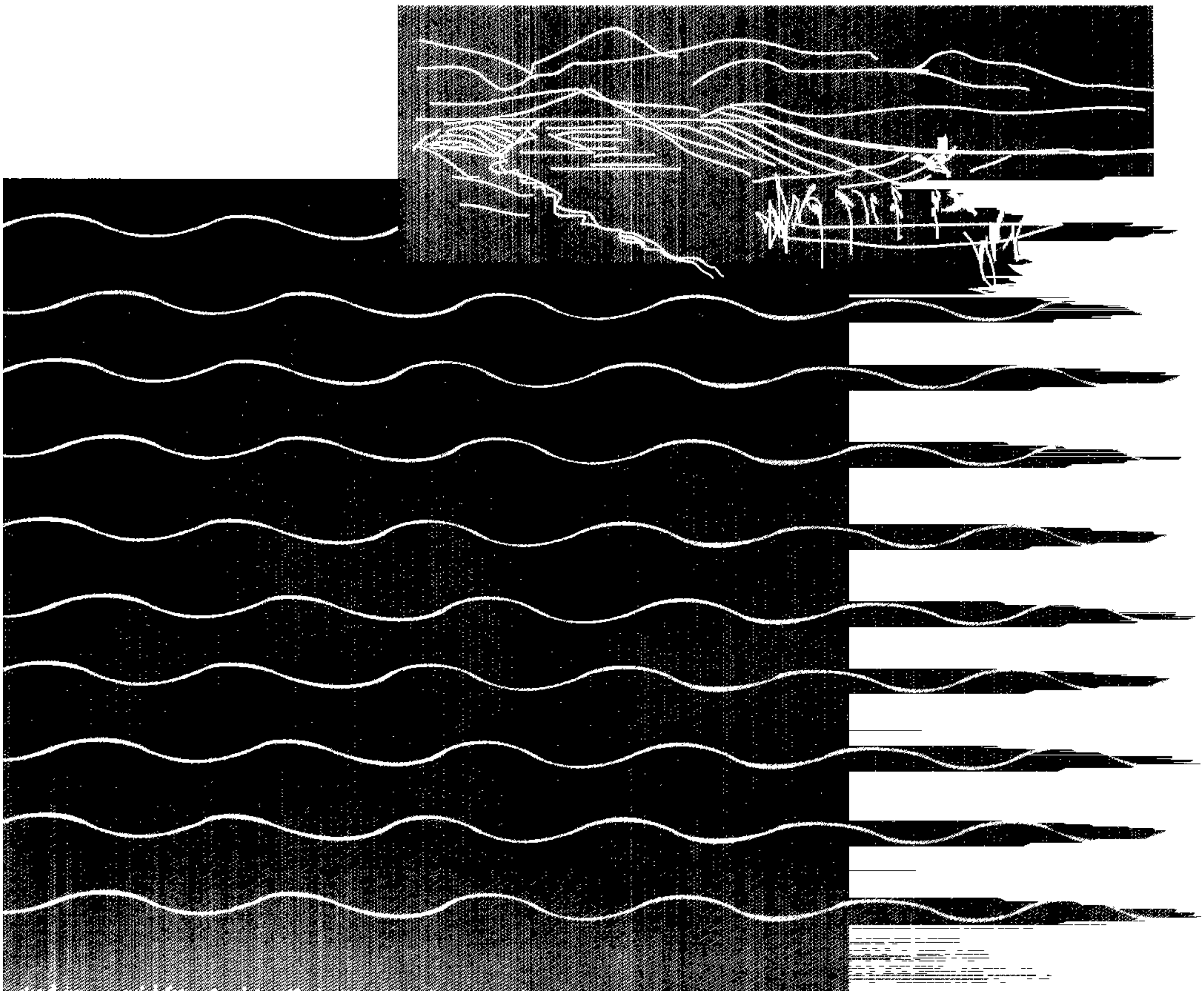
Exhibit CBD-6

A Management Plan For Agricultural Subsurface Drainage and Related Problems on the Westside San Joaquin Valley

September 1990



A Management Plan
for
Agricultural Subsurface Drainage and Related Problems on the Westside San Joaquin Valley

Final Report
of the
San Joaquin Valley Drainage Program

September 1990

U.S. DEPARTMENT OF THE INTERIOR
Bureau of Reclamation
Fish and Wildlife Service
Geological Survey

CALIFORNIA RESOURCES AGENCY
Department of Fish and Game
Department of Water Resources

PREFACE

A comprehensive study of agricultural drainage and drainage-related problems on the westside San Joaquin Valley has resulted in the management plan presented in this final report of the Federal-State interagency San Joaquin Valley Drainage Program.

Understandably, some may be disappointed that no single, sure, and lasting solution to the drainage problem has been put forward. Rather, the management plan presented is complex and includes risks that could be costly. Moreover, it may be only the first step in solving the salt accumulation problem. Virtually everyone involved in examination of the drainage problem agrees, however, that there is no single solution and no easy answer to the problem.

But it is also generally agreed that the drainage problem is manageable and that this management logically begins in the valley with a broadly shared effort to reduce the amount of drainage water, to place the remaining water under control, and to contain and isolate toxicants such as selenium. Such actions would largely correct present problems of waterlogging of farmlands and could greatly reduce adverse impacts on fish and wildlife.

The in–valley actions recommended in the plan would also be necessary for any eventual export of salt from the San Joaquin Valley. The recommended actions would provide a regional drainage infrastructure that now exists only in scattered pieces. If the plan proposed here is implemented, a salt export decision need not be made for several decades.

A review of the history of the drainage problem suggests that some of the reasons the problem has grown to nearly 500,000 acres and is adversely affecting the environment include: (1) Continued hopes for a master drain, (2) expectations of a technological breakthrough in drainage water treatment, (3) the need for more information, and (4) a lack of cooperation among parties affected. Viewed as an accumulation of years of piecemeal efforts and neglect, the problem appears overwhelming. It is not. Systematic, shared work begun now can manage the problem and contribute to its eventual solution.

Ed Imhoff

Edgar A. Imhoff, Program Manager
San Joaquin Valley Drainage Program

CONTENTS

Chapter 3. WHAT THE STUDY HAS REVEALED OR CONFIRMED *(continued)*

Chapter 4. THE PLANNING FRAMEWORK 69

Chapter 5. IN-VALLEY MANAGEMENT OPTIONS AND PLANNING ALTERNATIVES 79

TABLES

TABLES *(continued)*

FIGURES

SAN JOAQUIN VALLEY DRAINAGE PROGRAM COMMITTEE AND TEAM MEMBERSHIP

The San Joaquin Valley Drainage Program is a Federal/State interagency program that was established in August 1984 by then Secretary of the Interior William Clark and California Governor George Deukmejian.

INTERGOVERNMENTAL COORDINATION TEAM

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Joseph Summers, Summers Engineering, Inc.

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Vernon Snoeyink, University of Illinois, Urbana

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Edgar Imhoff, Program Manager
Carroll Hamon, Deputy Program Manager and CA Department of Water Resources Representative
Henry Hansen, US Bureau of Reclamation Representative
Stephen Moore, US Fish and Wildlife Service Representative
Larry Puckett, CA Department of Fish and Game Representative
Walter Swain, US Geological Survey Representative

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Chapter 1. SUMMARY OF THE PLAN AND RECOMMENDATIONS FOR ACTION

This report summarizes the results of an intensive study of the subsurface agricultural drainage problems of the western side of the San Joaquin Valley, and presents a plan and recommendations for managing those problems from 1990 to 2040. The study has led to a much better understanding of the causes and effects of the drainage and drainage-related problems, although much is yet to be learned and long-term monitoring of the problem will be necessary.

The study and resulting plan focus on in-valley management of the drainage and drainage-related problems. It appears that in-valley actions can manage the problems for several decades without a means of exporting drainage-related salts to the ocean. Ultimately, it may become necessary to remove salt from the valley.

The recommended plan, which is regional in both scope and detail, takes account of uncertainties in information. The plan is not site-specific, and, without more detailed analysis, it is not a plan from which structures may be built. Rather, it should be considered as a framework that will permit the present level of agricultural development in the valley to continue, while protecting fish and wildlife and helping to restore their habitat to levels existing before direct impact by contaminated drainage water. It is noteworthy that many of the valley's water and drainage districts and individual growers have already begun to take actions similar to those recommended in this report.

Figure 1 shows the San Joaquin Valley, the principal study area, and the five subareas used for planning.

SUMMARY OF THE PLAN

The plan recommended for management of subsurface drainage and drainage-related problems on the western side of the San Joaquin Valley contains the following major components:

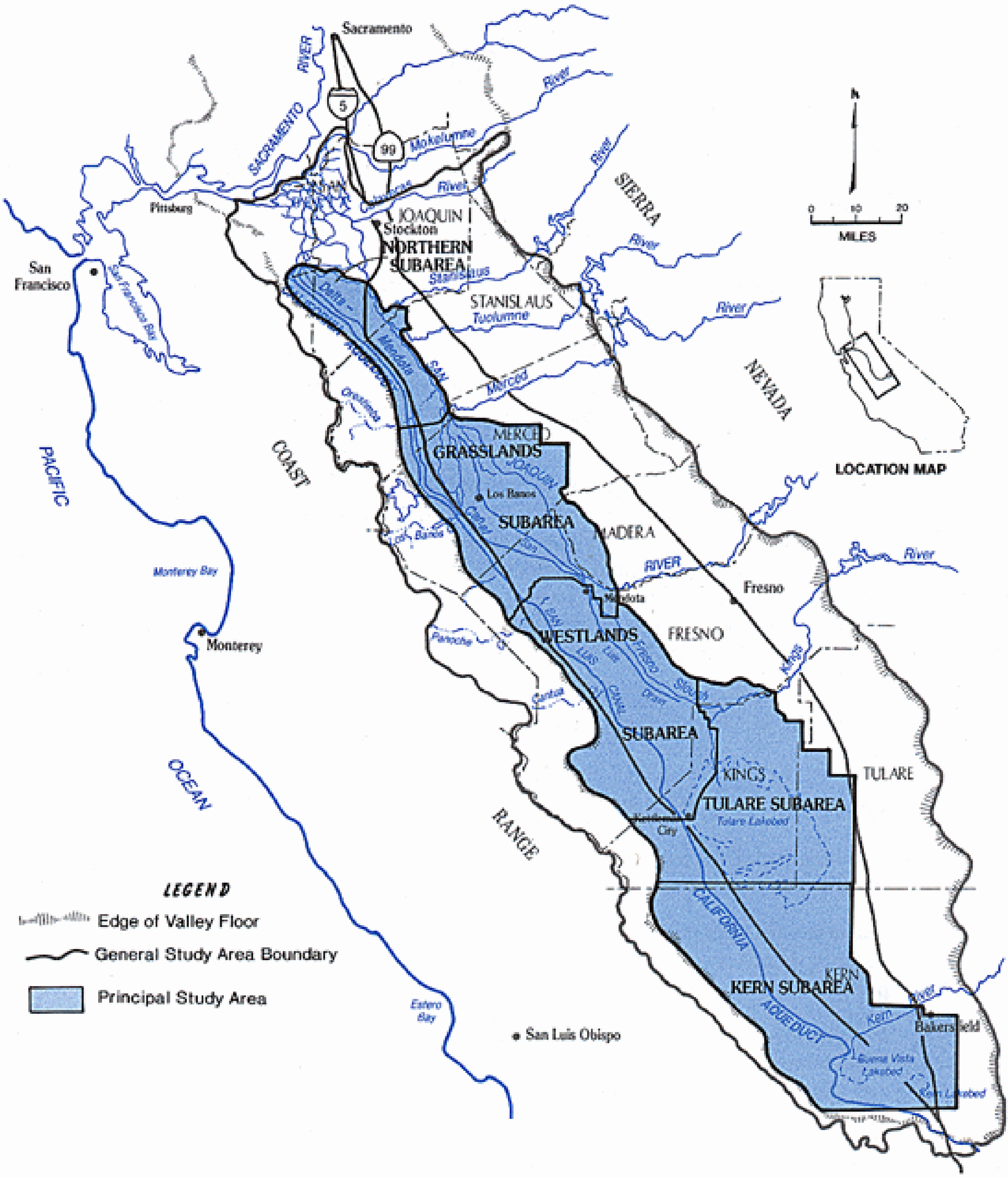
- ***Source control.*** Consisting mainly of on-farm improvements in the application of irrigation water to reduce the source of deep percolation. This in turn will reduce the amount of potential drainage problem water.

- ***Drainage reuse.*** A planned system of drainage-water reuse on progressively more salt-tolerant plants. This will reduce the volume of drainage water and concentrate salts and trace elements for easier containment and safe disposal.

- ***Evaporation system.*** Drainage-water evaporation ponds planned for storage and evaporation of drainage water remaining after reuse on salt-tolerant plants. Four types of ponds are included: (a) Nontoxic ponds in which selenium in drainage-water

Figure 1

PROGRAM STUDY AREA



inflow is less than 2 parts per billion (ppb); (b) selenium-contaminated ponds (inflowwater containing selenium in the range of 2 to 50 ppb) that must include safeguards for wildlife and an equivalent area of alternative freshwater habitat; (c) small selenium-contaminated ponds designed with facilities to greatly accelerate the rate of evaporation, thereby reducing the pond surface area; and (d) temperature-gradient solar ponds that generate electricity by using water from other ponds containing very high salt and trace-element concentrations.

- ***Land retirement.*** Cessation of irrigation of areas in which underlying shallow ground water contains elevated levels of selenium and the soils are difficult to drain.
- ***Ground-water management.*** Planned pumping from deep within the semiconfined aquifer, in places where near-surface water tables can be lowered and the water pumped is of suitable quality for irrigation or wildlife habitat.
- ***Discharge to the San Joaquin River.*** Controlled and limited discharge of drainage water from the San Joaquin Basin portion of the study area to the San Joaquin River, while meeting water-quality objectives.
- ***Protection, restoration, and provision of substitute water supplies for fish and wildlife habitat.*** Provision of freshwater supplies to substitute for drainage-contaminated water previously used on wetlands and to allow protection and restoration of contaminated fisheries and wetland habitat.
- ***Institutional change.*** Includes tiered water pricing, improved scheduling of water deliveries, water transfers and marketing, and formation of regional drainage management organizations to aid in implementing other plan components.

Table 1 summarizes the extent to which each plan component is included in the plan, based on the land area to which it applies or occupies and the water assigned for fish and wildlife uses.

Table 1. SUMMARY OF RECOMMENDED DRAINAGE MANAGEMENT PLAN

Plan Component	Subarea					
	Northern[a]	Grasslands	Westlands	Tulare	Kern	Total
	Land areas in 1,000s of acres by 2040					
Source Control	0	93.6	159.3	316.7	105.9	675.5
Drainage Reuse[b]	0	2.6	12.1	24.5	9.7	48.9
Evaporation System[b]	0	0.2	2.1	3.0	2.3	7.6
Evaporation Pond[b]	0	0.12	0.40	2.9	1.07	4.5
Alternative Habitat						
Land Retirement	0	3.0	33.0	7.0	32.0	75.0
Ground Water Management	0	10.0	19.0	40.0	0.0	69.0
Discharge to San Joaquin River (land area)	0	160.6	0	0	0	160.6
	1,000s of acre-feet annually by 2040					
Increased Water for Fish and Wildlife Uses, Including Substitute Water[c]	0	150.0[d]	4.0[e]	29.0[e]	11.0[e]	194.0

[a] Except for study and monitoring, no planned drainage management actions are recommended for the Northern Subarea.
[b] The acreages shown are for on-site facilities; the total land area served is essentially all the area under source control.
[c] Substitute water is that water supply for wetlands that replaces contaminated drainage water used through the mid-1980s.
[d] Consists of 129,000 acre-feet of substitute water supply for wetlands, 20,000 acre-feet of Merced River instream fish flow in October, and 1,000 acre-feet of evaporation pond alternative habitat.
[e] Water for evaporation pond alternative habitat at the rate of 10 acre-feet/acre/year.

No planned drainage management actions other than those being carried out currently are recommended for the Northern Subarea. However, drainage water from this area now flows to the San Joaquin River. In the event that water-quality objectives for the river become more restrictive, actions that would aid in meeting the objectives are discussed in the subarea plan.

Problem water is a term introduced in this report to describe the volume of near-surface ground water that, if reduced by source control or removed from plant root zones each year, would eliminate the drainage-related impediment to agricultural productivity. When placed in streams or open basins, some problem water is potentially hazardous to fish and wildlife and therefore must be managed to prevent environmental degradation. Drainage water that causes unacceptable levels of environmental degradation is viewed also as problem water for agriculture because it must be remedied — even if retirement of irrigated land is required. Table 2 shows the estimated reduction of problem water to be achieved by each plan component in each subarea. If the targets are met, agricultural production could be maintained for at least the duration of the planning period, without removal of salt from the valley. If salt export becomes necessary in the future, the actions recommended in this plan could create prerequisite conditions by providing collection facilities, by reducing drainage water volumes, and by isolating and controlling contaminants.

Table 2. PROBLEM WATER REDUCTION, 2040

Plan Component	Subarea								
	Northern	Grasslands		Westlands		Tulare		Kern	
		Acre-feet	Percent of Total	Acre-feet	Percent of Total	Acre-feet	Percent of Total	Acre-feet	Percent of Total
Source Control	0	32.7	(21)	55.8	(36)	63.2	(30)	37.1	(34)
Drainage Reuse	0	13.6	(9)	61.0	(40)	113.3	(54)	43.6	(39)
Evaporation System	0	0.7	—	4.0	(3)	12.3	(6)	6.0	(5)
Land Retirement	0	2.3	(1)	24.8	(16)	4.2	(2)	24.0	(22)
Ground-water Management	0	4.0	(3)	7.6	(5)	16.0	(8)	0	(0)
Discharge to San Joaquin River	0	102.1	(66)	0	(0)	0	(0)	0	(0)
TOTAL		**155.4**	**(100)**	**153.2**	**(100)**	**209.0**	**(100)**	**110.7**	**(100)**

a Except for study and monitoring, no planned drainage management actions are recommended for the Northern Subarea.

The costs of the recommended plan have been annualized over the 50-year planning period, 1990-2040, at an interest rate of 10 percent (Table 3). One-time costs include those for installation of facilities and purchase (as in the case of land retirement) of plan components. The category "Agricultural Drainage" includes all drainage-related components of the recommended plan, except on-farm drainage systems. "On-Farm Drains" includes new on-farm drainage systems expected to be installed between 1991 and 2040 and the annual operation of those drains during that period, as well as those already operating in 1990. "Fish and Wildlife" includes the costs of constructing and operating facilities and purchasing water so that clean water could be delivered to wetland habitat formerly supplied with contaminated drainage water.

The economic value of the direct benefits or regional economic impacts of implementing the recommended plan was not estimated, and no allocation of costs among beneficiaries has been performed. For drainage reuse, an estimate of the value of wood produced has been reflected as a cost offset. However, for source control and land retirement, any economic surplus that might result from the possible transfer of conserved water to other uses has not been included as a cost offset.

Table 3. ANNUALIZED COSTS OF THE RECOMMENDED PLAN
In $1,000s

Agricultural Drainage	
One-time	
Source control	2,940
Drainage reuse	6,194
Evaporation system	3,043
Land retirement	2,818
Ground-water management	962
San Luis Drain	2,300
Subtotal	18,257
Operation, maintenance, and replacement	
Source control	5,444
Drainage reuse	2,291
Evaporation system	1,915
Land retirement	300
Ground-water management	2,694
San Luis Drain	390
Subtotal	13,034
TOTAL	**31,291**
On-Farm Drains	
Installation	6,473
Operation, maintenance, and replacement	1,536
TOTAL	**8,009**
Fish and Wildlife	
Installation	153
Operation, maintenance, and replacement	18
Water supply	2,548
TOTAL	2,719
GRAND TOTAL	**42,019**

CONCLUSIONS AND RECOMMENDATIONS FOR ACTION

During this study, a massive amount of data has been collected; many reports have been published; and much analysis, planning, and public review have been completed. This has led to the plan for drainage management presented in Chapter 6. However, a plan alone will not manage or solve the drainage and drainage-related problems of the western side of the San Joaquin Valley; actions are required on many fronts to make the plan a reality. These actions can be grouped under implementation, planning, monitoring, additional study, and funding proposed actions. The conclusions and recommendations for action that follow are presented in each of those groups.

Implementation

Local initiatives need to be recognized, supported, and enhanced by coordinated, comprehensive Federal and State actions undertaken to manage drainage problems. Several components in the management plan are either being studied preparatory to action or are actually being carried out by organizations and private interests in the problem area. Those activities that meet the criteria and objectives of the long-term drainage management plan should be carried out as rapidly as possible. Generally, these activities will require approval or assistance from local, State, or Federal agencies. They should receive high priority.

Some changes in law and policy by local, State, and Federal agencies would provide the impetus or remove roadblocks for implementing some plan components. Policy actions by agencies supplying, distributing, and regulating irrigation water and managing drainage facilities are needed now and in the future. Institutional changes are also a part of the management plan, which requires concerted action by both the California Legislature and the U.S. Congress.

Because unattended plans often do not materialize, the efforts reported here will be followed by a short, new Federal-State effort between October 1990 and December 1991 that will develop a strategy for implementation of the plan.

Recommendation 1 – Implementation of Recommended Plan; Priority Activities

Local, State, and Federal water organizations and authorities should consider the recommended plan and explicitly adopt those parts appropriate for their long-term strategy of contributing to the management or solution of the drainage problems of the west side San Joaquin Valley.

The following plan components should be implemented as soon as final planning is complete, funding and applicable clearances can be obtained, and agreement can be reached. An asterisk (*) following a plan component indicates there is a related current local initiative that should become part of the plan component.

Northern Subarea

- Investigate, in detail, measures that may be needed if stricter salt standards are established for the San Joaquin River/Delta.

Grasslands Subarea

- Use the Grassland Task Force water districts as the nucleus of a regional drainage entity to coordinate and jointly manage subarea-wide drainage problems. *
- Provide the facilities required to intercept contaminated subsurface drainage water now being discharged into open channels within the grasslands wildlife habitat, and convey these to the San Luis Drain.
- Renovate and extend the San Luis Drain, bypassing 20,000 acre-feet of contaminated drainage water around wetlands (similar to the Zahm-Sansoni-Nelson plan). *
- Improve on-farm water conservation and source control on all irrigated lands and reduce deep percolation on lands having drainage problems by 0.35 acre-feet per acre per year (on the average) as soon as possible. *
- Intensify and complete local demonstration projects on source control and treatment of drainage water. (Work already under way in Broadview, Panoche, and Pacheco water districts.) *
- The U.S. Bureau of Reclamation should actively seek authority to reallocate 74,000 acre-feet of water annually from the Central Valley Project to replace drainage water used on wetlands before 1985.
- Restore drainage-contaminated wetlands.
- Provide 20,000 acre-feet of water to the Merced River each October to attract migrating fish from drainage water discharging to the San Joaquin River.

Westlands Subarea

- Improve on-farm water conservation and source control on all irrigated lands and reduce deep percolation on lands having drainage problems by 0.35 acre-feet per acre per year (on the average) as soon as possible. *
- Accelerate the pace and increase the number of field demonstrations of source control measures and drainage water treatment research, including especially reuse of drainage water on trees and removal of selenium from drainage water. *
- Develop guidelines for retirement of irrigated lands that have high selenium concentrations in shallow ground water and that are difficult to drain.
- Design and develop a 5,000-acre demonstration unit of closely-spaced, low-volume wells in the semiconfined aquifer for planned drawdown of the high water table.

Tulare Subarea

- Develop a formal association of water districts (built around the existing Tulare Lake Drainage District) for coordinated and joint management of subarea-wide drainage problems. *
- Improve on-farm water conservation and source control on all irrigated lands and reduce deep percolation on lands having drainage problems by 0.2 acre-feet per acre per year (on the average) as soon as possible. *

- Accelerate the pace and increase the number of field demonstrations of source control measures and evaporation pond experiments, including especially the reuse of water on trees and modification of pond systems and their management to make ponds bird–free or bird–safe. *
- Demonstrate in the field the use of alternative safe-water habitat near an existing evaporation pond containing elevated levels of selenium.
- Design and develop a 5,000-acre demonstration unit of closely-spaced, low-volume wells in the semiconfined aquifer for planned drawdown of the high water table in the area of good quality ground water in the Kings River Delta (Tulare Subarea water quality zone E).

Kern Subarea

- Kern County Water Agency and local water districts should form a drainage management entity responsible for coordination and joint management of subarea-wide drainage problems.
- Improve on-farm water conservation and source control on all irrigated lands and reduce deep percolation on lands having drainage problems by 0.35 acre-feet per acre per year (on the average) as soon as possible. *
- Initiate intensive studies of the ground–water resources of the old Buena Vista and Kern lakebeds.

Recommendation 2 – Source Control

The agencies with major responsibility for delivery of water to the study area (U.S. Bureau of Reclamation and California Department of Water Resources) should increase their work with the university extension systems and water districts to demonstrate ways to improve the efficiency of irrigation water application and thereby reduce potential drainage-water volumes.

Each water district should, by 1992, set objectives in their operation plans that would reduce deep percolation by the amounts stated in Recommendation 1 (preceding). State and Federal agencies should help local water districts accomplish their water conservation improvement plans.

Recommendation 3 – Financing Source Control Measures

Both the Federal and State governments should explore ways of providing a portion of the financing needed to implement irrigator source–control actions and to invigorate existing programs. The U.S. Soil Conservation Service and U.S. Bureau of Reclamation both have programs that could aid in financing irrigator actions. The State of California, through the Department of Water Resources, the Department of Food and Agriculture, and the State Water Resources Control Board, could provide loans and grants for source-control actions, if funds were made available.

Recommendation 4 – Joint Technical Assistance

The U.S. Department of the Interior and the State of California should jointly develop a technical assistance program to ameliorate the drainage problem, by providing water districts with geohydrologic and economic information and analytical techniques useful in investigating local areas for possible conjunctive surface- and ground-water use, land retirement, on-farm drainage, source control, and reuse. Technical assistance is also needed in environmental impact assessment, toxicity assessment, and habitat restoration.

Recommendation 5 – State of California Lead in Water Conservation

The State of California should expand and intensify its program of on-farm water conservation to focus especially on demonstrating alternative source control measures on drainage–problem lands.

Recommendation 6 – Federal and State Programs' Adjustment

The State of California and the U.S. Department of the Interior should jointly consider the findings, forecasts, and plans of the Drainage Program with respect to drainage problems, and should look for opportunities to encourage amelioration and resolution of these problems. This should be achieved through ongoing operations, planning, construction, and — if considered necessary — new legislation, promulgation of rules and regulations, and appropriate language in contracts and administrative reviews.

Recommendation 7 – Western U.S. Applications

The U.S. Department of the Interior should consider the information, techniques, and experience accumulated in the Drainage Program and extend appropriate aspects of the knowledge base to other land areas in the western United States that are experiencing similar agricultural drainage and drainage-related problems.

Planning

The general plan for reducing or solving drainage and drainage-related problems outlined in this report provides a framework into which many actions can be fitted. However, before many of the actions can move forward, additional work is needed to refine estimates of their scope and effects. Generally, this additional planning will occur at local, State, and Federal levels, and at combinations of each.

Recommendation 1 – Water District Plans

With financial and technical assistance from State and Federal agencies, water districts should lead in developing plans to:

- Identify lands in drainage problem areas in which the combined characteristics of high concentrations of selenium and difficult-to-drain soils would make these lands candidates for retirement from irrigation.
- Identify locations in drainage problem areas where there may be an opportunity to lower the high water table by pumping from deep in the semiconfined aquifer (above the Corcoran Clay), and design the facilities, reach agreements, and obtain policy approvals required to carry out pumping.

Recommendation 2 – State Water Project Area

Within the State Water Project service area, the State of California should lead in planning for the regional drainage-water treatment and disposal needs that will arise from management and reuse of drainage water within local water districts.

Recommendation 3 – Federal Water Service Area

Within the Federal water service area, the Department of the Interior should lead in planning for the regional drainage-water treatment and disposal needs that will arise from management and reuse of drainage water within local water districts.

Recommendation 4 – Joint Planning for Ground-Water Management

Plans for installation and operation of well fields designed to pump from the semiconfined aquifer to lower the high water table should be completed cooperatively by Federal and State agencies and water districts. In the Federal service area, the Bureau of Reclamation should work with Westlands, Broadview, Panoche, San Luis, and Firebaugh Canal water districts to design well fields for areas identified in this report. In the State service area, the Department of Water Resources should work with Kern County Water Agency and Empire Westside, Riverside, Stratford, and Laguna irrigation districts, Lakeside Irrigation Water District, Kings County Water District, and Kings River Conservation District for the same purpose. Services of the U.S. Geological Survey should be used in locating favorable areas and in developing plans.

Recommendation 5 – Joint Planning for Water Delivery

Federal and State fish and wildlife agencies, in cooperation with private wetland owners, and Federal and State water development agencies should jointly plan the facilities required for delivery of water to wildlife areas affected by subsurface drainage water.

Monitoring

To properly implement management of drainage and drainage-related problems, both the problems and the progress in solving them must be monitored. This is especially important because of the changing nature of the drainage problem and the flexible array of measures required for management. Monitoring all aspects of the problem and the effects of management will be critical to using the plan as a flexible guide to remedial actions.

Recommendation 1 – Local Water Agencies

All local water supply and drainage agencies should participate in joint, coordinated programs to monitor the volume and quality of drainage water in the collection, treatment, and/or disposal systems.

Recommendation 2 – Joint State/Federal

The U.S. Department of the Interior and the State of California should jointly design a scientifically reliable and cost-effective network of physical and biological monitoring stations that will detect change in the environment caused by subsurface agricultural drainage problems and attempts to solve these problems. Areas expected to experience expansion of high water tables should be included.

Additional Study

During the six-year life of the Drainage Program, the absence of reliable information made it necessary for the Program to fund basic research, as well as to fund investigations directly relevant to solving drainage problems. Some additional study is needed to provide detailed information for feasibility determinations.

Recommendation 1 – Study Needs

Water and land managers, universities, agencies, and individuals should emphasize the following study categories and subjects, and support the development of information transfer programs to extend study results to appropriate user groups.

Drainage Management

- Develop measures to renovate or close aged or toxic evaporation ponds.
- Develop a cost-effective treatment method to remove selenium from drainage water.
- Perform field tests of tolerance of agricultural crops, halophytes, and salt-tolerant trees to constituents in drainage water.
- Develop effective training programs for personnel involved in drainage management.
- Investigate the propagation and marketing of salt-tolerant crops that use saline drainage water as an irrigation supply.
- Demonstrate the use of an accelerated evaporation system, using a sprinkler system similar to the University of Texas at El Paso's experimental system and the use of a temperature-gradient solar pond system for salt disposal and generation of electricity.

Geohydrology

The following studies are interrelated by the nature of the geohydrologic system. The objective is to better understand the surface- and ground-water system's chemical and physical characteristics that will allow better management of the natural resources.

- Evaluate, in detail, the areal and vertical variability of ground-water quality in the Tulare Subarea and in all water-quality zones considered for the ground-water management component in the plan.
- Investigate solubility controls for specific elements of concern (selenium, arsenic, molybdenum, and uranium) in various geologic conditions. Specifically, expand studies to include basin and lacustrine environments that dominate the Tulare Basin where drain water disposal options are severely limited and conditions are highly varied.

- Develop reliable, consistent methods for estimating ground water pumping.
- Complete investigation of surface water and ground water interaction in the San Joaquin River so that the quantity, quality and timing of ground-water contributions to river flows can be evaluated.
- Complete development of a streamflow and solute transport model for the San Joaquin River and couple it with reservoir operations models so that management alternatives can be evaluated.
- Determine the capacity of geochemically reduced Sierra Nevada sediments to remove selenium.
- Determine the hydraulic and water-quality feasibility of controlling the water table by pumping from wells in selected areas.
- Continue development of quantitative analyses of ground water flow systems.

Economics

- Use the surface and subsurface conjunctive-use model of the San Joaquin Valley (as developed for the Drainage Program) to evaluate water transfers and marketing scenarios.

Fish and Wildlife

Contamination. Continue the effort initiated by the Program to determine the nature, geographic extent, and severity of contamination of fish, wildlife, and their habitats by subsurface drainage water. Special attention should be given to: evaporation ponds and neighboring public and private wildlife areas; agroforestry plantations; the San Joaquin River, Delta, and San Francisco Bay; and the six substances of concern discussed in this report (arsenic, boron, chromium, molybdenum, selenium, and total dissolved solids) and ten additional trace elements and metals: cadmium, copper, lithium, manganese, mercury, nickel, strontium, uranium, vanadium, and zinc.

Toxicity. Continue the effort initiated by the Program to define, for fish and wildlife, safe and toxic concentrations (and associated biological effects) of subsurface drainage water substances of concern in water and food. Special attention should be given to: independent toxicity of trace elements other than arsenic, boron, and selenium (for example, cadmium, chromium, copper, lithium, manganese, mercury, molybdenum, nickel, strontium, total dissolved solids, uranium, vanadium, and zinc); interactive effects of trace elements in drainage water; effects of water chemistry (for example, pH and salinity) on independent and interactive toxicity; and site-specific toxicity (for example, in valley aquatic and wetland habitats, evaporation ponds, and agroforestry plantations).

Protection, restoration, substitute water supply, and improvement. Continue the effort initiated by the Program to identify and evaluate measures to: protect remaining fish and wildlife resources of the San Joaquin Valley from drainage-related impacts; restore drainage water contaminated habitats; provide water supplies to substitute for drainage water previously used by fish and wildlife; and improve fish and wildlife resources.

Out-of-valley drainage water disposal. In the event that out-of-valley disposal is pursued in the future, develop information to assess the potential effects on fish and wildlife habitats and populations, and public uses of those resources in the receiving waters and lands. In light of recommendations for consideration of disposal in these areas, special attention should be given to the Sacramento–San Joaquin Delta, San Francisco Bay, and the Pacific Ocean (CVRWQCB, 1988a; NRC, 1989).

Public Health

To adequately quantify the risks of environmental chemical exposures, substantial information is necessary on the environmental fate of the chemicals, the toxicity of specific forms, and the degree to which humans are exposed to them. Although site- and organism-specific data are always preferred, surrogate data are used frequently to fill data gaps (for example, animal studies are extrapolated to assess likely human toxicity resulting from a chemical exposure). The following summarizes information needed to best assess the probability of adverse human health effects related to drainage contaminant exposures.

Environmental fate

- Further identify chemical forms of substances of concern in different environmental media (air, water, soil, sediment, biota).
- Further identify environmental conditions (pH, oxidation-reduction, etc.) in which different chemical forms of substances of concern occur in different environmental media.
- Continue studies conducted by the University of California to assess the uptake of substances of concern into edible biota related to specific environmental conditions.
- Place research emphasis on the environmental fate of substances of concern via typical routes of human exposure (for example, food-chain transfer of organic forms of trace elements).

Toxicology

- Perform additional chronic toxicity testing on specific chemical forms of substances clearly associated with the drainage problem.

Exposure assessment

- Further identify contaminant threshold concentrations in edible animals in tissues used for human consumption.
- Further identify contaminant threshold concentrations in edible plants in tissues used for human consumption.
- Characterize consumption patterns of populations at risk.

Risk quantification

- Quantify option- and site-specific public health risks.

Funding Proposed Actions

There has been no formal discussion or analysis of the way in which components of the plan and the various actions recommended would be funded. Undoubtedly the costs would be shared by the private and public sectors and it is essential that discussion begin soon of distribution of plan costs.

Recommendation 1 – Cost Allocation Principles

The following principles should be considered in discussing allocation of the costs of implementing the plan.

- All areas contributing to a problem of subsurface agricultural drainage water should share in the costs of resolution and management of that problem.
- With respect to contributing areas, the cost-sharing formulas should be based on best available scientific information, and they should be re-evaluated and updated periodically in light of new information.
- Both direct indicators (upslope–downslope hydraulic relationships, for example) and indirect indicators (water supply received, for example) should be considered for inclusion in cost-sharing formulas.
- All beneficiaries should pay for drainage-management costs in proportion to benefits received.
- There are both market and nonmarket national, State, and local benefits to be realized from the management of drainage problems. All beneficiaries should be identified.
- Because of the widespread occurrence of the drainage problem on the western side of the valley and the lack of scientific data on specific sites, costs should be distributed over the largest practicable land area — a whole service area or an association of water districts, for example — rather than one small water district.

Recommendation 2 – Study Plan Benefits

The U.S. Department of the Interior and the State of California should jointly study the benefits of implementation of the plan.

Recommendation 3 – Study Legislative Needs

The State of California should examine the need for new legislation to remove obstacles or to create opportunities for water marketing so that funds from water sales may be used for payment of drainage costs.

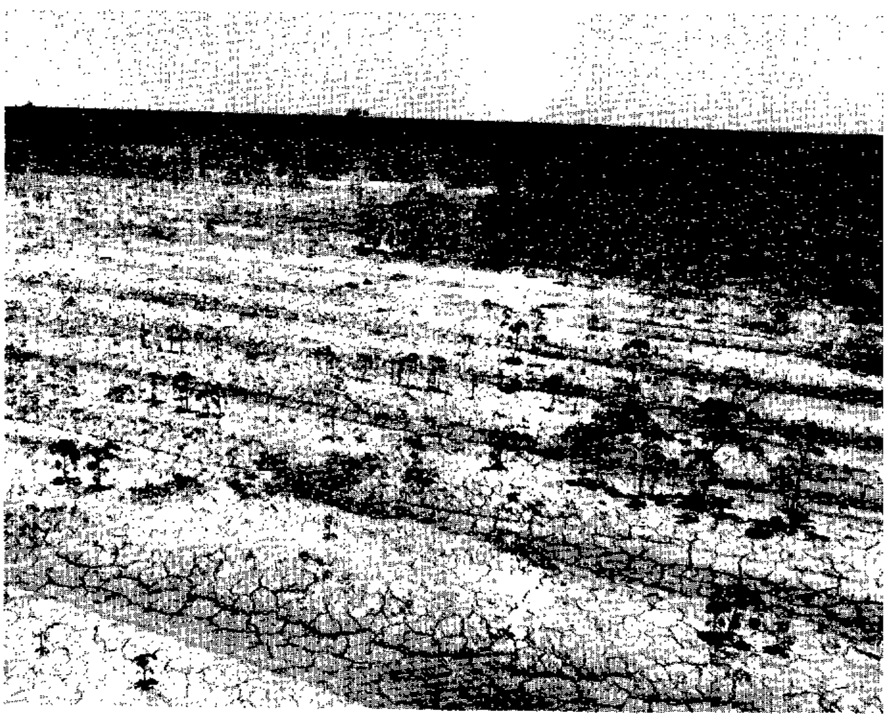
Chapter 2. THE PROBLEM

The San Joaquin Valley, which forms the southern portion of California's Central Valley, is bounded on the east by the Sierra Nevada and on the west by the Coast Ranges (Figure 1). It is made up of two geologic features — the San Joaquin Basin, drained by the San Joaquin River, and the Tulare Basin, a hydrologically closed basin that is is drained by the river only in extremely wet years. The two basins divide the San Joaquin Valley roughly into its northern and southern halves.

The general study area includes the entire San Joaquin Valley, from the drainage divide of the coastal mountains to the 1,000-foot elevation of the Sierra Nevada foothills. The principal study area comprises lands that are now directly affected by or contribute to agricultural subsurface drainage problems, as well as lands likely to be directly affected in the future. Most of these lands are on the western side of the valley and at its southern end.

A BRIEF HISTORY

The conditions associated with agricultural drainage in the San Joaquin Valley are not new to the region. Inadequate drainage and accumulating salts have been persistent problems in parts of the valley for more than a century, making some cultivated land unusable as far



Agricultural land south of Los Banos damaged by salt deposits caused by evaporation from ground water lying only a few feet below the land surface.

back as the 1880s and 1890s (Ogden, 1988). Widespread acreages of grain, first planted on the western side of the valley in the 1870s and 1880s, were irrigated with water from the San Joaquin and Kings rivers. This type of farming spread until, by the 1890s, the rivers' natural flows were no longer adequate to meet the growing agricultural demand for water. Poor natural drainage conditions, coupled with rising ground-water levels and increasing soil salinity, meant that land had to be removed from production and some farms ultimately abandoned.

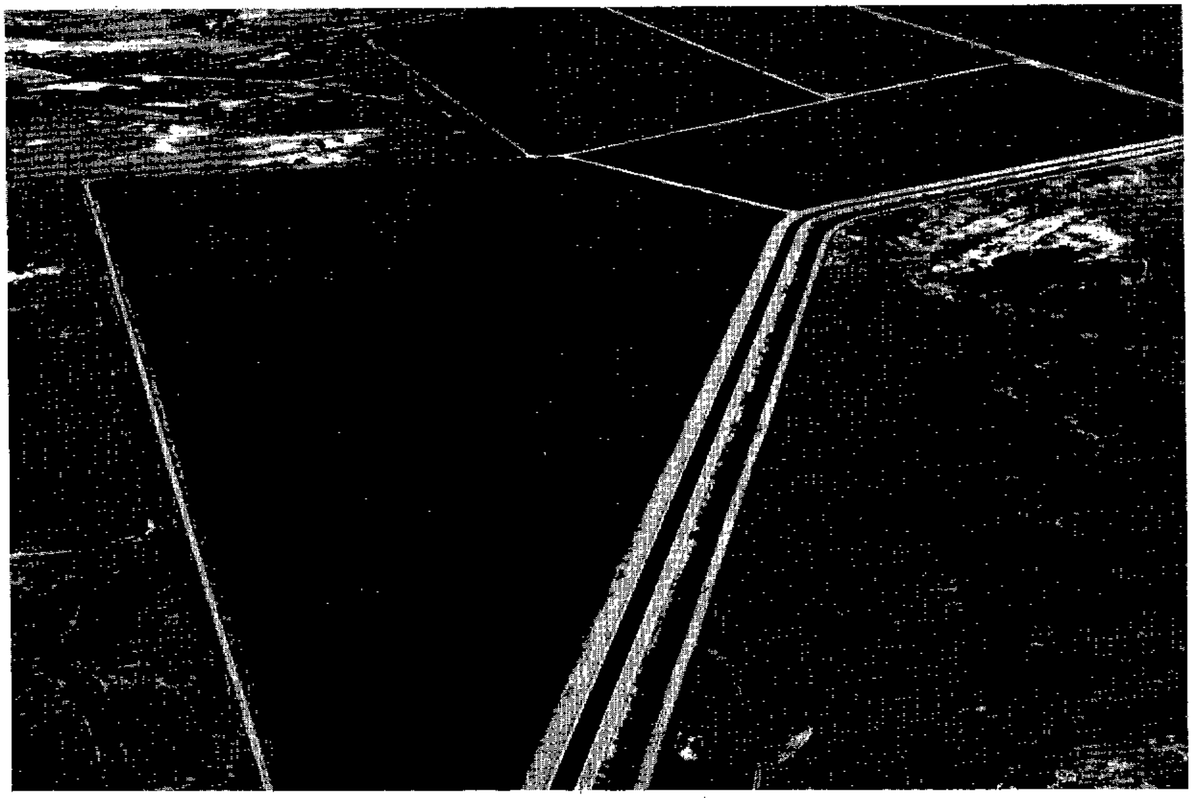
The development of irrigated agriculture in the San Joaquin Valley since 1900 owes a great deal to the improvements in pump technology that took place in the 1930s. These achievements led to the development of large turbine pumps that could lift water hundreds of feet from below ground. In time, heavy pumping triggered severe ground water overdraft because more water was being extracted than was being replaced naturally. Ground water levels and hydraulic pressure fell rapidly, and widespread land subsidence began to occur. By the late 1950s, estimated overdraft in Kern County had reached 750,000 acre-feet per year.

Initial facilities of the Federal Central Valley Project transported water from Northern California through the Sacramento-San Joaquin Delta and the Delta-Mendota Canal in 1951 to irrigate 600,000 acres of land in the northern part of the San Joaquin Valley. This water primarily replaced and supplemented San Joaquin River water that was diverted at Friant Dam to the southern San Joaquin Valley.

The CVP's San Luis Unit and the State Water Project, each authorized in 1960, began delivering Northern California water to agricultural lands in the southern San Joaquin Valley in 1968. Together they provide water to irrigate about 1 million acres. Authorization of the San Luis Unit also mandated construction of an interceptor drain to collect irrigation drainage water from its service area and carry it to the Delta for disposal. The Bureau of Reclamation's 1955 feasibility report for the San Luis Unit described the drain as an earthen ditch that would drain 96,000 acres. By 1962, Reclamation's plans had changed to a concrete-lined canal to drain 300,000 acres. In 1964, alternative plans added a regulating reservoir to temporarily retain drainage (USBR, 1964). A decision was made in the mid-1970s to use the reservoir to store and evaporate drainage water until the drainage canal to the Delta could be completed.

At this same time, questions were raised about the potential effects of untreated agricultural drainage on the quality of water in the Delta and San Francisco Bay. This concern was reflected in a rider added to the CVP appropriations act by Congress in 1965, which stated that ". . . the final point of discharge for the interceptor drain for the San Luis Unit shall not be determined until development by the Secretary of the Interior and the State of California of a plan which shall conform with the water quality standards of the State of California as approved by the Administrator of the Environmental Protection Agency." This proviso remains in effect today.

Initially, the San Luis Drain was conceived as a State/Federal facility, but the State twice declined to participate. The Bureau of Reclamation began construction in 1968 and, by 1975, had completed 85 miles of the main drain, 120 miles of collector drains, and the first phase of the regulating reservoir (Kesterson). In 1970, Kesterson Reservoir became part of a new national wildlife refuge managed jointly by Reclamation and the U.S. Fish and Wildlife Service.



Diked ponds in Kesterson Reservoir fed by the San Luis Drain (open canal in mid-photo) in the early 1980s.

Federal budget constraints and growing environmental concern about releasing irrigation runoff into the Delta halted work on the reservoir and the drain.

In 1975, the Bureau of Reclamation, the California Department of Water Resources, and the State Water Resources Control Board formed the San Joaquin Valley Interagency Drainage Program to find a solution to valley drainage problems that would be economically, environmentally, and politically acceptable. This group's recommendation was to complete the drain to a discharge point in the Delta near Chipps Island (IDP, 1979). In 1981, Reclamation began a special study to fulfill requirements for a discharge permit from the State Water Resources Control Board.

The 1983 discovery of deformities and deaths of aquatic birds at Kesterson Reservoir altered the perception of drainage problems on the western side of the valley. Selenium poisoning was determined to be the probable culprit. In 1984 the San Joaquin Valley Drainage Program was established as a joint Federal and State effort to investigate drainage and drainage-related problems and to identify possible solutions.

In 1985, the Secretary of the Interior ordered that discharge of subsurface drainage to Kesterson be halted, and the feeder drains leading to the San Luis Drain and the reservoir were plugged in 1986. The reservoir is now closed. The vegetation has been plowed under, and low-lying areas were filled in 1988.

Contamination-related problems similar to those identified at Kesterson are now appearing in parts of the Tulare Basin, which receives irrigation water from the State Water Project, in addition to other surface and ground water supplies. Wildlife deformities and deaths have been observed at several agricultural drainage evaporation ponds.

