops 1, 127 NE2d 609, app dismd 351 US 935, 100 L Ed 1463, 76 S Ct 833 (fluorination of water).

59. State ex rel. Wilkinson v Murphy, 237 Ala 332, 186 So 487, 121 ALR 283; Re Yun Quong, 159 Cal 508, 114 P 835; Ingram v Colgan, 106 Cal 120, 38 P 315, subsequent op on reh 106 Cal 113, 39 P 437; Chicago v Washingtonian Home of Chicago, 289 Ill 206, 124 NE 416, 6 ALR 1584; Lake View v Rose Hill Cemetery Co., 70 Ill 191; Aetna Ins. Co. v Chicago C. W. R. Co., 190 Iowa 487, 180 NW 649, 16 ALR 249; McGuire v Chicago, B. & Q. R. Co., 131 Iowa 340, 108 NW 902, later app 138 Iowa 664, 116 NW 801; affd 219 US 549, 55 L Ed 328, 31 S Ct 259; Randall v Patch, 118 Me 303, 108 A 97, 8 ALR 65; State v Starkey, 112 Me 8, 90 A 431; Rutledge Co-op. Ass'n v Baughman, 153 Md 297, 138 A 29, 56 ALR

§ 371. —Emerge

A specific ap
public necessity
the unusual situ
while emergency
diminish the rest
may furnish the
police measures.
may justify a law

It must be bo
cally lift all con
existence of an
cease to operate
was valid when p

1042; People v Braze
1053, affd 241 US 34
561; State ex rel. Ol
457, 219 NW 770, 58
Mont 201, 204 P 36
ster Presbyterian Ch
Neb 859, 189 NW 6
Vanhook, 182 NC 8
Public Utilities Com.
Ohio Ops 39, 78 NE2
v Riedell, 109 Okla
765; Mendiola v Grah
911; Streich v Board
147 NW 779; Ethere
795, 139 SE 508, 55
Zillmer v Kreutzberg,
1098.

60. AFL v American
20, 189 P2d 912, aff
222, 69 S Ct 258, 6 A

61. § 370, supra.

62. Home Bldg. & L
US 398, 78 L Ed 41
1481, affg 189 Minn
ALR 1507; Edgar A. L
258 US 242, 66 L Ed
Brown Holding Co.
65 L Ed 877, 41 S Ct
US 135, 65 L Ed 86
165; People by Van
Guaranty Co., 264 N
ALR 297; People ex
v La Fetra, 230 NY 4
152, error dismd 257
S Ct 47.

1 Cal L Rev 413 (
following earthquake).

Annotation: 14 A
(power to destroy buil

63. §§ 71, 82, supra.

64. Home Bldg. & L
US 398, 78 L Ed 41

§ 371. —Emergency police legislation.

A specific application of the doctrine that the police power is based on public necessity[61] is furnished by statutes which have been passed to cope with the unusual situations arising during emergencies.[62] The general rule that while emergency does not create power, increase granted power, or remove or diminish the restrictions imposed upon power granted or reserved, emergency may furnish the occasion for the exercise of power,[63] is fully applicable to police measures.[64] Thus, a limit in time in order to tide over a passing trouble may justify a law that could not be upheld as a permanent change.[65]

It must be borne in mind, however, that an emergency does not automatically lift all constitutional restraints,[66] and that a law depending upon the existence of an emergency or other certain state of facts to uphold it may cease to operate if the emergency ceases or the facts change, even though it was valid when passed.[67] The latter principle depends strictly upon the facts,

1042; People v Brazee, 183 Mich 259, 149 NW 1053, affd 241 US 340, 60 L Ed 1034, 36 S Ct 561; State ex rel. Olson v Guilford, 174 Minn 457, 219 NW 770, 58 ALR 607; Re Caselli, 62 Mont 201, 204 P 364; State ex rel. Westminster Presbyterian Church v Edgecomb, 108 *Neb 859, 189 NW 617, 27 ALR 437; State v* Vanhook, 182 NC 831, 109 SE 65; Akron v Public Utilities Com., 149 Ohio St 347, 37 Ohio Ops 39, 78 NE2d 890; State ex rel. Short v Riedell, 109 Okla 35, 233 P 684, 42 ALR 765; Mendiola v Graham, 139 Or 592, 10 P2d 911; Streich v Board of Education, 34 SD 169, 147 NW 779; Etheredge v Norfolk, 148 Va *795, 139 SE 508, 55 ALR 781; State ex rel.* Zillmer v Kreutzberg, 114 Wis 530, 90 NW 1098.

60. AFL v American Sash & Door Co., 67 Ariz 20, 189 P2d 912, affd 335 US 538, 93 L Ed 222, 69 S Ct 258, 6 ALR2d 481.

61. § 370, supra.

62. Home Bldg. & Loan Asso. v Blaisdell, 290 US 398, 78 L Ed 413, 54 S Ct 231, 88 ALR 1481, affg 189 Minn 422, 249 NW 334, 86 ALR 1507; Edgar A. Levy Leasing Co. v Siegel, 258 US 242, 66 L Ed 595, 42 S Ct 289; Marcus Brown Holding Co. v Feldman, 256 US 170, 65 L Ed 877, 41 S Ct 465; Block v Hirsh, 256 US 135, 65 L Ed 865, 41 S Ct 458, 16 ALR 165; People by Van Schaick v Title & Mortg. Guaranty Co., 264 NY 69, 190 NE 153, 96 ALR 297, People ex rel. Durham Realty Corp. v La Fetra, 230 NY 429, 130 NE 601, 16 ALR 152, error dismd 257 US 665, 66 L Ed 424, 42 S Ct 47.

1 Cal L Rev 413 (exercise of police power following earthquake).

Annotation: 14 ALR2d 73, §§ 5 et seq. (power to destroy building in emergency).

63. §§ 71, 82, supra.

64. Home Bldg. & Loan Asso. v Blaisdell, 290 US 398, 78 L Ed 413, 54 S Ct 231, 88 ALR 1481, affg 189 Minn 422, 249 NW 334, 86 ALR 1507; People by Van Schaick v Title & Mortg. Guaranty Co., 264 NY 69, 190 NE 153, 96 ALR 297; People ex rel. Durham Realty Corp. v La Fetra, 230 NY 429, 130 NE 601, 16 ALR 152, error dismd 257 US 665, 66 L Ed 424, 42 S Ct 47.

65. Block v Hirsh, 256 US 135, 65 L Ed 865, 41 S Ct 458, 16 ALR 165; Re Plumer (DC Cal) 9 F Supp 923.

An emergency, in order to justify the intervention of the reserve police power, must be temporary or it cannot be said to be an emergency. If a so-called emergency exists beyond a temporary period, then it is no longer an emergency, but a status, and can furnish no basis or authority for legislative action in contravention of, or inconsistent with, the provisions of the state and federal constitutions. First Trust Joint Stock Land Bank v Arp, 225 Iowa 1331, 283 NW 441, 120 ALR 932.

66. Mobile v Rouse, 233 Ala 622, 173 So 266, 111 ALR 349; Vanderbilt v Brunton Piano Co., 111 NJL 596, 169 A 177, 89 ALR 1080.