THE AREA OF CONCERN

The chief area of concern in this study is the western side of the San Joaquin Valley from the Sacramento-San Joaquin Delta on the north to the Tehachapi Mountains south of Bakersfield. This area coincides generally with the Federal Delta-Mendota Canal and San Luis Unit irrigation service areas and the State Water Project service area. Figure 2 shows those service areas, the Friant-Kern Service area on the eastern side of the valley, and the general study area boundary. Lands now directly affected by, contributing to, or likely to be directly affected by agricultural drainage problems make up the principal study area shown on Figure 1. To aid planning and analysis, the principal study area has been divided into the Northern, Grasslands, Westlands, Tulare, and Kern subareas. Subarea boundaries are based on hydrologic considerations, political boundaries, current drainage practices, and/or the nature of the drainage-related problems.

The San Joaquin Valley is a gently sloping, nearly unbroken alluvial plain, about 250 miles long and an average of 45 miles wide, that is characterized by a mild, dry climate. The temperate climate, productive soils, and the application of water by farmers have combined to make this one of the world's most productive agricultural areas. Nearly all crops grown commercially in the region require irrigation.

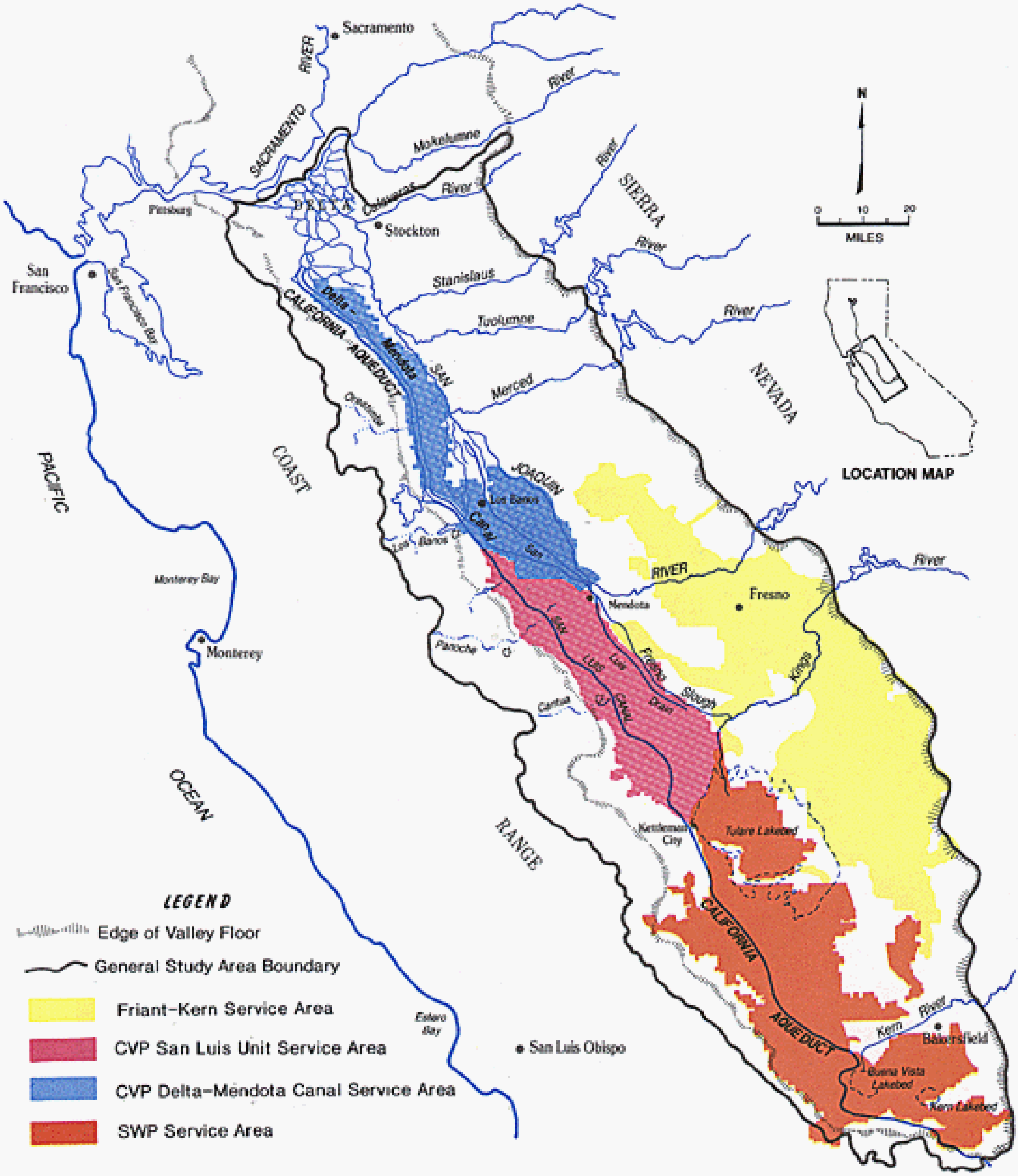
Soils on the western side of the valley are derived from the marine sediments that make up the Coast Range and are high in salts and trace elements that occur in a marine environment. Irrigation of these soils has dissolved these substances and accelerated their movement into the shallow ground water (Gilliom, et al., 1989a). Where water tables are high and agricultural drains are necessary, drainage water frequently contains elevated concentrations of these constituents.

The principal study area includes remnant natural and managed habitats of importance to a diversity of fish and wildlife species. Habitats include the Grasslands area, a large grasslands/wetlands complex in the southern San Joaquin Basin, where for several decades commingled surface and subsurface agricultural drainage water was used for habitat management; the San Joaquin River, into which an estimated 35,000 to 56,000 acre-feet per year of collected subsurface agricultural drainage water is currently discharged; evaporation ponds (primarily in the Tulare Basin), where subsurface drainage water is discharged and concentrated and which are used extensively by aquatic birds; and the beginnings of agroforestry plantations that are watered with subsurface drainage water and used by several terrestrial wildlife species.

The principal study area is predominantly rural. Communities tend to have fewer than 10,000 residents whose main economic existence is tied directly to agriculture. Although the population is sparse, compared to the central and eastern portions of the San Joaquin Valley, demographic shifts are occurring with an influx of people into the Tracy-Los Banos area from the San Francisco Bay region and into the Bakersfield area from the Los Angeles basin. Migrant farm workers also are major contributors to the area's economy and population.

Figure 2

MAJOR FEDERAL AND STATE IRRIGATION FACILITIES AND SERVICE AREAS



INTERESTS AFFECTED BY DRAINAGE PROBLEMS

Agriculture

Agriculture provides the economic base of the western side of the San Joaquin Valley (Archibald, 1990). About 90 percent of the 2,544,000 irrigable acres in the principal study area are in irrigated crop production at any one time. A diverse range of crops is grown there. Fruits and nuts are important in the Northern, Grasslands, and Kern Subareas, while the predominant crops in the Tulare and Westlands Subareas are field crops and cereal grains. Cotton is the leading field crop in both subareas.

Irrigation practices, methods, and efficiencies vary subarea by subarea. In 1980, the predominant method in the San Joaquin Valley was surface irrigation. The methods chosen depend on many factors — types of crops cultivated, cost of water, soil types, and current irrigation and drainage management practices. Farming practices and irrigation efficiencies are influenced by variations in soil type, climate, slope of the terrain, crops grown, and a grower's experience.

If current irrigation practices continue, areas in which ground-water levels are 5 feet or less from the surface of irrigated lands will continue to expand in the Westlands, Tulare, and Kern subareas. Such areas in the Northern and Grasslands subareas are unlikely to increase as long as they can be drained to the San Joaquin River. The total area in the western side at that level now is about 847,000 acres, of which 90,000 acres are managed as wetlands. By

Melons are an important crop in both the Grasslands and Westlands subareas.

2000, high ground-water levels may be adversely affecting about 1 million acres of irrigated land (W.C. Swain, 1990a and 1990b), or about 40 percent of irrigable farmland in the principal study area. This will reduce crop productivity, cause loss of farm income through conversion from salt-sensitive to salt-tolerant crops, increase costs of drainage management, and force land out of production.

Fish and Wildlife

[The following section is supported by information in the Drainage Program's Technical Report, Fish and Wildlife Resources and Agricultural Drainage in the San Joaquin Valley, California, October 1990.*]*

Before settlement of the San Joaquin Valley began in the 19th century, the richly diverse landscape supported large populations of both resident and migratory species of fish and wildlife. Today, most of these aquatic, wetland, riparian forest, and valley oak savannah habitats have been converted to agricultural, municipal, and other uses. Less than 1 percent of the freshwater lakes, only about 7 percent of the riparian forests, and less than 15 percent of the original wetlands remain. As a result, some native plants and animals have vanished from the landscape, and the continued existence of many others is in serious jeopardy. The populations of birds that once lived in or visited the valley as migrants have been greatly reduced, and the grizzly bear, the pronghorn antelope, and the gray wolf have disappeared entirely.

Impoundments on and diversions from the San Joaquin River and its tributaries have dramatically reduced the valley's fisheries. Native fish have declined drastically and introduced species are now dominant. Chinook salmon, once sufficiently abundant to have at least a spring run and a fall run, have been greatly reduced in population.

About 200,000 acres of private and public land and water in the San Joaquin Valley are presently managed as parks, refuges, and preserves, primarily for the benefit of fish and wildlife. These areas, which protect the surviving native habitats, include State and Federal wildlife areas, State fishery facilities, private duck clubs, special management areas, and private nature preserves. Until recently, about half the water supplies used in these areas was provided by agricultural drainage, but use of drainage water for such purposes has been discontinued on almost all wildlife areas because it may endanger the health of fish and wildlife. The location of major public wildlife areas in the San Joaquin Valley is shown in Figure 3.

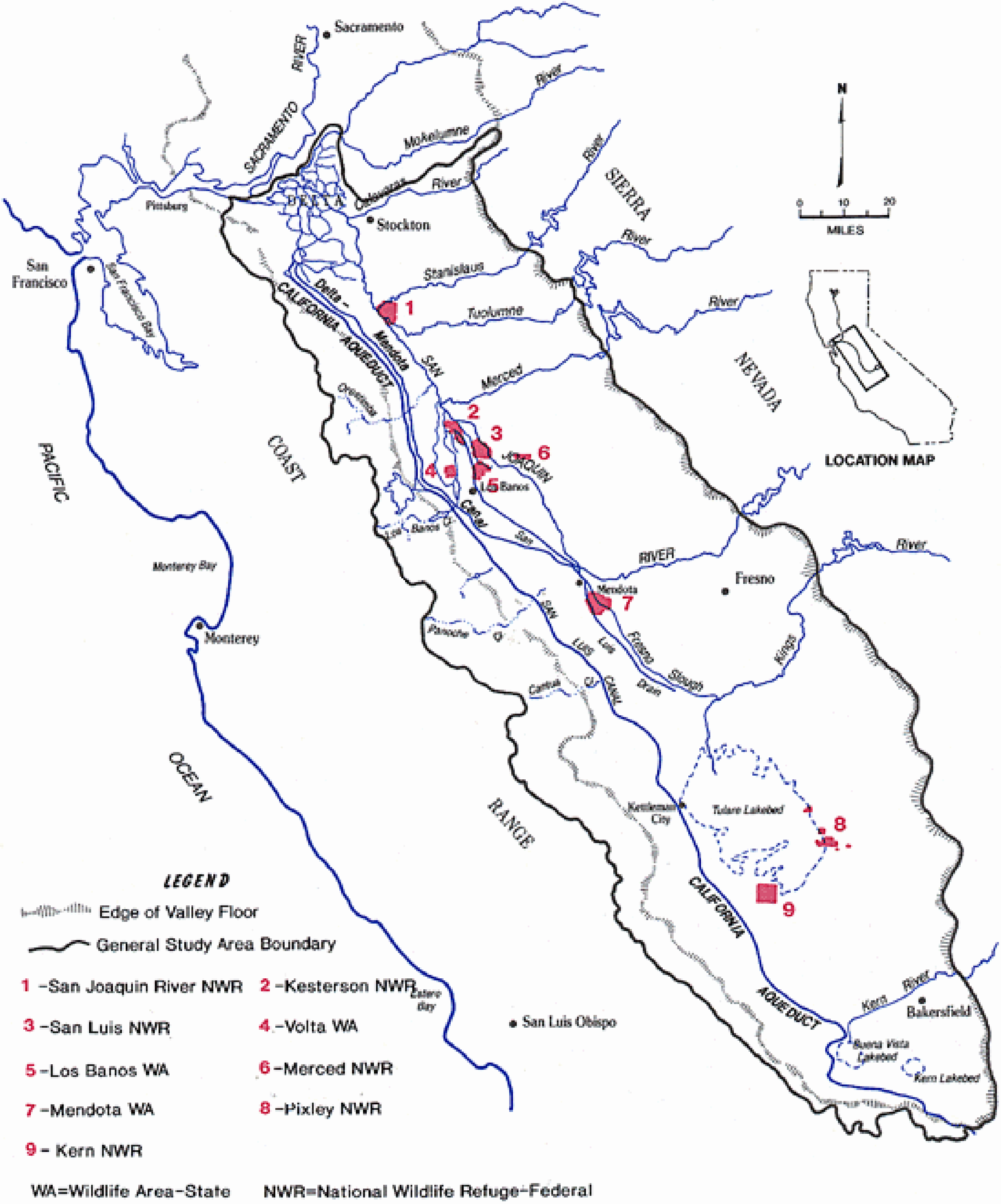
Laboratory research has demonstrated that elevated waterborne and/or dietary concentrations of several trace elements in some San Joaquin Valley drainage waters are toxic to fish and wildlife. Selenium is the most prominent of these; other constituents of concern include arsenic, boron, chromium, molybdenum, and salts.

Water Quality

The State of California, through the State Water Resources Control Board (State Board) and the nine Regional Water Quality Control Boards (Regional Boards), is responsible for protecting the quality of the State's water for beneficial uses. Regulation of deleterious waste discharges into both surface and ground water of the State is their responsibility. The Central Valley Regional Water Quality Control Board has adopted and the State Board has approved objectives for allowable concentrations of selenium, boron, and molybdenum at various sites on the San Joaquin River and tributaries (CVRWQCB, 1988a). [The U.S. Environ-

Figure 3

MAJOR PUBLIC WILDLIFE AREAS IN THE SAN JOAQUIN VALLEY



mental Protection Agency, however, has disapproved certain of the Board's objectives, and the matter is presently unresolved.] State water-quality objectives now and in the future will limit the discharge of agricultural drainage water to be assimilated by these streams. The Regional Boards issue permits for construction and operation of drainage-water evaporation ponds. Since events at Kesterson, the Regional Boards have become more concerned about the operation and eventual closure of these facilities.

Actions proposed by the Drainage Program are consistent with the State's present water-quality objectives. However, concern over the quality of the State's surface and ground water is expected to continue growing and introduction of agricultural drainage water into either body will likely be more strictly regulated in the future. In anticipation of these developments and in view of new scientific findings, assumptions based on more stringent objectives have been included in the alternative plans in Chapter 5 to show changes in required actions and associated costs.

Public Health

For the most part, contaminated agricultural drainage water is most likely to harm humans through indirect contact, such as consumption of contaminated fish or wildlife, plants, or livestock (Klasing and Pilch, 1988). Hazards intensify when contaminants are bioconcentrated by plants and animals or by evaporation, as in evaporation ponds. Direct dermal contact with drainage water contaminants studied to date is unlikely to pose significant health risks; however, inhalation of some particulate sediments (chromium, nickel, and silica, for example) has been shown to cause adverse health effects under some conditions.

Public health effects have been considered during this study, and plans were based on a criterion to minimize potential adverse public health risks from any drainage-water management strategy. Conclusions from studies of various potentially harmful constituents of drainage water as public health risks are presented in Chapter 3.

Chapter 3. WHAT THE STUDY HAS REVEALED OR CONFIRMED

When the San Joaquin Valley Drainage Program was initiated in late 1984, there were many questions and conflicting opinions about westside San Joaquin Valley drainage and drainage-related problems. Through Program-supported studies from 1985 to 1990, some questions have been answered, some myths discredited, and some controversy resolved; but other questions and issues remain. The drainage problem was a long time developing. It will likely be solved only through the diligence and cooperation of many individuals and organizations over a considerable period. Further study will undoubtedly be essential to these efforts.

A common base of knowledge is paramount to understanding the causes and for developing potential solutions to drainage problems. This chapter describes major advancements in knowledge of various aspects of the drainage problem.

GEOHYDROLOGY

Understanding the geologic makeup and hydrologic characteristics of the study area is necessary to understanding the cause of the drainage problem.

Geology

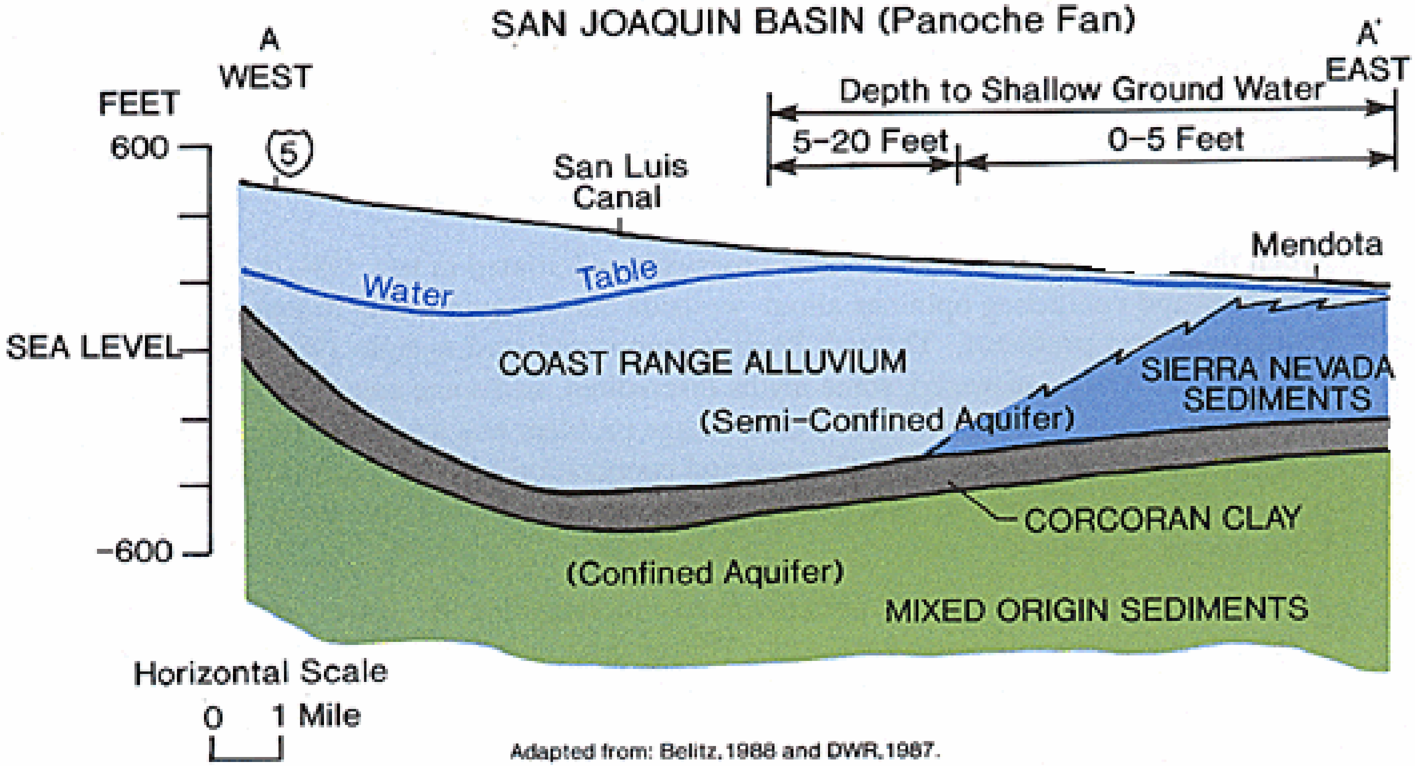
The Corcoran Clay, a clay layer 20 to 200 feet thick that underlies all but a small part of the study area, was formed as a lakebed about 600,000 years ago and is an important geologic feature of the San Joaquin Valley (Figure 4). Lying as much as 850 feet deep along the Coast Ranges and 200 to 500 feet deep in the valley trough, the Corcoran Clay effectively divides the ground-water system into two major aquifers — a confined aquifer below it and a semiconfined aquifer above it (Page, 1986).

In the San Joaquin Basin, the semiconfined aquifer can be divided into three geohydrologic units, based on the sources of the soils and sediments. These are Coast Range alluvium, Sierra Nevada sediments, and flood-basin deposits. The Coast Range alluvial deposits, which range in thickness from 850 feet along the slopes of the Coast Range to a few feet along the valley trough, were derived largely from the erosion of marine rocks that form the Coast Ranges and contain abundant salt. Some of the marine sediments contain elevated concentrations of selenium and other trace elements. The Sierra Nevada sediments on the eastern side of the valley generally do not contain elevated selenium concentrations. The flood-basin deposits are a relatively thin layer in areas of the valley trough that have been created in recent geologic time. These three geohydrologic units differ in texture, hydrologic properties, chemical characteristics, and oxidation state.

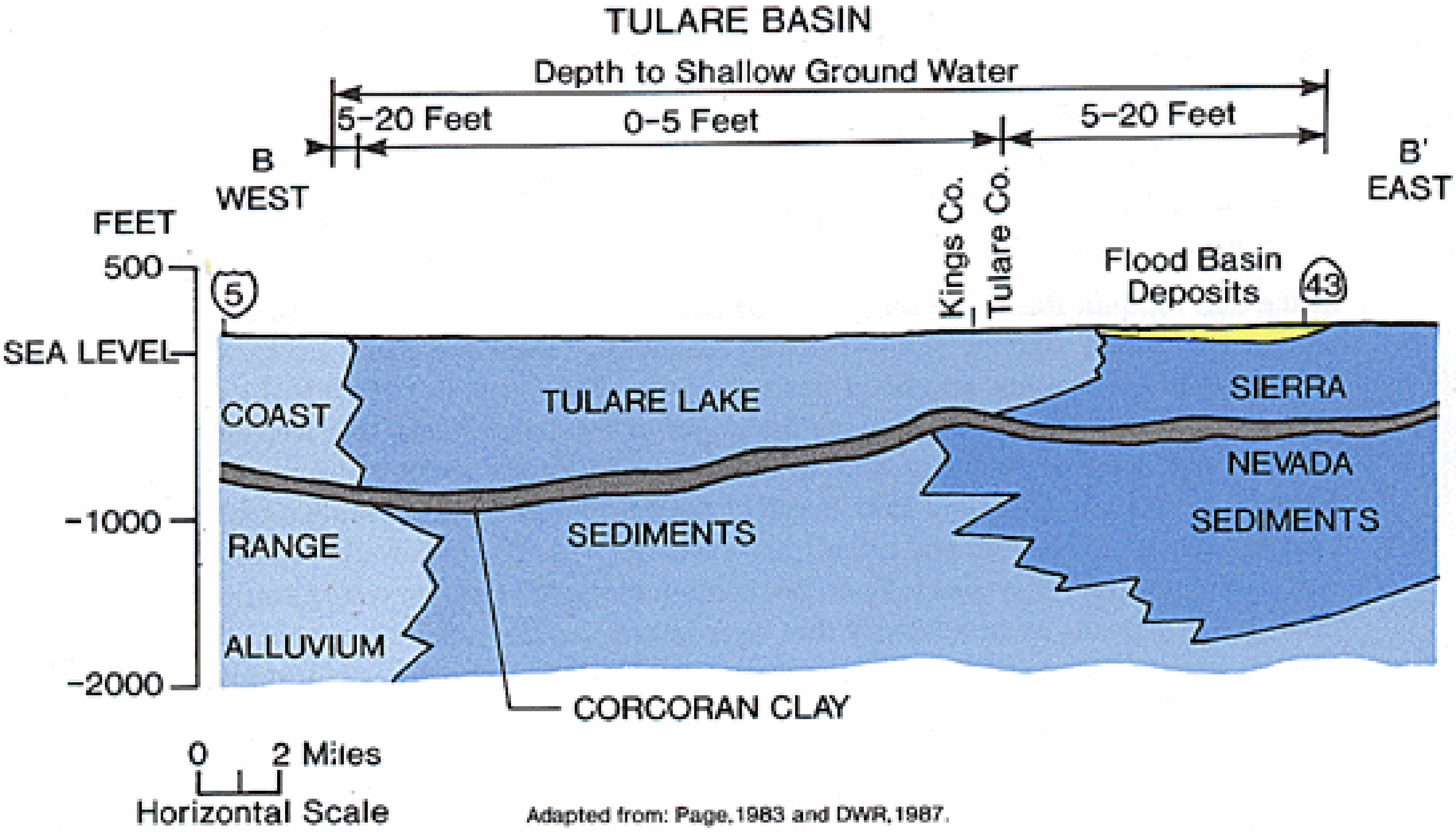
Figure 4

GENERALIZED GEOHYDROLOGICAL CROSS-SECTIONS IN THE SAN JOAQUIN AND TULARE BASINS

(Locations Shown in Figure 6)



Adapted from: Belitz, 1988 and DWR, 1987.



Adapted from: Page, 1983 and DWR, 1987.

In the Tulare Basin, the semiconfined aquifer consists of the same three geohydrologic units found in the San Joaquin Basin, plus one additional unit, Tulare Lake sediments. The Tulare Basin is characterized by the presence of several dry lakebeds, including Tulare, Buena Vista, and Kern.

The marine sediments from which most soils in the study area are derived contain salts and potentially toxic trace elements, such as arsenic, boron, molybdenum, and selenium. When these soils are irrigated, the substances dissolve and leach into the shallow ground water (Gilliom, et al., 1989a). Selenium is largely a westside phenomenon. Soils derived from Coast Range sediments are generally far saltier than soils formed from Sierran sediments. In fact, selenium in livestock feed grown in some areas of the eastern side of the valley is so low that it must be added to the livestock diet. Figure 5 shows selenium in the top 12 inches of soil, as determined by a survey in the mid-1980s. Most soluble selenium has been leached from the soils over the past 30 to 40 years, and it now occurs in solution in the shallow ground water. It is drained from there when growers attempt to protect crop roots from salts and a high water table. Generally, growers need not be concerned about protecting crops from selenium.

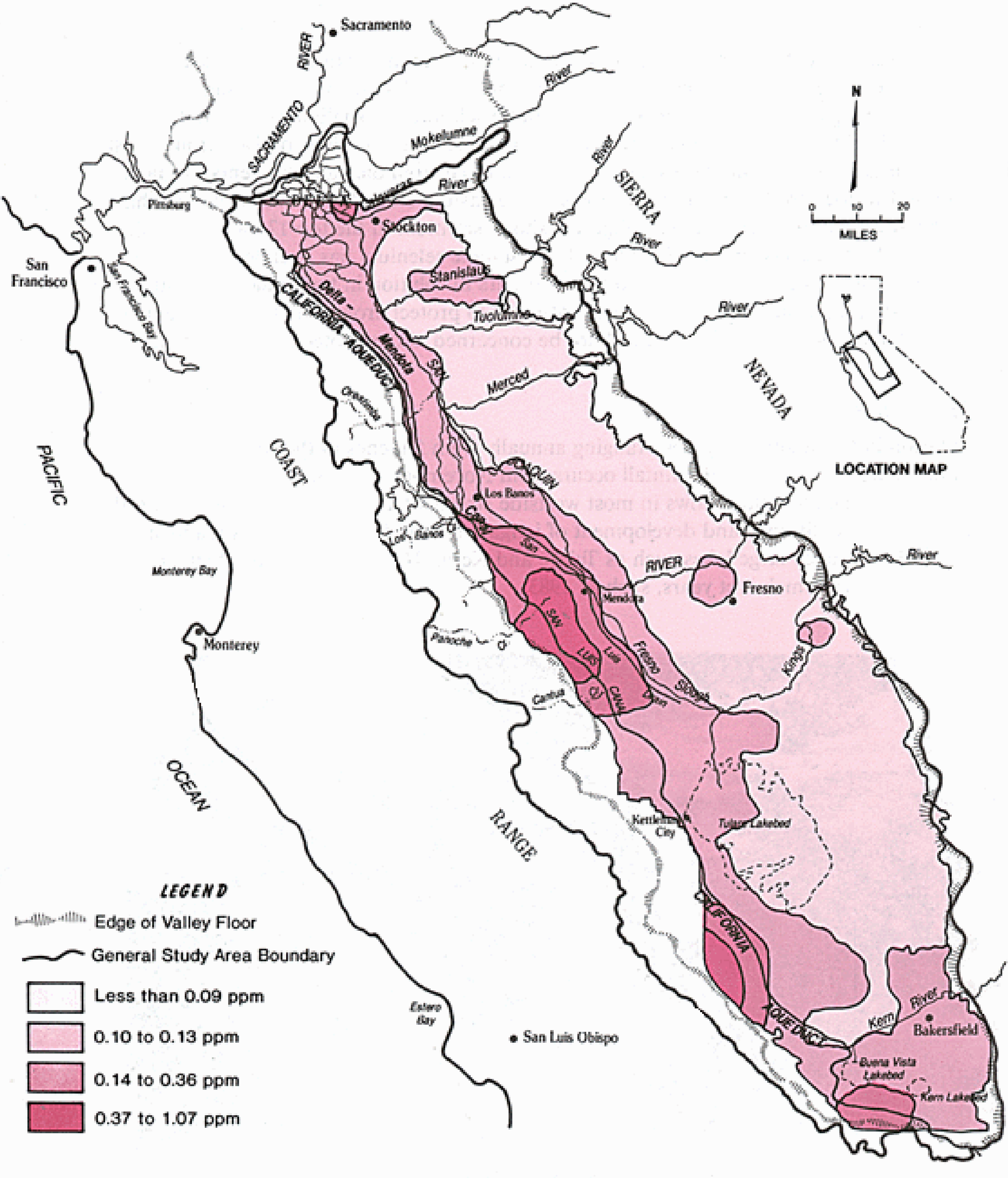
Surface Water

Precipitation in the study area is low, ranging annually from 5 inches in the south to 10 inches in the north. Virtually all rainfall occurs from November through April, and, by midsummer, the small natural flows in most westside streams have ended or dwindled to little more than trickles. Storage and development of irrigation facilities on eastside streams have reduced inflow to once-large lakes such as Tulare and Kern. Now water reaches their dry lakebeds only in extremely wet years, such as 1983.

Natural vegetation growing on the westside San Joaquin Valley without irrigation.

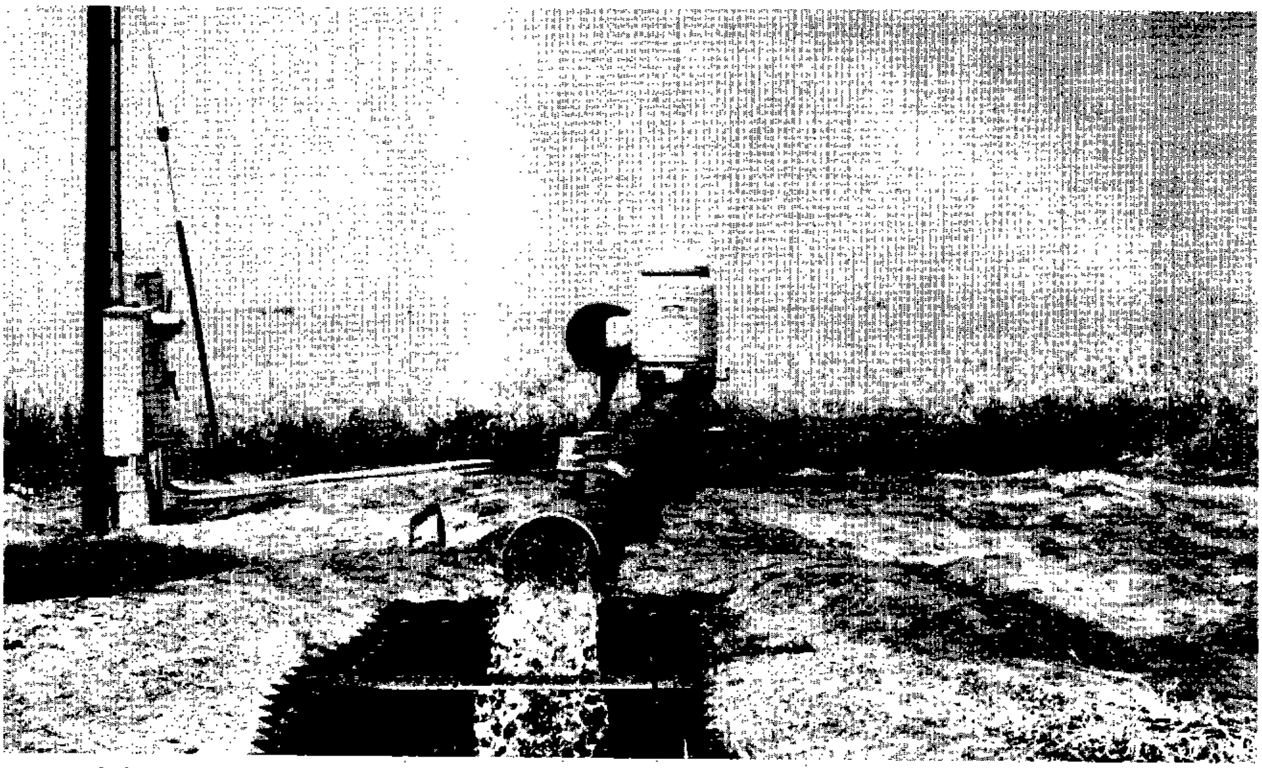
Figure 5

SELENIUM CONCENTRATIONS IN SOILS
(Total Selenium in Top 12 Inches of Soil)



Adapted from Tidball et. al., 1986

The San Joaquin River and its major westside tributaries, Salt Slough and Mud Slough, are important to the study area because they convey drainage water away from the Northern and Grasslands subareas. San Joaquin River flows are controlled by dams on tributaries and on the main stem upstream from Fresno. Water stored in Millerton Reservoir is diverted through the Friant-Kern and Madera canals. Irrigation water historically diverted from the lower reaches of the San Joaquin River was replaced with Central Valley Project water provided through the Delta-Mendota Canal, beginning in 1951. Now, the San Joaquin River is essentially dry much of the year from below Gravelly Ford to the point at which irrigation return flow and local runoff replenish the river. Development on major eastside tributaries has also reduced the flow of the San Joaquin River. The combination of these actions causes problems in water quantity and quality, both for fish and for other downstream river users, especially in the South Delta area.



Irrigation water is still pumped from both above and below the Corcoran Clay, especially during drought periods when surface water supplies are short.

Ground Water

Pumping of ground water for irrigation from 1920 to 1950 drew ground-water levels down as much as 200 feet in large portions of the study area (Belitz, 1988). High pumping costs, land subsidence, and declining water quality created a need for new water supplies. By 1951, Federal Central Valley Project water was being pumped from the Delta and delivered to the Northern and Grasslands subareas through the Delta-Mendota Canal. By 1968, water was being delivered to the Westlands, Tulare, and Kern subareas through facilities of the CVP's San Luis Unit and the State Water Project.

With a reliable supply of surface water, ground-water pumping for irrigation lessened and the ground-water reservoir gradually began to refill. The semiconfined aquifer above the Corcoran Clay is now fully saturated in much of the westside area. Water tables continue to rise, and the waterlogged area is expanding. During the period 1977-1987, the 0-to-5-foot area expanded from 533,000 acres to 817,000 acres (W.C. Swain, 1990a). Figure 6 shows areas in which the water table was less than 5 feet deep, 5 to 10 feet deep, and 10 to 20 feet deep during part of 1987.

Irrigation-induced leaching of the soil and accumulation of salts from both the leaching and from imported water have concentrated dissolved salts in the upper portion of the semiconfined aquifer. Most of these salts are now located in a zone 20 to 150 feet below the ground surface (DuBrovsky and Neil, 1990). Ground-water quality is generally better above and below this zone. Figures 7 through 11 show concentrations of salinity, selenium, boron, molybdenum, and arsenic in shallow ground water (less than 20 feet below the land surface). This shallow ground water, and, in some places, water located even deeper, is the source of subsurface drainage water.

There are still zones in the semiconfined aquifer above the Corcoran Clay in which ground water is present in quality and quantity suitable for irrigation. Figure 12 shows the location of zones with salinity less than 1,250 parts per million (ppm) for several aquifer thicknesses saturated with water of that quality. The map was prepared by using a geographic information system and combining and evaluating water quality data and well construction information for the study area, as obtained from the U.S. Geological Survey, the U.S. Bureau of Reclamation, the Department of Water Resources, the Central Valley Regional Water Quality Control Board, and local water agencies. The procedures used were designed to produce a conservative estimate of the total depth of ground water that meets the specific water quality criterion of 1,250 parts per million total dissolved solids. Lenses of good quality water (less than 1,250 ppm TDS) overlying poor quality water (more than 1,250 ppm TDS) were not included in the total depth calculations. In some areas, notably in the southern Westlands Subarea, data from studies conducted in the 1960s were used in the absence of more recent data. Elsewhere, data from 1970 to 1989 predominated (Quinn, 1990).

DRAINAGE-WATER CONSTITUENTS

Salinity

Drainage water contains dissolved mineral substances often referred to as "salts." These salts include sulfates, chlorides, carbonates, and bicarbonates of the elements sodium, calcium, magnesium, and potassium. The term "salinity" refers to the salt content of solutions containing dissolved mineral salts, which is commonly measured as either total dissolved solids (TDS) in parts per million (ppm) or electrical conductivity (EC) in microsiemens per centimeter (μS/cm). There are three sources of salts in the study area: (1) Water imported from the Sacramento-San Joaquin Delta; (2) soils; and (3) ground water. The imported water is of generally good quality; that is, its average salinity is less than 350 ppm. But because of the large volume of such water, about 1,600,000 tons[1] of salts are imported per year (D.G. Swain, 1990).

1 Calculated by: Firm water supply imported annually (3,400,000 acre-feet) x salinity (350 ppm TDS) x conversion factor (0.00136) = 1,620,000 tons.

Figure 6

AREAS OF SHALLOW GROUND WATER 1987

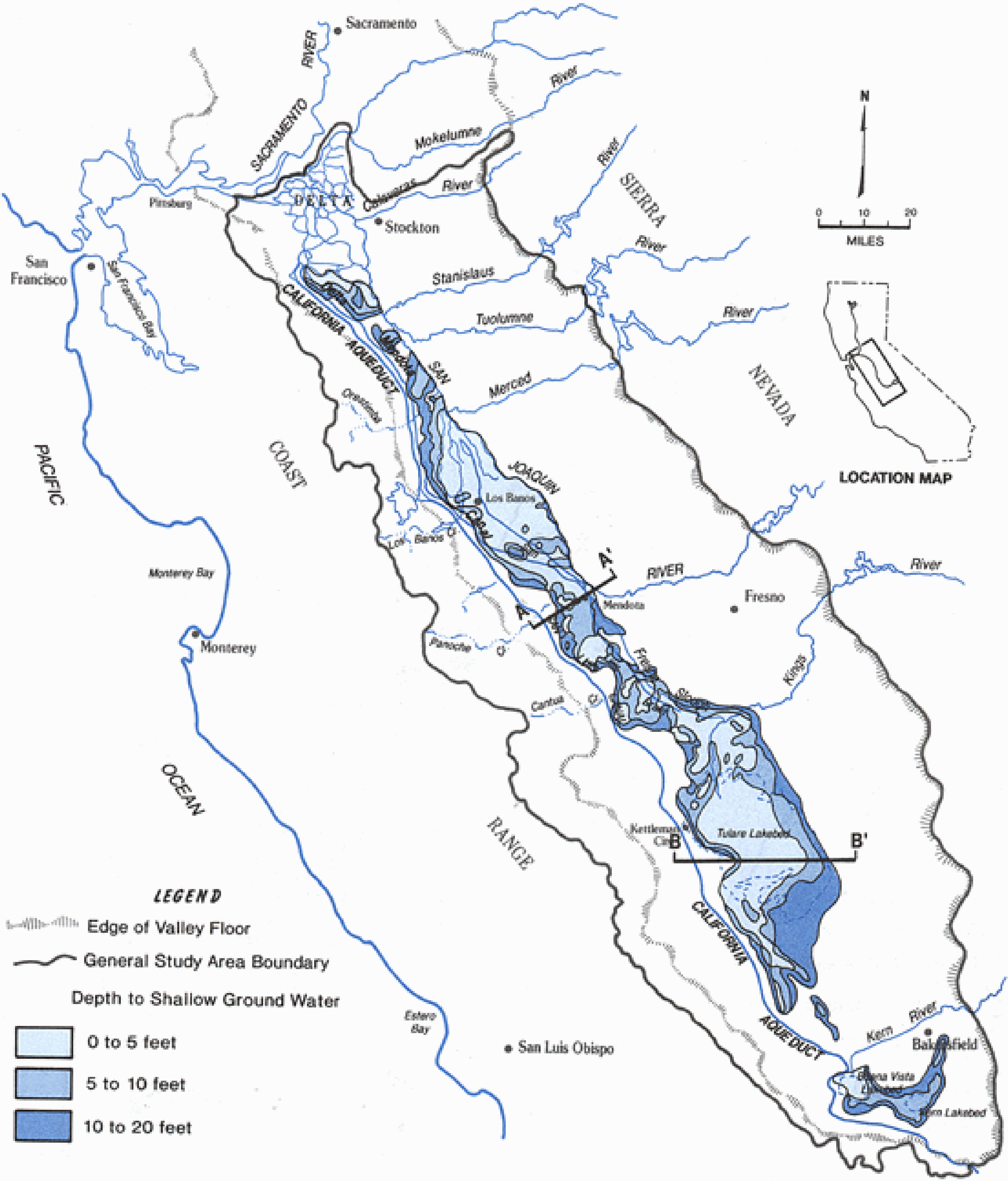


Figure 7

SALINITY IN SHALLOW GROUND WATER
Sampled between 1984 and 1989

(Measured as Electrical Conductivity in microsiemens per centimeter [µS/cm]).

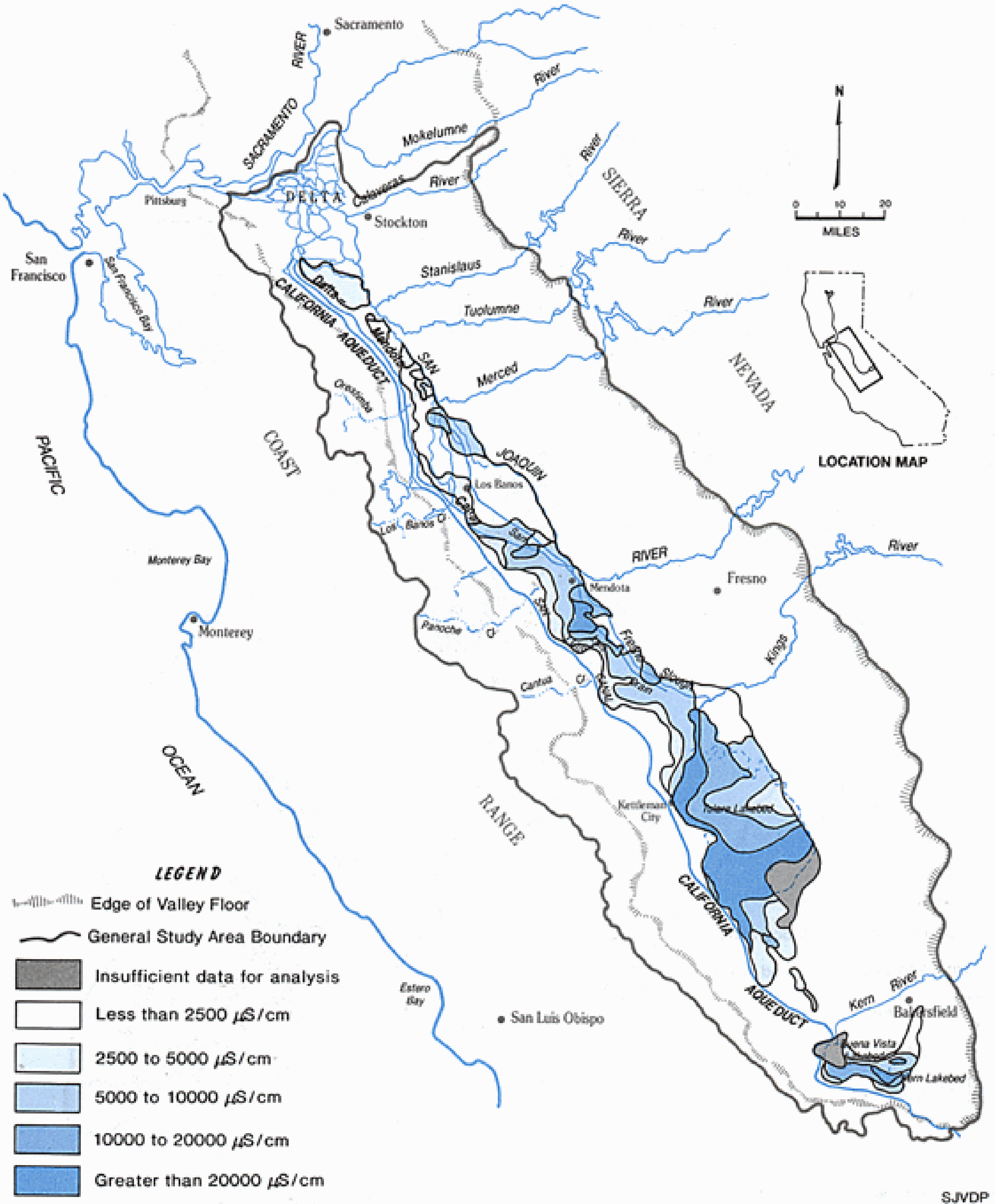


Figure 8

SELENIUM CONCENTRATIONS IN SHALLOW GROUND WATER
Sampled between 1984 and 1989

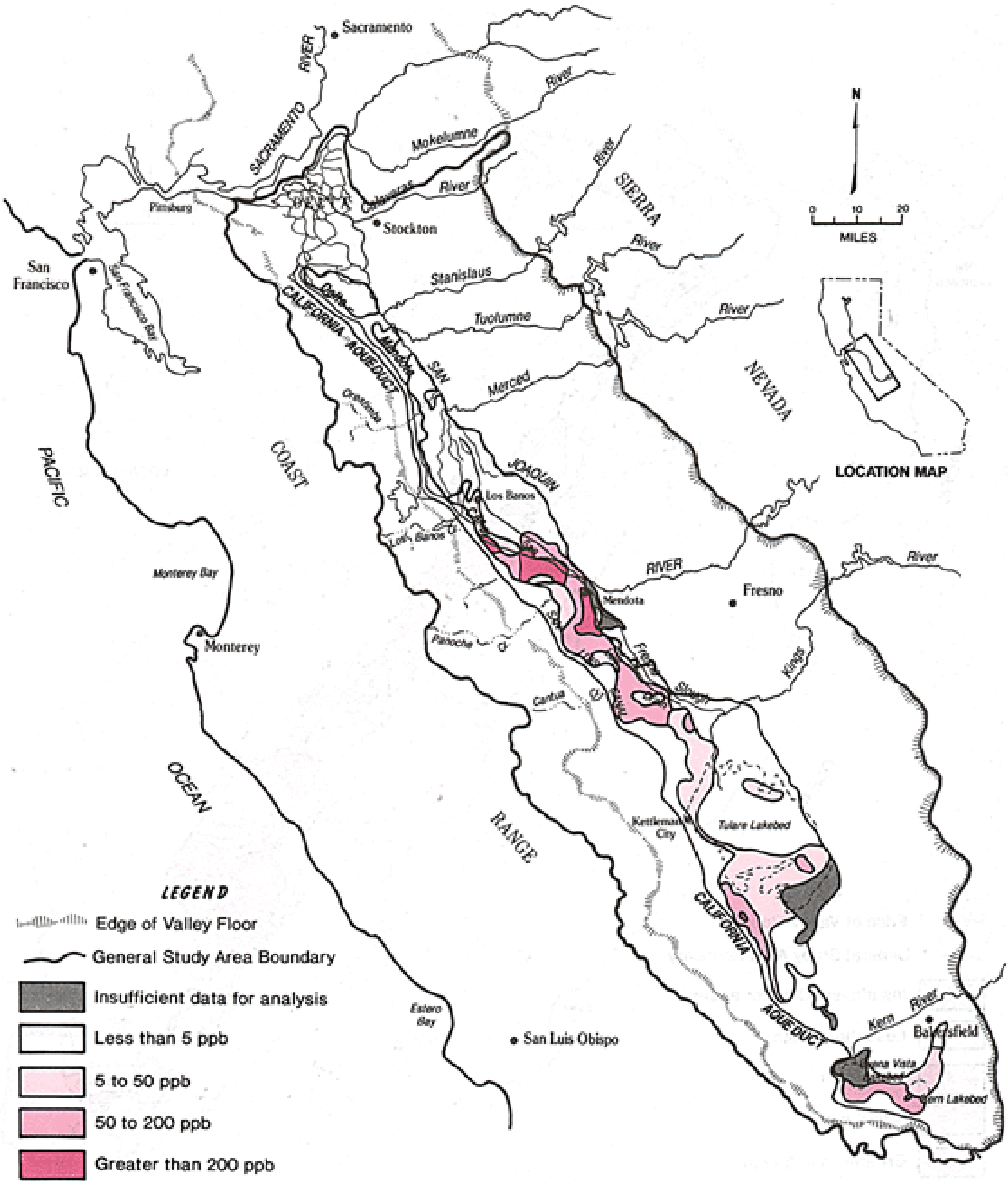


Figure 9

BORON CONCENTRATIONS IN SHALLOW GROUND WATER
Sampled between 1984 and 1989

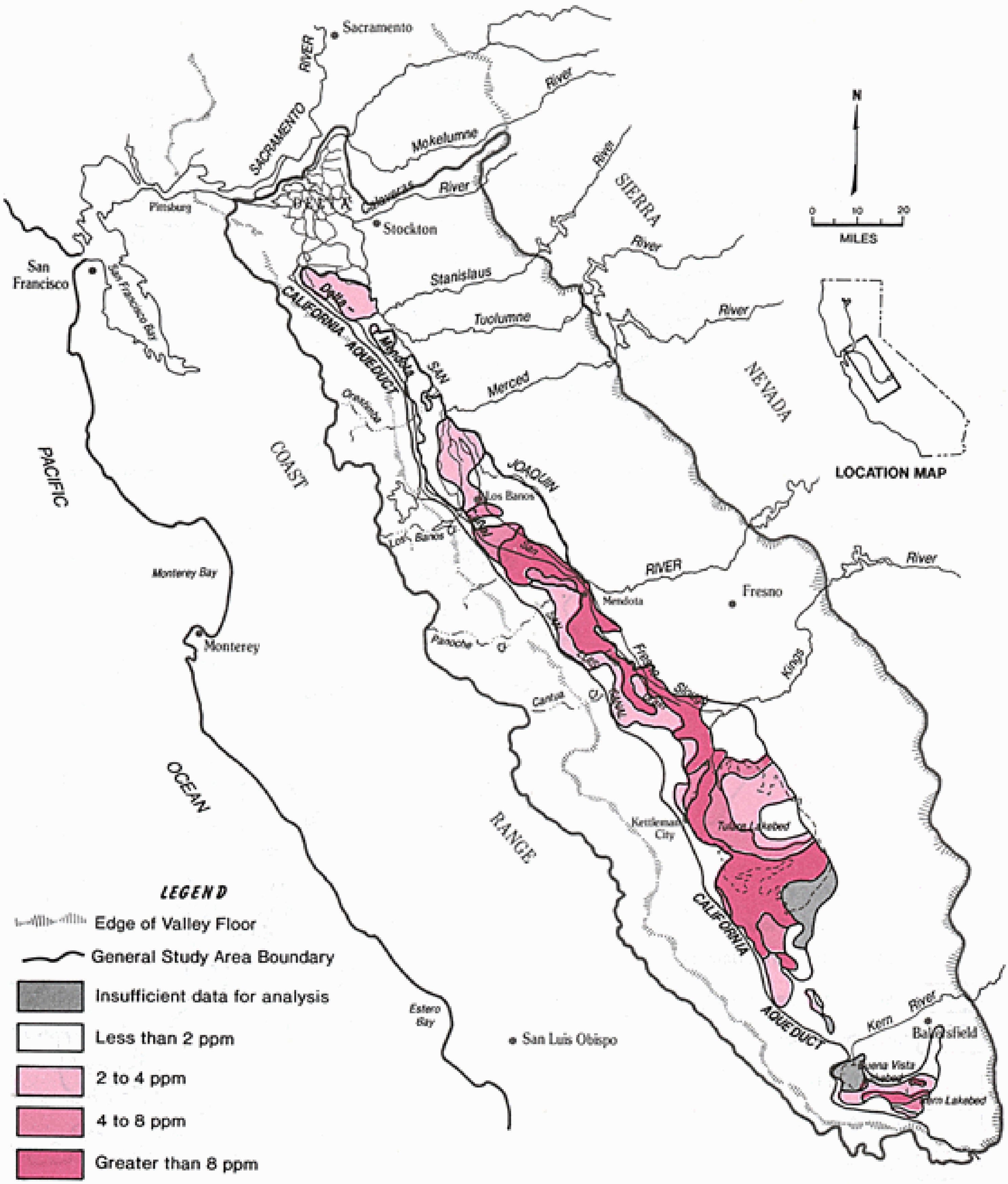


Figure 10

MOLYBDENUM CONCENTRATIONS IN SHALLOW GROUND WATER
Sampled between 1984 and 1989

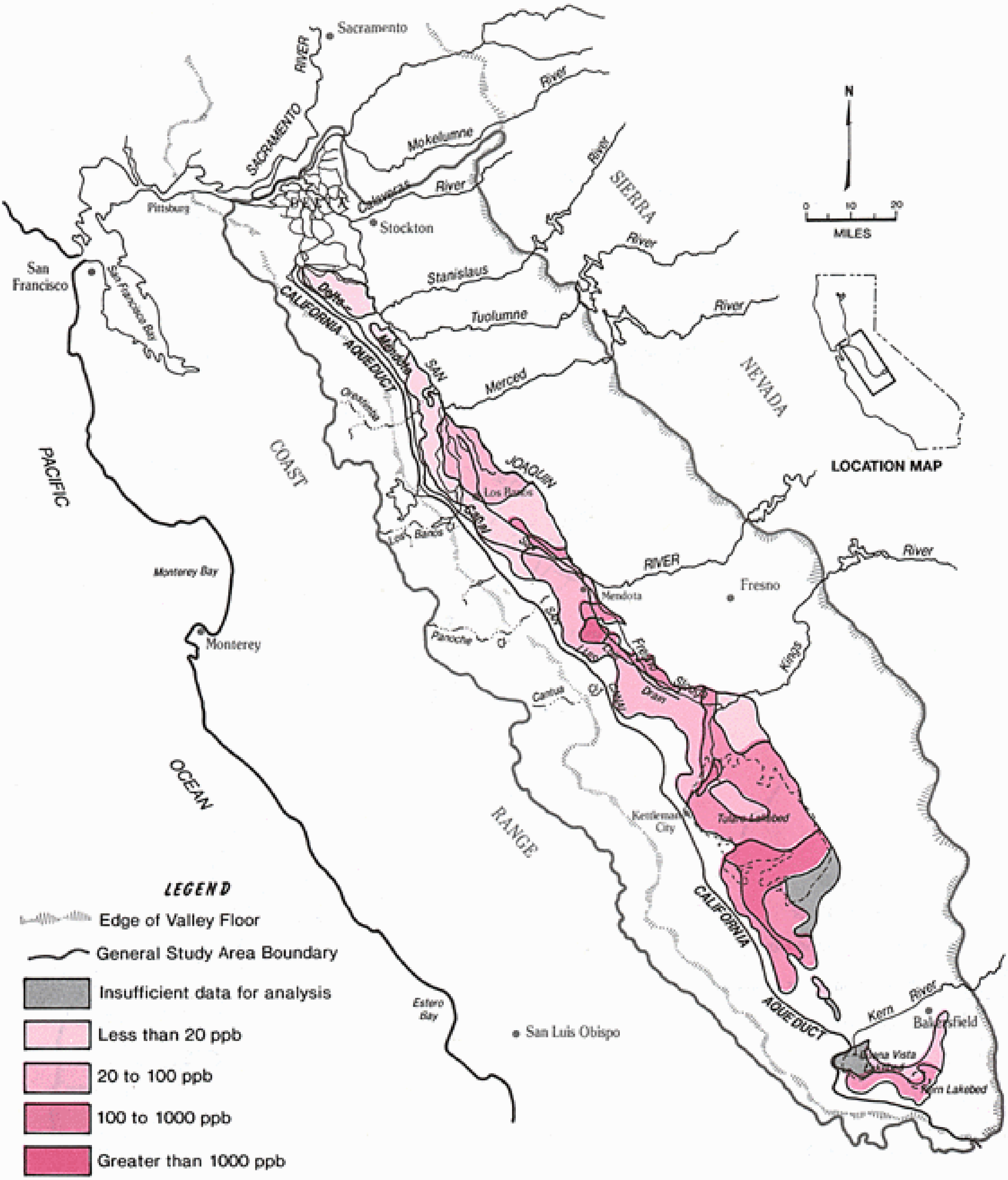


Figure 11

ARSENIC CONCENTRATIONS IN SHALLOW GROUND WATER
Sampled between 1984 and 1989

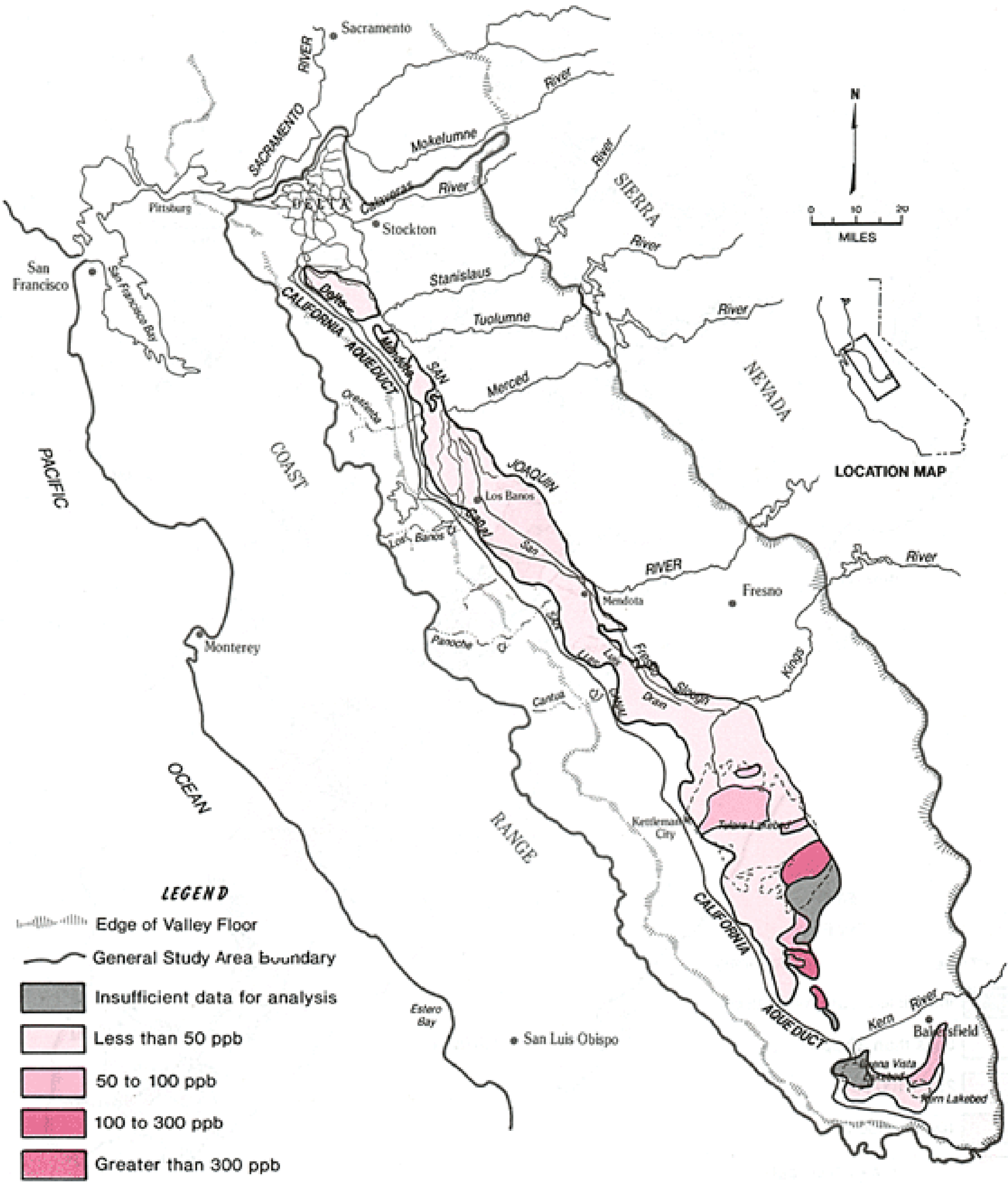
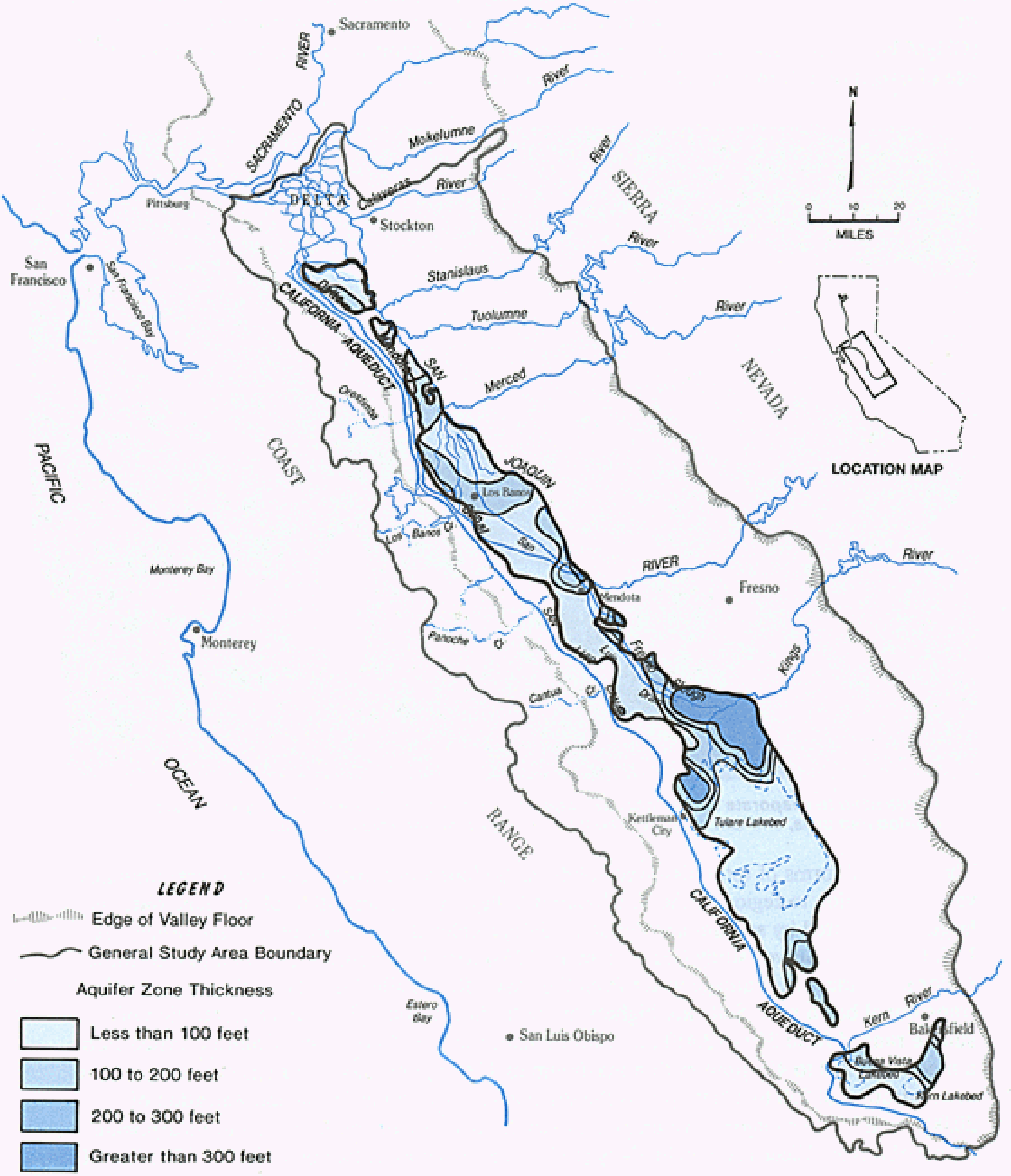
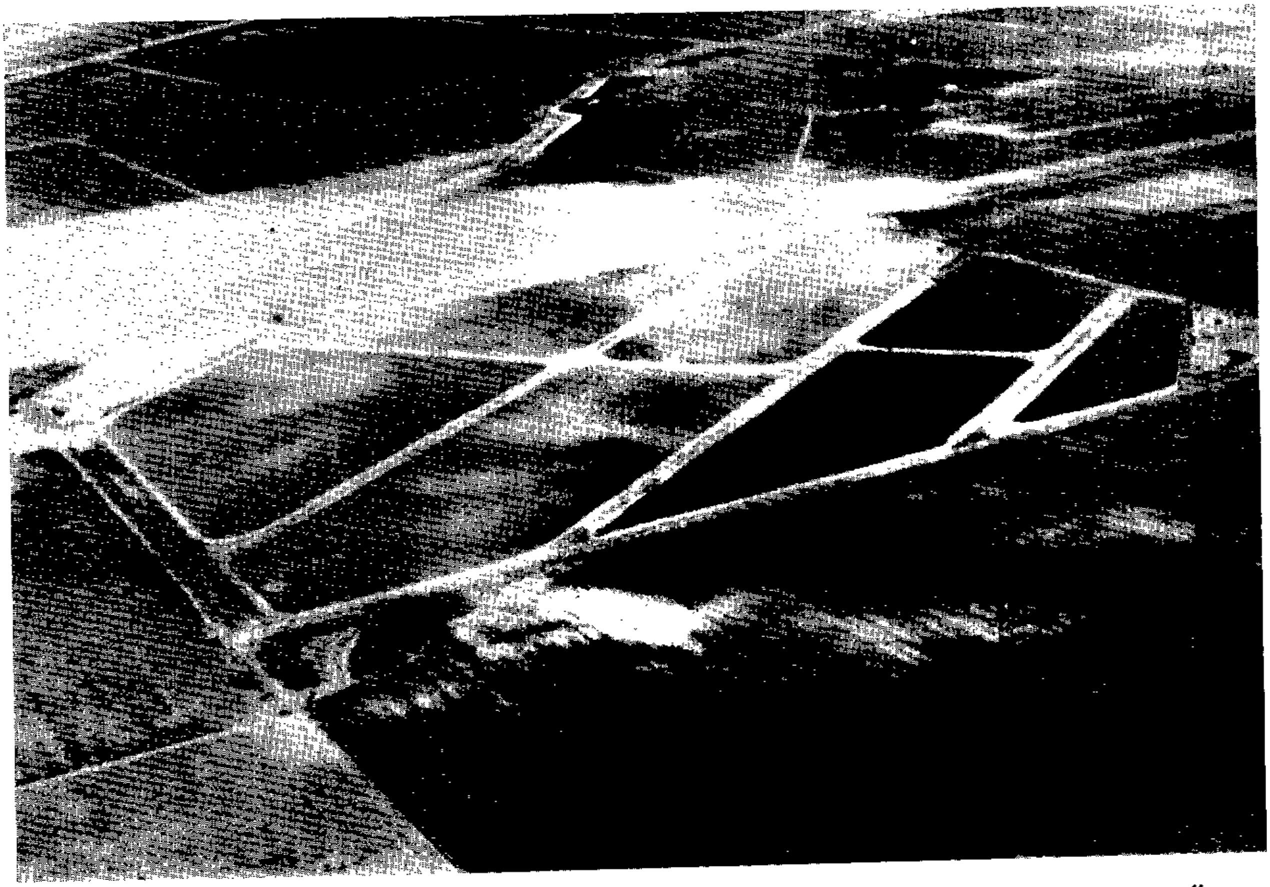


Figure 12

AQUIFER ZONES ABOVE THE CORCORAN CLAY WITH LESS THAN 1,250 ppm TOTAL DISSOLVED SOLIDS (Sampled between 1960 and 1989)



A buildup of salts in the soil can adversely affect agricultural productivity. The arid soils on the westside San Joaquin Valley contain substantial amounts of naturally acquired soluble salts that can leach into the ground water below the root zone. These salts contribute heavily to the salinity of the soil solution and, subsequently, to the drainage water, if a field is drained. About half the soluble salts in the crop root zone are derived from the soil (CH_2M Hill, 1988). Evapotranspiration increases the concentration of salts in the soil, and use of irrigation return flows also further concentrates them.



Ponds used to evaporate subsurface drainage water often cover several hundred acres, are generally divided into cells, and can evaporate about 4 feet of water per acre each year.

The chemical forms of total dissolved solids (salts) found in subsurface agricultural drainage vary from region to region in the San Joaquin Valley. The composition of drainage water is largely dominated by sodium and sulfate, although chloride is dominant in some places. A U.S. Geological Survey study (Deverel, et al., 1984) described concentration ranges for these major substances in drainage water from the Coast Range alluvium, the basin trough, and the transitional basin rim. Salts are highest in the basin rim zone. Median concentration of sulfate ranged from 310 to 3,450 ppm, with a maximum of 65,000 ppm. Chloride varied from a median of 220 to 455 ppm, with a maximum of 16,000 ppm. Sodium ranged from a median concentration of 230 to 1,100 ppm in the three zones, with a maximum concentration of 30,000 ppm. Other major substances are calcium, magnesium, potassium, and bicarbonate plus carbonate. Electrical conductivity (EC) ranges from a median of 1,900 to 6,055 μS/cm in the three zones, while the maximum observed value was 68,000 μS/cm. By comparison, the electrical conductivity of seawater is about 50,000 μS/cm.

High concentrations of nitrate with values greater than 70 ppm have also been observed in some areas. Nitrates are considered to have a dissolved salt source, although certain pollutant-type sources such as fertilizers and feedlots have also been documented. A potential public health hazard may exist if nitrates in public water supplies exceed 45 ppm. Nitrates and sulfates in drainage water also have been shown to hinder selenium removal in certain treatment processes (Hanna, et al., 1990).

Extensive sampling and analyses by Federal and State scientists during the period 1984-1989 have shown that pesticides are rarely detected in westside subsurface drainage water. However, pesticides have been observed in field irrigation runoff (tailwater), and commingling of tailwater and subsurface water does occur in parts of the valley (Gilliom and Clifton, 1987).

Evaporation ponds are one of the most common means to dispose of subsurface drainage water in the southern San Joaquin Valley. High salinity in the ponds, entering either from outside sources or developing from evaporation, produces concentrations of salts that may cause environmental problems. The dominant minerals (salts) in the evaporation ponds are typically sodium sulfate and sodium chloride, mainly due to the composition of geologic formations contributing to subsurface drainage systems. Inflow TDS concentrations were observed to range from 2,500 to 65,000 ppm in one study (CVRWQCB, 1988c). Concentrations in the ponds affected by evaporation have been measured as high as 388,000 ppm. (Seawater is about 31,000 ppm TDS.) During the evaporation-driven process of concentration, numerous physical, chemical, and biological processes affect the reactivity, solubility, and availability of trace element constituents in these high-salinity evaporation ponds (K.K. Tanji, in press).

Trace Elements

Toxic and potentially toxic trace elements occur naturally in some soils on the western side of the San Joaquin Valley, and they are leached into the shallow ground water during irrigation. These elements, originally found in the geologic formations of the Coast Ranges, can be mobilized, transported, and concentrated in irrigation drainage water. Another minor source of trace elements is imported irrigation water.

Over the past several years, many studies have evaluated the chemical composition of agricultural drainage water. These studies, conducted by government agencies and other researchers, have produced evidence of the existence of a large group of trace elements or chemical substances that may be found at elevated concentrations at some time or place in irrigation drainage water. This group of elements or chemical constituents, called "substances of concern," comprises 29 substances (Table 4). Basically, these substances are of concern in the environment because of their actual or possible adverse effects on water quality, public health, agricultural productivity, and/or fish and wildlife.

Table 4. SUBSTANCES OF CONCERN

Of Primary Concern	Of Probable Concern	Of Possible Concern	Of Possible Concern	Of Limited Concern	Probably Not of Concern at Present
	Subject to future California water-quality objectives	*Elevated concentrations at some sites*	*Little information available*	*Known toxic elements in low concentrations*	
Selenium Boron Molybdenum Arsenic Salts	Cadmium Chromium Copper Manganese Nickel Zinc	Uranium Vanadium Nitrates	Tellurium Antimony Lithium Germanium Bismuth Strontium Fluoride Beryllium	Lead Silver Mercury	Magnesium Iron Barium Aluminum

Criteria used by the Drainage Program as evidence of primary concern include these factors: (1) The substance has been cited in State/Federal water-quality regulations (there are water-quality criteria affecting its concentration, use, and distribution); (2) it is known to cause toxicity and create other problems for fish and wildlife; and (3) it can become hazardous to other wildlife and to humans by accumulating in the food chain or by direct exposure to contaminated soils, sediments, air, or ground water and surface water.

The trace elements of primary concern are selenium, boron, molybdenum, and arsenic, all of which occur naturally in westside soils. Arsenic is of concern primarily in the Tulare and Kern Subareas, where it has been observed in elevated concentrations in shallow ground water. In other locations, such as parts of Westlands Water District, concentrations of hexavalent chromium in shallow ground water have been observed above usual background levels. The State Water Resources Control Board and the Drainage Program have also identified salts as substances of primary concern.

In addition, other elements for which the State Board eventually may establish site-specific water-quality criteria are cadmium, copper, manganese, nickel, and zinc (SWRCB, 1987). Samples from some evaporation ponds have shown high concentrations of uranium. Elevated concentrations of vanadium have also been found in some evaporation ponds. Other substances have also been measured in ongoing monitoring programs. These include nitrates, tellurium, mercury, antimony, germanium, bismuth, strontium, fluoride, beryllium, lead, magnesium, iron, aluminum, lithium, silver, and barium. In some instances, there is not enough information on the effects of these elements to establish them as substances of primary concern, and in others, the concentrations are not high enough to establish a definite level of concern.

Selenium leads the four elements of primary concern, primarily because it is widely distributed in the study area and because of its proven and potential toxicity. Water and mudflows have transported the selenium to the valley in particulate and dissolved forms derived from the weathering and erosion of source rocks. Decades of irrigation have transferred soluble selenium from the upper soils to the shallow ground water, where its highest concentrations occur generally along the edge of the valley trough in the lower parts of the Coast Range alluvial fans.

Selenium concentrations in shallow ground water show a wide range of values. In the U.S. Geological Survey's study of three physiographic zones (Coast Range alluvium, the basin rim, and the basin trough) on the western side of the valley (Deverel, et al., 1984), values ranged from less than 1.0 part per billion (ppb) to 3,800 ppb, with a median concentration for all zones of 6.0 ppb. Water entering Kesterson Reservoir in the spring of 1984 had an average of 385 ppb. To protect freshwater aquatic life, the Environmental Protection Agency recently established ambient water-quality criteria for selenium — 5.0 ppb for chronic toxicity and 20 ppb for acute toxicity (USEPA, 1987). Saltwater limits are higher. The State Board has established a monthly mean objective for selenium of 5.0 ppb for a specific area of the San Joaquin River.

Evaporation ponds can accumulate and concentrate trace elements that may be hazardous to wildlife, especially waterfowl and shore birds that use the ponds. A study of 22 ponds by the Central Valley Regional Water Quality Control Board indicates that trace-element concentrations vary widely (CVRWQCB, 1988c). Each of the four primary substances of concern (selenium, boron, molybdenum, and arsenic) occurs in high concentrations in one or more of the ponds. Selenium, for example, in these 22 ponds ranges from less than 1.0 ppb to 1,900 ppb, with a median value of 17 ppb.

Elevated concentrations of boron (greater than 2.0 ppm) are found in parts of all the subareas under study, except the Northern Subarea. Although boron is essential to the nutrition of certain plants, concentrations in excess of 0.5 ppm are known to be harmful to some crops. For this reason, it is regarded primarily as an agricultural crop problem. The State Board established water-quality objectives for boron in the San Joaquin River that ranged from 0.8 to 1.3 ppm, depending on the time of year or whether it is a critically dry water year. The Regional Board's studies show that boron in evaporation ponds ranges from 2.5 to 840 ppm, with a median concentration of 20 ppm.

Molybdenum has been found in elevated concentrations (greater than 20 ppb) in various areas of the San Joaquin Valley, particularly in the Tulare and Kern subareas. Molybdenum in very low concentrations is essential to many plants and some mammal species. In high concentrations, it can be injurious to the growth of many kinds of plants. It can be toxic to livestock through bioaccumulation, particularly in ruminant animals (cattle and sheep). A technical committee of SWRCB recommended a 10-ppb criterion in water to protect agricultural uses. The EPA has not set any water-quality criteria for molybdenum. Molybdenum is an abundant element in evaporation ponds, ranging in concentration from 7.0 to 7,775 ppb at the inlets to the ponds and 58 to 40,000 ppb in the ponds. Few studies have been performed to assess the potential consequences of elevated dietary molybdenum in humans.

Arsenic is a known toxicant that has been shown to become concentrated at relatively high levels in evaporation ponds in the Tulare Basin. Arsenic values in evaporation ponds range from 2.0 to 900 ppb in the inlets to the ponds and 1.0 to 13,000 ppb in the ponds. Occurrences in other parts of the San Joaquin Valley are not as frequent, nor are the levels as high, on the average. Certain chemical forms of inorganic arsenic are suspected human carcinogens. The EPA has set 50 ppb as the current maximum contaminant level for arsenic compounds in drinking water and established 190 ppb as the water-quality criterion for freshwater aquatic life.

Uranium was not one of the elements of concern studied in earlier evaluations of drainage-water constituents. However, the presence of elevated concentrations of uranium in Tulare Basin evaporation ponds has been documented (CVRWQCB, 1988b). These ranged from 30 to 11,000 ppb in studies conducted in 1987-88. The mean concentration for all pond samples was 675 ppb, while the mean concentration in the inflow samples of the three basins studied was 280 ppb. Over 60 percent of the evaporation pond area exceeded a Canadian marine water-quality objective of 500 ppb uranium. At the present time, there is no information regarding the role uranium may play in the toxicity problems of the evaporation ponds. In 1988-89, the USGS studied the occurrence of uranium in shallow ground water in parts of the Tulare Subarea. Results have not yet been published.

The toxicity of drainage-water constituents is influenced by their chemical interaction with other substances. The understanding of these interactions is limited. In addition to the independent effects of trace elements, antagonistic or synergistic interactions may occur among various constituents.

The list of substances that may be of concern in drainage water is not final at this time. Certain other substances not now listed have occasionally been detected in drainage-water samples or in water influenced by subsurface drainage. Future studies and continued monitoring may produce data that will indicate whether certain chemicals not presently thought to be important will have to be more thoroughly appraised.

DRAINAGE-WATER TREATMENT AND REUSE

At the beginning of the Drainage Program, major effort was focused on treatment of drainage water to make it environmentally acceptable and/or reusable. Selenium became the principal concern in those efforts because of confirmed associations between adverse effects on wildlife and the presence of selenium in drainage water. Unlike other substances of primary concern, no practical treatment method for selenium removal was known to exist.

Treatment Processes

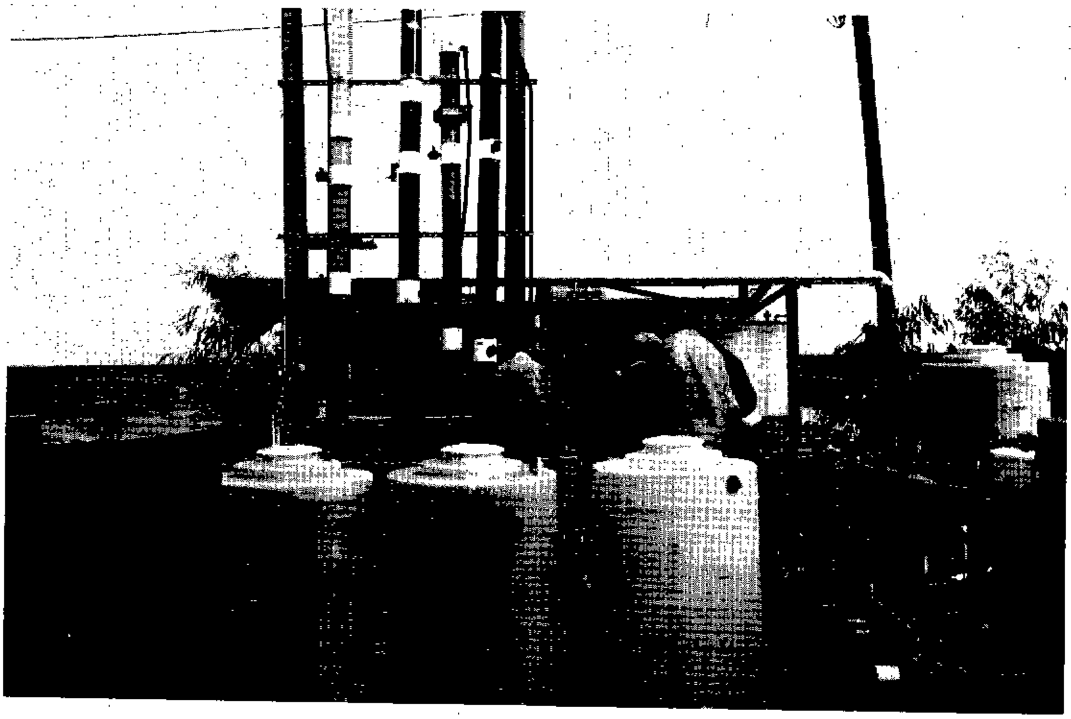
Problems at Kesterson Reservoir generated about 150 ideas and suggestions that were submitted to the Drainage Program. Many were oriented toward drainage water treatment and many were research proposals. The staff initially screened all the ideas and submitted about 30 of them to the Program's Treatment and Disposal Subcommittee for evaluation and final screening. The subcommittee further narrowed the choices, but because of funding limitations, only the most promising methods were pursued.

The Drainage Program investigated the 11 processes listed in Table 5 but did not fund all the developmental research. Others (for example, Westlands Water District, Panoche Drainage District, and the California Department of Water Resources) also funded research on treatment processes. Chapter 3 of the Drainage Program's *Preliminary Planning Alternatives* summarized the various treatment processes investigated. Technical reports on the various treatment processes have been prepared and a review and evaluation of each treatment process has been completed (Hanna, et al., 1990).

Anaerobic–Bacterial Process

This process was tested by EPOC AG in a small-scale pilot plant, using a biological reactor (including upflow fixed-film beds, fluidized beds, and sludge blanket reactors) and microfiltration. EPOC AG concluded in 1987 that the biological process is a practical and proven method for treatment of selenium-laden drainage.

The optimum treatment train was sludge blanket to fluidized bed to microfiltration. The process lowered selenium levels in the feedwater from 300 to 500 ppb down to 12 to 40 ppb, and thence to below 5.0 ppb with ion exchange "polishing." However, interpretation of the data generated by the EPOC AG pilot plant is complicated by the ever-changing nature of the plant's operation. It operated under field conditions, with wide changes in drainage water quality and diurnal and seasonal temperature variation, as well as in other significant parameters.



The anaerobic-bacterial process of removing selenium from drainage water was tested in this small plant near Mendota in 1986 and 1987.

Laboratory-scale research at the University of California, Davis, was conducted as followup to the work by EPOC AG, mainly to determine the mechanisms of selenium removal in the anaerobic-bacterial process (Schroeder, et al., 1989). It was determined from studies using sequencing batch reactors and fluidized bed reactors that selenate reduction occurred simultaneously with nitrate reduction. It was theorized that selenate reduction was primarily a detoxification mechanism, rather than a respiratory process. In respiration, nitrate would be used before selenate. The researchers postulated that the bacteria are detoxifying their environment of high concentrations of selenate, while simultaneously respiring on nitrate.

Facultative–Bacterial Process

This process was studied in the laboratory at the U.S. Bureau of Mines Research Center in Salt Lake City, Utah (Altringer, et al., 1987). Selenium was reduced from selenate to selenite, using facultative bacteria that can live with or without oxygen, and precipitated from solution in elemental form. This study also demonstrated that the mechanism of selenium removal is influenced by nutrient addition, oxygen supply, and temperature. Aerobic conditions encouraged bacterial growth, but selenate reduction was enhanced when the air supply was restricted.

Table 5. STATUS OF DRAINAGE-WATER TREATMENT PROCESSES TO REMOVE OR IMMOBILIZE SELENIUM

Process	Research	Development	Testing and Evaluation
Biological			
Anaerobic-bacterial			X
Facultative-bacterial	X		
Microalgal-bacterial		X	
Microbial volatilization in evaporation pond water	X		
Microbial volatilization from soils and sediments			X
Physical and Chemical			
Geochemical immobilization	X		
Iron filings			X
Ferrous hydroxide		X	
Ion exchange	X		
Reverse osmosis to remove salts and other contaminants			X
Generate electrical energy and heat for desalination with a cogeneration process			X

In many respects, the mechanism of selenium removal in this process appears similar to that occurring in the anaerobic-bacterial and microalgal-bacterial processes. It involves reducing selenate to selenite to elemental selenium, which accumulates in the biological sludge of the reactors. The same bacteria genus contained in EPOC AG's anoxic fixed-film reactor sludge was shown in this study to reduce selenate first and adapt well under high selenium concentrations. The study also demonstrated that optimal selenate reduction by facultative bacteria occurs under anoxic conditions.

Microalgal-Bacterial Process

This process was investigated by the University of California at Berkeley (Oswald, et al., 1990). The process is based on the principle that soluble selenate can be reduced by microorganisms to less-soluble selenite and elemental selenium in an anoxic sludge blanket reactor. While elemental selenium settles and accumulates in the reactor sludge, selenite suspended in the reactor effluent can be precipitated with ferric chloride and removed by a dissolved air flotation system.

The carbon source for the biological reactor is algae cultivated in high-rate algal ponds fed by drainage water. If drainage nitrate levels are above that which can be assimilated by pond algae, a denitrification reactor is added upstream from the selenate-reducing reactor.

The researchers believe that excess algae can be fermented to produce methane for power generation, carbon dioxide can be recycled for pH control in the algae ponds, and the digested sludge can be diverted to the biological reactors to supplement the algal feed. Although the field tests did not reach steady-state conditions, the process showed promise of greater than 95-percent removal of selenium.

Microbial Volatilization of Selenium in Evaporation Pond Water

This process was studied primarily as an in-situ means to maintain selenium levels in evaporation ponds below the hazardous waste criterion of 1.0 ppm. It was not intended to meet the more stringent criteria for wildlife protection.

Investigators in 1990 reported that compounds high in protein, such as casein, dramatically accelerate biological removal of selenium, but substantial amounts of the compounds are apparently required, probably creating eutrophic ponds (Frankenburger and Thompson-Eagle, 1989). Bacteria were identified as the predominant active selenium methylators in pond water. The researchers conclude that further studies are needed to determine whether protein-mediated methylation can be optimized through the addition of coenzymes, methyl donors, and aeration, as well as through the addition of specific microbial inoculants. They further conclude that it may be possible to design a pilot bioreactor to test selenium removal. This technique lags in developmental efforts.

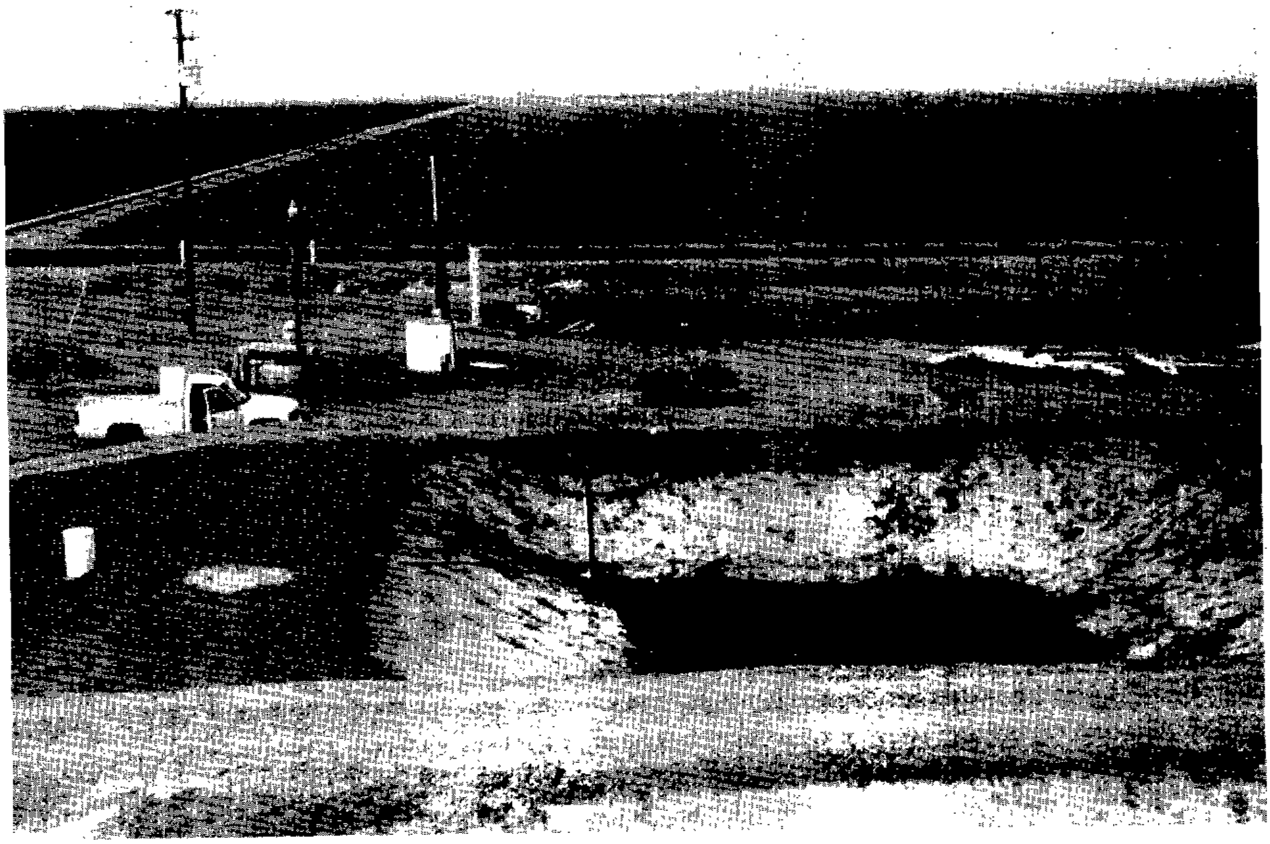
Microbial Volatilization of Selenium from Soils and Sediments

This process is being investigated by researchers from the University of California at Riverside to determine whether biomethylation of selenium could be accelerated and used as a bioremediation technique to remove selenium from Kesterson Reservoir and the San Luis Drain (Frankenburger and Karlson, 1989). Indigenous soil fungi are the primary organisms that volatilize the selenium, and dimethylselenide is the primary gaseous end product. The process was field-tested, following treatment methods in which different additives were used. This work was done at Kesterson Reservoir, on San Luis Drain sediments, and at a Peck Ranch evaporation pond. All treatments included moisture application and rototilling.

At Kesterson Pond 4, where selenium concentration in the upper 6 inches of soil averaged about 39 milligrams per kilogram, treatment using citrus peel + ammonium nitrate + zinc sulfate and treatment using casein were most effective. The average emission rate with the citrus peel treatment was about 40 times greater than it was for background level. It was estimated that the treatment would require about seven years to achieve the cleanup goal of 4 mg/kg from the initial concentration of 39 mg/kg. The selenium volatilization rate is highly temperature-dependent, with the highest rates occurring in the late spring and summer months.

Geochemical Immobilization

A physical/chemical attenuation process to transform and immobilize selenium in place was investigated by UC Riverside researchers (Neal and Sposito, 1988). The study was conducted to identify the pertinent variables in an irrigated soils system designed to implement management techniques that would control the eventual fate of selenium by immobilizing it in the soil profile. The researchers concluded that the chemical form in which selenium exists in the aqueous phase governs the applicability of this process. If, as in the soils of the western San Joaquin Valley, selenate predominates, farm level management practices to achieve physical/chemical attenuation would have little success in immobilizing selenium.



Panoche Water District is testing the removal of selenium by passing drainage water through a bed of iron filings in the bottom of this basin.

Iron Filings

In 1985, Harza Engineering Company tested its patented heavy metals adsorption process for removing selenium from drainage water at Panoche Drainage District. In this process, heavy and toxic metals are adsorbed onto iron filings and removed from solution as drainage water flows through a bed of "activated" iron filings. Before the beds are exhausted, the iron filings are replaced, activated, and returned online. The spent material can be disposed of at landfills or recycled to the metal-working industry.

A problem arose in initial field testing. The filings solidified and clogged the bed. A study was conducted at the University of Wisconsin, Madison, to determine the mechanism by which selenium is removed and the selenium specie formed to effect removal (Harza, 1989). It was concluded that selenium is removed by chemical adsorption on iron oxyhydroxide surfaces at an orange-brown layer of iron filings, where drainage water enters the column. Before the oxyhydroxide layer forms, selenium can be removed throughout the iron-filing bed by physical adsorption. There is still uncertainty regarding the exact mechanism whereby selenium is removed in the Harza process.

The study did not conclusively define the cause of the bed-clogging problem. The formation of magnetite (Fe_3O_4), a ferromagnetic solid that restricts flow, was suggested as a possible cause. Other possibilities, such as calcite precipitation, were also suggested, but bed-hardening also occurred in columns with selenate-spiked distilled water.

Pilot tests are presently being conducted in treatment ponds at Panoche Drainage District. Information from these tests should help to better evaluate the effectiveness and cost of this process.

Ferrous Hydroxide

Studies of this process were conducted by staff of the U.S. Bureau of Reclamation's Denver Office (Rowley, et al., 1990). The process is based on a reaction in which ferrous hydroxide reduces selenate to elemental selenium. The reaction rate depends on pH, for which the optimum range is 8 to 10. Temperature affects the rate of selenate removal by about doubling the rate for each 10° C increase. Most of the tests were conducted at 20° C, the approximate average temperature of drainage water.