The character of the situation sought to be remedied, and not the existence of an emergency, is the governing factor in determining whether a statute is a valid exercise of the police power. Wholesale Tobacco Dealers Bureau, Inc. v National Candy & Tobacco Co., 11 Cal 2d 634, 82 P2d 3, 118 ALR 486.

Where the legislature, in enacting measures to cope with a social emergency, assumes power which by the constitution of the state is expressly forbidden to it and is forever taken out of the powers of government of the state, the legislature is prevented by the constitution from exercising such power, no matter what the emergency may be. State ex rel. Cleveringa v Klein, 63 ND 514, 249 NW 118, 86 ALR 1523.

67. Home Bldg. & Loan Asso. v Blaisdell, 290

and mere failure of the legislature to limit the operation of an emergency statute to a definite term will not render the law invalid so long as the conditions which justify its passage remain.[68] On the other hand, emergency legislation may properly be made operative from the date of beginning of the emergency, rather than from the date of the enactment of the statute.[69]

The rule is well settled that if emergency statutes are promotive of the public welfare, they are a valid exercise of the police power.[70]

In the enactment of emergency police measures, the prevailing view is that the question whether an emergency exists is primarily for the legislature to determine, but that such determination, although entitled to great respect, is not conclusive, because the courts in such cases possess the final authority to determine whether an emergency in fact exists.[71]

§ 372. —Necessity as determinable on basis of locality.

In connection with the rule that the police power is coextensive with the necessities of the case, it is to be noted that the United States Supreme Court has recognized that the exercise of the police power may and should have reference to the peculiar situation and needs of the community.[72] The laws and policy of a state may be framed and shaped to suit its conditions of climate and soil.[73] Consequently, it is established that the validity of police regulations may depend in part on geographic and local considerations.[74]

It is no valid objection to a police regulation that it is made applicable only to a segregated area or district.[75]

Appellate courts, when called upon to determine the validity of police

US 398, 78 L Ed 413, 54 S Ct 231, 88 ALR 1481, affg 189 Minn 422, 249 NW 334, 86 ALR 1507; Chastleton Corp. v Sinclair, 264 US 543, 68 L Ed 841, 44 S Ct 405; Re Blaney, 30 Cal 2d 643, 184 P2d 892; First Trust Co. v Smith, 134 Neb 84, 277 NW 762; East New York Sav. Bank v Hahn, 293 NY 622, 59 NE2d 625, affd 326 US 230, 90 L Ed 34, 66 S Ct 69, 160 ALR 1279; People by Van Schaick v Title & Mortg. Guaranty Co., 264 NY 69, 190 NE 153, 96 ALR 297.

68. People by Van Schaick v Title & Mortg. Guaranty Co., 264 NY 69, 190 NE 153, 96 ALR 297.

69. Twentieth Century Associates, Inc. v Waldman, 294 NY 571, 63 NE2d 177, 162 ALR 197.

70. Home Bldg. & Loan Asso. v Blaisdell, 290 US 398, 78 L Ed 413, 54 S Ct 231, 88 ALR 1481; Edgar A. Levy Leasing Co. v Siegel, 258 US 242, 66 L Ed 595, 42 S Ct 289; People by Van Schaick v Title & Mortg. Guaranty Co., 264 NY 69, 190 NE 153, 96 ALR 297; State ex rel. Cleveringa v Klein, 63 ND 514, 249 NW 118, 86 ALR 1523.

71. § 249, supra.

72. New Mexico ex rel. E. J. McLean & Co. v Denver & R. G. R. Co., 203 US 38, 51 L Ed 78, 27 S Ct 1.

73. Bacon v Walker, 204 US 311, 51 L Ed 499, 27 S Ct 289.

A state may accommodate its laws to the conditions of an arid country and the necessity of irrigation to its development, or it may enact laws suited to the conditions existing in a mining region. Bown v Walling, 204 US 320, 51 L Ed 503, 27 S Ct 292.

74. The necessity for the exercise of the police power increases with the increase in the density of population. Turner v Kansas City, 354 Mo 857, 191 SW2d 612.

Public needs, as interpreted and applied to the public welfare in densely populated districts, are quite different from public needs of rural communities. MacNab v Board of Park Com'rs, 108 Ohio St 497, 1 Ohio L Abs 780, 141 NE 332.

A police regulation relating to tenements, lodginghouses, and boardinghouses may be reasonable in reference to conditions which exist in a large city, but might be unreasonable if applied to the state at large. Bonnett v Vallier, 136 Wis 193, 116 NW 885.

75. Des Moines v Manhattan Oil Co., 193 Iowa 1096, 184 NW 823, 23 ALR 1322, supp op, reh overr 193 Iowa 1117, 188 NW 921, 23 ALR 1337.

regulations, frequer
tribunals and bodies
are in a better positi
ble latitude is somet
appellate court may

§ 373. Flexibility.

The police powe
circumscribed by fix
and modification wit
tal control may be a
conditions.[80] The po

76. Adams v Milwaukee,
971, 33 S Ct 610, affg 1
518; Colletti v State, 12 C
overr.

77. Schmidinger v Chica
Ed 364, 33 S Ct 182; Chi
v McGuire, 219 US 549,
259; McLean v Arkansas,
315, 29 S Ct 206; Green
Co. (CA10 Wyo) 65 F2
State v Gateway Mortuari
287 P 156, 68 ALR 1512
Ohio St 416, 124 NE 237
v State, 12 Ohio App 104

78. Thomas Cusack Co.
526, 61 L Ed 472, 37 S C
187 US 606, 47 L Ed 323,
v State, 12 Ohio App 104

79. § 362, supra.

80. Holden v Hardy, 16
780, 18 S Ct 383; Murp
131 Conn 292, 40 A2d
Hoff v State, 39 Del 134,
Inc. v Mayo, 103 Fla 552,
rel. Davis v Rose, 97 Fl
Fenske Bros., Inc. v Upho
Union, 358 Ill 239, 193 N
cert den 295 US 754, 79
645; Pittsburgh, C., C. &
180 Ind 245, 102 NE 25;
147 Md 282, 128 A 50, 38
Brazee, 183 Mich 259, 14
US 340, 60 L Ed 1034, 3
rel. Beery v Houghton, 16
569, 54 ALR 1012, affd 2
832, 47 S Ct 474; Lincoln
v Northwestern Iron &
507, 31 NW2d 477, affd 3
212, 69 S Ct 251, 6 A
Southern Pac. Co., 215 N
revd on other grounds 2
1086, 37 S Ct 524; Smith
Co., 191 NC 643, 132 SE

regulations, frequently incline toward acquiescing in the opinion of local tribunals and bodies,[76] because the latter are familiar with local conditions and are in a better position to judge the necessity of such enactments.[77] Considerable latitude is sometimes allowed for possible peculiar conditions of which the appellate court may have only little knowledge.[78]

c. Flexibility and Inalienability

§ 373. Flexibility.

The police power of the state, never having been exactly defined or circumscribed by fixed limits,[79] is considered as being capable of development and modification within constitutional limits, so that the powers of governmental control may be adequate to meet changing social, economic, and political conditions.[80] The power is a continuing one,[81] is very broad and comprehen-

76. Adams v Milwaukee, 228 US 572, 57 L Ed 971, 33 S Ct 610, affg 144 Wis 371, 129 NW 518; Colletti v State, 12 Ohio App 104, motion overr.

77. Schmidinger v Chicago, 226 US 578, 57 L Ed 364, 33 S Ct 182; Chicago, B. & Q. R. Co. v McGuire, 219 US 549, 55 L Ed 328, 31 S Ct 259; McLean v Arkansas, 211 US 539, 53 L Ed 315, 29 S Ct 206; Green River v Fuller Brush Co. (CA10 Wyo) 65 F2d 112, 88 ALR 177; State v Gateway Mortuaries, Inc., 87 Mont 225, 287 P 156, 68 ALR 1512; Allion v Toledo, 99 Ohio St 416, 124 NE 237, 6 ALR 426; Colletti v State, 12 Ohio App 104, motion overr.

78. Thomas Cusack Co. v Chicago, 242 US 526, 61 L Ed 472, 37 S Ct 190; Otis v Parker, 187 US 606, 47 L Ed 323, 23 S Ct 168; Colletti v State, 12 Ohio App 104, motion overr.

79. § 362, supra.

80. Holden v Hardy, 169 US 366, 42 L Ed 780, 18 S Ct 383; Murphy, Inc. v Westport, 131 Conn 292, 40 A2d 177, 156 ALR 568; Hoff v State, 39 Del 134, 197 A 75; L. Maxcy, Inc. v Mayo, 103 Fla 552, 139 So 121; State ex rel. Davis v Rose, 97 Fla 710, 122 So 225; Fenske Bros., Inc. v Upholsterers' International Union, 358 Ill 239, 193 NE 112, 97 ALR 1318, cert den 295 US 734, 79 L Ed 1682, 55 S Ct 645, Pittsburgh, C., C. & S. L. R. Co. v State, 180 Ind 245, 102 NE 25; Goldman v Crowther, 147 Md 282, 128 A 50, 38 ALR 1455; People v Brazee, 183 Mich 259, 149 NW 1053, affd 241 US 340, 60 L Ed 1034, 36 S Ct 561; State ex rel. Beery v Houghton, 164 Minn 146, 204 NW 569, 54 ALR 1012, affd 273 US 671, 71 L Ed 832, 47 S Ct 474; Lincoln Federal Labor Union v Northwestern Iron & Metal Co., 149 Neb 507, 31 NW2d 477, affd 335 US 525, 93 L Ed 212, 69 S Ct 251, 6 ALR2d 473; Jensen v Southern Pac. Co., 215 NY 514, 109 NE 600, revd on other grounds 244 US 205, 61 L Ed 1086, 37 S Ct 524; Smith v Fidelity & Deposit Co., 191 NC 643, 132 SE 792, error dismd 273 US 505, 72 L Ed 396, 48 S Ct 156; Pontiac Improv. Co. v Board of Com'rs, 104 Ohio St 447, 135 NE 635, 23 ALR 866; Interurban R. & T. Co. v Public Utilities Com., 98 Ohio St 287, 120 NE 831, 3 ALR 696; Wessell v Timberlake, 95 Ohio St 21, 116 NE 43; Herrin v Arnold, 183 Okla 392, 82 P2d 977, 119 ALR 1471; State ex rel. Short v Riedell, 109 Okla 35, 233 P 684, 42 ALR 765; Ex parte Tindall, 102 Okla 192, 229 P 125; Hyde v Albert E. Peirce & Co., 147 Or 5, 31 P2d 755; Mendiola v Graham, 139 Or 592, 10 P2d 911; Daniels v Portland, 124 Or 677, 265 P 790, 59 ALR 512; Nance v O. K. Houck Piano Co., 128 Tenn 1, 155 SW 1172; Motlow v State, 125 Tenn 547, 145 SW 177, error dismd 239 US 653, 60 L Ed 487, 36 S Ct 161; Mumpower v Housing Authority of Bristol, 176 Va 426, 11 SE2d 732; Bowman v Virginia State Entomologist, 128 Va 351, 105 SE 141, 12 ALR 1121; Peel Splint Coal Co. v State, 36 W Va 802, 15 SE 1000.

The police power is necessarily expansive, to meet new conditions or standards. State v Henry, 37 NM 536, 25 P2d 204, 90 ALR 805.

It is apparent that the police power is not a circumscribed prerogative, but is elastic and, in keeping with the growth of knowledge and the belief in the popular mind of the need for its application, capable of expansion to meet existing conditions of modern life, and thereby keep pace with the social economic, moral, and intellectual evolution of the human race. There is nothing known to the law that keeps more in step with human progress than does the exercise of this power. Miller v Board of Public Works, 195 Cal 477, 234 P 381, 38 ALR 1479, error dismd 273 US 781, 71 L Ed 889, 47 S Ct 460.

81. Plantation v Utilities Operating Co. (Fla) 156 So 2d 842, app dismd 379 US 2, 13 L Ed 2d 21, 85 S Ct 32; Kalbfell v St. Louis, 357 Mo 986, 211 SW2d 911.

The police power is in a constant state of evolution in order that it may meet the calls for

It is obvious that the tendency is to extend rather than to restrict the police power.[86] Since its limits are to be determined with regard to the particular subject of its exercise,[87] its scope, in promoting the public convenience or general prosperity, enlarges correspondingly. Thus, it is the proper function of the legislative department of government in the exercise of the police power to consider the problems and risks that arise from the use of new inventions and to endeavor to adjust private rights and harmonize conflicting interests by comprehensive statutes for the public welfare.[88]

Matters under restriction at previous periods of civilized progress are not a testing device into which the adaptable police power may be fitted, and although it is fundamentally true that whatever may be enjoined by a court of equity may be legislation by declared malum prohibitum,[89] the police power is by no means limited to dealing with what were nuisances at common law.[90]

On the other hand, what was at one time regarded as an improper exercise of the police power may now, because of changed living conditions, be recognized as a legitimate exercise of that power,[91] and the state may, in the exercise of the power, declare an act or conduct invalid or unlawful which has theretofore been regarded as valid.[92] Similarly, practices harmless in and of themselves may, from changed circumstances, become the source of evil or may have evil tendencies justifying restrictive legislation.[93] It must also be noticed, however, that a police regulation, although valid when made may become arbitrary and confiscatory in operation by reason of later events.[94]

86. *Steinberg-Baum & Co. v Countryman*, 247 Iowa 923, 77 NW2d 15; State ex rel. Olson v Guilford, 174 Minn 457, 219 NW 770, 58 ALR 607; Pontiac Improv. Co. v Board of Com'rs, 104 Ohio St 447, 135 NE 635, 23 ALR 866.

There is nothing in government more dangerous to the liberty and the rights of the individual than a too ready resort to the police power. State v Harris, 216 NC 746, 6 SE2d 854, 128 ALR 658.

87. § 382, infra.