The reaction time for selenate removal is inversely proportional to the ferrous hydroxide concentration, which was commonly used in the range of 2.5 to 20 millimoles per liter. The reaction times were very short (99-percent selenate removal in less than one minute) when deionized water was used for testing, but substantially longer times were required when drainage water was used. Field tests near Mendota resulted in 90-percent selenate removal after four hours.

It was concluded that high concentrations of bicarbonate would decrease the reaction rate by half, while high concentrations of nitrate would reduce the reaction rate by a factor of 5. If high concentrations of both ions were present, the initial rate of reaction would be reduced by a factor of 17. Although oxygen does not appear to affect the rate of selenate removal, it oxidizes about 1.6 millimoles per liter of ferrous hydroxide if the water is saturated at 20° C.

Ion Exchange

Use of selenium-selected resins to remove selenium was investigated in laboratory tests on drainage-water samples (Boyle, 1988). Two strong anion-base resins, both similar to commercial resins, showed selectivity for the selenate ion over the sulfate ion. The investigators concluded that this indicated ion exchange is a promising method. However, studies have not been conducted to demonstrate field-scale reliability and costs.

Reverse Osmosis to Remove Salts and Contaminants

This is a versatile, proven treatment process capable of removing salts, as well as trace-element contaminants, but it is also much more costly than the other treatment processes. The California Department of Water Resources operated a drainage-water desalting demonstration plant at Los Banos from the fall of 1983 to August 1986. DWR concluded that additional work is required on the pretreatment system to establish the feasibility of a drainage water desalting facility. DWR has issued a report on the pretreatment systems tested (DWR, 1986), and reports on other components of the project (ion exchange and reverse osmosis) are being completed.

Cogeneration

This process uses waste heat from the thermal generation of energy to evaporate drainage water. However, from review of a cogeneration study completed in 1989 (RMI, 1989), the Drainage Program concluded that cogeneration using natural gas fuel is not promising for evaporation of unconcentrated drainage water because of the high cost and the relatively small amount of drainage water treated (about 7,500 acre-feet annually in conjunction with a 100-megawatt powerplant).

Westlands Water District, with Drainage Program participation, conducted a preliminary study of burning salt-tolerant agroforest biomass to evaporate drainage water concentrated by agroforestry crops (RMI, 1990). RMI concluded that wood fuel cannot be economically substituted for natural gas to fuel a cogeneration component of a drainage water evaporation plant.

Future of Treatment Processes

The implementation of any drainage water treatment process is burdened largely by three major items: (1) The need to keep costs low and affordable for agricultural application, (2) the stringent performance criteria imposed by the need to reduce selenium to extremely low concentrations (less than 5 ppb) in receiving water, and (3) the early developmental status of technology for selenium removal from drainage water. Because selenium-removal technology, unlike reverse-osmosis desalting, has not progressed to large-scale application, it is premature to recommend a specific treatment process at this time. However, selenium removal research indicates that treatment may be a viable drainage management strategy under certain conditions and, therefore, further treatment research is justified.

Because the Drainage Program wanted to encourage the search for an economical way to remove selenium from drainage water, its Interagency Technical Advisory Committee's Treatment and Disposal Subcommittee was asked for advice on which process to pursue. The subcommittee recommended support of a 30,000-gallon-per-day demonstration plant using the anaerobic-bacterial process field-tested by EPOC AG. The Department of Water

Resources intends to fund the demonstration plant in 1990, with support from the U.S. Bureau of Reclamation.

In the EPOC AG field-pilot tests, selenium in drainage water at a concentration of 300 to 550 ppb was lowered to about 10 to 40 ppb after microfiltration and to less than 10 ppb after polishing in boron selective ion-exchange resins. EPOC AG has reported estimated treatment costs for a 1-million-gallon-per-day prototype plant of about $76 per acre-foot to construct (capital at 4 percent, with 20-year plant life) and $148 per acre-foot to operate. Total product cost would be about $224 per acre-foot. It was also estimated that, for a 10-mgd plant, the total unit treatment cost would decline to about $145 to $175 per acre-foot, depending on the availability and cost of a carbon source. These estimates did not include waste-stream disposal costs.

A study sponsored by the Drainage Program reviewed and evaluated each treatment process investigated, and, when cost estimates were available, adjusted them on a common basis (Hanna, et al., 1990). Revisions of EPOC AG's cost estimates were based on increases in the interest rate from 4 percent to 9⅜ percent, electricity rates from $0.045 to $0.08 per kilowatt-hour, labor costs from $28,470 to $40,000 per person per year, and capital costs by 35 percent. Added to these were replacement costs and 27 percent for overhead and profit. Those changes raised the estimated total product cost from $224 to $456 per acre-foot for a 1-mgd plant and from $175 to $301 for a 10-mgd plant. Neither estimate includes costs of polishing to lower selenium levels to less than 10 ppb, or of waste-stream disposal.

Reuse

If drainage water could be economically reused, it would be a resource, not a waste disposal problem. The Drainage Program funded investigations of the reuse of drainage water for irrigation of salt-tolerant trees and halophytes. It also reviewed the results of reuse investigations conducted by others. These mainly concerned the use of drainage water in powerplant cooling, temperature-gradient solar ponds, aquaculture, salt and mineral recovery and marketing, and agriculture.

There are no current plans for siting major thermal powerplants in the valley and hence no significant demands for drainage water for cooling. Treatment costs would be substantial to produce drainage water acceptable for powerplant cooling. Possibilities exist, though, that energy-producing solar ponds could be used in drainage water management because of the increasing demand for, and cost of, electrical energy and because of growing concern for air quality in California. Both the Bureau of Reclamation and the Department of Water Resources are pursuing further solar pond investigations.

The potential for both salt and mineral recovery and aquacultural reuse rests largely with the marketability of the products — primarily sodium sulfate, in the case of salt recovery, and the products grown in drainage water, in the case of aquaculture. Such markets do not appear promising at present because sources are available elsewhere, but these are subject to change in the future.

Reuse of drainage water by irrigating salt-tolerant crops or by blending with normal irrigation supplies are the only reuse options that appear promising at this time.

AGRICULTURAL ECONOMY

Agriculture is the mainstay of the economy of the westside San Joaquin Valley. Knowledge of the agricultural economy and the way in which it relates to the region, the State, and the nation are important to understanding and planning for management of the drainage problem. The information that follows is from the Census of Agriculture reports (1978, 1982, 1987), Census of Manufacture reports (1978, 1982, 1983, and 1985), and data from the California Department of Food and Agriculture and a commercial agricultural lending agency, as presented in a report sponsored by the Drainage Program (Archibald, 1990). Additional information is available in the full report.

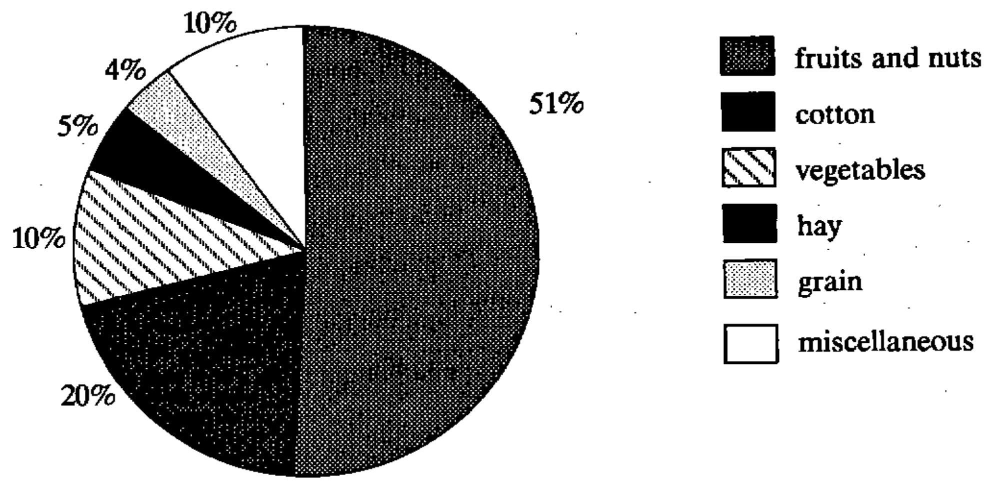
The Contribution of Agriculture

California leads the nation in the market value of agricultural production. In 1987, California's total value of agricultural output was $13.92 billion; this represented 10.2 percent of the total $136 billion U.S. agricultural production. Of the California total, $9.27 billion was contributed by crops and $4.65 billion by livestock, poultry, and related products.

The San Joaquin Valley is California's largest single agricultural area, contributing $6.82 billion (49 percent) of the State's total agricultural output. Crops accounted for $4.45 billion (65 percent), and livestock and livestock products contributed $2.37 billion (35 percent). Figure 13 provides a breakdown of the total crop production value in the San Joaquin Valley.

Of the total value of crop production in the U.S., 50.9 percent was derived from irrigated land and 49.1 percent from nonirrigated land. In contrast, only 19.9 percent of the value of livestock and livestock products was derived from irrigated land, while 80.1 percent was

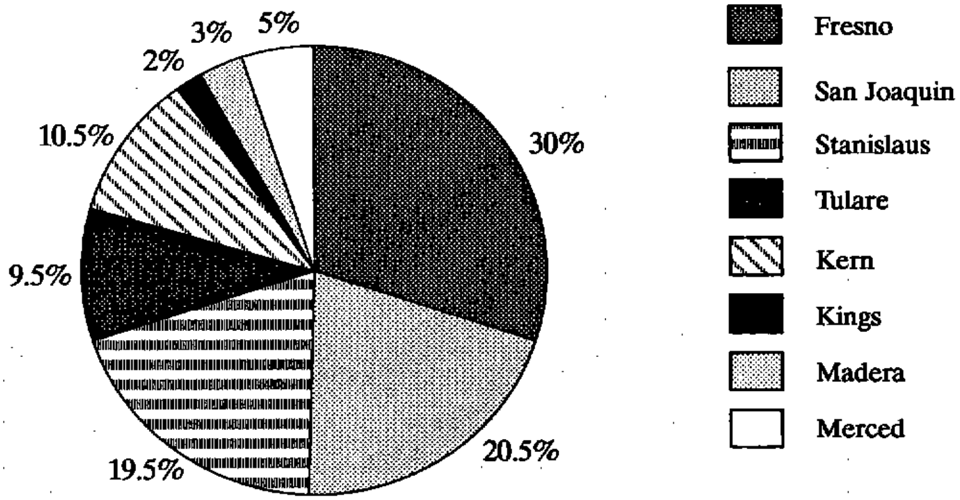
Figure 13. SAN JOAQUIN VALLEY TOTAL CROP PRODUCTION VALUE (Value = $4.45 billion in 1987)



contributed by nonirrigated land. Irrigated land in California accounted for about 45 percent of total U.S. crop production on irrigated land, and the San Joaquin Valley alone contributed about 21 percent of the U.S. total.

The importance of agriculture to the economy of California can be estimated by examining employment statistics. Statewide in 1987, agriculturally induced employment accounted for at least 17.3 percent of employment and 18.5 percent of total payroll. Within the San Joaquin Valley, these categories were 48.6 and 54.2 percent, respectively. Figure 14 shows agriculturally induced employment in the San Joaquin Valley.

Figure 14. AGRICULTURALLY INDUCED EMPLOYMENT IN THE SAN JOAQUIN VALLEY BY COUNTY, 1987



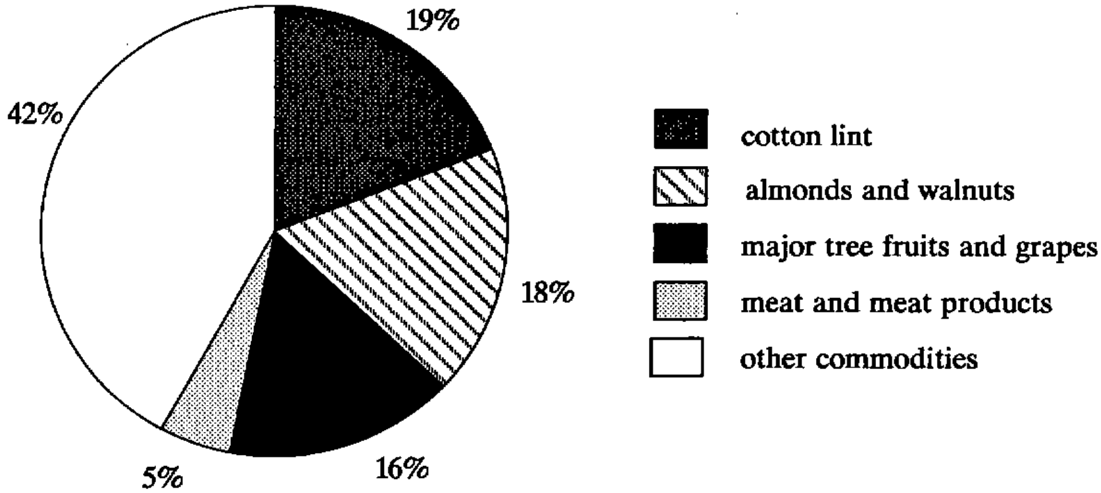
In 1987, agriculturally induced employment in each valley county was even more striking, representing more than 50 percent of employment in Kings, Madera, Merced, and Stanislaus counties and about 50 percent in Fresno, San Joaquin, and Tulare counties. In Kern County, agriculture accounted for only 20 percent of employment, reflecting the development and growing importance of other industries, such as petroleum.

Exports

California also leads the nation in agricultural export value. The State's export value declined during the 1980s, as did U.S. export value, but the State's value recovered significantly by 1987. The leading single export commodity from California is cotton lint. Figure 15 shows a breakdown of the value of California commodity exports. In 1987, 62 percent of California's cotton output was exported. This accounted for nearly half the value of U.S. cotton exports. About 60 percent of the State's almond crop and 45 percent of the walnut crop were exported. This was the entire amount of U.S. exports of these two crops.

Given these levels of exports, an estimated 1.76 million acres of California cropland were dedicated to producing for export markets in 1987. Cotton dominates exports in terms of land use. In 1987, production from 710,000 acres of cotton was required to meet California's

Figure 15. SHARE OF CALIFORNIA COMMODITY EXPORTS, BY VALUE, 1987



export market. Of that area, 682,000 acres were in the San Joaquin Valley, and 450,000 of those acres are on the valley's western side. The rise in incomes in countries importing agricultural products from California favors growth in higher value export crops, such as fruits, nuts, and beef. For the 1990s, based on expectations of income and population growth in importing countries, the U.S. Department of Agriculture projects a 3-percent annual growth rate for agricultural exports, led by growth in high-value products. Food grain exports are not expected to grow as fast as feed grain exports, because importing countries are increasing their domestic meat production and must import feed grains.

Land Use

Total California farmland in 1987 was 30.6 million acres, with about one-third (10.5 million acres) in the San Joaquin Valley. Farmland on the western side of the valley accounts for one-third (3.4 million acres) of the valley total. About 7.5 million acres of cropland are irrigated, with irrigated pasture accounting for only 5 percent of the total. Over half (57 percent) of the State's irrigated cropland is in the valley, and 40 percent of this is on the western side. Together, the Westlands, Tulare, and Kern Subareas account for more than 75 percent of westside irrigated cropland.

California farmland as a whole declined 2.3 percent from 1982 to 1987, a drop that was consistent with the national pattern, which declined 2.26 percent in the same period. For the valley, the decline was 3.0 percent; on the western side, it was 11 percent.

A partial explanation for the decline of irrigated westside cropland is the acreage enrolled in the Federal Commodity Acreage Reduction Program and the Conservation Reserve Program. Idled cropland in the valley increased 125 percent from 1982 to 1987, or 13.4 percent of total irrigated cropland in 1987. Land under the Acreage Reduction Program increased 256 percent from 1982 to 1987, to a total of 7.1 percent. Land set aside under the Conservation

Reserve Program for the valley as a whole was less then 1 percent of irrigated land. Drought conditions in 1987 also help explain the reduction in irrigated acreage.

Forty-three percent of irrigated cropland on the western side of the San Joaquin Valley was in cotton in 1987. In the five subareas, the share of cropland in cotton ranged from 2.1 percent in the Northern Subarea to 52.2 percent in the Westlands Subarea (Figure 16). The cotton shares for the Kern, Tulare, and Grasslands subareas are 51.0, 49.5, and 34.6 percent, respectively. Other field crops, including feed grains, hay, wheat, sugar beets, dry beans, oilseeds, and rice, accounted for 34.3 percent of the valley's cropland and 38.4 percent of the westside cropland in 1987. The shares of cropland in these field crops ranged from 28.7 percent in the Westlands Subarea to 51.9 percent in the Northern Subarea. Most dry beans have been grown in the Northern Subarea; most sugar beets, in the Northern and Grasslands subareas; and most oilseeds, in the Tulare Subarea. Conversely, hay has been grown throughout the west side, but minimally in the Westlands Subarea. Cotton is minimal in the Northern Subarea, as is wheat in the Grasslands Subarea.

In 1987, fruit and nut acreage represented 8.3 percent of cropland on the western side and 33.4 percent in the San Joaquin Valley as a whole (Figure 16). Together, almonds, walnuts, and apricots accounted for 92 and 86 percent of tree and vineyard cropland in the Northern and Grasslands subareas, respectively.

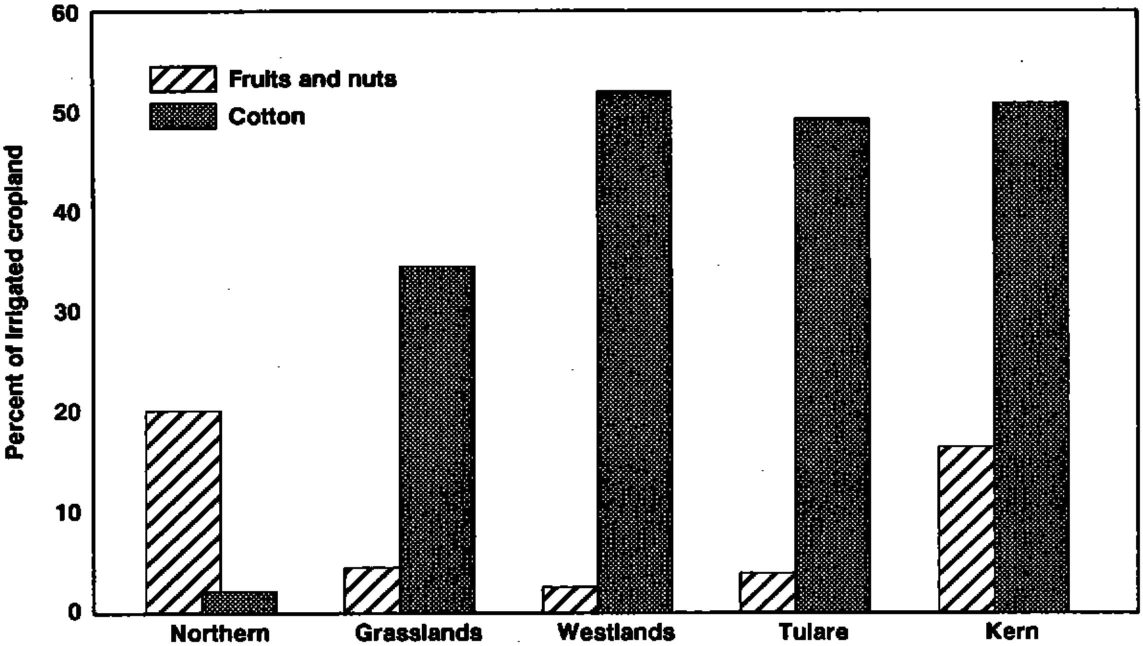
In 1987, vegetables accounted for 10.3 percent of cropland on the western side, up from 7.7 percent in 1982 and 7.3 percent in 1978. This represented an increase of 17,000 acres during the 10-year period. The share of cropland in vegetables ranged among the subareas from a high of 25.8 percent in the Northern Subarea to a low of 2.8 percent in the Tulare Subarea. Westlands Water District, which makes up most of the Westlands Subarea, had the greatest vegetable acreage, with140,868 acres (Westlands Water District, 1988). Tomatoes, cantaloupes, lettuce, romaine, and dry onions occupied about 62 percent of land planted to vegetables in the valley. Tomatoes were the dominant crop, with 36 percent of the vegetable acreage.

Production Expenses

The western side of the San Joaquin Valley accounted for 29 percent of total valley agricultural production expenses in 1987. Given that the westside share of irrigated cropland is 40 percent, this indicates lower per-acre expenses for the western side than for the remainder of the valley. This could reflect a combination of a greater ratio of field and row crops to trees and vines on the western side and some economies of scale associated with large operations. Labor expenditures exceeded 20 percent of the total, followed by chemicals and machinery (including equipment), each at 10 percent, and energy at 6 percent. The shares of expenditures for labor, interest, and property taxes are lower than for the rest of the valley. Westside growers, however, dedicate a larger fraction of their production expenses to machinery, energy, chemicals, and irrigation water. In the subareas, cash rents per acre appear to decline as a proportion of total expenditures from north to south. The proportion of expenses in the form of interest payments was greater in the Northern Subarea, reflecting higher land values and per-acre investments in orchards. Energy expenditures in the Tulare and Kern Subareas were greater in proportion to other expenses than in other areas, reflecting the greater dependence on pumped ground water as an irrigation supply.

Westside land values have followed the national pattern, increasing from 1970 to the early 1980s and then declining, with some recent evidence of recovery. Westside land prices are about five times the national average and are highest in the Northern Subarea, where orchards are prevalent.

Figure 16. IRRIGATED CROPLAND IN COTTON, FRUITS, AND NUTS, BY SUBAREA – 1987



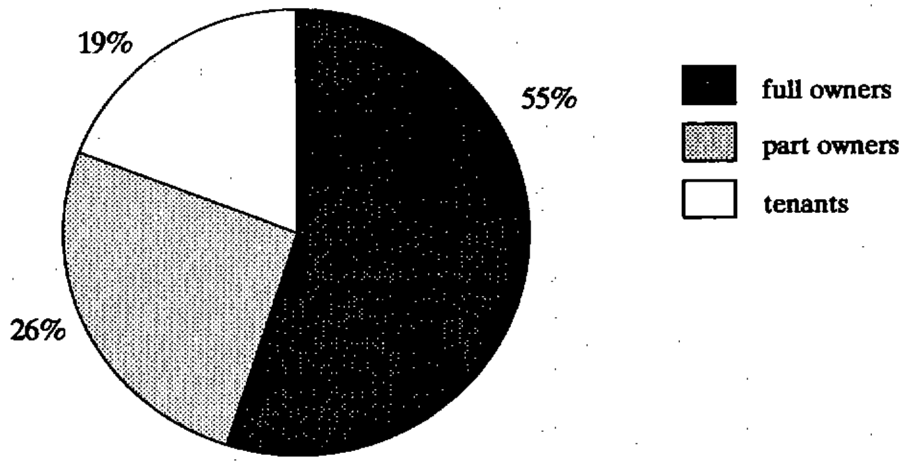
Farm Structure

Farms are fewer but substantially larger on the western side than in the rest of the valley. Average farm size in the principal study area was about 500 acres in 1987, while the average for the rest of the valley was about 100 acres. Farms in the Westlands Subarea averaged 1,100 acres in 1987; in the Tulare and Kern subareas, 500+ acres; in the Grasslands Subarea, 400+ acres; and in the Northern Subarea, 200 acres.

Farm tenure types fall into three classifications: (1) Full owners, who operate only the land they own; (2) part owners, who operate farmland they own, as well as land they rent; and (3) tenants, who operate only land they rent (Figure 17). Full ownership as a percentage of all forms of land tenure on the western side exceeded 50 percent in all subareas, except in Westlands, where it was 44 percent.

Farm operations are also divided into three basic types of management structures: corporations, partnerships, and individual or family owners. Corporations are further divided into three groups: family-held; other-than-family-held; and others, including cooperatives. In 1987, individual owners and family corporations together accounted for 76.3 percent of the farms on the westside San Joaquin Valley. In the Northern and Grasslands Subareas, corporations accounted for less than 1 percent of farms and less than 2 percent in

Figure 17. PERCENT OF FARMS BY TENURE OF OPERATOR, WESTSIDE SAN JOAQUIN VALLEY, 1987



each of the other subareas. All subareas had more than 70 percent of farms under individual ownership or in family corporations.

Less than 0.5 percent of farmland in the Northern and Grasslands Subareas was owned by corporations. During the 10-year period, 1978-1987, the portion of land owned by corporations in the Westlands and Kern Subareas increased from 6 percent to 8 percent and from 7 percent to 8 percent, respectively. In the Tulare Subarea, the portion increased from 7 percent to 16 percent. During the same period, land owned by partnerships in the Grasslands and Kern Subareas increased from 32 percent to 40 percent and from 35 percent to 40 percent, respectively. In the Westlands Subarea, the portion increased from 28 percent to 34 percent, while in the Tulare Subarea it increased from 25 percent to 35 percent. Only the Northern Subarea reported a decrease in land owned by partnerships during this period — from 38 percent to 36 percent.

Federal Agricultural Programs

Commodity Credit Corporation (CCC) payments to farm operators include loans for corn, wheat, sorghum, barley, oats, cotton, rye, rice, and honey. Government payments include deficiency payments, paid diversions, soil conservation reserve payments, payments from the Dairy Termination Program, other conservation programs, and other Federal farm programs under which payments are made directly to the farm operator. In 1987, CCC and other government payments to U.S. farms totaled $17.9 billion; $570 million was for loans and the remainder for payments. California received $69.1 million in CCC loans and $238 million for government payments. Total CCC payments for the San Joaquin Valley were $17 million, amounting to 28 percent of California payments. The valley received $126 million in government payments, or 53 percent of the State total. CCC loans to the western side for all program crops totaled $11.7 million.

Cotton was the most important source of CCC payments (83.6 percent) on the western side. In the Kern Subarea, 97 percent of CCC loan payments was for cotton, and the Grasslands and Westlands subareas received 75 and 84 percent, respectively, for cotton. The Northern Subarea received almost 40 percent of its CCC payments for corn, almost 50 percent for rice, and the balance for wheat. Feed-grain payments were negligible in the other subareas.

While more than 25 percent of U.S. cotton farms participate in the CCC loan program, only 10 percent do so on the western side of the valley and in the State. In 1987, the Grasslands Subarea accounted for 13.8 percent of the westside acreage in program crops, but farmers in the subarea received 23 percent of the CCC loans. The Westlands Subarea had 27.2 percent of the acreage in program crops and received 33.1 percent of the payments. The Kern Subarea had about 25 percent of the acreage and CCC receipts. The Tulare Subarea had 32.8 percent of the acreage and 18.3 percent of loan payments.

In 1987, westside farms received 0.6 percent of total U.S. payments and CCC loans to all farms, 2.5 percent of payments and loans to farms with any land irrigated, and 7.3 percent of payments and loans to irrigated farms. The San Joaquin Valley as a whole contributed 21.3 percent of the value of U.S. agricultural output from irrigated farms and received 10.5 percent of government payments to irrigated farms.

FISH AND WILDLIFE RESOURCES

[Data, references, and analyses supporting the information included in this section can be found in the Drainage Program's 1989 report, Preliminary Planning Alternatives.*]*

Habitat Losses and Population Declines

Long ago, seasonal flooding of large areas of the San Joaquin Valley floor created a patchwork of aquatic, wetland, riparian forest, and valley oak savannah habitats. Surrounding these overflow lands were large areas of California prairie and San Joaquin saltbush. In the southern part of the valley, Tulare Lake and four smaller lakes were interconnected by a vast network of sloughs, riparian forests, and wetlands. On the average, during the past few thousand years, all five lakes in the Tulare Basin covered a total of about 516,000 to 625,000 acres, or about 800 to 1,000 square miles.

The diversity of habitats in the valley supported large populations of resident and migratory species of fish and wildlife. Before the region was settled, the year-round native plant and animal life in the Tulare Basin was so abundant that it supported the densest population of native Americans on the North American continent that was not engaged in agriculture. During the late 1800s, enormous numbers of waterfowl and fur-bearing mammals were commercially harvested throughout the San Joaquin Valley, and Tulare Lake supported a small commercial fishery for western pond turtles and native minnows.

Widespread development of agricultural lands, draining of the once-extensive lakes, drastically reduced instream flows, and declining water quality have taken a substantial toll on the native aquatic, wetland, riparian, and terrestrial habitats of the San Joaquin Valley. The present acreage of natural freshwater lakes on the valley floor is less than 1 percent of

Migrating ducks rising from a pond in wetlands of the Grasslands Subarea on the Pacific Flyway.

the historic extent. Current acreages of wetland and riparian habitats are less than 15 percent and about 7 percent, respectively, of their historic extent. San Joaquin saltbush habitat now occupies less than 7 percent of its historic acreage. Such drastic reductions of these habitats have caused the decline of many species of plants and animals endemic to the valley. Several species that once occurred in the valley no longer exist there or have become extinct, and 29 others are listed as endangered by the Federal or State governments.

Water Supplies and Needs

About 200,000 acres of public and private land in the San Joaquin Valley are managed primarily for the benefit of fish and wildlife. These areas need over 400,000 acre-feet per year of fresh water to satisfy optimum management needs. Reliable firm supplies of fresh water for these areas currently total about 30 percent of needs.

At present, about 4.7 million acres of irrigated agricultural land in the San Joaquin Valley receive about 17.6 million acre-feet per year of irrigation water. Until recently, surface and subsurface agricultural drainage from some of these lands, commingled with other surface water, provided over 50 percent of the water used by fish and wildlife areas, and these waters still provide instream flows for fisheries and other beneficial uses.

Several major dam, reservoir, and canal systems have been constructed and are operated in the Central Valley to serve agricultural and urban water needs. These projects have created many severe problems for fisheries in the San Joaquin and other river systems. Although specific instream flow needs for many streams and associated fisheries in the valley have not yet been determined, it is apparent that instream flows in the mainstem San Joaquin (above its confluence with the Merced River) and in the major tributaries are currently inadequate to sustain migration of salmon. Further study is needed to determine instream flow needs of San Joaquin River fisheries. Additional planning, analysis, and field testing of methods to provide adequate and firm supplies of clean, fresh water for valley fish and wildlife are also warranted.

Toxicity of Drainage-Water Contaminants

Analyses of subsurface agricultural drainage water have revealed high salinity and elevated concentrations of toxic or potentially toxic elements (including arsenic, boron, cadmium, chromium, copper, lithium, manganese, molybdenum, nickel, selenium, strontium, uranium, vanadium, and zinc). Recent laboratory and field toxicity research reveals that fish and wildlife are more sensitive to the toxic properties of several of these chemical elements than previously believed. This is illustrated by the following examples for selenium, boron, and salts.

The U.S. Environmental Protection Agency's ambient freshwater aquatic life water-quality criterion for selenium was recently reduced from 35 to 5 ppb. The State Water Resources Control Board and the Central Valley Regional Water Quality Control Board have recommended that water used for wetlands management in the Grasslands Subarea contain average selenium concentrations of 2 ppb or less. Furthermore, University of California scientists have identified 1.0 to 1.5 ppb waterborne selenium as the range that causes no adverse effects. Selenium concentrations in North Mud and Salt Sloughs in the Grasslands Subarea average 6.0 ppb. Selenium concentrations in the 7,000 acres of evaporation ponds average 49 ppb, based on acreage-weighted means, and range above 1,000 ppb.

Boron, which was previously thought to be nontoxic to wildlife, has been shown to have adverse effects upon wildlife at concentrations of 900 ppm (dry weight) in the diet. Waterfowl food-chain organisms collected from Kesterson Reservoir and several other evaporation ponds in the valley have been found to contain concentrations of boron that approach or exceed this toxic threshold.

Highly saline water, free from elevated concentrations of trace elements, can also pose a health threat to wildlife. For example, freshwater ducklings are very sensitive to salty water. Toxicity tests with mallard ducklings have shown that molt was slowed when they were provided a single source of drinking water containing

Embryo of a black-necked stilt deformed by selenium poisoning.

3,000 ppm total dissolved solids, and growth was reduced when their sole source of drinking water was 7,720 µS/cm electrical conductivity. In addition to containing elevated concentrations of various trace elements, evaporation ponds in the San Joaquin Valley, heavily used by ducks and other aquatic birds for nesting and rearing of young, are also very saline — up to 388,000 ppm TDS — and average 31,850 ppm TDS, about equal to seawater. The combination of saline ponds and the extremely limited acreage of freshwater wetlands in the southern San Joaquin Valley during the spring breeding season potentially increases this toxic threat to aquatic birds.

Finally, the toxicity to fish and wildlife of various salts and trace elements carried in drainage water depends upon, among other variables, the species, life stage, health, and diet of the target organism; the chemical form of the contaminant; the bioavailability of the contaminant (which for waterborne concentrations can be affected by other chemical characteristics of the water); and the interactions (additive, synergistic, and antagonistic) of multiple contaminants. Very little information is available regarding many of these complex issues, and additional research is warranted.

Contamination and Biological Effects

Elevated concentrations of drainage-water contaminants have been discovered in water, sediments, food-chain organisms, and major vertebrates in a number of San Joaquin Valley areas outside Kesterson Reservoir and the San Luis Drain. These areas include rivers, streams, and ponds; riparian zones and wetlands; and upland sites. All these areas (both natural and manmade) provide fish and/or wildlife habitat. In several of them, elevated contaminant concentrations exceed documented toxicity thresholds, and studies have documented adverse biological effects that are believed to be contaminant-related.

In the San Joaquin Basin, the same drainage water that previously was used to flood wetlands in the Grasslands area is now being discharged into various canals and natural channels for conveyance to the San Joaquin River. In the Tulare Basin, the number and size of evaporation ponds receiving drainage water have continued to increase.

Evaporative concentration is dramatically increasing the waterborne concentrations of drainage-water contaminants such as boron and molybdenum in these ponds. In addition, through bioconcentration and possibly biomagnification, aquatic plants and animals can accumulate tissue concentrations of some drainage contaminants 100 to 10,000 times greater than those in the water. Statistically significant adverse biological effects (including impaired egg hatchability, elevated frequencies of embryo deformities, and reproductive failure) have been documented at seven of the valley's evaporation pond systems (about 58 percent of the ponds studied, which represent about 60 percent of the total acreage of ponds in the valley). Not all evaporation ponds have been studied, and efforts to date have focused upon breeding birds. Additional research is needed to determine whether adverse biological effects are occurring at other ponds and what effects, if any, operation of the ponds is having on wintering waterfowl and shorebirds, endangered species, and public health. Additional field research is also needed to field-test techniques for decontaminating and restoring drainage-water-contaminated fish and wildlife habitats and significantly reducing or eliminating the hazards posed to wildlife by evaporation ponds.

A test plot of eucalyptus trees (background) and atriplex (fore- and midground) being irrigated with drainage water. Plant transpiration reduces the water volume and concentrates the salts in the remaining drainage.

Agroforestry Plantations

Agroforestry plantations are being established in the study area in an attempt to reduce the magnitude of agricultural drainage-related problems. The trees (primarily eucalyptus) and halophytes (such as atriplex) are used to: (1) Lower the ground-water table and (2) reduce the volume of drainage water by increasing evapotranspiration. Recent studies have shown that the plantations provide habitat for several species of wildlife, including mourning doves, ring-necked pheasants, blacktailed jackrabbits, desert cottontails, a wide variety of songbirds, and possibly some large mammals such as foxes and coyotes. The plantations may benefit both farmers and wildlife. However, where they are irrigated with concentrated drainage water, more research is needed to determine whether these sites pose a contaminant hazard to wildlife. Appropriate management practices that will either increase wildlife values or reduce or eliminate contaminant hazards must be identified.

PUBLIC HEALTH

Public health concerns associated with drainage water were investigated during this study (Klasing and Pilch, 1988; Klasing, et al., 1990). Table 6 summarizes the concerns with drinking water, food crops, fish and game, and occupational exposures.

Safety of Food Crops

To date, selenium concentrations have been measured in about 125 food-crop samples grown in the western San Joaquin Valley, as well as in the milk and liver of some cows raised in the area. Overall, selenium concentrations in crops from the study area were similar to typical

U.S. selenium concentrations reported for those samples. Of the food samples analyzed, even daily consumption of the crops with the highest selenium levels found in the western part of the valley would not approach the quantity necessary for selenium toxicity. At most, they would provide part of the nutritional requirement for selenium in the human diet. The selenium content of cow's milk and liver obtained from the study area were similar to that for crops; however, the extent to which these cattle may have been exposed to elevated concentrations of selenium is unknown.

Certain crops in isolated areas may possibly contain higher concentrations of selenium than have been previously measured. If this is the case, persons who place heavy reliance on those foodstuffs to meet their dietary needs (such as may occur with subsistence gardening) would increase the risk of selenium toxicity. However, this has not been reported to have occurred in the westside San Joaquin Valley. Most consumers eat a variety of foodstuffs from many geographic areas. Persons whose consumption patterns are limited either to a small number of foodstuffs or to a very small geographic region may increase their risk of both deficiencies and excesses of trace elements in their diet.

The risk to public health from potentially elevated concentrations of other agricultural drainage-water contaminants in foodstuffs is not known at this time. Currently, several other elements (arsenic, boron, and molybdenum) that have been found to be elevated in some agricultural drainage water are being analyzed in local food crops.

Safety of Consuming Fish and Game

Because selenium can be concentrated by some aquatic plants and invertebrates to levels far higher than those found in the water in which they grow, selenium from agricultural drainage water has become toxic to some aquatic birds that feed in drainage-contaminated aquatic environments. Fish and aquatic birds may in turn accumulate relatively high concentrations of selenium in their tissues, becoming a potential health risk to humans who consume them. A survey of these species at specific locations within the western San Joaquin Valley has shown that unrestricted consumption of contaminated fish or game over an extended period could cause recognizable signs of selenium toxicity. To date, however, selenium toxicity in humans has not been reported to public health officials or confirmed as a result of such consumption.

Studies of other agricultural drainage-water contaminants in the tissues of fish and wildlife have not shown risks that exceed those from exposure to selenium. Therefore, procedures currently recommended to reduce selenium exposure from contaminated fish and wildlife (for example, health advisories to limit consumption of such game) can be expected to also protect the consumer from overexposure to other drainage contaminants.

Table 6. PUBLIC HEALTH CONCERNS ASSOCIATED WITH DRAINAGE WATER

Constituent	Drinking Water	Food Crops	Fish and Game	Occupational Exposures
Selenium	Some domestic wells in high-selenium areas may exceed the present EPA-recommended safe level of 10 ppb. However, EPA has proposed raising the level to 45 ppb. See the Federal Register, May 22, 1989; vol. 54, no. 97.	Field tests suggest that normal consumption of crops is unlikely to exceed recommended dietary allowances.	Consumption of fish and game from evaporation ponds and other contaminated areas that exceed safe levels should be restricted. In most other cases, normal consumption would be unlikely to cause toxicity.	Workers should restrict their exposure of direct contact with ele-vated levels of contaminants.
Molybdenum	Daily consumption of water from some domestic wells in high-molybdenum areas may exceed recommended health levels.	No standard defined.	No health-related data available.	Same as above.
Arsenic	Some domestic wells in high-arsenic areas may exceed recommended safe levels.	Regulatory standards are not developed.	Consumption of fish and game from evaporation ponds and other contaminated areas should be restricted.	Same as above.

Safety of Foraging

Preliminary investigation of persons who forage in the western side of the San Joaquin Valley has not shown evidence of overexposure to selenium. However, substantial difficulties exist in obtaining and evaluating survey data of this nature. Thus, it cannot be assumed that the population of foragers in this region is safe from exposure to potentially toxic concentrations of agricultural drainage-water contaminants. Persons who make a regular practice of foraging would likely be at similar or greater risk from exposure to drainage contaminants than would fishermen and hunters, who are likely to eat a more varied diet.

Occupational Exposures to Drainage Contaminants

Concentrations of selenium in the blood and urine of personnel monitored during closure and cleanup operations at Kesterson Reservoir were within normal limits. Thus, it seems unlikely that such occupational exposures at sites similarly contaminated would cause above-normal selenium levels. Occupational exposures to other contaminants have not been evaluated. Because occupational activity may result in significant contaminant exposures by inhalation or dermal routes rather than by ingestion, different methods for assessing exposure and adverse health effects may be warranted. As an example, certain chemical forms of chromium and arsenic (and several other metals) are known to cause respiratory cancers or other chronic pulmonary diseases when inhaled. No investigation has been made of specific risks to workers from inhalation or dermal exposures to contaminants found at sites where drainage water has accumulated and concentrated (such as evaporation ponds or treatment facilities). No evidence is available to suggest that health risks from these exposure routes would be elevated for the general population.

Safety of Drinking Water

Some ground-water sources of drinking water in westside San Joaquin Valley have concentrations of certain drainage constituents that can adversely affect human health, particularly when consumed over a long period. Arsenic, selenium, and nitrates have all been found in some domestic wells in the valley in concentrations that exceed current water-quality guidelines. With the exception of nitrates, these elevated concentrations are merely background levels that, in many cases, can be considered normal for these elements in the study area. Nonetheless, it is important to document when concentrations of substances exceed criteria set to protect an area's public health so that this information can be used in formulating drainage planning alternatives.

SOCIAL CONDITIONS

Community Infrastructure

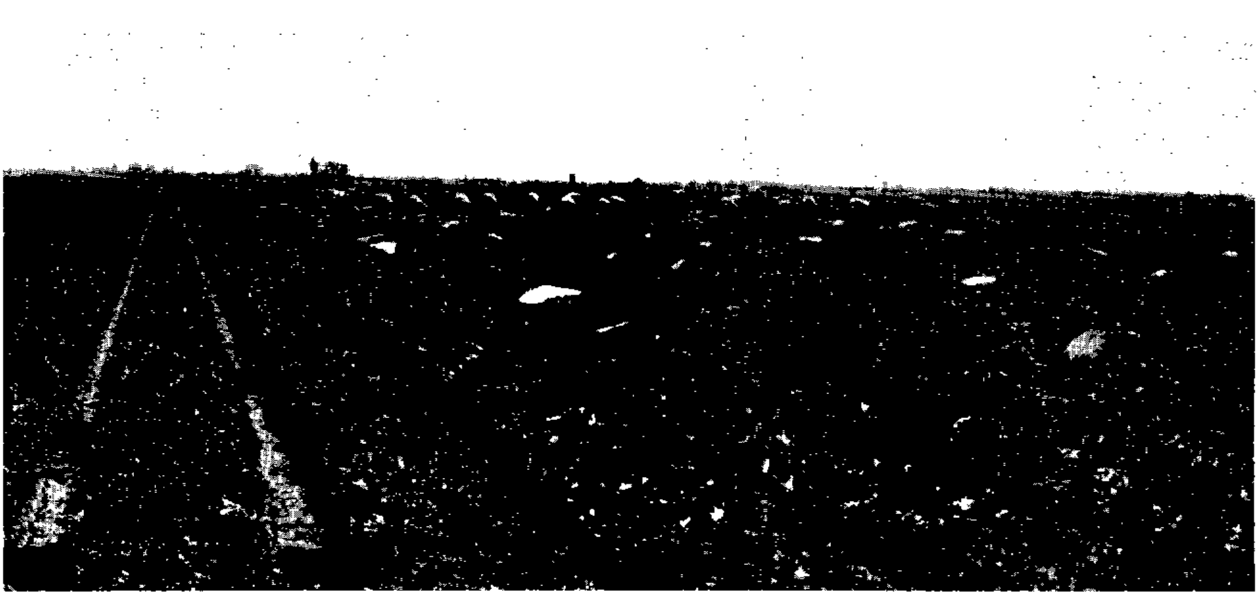
While the economies of the communities on the western side of the San Joaquin Valley are primarily based on agriculture, these towns have sufficient infrastructure and other commercial resources to adapt to broad changes in the valley economy. A number of these communities are currently experiencing significant growth caused by residential-development overflow from coastal metropolitan areas. The rural character of these towns is being rapidly altered as they become more suburban, with residents commuting to cities on the eastern side of the San Joaquin Valley, to the Santa Clara Valley, and to the San Francisco Bay area. The direct dependence of westside community residents on agriculture is diminishing because a larger proportion is working in nonagricultural jobs.

The extent and rapidity of this suburbanization were not anticipated, and the emergence of zoning changes and subdivision development poses new problems for farms and wetlands in the surrounding areas. Given this continuing growth and high real estate prices in the metropolitan areas from which the newcomers originate, this transformation is expected to continue and even accelerate.

Farm Labor

Farm workers in the San Joaquin Valley are typically immigrants. Most come from Mexico, but significant numbers also come from Central America, Asia, and the Middle East. Only about ten percent of California's farm laborers were born and raised in the United States, and only about half of these are from California. Once they have arrived, a large minority of farm workers continues to migrate, either by moving back and forth between the U.S. and Mexico during the year or by following seasonal cropping patterns around the State. About 37 percent of the State's farm workers take part in one of these forms of continuing migration (Mines and Martin, 1986).

Crop specialization on valley farms has created seasonal employment for farm workers, who often secure a succession of short-term jobs to remain employed for most of the year. Although mechanization, new seeds, and improved production techniques are causing seasonality to decline, large numbers of seasonal farm workers are still employed in California (Martin, 1987).



Large numbers of farm workers are needed to tend and harvest crops on the westside San Joaquin Valley.

Farmers in the San Joaquin Valley depend more on hired labor than do farmers elsewhere in the U.S. Most farmers rely either on foremen to recruit laborers, usually without the direct involvement of top management, or on farm labor contractors, who hire farm workers and then contract with growers to provide a temporary workforce. The use of intermediaries to meet farm labor demands is becoming increasingly important in the State (Martin, 1987).

Issues surrounding farm workers' health and safety are growing in importance as concern for public health and environmental quality focus attention on farm chemical use and other management practices.

Water Supply and Drainage Management Organizations

Most agricultural water management processes in the San Joaquin Valley either originate in organizations or are strongly mediated by them. At the most general level, valley water management is institutionalized within organizations and networks of interorganizational relationships that structure linkages among water users, local water management organizations, and government agencies. Responsibility for water-use policy, planning, and day-to-day activities affecting drainage-related agricultural water management in the valley is dispersed among a large number of public and private water management organizations. Public water management involves water agencies, joint power authorities, hundreds of special districts, county governments, and a plethora of State and Federal administrative and regulatory agencies. Private water management is structured by incorporated and unincorporated river water associations and nonprofit mutual water companies, numerous agricultural corporations, family farms, and other groups (Coontz, 1989 and 1990a).

Water Management Networks

No single organization or network shapes overall water management or is found in all phases of water management throughout the valley. Valley water management is shaped by a variety of networks of private and public water management organizations. Network structures affecting agricultural water management at any given location and for specific kinds of water management activities are unique configurations of arrangements among various organizations. "Application" and "regulatory" networks are among the more important types affecting agricultural water management practices (Coontz, 1990b).

Application networks develop programs to provide professional and/or financial assistance to both on-farm and local organization water managers with the aim of improving water management practices and facilities. University researchers, Federal and State agencies, and contract consulting firms are the cornerstones of application networks.

Regulatory networks are composed of relationships among government regulatory agencies and various groups with interdependent interests tied to drainage management. Regulatory networks mediate conflicting interests by attempting to constrain and/or induce the discretionary activity of network participants so that they conform to a limited range of accepted actions and/or results. At least two qualitatively different regulatory networks, roughly corresponding to the valley's two hydrologic basins, shape regional regulatory strategies. These are a prescription-oriented network in the Tulare Lake Basin, which defines a range of acceptable actions to resolve drainage problems, and a performance-oriented network in the San Joaquin River Basin, which places more emphasis upon defining and meeting water-quality objectives.