88. People v Lindé, 341 Ill 269, 173 NE 361, 72 ALR 997; Smith v New England Aircraft Co., 270 Mass 511, 170 NE 385, 69 ALR 300; Commonwealth v Kingsbury, 199 Mass 542, 85 NE 848.

89. Hall v Johnson, 87 Or 21, 169 P 515.

90. Bowman v Virginia State Entomologist, 128 Va 351, 105 SE 141, 12 ALR 1121.

91. Miller v Board of Public Works, 195 Cal 477, 234 P 381, 38 ALR 1479, error dismd 273 US 781, 71 L Ed 889, 47 S Ct 460.

Regulations, the wisdom, necessity, and validity of which, as applied to existing conditions, are so apparent that they are now uniformly sustained, a century ago, or even a half century ago, probably would have been rejected as arbitrary and oppressive. Euclid v Ambler Realty Co., 272 US 365, 71 L Ed 303, 47 S Ct 114, 4 Ohio L Abs 816, 54 ALR 1016.

92. Booth v People, 186 Ill 43, 57 NE 798, affd 184 US 425, 46 L Ed 623, 22 S Ct 425.

93. Rast v Van Deman & Lewis Co., 240 US 342, 60 L Ed 679, 36 S Ct 370.

It follows from the continuous nature of the police power that a business which was entirely unobjectionable when established may, because of a change in situation from the growth of population or otherwise, become a menance to the public health and welfare, and be required to yield to the public good. The legislature may then prohibit its further conduct, even though such business has been conducted in the locality for a long time. Dobbins v Los Angeles, 195 US 223, 49 L Ed 169, 25 S Ct 18; Motor Transit Co. v Railroad Com. of California, 189 Cal 573, 209 P 586; Ex parte Hadacheck, 165 Cal 416, 132 P 584, affd 239 US 394, 60 L Ed 348, 36 S Ct 143.

It is competent in a proper case for the legislature, under its general police power, to impose a new duty for the protection or safety of the public, the violation of which, if it directly and without any intervening cause results in injury or damage, will give rise to a cause of action. Ward v Ely-Walker Dry Goods Bldg. Co., 248 Mo 348, 154 SW 478.

94. Nashville, C. & S. L. Railway v Walters, 294 US 405, 79 L Ed 949, 55 S Ct 486; Ahle State Bank v Bryan, 282 US 765, 75 L Ed 690, 51 S Ct 252; Skalko v Sunnyvale, 14 Cal 2d 213, 93 P2d 93.

What was a reasonable exercise of the police

The position has been taken that the power itself does not expand, but is of such a nature in its original scope as to correct new evils as they arise. In this connection it has been stated that much confusion is eliminated by pointing out that instead of the police power being expanded to meet new conditions, the new conditions are, as they arise, brought within the immutable and unchanging principles underlying the power.[95]

There is authority to the effect that the police power is of such elasticity that the principle of stare decisis has no application to an exercise of the power.[96] Stare decisis is a rule of property. This position is taken because, if it were not, mistaken decisions would destroy that very power of society to protect itself, and a new constitution would be created by the courts. The courts cannot decide away that which the state itself cannot contract away.[97]

§ 374. Inalienability.

It is a fundamental principle of constitutional law that in matters relating to the police power, each successive legislature is of equal authority.[98] A legislative body cannot part with its right to exercise such power; it inherently has authority to use the power again and again, as often as the public interest may require.[99] Hence, one session or body of the legislature may not, by any contract with an individual, restrain the power of a subsequent legislature to legislate for the public welfare.[1] The governmental power of self-protection

power in the days of our fathers may today seem so utterly unreasonable as to make it difficult for us to comprehend the existence of conditions that would justify it. Miller v Board of Public Works, 195 Cal 477, 234 P 381, 38 ALR 1479, error dismd 273 US 781, 71 L Ed 889, 47 S Ct 460.

The police power is a flexible, broad, variable process of government intent upon keeping to date with all public and social needs in the light of present society, and therefore what might have been invalid when enacted may become valid and what may have been valid when enacted may become invalid in the light of existing conditions. New York State Thruway Authority v Ashley Motor Court, Inc. (3d Dept) 12 App Div 2d 223, 210 NYS2d 193, affd 10 NY2d 151, 218 NYS2d 640, 176 NE2d 566, remittitur amd 10 NY2d 814, 221 NYS2d 518, 178 NE2d 232.

As to emergency police legislation, generally, see § 371, supra.

95. Stettler v O'Hara, 69 Or 519, 139 P 743, affd 243 US 629, 61 L Ed 937, 37 S Ct 475.

96. AFL v Watson (DC Fla) 60 F Supp 1010, revd on other grounds 327 US 582, 90 L Ed 873, 66 S Ct 761.

The propriety of an exercise of the police power is to be tested by present-day conditions rather than by past precedents. Wholesale Tobacco Dealers Bureau, Inc. v National Candy & Tobacco Co., 11 Cal 2d 634, 82 P2d 3, 118 ALR 486.

To continue to apply principles in accord with circumstances no longer existing and to refuse to curtail new evils from fear of demolishing outworn precedents is to close the eyes to the necessities of the times and thus fail to give to constitutional guaranties their true import. Wilson v Zanesville, 130 Ohio St 286, 4 Ohio Ops 311, 199 NE 187 (ovrld on application of principle Cincinnati v Correll 141 Ohio St 535, 26 Ohio Ops 116, 49 NE2d 412).

97. AFL v Watson (DC Fla) 60 F Supp 1010, revd on other grounds 327 US 582, 90 L Ed 873, 66 S Ct 761; Schmitt v F. W. Cook Brewing Co., 187 Ind 623, 120 NE 19, 3 ALR 270.

As to the inability of a state to contract away the police power, see § 374, infra.

98. State Public Utilities Com. ex rel. Quincy R. Co. v Quincy, 290 Ill 360, 125 NE 374; Board of Education v Phillips, 67 Kan 549, 73 P 97; State ex rel. Minot v Gronna, 79 ND 673, 59 NW2d 514; Shealy v Southern R. Co., 127 SC 15, 120 SE 561.

99. East Hartford v Hartford Bridge Co., 51 US 511, 13 L Ed 518; Goszler v Corporation of Georgetown, 19 US 593, 5 L Ed 339; State Public Utilities Com. ex rel. Quincy R. Co. v Quincy, 290 Ill 360, 125 NE 374; Application of Minneapolis S. R. Co., 228 Minn 435, 37 NW2d 533; State ex rel. Minot v Gronna, 79 ND 673, 59 NW2d 514; Shealy v Southern R. Co., 127 SC 15, 120 SE 561.

As to police power as a continuing one, see § 373, supra.

1. Texas & N. O. R. Co. v Miller, 221 US 408,

cannot be contracted
use of property be
regulation in partic
injury.[2]

The foregoing pri
cannot barter or ba
contract divest itsel
legislation falling wi

55 L Ed 789, 31 S Ct 53
101 US 814, 25 L Ed 10
94 US 645, 24 L Ed 302.

The police power, inse
essential to the health of
be contracted away. Ne
Co. v Drainage Com. of
453, 49 L Ed 831, 25 S C

The authority of the le
cise of its police powers
controlled by the action
ture. White v Farmers' Hi
voir Co., 22 Colo 191, 43

2. Colorado & S. R. Co.
281, 121 P 747; State Pu
rel. Quincy R. Co. v Qui
NE 374; Shealy v Souther
120 SE 561.

3. Home Bldg. & Loan
US 398, 78 L Ed 413, 5
1481, affg 189 Minn 42
ALR 1507; Contributors
pital v Philadelphia, 245
38 S Ct 35; Atlantic C. L.
232 US 548, 58 L Ed 721,
Case, 188 US 321, 47 L
Holden v Hardy, 169 US
S Ct 383; New York, N.
Bridgeport Traction Co.,
953; State ex rel. Triay v
So 61; State Public Uti
Quincy R. Co. v Quincy,
374; Pittsburgh, C., C. &
pell, 183 Ind 141, 106 NE
v Douglass, 100 Ky 116,
US 488, 42 L Ed 553, 18
v Kansas C., S. & G. R. C
So 290, 62 ALR 1512; Dir
Paper Co., 110 Me 374,
Hyman, 98 Md 596, 57 A
89 Md 565, 43 A 771; De
B. I. R. Co., 95 Mich 456,
v Chicago, S. P. M. & O.
322, 166 NW 335; State v
Minn 445, 111 NW 289;
Love, 111 Miss 699, 72 S
affd 250 US 603, 63 L E
State ex rel. Laclede Gas
130 Mo 10, 31 SW 594, a
Ed 955, 18 S Ct 505; Wen
394, 91 NW 421; Chicago
State, 47 Neb 549, 66 N

cannot be contracted away. Neither can the exercise of rights granted nor the use of property be withdrawn from the implied liability to governmental regulation in particulars essential to the preservation of the community from injury.[2]

The foregoing principles are embodied in the familiar rule that the state cannot barter or bargain away the right to use the police power,[3] or by any contract divest itself of the power to provide for acknowledged objects of legislation falling within the domain of the police power.[4] Accordingly, the

53 L Ed 789, 31 S Ct 534; Stone v Mississippi, 101 US 814, 25 L Ed 1079; Boyd v Alabama, 94 US 645, 24 L Ed 302.

The police power, insofar as its exercise is essential to the health of a community, cannot be contracted away. New Orleans Gas Light Co. v Drainage Com. of New Orleans, 197 US 453, 49 L Ed 831, 25 S Ct 471.

The authority of the legislature in the exercise of its police powers cannot be limited or controlled by the action of a previous legislature. White v Farmers' Highline Canal & Reservoir Co., 22 Colo 191, 43 P 1028.

2. Colorado & S. R. Co. v Ft. Collins, 52 Colo 281, 121 P 747; State Public Utilities Com. ex rel. Quincy R. Co. v Quincy, 290 Ill 360, 125 NE 374; Shealy v Southern R. Co., 127 SC 15, 120 SE 561.

3. Home Bldg. & Loan Asso. v Blaisdell, 290 US 398, 78 L Ed 413, 54 S Ct 231, 88 ALR 1481, affg 189 Minn 422, 249 NW 334, 86 ALR 1507; Contributors to Pennsylvania Hospital v Philadelphia, 245 US 20, 62 L Ed 124, 38 S Ct 35; Atlantic C. L. R. Co. v Goldsboro, 232 US 548, 58 L Ed 721, 34 S Ct 364; Lottery Case, 188 US 321, 47 L Ed 492, 23 S Ct 321; Holden v Hardy, 169 US 366, 42 L Ed 780, 18 S Ct 383; New York, N. H. & H. R. Co. v Bridgeport Traction Co., 65 Conn 410, 32 A 933; State ex rel. Triay v Burr, 79 Fla 290, 84 So 61; State Public Utilities Com. ex rel. Quincy R. Co. v Quincy, 290 Ill 360, 125 NE 374; Pittsburgh, C., C. & S. L. R. Co. v Chappell, 183 Ind 141, 106 NE 403; Commonwealth v Douglass, 100 Ky 116, 24 SW 233, affd 168 US 158, 42 L Ed 553, 18 S Ct 199; Shreveport v Kansas C., S. & G. R. Co., 167 La 771, 120 So 290, 62 ALR 1512; Dirken v Great Northern Paper Co., 110 Me 374, 86 A 320; State v Hyman, 98 Md 596, 57 A 6; State v Broadbelt, 89 Md 565, 43 A 771; Detroit v Ft. Wayne & B. I. R. Co., 95 Mich 456, 54 NW 958; St. Paul v Chicago, S. P. M. & O. R. Co., 139 Minn 322, 166 NW 335; State v Great N. R. Co., 100 Minn 445, 111 NW 289; Bank of Oxford v Love, 111 Miss 699, 72 So 133, 8 ALR 894, affd 250 US 603, 63 L Ed 1165, 40 S Ct 22; State ex rel. Laclede Gas Light Co. v Murphy, 130 Mo 10, 31 SW 594, affd 170 US 78, 42 L Ed 955, 18 S Ct 505; Wenham v State, 65 Neb 394, 91 NW 421; Chicago, B. & Q. R. Co. v State, 47 Neb 549, 66 NW 624, affd 170 US 57, 42 L Ed 948, 18 S Ct 513; Cincinnati v Public Utilities Com., 98 Ohio St 320, 3 Ohio L Abs 19, 121 NE 688, 3 ALR 705 (ovrld on other grounds United Fuel Gas Co. v Ironton 107 Ohio St 173, 1 Ohio L Abs 881, 140 NE 884, 29 ALR 342) and (ovrld on other grounds New Boston v Public Utilities Com. 108 Ohio St 352, 1 Ohio L Abs 882, 140 NE 607); State v Bunting, 71 Or 259, 139 P 731, affd 243 US 426, 61 L Ed 830, 37 S Ct 435; State v Rolines, 33 RI 211, 80 A 432; Shealy v Southern R. Co., 127 SC 15, 120 SE 561; Sabre v Rutland R. Co., 86 Vt 347, 85 A 693; McKenna v State Highway Com., 28 Wis 2d 179, 135 NW2d 827.

The state cannot bargain away its right and duty to adopt such measures as it may from time to time deem advisable for the promotion of the health and morals of persons confined in its penal institutions. Jones Hollow Ware Co. v Crane, 134 Md 103, 106 A 274, 3 ALR 1658.