Regional Institutional Spheres

In addition to organizations and networks, regional institutional spheres are important social structures that shape agricultural water management. They are configurations of unique political, economic, and social arrangements among and between water users and local water management organizations within a region. These spheres are more geographically restricted than regulatory networks and application networks. The principal institutional factors contributing to regionally specific variations that influence relationships among and between water managers within a region to outside organizations or government agencies include: (1) The degree to which formal or informal water management arrangements dominate, (2) the extent to which State or Federal agencies are integrated into water supply management, especially by the institutional structure of water rights and water contracts, (3) the degree to which agricultural water supply management and drainage management represent separate or integrated management structures, and (4) the relative importance of market relations in regional water management. The Drainage Program's five subareas roughly correspond to major regional institutional spheres (Coontz, 1990b).

THE EXISTING INSTITUTIONAL STRUCTURE

> *[Information in this section is summarized from a comprehensive study of water resources institutions sponsored by the Drainage Program (Thomas and Leighton-Schwartz, 1990).]*

Water management institutions and laws that can both contribute to and help solve drainage and drainage-related problems are best described by illustrating the "chain of custody" of the water that ultimately results in problem drainage. Governing all water use in the State is the

Constitution of the State of California. The Constitution provides that all water within the State is the property of the people of California.

Though conceptually the physical resource remains a public asset, individuals may acquire an exclusive right to its use in the nature of a property right. But it is a highly qualified one. The State Water Resources Control Board oversees the allocation of these rights and the protection of water resources for the people of California. Private rights are conferred to those who exercise physical control over the water — be it surface or ground water — and put the water to a reasonable and beneficial use. Recognized beneficial uses pertinent to the drainage problem include irrigation, ground-water storage, and fish and wildlife uses. An "environmental water right" vests only where the water is diverted from its natural channel, as when it is applied to a refuge, but it does not vest when the water is left in the waterway.

Specifically, appropriative and riparian water rights (post-1914) are now administered through water permits issued by the State Board. Most of the irrigation water that eventually contributes to drainage is supplied through the Federal and State Water Projects as appropriative rights holders. However, appreciable amounts are supplied from ground-water pumping and local surface water. The Bureau of Reclamation holds water permits from the State Board entitling it to store, divert, and deliver water to the San Joaquin Valley through the Central Valley Project. The California Department of Water Resources holds permits for the water it develops and distributes to the valley through the State Water Project.

In protecting the public's water resources, the State Board retains authority to modify these permits to prevent the unreasonable use of water. However, unlike the diversion of surface water, there is no State-administered permit system for ground-water extraction. Nonetheless, the State Board's authority to prevent waste and unreasonable use of water comes not only from its contractual rights under the permits it issues, but also from the State Constitution, which does extend to the use of ground water. This authority is codified in State law and provides that the State Board, on its own motion or by petition of DWR or an aggrieved person, may prevent the unreasonable use of any surface or ground water.

In theory, this authority allows the State Board to require the Bureau of Reclamation and DWR, their contractors, or the end water user to take steps to reduce the generation of surface and subsurface drainage caused by excessive water application. In practice, however, the State Board has never used this power to address the drainage problem, and its exercise is sufficiently discretionary and judgmental that it is unlikely to provide a reliable solution to the overall problem.

Moving down a link in the chain of water management and use, the Bureau of Reclamation and DWR provide water to local water entities, including water agencies, water districts, irrigation districts, mutual water companies, and joint-powers authorities through contracts. These irrigation water service contracts vary significantly, but generally impose repayment, place, and manner-of-use restrictions on the districts. Pursuant to Federal contracts, which are effective for 40 years and automatically renewable, water entitlement is a stated maximum volume of firm water supply in acre-feet per year and currently priced between $3.50 per acre-foot and $19.31 per acre-foot. The price depends on the cost of facilities that were necessary to develop and deliver the water at the time of the contract and annual operation and maintenance costs. When these contracts are renewed, water charges will be based on annually adjusted cost-of-service rates. In 1990, Central Valley Project irrigation cost-of-service rates for the Delta-Mendota Canal and San Luis service areas varied between $13.58 and $23.01 per acre-foot (USBR, 1989). Water use is restricted to agriculture, and may be neither transferred to another nor used outside the district's boundaries without the approval of the Bureau of Reclamation.

Pursuant to State Contracts, which are effective for 75 years, the amount of total annual firm entitlement of State Water Project water that may be delivered in any month for agricultural use is limited to 18 percent of a contractor's annual entitlement amount. The price, which is based on the estimated actual operation, maintenance, energy, and capital recovery cost, is calculated annually. The 1990 price of State Water Project water in the San Joaquin Valley ranges from $32 per acre-foot to $67 per acre-foot (DWR, 1989). Transfers of SWP water must be approved by DWR. DWR seeks concurrence of all SWP contractors on transfers.

The final link in the chain is the sale of the water from the district to the grower. Generally, growers have pro rata shares or entitlement to the district's water, and pay for it at a rate designed to defray the costs of capital facilities, contract charges from project operations, and administrative expense. A few districts are currently experimenting with tiered or progressive water rates that are designed to induce conservation of water in excess of minimal evapotranspiration and leaching requirements. Some also impose rules on the recycling of tailwater. Generally, however, growers are left unfettered with regard to their decisions on how much water to apply, when, and in what manner. Some districts, most notably Westlands Water District, do provide informational programs to their growers on these variables, expressly designed to help the growers minimize drainage generation.

The regulatory institutions that govern the ultimate fate of drainage water in the valley's environment are predominantly State-created. The functions and dysfunctions of the regulatory system can be conveniently explained by referring to the public resources put at risk by drainage water. Existing regimes cover three of these resources: surface water, ground water, and wildlife.

The State Board protects both surface- and ground-water quality in the State through water-quality standards developed by Regional Water Quality Control Boards. Water-quality standards consist of "beneficial-use" designations and "water-quality objectives" which are established to protect the beneficial uses. These are set as part of regional or statewide water-quality control plans in quasi-legislative proceedings.

The Central Valley Regional Board has established a plan to protect San Joaquin basin surface water. The protection scheme, which is applicable to districts in the Northern and Grasslands subareas and the Westlands Water District, requires that drainers meet water-quality objectives for selenium, boron, and molybdenum. The Regional Board may revise the standards it established for selenium and boron because the Environmental Protection Agency, which has authority to oversee State water-quality protection, has determined that they do not protect beneficial uses. This scheme requires that drainers provide the Regional Board with plans, known as Drainage Operation Plans. The DOPs should include measures to reduce drainage and, hence, the amount of pollution discharged to the river.

Ground water is protected through State and Federal programs. Federal law provides little more than planning authority in protecting ground-water quality, but drives the protection of subsurface drinking water in California through standards established by the EPA. The primary focus of the Federal program is the prevention of contamination, rather than correction of existing pollution problems.

The more comprehensive ground-water protection schemes are those imposed by the State. California's ground-water strategy is to maintain ground-water quality at a level that satisfies present and future drinking water needs and other beneficial uses (such as irrigation) and, where feasible, to restore ground-water quality to these levels.

The State provides for two distinct kinds of ground-water protection standards: those relating to water quality and those relating to drinking water. Drinking-water standards address the quality of water at the point of delivery to consumers. Water-quality standards and drinking-water standards are established under two separate statutory schemes, administered by two different State agencies. The former is regulated by the State Board and the Regional Boards, and the latter is regulated by the California Department of Health Services. Additional protection is provided by the Department of Water Resources in its regulation of the design and construction of wells.

Protection of both wildlife and ground water from drainage disposed of in evaporation ponds has come largely from the State. DHS and the Central Valley Regional Board are the agencies charged with regulatory responsibilities. DHS basically deferred regulation of valley ponds to the Regional Board, which issues permits for the pond operations. Ponds that contain drainage water that exceeds State hazardous waste threshold limits may be operated under an exception to the State's land disposal ban. This exception expires in 1992.

The U.S. Fish and Wildlife Service is the principal Federal agency responsible for protecting and enhancing the nation's fish and wildlife resources, including preventing the unlawful take of migratory birds under the Migratory Bird Treaty Act. Its authority to protect migratory birds is broad. The agency may request Federal prosecution of evaporation pond owners and operators, which might lead to closure of ponds. To date, the USFWS has not prosecuted any San Joaquin Valley evaporation pond owners or operators.

The California Department of Fish and Game has similar authority under State laws. Under the State Fish and Game Code, DFG may seek action by the Attorney General against the impairment of fish and wildlife, including drainage-related impairment such as contamination of surface-water habitats from drainage discharges.

The fish and wildlife agencies may themselves be regulated by other Federal and State agencies. Specific to the drainage problem, USFWS and DFG are subject to the Regional Board's regulations for operations of their refuges and wildlife areas that discharge drainage water. The USFWS has prepared a Drainage Operations Plan for operation of the San Luis National Wildlife Refuge.

Chapter 4. THE PLANNING FRAMEWORK

Planning takes place within an established framework of public sector policy and law and private sector resource use and management. This framework must be acknowledged in developing plans for solving drainage and related problems, and planning objectives and criteria must be based on it.

This chapter outlines drainage-related public policy, local drainage management initiatives, and the planning objectives, methods, and criteria upon which plans presented in the following chapters are based.

PUBLIC POLICY

The policy base adopted for Drainage Program planning is discussed in the following sections in terms of drainage service, environmental protection, drainage studies and monitoring, and constraints.

Drainage Service

The need for management of drainage water has long been recognized by both the State and Federal governments and has been stated in a number of official documents, especially in the Federal legislation and administrative arrangements for supplying water to the western side of the San Joaquin Valley. Official recognition of the need for solving the drainage problem, if not indeed commitments for actually solving it, appears in legislative statements about "drainage service" or "drainage management plans."

The legislation authorizing the San Luis Unit of the Federal Central Valley Project requires that an interceptor drain be provided for the Unit. Beginning in 1965 and each year since then, Congress has included a provision in the CVP appropriations act that prohibits selection of a final point of discharge for the San Luis Drain until certain conditions have been met. An appraisal-level study of the San Joaquin Valley Drain serving the entire valley was authorized in 1974 and completed in 1979 (IDP, 1979), and a feasibility study was authorized in 1980 but was never completed. The funding of studies indicates the Federal government recognizes the need for a drainage solution. Construction of an 85-mile portion of the San Luis Drain demonstrates a Federal commitment to solve the problem. A 1986 Federal court order in the compromise settlement of *Westlands Water District* v. *United States of America* requires the United States to develop and adopt a drainage plan acceptable to Westlands by December 31, 1991.

The State of California has also acknowledged in a number of documents the need to manage agricultural drainage in the San Joaquin Valley. *The California Water Plan* (DWR, 1957) recognized the need for drainage in areas proposed to be irrigated, especially on the western side of the San Joaquin Valley. The Tulare Basin has subsequently become a part of the area provided irrigation water from the State Water Project. In discussions with the Federal government regarding a master drain from the San Joaquin Valley, the State has, at various times since 1957, tentatively agreed to participate in such a drain, but has never actually done so.

Environmental Protection

Federal and State environmental protection laws, regulations, and local ordinances affect possible drainage-related strategies and provide objectives and constraints that must be satisfied in drainage plans. The primary laws relevant to drainage problems are:

Federal	State
Fish and Wildlife Coordination Act	California Environmental Quality Act
Migratory Bird Treaty Act	California Administrative Code:
National Environmental Policy Act	Title 22 (Hazardous Wastes)
Resource Conservation and Recovery Act	Title 14 (Natural Resources)
Federal Endangered Species Act	California Fish and Game Code
Clean Water Act	California Water Code
	Porter-Cologne Water Quality Control Act
	Toxic Pits Cleanup Act
	California Endangered Species Act

For planning, it is assumed that, at a minimum, drainage plans will have to meet the objectives and standards embodied in or developed pursuant to these laws. The primary standards to be met from both State and Federal laws are included in the Level A performance standards presented in the "Planning Objectives" section of this chapter.

Plans developed to comply only with present laws may not provide sufficient guidance for future decision-making. Efforts are under way to increase protection from additional potentially harmful substances introduced into the environment and to lower the permissible concentration of a toxicant or contaminant in the environment. Moreover, the trend of scientific discovery is toward revealing an increasingly complex natural environment. It is possible that even more stringent standards for environmental protection may apply in the future. To address a range of possible future conditions, plans will be developed for more stringent (Level B) performance standards. These standards are also presented in the "Planning Objectives" section of this chapter.

The A and B levels of performance are presented to bracket a range of probable future conditions. Judgment must be exercised in limiting the enormous range of possible future conditions. For example, the Drainage Program has assumed that water-quality objectives will be set in terms of concentrations of substances allowable in receiving water, rather than in terms of the total load allowed in drainage water. This is a subjective assumption, not a declaration of a preference.

Drainage Studies and Monitoring

Intensive studies of causes and impacts of contaminant-related drainage problems began in 1983 and were continued through the balance of the decade (see "Selected Bibliography" at the back of this report). Although much has been learned, knowledge of some aspects of drainage problems is still limited, and many uncertainties about solving the problems remain. Areas of limited knowledge include interactive and long-term effects of contaminants on fish and wildlife, levels of public health risk posed by contaminants, specific causes of water table rise and deterioration of water quality on small land units, the long-term sustainability of agriculture under existing hydrologic and economic conditions in the valley, and future drainage conditions. To learn more, the effects of the drainage problem on the environment should be monitored.

The basic strategy of monitoring should be to identify and collect information on biota, soils, and the water regime so that changes in drainage problems and conditions can be determined, particularly in response to actions taken to solve the problem. Plans can then be re-evaluated periodically and adjusted in light of new knowledge and new conditions. Design, funding, and implementation of a comprehensive long-term monitoring program are needed.

Constraints

In addition to the laws and performance standards cited previously, two Drainage Program policies further constrain planning. All alternative plans must: (1) Meet the water-quality objectives of the State of California, and (2) focus on in-valley solutions. [Action by the Drainage Program Policy and Management Committee on June 15, 1987.]

Objectives for both surface- and ground-water quality adopted by the Central Valley Regional Water Quality Control Board and approved by the State Water Resources Control Board have become objectives for plan development. Level B performance standards make provision for more stringent standards in the future.

The focus on in-valley solutions precluded study by the Program of the removal of drainage water from the valley by any means other than the San Joaquin River. This policy did recognize, however, the need to study and describe the distribution and fate of salts in the drainage problem area.

LOCAL DRAINAGE MANAGEMENT INITIATIVES

Initiatives by local water management organizations to manage drainage and related problems are presently under way in each subarea, and it appears they will contribute to improving management of the problem. Most local initiatives to improve existing water supply and drainage management practices involve outside cooperators, sponsors, regulators, or other participants. These efforts are typically implemented through a variety of organizational and institutional arrangements that link individual water users, local and regional water management organizations, university researchers, and State and Federal agencies (Coontz, 1990b). Local initiatives should be encouraged, supported, and coordinated as part of an overall management plan.

Many local initiatives are not mentioned in the alternatives and recommended plan presented in the following chapters because the plan is not detailed. Some of the more significant of these include: (1) on-farm water management evaluation and conservation programs; (2) drainage reuse, treatment, and disposal studies and demonstration projects; and (3) construction of new water management facilities and improvements to existing facilities. Local initiatives seeking to reduce drainage volumes, effect institutional change, restore and protect fish and wildlife habitat, and develop workable methods of treating and disposing of drainage water are important contributors to management of the problem and are considered part of the plan.

PLANNING OBJECTIVES

The technical objectives that guided formulation of alternative plans are stated in terms of specific aspects of drainage and drainage-related problems: water quantity, water quality, land use, and public health.

- Water quantity objectives pertain to control of ground-water levels by managing the water in and out of the shallow aquifer and to provision of fish and wildlife water supplies.
- Water quality objectives involve allowable water constituent levels of the San Joaquin River, Salt and Mud Sloughs, ground water pumped to lower water tables, evaporation pond influent, and wetland and agricultural water supplies.
- Land use objectives stress future maintenance of agricultural productivity.
- Public health objectives are concerned with protecting the public from the possibility of contaminated fish, wildlife, and agricultural foodstuffs.

Table 7 lists the planning objectives and quantifies them, where applicable. Performance Levels A and B are shown for each objective, even when they are the same. The need for and use of performance levels were described previously in the section of this chapter on "Environmental Protection."

PROGRAM PLANNING METHODS

The method used to formulate and evaluate alternative plans is described in the Drainage Program's report, *Formulating and Evaluating Drainage Management Plans for the San Joaquin Valley* (1988). [Details of the planning procedures and their application are presented in a Drainage Program technical report (D.G. Swain, 1990).] Early in this Program, over a hundred ideas and concepts for solving part or all of the drainage problem were screened and reduced to some 80 drainage and drainage-related management options. These options were further evaluated through an extensive review period for technical feasibility, potential effectiveness in solving the drainage problem, cost, and acceptability to the public. This reduced the number to about a dozen major options that could be combined in various ways to manage or solve drainage problems on the western side of the valley.

For each subarea, those options effective in reducing the drainage-water problem were combined into three planning alternatives that emphasize: (1) Source Control (the conservation and reuse of agricultural water), (2) Ground-Water Management (the extraction

Table 7. PLANNING OBJECTIVES, CRITERIA, AND STANDARDS

ITEM	OBJECTIVE: Performance Level A	OBJECTIVE: Performance Level B
WATER QUANTITY		
Plan/design average regional deep percolation that must be managed after 0.02-0.35 ac-ft/acre/yr reduction by source control measures	0.4 ac-ft/ac/yr	0.4 ac-ft/ac/yr
Plan/design minimum depth to water table	5 feet	5 feet
Criteria for conditions required for deep pumping of semiconfined aquifer	Minimum combined aquifer thickness of 100 feet	Minimum combined aquifer thickness of 200 feet
Water supply to fish and wildlife	a. Water conserved by reducing deep percolation could be used to meet drainage water replacement water needs and alternative habitat water requirements associated with evaporation ponds. Water for restoration of drainage-contaminated wetlands will also be included. b. Additional water supplies needed to improve fish and wildlife resources will be quantified, and possible sources and means of supply will be identified.	
WATER QUALITY (Mean monthly values, unless otherwise noted)		
San Joaquin River (Mouth of Merced River to Vernalis)		
Total Dissolved Solids, near Newman (ppm)	—[a]	650 [b]
Total Dissolved Solids, near Vernalis (ppm)	450 [c]	450 [c]
Boron, near Newman (ppm)	0.8 [d] (3/15 - 9/15); 1.0 [d] (9/16 - 3/14); 1.3 [d] (Critical year only)	0.7 [b]
Selenium, near Newman (ppb)	5 [d]; 8 [d] (Critical year only)	2 [k]
Molybdenum, near Newman (ppb)	10 [d]	10 [b]
Salt and Mud Sloughs and San Joaquin River, Sack Dam to Mouth of Merced River		
TDS (ppm)	—[a]	2,000 [b]
Boron (ppm)	2 [d]	2 [b]
Selenium (ppb)	10 [d]	2
Molybdenum (ppb)	19 [d]	10 [b]
Pumped Ground-Water Aquifer Limits		
TDS (ppm)	1,250	1,250
Boron (ppm)	1.0	0.5
Selenium (ppb)	5.0	2.0

a Objectives not presently established or estimated.

b State Water Resources Control Board staff recommendations in "Regulation of Agricultural Drainage to the San Joaquin River," August 1987. USEPA has disapproved certain of the Board's objectives and the matter is presently unresolved.

c U.S. Bureau of Reclamation and South Delta Water Agency agreement.

d Central Valley Regional Water Quality Control Board Resolution No. 88-195, Adoption of Amendments to the Water-Quality Control Plan for the San Joaquin River Basin (5C).

e Grassland Water District agreement with agricultural drainers.

Table 7. PLANNING OBJECTIVES, CRITERIA, AND STANDARDS (continued)

ITEM	OBJECTIVE: Performance Level A	OBJECTIVE: Performance Level B
WATER QUALITY *(continued)*		
Evaporation Pond Influent (concentrations that may eliminate the need for hazing and alternative habitat)		
Selenium (ppb)	5	2
Molybdenum (ppb)	—[a]	—[a]
Arsenic (ppb)	—[a]	—[a]
Wetland Water Supply (average monthly concentration)		
TDS (ppm)	2,500[e]	1,250
Boron (ppm)	4[e]	1
Selenium (ppb)	2	2
Molybdenum	—[a]	—[a]
Arsenic	—[a]	—[a]
Agricultural Water Supply (average monthly concentration) [f]		
TDS (ppm)	500[g] 2,500[h]	1,250[g] 2,500[h]
Boron (ppm)	0.5[g] 2.0[i]	1.0[g] 4.0[i]
LAND USE		
Agricultural use	Maintain existing irrigable lands in production, except for land needed for drainage water reuse (trees), disposal activities, and urbanization.	Maintain irrigated agriculture on lands overlying exceptionally high concentrations of selenium in ground water, if economically feasible; if not feasible, retire the land.
PUBLIC HEALTH		
Fish		
Selenium objective for San Joaquin River (ppb)	5	2
Wildlife		
Selenium objective for evaporation ponds (ppb)	5[j]	1.0–1.5[k]
Agricultural Foodstuffs	Use irrigation water (both surface & ground water) & soil that will not produce a health risk in agricultural crops, animals, or animal byproducts.	Use irrigation water (both surface & ground water) & soil that will not produce a health risk in agricultural crops, animals, or animal byproducts.

f Level B criteria for agricultural water supply show the effect of increased (compared to Level A) water conservation on farmland and increased restrictions on drainage discharge; that is, more salt and boron would be excluded from receiving water through reuse and recirculation of drainage water.

g This objective is based on crop yield vs. irrigation efficiency and uniformity analysis for beans (a salt/boron-sensitive crop) and cotton (a salt-tolerant crop).

h Water-quality limit for direct use of water (without blending) for irrigation of salt-tolerant crops, using management strategies proposed (Rhodes, 1987).

i Diluted subsurface drainage used for irrigation of cotton and other boron-tolerant agricultural crops.

j Ambient fresh-water aquatic life criterion (USEPA, 1987). May require warnings for consumption of fish and wildlife by pregnant women and young children.

k "No adverse effects level" (UCCC, 1988); "no adverse effects level" (Davis et al., 1988).

of irrigable water from deep within the semiconfined aquifer to lower the near-surface water table in waterlogged land areas), and (3) Land Retirement (the retirement of irrigated agricultural lands overlying shallow ground water that contains greatly elevated concentrations of dissolved selenium and that are difficult to drain). Planning alternatives were devised for both Level A and Level B performance standards.

Comparison of the alternatives permitted drawing conclusions that were useful in formulating the recommended plan. The plan is the optimum mix of the planning alternatives used to reduce the drainage-water problem, coupled with fish and wildlife resource components.

ESTIMATING THE VOLUME OF WATER CAUSING DRAINAGE PROBLEMS

The term *problem water* was coined by the Drainage Program to represent the volume of subsurface water that occurs (or will occur) in a given place to cause a drainage problem. A drainage problem exists when there is a condition of too much shallow ground water occurring in the root zone of crops — associated often with concentrations of dissolved salt or boron in that water that reduce crop production and/or increase farm management costs. A grower experiencing economic loss under this condition has three choices: (1) Grow more salt-tolerant or boron-tolerant plants (at less profit), (2) abandon irrigated agriculture on this land, or (3) apply drainage management to this land. Such management usually begins with installing artificial drains to remove the subsurface drainage volume. If potential toxicants such as selenium are present in the drained water, storage or disposal becomes more difficult, costly, and potentially hazardous to the environment.

Problem water is generally ground water that is less than 5 feet from the surface of the land. In a hydrologic sense, considerably deeper water can move along a pressure gradient and up from greater depths into the 0- to 5-foot zone (Belitz, 1988); thus, as long as the regional water table remains high, other ground water is continually replenishing the problem water. The irrigated area that is, and likely will be, affected by a 0- to 5-foot water table is shown in Table 8. The forecasts are based on observed trends between 1977 and 1987, modified by physical limitations of the total area that will develop high water table conditions. These lands are considered to have a potential drainage problem. They are considered to have an actual drainage problem if and when the quality of water in the root zone causes one of the grower reactions indicated previously. The estimated extent of the drainage problem area (underlain by problem water) is shown in Table 9. The drainage problem area is smaller than the area with a water table less than 5 feet from the ground surface because of water-quality conditions.

The shallow ground-water area (0 to 20 feet from the land surface) was divided into water-quality zones to aid in determining drainage problem areas and to aid in planning. The divisions, which were made on the basis of the concentration of salts and trace elements in the shallow ground water, are shown on Figure 18. Problem water occurs in these zones and, by 2040, will affect most of the land within the zones.

The annual volume of problem water targeted for management is the average annual amount of water added each year to the root zone (largely through irrigation) in excess of water that percolates to deep aquifers. This problem water is water that remains in the root zone area, redissolving salts and other substances, evaporating up through the soil column, and becoming loaded with increasing concentrations of minerals as the summer irrigation season advances. Table 10 provides an estimate of the annual volume of problem water in each subarea for 2000 and 2040. For the whole study area, the unit volume of problem water in 2000 is forecasted as about 0.70 acre-foot per acre of problem area; and for 2040, it is forecasted as about 0.75 acre-foot per acre. The increase is due to the slow but steady trend toward increased mineralization that will occur in some subareas before a coordinated effort to manage the drainage problem can get under way at the scale required.

Table 8. FORECAST OF IRRIGATED AREA WITH WATER TABLE LESS THAN 5 FEET FROM GROUND SURFACE (Based on Existing Trends) In 1,000s of acres

Subarea	1990	2000	2040
Northern	49	49	49
Grasslands[1]	230	230	230
Westlands	104	170	227
Tulare	320	359	387
Kern	62	110	164
TOTAL	**765**	**918**	**1,057**

[1] Excludes 90,000 acres of wetland habitat with a high water table.

Note: All currently drained lands are included, even though drainage may have lowered the water table below 5 feet.

Table 9. FORECASTS OF EXTENT OF DRAINAGE PROBLEM AREA In 1,000s of acres

Subarea	2000	2040
Northern	34	44
Grasslands	116	207
Westlands	108	204
Tulare	125	348
Kern	61	148
TOTAL	**444**	**951**

Note: Total area in 2000 revised upward from 409,000 acres in SJVDP's *Preliminary Planning Alternatives,* August 1989.

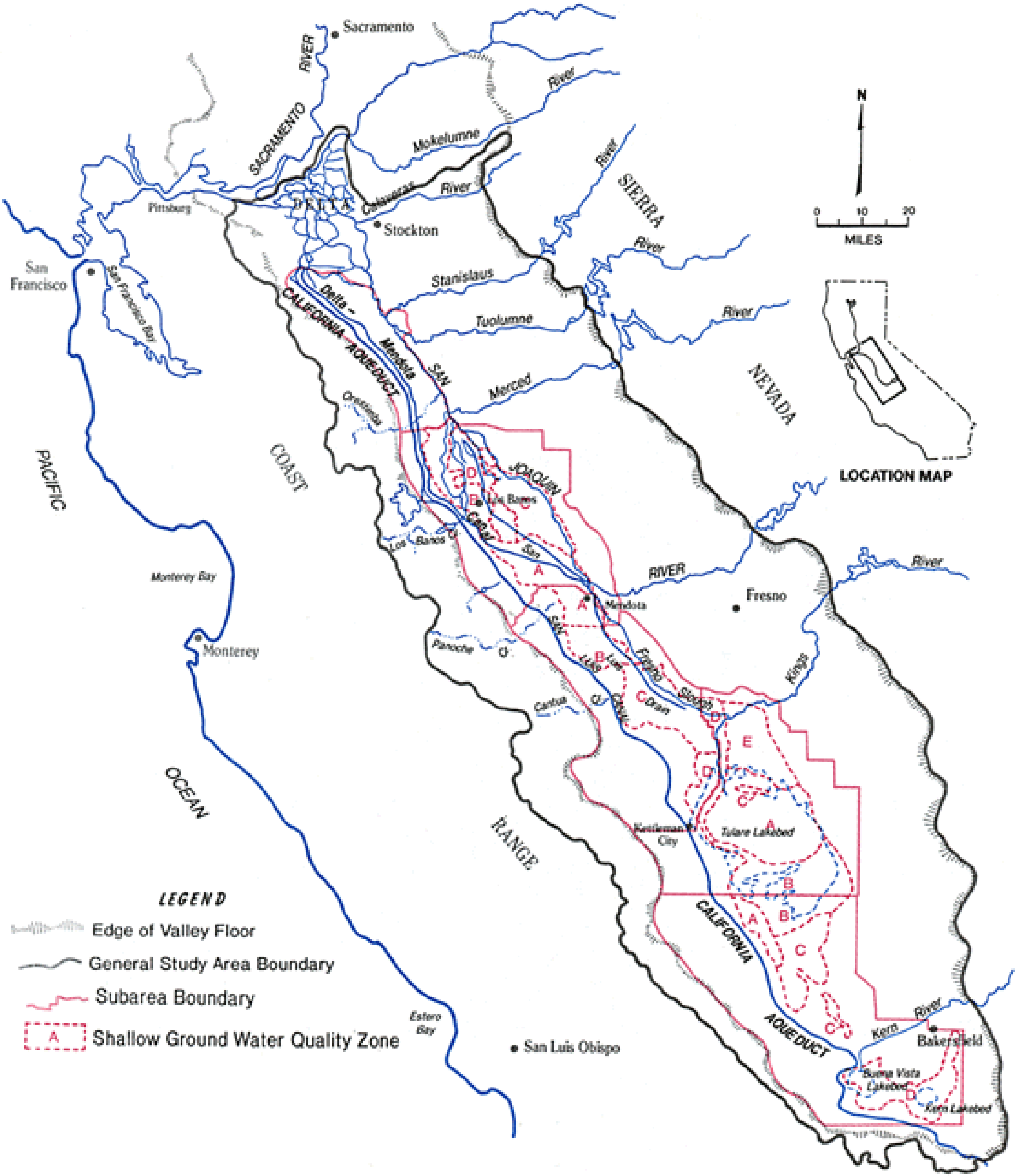
Table 10. ESTIMATE OF ANNUAL PROBLEM WATER VOLUME
In 1,000s of acre-feet

	2000	2040
Northern	26	38
Grasslands	86	155
Westlands	81	153
Tulare	75	209
Kern	46	111
TOTAL	**314**	**666**

In most areas where the ground-water table is less than 5 feet from the land surface, water is drawn upward and evaporates, leaving a deposit of salts on the surface and in the root zone that retards or prevents the growth of many crops.

Figure 18

SHALLOW GROUND–WATER QUALITY ZONES



Chapter 5. IN-VALLEY MANAGEMENT OPTIONS AND PLANNING ALTERNATIVES

This chapter reports the results of analyses made by use of the planning process described in Chapter 4. The analyses are a necessary transition step toward laying out a recommended plan.

First, an estimate is presented of the future drainage problem and its consequences, assuming present trends continue and no coordinated and comprehensive action is taken by local, State, and Federal entities to solve drainage problems. This is called the Future-Without Alternative, and it is useful as a basis for comparison with planned actions for the future. Next, planning building blocks, called "options," are described. These can be fitted together in compatible mixes to form alternatives to the future-without alternative. Finally, three planning alternatives that emphasize different strategies are formulated and displayed as a basis for designing the recommended plan presented in Chapter 6.

THE FUTURE-WITHOUT ALTERNATIVE

The future-without alternative represents conditions that could develop in the valley if coordinated, comprehensive actions are not taken by local, State, and Federal entities to solve drainage and drainage-related problems. The President's Council on Environmental Quality requires that all Federal planning studies include a future-without alternative as part of project planning. The future-without alternative is intended to give planners and the public a common ground from which to judge the need for actions to change present trends. It is also a baseline against which the economic, environmental, social, institutional, and physical effects of planned actions may be measured to determine their positive or negative effects.

Development of the future-without alternative involves: (1) Describing a general, overall theme for the future in the valley; (2) developing a set of assumptions about economic, environmental, social, institutional, and physical conditions in the valley and projecting trends; and (3) quantifying the effect of these assumptions on the planning subareas.

The Overall Theme

In February and March 1987, the San Joaquin Valley Drainage Program conducted multi-disciplinary workshops designed to develop future scenarios of conditions that would likely prevail in the absence of a coordinated, comprehensive plan to solve the valley's drainage and drainage-related problems. Participants included valley farmers, wildlife refuge managers, water district managers, academicians and researchers, and Federal and State agency personnel. The groups discussed major themes and trends that were forcing changes in agricultural drainage-related conditions in the valley. They concluded that central themes shaping future trends were related primarily to the public's desire to protect fish and wildlife and to sustain agriculture in the valley (SJVDP, 1987).

Assumptions About the Future

Assumptions regarding future economic, environmental, social, institutional, and physical conditions and trends in the valley are summarized below. Two overriding assumptions are that no catastrophic natural events and no major changes in the national political, economic, or social climate would occur.

More specific assumptions and trends are:

- The present trend toward less Federal government participation and more privatization would continue. Government expenditures for major water projects would continue to decline, and Federal farm subsidies would be reduced gradually. More responsibility for natural resources management would fall on State and local governments and the private sector.
- Public pressure for environmental protection would increase, leading to more stringent environmental regulations, and increased governmental enforcement of those regulations. This could result in user charges, taxes, and penalties to aid environmental protection.
- Agricultural economic conditions would remain relatively stable. The United States, the State of California, and the San Joaquin Valley would compete favorably in world agricultural markets. Irrigated agriculture in the valley would be able to afford and install some drainage improvements but would not be able to do so uniformly, and some land would be removed from production as a result of drainage and related problems.
- California's population would continue to grow, increasing the urbanization of the San Joaquin Valley, including westside agricultural lands, more of which would be converted to urban, residential, commercial, and industrial uses (with their attendant transportation and communication needs). Air pollution, waste generation, and noise would increase.
- Importation of water to the study area would not be significantly increased.
- There would be a shift in the northern part of the valley from agricultural water use to urban uses.
- Existing public wildlife areas would be preserved and protected, but no new areas or water supplies would be developed. Wetlands acreage on both public and private wildlife areas would diminish as their intermittent water supplies disappeared.
- Overall, surface- and ground-water quality in the study area would continue to deteriorate.
- The land area adversely affected by a high ground-water table would increase. The shallow ground water would become more saline, and, as a result, agricultural land would be removed from production.

- Except for use of the San Joaquin River, in conformance with water-quality objectives, no drainage outlet from the valley would be provided.
- The rate of adoption of water conservation measures in drainage problem areas would increase.
- Independent and uncoordinated actions related to agricultural drainage would result in litigation, not only between agricultural and environmental interests but also among groups having similar interests.
- Piecemeal legislation and institutional change would add to the drainage problem, causing the range of choices for water, land, and fish and wildlife managers to narrow and bringing significantly higher costs to most concerned parties.

The Shape of the Future Under the Future-Without Alternative

The future-without alternative, as shaped by assumptions described in the previous section, is described here in terms of land-use change and assessments of the hydrologic, economic, fish and wildlife, public health, and social effects of that change.

Land-Use Change

Analysis of present trends toward change in the future hydrologic system of the western side provided estimates of irrigated land, land abandoned due to salinization, and land drained by 2000 and 2040 (Table 11). The main conclusion drawn from these estimates and from backup data compiled in the Drainage Program's technical reports is that the absence of a clear, comprehensive approach to drainage management would likely lead to soil salinization and the abandonment of about 460,000 acres of irrigated agricultural land by 2040. The result would be major losses in agricultural production.

Table 11. IRRIGATED LAND CHANGES UNDER THE FUTURE-WITHOUT ALTERNATIVE
In 1,000s of acres

	1990			2000				2040			
SUBAREA	Drained Area	Irrig-able Area	Irri-gated Area[1]	Drained Area	Aban-doned Lands[2]	Change to Urban Land Use	Irri-gated Area[3]	Drained Area	Aban-doned Lands[4]	Change to Urban Land Use	Irri-gated Area[3]
Northern	24	165	157	34	0	5	152	51	0	25	133
Grasslands	51	365	329	85	0	4	325	152	40	20	225
Westlands	5	640	576	50	28	0	551	49	140	5	446
Tulare	42	612	551	86	38	0	517	94	190	5	325
Kern	11	762	686	14	18	5	665	40	90	35	573
TOTAL	**133**	**2,544**	**2,299**	**269**	**84**	**14**	**2,210**	**386**	**460**	**90**	**1,802**

1 Irrigated area is 95% of the irrigable area in the Northern Subarea and 90% of all other subareas.
2 Calculated as 20 % of the 2040 abandoned land estimate, except Grasslands, where discharge to the river is expected to forestall salinization and resultant abandonment until after 2000.
3 Irrigated area is 90% of the difference between the irrigable area and the sum of the land abandoned and land changed to urban, except in the Northern Subarea where the factor is 95%.
4 Values based on WADE model analysis, using estimated 2040 area with water table less than 5 feet from ground surface, and present salinity and selenium concentrations in shallow ground water (0 to 20-foot depth).

By 2040, salinization of irrigated land could be expected to diminish the irrigated area by about 11 percent in the Grasslands Subarea, 22 percent in the Westlands Subarea, 31 percent in the Tulare Subarea, and 12 percent in the Kern Subarea. No irrigated land in the Northern Subarea would be affected.

Hydrologic Effects

A general reduction in irrigated agricultural water requirements is expected in areas with shallow ground water at or near 5 feet in depth. This could occur because of increasing contributions of a very high water table to evapotranspiration and abandonment of waterlogged lands. The shallow ground water would become more saline, as would overlying lands. On affected lands, this condition would change farming practices and selection of crops grown. Eventually, the value of the lands for irrigated agriculture would decline to a level that would force abandonment of the lands. Changes in land use within the study area, including conversion of irrigated lands to residential and commercial development, would also reduce irrigation deliveries.

Limited opportunities to dispose of drainage would gradually reduce water deliveries to the lands with rising soil salinity during the next 50 years. Estimated reductions of irrigable land areas and irrigation water requirements due to salinization, changes in land use, and a modest increase in irrigation application efficiencies are shown in Table 12.

The quality of water provided by the State and Federal water projects would not change significantly throughout the planning horizon. However, the water in crop root zones would become more saline and, in places, would become loaded with boron due to increased evaporation of water from a near-surface water table.

The present quantity of firm water supply available for wildlife management areas would probably diminish under the future-without alternative. In a normal year, firm water deliveries of 97,000 and 17,000 acre-feet are available, respectively, to wetlands within the Grasslands and Northern subareas. These amounts do not allow for any replacement of the selenium-contaminated drainage water used for wetland management.

Table 13 shows that the quantity of subsurface drainage would be expected to more than double the present level by 2040. These estimates reflect the effects of increasing on-farm source control measures to reduce deep percolation by an average of 0.20 acre-foot per acre in the Grasslands, Westlands, and Kern subareas and 0.05 acre-foot per acre in the Tulare Subarea. The estimate reflects no reduction in the Northern Subarea. In contrast, the average target adopted for the Drainage Program's planning alternatives is 0.35 acre-foot per acre in the Grasslands, Westlands, and Kern subareas, and 0.20 acre-foot per acre in the Tulare Subarea, with no reduction in the Northern Subarea.

Table 12. CHANGE IN IRRIGABLE AREA AND WATER REQUIREMENT UNDER THE FUTURE-WITHOUT ALTERNATIVE

Subarea	Irrigable Area[1] (1,000s of acres)			Total Irrigation Water Requirement[2] (1,000s of acre-feet)		
	Present	2000	2040	Present	2000	2040
Northern	165	160	140	530	520	460
Grasslands	365	361	305	1,180	1,140	970
Westlands	640	612	495	1,580	1,470	1,190
Tulare	612	574	417	1,300	1,220	880
Kern	762	739	637	2,040	1,870	1,610
TOTAL	**2,544**	**2,446**	**1,994**	**6,630**	**6,220**	**5,110**

1 In any given year, about 90% of this area is actually being irrigated, except for the Northern Subarea, where 95% is irrigated..

2 The procedure used to estimate the water requirement is described in D.G. Swain (1990).

Table 13. ESTIMATED SUBSURFACE DRAINAGE VOLUME UNDER THE FUTURE-WITHOUT ALTERNATIVE In 1,000s of acre-feet

Subarea	Present	2000	2040
Northern	18	26	37
Grasslands	38	54	105
Westlands	4	28	27
Tulare	32	47	52
Kern	8	8	22
TOTAL	**100**	**163**	**243**

The present weighted average concentration of salts in drainage water estimated to occur in each of the water quality zones varies from about 1,000 to 25,000 parts per million total dissolved solids. Under future-without conditions, the quality of the shallow ground water would improve gradually in areas of high salinity where drainage is provided and salts are leached from soils. However, in undrained areas with a high water table, the lands may have become salinized before the quality of shallow ground-water had improved significantly.

Economic Effects

The future-without conditions were analyzed for 2040, and the agriculturally related economic impacts are compared to present conditions in Table 14. Overall, the future-without would exhibit a net decline in irrigated acreage, income, sales, and jobs. About 554,000 acres would be abandoned or converted to noncrop uses, with an associated loss of crop value of about $440 million per year. The negative impacts on retail sales in the surrounding communities would be about $63 million annually. Personal income in the study area would be reduced by over $123 million annually.

Table 14. REDUCTION IN RETAIL SALES, INCOME, AND EMPLOYMENT FROM PRESENT TO FUTURE-WITHOUT CONDITIONS, 1987-2040

Item	Subarea				Total
	Grasslands	Westlands	Tulare	Kern	
Reduction in irrigated crop area (1,000s of acres)	62	151	210	131	554
Lost crop value	42,747	130,344	175,452	92,712	441,255
Direct retail sales	1,555	4,743	6,385	3,374	16,057
Indirect and induced retail sales	4,545	13,903	18,804	9,913	47,165
Total retail sales	**6,100**	**18,646**	**25,189**	**13,287**	**63,222**
Direct personal income	5,362	16,532	22,637	11,859	56,390
Indirect and induced personal income	7,285	29,805	14,376	15,441	66,907
Total income	**12,647**	**46,337**	**37,013**	**27,300**	**123,297**
Direct employment	399	1,183	1,519	822	3,923
Indirect and induced employment	1,020	2,160	1,022	1,071	5,273
Total employment	**1,419**	**3,343**	**2,541**	**1,893**	**9,196**

Note: Crop value, retail sales, and income are in 1,000 (1990) dollars per year and employment is in person-years per year.

Employment projections indicate that total agricultural employment in the four subareas would fall by nearly 4,000 jobs. The loss of agricultural production would cause more than 5,000 jobs to be lost in the supporting industries and communities serving agriculture. Overall employment losses could reach nearly 9,200 jobs.

The secondary and induced impacts would be felt statewide, with the greatest experienced in the valley communities and the balance predominantly felt in the San Francisco Bay area and the Los Angeles basin.

This analysis does not take into account the value of resources freed after lands are abandoned. Depending on the assumptions concerning the reallocation of water and the fate of the lands abandoned, other positive values could be expected. Alternative uses for the abandoned or reallocated resources could be expected to exhibit some compensating income and employment characteristics.

The loss of fish and wildlife habitat and populations in the San Joaquin Valley associated with future-without conditions would mean less direct recreational use of these resources. This would result in regional economic impacts in the form of reduced retail sales, personal income, and employment. In addition, the value society receives from simply knowing that environmental resources in the valley exist and that the option exists to use these resources would be reduced under future-without conditions. No estimates have been made of the economic values and regional economic impacts for future-without conditions, compared to present conditions.

Other agricultural areas that produce similar crops could benefit when competitors abandon their lands. The net result of such a regional shift has not been analyzed. However, it is expected that the bulk of net acreage and crop reductions would occur in relatively salt-tolerant row and grain crops, such as cotton and wheat.

Clearly, a major reallocation of resources would occur. Water, land, and labor would be only part of the picture. The losses to the financial community and the local tax base would be substantial. Losses in land asset value could encourage a new round of investment at a lower cost. However, a net outmigration of investment capital would probably occur in heavily impacted valley communities.

Effects on Fish and Wildlife Resources

Without a firm supply of suitable quality water delivered when needed, the total acreage of healthy wetlands in the valley would continue to decline. At present, there are about 85,000 to 90,000 acres of seasonal and permanent wetlands in the valley. It is estimated that, by 2040, only about 55,000 acres (those with firm water supplies) would remain. Populations of migratory and resident wildlife species dependent on those scarce habitats would decline. Effects on populations of wintering migratory birds (waterfowl, shorebirds, and long-legged wading birds, for example) would probably be especially severe as birds crowded into ever-smaller areas of habitat, increasing the incidence and impact of avian diseases. Opportunities for such human uses of these wildlife resources as bird watching, nature study, and waterfowl hunting would diminish or even be prohibited.

Even with hazing and other similar efforts, evaporation ponds containing elevated concentrations of selenium, boron, arsenic, molybdenum, uranium, other trace elements, and salts would constitute an extremely serious contaminant hazard to wintering and resident populations of aquatic birds. Operation of toxic ponds could also pose contaminant hazards to endangered predators known to occur in the southern end of the valley (for example, the bald eagle, American peregrine falcon, and San Joaquin kit fox). The development and operation of expanded or new pond acreage would likely impact populations of several other endangered species. Because elevated concentrations of selenium were found in tissues of birds taken from some evaporation ponds, a public health warning was issued, advising hunters to limit or discontinue their consumption of waterbirds taken from those ponds. All these contaminant hazards would be compounded by the decreasing acreage of clean wetlands habitat.

Agroforestry plantations, developed to aid drainage management, would provide valuable new habitat for a variety of birds, mammals, and other species of wildlife, if the tree farms do not pose a contaminant hazard.

Water-quality objectives for the San Joaquin River basin adopted by the Central Valley Regional Water Quality Control Board still allow certain waterways to contain concentrations of selenium considered by some researchers to be toxic to wildlife. The actual effects on the fishery are unknown, due to a lack of toxicity studies.

Because of inadequate instream fishery flows from eastside tributaries to the San Joaquin River and high volumes of subsurface agricultural drainage water flows from the Grasslands area, upstream migrating adult salmon pass from the San Joaquin River into Mud and Salt Sloughs instead of the Merced River to spawn. This situation has prompted expensive efforts to trap and artificially spawn adult fish and transport the eggs to the Merced River Fish Facility for hatching and rearing. In a future-without scenario, this situation could be expected to continue indefinitely.

Several efforts have recently been initiated to address the inadequate instream fishery flows (for example, in the mainstem San Joaquin River between the Merced River and Friant Dam) and related environmental problems in the basin. Such efforts include the California Department of Water Resources' San Joaquin River Management Program, the U.S. Bureau of Reclamation's San Joaquin River Basin Resource Management Initiative, and litigation regarding renewal of 40-year water contracts from the Friant project. It is uncertain whether any of these efforts will provide flows in the mainstem San Joaquin River of adequate quantity and quality to support a viable fishery, including restoration of Chinook salmon runs.

In addition, loading of selenium and other drainage-related contaminants into the Bay-Delta ecosystem would continue under the future-without alternative. It is unknown what effects, if any, long-term loading of these systems with such trace elements would have on the health of the fishery, on other water-dependent wildlife, or on humans consuming such animals.

Public Health Effects

The greatest risk to public health from the lack of a coordinated action to solve the drainage problem is likely to arise from increased use of conventional evaporation ponds for disposal of agricultural drainage water. Where bioaccumulation of trace elements occurs through the aquatic food chain, consumption of contaminated game would increase human exposure to elevated concentrations of these elements. Decommissioning of evaporation ponds might also pose occupational hazards from inhalation of airborne contaminants.