4. Phillips Petroleum Co. v Jenkins, 297 US 629, 80 L Ed 943, 56 S Ct 611, reh den 298 US 691, 80 L Ed 1409, 56 S Ct 745; Sanitary Dist. of Chicago v United States, 266 US 405, 69 L Ed 352, 45 S Ct 176; Great N. R. Co. v Minnesota, 246 US 434, 62 L Ed 817, 38 S Ct 346; Contributors to Pennsylvania Hospital v Philadelphia, 245 US 20, 62 L Ed 124, 38 S Ct 35; Chicago & A. R. Co. v Tranbarger, 238 US 67, 59 L Ed 1204, 35 S Ct 678; Standard Chemical & Oil Co. v Troy, 201 Ala 89, 77 So 383; Birmingham M. R. Co. v Parsons, 100 Ala 662, 13 So 602; American Union Tel. Co. v Western Union Tel. Co., 67 Ala 26; Colorado & S. R. Co. v Ft. Collins, 52 Colo 281, 121 P 747; State Public Utilities Com. ex rel. Quincy R. Co. v Quincy, 290 Ill 360, 125 NE 374; Chicago v O'Connell, 278 Ill 591, 116 NE 210, 8 ALR 916; Otis Elevator Co. v Chicago, 263 Ill 419, 105 NE 338; Union Traction Co. v Muncie, 80 Ind App 260, 133 NE 160; Aetna Ins. Co. v Chicago G. W. R. Co., 190 Iowa 487, 180 NW 649, 16 ALR 249; Hunter v Colfax Consol. Coal Co., 175 Iowa 245, 154 NW 1037, 157 NW 145; Board of Education v Phillips, 67 Kan 549, 73 P 97; South C. & C. S. R. Co. v Berry, 93 Ky 43, 18 SW 1026; Shreveport v Kansas C., S. & G. R. Co., 167 La 771, 120 So 290, 62 ALR 1512; Dirken v Great Northern Paper Co., 110 Me 374, 86 A 320; Jones Hollow Ware Co. v Crane, 134 Md 103, 106 A 274, 3 ALR 1658; St. Paul v Chicago, S.

legislature cannot surrender,[5] abdicate,[6] or limit such powers,[7] either by affirmative action or by inaction,[8] or abridge them by any grant, contract, or delegation whatsoever,[9] and a statute which embodies a legislative attempt to

F. M. & O. R. Co., 139 Minn 322, 166 NW 335; Cape Girardeau v St. Louis S. F. R. Co., 305 Mo 590, 267 SW 601, 36 ALR 1488; Miles City v Board of Health, 39 Mont 405, 102 P 696; State v Lookabill, 176 Neb 254, 125 NW2d 695, mod on other grounds 176 Neb 415, 126 NW2d 403; Re Boyce, 27 Nev 299, 75 P 1; Wallace v Mayor, etc., of Reno, 27 Nev 71, 73 P 528; Shelby v Cleveland Mill & Power Co., 155 NC 196, 71 SE 218; Interurban R. & T. Co. v Public Utilities Com., 98 Ohio St 287, 120 NE 831, 3 ALR 696; State v Bunting, 71 Or 259, 139 P 731, affd 243 US 426, 61 L Ed 830, 37 S Ct 435; Shealy v Southern R. Co., 127 SC 15, 120 SE 561; State ex rel. George v City Council of Aiken, 42 SC 222, 20 SE 221; Miller v Letzerich, 121 Tex 248, 49 SW2d 404, 85 ALR 451; Salt Lake City v Utah Light & Traction Co., 52 Utah 210, 173 P 556, 3 ALR 715; Re Guerra, 94 Vt 1, 110 A 224, 10 ALR 1560; Sabre v Rutland R. Co., 86 Vt 347, 85 A 693.

Sovereign authority cannot divest itself of its ordinary police power over persons, whether natural or artificial any more than it can of the power to make laws or to punish crime. Cosmopolitan Club v Virginia, 208 US 378, 52 L Ed 536, 28 S Ct 394; Westport v Mulholland, 159 Mo 86, 60 SW 77; Pennsylvania R. Co. v Ewing, 241 Pa 581, 88 A 775.

5. State ex rel. Wilkinson v Murphy, 237 Ala 332, 186 So 487, 121 ALR 283; McInerney v Ervin (Fla) 46 So 2d 458; State Public Utilities Com. ex rel. Quincy R. Co. v Quincy, 290 Ill 360, 125 NE 374; Shreveport Traction Co. v Shreveport, 122 La 1, 47 So 40; St. Paul v Chicago, S. P. M. & O. R. Co., 139 Minn 322, 166 NW 335; Chicago, B. & Q. R. Co. v State, 47 Neb 549, 66 NW 624, affd 170 US 57, 42 L Ed 948, 18 S Ct 513; People ex rel. New York Electric Lines Co. v Squire, 107 NY 593, 14 NE 820, affd 145 US 175, 36 L Ed 666, 12 S Ct 880; Sammons v Beaufort, 225 SC 490, 83 SE2d 153; Shealy v Southern R. Co., 127 SC 15, 120 SE 561; Shea v Olson, 185 Wash 143, 53 P2d 615, 111 ALR 998, adhered to 186 Wash 700, 59 P2d 1183, 111 ALR 1011.

The state may not surrender, or bind itself not to exert, its police power. Phillips Petroleum Co. v Jenkins, 297 US 629, 80 L Ed 943, 56 S Ct 611, reh den 298 US 691, 80 L Ed 1409, 56 S Ct 745.

6. Goodpaster v Southern Ins. Agency, Inc., 293 Ky 420, 169 SW2d 1.

7. Northern P. R. Co. v Minnesota, 208 US 583, 52 L Ed 630, 28 S Ct 341; Jacksonville v Ledwith, 26 Fla 163, 7 So 885; State Public Utilities Com. ex rel. Quincy R. Co. v Quincy, 290 Ill 360, 125 NE 374; Venner v Chicago C. R. Co., 246 Ill 170, 92 NE 643 (ovrld on other grounds Doggett v North American Life Ins. Co. 396 Ill 354, 71 NE2d 686); State v Broadbelt, 89 Md 565, 43 A 771; Lake Roland E. R. Co. v Mayor, etc., of Baltimore, 77 Md 352, 26 A 510; St. Paul v Chicago, S. P. M. & O. R. Co., 139 Minn 322, 166 NW 335; State ex rel. Laclede Gas Light Co. v Murphy, 130 Mo 10, 31 SW 594, affd 170 US 78, 42 L Ed 955, 18 S Ct 505; Shealy v Southern R. Co., 127 SC 15, 120 SE 561; Victoria v Victoria Ice Light & Power Co., 134 Va 134, 114 SE 92, 28 ALR 562; State v Sensenbrenner, 262 Wis 118, 53 NW2d 773.

8. Industrial Com. v Navajo County, 64 Ariz 172, 167 P2d 113; Blackman Health Resort v Atlanta, 151 Ga 507, 107 SE 525, 17 ALR 516; State Public Utilities Com. ex rel. Quincy R. Co. v Quincy, 290 Ill 360, 125 NE 374; St. Paul v Chicago, S. P. M. & O. R. Co., 139 Minn 322, 166 NW 335; State ex rel. Minneapolis v St. Paul, M. & M. R. Co., 93 Minn 380, 108 NW 261, affd 214 US 497, 53 L Ed 1060, 29 S Ct 698; Shealy v Southern R. Co., 127 SC 15, 120 SE 561.

When the state's police power exists, it is not lost by nonexercise, but remains to be exerted as local exigencies may demand. Kelly v Washington, 302 US 1, 82 L Ed 3, 58 S Ct 87.

9. Denver & R. G. R. Co. v Denver, 250 US 241, 63 L Ed 958, 39 S Ct 450; Holden v Hardy, 169 US 366, 42 L Ed 780, 18 S Ct 383; Goszler v Corporation of Georgetown, 19 US 593, 5 L Ed 339; Alabama State Federation of Labor v McAdory, 246 Ala 1, 18 So 2d 810, cert dismd 325 US 450, 89 L Ed 1725, 65 S Ct 1384; Ft. Smith v Hunt, 72 Ark 556, 82 SW 163; Georgia R. & P. Co. v Railroad Com., 149 Ga 1, 98 SE 696, 5 ALR 1; State Public Utilities Com. ex rel. Quincy R. Co. v Quincy, 290 Ill 360, 125 NE 374; Fernandez v Alford, 203 La 111, 13 So 2d 483; St. Paul v Chicago, S. P. M. & O. R. Co., 139 Minn 322, 166 NW 335; Kalbfell v St. Louis, 357 Mo 986, 211 SW2d 911; Cape Girardeau v St. Louis S. F. R. Co., 305 Mo 590, 267 SW 601, 36 ALR 1488; People ex rel. New York Electric Lines Co. v Squire, 107 NY 593, 14 NE 820, affd 145 US 175, 36 L Ed 666, 12 S Ct 880; Shealy v Southern R. Co., 127 SC 15, 120 SE 561; Sowma v Parker, 112 Vt 241, 22 A2d 513.

The police power can neither be abdicated nor bargained away, and is inalienable even by express grant. Chicago & A. R. Co. v Tranbarger, 238 US 67, 59 L Ed 1204, 35 S Ct 678; Atlantic C. L. R. Co. v Goldsboro, 232 US 548, 58 L Ed 721, 34 S Ct 364; Chicago, S. P. M. &

surrender or limit the state's police powers would be unconstitutional and void.[9] Pursuant to this principle, it is held that the exercise of the police power cannot be limited by contract, and it is immaterial on what consideration the contracts rest, since in all cases it is beyond the authority of a state or its municipalities to abrogate this power so necessary to the public safety.[10] And a municipality cannot, by contract, foreclose the exercise of the police power,[11] unless clearly authorized to do so by the supreme legislative power.[12] And the courts cannot decide away that which the state itself cannot contract away.[14] Nor, since estoppel is no stronger than a contract entered into by the sovereign, can the government be estopped by its past conduct to exercise the police power.[15]

O. R. Co. v Douglas County, 134 Wis 197, 114 NW 511.

The exercise of any part of the police power of the state may not be alienated or delegated to an independent contractor. Industrial Com. v Navajo County, 64 Ariz 172, 167 P2d 113.

10. State v Sensenbrenner, 262 Wis 118, 53 NW2d 773.

11. Phillips Petroleum Co. v Jenkins, 297 US 629, 80 L Ed 943, 56 S Ct 611, reh den 298 US 691, 80 L Ed 1409, 56 S Ct 745; Home Bldg. & Loan Asso. v Blaisdell, 290 US 398, 78 L Ed 413, 54 S Ct 231, 88 ALR 1481; Chicago & A. R. Co. v Tranbarger, 238 US 67, 59 L Ed 1204, 35 S Ct 678; Northern P. R. Co. v Minnesota, 208 US 583, 52 L Ed 630, 28 S Ct 341; New Orleans Gas Light Co. v Drainage Com of New Orleans, 197 US 453, 49 L Ed 831, 25 S Ct 471; Colorado & S. R. Co. v Ft. Collins, 52 Colo 281, 121 P 747; Georgia R. & P. Co. v Railroad Com., 149 Ga 1, 98 SE 696, 5 ALR 1; Idaho Power & Light Co. v Blomquist, 26 Idaho 222, 141 P 1083; Pittsburgh, C. C. & S. L. R. Co. v Chappell, 183 Ind 141, 106 NE 403; Shreveport v Kansas C., S. & G. R. Co., 167 La 771, 120 So 290, 62 ALR 1512; Raymond Lumber Co. v Raymond Light & Water Co., 92 Wash 330, 159 P 133.

The state cannot, by virtue of the contract clause of the Federal Constitution, divest itself by contract of the right to exert its governmental authority in matters which from their very nature so concern that authority that to restrain its exercise by contract would be a renunciation of power to legislate for the preservation of society or to secure the performance of essential governmental duties. Contributors to Pennsylvania Hospital v Philadelphia, 245 US 20, 62 L Ed 124, 38 S Ct 35.

The right to exercise the police power is a continuing one which cannot be contracted away, and a requirement that a company or an individual comply with reasonable police regulations without compensation is the legitimate exercise of the power and not in violation of the constitutional inhibition against the impairment of the obligation of contracts. Northern P. R. Co. v Minnesota, 208 US 583, 52 L Ed 630, 28 S Ct 341.

12. Chicago, B. & Q. R. Co. v Nebraska, 170 US 57, 42 L Ed 948, 18 S Ct 513; Lingo Lumber Co. v Hayes (Tex Civ App) 64 SW2d 835; Murphy v Phillips (Tex Civ App) 63 SW2d 404, app dismd 123 Tex 408, 73 SW2d 92, ans conformed to (Tex Civ App) 73 SW2d 1047.

Franchises, privileges, and contracts granted by municipalities affecting matters coming within the police power of the state must be considered as having been granted or passed with reference to the power of the state to legislate with respect to such matters unfettered by provisions of such franchises. Grand Trunk W. R. Co. v South Bend, 227 US 544, 57 L Ed 633, 33 S Ct 303; Dobbins v Los Angeles, 195 US 223, 49 L Ed 169, 25 S Ct 18; People of New York ex rel. New York Electric Lines v Squire, 145 US 175, 36 L Ed 666, 12 S Ct 880; Railroad Co. v Richmond, 96 US 521, 24 L Ed 734; Colorado & S. R. Co. v Ft. Collins, 52 Colo 281, 121 P 747; Cape Girardeau v St. Louis S. F. R. Co., 305 Mo 590, 267 SW 601, 36 ALR 1488; State ex rel. Webster v Superior Court of King County, 67 Wash 37, 120 P 861.

The constitutional provision against the impairment of contract obligations does not apply where the legislation which is alleged to impair a contract right, under an ordinance granting a privilege, is an exercise of the police power. Union Dry Goods Co. v Georgia Public Service Corp., 142 Ga 841, 83 SE 946, affd 248 US 372, 63 L Ed 309, 39 S Ct 117, 9 ALR 1420.

13. Home Tel. & Tel. Co. v Los Angeles, 211 US 265, 53 L Ed 176, 29 S Ct 50; Sumter Gas & Power Co. v Sumter (CA4 SC) 283 F 931, revd on other grounds 266 US 639, 69 L Ed 482, 45 S Ct 11; Hoyne v Chicago & O. P. E. R. Co., 294 Ill 413, 128 NE 587.

14. AFL v Watson (DC Fla) 60 F Supp 1010, revd on other grounds 327 US 582, 90 L Ed 873, 66 S Ct 761.

15. Acker v Baldwin, 18 Cal 2d 341, 115 P2d 455; Laurel Hill Cemetery v San Francisco, 152 Cal 464, 93 P 70, affd 216 US 358, 54 L Ed 515, 30 S Ct 301.