Because ground- and surface-water quality in the valley will continue to deteriorate, potential human exposure to water contaminants will become greater. Future population growth and urban expansion projected for the San Joaquin Valley will bring people closer to all sources of agricultural drainage-water contaminants (air, soil, water, and biota) and thus reinforce the likelihood of adverse effects from exposure of such contaminants.

Social Effects

Farmland is expected to be abandoned more rapidly toward the end of the planning period. However, since the impacts would be spread over several decades, their effect upon farm operators, employees, and rural communities would permit adjustment that would moderate the cumulative social effects associated with the loss of productivity.

While land is being abandoned, the value and marketability of drainage-affected agricultural land would slowly stagnate, while uncertainty about the future would grow. Without an integrated regional solution, individual farmers would have increasing difficulty acquiring financing for farm operations and installation of drainage management facilities.

Patterns of land abandonment would likely be irregular, with farmers attempting to preserve the most productive lands for high-value crops and selecting less productive lands for on-farm drainage disposal. The remaining irrigated lands would be used more intensively as lands with drainage problems were abandoned. Over time, the cropping pattern in the approximate 1-million-acre drainage problem area would become less diverse, with production shifts toward less profitable salt-tolerant crops. Farmers with marginal technical capacity and financial resources would suffer the most severe consequences; many small and/or undercapitalized farm operations would go out of business.

Those who farm lands without drainage problems could acquire a competitive economic advantage over those who farm lands with high water tables and associated high salinity, by realizing increases in land value and profitability. Nevertheless, the total agricultural production (and associated agribusiness) in the San Joaquin Valley would likely decline significantly from present levels.

There would also be a significant conversion of farmland to alternative uses, either wildlife habitat or residential/commercial development. San Joaquin Valley towns within the drainage study area would become less dependent upon their traditional agricultural support base and more autonomous as fully developed small cities. Population expansion associated with the growth of valley communities would likely put greater pressures upon wildlife refuges and recreational lands.

The current level of cooperation among water districts in water management activities could deteriorate as drainage conditions worsened in the valley. As the value of the assessment base of farmland dropped due to lower land values, water districts would be less able to take action to resolve drainage problems. The smaller districts would be more adversely affected (at least five of them in the drainage study area could lose more than 50 percent of their assessment base through land abandonment). Some water management districts might be forced to merge and/or centralize operations to meet growers' needs and would probably not be capable of resolving drainage problems without considerable assistance from other agencies.

OPTIONS FOR DRAINAGE-WATER MANAGEMENT

The Drainage Program has identified a broad range of individual structural and nonstructural management options, which analyses show have potential for helping to solve subsurface agricultural drainage and related problems in the San Joaquin Valley. Some 80 options, classified into seven categories, were identified and described in the Program's *Preliminary Planning Alternatives* report of August 1989. The options are the basic building blocks of the alternative plans. However, no single option will achieve all the desired results. Several of them, fitted together into a coordinated, comprehensive plan for action, could be effective in managing drainage problems. The mix of options will have to be varied to accommodate local and regional differences in drainage problems and opportunities for solution. Different mixes of options are emphasized in the alternatives described later in this chapter. The options shown through analysis to be most useful in drainage problem management at this time are briefly discussed in the following sections.

Drainage-Water Source Control

A first step in solving valley drainage problems is to reduce the production of potential drainage water; that is, to control drainage production at the source. Source control options encompass a broad array of measures to apply irrigation water more efficiently and to manage land and water in ways that reduce the magnitude and adverse effects of drainage and drainage-related problems. Options included in the alternatives are:

- Water conservation:
  - Improve existing irrigation practices and/or adopt new irrigation methods.
  - Improve irrigation scheduling.
  - Improve management of irrigation systems.
  - Manage the water table to increase its contribution to crop evapotranspiration.
- Change in land use:
  - Cease irrigation of lands that have high salinity and selenium concentrations in underlying shallow ground water and that are difficult to drain.

Each of the alternatives presented later in this chapter includes some degree of source control. Water conservation and retirement of lands from irrigated agriculture are discussed separately as drainage management plan components.

Ground-Water Management

In some parts of the principal study area, water in the semiconfined aquifer above the Corcoran Clay (Figure 4) is of suitable quality for direct application in irrigation.[1] This water occurs in both the Sierran sediments and the Coast Range alluvium parts of the aquifer. Where there is an adequate vertical hydraulic connection between waterlogged lands and this deeper, usable ground-water zone, pumping from the zone may be used to lower the water table. Planned application of pumped water as a substitute for a portion of the surface-water irrigation supply could bring the system into hydrologic balance and stabilize the water table at a lower depth. This would make part of the surface-water supply currently required for that area available for other uses.

Drainage-Water Treatment

Various drainage-water treatment processes have been investigated at several levels of development. The goal of these investigations has been to identify methods of removing trace elements of concern (mainly selenium) from drainage water.

These processes have not been investigated equally or developed to the same level of technology. A review of the capabilities and limitations of processes investigated was completed and is presented in Hanna, et al., 1990. A few, such as anaerobic-bacterial treatment, high-rate algal ponds, and ferrous hydroxide, have advanced beyond laboratory bench-scale research. However, investigations of even these methods are incomplete, and more work with larger scale "pilot" or "prototype" plants is needed to establish technical performance and reliable cost estimates. Moreover, there has been no substantial operational experience with any drainage-water treatment process. The most promising new processes for selenium removal are biological processes. Of these, research is most advanced on the anaerobic-bacterial process. Research and demonstration are continuing on the physical and chemical removal of selenium, such as the work being done on iron filings at Panoche Water District, and this procedure should be pursued further. Reverse osmosis and other desalting methods are proven but high-cost methods.

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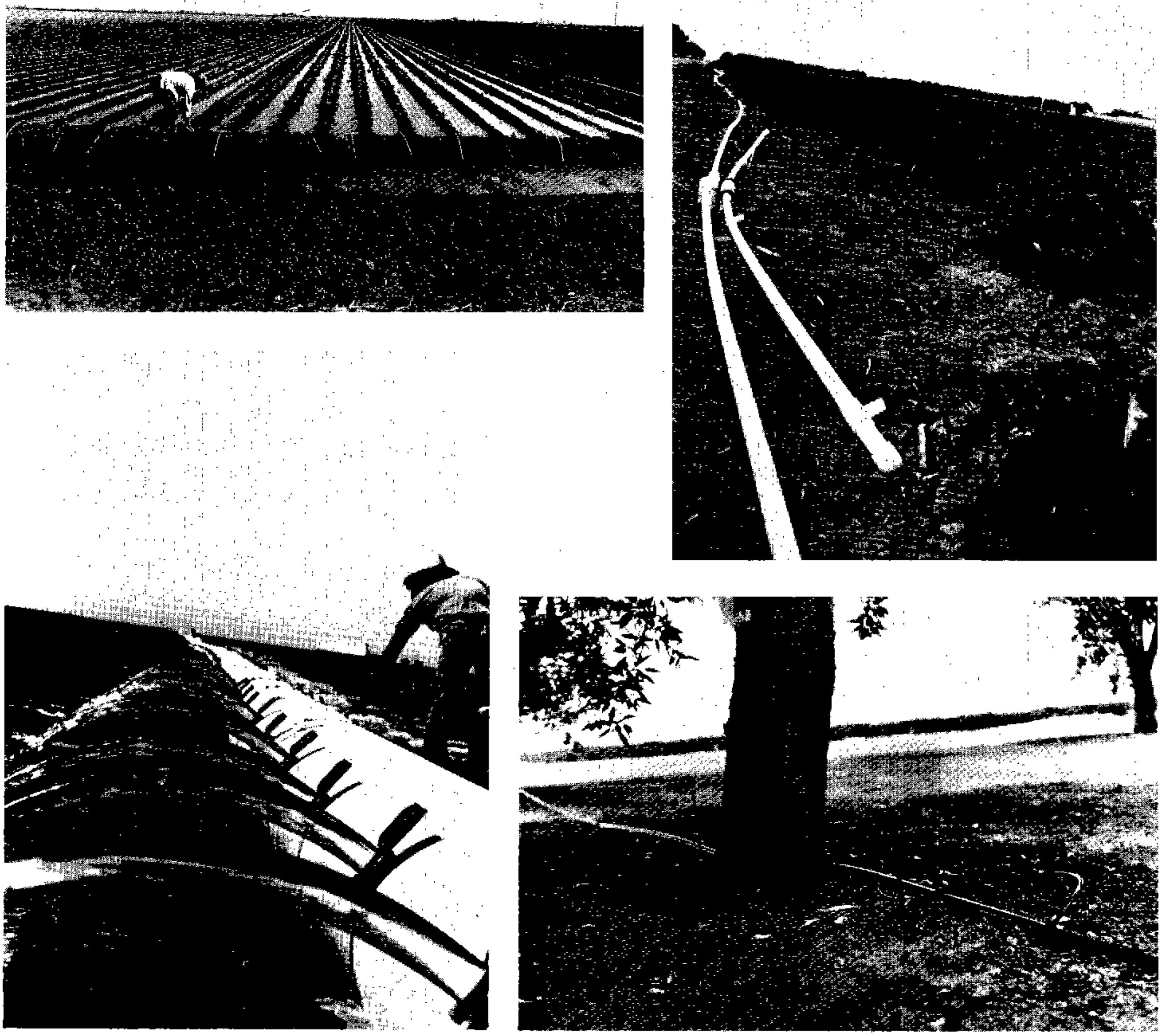
[1] Blending with other irrigation water supplies to make possible the use of saline ground water on crops normally grown in the drainage problem area was not included as an alternative plan component.



Irrigation water can be applied more efficiently by using shortened furrow lengths (upper left), drip systems (upper right), gated pipe (lower left), and microsprinklers (lower right).

Treatment of drainage water is not included in the alternatives because the uncertainties of their effectiveness and/or their high cost make investment in them a fiscal risk at this time. However, the Drainage Program recommends additional study of treatment processes because of their long-term potentials (see Chapter 1).

Drainage-Water Reuse

Of the various possible reuses of drainage water, irrigation (including salt-tolerant trees and halophytes), fish and wildlife habitat water supply, and solar ponds for energy production appear to have the greatest promise at this time. The options considered for the alternatives are:

- Reuse of subsurface drainage water for agriculture:

  Reuse on very salt-tolerant crops having an upper permissible limit of 2,500 ppm TDS in water supply; cotton (after plant emergence), for example.

  Reuse on salt-tolerant trees having an upper permissible limit of 10,000 ppm TDS in water supply; eucalyptus trees, for example.

  Reuse on halophytes having an upper permissible limit of 25,000 ppm TDS in water supply; atriplex, for example.

- Use of concentrated drainage water in solar ponds (from agricultural reuse options or from evaporation ponds) for energy production.
- Use of drainage water for fish and wildlife habitat when there is very low toxic risk.

Each alternative includes some amount of drainage-water reuse.

Drainage-Water Disposal

Drainage-water disposal options include: (1) Discharge to the San Joaquin River, with and without dilution; (2) discharge to evaporation ponds; (3) deep percolation into ground water; (4) injection into deep geologic formations; and (5) use for irrigation on the eastern side of the valley. The following are considered for inclusion in the alternatives at this time:

- Discharge to the San Joaquin River without dilution (including use of portions of the San Luis Drain to convey drainage water to treatment or disposal areas).
- Discharge to ponds to evaporate drainage water and concentrate dissolved constituents.
- Deep percolation into the semiconfined aquifer.

Westlands Water District continues to experiment with deep-well injection and, if successful, may use option (4), immediately above.

Fish and Wildlife Measures

Fish and wildlife measures have been developed that address the Drainage Program's goal to "protect, restore, and to the extent practicable improve fish and wildlife resources of the San Joaquin Valley." Options included here are those which could be undertaken in concert with other options to address drainage-related problems. Options for improvement of fish and wildlife resources are discussed in the Drainage Program's *Preliminary Planning Alternatives* report. Options considered for inclusion in the alternatives at this time are:

- Protection (in addition to the assumed enforcement of water-quality, wildlife, and other environmental laws):

    Modify evaporation pond design, construction, operation, and monitoring so that ponds are bird-safe or bird-free.

    Develop definite plans for evaporation pond closure when closure appears to be necessary or inevitable.

    Provide alternative habitat (including adequate water supplies) near evaporation ponds that require hazing because they are unsafe for birds.

- Restoration:

    Flood and flush habitat with freshwater.

    Manage soil and vegetation to decontaminate wildlife habitat.

- Substitute water supplies for fish and wildlife to replace contaminated drainage water. Substitute water would also improve protection and assist restoration. (These options must include modifications of existing supply or drainage systems to allow delivery of water to fish and wildlife areas directly, or by exchange arrangements.)

    Use water saved from source-control options (that is, on-farm water conservation and/or land retirement).

    Use wetland areas to seasonally store agricultural water supplies for release during April and May to improve fish habitat in the San Joaquin River.

    Use ground water produced by ground-water management options.

    Use nontoxic drainage water to produce saline wetlands.

Institutional Changes

Growers and private and public fish and wildlife managers operate within a framework of Federal, State, and local laws, policies, and practices. Some changes in the existing institutional framework may help solve drainage problems, directly or indirectly, by allowing implementation of plan components that otherwise might not be undertaken. The options listed here appear to be those most likely to be used in helping solve the drainage problem. A long list of potential institutional changes was provided and discussed in the Drainage Program's *Preliminary Planning Alternatives* report. Analysis of potential changes is provided in the Natural Heritage Institute report on institutional change (Thomas and Leighton-Schwartz, 1990). The primary options being considered are:

- Use of tiered irrigation water pricing, or other types of financial incentives, by water districts, the Central Valley Project, or the State Water Project.
- Drainage contribution surcharge on irrigation water.
- Modification of water-transfer and water-marketing policy and laws.
- Formation of regional drainage management entities that might be structured as special districts, joint powers authorities, or nonprofit mutual benefit cooperatives.

Evaluation of Options

Before options are used in alternatives, it is necessary to: (1) Determine the geographical applicability of the options, and (2) evaluate their cost, performance, and impacts. The shallow ground water quality zones shown in Figure 18 are the units used for evaluation.

Options are applied within the framework of objectives and standards shown in Table 7. The applicability of drainage management options to each of the drainage water quality zones, under either performance Level A or B, is displayed in Tables 15 and 16, respectively. Source control is applicable in every area. Discharge of drainage water to the San Joaquin River is applicable in the Northern Subarea and in two areas of the Grasslands Subarea. Salt-tolerant trees can be grown to transpire drainage water in 10 of the 16 areas. Trees cannot be grown in the other six areas because drainage water from field crops (water supply for trees) will exceed 10,000 ppm total dissolved solids (salt). Growing extremely salt-tolerant plants, such as saltbush, is not precluded in any area. Table 15 shows that, under performance Level A, land retirement may be applicable in some shallow ground-water areas where dissolved selenium is above 200 ppm. Table 16 shows that, under performance Level B, much more area is candidate for retirement when the criterion is lowered to 50 ppb. Existing evaporation ponds may be continued under both A and B performance levels, but only if they are bird-safe or can be made bird-free. The assumed safe level of selenium concentration for Levels A and B are 5 ppb and 2 ppb, respectively. In the ground-water management option, water may be pumped from the semiconfined aquifer when the thicknesses of suitable aquifer materials exceed 100 feet (Level A) or 200 feet (Level B) and the quality of the water produced is suitable for irrigation.

The results of an evaluation of the options considered effective and available are presented in Table 17. The evaluation is based on uncertainty analyses, economic analyses, and standard impact assessment techniques.

In addition to the restraints provided by the planning objectives, criteria, and standards given in Table 7, the evaluation of options in Table 17 should shape the extent to which a given option can be used in an alternative. Table 17 indicates that virtually all options have some limitations or produce an adverse effect on an important parameter of interest; for example, fish and wildlife, the economy, or the local community. Conversely, each option shows characteristics and effects beneficial to some interests. Judgment has to be exercised in determining the emphasis to place on a given option, considering the balance of effects. The lowest-net-cost option is sought, but not at the expense of significant risk to other interests.

The evaluation reveals that, although some options are cost-effective, certain risks must be acknowledged. For example, the feasibility of discharge to the San Joaquin River might be affected significantly by possible future changes in water-quality regulations. Similarly, reuse might be affected by significant adverse effects on wildlife. In contrast, the risks of reuse of drainage water are less than the risks of evaporation ponds, and reuse has a comparative cost advantage. (Measures considered promising to make evaporation ponds bird-free or bird-safe are included in cost estimates.) Therefore, it is concluded that, comparatively, use of evaporation ponds should be minimized and reuse maximized.

Table 15. APPLICABILITY OF DRAINAGE MANAGEMENT OPTIONS
LEVEL "A" PERFORMANCE STANDARDS

Subareas and Water Quality Zones	Drainage Source Control	San Joaquin River Discharge[1]	Salt-Tolerant Trees	Halo-phytes	Land Retirement[2]	Existing Evaporation Ponds	New Evaporation Ponds[3]	Ground Water Management[4]
Grasslands								
A	X	Y(15.5k AF)	X	X	Y(37.4k Ac.)	Y(0.1k Ac.)	NA(>5 ppb Se)	Y(25k Ac.)
B	X	Y(4.0k AF)	X	X	NA(<200 ppb Se)	NA	X	Y(51k Ac.)
C	NR	X	NR	NR	NR	NR	NR	NR
D[5]	NR-W	NR-R	NR-W	NR-W	NR-W	NR-W	NR-W	NR-W
Westlands								
A	X	NA	X	X	Y(7.6k Ac.)	NA	NA(>5 ppb Se)	Y(9k Ac.)
B	X	NA	NA(>10k ppm TDS)	X	Y(7.0k Ac.)	Y(0.1k Ac.)	NA(>5 ppb Se)	NA(<100 ft. thick)
C	X	NA	X	X	NA(<200 ppb Se)	NA	NA(>5 ppb Se)	Y(69k Ac.)
D	X	NA	X	X	NA(<200 ppb Se)	Y(0.4k Ac.)	NA(>5 ppb Se)	Y(43k Ac.)
Tulare								
A	X	NA	X	X	NA(<200 ppb Se)	Y(0.5k Ac.)	X	Y(34k Ac.)
B	X	NA	NA(>10k ppm TDS)	X	NA(<200 ppb Se)	Y(3.6k Ac.)	NA(>5 ppb Se)	NA(<100 ft. thick)
C	X	NA	X	X	NA(<200 ppb Se)	Y(0.2k Ac.)	NA(>5 ppb Se)	NA(<100 ft. thick)
D	X	NA	NA(>10k ppm TDS)	X	NA(<200 ppb Se)	Y(0.3k Ac.)	NA(>5 ppb Se)	Y(38k Ac.)
E	X	NA	X	X	NA(<200 ppb Se)	Y(0.3k Ac.)	X	Y(100k Ac.)
Kern								
A	X	NA	NA(>10k ppm TDS)	X	Y(2.2 Ac.)	Y(1.3k Ac.)	NA(>5 ppb Se)	NA(<100 ft. thick)
B	X	NA	NA(>10k ppm TDS)	X	NA(<200 ppb Se)	NA	NA(>5 ppb Se)	NA(<100 ft. thick)
C	X	NA	X	X	NA(<200 ppb Se)	Y(0.2k Ac.)	X	NA(<100 ft. thick)
D	X	NA	NA(>10k ppm TDS)	X	Y(0.9k Ac.)	Y(0.2k Ac.)	NA(>5 ppb Se)	NA(<100 ft. thick)

1 Applicability of option depends on the selenium criterion (mean monthly concentration of 8 ppb) and a critical water year hydrology (for example, 1986-87) for San Joaquin River near Newman. Selenium load is expected to decrease up to 50% by 2040 as a result of the gradual removal of selenium from the shallow ground water and soils due to the leaching process.

2 The selenium concentration of 200 ppb in the shallow ground water was used to select lands on which irrigated agriculture would be discontinued.

3 New evaporation ponds can be used when drainage water selenium concentration exceeds 5 ppb and is ≤50 ppb only if ponds can be made bird-safe or bird-free. Measures necessary to make ponds bird-free will include alternative habitat with an adequate firm water supply.

4 Option limited by the aquifer thickness and quality of the ground water (less than 1,250 ppm TDS).

5 Managed wildlife wetland area.

X Option is applicable without any limitation in its application.

Y Option is applicable but limited to the quantities and units included in the parentheses.

NA Option not applicable because it fails to meet the performance standard in parentheses (see Table 7) or not physically available in the instances of discharge to the San Joaquin River.

NR Option not suggested because increased conservation with resulting increased salinity will reduce the likelihood that drainage water can be used for wetland habitat.

NR-W Option is not applicable since shallow ground water within wetlands is not a problem; it benefits waterfowl.

Table 16. APPLICABILITY OF DRAINAGE MANAGEMENT OPTIONS
LEVEL "B" PERFORMANCE STANDARDS

Subareas and Water Quality Zones	Drainage Source Control	San Joaquin River Discharge[1]	Salt-Tolerant Trees	Halo-phytes	Land Retirement[2]	Existing Evaporation Ponds	New Evaporation Ponds[3]	Ground Water Management[4]
Grasslands								
A	X	Y(4.5k AF)	X	X	Y(90.0k Ac.)	Y(0.1k Ac.)	NA(>5 ppb Se)	Y(17k Ac.)
B	X	Y(4.0k AF)	X	X	Y(0.3k Ac.)	NA	X	Y(16k Ac.)
C	NR	X	NR	NR	NR	NR	NR	NR
D[5]	NR-W	NR-R	NR-W	NR-W	NR-W	NR-W	NR-W	NR-W
Westlands								
A	X	NA	X	X	Y(23.2k Ac.)	NA	NA(>2 ppb Se)	NA(<200 ft. thick)
B	X	NA	NA(>10k ppm TDS)	X	Y(39.4k Ac.)	Y(0.1k Ac.)	NA(>2 ppb Se)	NA(<200 ft. thick)
C	X	NA	X	X	Y(57.9k Ac.)	NA	NA(>2 ppb Se)	Y(54k Ac.)
D	X	NA	X	X	NA(<50 ppb Se)	Y(0.4k Ac.)	NA(>2 ppb Se)	Y(31k Ac.)
Tulare								
A	X	NA	X	X	NA(<50 ppb Se)	Y(0.5k Ac.)	X	Y(21k Ac.)
B	X	NA	NA(>10k ppm TDS)	X	NA(<50 ppb Se)	Y(3.6k Ac.)	NA(>2 ppb Se)	NA(<200 ft. thick)
C	X	NA	X	X	NA(<50 ppb Se)	Y(0.2k Ac.)	NA(>2 ppb Se)	NA(<200 ft. thick)
D	X	NA	NA(>10k ppm TDS)	X	NA(<50 ppb Se)	Y(0.3k Ac.)	NA(>2 ppb Se)	Y(33k Ac.)
E	X	NA	X	X	NA(<50 ppb Se)	Y(0.3k Ac.)	X	Y(95k Ac.)
Kern								
A	X	NA	NA(>10k ppm TDS)	X	Y(219.5 Ac.)	Y(1.3k Ac.)	NA(>2 ppb Se)	NA(<200 ft. thick)
B	X	NA	NA(>10k ppm TDS)	X	NA(<50 ppb Se)	NA	NA(>2 ppb Se)	NA(<200 ft. thick)
C	X	NA	X	X	NA(<50 ppb Se)	Y(0.2k Ac.)	X	NA(<200 ft. thick)
D	X	NA	NA(>10k ppm TDS)	X	Y(23.6k Ac.)	Y(0.2k Ac.)	NA(>2 ppb Se)	NA(<200 ft. thick)

[1] Applicability of option depends on the selenium criterion (mean monthly concentration of 2 ppb) and a critical water year hydrology (for example, 1986-87) for San Joaquin River near Newman. Selenium load is expected to decrease up to 50% by 2040 as a result of the removal of salts from the shallow ground water and soils due to the leaching process.
[2] The selenium concentration of 50 ppb in the shallow ground water was used to select lands on which irrigated agriculture would be discontinued.
[3] New evaporation ponds can be used when drainage water selenium concentration exceeds 2 ppb and is ≤50 ppb only if ponds can be made bird-safe or bird-free. Measures necessary to make ponds bird-free will include alternative habitat with an adequate firm water supply.
[4] Option limited by the aquifer thickness and quality of the ground water (less than 1,250 ppm TDS).
[5] Managed wildlife wetland area.
X Option is applicable without any limitation in its application.
Y Option is applicable but limited to the quantities and units included in the parentheses.
NA Option not applicable because it fails to meet the performance standard in parentheses (see Table 7) or is not physically available in the instances of discharge to the San Joaquin River.
NR Option not suggested because increased conservation with resulting increased salinity will reduce the likelihood that drainage water can be used for wetland habitat.
NR-W Option is not applicable since shallow ground water within wetlands is not a problem; it benefits waterfowl.

Table 17

SUMMARY EVALUATION OF OPTIONS CONSIDERED FOR DRAINAGE MANAGEMENT ALTERNATIVES[1]

Option	Annual Cost/ Acre of Land Served	Remarks on Costs	Engineering (Physical) Feasibility	Social Effects	Institutional	Effects on Environment[3] and Public Health	Agriculture	Fish and Wildlife	Economic
Source control (on-farm reduction of applied water)	$60	Costs based on currently available methods to reduce irrigation water application.	(+) Available and proven technology; (0) would solve only part of problem. Some deep percolation would continue.	(+) Enhances local control; (+) spinoff advantages in more trained personnel.	(+) Simplicity (means are available); (0) depends on acceptance by private sector.	(+) Reduces risk of insect or vector problem; (0) may increase concentration of dissolved constituents in receiving waters.	(+) Increases overall efficiency of irrigated farming and may increase production; (-) generally requires additional economic and labor input.	(+) Frees water that could be reallocated for fish and wildlife.	(+) Lowest cost drainage management method available to grower.
Reuse: salt-tolerant crops, trees, halophytes[2]	$150-160	Includes evaporation ponds for final disposal. Total costs are reduced by $45/ton of wood fiber.	(+) Proven technology, although yet to be demonstrated at scale needed; (-) complex operation requiring on-farm changes; (0) needs disposal process; e.g., evaporation ponds, to complete process.	(0) Raises skill requirements for farm labor; (-) possible increasing commitment to salt-tolerant tree monoculture.	(0) Need to implement on large scale probably invites more government involvement.	(-) Adverse air impact possible if wood fiber used in valley for co-generation of power; (+)tree-growing would benefit air quality through consumption of CO_2 and production of O_2.	(-) Trees and shrubs would not yield a net profit as alternate crops; (0)may allow some on-farm management of drainage water.	(0) Increases terrestrial habitat, but may create new contaminant hazards.	(+) Could produce substantial benefits from harvested wood, but value of shrubs uncertain.
Ground water management[2]	$160-185	Based on 200-gpm wells on ½-mile grid. Total costs lowered by $50/AF value of water produced.	(0) Proven technology, but no operational experience for this purpose.	(0) Requires voluntary compliance or imposed control.	(-) May require change in laws or their administration; litigation likely on effect	(-) Could accelerate degradation of potential and existing water supplies.	(+) Provides additional alternate water supply during drought; (-) during wet years pumping is still required.	(+) Produces water that may be adequate in quality and could be made available for fish and wildlife.	(0) Relatively expensive, but provides water supply; (-) accelerates degradation of water, making leaching more expensive.

Table 17 (continued)

SUMMARY EVALUATION OF OPTIONS CONSIDERED FOR DRAINAGE MANAGEMENT ALTERNATIVES[1]

Option	Annual Cost/ Acre of Land Served	Remarks on Costs	Engineering (Physical) Feasibility	Social Effects	Institutional	Effects on Environment[3] and Public Health	Agriculture	Fish and Wildlife	Economic
Discharge through San Luis Drain to San Joaquin River[2]	$120	Costs include cleaning, extending and maintaining part of San Luis Drain chiefly for Grasslands drainage problem area A.	(+) Simple but could require many years to implement, depending on environmental regulations, funding, and time requirements.	(0) Trends toward regional management of drainage; (-) likely objection by downstream water users despite water quality objectives being met.	(0) See "Social Effect" column; (-) objections from other regions are likely.	(+) Minimizes risks of consuming selenium from fish and wildlife taken in Grasslands; (-) some occupational exposure possible during cleanup and disposal of 60–100 cu yd of sediment.	(-) Conceptually effective, but entities dependent on this service could be jeopardized by any shift from regulations on contaminant concentration to regulations on load; (+) achieves salt balance.	(+) Drainage water bypassing sloughs and wetlands would provide additional protection. (Receiving water quality objectives would have to be met.)	(0) Cost to rehabilitate drain may be offset by benefit of providing drainage service.
Evaporation ponds: existing, new, and accelerated[2]	$180-300	Costs rise as inflow selenium increases; cost of construction and operation of alternate wetland habitat included. Closure or solid waste disposal is not included.	(0) Some aspects require technology now under development and a careful integration of ponds into total drainage system.	(0) Raises skill needs for pond operators.	(-) Uncertainty about extent of implementation of federal and state laws.	(-) Some existing ponds contaminate wildlife with selenium to unsafe levels (as game); (-) unless well-managed and with applications of emerging technologies, ponds will be hazardous; (-) long-term problem of disposal of toxic precipitates; (-) possible occupational hazard.	(+) Method allows a range of size of operations; only single, effective means of disposal now available to some lands; (-) becoming more costly and difficult to meet environmental objectives.	(-) Some existing ponds produce significant adverse effects; (0) existing and new ponds would have to be bird-safe or bird-free; (0) one-for-one alternative habitat could be protective.	(-) May be very high cost if selenium concentrations are high. May not be affordable.
Land retirement	$170	Estimated fair market value of $1,500/ac for problem land and $20/ac/yr land maintainance cost.	(+) Simple; (0) requires some decommissioning of facilities.	(0) to (-) Impacts on communities depend on amount of land retired and where freed water is used.	(0) May require new institutional arrangements; (-) repayment of federal and state water contracts.	(-) Eliminates any onsite hazards associated with drainage water and its problem solution, assuming alternate land use and management are not a problem.	(-) Lands lost for agricultural production, perhaps permanently. (+) Frees water that could be reallocated to agricultural use in water-short areas.	(+) Frees water that could be reallocated for fish and wildlife; (0) reuse of retired land as wildlife habitat is unproven.	(+) Requires only willing buyer and seller; (-) on economy, unless water remains in impacted area; (+) water in other uses could increase in value.

Table 17 (continued)

SUMMARY EVALUATION OF OPTIONS CONSIDERED FOR DRAINAGE MANAGEMENT ALTERNATIVES[1]

Option	Annual Cost/Acre of Land Served	Remarks on Costs	Engineering (Physical) Feasibility	Social Effects	Institutional	Effects on Environment[5] and Public Health	Agriculture	Fish and Wildlife	Economic
Biological treatment[2] (10-mgd plant)	$250	Estimates omit cost of sludge disposal. No cost reduction for byproduct recovery.	(0) Process works at small pilot scale but cannot meet water quality objectives without dilution; (-) needs field demonstration of pilot plant.	(0) Raises skill requirements for farm labor and new service.	(0) Tends to build case for regional management of drainage.	(+) Assuming proper design, operation, and control of hazards, similar to existing municipal sewage treatment plants.	(+) Could be highly beneficial to agriculture, if costs could be lowered.	(+) Toxicants would be removed and segregated; (0) or (-) if performance level requires diluting with fresh water.	(+) Effective toxicant removal could produce byproducts that would enhance economy; (-) may be unaffordably expensive.
Discharge directly to San Joaquin River[3]	$60	Costs are for on-farm tile drains, plus water control facilities required to bypass or protect wetlands.	(0) Requires more effective monitoring of nonpoint sources; (+) simple to build.	(0) Raises skill needs and tends to support concept of regional mangement of drainage.	(0) Could be construed as preferred right to drainage held by exchange contractors, similar to riparian rights for water supply.	(0) Selenium standards would be met; (0) boron may be a limiting factor in the river.	(-) Conceptually effective, but dependend entities could be jeopardized by shifts from regulations on contaminant concentration to those on load; (+) maintains salt balance.	(0) or (+) If controlled and monitored appropriately; otherwise, (-).	(-) Could adversely affect downstream water users if selenium and/or boron (temporarily) became excessive.
Provision of water to fish and wildlife[4]	Assessment incomplete		(0) Requires full suite of planning, funding, design, and building for some areas; (+) other areas could be served immediately.	(+) Enhances recreation and variety and general liveability of local areas.	(+) Progress in this direction would lessen threats of litigation and improve the image of agriculture.	(+) Improved water conditions will increase stability of ecosystems and lessen public health risks.	(-) If seen as a competion for water; (+) possible balancing effects if increased water draws birds away from evaporation ponds.	(+) Meets some needs for protection, restoration, and substitute water supply.	(+) Improve resources valued by Californians; (+) improve hunting, fishing, and other activities.

1 Guide to ratings entered on evaluation sheet: (+) = potential beneficial effect, enhancing interests implied by column heading; (-) = potential negative effect, adverse to interests implied; (0) = neutral, or positive and negative aspects counterbalance.
2 Source control is included within the costs shown as an initial step in application of this component.
3 Able to drain directly to San Joaquin River because of low concentrations of selenium in water service area of exchange contractors.
4 This item pertains to water-supply deficit due to drainage-related causes.
5 Includes state water-quality objectives.

PLANNING ALTERNATIVES

Three planning alternatives were formulated that emphasize: (1) The conservation and reuse of agricultural water, (2) the extraction of irrigable water from deep within the semiconfined aquifer to lower the near-surface water table in waterlogged land areas, and (3) the retirement of irrigated agricultural lands overlying shallow ground water that contains greatly elevated concentrations of dissolved selenium. Two levels of performance, A and B, were applied to each alternative. These alternatives were devised to compare potential reduction in problem water volumes, if differing options for managing the drainage problem were emphasized. Four strategies involving major options that were employed in formulating the planning alternatives are discussed in the following sections.

Drainage Management Strategies Underlying the Alternatives

Four main strategies for management of drainage problems have emerged during the course of this study. These are source control, drainage water reuse, ground-water management, and land retirement. Each strategy is used to reduce problem water volumes in the three planning alternatives.

Source Control

The major source of recharge to the ground water system and subsequent production of drainage water is the portion of applied irrigation water that percolates past the crop root zone into the semiconfined aquifer. Some water must pass the root zone to leach salts and maintain soil productivity. Unnecessary deep percolation can be reduced mainly through better management of irrigation systems.

Current average deep percolation in the study area is estimated to vary from about 0.90 to 1.05 feet (Burt and Katen, 1988; D.G. Swain, 1990). Assuming 0.3 foot is the minimum amount necessary to achieve required salt leaching and is also the amount moving downward through the Corcoran Clay, nonbeneficial deep percolation contributes 0.60 to 0.75 foot annually to potential problem water.

Higher irrigation efficiencies leading to reduced deep percolation can be achieved by individual options or combinations of options. The most effective of these appear to be: (1) Improving management of irrigation systems, (2) improving present irrigation practices (for example, shortening furrows and using tailwater return systems, thus increasing uniformity of water application) and adopting new irrigation methods, and (3) improving irrigation scheduling. These and other options are discussed more fully in the Drainage Program's 1989 report, *Preliminary Planning Alternatives*.

Not all potential problem water is generated by deep percolation at a given site. Some lateral movement of water from upslope areas may also contribute to drainage problems downslope. This contribution varies considerably, depending upon local geologic and hydrologic conditions, but a drainage problem most often arises from practices and conditions at the site. Reduction of deep percolation, even in areas without present drainage problems, can help reduce the long-term regional drainage problem.

Drainage-Water Reuse

The concept of drainage-water reuse is shown in Figure 19. The objective is to reduce the volume of drainage water requiring ultimate disposal by reusing it on progressively more salt-tolerant crops. The volume of water would be reduced by evapotranspiration, with dissolved constituents such as salt, boron, and selenium becoming more concentrated and probably easier to manage in an environmentally safe manner. Volume reduction through reuse would substantially reduce disposal costs and treatment costs, if treatment became necessary.

The initial good-quality water supply would be used to grow high-value, salt-sensitive crops, such as vegetables. Drainage water captured in the tile drainage system under these lands would be collected and pumped into a local distribution system to become the water supply for a salt-tolerant field crop, such as cotton. (If this were not practicable, the drainage could go directly to trees.)

Drainage from these fields would become the water supply for salt-tolerant trees, such as eucalyptus. Trees would be used at this stage, not only because of their tolerance to salt, but also because they are capable of high transpiration rates (about 5 feet of water per year). Finally, drainage from the trees would be used on halophytes that grow in extremely saline conditions, such as atriplex or salt bush. Even halophytes have limits for total dissolved salts and certain other substances, such as boron. The levels of boron and total salinity of water in the root zone must be monitored and the fields drained to maintain growth.

At that stage of the reuse process, the extremely concentrated drainage water must be disposed of, or it could be stored in small evaporation ponds, treated to remove toxicants, or, when possible, injected into deep geologic formations. Water and salts from the evaporation ponds could also be used at solar-energy ponds or cogeneration facilities.

Figure 20 illustrates pond configurations that might be used as part of a drainage water management system. The *standard* evaporation pond shown would be similar to ponds traditionally used in the valley, except that it would be improved with steepened sides and greater depths to reduce wildlife food supplies and discourage wildlife use. In contrast to traditional ponds, the new standard pond would be smaller so that birds could be more effectively hazed from it to alternative safe wetland habitat (not shown on sketch) that would be provided in the vicinity.

The *nontoxic* evaporation pond would also provide safe wildlife habitat and would be designed for that purpose. The northern portion of the Tulare Subarea (Kings River Delta) appears to be an area in which drainage water could evaporate in ponds that would be safe for wildlife use.

The *accelerated rate* ponds would employ mechanical devices to increase the rate of evaporation. Used in a facility in El Paso, Texas, the device shown here reduced the volume of applied water by about 25 percent in one pass through the system. Use of an accelerated evaporation system greatly reduces pond area, but it increases the cost.

The *solar* pond shown would use very concentrated drainage water from either the standard or accelerated pond. The area covered by a solar pond would be small. This type of pond does not appear to attract birds. The value of the electrical energy generated would offset some of the total drainage system costs.

Figure 19. THE CONCEPT OF DRAINAGE-WATER REUSE

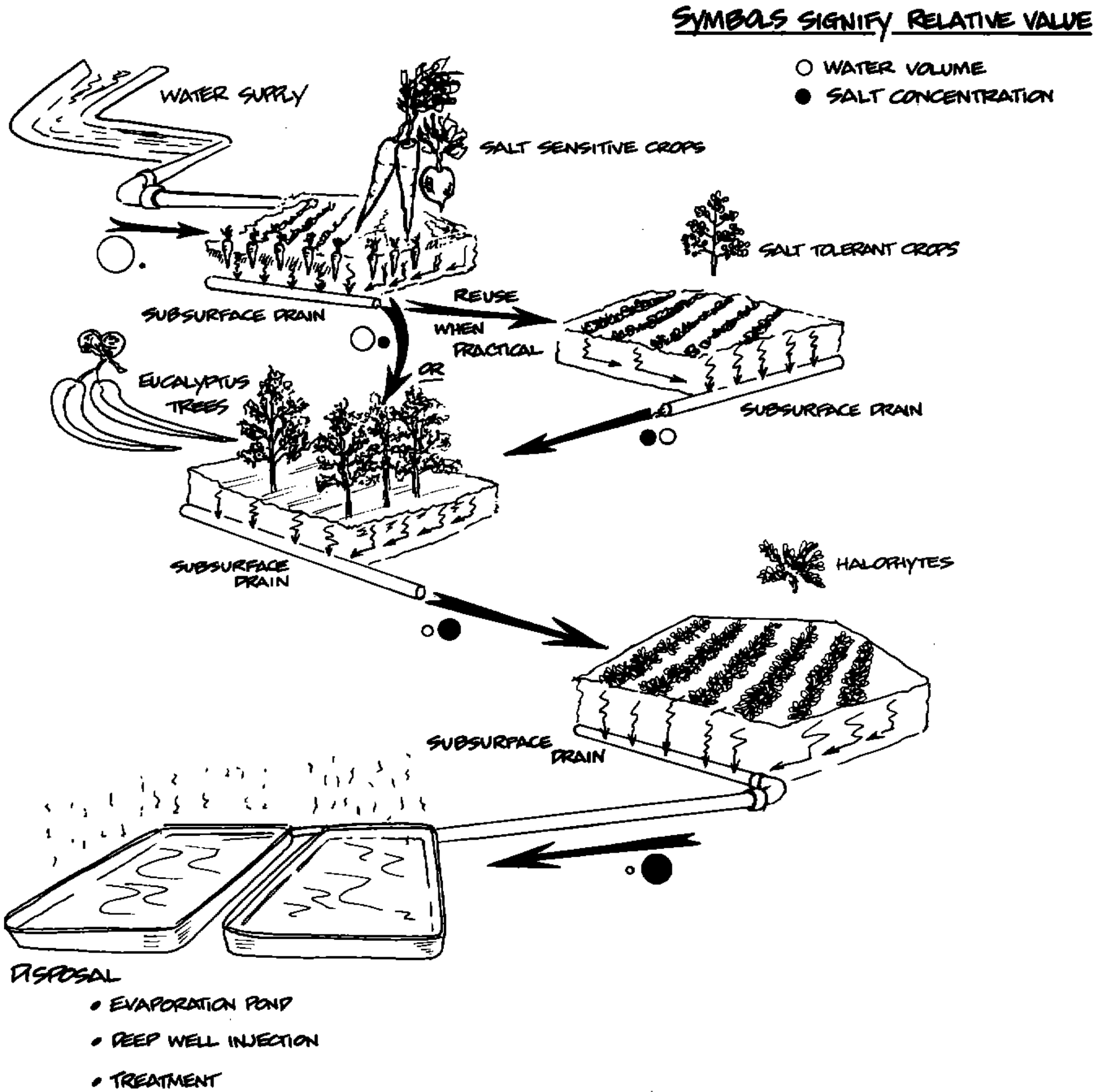


Figure 20. POND CONFIGURATIONS

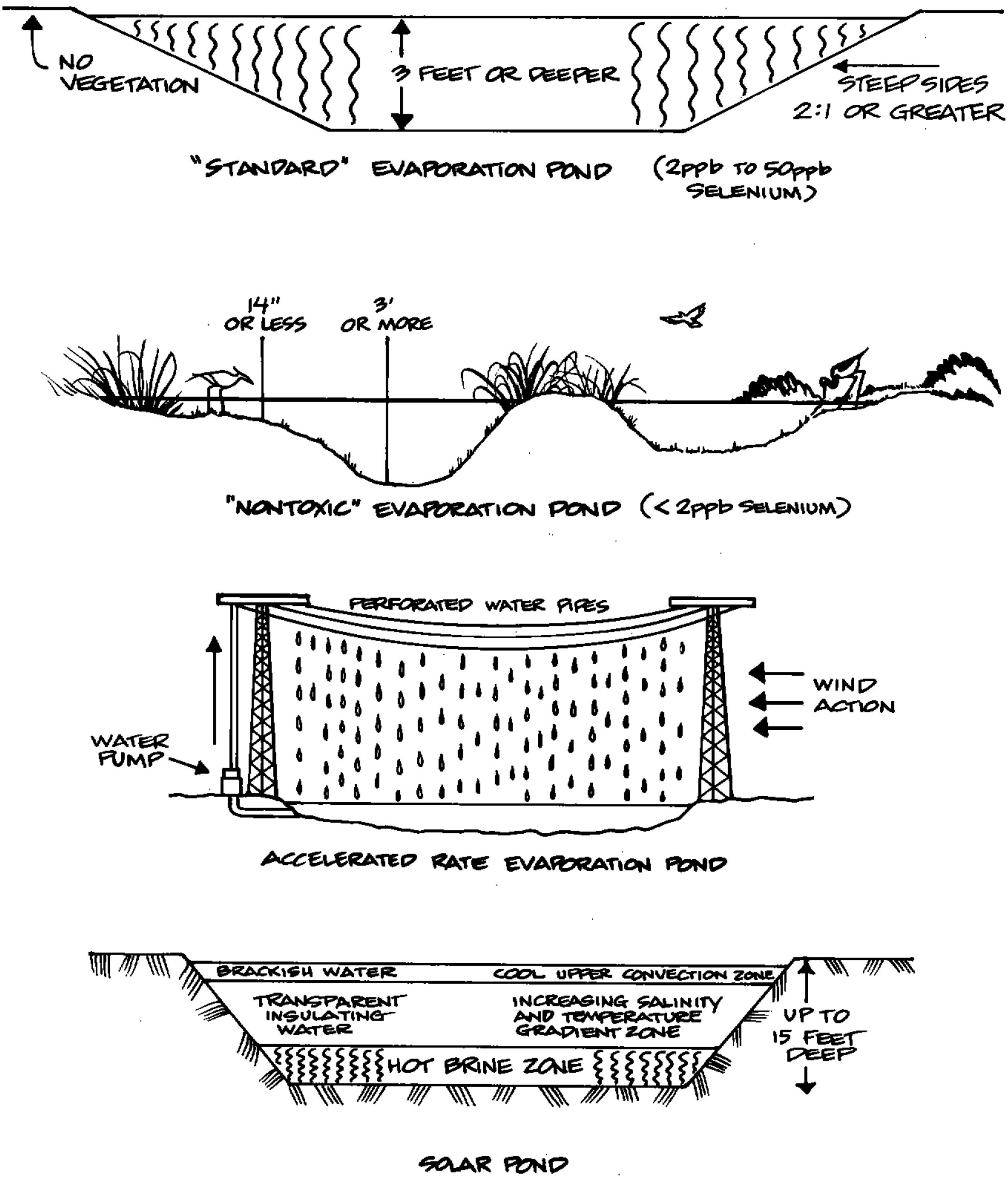
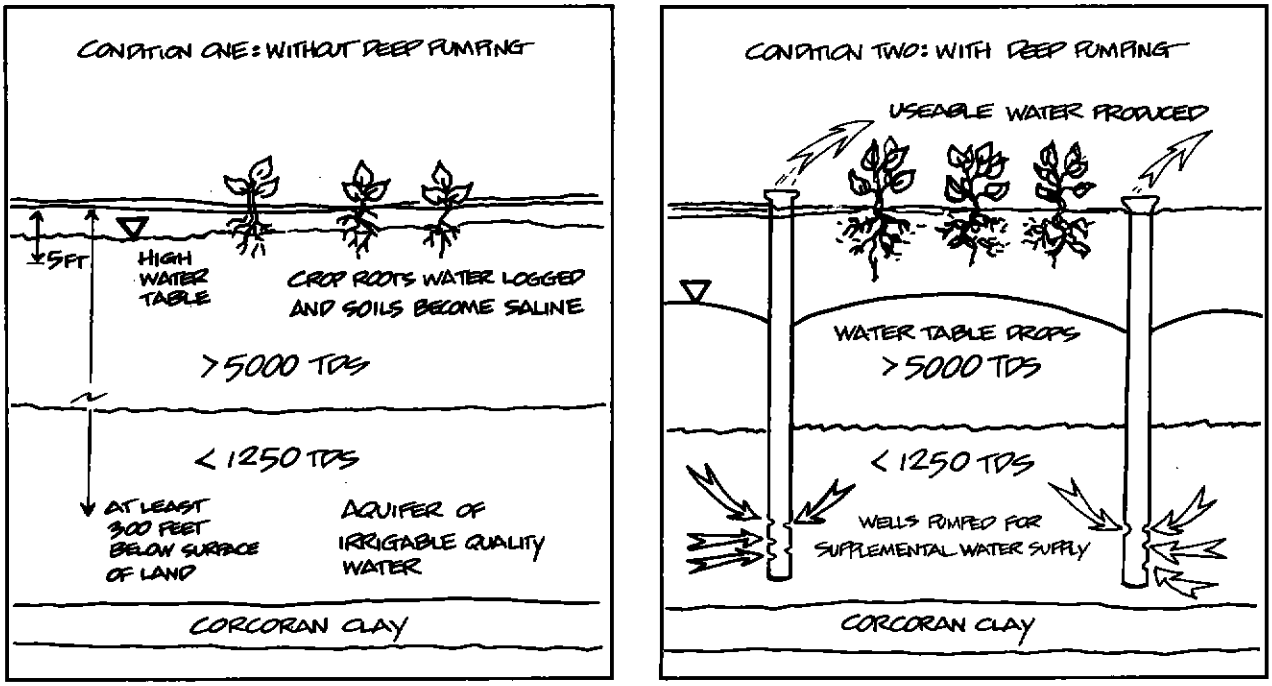


Figure 21. THE CONCEPT OF GROUND-WATER MANAGEMENT



The major benefit from the reuse strategy is the reduction of drainage-water volume. Volume could be reduced as much as 80 to 95 percent, depending on the crops, soils, and management of the system. A reduction in drainage-water volume translates to lower cost in final drainage-water management.

Ground-Water Management

The concept of ground-water management is to pump water, generally for irrigation, from the semiconfined aquifer above the Corcoran Clay to lower near-surface saline water tables (illustrated in Figure 21) and create a hydrologic balance that will keep the shallow water table below the crop root zone. In an unplanned manner, this strategy is currently being applied, to a minor extent, in the drainage problem area because some 2 million acre-feet of ground water is extracted annually from westside aquifers to supplement surface-water supplies. Although most of the pumping is from below the Corcoran Clay, the stress on the hydrologic system helps alleviate the subsurface drainage problem by providing storage space for deep percolation.

In this strategy, the ground water extracted would be in addition to present extractions, and would be designed specifically for each drainage problem area in which it was applicable. Wells would be perforated to produce water only from selected zones of the semiconfined aquifer. This method would be technically feasible only if all the following conditions existed in the subsurface aquifers under the drainage problem area: (1) Adequate vertical hydraulic interconnection between the deep aquifer and the waterlogged surface lands (not applicable to the Tulare lakebeds where thick clays are present); (2) a sufficient volume of water in the deep aquifer to allow withdrawal for a reasonable period of time (for example, 20 years); and (3) a production (from the well) water quality of less than 1,250 ppm TDS, so it may be used for agricultural irrigation. Reconnaissance-level geohydrologic investigations indicate that these conditions probably exist beneath those parts of drainage problem areas shown in Figure 12.

Several aspects of this strategy need to be recognized as potentially limiting its overall feasibility, even though the controlled pumping that would occur under the strategy could be an improvement over existing pumping conditions. First, the periods during which wells must be pumped to lower the water table to the required depth and the period in which they are pumped to supply water for irrigation or other beneficial uses may not correspond. Second, the application of this alternative might be viewed as a planned degradation of ground water. This interpretation might be reached, even though the present extent of ground-water pumping produces a regional hydraulic stress that is causing water passing the root zone to move downward at an annual rate of 1 to 3 feet vertically, transporting with it accumulated salt, boron, selenium, and other substances. Third, if this alternative were to be economically feasible, the aquifer must be capable of producing water suitable for beneficial uses for at least 20 years.

Although recent study has removed considerable uncertainties (Schmidt, 1988 and 1989; Quinn, 1990; CH_2M Hill, 1990; Phillips, 1990), an additional significant limiting factor is the continuing lack of adequate geohydrologic information on ground-water systems in some parts of the drainage problem area.

Land Retirement

The essential strategy of land retirement is to stop irrigating lands with poor drainage characteristics beneath which now lies shallow ground water so contaminated with selenium (and other substances) that drainage would be extremely difficult and the water produced would be costly to manage. Hydrologic investigations (Gilliom, et al., 1989b) indicate that, if a substantial land area (say, +5,000 acres) were retired from irrigation, the shallow water table beneath those lands would drop. To some extent, instead of contributing to their contamination, the dewatered area beneath the retired lands would then become a sink to receive some contaminated water from adjacent lands. Figure 22 illustrates how land retirement would lower ground-water levels.

The feasibility of this strategy hinges on the existence of shallow ground-water areas in which concentrations of selenium are much greater than those of surrounding areas. Figure 23 shows areas in which selenium concentrations in shallow ground water are more than 50 and 200 parts per billion. Areas over 200 parts per billion are considered to be "hot spots" and special candidates for retirement. The feasibility of land retirement also may depend on the existence of compensating benefits in the form of overall reduced costs of handling the drainage problem regionally, or in economic return to landowners from the sale or lease of the water supply no longer used for irrigation.

A related aspect of land retirement is that it could be considered a land reserve and, if at some future time, the problem necessitating retirement were to be resolved, the land could be used again for irrigated agriculture.

Figure 22. THE CONCEPT OF LAND RETIREMENT

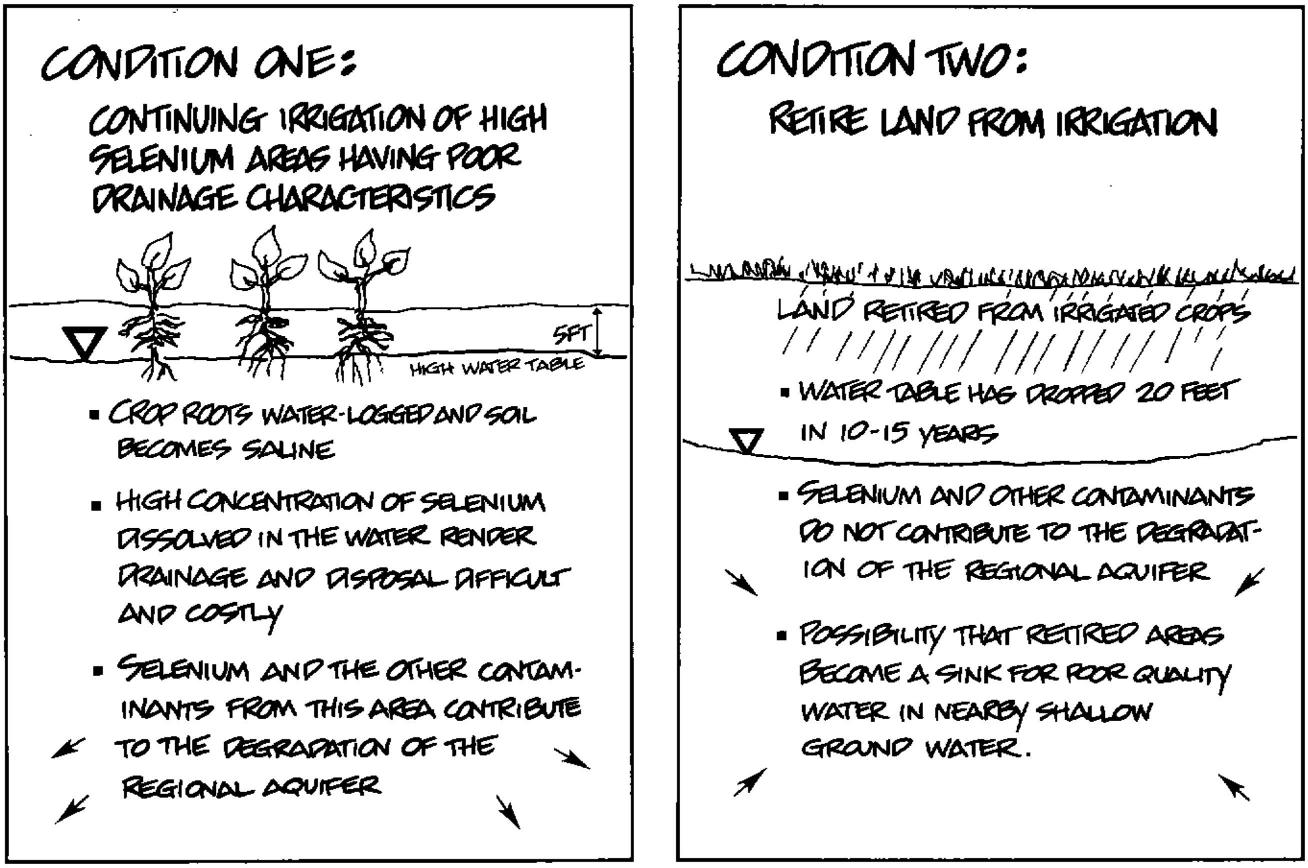
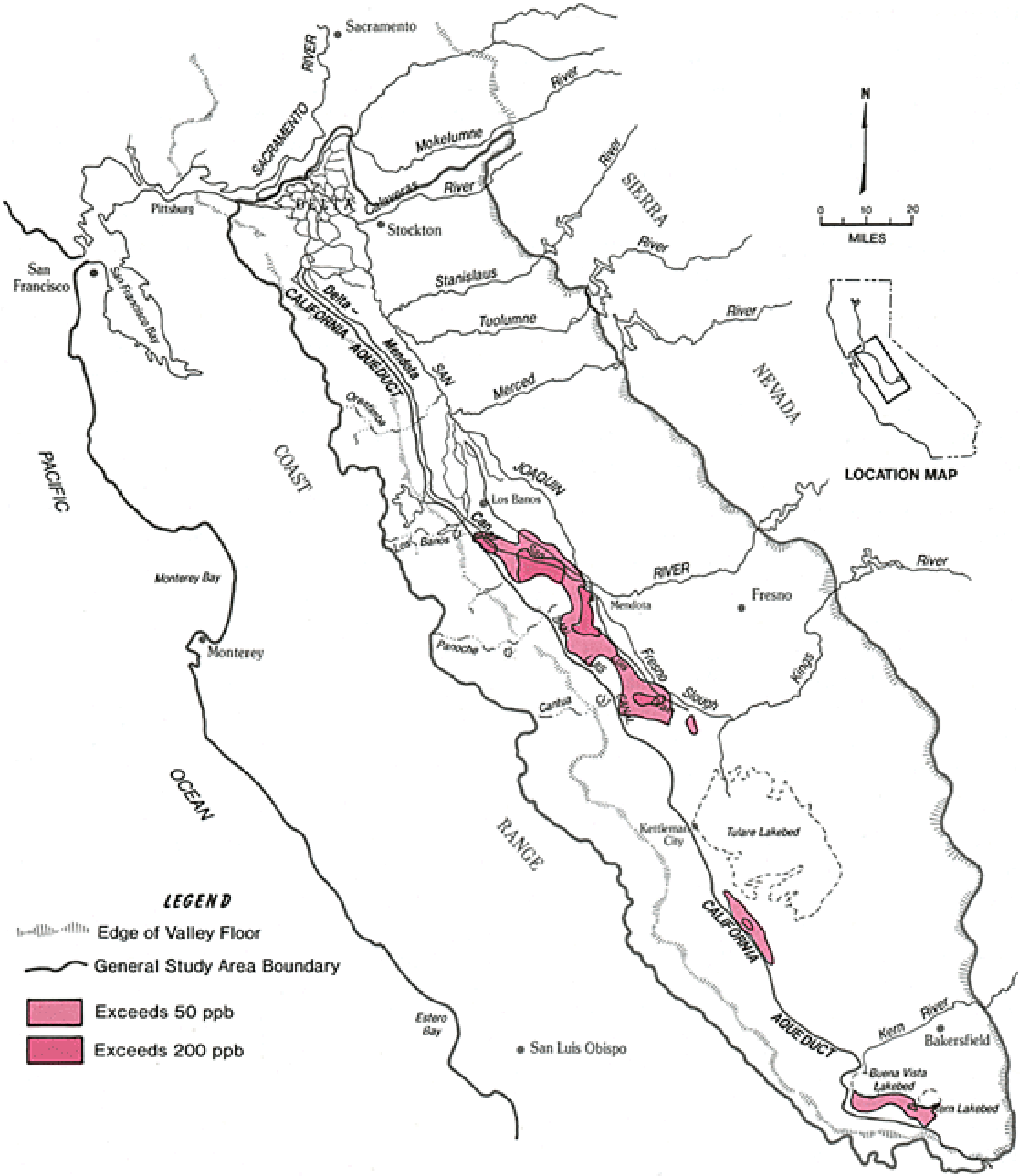


Figure 23

AREAS OF HIGHEST OBSERVED SELENIUM CONCENTRATIONS IN SHALLOW GROUND WATER



Description of Alternatives

The following alternatives are analyzed and evaluated to subarea scope and detail.

Northern Subarea

Alternatives for problem water reduction were not prepared for the Northern Subarea because two factors that tend to motivate major changes in management of drainage problems are largely missing in this part of the valley. First, the shallow ground water is of relatively good quality and low in concentrations of dissolved gypsum, a substance that contributes greatly to problems of westside salinization of soil and ground water (D.G. Swain, 1990).

Second, growers in the Northern Subarea are solving their drainage problems by draining their land and discharging about 20,000 acre-feet per year to the San Joaquin River. If water-quality objectives on the river do not change materially, growers would likely continue discharging to the river.

In addition to controlled subsurface drainage water, the San Joaquin River also receives about 100,000 acre-feet of ground water seepage annually from the Northern Subarea (CH_2M Hill, 1988), an unknown portion of which is related to irrigation water application. Because of the large volume, this flow contributes about 25 percent of the annual salt load flowing into the San Joaquin River at Vernalis, primarily during low flows.

Nishimura and Baughman (1989) have considered this phenomenon and remedial actions that might be both possible and necessary if more strict salt objectives were set for the San Joaquin River. One of the concepts mentioned prominently is a line of shallow wells that would be pumped during high river flows to evacuate the shallow ground water and create additional storage space for drainage water that would otherwise seep into the river during low-flow periods. Hydraulic and engineering studies conducted by the U.S. Bureau of Reclamation were reviewed by D.G. Swain (1990), who concludes that the concept of seasonal evacuation to halt the seepage (which could pose a problem during low flows) would not be effective because the San Joaquin River lacks the capacity to assimilate salt in most high-flow seasons. There would simply be too few opportunities to pump the interceptor wells because of the limited number of days in which the river has assimilitative capacity.

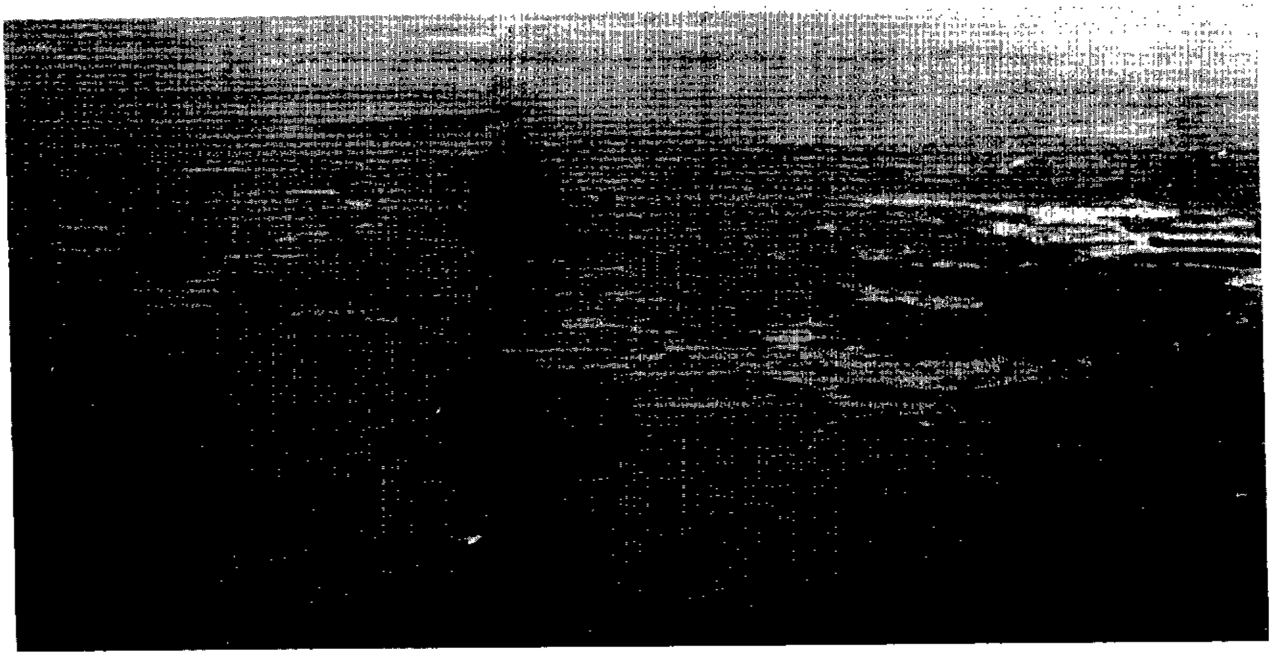
If measures were to be adopted within the subarea to lower the shallow water table adjacent to the San Joaquin River, these could reduce some of the salt load to the river because more salt would be stored in ground water. Two measures that are technically available are: (1) Improving on-farm water application to reduce deep percolation to ground water, and (2) changing the present pattern of surface- and ground-water use to greatly increase the volume of ground water extracted. Presently, only an estimated 30,000 acre-feet per year are pumped from the combined semiconfined and confined aquifers. (In the Northern Subarea, the aquifers are highly interconnected through gravel-packed and multiple-zone wells.) At present, about 94 percent of the agricultural water supply in the Northern Subarea is obtained from the combined sources of the San Joaquin River and the Delta-Mendota Canal. Substituting ground water pumped from below the irrigated area for a portion of this imported surface water would lower the water table and reduce seepage to the San Joaquin River. However, the subsurface drainage that would be discharged to the river would become more saline.

Grasslands Subarea

Figure 24 shows how various options would be combined to reduce problem water in the three planning alternatives. When read horizontally, the graphs show the effect on each option resulting from a shift from Level A to Level B performance standards. When read vertically, they show the effect on each option as the emphasis is changed from source control to ground-water management to land retirement. (Graphs are provided for this purpose in each subarea that follows.) Each Grasslands planning alternative includes the continued use of the San Joaquin River for disposal of some drainage water, although volumes would be reduced 15 to 20 percent under Level B selenium criteria, compared to the existing Level A criteria.

Table 18 shows major features of Grasslands Subarea planning alternatives. Under the alternatives emphasizing source control, the maximum water conservation from source control increases from about 30,000 acre-feet per year in 2000 to 50,000 acre-feet per year in 2040. Source control, featuring available water conservation technologies (such as shortening furrows and using a tailwater return system), is included only in water quality zones A and B (Figure 18), where it would reduce the volume of problem water by 30 to 40 percent, depending upon the criteria. Source control would not be applied in water quality zone C and 50 percent of Zone B (where there are some problems with waterlogging) because that drainage water is considered reusable for irrigating, managing wetlands, and/or increasing flow and improving quality of the San Joaquin River.

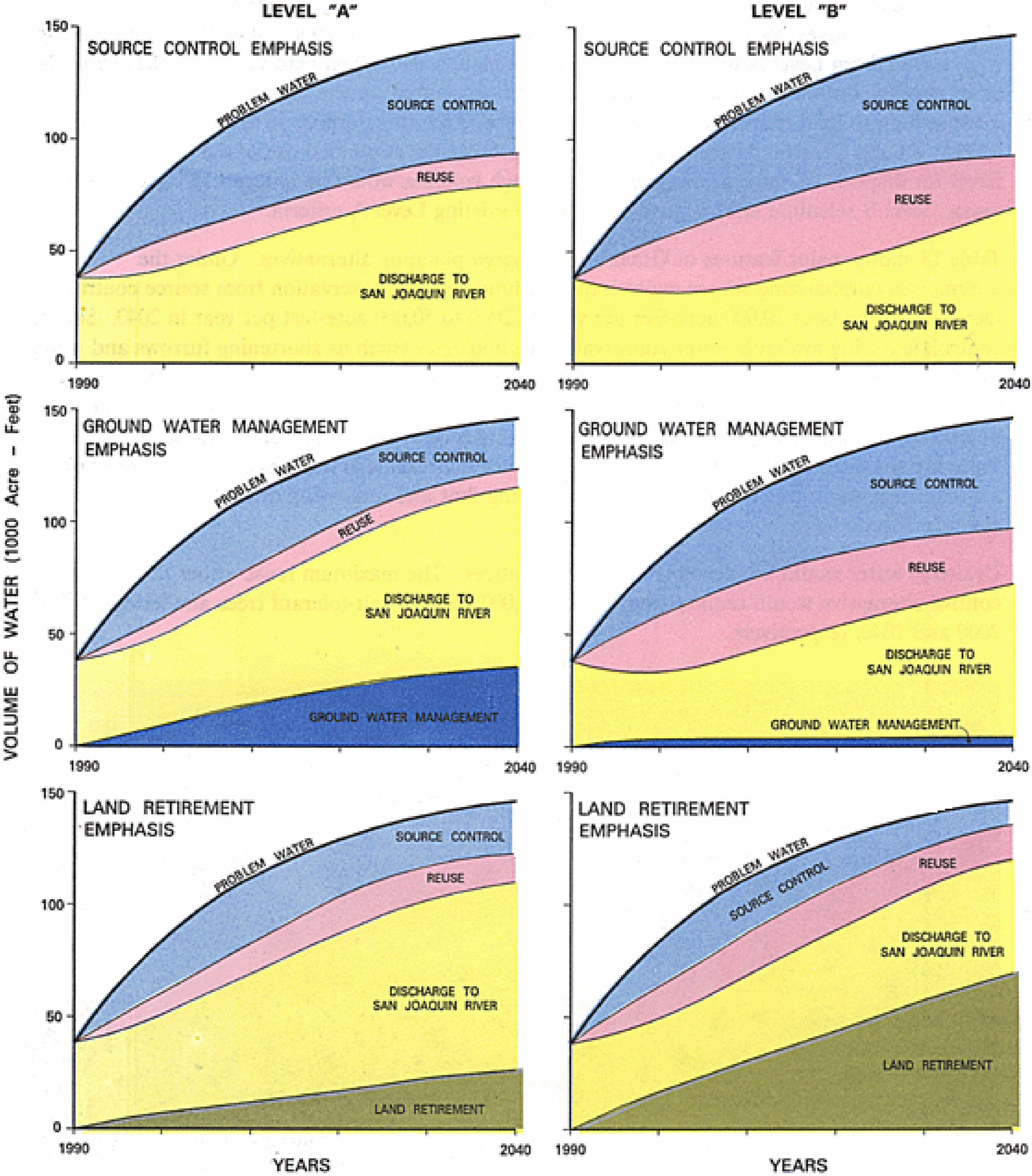
Drainage water would be reused under all alternatives. The maximum reuse under the source control alternative would require from 3,000 to 6,000 acres of salt-tolerant trees and halophytes by 2000 and 2040, respectively.



Wetlands in the Grasslands Subarea, which are laced with waterways, are flooded during the fall and winter waterfowl migration season.

Figure 24

PROBLEM WATER REDUCTION
GRASSLANDS SUBAREA



NOTE: Actions that reduce problem water less than 5000 acre-feet annually are not shown, but are discussed in the text.

Table 18. MAJOR FEATURES OF GRASSLANDS SUBAREA PLANNING ALTERNATIVES

In 1,000s

Performance Level and Plan Emphasis	Shallow Ground Water Area[1] Acres	Land Affected[2] Acres	Problem Water Volume[3] Acre-feet	Conserved-Water[4] Acre-feet	Land Re-using Drainage[5] Acres	Land Retired[6] Acres	Land Overlying GW Pumping[7] Acres	Area of Existing Evaporation Ponds Acres	Area of New Evaporation Ponds Acres
A-2000									
Source Control	218.0	116.0	86.5	30.1	3.1	0.0	0.6	0.1	0.0
Ground Water Management	218.0	116.0	86.5	29.4	1.6	1.9	8.9	0.1	0.0
Land Retirement	218.0	116.0	86.5	26.4	2.1	10.7	0.7	0.1	0.0
A-2040									
Source Control	218.0	196.0	147.0	53.6	3.1	0.0	0.6	0.1	0.0
Ground Water Management	218.0	196.0	147.0	23.8	2.3	0.0	60.8	0.1	0.0
Land Retirement	218.0	196.0	147.0	26.6	2.8	32.3	0.8	0.1	0.0
B-2000									
Source Control	218.0	116.0	86.5	30.1	5.4	0.0	1.2	0.1	0.0
Ground Water Management	218.0	116.0	86.5	30.1	5.4	0.0	1.2	0.1	0.0
Land Retirement	218.0	116.0	86.5	22.1	3.7	23.0	0.2	0.1	0.0
B-2040									
Source Control	218.0	196.0	147.0	53.6	5.8	0.0	1.3	0.1	0.0
Ground Water Management	218.0	196.0	147.0	53.6	5.8	0.0	1.3	0.1	0.0
Land Retirement	218.0	196.0	147.0	13.8	3.0	70.2	0.7	0.0	0.0

1 Irrigated land area with a depth to shallow ground water less than 5 feet.
2 That portion of shallow water areas drained.
3 The forecasted annual drainage volume that must be managed; drained land x 0.75 acre-feet per acre of deep percolation
4 Water supply conserved by on-farm water conservation measures and management practices on problem water lands.
5 Acreage in trees and halophytes.
6 Lands targeted for retirement from irrigated agriculture (excluding lands designated for other uses).
7 Land area where pumping from the semiconfined aquifer is used to lower shallow water table below crop root zone.

Because of geohydrologic conditions, opportunities for deep pumping of the semiconfined aquifer are limited to about 60,000 acres, largely in problem zone A. No new evaporation ponds would be included with any alternative.

Under the land retirement alternative, retirement of irrigated land would be greater under Level B criteria and would increase from about 23,000 to 70,000 acres between 2000 and 2040.

Westlands Subarea

Figure 25 shows how various options would be combined to reduce problem water in the three planning alternatives. Each planning alternative places major reliance on source control for reducing problem water — up to a maximum of about 60 percent in 2040, under the source control alternative.

Table 19 shows major features of Westlands Subarea planning alternatives. The maximum water conservation from source control would be 38,000 acre-feet annually by 2000, and 92,000 acre-feet annually by 2040, under either performance Levels A or B.

Reuse of drainage water is a major feature of all alternatives for the Westlands Subarea. Under maximum reuse, 9,000 to 14,000 acres of trees and halophytes would be used to reduce problem water volume in 2000 and 2040, respectively.

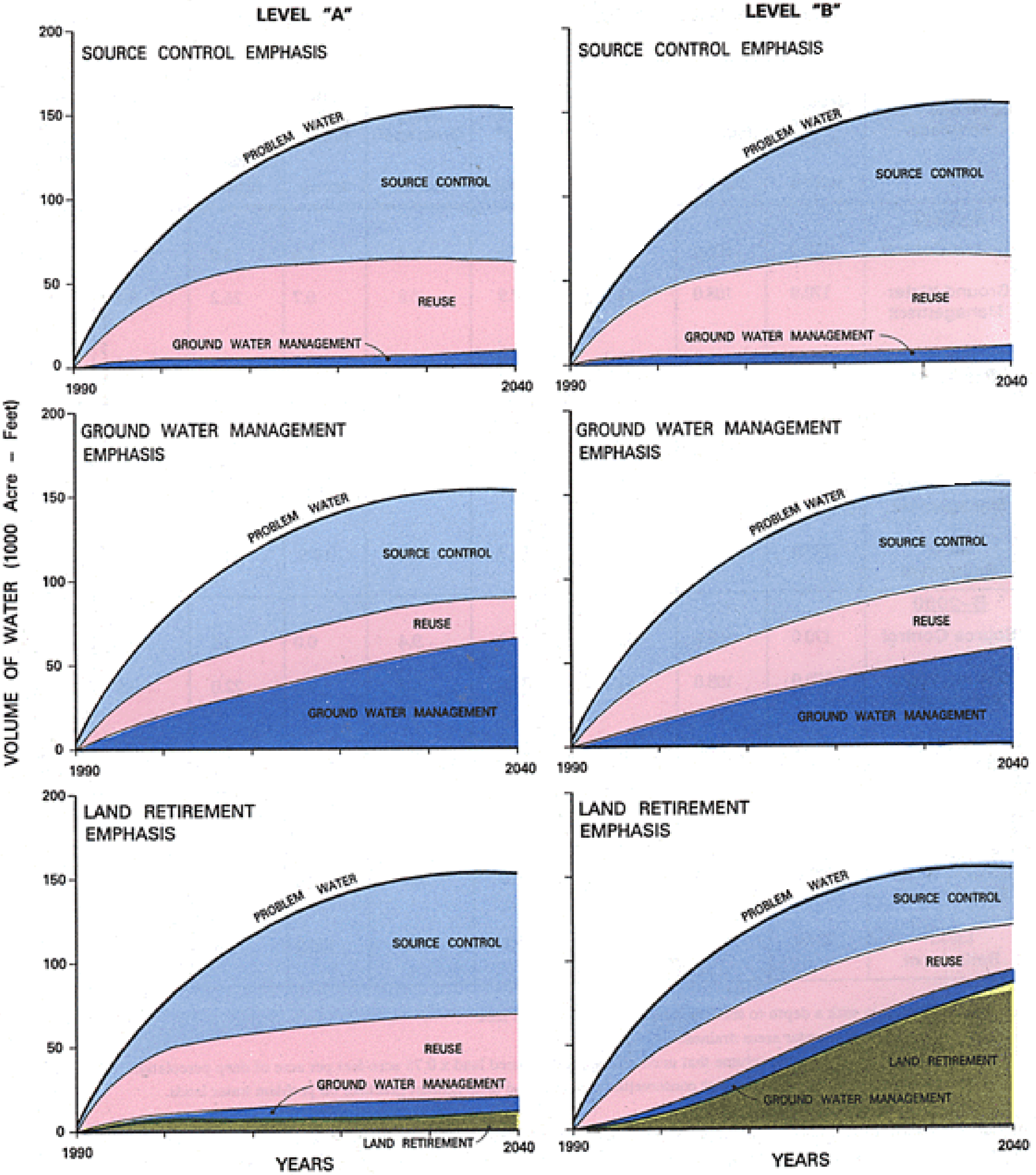
Subsurface physical conditions most strongly favor deep pumping from the semiconfined aquifer to lower shallow ground-water levels in water quality zones C and D (Figure 18). Level A criteria, ground-water management alternative, shows the area of maximum pumping would increase from about 26,000 acres in 2000 to 107,000 acres in 2040.

Under Level B criteria for the land retirement alternative (all shallow ground-water areas above 50 ppb selenium), 12,000 acres would be retired from irrigation by 2000 and 107,000 acres by 2040. In contrast to areas suitable for ground-water management in the southeastern part of Westlands Subarea, areas that fit the criteria for land retirement are located primarily in the northern part. No new evaporation ponds would be included under any alternative.

Figure 25

PROBLEM WATER REDUCTION

WESTLANDS SUBAREA



NOTE: Actions that reduce problem water less than 5000 acre-feet annually are not shown, but are discussed in the text.

Table 19. MAJOR FEATURES OF WESTLANDS SUBAREA PLANNING ALTERNATIVES

In 1,000s

Performance Level and Plan Emphasis	Shallow Ground Water Area[1] Acres	Land Affected[2] Acres	Problem Water Volume[3] Acre-feet	Conserved-Water[4] Acre-feet	Land Reusing Drainage[5] Acres	Land Retired[6] Acres	Land Overlying GW Pumping[7] Acres	Area of Existing Evaporation Ponds Acres	Area of New Evaporation Ponds Acres
A-2000									
Source Control	170.0	108.0	81.1	37.9	9.4	0.0	3.5	0.1	0.0
Ground Water Management	170.0	108.0	81.1	37.9	5.8	0.7	26.2	0.1	0.0
Land Retirement	170.0	108.0	81.1	34.4	8.4	10.2	3.1	0.1	0.0
A-2040									
Source Control	227.0	205.0	153.9	92.4	13.8	0.0	5.1	0.5	0.0
Ground Water Management	227.0	205.0	153.9	62.4	7.8	0.0	106.9	0.5	0.0
Land Retirement	227.0	205.0	153.9	85.7	12.5	14.5	4.6	0.3	0.0
B-2000									
Source Control	170.0	108.0	81.1	37.9	9.4	0.0	3.5	0.3	0.0
Ground Water Management	170.0	108.0	81.1	37.9	6.2	0.0	22.0	0.5	0.0
Land Retirement	170.0	108.0	81.1	33.9	8.5	11.5	2.7	0.3	0.0
B-2040									
Source Control	227.0	205.0	153.9	92.4	13.6	0.0	5.7	0.1	0.0
Ground Water Management	227.0	205.0	153.9	56.6	10.7	0.0	97.8	0.5	0.0
Land Retirement	227.0	205.0	153.9	39.9	7.2	106.9	2.0	0.0	0.0

1 Irrigated land area with a depth to shallow ground water less than 5 feet.
2 That portion of shallow water areas drained.
3 The forecasted annual drainage volume that must be managed; drained land x 0.75 acre-feet per acre of deep percolation.
4 Water supply conserved by on-farm water conservation measures and management practices on problem water lands.
5 Acreage in trees and halophytes.
6 Lands targeted for retirement from irrigated agriculture (excluding lands designated for other uses).
7 Land area where pumping from the semiconfined aquifer is used to lower shallow water table below crop root zone.

Tulare Subarea

Figure 26 shows how various options would be combined in the Tulare Subarea to reduce problem water. Table 20 shows major features of Tulare Subarea planning alternatives. All plans include major reliance on source control for reducing problem water, up to a maximum of about 60 percent in 2040 under the source control alternative. The maximum water conservation through source control would be 44,000 acre-feet annually by 2000 and 156,000 acre-feet annually by 2040, under the source control alternative.

Reuse of drainage water is a major feature of the alternatives presented for the Tulare Subarea. Under the maximum reuse option, from 11,000 to 23,000 acres of trees and halophytes would be used in 2000 and 2040, respectively.

Conditions favorable for deep pumping of the semiconfined aquifer occur largely in areas influenced by the Kings River Delta: water quality zones A, D, and E (Figure 18). The planning criteria would allow pumping under a maximum of about 20,000 acres in 2000 and 135,000 acres in 2040. Ground-water management or evaporation ponds may be used in zone E, where drainage water is generally very low in dissolved selenium. No new evaporation ponds are included in any alternative. Further study may reveal that evaporation ponds in the South Kings River Delta (zone E) would be bird-safe because of low contaminant concentrations in drainage water.

No shallow ground water in the Tulare Subarea is known to be high enough in selenium concentration to exceed the 200 ppb planning criterion for land retirement. Alternatives emphasizing land retirement are included, but they are almost identical to the source control alternatives.

Kern Subarea

Figure 27 shows how various options would be combined in the Kern Subarea to reduce problem water in the three planning alternatives. Table 21 shows major features of the planning alternatives. All plans include major reliance on source control for reducing problem water, up to a maximum of about 55 percent in 2040, under the source control alternative. The maximum water conservation that would occur through source control would be 21,000 acre-feet annually by 2000 and 68,000 acre-feet annually by 2040, under several alternatives. Reuse is also an important component of the alternatives presented for the Kern Subarea. Under maximum reuse, from 6,000 to 12,000 acres of trees and halophytes would be grown in the subarea in 2000 and 2040, respectively.

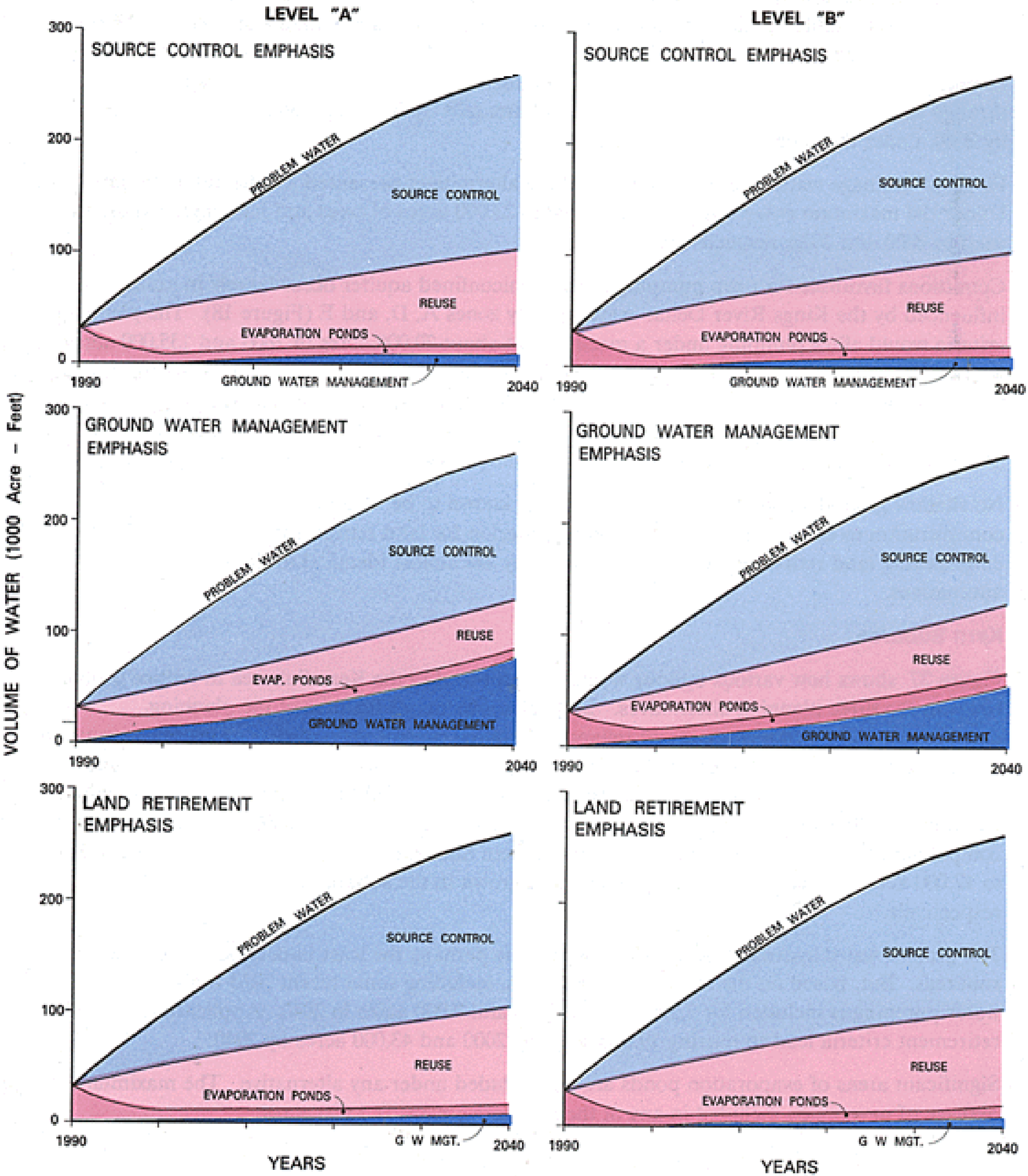
The ground water hydrology of the Kern Subarea is perhaps the least understood of all the subareas. But, based on the available information, including some recent field work, ground water pumping is included for 1,500 acres in 2000 and 7,000 acres in 2040. Application of land retirement criteria lead to retiring 19,000 acres by 2000 and 43,000 acres by 2040.

Significant areas of evaporation ponds are not included under any alternative. The maximum acreage of new ponds included in any of the alternative plans is 1,600 acres.

Figure 26

PROBLEM WATER REDUCTION

TULARE SUBAREA



NOTE: Actions that reduce problem water less than 5000 acre-feet annually are not shown, but are discussed in the text.

Table 20. MAJOR FEATURES OF TULARE SUBAREA PLANNING ALTERNATIVES

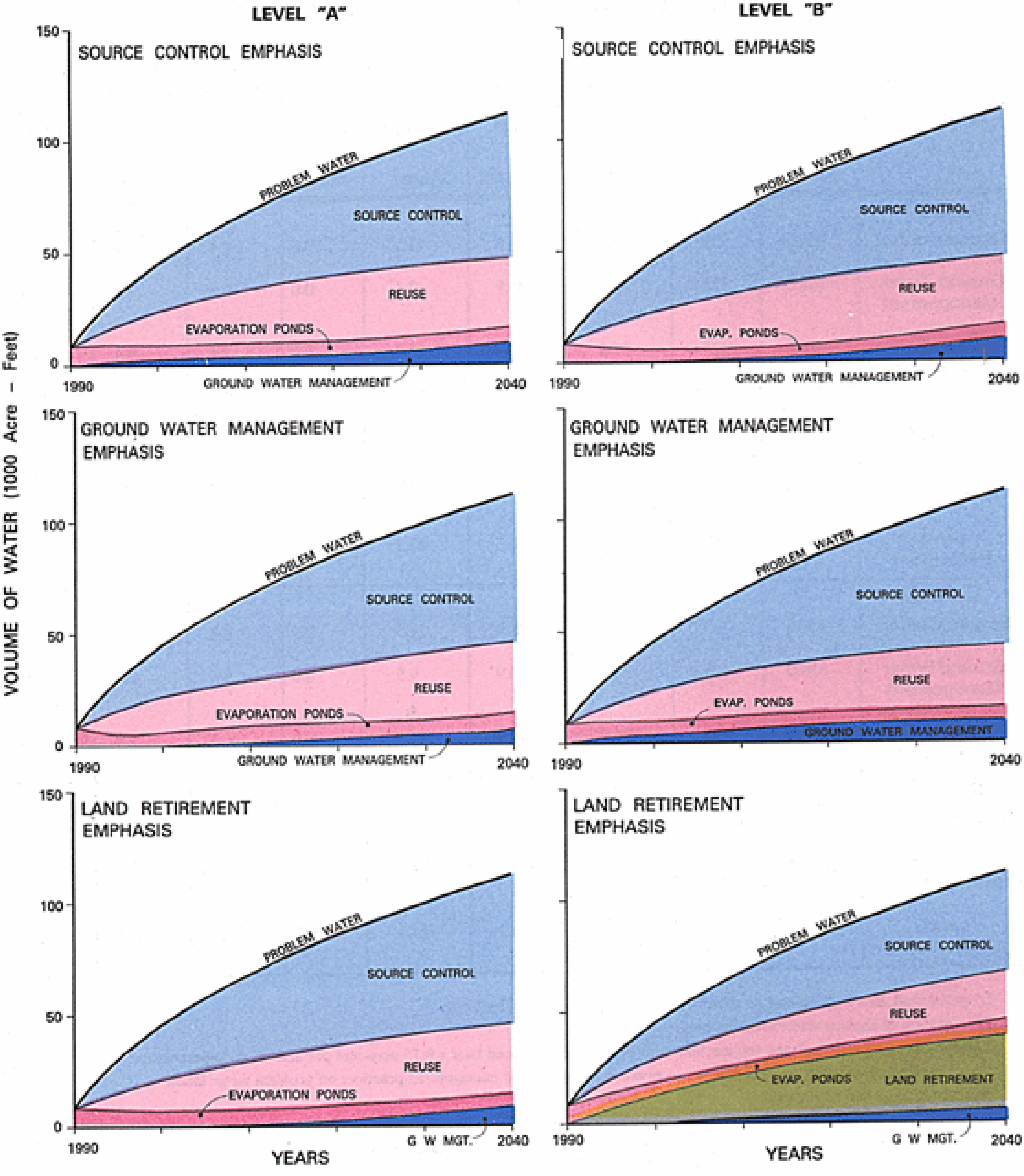
In 1,000s

Performance Level and Plan Emphasis	Shallow Ground Water Area[1] Acres	Land Affected[2] Acres	Problem Water Volume[3] Acre-feet	Conserved-Water[4] Acre-feet	Land Reusing Drainage[5] Acres	Land Retired[6] Acres	Land Overlying GW Pumping[7] Acres	Area of Existing Evaporation Ponds Acres	Area of New Evaporation Ponds Acres
A-2000									
Source Control	359.0	125.0	94.0	43.9	11.3	0.0	0.4	2.4	0.0
Ground Water Management	359.0	125.0	94.0	43.9	7.4	0.0	19.3	2.5	0.0
Land Retirement	359.0	125.0	94.0	43.9	10.7	0.0	1.4	2.4	0.0
A-2040									
Source Control	387.0	347.0	260.4	156.3	23.3	0.0	7.1	2.0	0.0
Ground Water Management	387.0	347.0	260.4	132.5	12.6	0.0	135.4	2.0	0.0
Land Retirement	387.0	347.0	260.4	156.3	23.3	0.0	6.7	2.0	0.0
B-2000									
Source Control	359.0	125.0	94.0	43.9	11.3	0.0	0.8	2.4	0.0
Ground Water Management	359.0	125.0	94.0	43.9	9.5	0.0	8.4	2.4	0.0
Land Retirement	359.0	125.0	94.0	43.9	11.3	0.0	0.4	2.4	0.0
B-2040									
Source Control	387.0	347.0	260.4	156.3	23.3	0.0	5.7	2.5	0.0
Ground Water Management	387.0	347.0	260.4	132.5	17.0	0.0	94.5	2.5	0.0
Land Retirement	387.0	347.0	260.4	156.3	23.3	0.0	5.7	2.5	0.0

1 Irrigated land area with a depth to shallow ground water less than 5 feet.
2 That portion of shallow water areas drained.
3 The forecasted annual drainage volume that must be managed; drained land x 0.75 acre-feet per acre of deep percolation
4 Water supply conserved by on-farm water conservation measures and management practices on problem water lands.
5 Acreage in trees and halophytes.
6 Lands targeted for retirement from irrigated agriculture (excluding lands designated for other uses).
7 Land area where pumping from the semiconfined aquifer is used to lower shallow water table below crop root zone.

Figure 27

PROBLEM WATER REDUCTION
KERN SUBAREA



NOTE: Actions that reduce problem water less than 5000 acre-feet annually are not shown, but are discussed in the text.

Table 21. MAJOR FEATURES OF KERN SUBAREA PLANNING ALTERNATIVES

In 1,000s

Performance Level and Plan Emphasis	Shallow Ground Water Area[1] Acres	Land Affected[2] Acres	Problem Water Volume[3] Acre-feet	Conserved-Water[4] Acre-feet	Land Reusing Drainage[5] Acres	Land Retired[6] Acres	Land Overlying GW Pumping[7] Acres	Area of Existing Evaporation Ponds Acres	Area of New Evaporation Ponds Acres
A-2000									
Source Control	110.0	61.0	45.8	21.4	6.0	0.0	2.6	1.3	0.1
Ground Water Management	110.0	61.0	45.8	21.4	6.0	3.2	2.5	1.3	0.0
Land Retirement	110.0	61.0	45.8	20.2	5.7	3.2	2.5	1.2	0.1
A-2040									
Source Control	167.0	150.0	112.6	67.5	11.7	0.0	6.9	1.5	0.0
Ground Water Management	167.0	150.0	112.6	67.6	11.2	0.0	6.9	1.6	0.0
Land Retirement	167.0	150.0	112.6	66.2	11.5	3.1	5.6	1.6	0.0
B-2000									
Source Control	110.0	61.0	45.8	21.4	6.0	0.0	2.6	1.2	0.1
Ground Water Management	110.0	61.0	45.8	21.4	6.0	0.0	2.6	1.3	0.0
Land Retirement	110.0	61.0	45.8	14.8	4.1	18.7	1.5	1.0	0.0
B-2040									
Source Control	167.0	150.0	112.6	67.6	11.2	0.0	6.7	1.6	0.0
Ground Water Management	167.0	150.0	112.6	67.6	11.2	0.0	6.9	1.6	0.0
Land Retirement	167.0	150.0	112.6	44.5	8.7	42.6	4.8	1.6	0.0

1 Irrigated land area with a depth to shallow ground water less than 5 feet.
2 That portion of shallow water areas drained.
3 The forecasted annual drainage volume that must be managed; drained land x 0.75 acre-feet per acre of deep percolation
4 Water supply conserved by on-farm water conservation measures and management practices on problem water lands.
5 Acreage in trees and halophytes.
6 Lands targeted for retirement from irrigated agriculture (excluding lands designated for other uses).
7 Land area where pumping from the semiconfined aquifer is used to lower shallow water table below crop root zone.