In some states it is specifically provided in the state constitutions that the exercise of the police power may never be abridged.[16]

The corollary that the discretion of the legislature with respect to exercise of the police power cannot be parted with any more than the power itself is as firmly established as the general rule.[17] Thus, the legislative authority cannot redelegate to anyone the ultimate right to determine when, to what extent, and under what circumstances the police power may properly be exercised in any given case.[18]

3. Who May Exercise Power

§ 375. States.

The police power under the American constitutional system has been left to the states,[19] and is normally vested in and exercised by the legislative branch,[20] or by political subdivisions of the state[21] or administrative bodies and agencies[22] to which the legislature has made a proper delegation of its authority in

16. Cape Girardeau v St. Louis S. F. R. Co., 305 Mo 590, 267 SW 601, 36 ALR 1488; Thompson v Smith, 155 Va 367, 154 SE 579, 71 ALR 604.

In Fernandez v Alford, 203 La 111, 13 So 2d 483, the court said that the Louisiana constitutional provison to the effect that "the exercise of the police power in the State shall never be abridged" meant that the state legislature should not irrevocably surrender the police power of the state.

17. Texas & N. O. R. Co. v Miller, 221 US 408, 55 L Ed 789, 31 S Ct 534; St. Louis & S. F. R. Co v Mathews, 165 US 1, 41 L Ed 611, 17 S Ct 243; Butchers' Union, etc., Co. v Crescent City, etc., Co., 111 US 746, 28 L Ed 585, 4 S Ct 652; Beer Co. v Massachusetts, 97 US 25, 24 L Ed 989; Standard Chemical & Oil Co. v Troy, 201 Ala 89, 77 So 383; State Public Utilities Com. ex rel. Quincy R. Co. v Quincy, 290 Ill 360, 125 NE 374; Board of Education v Phillips, 67 Kan 549, 73 P 97; St. Paul v Chicago, S. P. M. & O. R. Co., 139 Minn 322, 166 NW 335; State ex rel. Robertson v Lane, 126 Minn 78, 147 NW 951; Oklahoma Alcoholic Beverage Control Board v Milam (Okla) 393 P2d 823; National Bank of Tulsa Bldg. v Goldsmith, 204 Okla 45, 226 P2d 916; State v Kofines, 33 RI 211, 80 A 432; Shealy v Southern R. Co., 127 SC 15, 120 SE 561; State ex rel. George v City Council of Aiken, 42 SC 222, 20 SE 221.

18. National Bank of Tulsa Bldg. v Goldsmith, 204 Okla 45, 226 P2d 916; Sutherland v Miller, 79 W Va 796, 91 SE 993.

19. Keller v United States, 213 US 138, 53 L Ed 737, 29 S Ct 470; Patterson v Kentucky, 97 US 501, 24 L Ed 1115; Slaughter-House Cases, 83 US 36, 21 L Ed 394; McInerney v Ervin (Fla) 46 So 2d 458; Bruck v State, 228 Ind 189, 91 NE2d 349; Western Union Tel. Co. v Pendleton, 95 Ind 12, revd on other grounds 122 US 347, 30 L Ed 1187, 7 S Ct 1126; Fry v State, 63 Ind 552; Sanders v Commonwealth, 117 Ky 1, 77 SW 358; State v Old Tavern Farm, Inc., 133 Me 468, 180 A 473, 101 ALR 810, Brewer v Valk, 204 NC 186, 167 SE 638, 87 ALR 237; Smith v Fidelity & Deposit Co., 191 NC 643, 132 SE 792, error dismd 275 US 505, 72 L Ed 396, 48 S Ct 156; State v Moore, 104 NC 714, 10 SE 143; C. A. King & Co. v Horton, 116 Ohio St 205, 5 Ohio L Abs 174, 156 NE 124, error dismd 276 US 600, 72 L Ed 725, 48 S Ct 322; Hyde v Albert E. Peirce & Co., 147 Or 5, 31 P2d 755; State v Kofines, 33 RI 211, 80 A 432; Shealy v Southern R. Co., 127 SC 15, 120 SE 561; State v McKay, 137 Tenn 280, 193 SW 99; Murphy v Phillips (Tex Civ App) 63 SW2d 404, app dismd 123 Tex 408, 73 SW2d 92, ans conformed to (Tex Civ App) 73 SW2d 1047; Re Guerra, 94 Vt 1, 110 A 224, 10 ALR 1560; State ex rel. Morris v West Virginia Racing Com., 133 W Va 179, 55 SE2d 263, Brown v Board of Education, 106 W Va 476, 146 SE 389, 64 ALR 297;

Annotation: 28 L ed 923.

The police power is the inherent governmental power which, under the federal system established by the Constitution of the United States, is reserved to the several states. Lincoln Federal Labor Union v Northwestern Iron & Metal Co., 149 Neb 507, 31 NW2d 477; affd 335 US 525, 93 L Ed 212, 69 S Ct 251, 6 ALR2d 473.

20. § 376, infra.

21. As to exercise of the police power by municipal corporations, see 56 Am Jur 2d, Municipal Corporations, Counties, and Other Political Subdivisions §§ 423 et seq.

22. See 1 Am Jur 2d, Administrative Law §§ 116, 118.

this respect. It has a
them to the general
the United States.[23]
tution of the United
United States by th
reserved to the state
a government of en
than those expressly
tion, and the vast fi
reserved to the stat
relative rights and d
its jurisdiction for t
limit to state exercis
shall not prove repu
tion.[26]

The provisions of

23. Hammer v Dagenha
Ed 1101, 38 S Ct 529,
other grounds United St
100, 85 L Ed 609, 61
1430); House v Mayes, 2
213, 31 S Ct 234; Wester
berg, 204 US 359, 51 L
Jacobson v Massachusetts
643, 25 S Ct 358; State
193 Ala 500, 68 So 993;
Ill 74, 110 NE 870; Br
186, 167 SE 638, 87 ALR
& Deposit Co., 191 NC 6
dismd 275 US 505, 72 L
Durham v Southern R. C
SE 17, 35 ALR 1313, affd
231, 45 S Ct 51; Stat
Glander, 148 Ohio St 18
74 NE2d 82, cert den 3
394, 68 S Ct 157; Chicag
Beatty, 34 Okla 321, 118
Okla 328, 126 P 736, r
234 US 753, 58 L Ed 157
v Albert E. Peirce & Co
755; Shealy v Southern R
SE 561; Murphy v Philli
SW2d 404, app dismd 1
92, ans conformed to (T
1047; Sabre v Rutland R.
693; State Board of Heal
Vt 276, 73 A 581; Buck
130 SE 516, 51 ALR 855
L Ed 1000, 47 S Ct 5
Henry, 110 Va 879, 65
Morris v West Virginia
Va 179, 55 SE2d 263;
Education, 106 W Va
ALR 297.

The police powers of
of the immense mass of
braces everything within
not surrendered to the g
of which may be most ad