SUMMARY AND CONCLUSIONS FROM ANALYSES OF SUBAREA PLANNING ALTERNATIVES

Table 22 summarizes the major components of drainage management alternatives for the study area (the four subareas for which alternatives were prepared).

The alternatives were developed to show the effects of emphasizing different strategies for managing drainage water. The conclusions that follow are based on analysis of the alternatives and are used in formulating the recommended plan presented in Chapter 6:

- Few major differences exist among the six alternatives presented in each subarea, due primarily to the narrow ranges of choice actually available when physical constraints, present and likely environmental regulations, and costs are considered. The lack of difference is also due to the inclusion of source control and reuse in all alternatives. These options were included because they are available technologies that could be applied throughout the study area and because of their comparative cost advantage.

- The opportunity for discharge of drainage water to the San Joaquin River causes the Grasslands Subarea to differ considerably from other subareas.

- The planning alternatives show that the amount of water conserved by on-farm methods of drainage-water source control ranges from about 250,000 to 370,000 acre-feet annually by 2040. When land retirement and ground-water management are added to source control, the range of water conserved increases to 530,000 to 950,000 acre-feet annually by 2040. Water conserved by source control and ground-water management would benefit the water user, and values are taken to lower the costs of these options. It is assumed that at least 2.6 acre-feet per acre of water would be freed by land retirement, but no value is taken in this analysis because the value of the water is included in the market value of the irrigated lands to be purchased.

- The analyses show how specific alternatives serve certain objectives that could be considered auxiliary to the objective of all plans of the Drainage Program — solving the drainage water problem. For example, the objective of conserving water at least cost would be served best by maximizing the source control and reuse options. If minimizing risk from toxicants were the dominant objective, then the land retirement component should be maximized.

- A practical mix of drainage management options will not be found by formulating plans to adhere strictly to the criteria for performance Level A or performance Level B. However, analysis of alternatives formulated in that way provides a base for designing a plan that is more efficient than either Level A or B, or the future-without alternative.

- Because of the complexities of the interactive factors involved in solving the drainage problems and the many unknowns, only limited success has been achieved in modeling the natural and cultural features of the problem area. This has prevented asking "what-if" questions that could generate an infinite number of alternatives. Professional judgment, local experience, and public review will evidently continue to be the most important resources in developing a successful plan.

Table 22. MAJOR FEATURES OF STUDY AREA PLANNING ALTERNATIVES

In 1,000s

Performance Level and Plan Emphasis	Shallow Ground Water Area[1] Acres	Land Affected[2] Acres	Problem Water Volume[3] Acre-feet	Conserved-Water[4] Acre-feet	Land Reusing Drainage[5] Acres	Land Retired[6] Acres	Land Overlying GW Pumping[7] Acres	Area of Existing Evaporation Ponds Acres	Area of New Evaporation Ponds Acres
A-2000									
Source Control	857.0	410.0	307.4	133.3	29.8	0.0	7.1	4.2	0.1
Ground Water Management	857.0	410.0	307.4	132.4	20.8	5.8	56.9	4.4	0.0
Land Retirement	857.0	410.0	307.4	124.9	26.9	24.1	7.7	4.0	0.1
A-2040									
Source Control	999.0	898.0	673.9	369.9	51.7	0.0	19.7	4.1	0.1
Ground Water Management	999.0	898.0	673.9	286.3	33.9	0.0	310.0	4.2	0.01
Land Retirement	999.0	898.0	673.9	334.8	50.1	49.9	17.7	4.0	0.1
B-2000									
Source Control	857.0	410.0	307.4	133.3	32.1	0.0	8.1	4.0	0.1
Ground Water Management	857.0	410.0	307.4	133.3	27.1	0.0	34.2	4.3	0.0
Land Retirement	857.0	410.0	307.4	114.7	27.6	53.2	4.8	3.8	0.0
B-2040									
Source Control	999.0	898.0	673.9	369.9	53.9	0.0	19.4	4.3	0.1
Ground Water Management	999.0	898.0	673.9	310.3	44.7	0.0	200.5	4.7	0.1
Land Retirement	999.0	898.0	67.3	254.5	42.2	219.7	13.2	4.1	0.1

1 Irrigated land area with a depth to shallow ground water less than 5 feet.
2 That portion of shallow water areas drained.
3 The forecasted annual drainage volume that must be managed; drained land x 0.75 acre-feet per acre of deep percolation
4 Water supply conserved by on-farm water conservation measures and management practices on problem water lands.
5 Acreage in trees and halophytes.
6 Lands targeted for retirement from irrigated agriculture (excluding lands designated for other uses).
7 Land area where pumping from the semiconfined aquifer is used to lower shallow water table below crop root zone.

Chapter 6. THE RECOMMENDED PLAN

The plan presented here is intended as a regional framework for management of drainage and drainage-related problems on the western side of the San Joaquin Valley. It consists of a set of actions that are quantified to the degree possible with information currently available. Actions are planned to continue over the 50-year period, from 1990, through a near-term planning horizon (2000), and on to a long-term planning horizon (2040). Actions are quantified and described for the two planning horizons.

Under the assumptions and conditions of the plan, no decision need be made now on exporting salt from the San Joaquin Valley. As explained in a later section of this chapter, "Rationale on Salt Balance," that decision can be deferred. Most, if not all, of the actions proposed in the recommended plan would be required as the first phase of any out-of-valley export system.

Uncertainties in the scientific information base, plus difficulties in forecasting human events, necessitate that the plan be updated from time to time as monitoring, additional studies, and local actions reveal new facts.

PLAN FORMULATION PROCEDURE

The recommended plan contains some aspects of both A and B performance levels from alternatives presented in Chapter 5. Performance standards used in formulating the recommended plan are shown in Table 23. The applicability of drainage management options in each water quality zone was assessed by using the performance standards (Table 24).

The sequence of plan formulation is illustrated in Figures 28, 29, and 30. The following discussions are provided as a guide to the decision points and places where judgment was applied. A detailed and comprehensive explanation of the technical processes and data used in formulating the plan is set forth in a report by the SJVDP (D.G. Swain, 1990).

Land Retirement Decisions

Land retirement was generally considered for inclusion as a plan component on lands that are saline and/or difficult to drain (class 4, USBR classification, for example) and where shallow ground water contains high selenium levels (50 ppm or more). Such decisions must, however, be based on all factors at the site and on the other alternatives available for managing the drainage problem. They do not preclude the future option of re-establishing irrigated agriculture if circumstances should change.

Source Control Decisions

Measures to control subsurface drainage at the source should generally be applied to all lands with drainage problems, except those that may be retired from irrigated agriculture. The specific

Table 23. PERFORMANCE STANDARDS USED TO FORMULATE RECOMMENDED PLAN

Category	Feature	Planning Criteria
WATER QUALITY (mean monthly)	SAN JOAQUIN RIVER near NEWMAN	BORON ≤0.7 ppm SELENIUM ≤5 ppb MOLYBDENUM ≤10 ppb
	SALT and MUD SLOUGHS	SALINITY ≤2,000 ppm TDS BORON ≤2 ppm SELENIUM ≤2 ppb MOLYBDENUM ≤10 ppb
	AGRICULTURAL WATER SUPPLY	SALINITY ≤1,250 ppm TDS BORON ≤1 ppm OR 1,250 ppm TDS ≤SALINITY ≤2,500 ppm TDS BORON ≤2 ppm (with dilution or restricted use)
	WETLAND WATER SUPPLY	SALINITY ≤1,250 ppm TDS BORON ≤1 ppm SELENIUM ≤2 ppb
	REUSE OF SUBSURFACE DRAINAGE ON SALT-TOLERANT PLANTS	EUCALYPTUS TREES ≤10,000 ppm TDS HALOPHYTES ≤25,000 ppm TDS
	EVAPORATION POND	INFLUENT QUALITY SELENIUM ≤2 ppb (No alternative habitat required) SELENIUM >2 and <50 ppb (Alternative habitat required) SELENIUM ≥50 ppb (No traditional evaporation ponds)
WATER QUANTITY	PUMPING SEMICONFINED AQUIFER	INITIAL AQUIFER THICKNESS ≥200 feet INITIAL SALINITY <1,250 ppm TDS[a]
	GRASSLANDS WETLAND HABITAT SUBSTITUTE WATER SUPPLY	SUPPLY 129,000 acre-feet per year (74,000 acre-feet per year of fresh water plus facilities to provide at least 55,000 acre-feet of spills and tailwater)
	WATER SUPPLY FOR EVAPORATION POND ALTERNATIVE HABITAT	SUPPLY 10 acre-feet per acre per year
	SUPPLEMENTAL FISHERY FLOWS - MERCED RIVER near STEVINSON	SUPPLY 20,000 acre-feet per year (provided in October)
	DESIGN LIMIT TO REGIONAL DEEP PERCOLATION	LIMIT IS 0.4 acre-foot per acre per year[b]
LAND USE	WILDLIFE HABITAT	ALTERNATIVE HABITAT EQUAL IN SIZE TO EVAPORATION POND AREA WHERE Se INFLUENT >2 and <50 ppb
	RETIREMENT OF IRRIGATED AGRICULTURAL LANDS	LANDS WITH ≥50 ppb Se CONC. IN SHALLOW GROUND WATER AND RELATIVELY LOW PRODUCTIVITY (CLASS 4) DUE TO HIGH SALINITY AND POOR DRAINAGE CONDITIONS

[a] As salinity of pumped water exceeds 1,250 ppm TDS, its use as irrigation water becomes limited; however, it is considered usable for very salt-tolerant crops if salinity does not exceed 2,500 ppm TDS.

[b] That portion of applied irrigation water passing the root zone which requires drainage management. An additional 0.1 to 0.3 ac-ft/ac/yr of deep percolation is assumed to move downward through the Corcoran Clay layer.

Table 24. APPLICABILITY OF DRAINAGE MANAGEMENT OPTIONS
(Recommended Plan Performance Standards)

Subareas and Water Quality Zones	Drainage Source Control	San Joaquin River Discharge[1]	Salt-Tolerant Trees	Halophytes	Land Retirement[2]	Existing Evaporation Ponds	New Evaporation Ponds[3]	Ground Water Management
Grasslands								
A	X	Y(21k AF)	X	X	Y(3k Ac.)	Y(0.1k Ac.)	NA(>2 ppb Se)	Y(9k Ac.)
B	X	Y(15k AF)	X	X	NA(<50 ppb Se)	NA	X	NA(200 ft thick)
C	X	X	NR	NR	NR	NR	NR	NR
D[4]	X	NR-W	NR-W	NR-W	NR-W	NR-W	NR-W	NR-W
Westlands								
A	X	NA	X	X	Y(5K Ac.)	NA	NA(<2 ppb Se)	NA(>200 ft th ick)
B	X	NA	NA(>10k ppm TDS)	X	Y(15K Ac.)	Y(0.1k Ac.)	NA(>2 ppb Se)	NA(<200 ft thick)
C	X	NA	X	X	Y(13K Ac.)	NA	NA(>2 ppb Se)	Y(38k Ac.)
D	X	NA	X	X	NA(<50 ppb Se)	Y(0.4k Ac.)	NA(>2 ppb Se)	Y(24k Ac.)
Tulare								
A	X	NA	X	X	NA(<50 ppb Se)	Y(0.5k Ac.)	X	Y(916k Ac.)
B	X	NA	NA(>10k ppm TDS)	X	Y(7k Ac.)	Y(3.6k Ac.)	NA(>2 ppb Se)	NA(<200 ft thick)
C	X	NA	X	X	NA(<50 ppb Se)	Y(0.2k Ac.)	NA(>2 ppb Se)	NA(<200 ft thick)
D	X	NA	NA(>10k ppm TDS)	X	NA(<50 ppb Se)	Y(0.3k Ac.)	NA(>2 ppb Se)	Y(31k Ac.)
E	X	NA	X	X	NA(<50 ppb Se)	Y(0.3k Ac.)	X	Y(90k Ac.)
Kern								
A	X	NA	NA(>10k ppm TDS)	X	Y(24 Ac.)	Y(1.3k Ac.)	NA(>2 ppb Se)	NA(<200 ft thick)
B	X	NA	NA(>10K ppm TDS)	X	NA(<50 ppb Se)	NA	NA(.2 ppb Se)	NA(<200 ft thick)
C	X	NA	X	X	NA(<50 ppb Se)	Y(0.2k Ac.)	X	NA(<200 ft thick)
D	X	NA	NA(>10k ppm TDS)	X	Y(8k Ac.)	Y(0.2k Ac.)	NA(>2 ppb Se)	NA(<200 ft thick)

1 Applicability of option depends on selenium criterion (mean monthly concentration of 2 ppb) and critical year hydrology (1986-87) for San Joaquin River near Newman. Selenium load expected to drop up to 50 percent by 2040 as a result of removing salts from the shallow ground water and soils.

2 A combination of ≥50 ppb selenium concentration in the shallow ground water and relatively low land productivity due to high soil salinity and poor drainage conditions (USBR Class 4 or equivalent SCS soil classification) was used to select lands on which irrigated agriculture would be discontinued.

3 New evaporation ponds can be used when drainage water selenium concentration exceeds 2 ppb and is ≤50 ppb; however, mitigation measures including alternative habitat must be provided.

4 Manage wildlife wetland area.

X Option is applicable without any limitation in its application.

Y Option is applicable but limited to the quantities and units included in the parentheses.

NA Option not applicable because it failed to meet the performance standard in parentheses (see Table 7) or not physically available in the instances of discharge to the San Joaquin River.

NR Option not suggested because increased conservation with resulting increased salinity will lower the likelihood that drainage water can be used for wetland habitat.

NR-W Option is not applicable since shallow ground water within wetlands benefits waterfowl.

Figure 28
OVERALL PLAN FORMULATION SEQUENCE

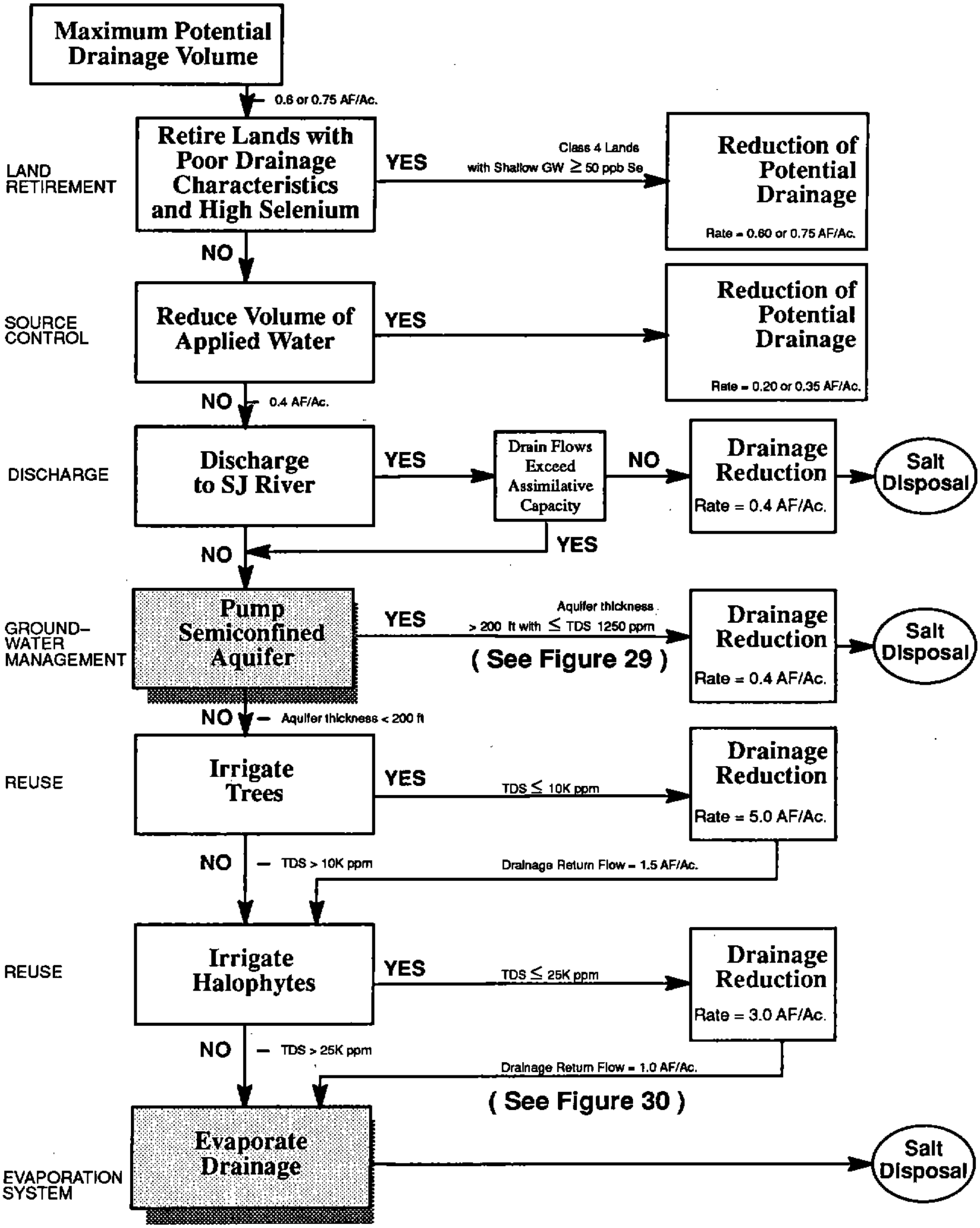


Figure 29
PLAN FORMULATION SEQUENCE
Pump Semiconfined Aquifer

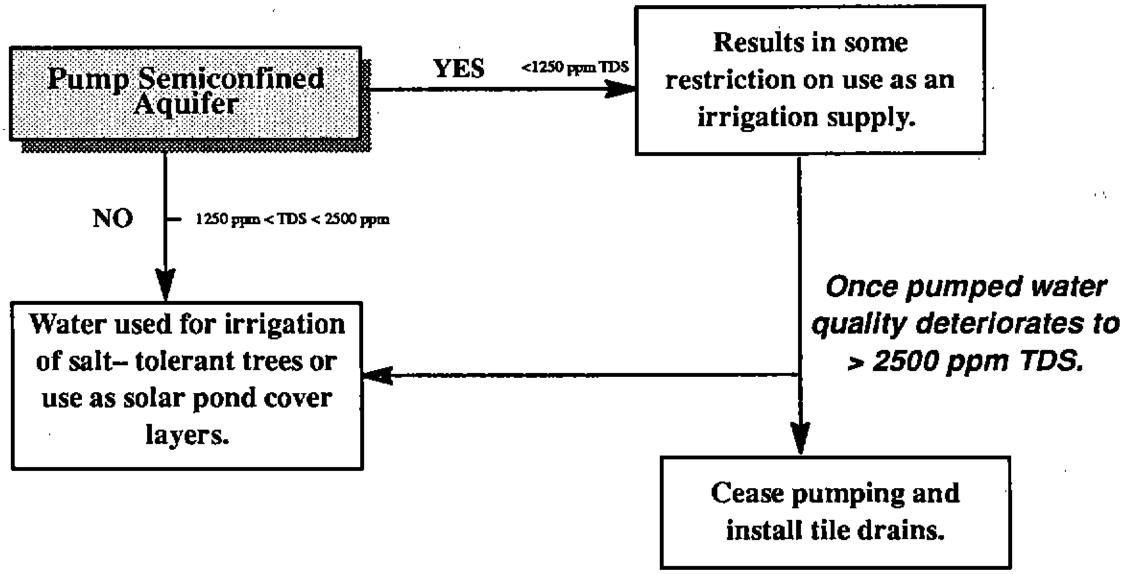
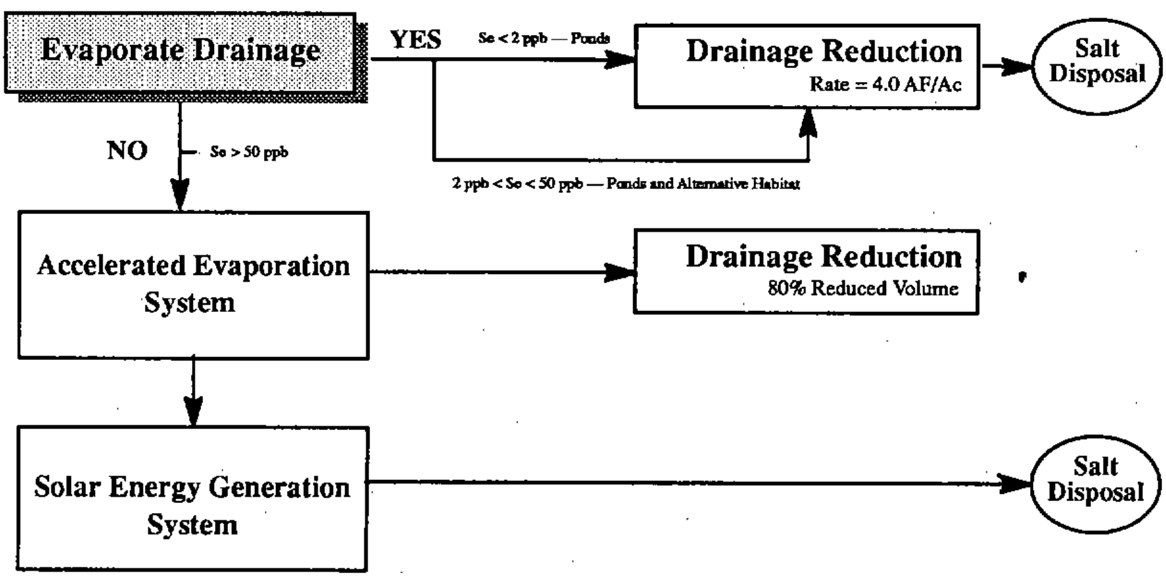


Figure 30
PLAN FORMULATION SEQUENCE
Evaporate Drainage



source control measures adopted will vary according to the types of crops grown and individual grower preference. Application of source control measures could eliminate an average of nearly 50 percent of the total problem water volume (pre-1985 conditions) by reducing deep percolation and, hence, potential drainage water. The rate at which source control can be implemented is generally controlled by the rate at which investments can be made to improve irrigation practices. The recommended plan takes this into account.

In the recommended plan, source control measures were not applied to water-quality Zone C and a portion of Zone B in the Grasslands Subarea. These zones contain low selenium and moderately saline water of a quality suitable for use in wetlands or for direct discharge to the San Joaquin River during much of the year.

The water collected in on-farm drains would have four possible fates: discharge to the San Joaquin River, water supply for wildlife areas (if selenium concentration is low), reuse on salt–tolerant plants, and/or discharge to evaporation ponds.

Decisions on Discharge to the San Joaquin River

The levels of performance required of the recommended plan in affecting the quality of water in the San Joaquin River were determined by State water-quality objectives and by scientific investigations of the U.S. Fish and Wildlife Service. It was determined that the selenium objectives of 5 ppb in the river and of 2 ppb in Mud and Salt sloughs were the most difficult objectives to be met. For planning, it was assumed that, if the selenium objective were met, then the boron and salt objectives could also be met.

Accordingly, the Drainage Program focused on the assimilative capacity of the San Joaquin River. The plan identifies means to collect and isolate (from wetlands) a comparatively small volume of high-selenium water in the Grasslands Subarea. That drainage volume would then be conveyed through a rehabilitated and extended San Luis Drain for discharge to the San Joaquin River below its confluence with the Merced River. It was also decided that the plan should include supplementing the Merced River with fresh water obtained from the eastern side of the San Joaquin Valley.

Replacement of the contaminated agricultural drainage water delivered and used in wetland areas before 1985 is a requirement of all plans. Mud and Salt Sloughs would not be used to convey water to wildlife habitat unless the selenium concentration of the supply is less than 2 ppb.

Reuse Decisions

It was assumed that, with some exceptions for the Grasslands Subarea, all water collected in tile drains would be reused on salt–tolerant trees and halophytes. This component is included in the plan under the conditional requirement that monitoring and analyses of the concentration of toxicants in biota (selenium, for example) would be necessary to give warning of any incipient problem and allow for remedial measures (keeping eucalyptus groves free of forest litter, for example). Reuse would eliminate a significant volume of problem water. The drainage water from trees and halophytes would be disposed of in evaporation ponds and solar ponds.

Evaporation Pond Decisions

The quality of drainage water (primarily selenium concentration) determines the selection, design, and operation of an evaporation system. It was assumed that all evaporation ponds would be designed and built according to criteria of the California Department of Fish and Game, which specify steep side slopes and minimum allowable pond depth (Bradford, et al., 1989). In addition, if influent selenium concentration is greater than 2 ppb, alternative, safe habitat equal to the pond area would be provided to facilitate hazing waterfowl from the pond area. If the influent concentration exceeds 50 ppb, an accelerated-rate evaporation pond would be used to reduce the required pond area because open ponds would not be considered feasible in the long run under these conditions. When possible, evaporation ponds would be located on the least productive agricultural land and at the lowest elevations of the drained areas.

Treatment for Selenium Removal

Although it is probable that an economical biological treatment process to remove selenium from drainage water will become available within the next 10 to 20 years, treatment is not included in the recommended plan. Instead, plan components are based on available technology. Treatment methods to remove selenium should be pursued and, when available, might replace or modify ground-water management or the evaporation processes. Treatment research should be continued not only on selenium removal but also on other toxic substances, such as arsenic, which are sometimes found in high concentrations in drainage water.

Ground-Water Pumping Decisions

Some growers now pump irrigation water from certain zones of the semiconfined aquifer. This pumping could be done in a more systematic and coordinated manner to focus specifically on lowering, and maintaining at lower levels, the shallow water table of drainage problem areas. Criteria for selecting potential pumping areas include adequate thicknesses of aquifers and water quality. Because pumping would eventually draw poor-quality water from higher in the aquifer into the producing wells, the length of time pumping could be continued was determined by the thickness of the aquifer zone and the rate of pumping. For an area to be included in the plan, the estimated life of the well field had to exceed 20 years. Application of planning criteria made a relatively minor amount of problem water area amenable to this component.

Rationale on Salt Balance

Implementation of the recommended plan would allow maintenance of a salt balance in the plant root zone. Primarily, this would be accomplished by source control and by drainage to remove shallow ground water and the salts it contains from crop root zones. This is in contrast to future-without conditions (described in Chapter 5), in which a salt balance could not be maintained and would lead to salinization and abandonment of lands within the next few decades because of problems associated with a persistently high water table.

The main value of actions proposed in the recommended plan would be to reduce or dampen the present effects of the dissolution-evaporation cycle in which salts are precipitated in soils through evaporation of water from a near–surface water table. The present principal source of salts is not imported water but the high concentrations of natural salts that have been leached from soils (particularly during the last 30 to 40 years) and are now concentrated in shallow ground water (CH_2M Hill, 1988). These salts tend to recycle seasonally through the soil under high water table conditions.

Implementation of the recommended plan would maintain the water levels below the root zone. The problem water would be managed by tile drains, land retirement and ground-water pumping. The shallow water table would be lower and thus contribute less to evapotranspiration.

How long can such a strategy work, since about 3 million tons of salt per year are being added to the shallow ground-water system of the study area? The Drainage Program's answer is based on the assumption that the potential to continue to store salts in the subsurface (as now occurs) will be approaching exhaustion when subsurface water is saturated with salts in concentrations that exceed 2,500 ppm. When that water-quality condition is reached in the semiconfined aquifer, it is theorized, it will also have contributed to increased degradation of the confined aquifer (below the Corcoran Clay layer). Assuming that growers will not pump water of this salt content, most of the beneficial hydraulic stresses that moved drainage water downward will have ended. The water table will rise again, and it will become difficult to manage salt in crop root zones.

As a basis for estimating the useful life of the semiconfined aquifer, available ground-water data were analyzed for 1.7 million acres of land, including all waterlogged areas. Analyses showed that about one-third of these lands already overlie portions of the semiconfined aquifer where ground water generally exceeds 1,250 ppm TDS. Total dissolved solids of 1,250 ppm is considered the maximum allowable limit for most irrigation use. For the remaining two-thirds of these lands, estimates were made of the rate at which saline ground water (greater than 2,500 ppm TDS) would displace the usable ground water by downward movement beneath the problem water areas. It was assumed that the flow in the semiconfined aquifer was essentially vertical and was governed by the rate of movement through the Corcoran Clay.

The rate of downward movement of salts in the semiconfined aquifer was estimated at several locations in each of the subarea water-quality zones. The thickness of the usable aquifer and the rate of movement then determined the aquifer life. Aquifer life was considered to be exhausted when the quality of pumped ground water exceeded 2,500 ppm TDS. From the several locations analyzed in each subarea water-quality zone, the minimum and maximum aquifer thickness and life were based on one location each. The mean aquifer thickness and life were based on all locations analyzed. The number of locations varied from zone to zone. Table 25 shows the estimated useful aquifer life for water-quality zones in the Grasslands, Westlands, and Tulare subareas. The Northern Subarea is considered to be in salt balance, and insufficient information is available to estimate aquifer life in the Kern Subarea.

Under the assumptions and conditions stated above, the western valley has several decades remaining before salt removal and/or export will be required.

The process of salt contamination of ground water was set in motion decades ago with the onset of intense irrigation (Gilliom, et al., 1989a), and it will continue — to some extent — within the realm of probable use and management of water in the valley, regardless of the handling of the regional drainage problems. If it were possible to balance salt inflow and outflow in the valley, this would help slow the rate of salt contamination of ground water.

Table 25. ESTIMATED USEFUL LIFE OF THE SEMICONFINED AQUIFER

Subarea Water Quality Zone	Percent of Water Quality Zone Area with Usable Ground Water[a]	Present Thickness and Remaining Life of Semiconfined Aquifer					
		Mean		Minimum		Maximum	
		Thickness[b] (feet)	Life[c] (years)	Thickness[b] (feet)	Life[c] (years)	Thickness[b] (feet)	Life[c] (years)
Grasslands							
A	35	50	75	350	525	160	250
B	79	50	25	200	100	130	65
C	66	50	150	150	450	90	270
Westlands							
A	33	50	35	200	190	150	110
B	64	50	30	350	210	180	110
C	70	50	30	450	270	190	115
D	781	50	25	400	200	220	110
Tulare							
A	19	50	75	250	375	125	185
D	100	50	25	500	250	330	165
E	88	50	25	450	225	335	170

a Usable ground water contains less than 1250 ppm TDS.

b Thickness refers to that part of the semiconfined aquifer containing usable ground water.

c Life of the aquifer is the estimated time for saline ground water (greater than 2,500 ppm TDS) to completely displace presently usable ground water. in the semiconfined aquifer. It is calculated by dividing the aquifer thickness of usable ground water by the average rate of water movement across the Corcoran Clay. It was assumed that pumping from the confined aquifer beneath the Corcoran Clay will be maintained at current rates.

Management of drainage problems in the manner presented in the recommended plan tends to enhance near-term (up to 50 years) protection of soils and off-site impacts of drainage discharges, while continuing to diminish the life (for direct irrigation) of westside aquifers.

A functionally beneficial aspect of the recommended plan is that it includes the preliminary steps that would likely be needed when salt removal from the valley becomes necessary and feasible. These steps include integrated in-valley systems to collect and reduce the volume of drainage water, accompanied by containment and control of contaminants, such as selenium.

PLAN FEATURES COMMON TO ALL SUBAREAS

Several plan features are common to all subareas. The following discussion is intended to reduce the need for repetitive description of the recommended subarea plans.

The features that are an essential part of the plans for all subareas (exclusive of the Northern Subarea) are: drainage-water source control, reduction of drainage-water volume by reuse, disposal of concentrated drainage-water, changes in water institutions, and monitoring of the drainage-water environment.

Drainage-Water Source Control

Improvement in the application of irrigation water to reduce the source of deep percolation has been shown to be the most effective and least costly means of reducing the amount of potential drainage problem water. Recognizing the necessity to leach salts past the root zone and the nonuniformity of soils, even in a single agricultural field, there is justifiable argument about the amount of improvement that can be achieved in irrigation water application to reduce deep percolation. Field demonstrations show, however, that irrigation water application can be improved (Boyle, 1990, 1989a, 1989b). Target reductions in deep percolation believed attainable through on-farm water conservation measures by 2000 and sustainable beyond that time are shown, by subarea, in Table 26. The comparatively low target for the Tulare Subarea reflects the average higher efficiencies in water application that prevail in that subarea now.

Table 26. RECOMMENDED TARGETS FOR REDUCTION IN DEEP PERCOLATION IN 2000

Subarea	Target Reduction (acre-feet/acre)
Northern	0.0[a]
Grasslands	0.35
Westlands	0.35
Tulare	0.20
Kern	0.35

[a] See discussion for Northern Subarea under "Description and Evaluation of Recommended Plan (by Subarea)" later in this chapter.

The target deep percolation reductions in Table 26 are included as part of the recommended plan for all irrigated lands in each subarea.

Reducing deep percolation on lands lying upslope (up the hydraulic gradient) from drainage problem areas would benefit downslope areas. The results of geologic investigations (Quinn, 1990) suggest that, over decades, the aquifers above the Corcoran Clay function as a set of regional aquifers. Therefore, water conservation on upslope areas is important, even though the impact on a downslope problem water area will probably not be nearly as immediate and direct as will water conservation practiced directly on downslope lands with drainage problems. Even on upslope lands, which are significantly larger in total area than downslope lands, a moderate level of water conservation could have a significant effect on the waterlogging problems — in the long run.

An exception to the universal inclusion of source control in the recommended plan is in the Northern Subarea and parts of the Grasslands Subarea lying in the basin trough. In these areas, source control is not included because of the relatively low levels of selenium occurring in the shallow ground water and the composition of the dissolved salts that are low in gypsum (W.C. Swain, 1990c). Program analyses (D.G. Swain, 1990) indicate that application of source control in these areas would not contribute to meeting present State water quality objectives nor appreciably reduce the salt load in the San Joaquin River — assuming that the present policy agreement requiring releases from New Melones Reservoir remains in effect to dilute the salt load in the San Joaquin River.

Reduction of Drainage-Water Volume by Reuse

The large volume of drainage water that is generated annually[1] (from 0.60 to 0.75 foot per acre in the water-quality zones) presents a difficult but not insurmountable problem for in-valley management. Assuming that source control measures would eliminate from 0.2 to 0.35 acre-foot per acre, the balance of 0.40 acre-foot per acre would have to be collected and reduced in the most economic means available, while meeting acceptable levels of environmental protection.

The first essential collection device in reuse is on-farm tile drains. Presently, there are only 133,000 acres of installed drains in all the westside area. The Drainage Program projects that the area drained by on-farm systems will increase to about 760,000 acres by 2040 (Table 27).

Table 27. PROJECTED ON-FARM TILE DRAINAGE ACREAGE
(Acres)

SUBAREA	1990	2000	2040
Northern	24,000	34,000	44,000
Grasslands	50,000	108,000	192,000
Westlands	5,000	69,000	140,000
Tulare	43,000	96,000	277,000
Kern	11,000	53,000	106,000
TOTAL	**133,000**	**360,000**	**759,000**

Subsurface water collected in the farm drains would be transported to the primary water reduction facility used in the recommended plan: salt-tolerant tree plantations and fields of halophytes. These plants would be irrigated with enough drainage water to leach salts from the root zone and meet the maximum capacity of the given species to transpire water. Transpiration is about 5 acre-feet per acre per year for eucalyptus trees and 3 acre-feet per acre per year for halophytes. Drainage from the trees and halophytes would average about 1.5 acre-feet per acre per year for a total application rate of 6.5 and 4.5 acre-feet per acre per year, respectively. An acre of trees would serve an average of about 16 acres of drained cropland. The trees would be located as close to the drained farmlands as possible.[2] The tree plantations would require subsurface drains, not only to remove salts from the root zone but also to provide feed water for the fields of halophytes, which would be located near the trees. In some parts of the Westlands, Tulare, and Kern subareas, drainage water would be too salty to use on trees and, therefore, halophytes would be the primary drainage reduction mechanism.

The acreages of trees and halophytes required for the recommended plan are given in Table 28. The atypical decline in acreages in the Grasslands Subarea is explained in the Grasslands plan later in this chapter.

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[1] If on-farm drains were available, the estimated volume in 1990 would be about 300,000 acre-feet per year. Based on analyses of water table measurements for 1977, 1983, and 1986-87, this volume is forecasted to more than double from 1990 to 2040.

[2] In addition to proximity to drained croplands, important land suitability criteria for the reduction facilities are: elevation, soils that can be drained, the absence of soil characteristics adverse to the species selected, and soils not suited for high-value crops.

Table 28. PRIMARY DRAINAGE-WATER REDUCTION FACILITIES
(Approximate acres)

Subarea	2000		2040	
	Trees	Halophytes	Trees	Halophytes
Grasslands	2,400	900	1,900	700
Westlands	3,900	2,100	8,000	4,100
Tulare	4,000	4,600	12,,300	12,300
Kern	1,600	3,300	3,600	6,000
TOTAL	11,900	10,900	25,800	23,100

Disposal of Concentrated Drainage Water

Other than in the Grasslands Subarea, the primary means of disposal of the residual drainage water and dissolved solids it contains would occur in evaporation and solar pond facilities. These pond systems would bear little resemblance, in structure or operation, to present evaporation ponds. A number of features would be changed to improve their safety and efficiency.

In the staged design of the recommended plan, ponds would follow drainage-water-volume reduction and, consequently, less pond area would be required than would be under current conditions. Compared to present pond acreages, the total acreage of ponds in 2040 would be about half the present, and each unit of pond area would serve about 8 to 10 times as much drained land as do ponds in 1990.

The estimated life of an evaporation pond is 30 years. Old ponds would be closed safely, and new ponds would replace them. The pond area in 2040, by type, in each subarea, is given in Table 43.

Institutional Components

The recommended plan contains several institutional components that are included in all subareas: tiered water pricing, improved scheduling of irrigation deliveries, water marketing, and formation of regional drainage management organizations. These are either new to the subarea or have never been applied at the scale that would be needed to implement this plan.

Tiered Water Pricing

Tiered water pricing means increasing irrigation water rates as more water is applied. This would provide incentives for water conservation. Although water districts are not allowed to make profits, water revenue surpluses could be used to help finance on-farm water conservation measures. Tiered water pricing is already being implemented by three water districts in the Grasslands Subarea.

Improved Scheduling of Water Deliveries

The aim of improved scheduling of water deliveries is to enable growers to obtain irrigation water deliveries when their land and crops need the water, not when the delivering entity can supply the water. In all the subarea plans, costs have been included, under the category of source control, to effect considerable improvements in scheduling water deliveries. These changes would build on the present programs of the California Department of Water Resources and several local water districts.

Water Transfers and Marketing

This would provide incentives for water conservation, wherein local water districts and/or irrigators would be permitted to retain some portion of the increase in the value of water sold for a profit. The portion of the increase in value retained by the suppliers in a transfer would also help fund water conservation measures. The Department of Water Resources and the Bureau of Reclamation are the principal agencies that could develop and implement policies and programs for water transfers and marketing.

Some transfers would require the approval of the State Water Resources Control Board. All transfers of State Water Project and Central Valley Project water would require, respectively, the authorization of the Department and the Bureau as project operator. Thomas and Leighton–Schwartz (1990) declare there are no serious legal impediments to the transfer of water made available by reclamation or conservation from drainage problem areas in the western San Joaquin Valley. Purpose and place of use restrictions in the CVP permits and contracts may be amended to facilitate transfers of project water to other uses or areas. The increases in repayment obligations in moving water from irrigation to municipal and industrial use do not appear to be substantial disincentives, according to Thomas.

Regional Drainage Management Organizations

Regional drainage management organizations are recommended for the Grasslands and Tulare subareas, with all upslope and downslope areas to be included within the boundaries of the organization. Such organizations would coordinate the drainage-related operations of existing local water entities, with respect to activities and issues that transcend local entity boundaries. Local water entities are in the best position to effectively manage the subsurface drainage problem because they deal with water throughout the hydrologic cycle in a given land area. Generally, they have the authority to manage drainage water; where they do not, the authority could be obtained through legislation. However, in recognition of hydrologic and economic linkages and relationships among local water entities, some drainage problems could probably be managed best at a regional level. For such needs, either regional entities or joint–power authorities could be formed.

A regional drainage management organization could reduce drainage management costs, bring about coordination among several local entities, and help internalize the costs of drainage management.

Westlands Water District could serve as the regional drainage management entity for the Westlands Subarea. In the Kern Subarea, Kern County Water Agency, through joint-powers agreement with the water districts or some other organizational arrangement, could serve as the regional drainage management entity.

Monitoring of the Drainage-Water Environment

The drainage problem that affects, or is related to, more than 1 million acres is not presently being monitored in a comprehensive, effective, and efficient manner. An extremely important premise underlying successful implementation of this plan is that the many facets and dimensions of the problem — ground-water levels, soil conditions, land uses, water quality, volume of drainage, conditions of evaporation ponds, impacts on biota, public health risks — must be monitored on a long-term, systematic basis. The objective of monitoring is to determine the effect of actions and whether they should be changed. In 1990, no one can forecast with certainty what conditions will be in 2040. The strategy presented in this plan will, no doubt, have to be adjusted in response to unforeseen human events and responses of natural systems.

DESCRIPTION AND EVALUATION OF THE RECOMMENDED PLAN

Northern Subarea

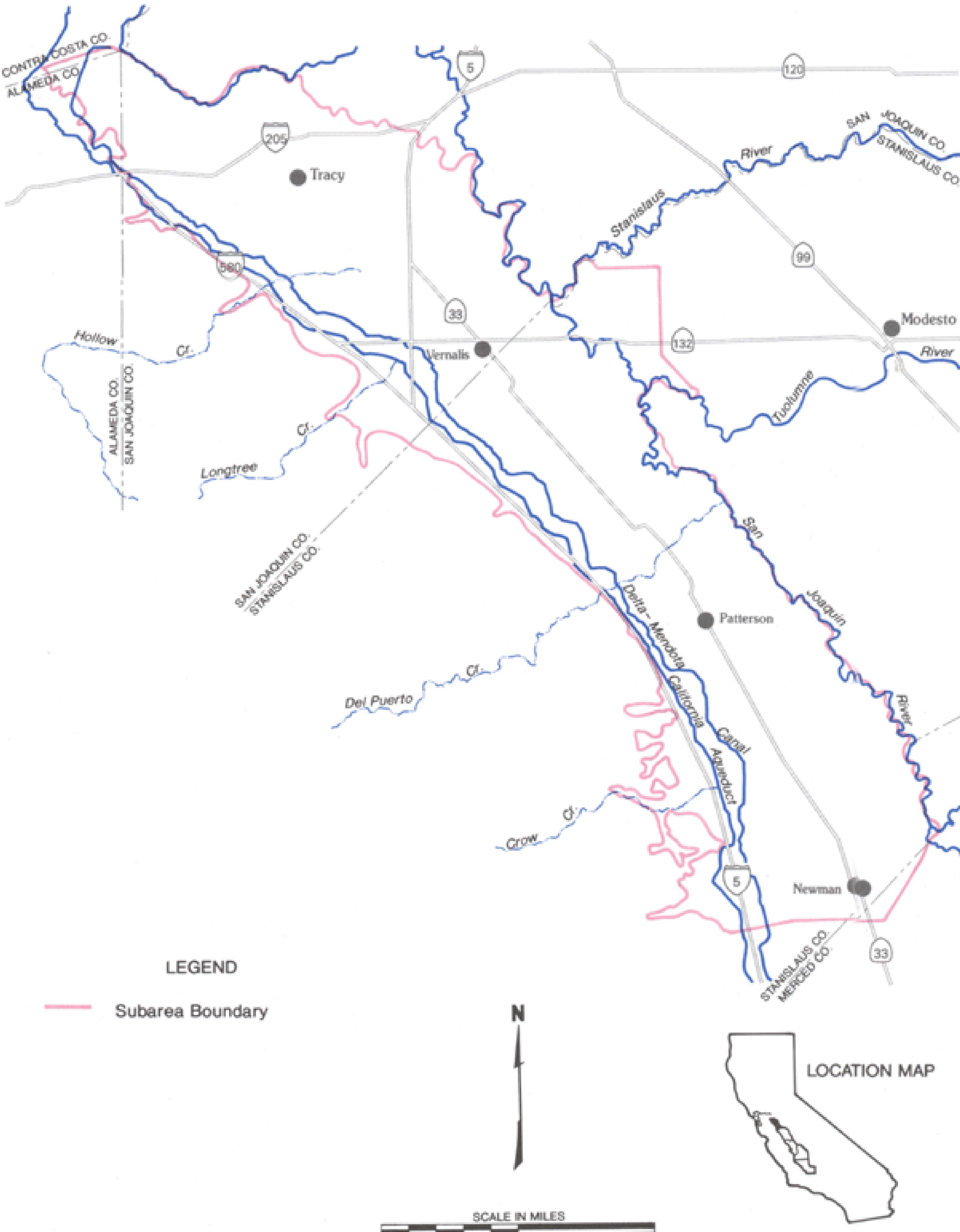
No actions are recommended as part of a regional plan for the Northern Subarea (Figure 31). This is based on two assumptions: (1) State water-quality regulations for the San Joaquin River will continue to allow salt discharge to the river from ground-water seepage and from surface and subsurface drainage water originating from irrigation in the Northern Subarea, and (2) fresh water will continue to be released from New Melones Reservoir to help meet State water-quality objectives at the Vernalis gaging station.

It was stated earlier in this report that both a water balance and a salt balance have nearly been achieved under existing hydrologic conditions in this subarea. As long as drainage water and seepage can be discharged to the San Joaquin River under the assumptions stated above, then no actions beyond those in place now would be required. However, if more restrictive objectives are adopted for either boron or salt in the river, this balance would have to be interrupted to reduce drainage water and salt and boron load.

In the event of possible new water-quality restrictions, the following two measures would aid in reducing drainage discharge to the river. Source control measures to reduce deep percolation on about 50,000 acres of irrigated land with water tables less than 5 feet from the surface would reduce drainage water inflow to the river; however, they would also increase concentrations of salt in the remaining subsurface drainage water. (For estimates and calculations, see AWMS, 1987, and D. G. Swain, 1990). Increased pumping of deep ground water to replace some of the surface water currently being used for irrigation would lower the high water table and reduce both drainage volume and seepage of salty ground water to the river.

A measure that should be studied further in relation to more restrictive water-quality objectives in the San Joaquin River is pumping shallow ground water into the river during high flows to create underground storage space for percolating agricultural drainage water. If feasible, this would improve river water quality by storing salty drainage water during low river flow. There are technical problems that may be insurmountable in terms of storage space and the short periods of time during which the flows could be accepted in the river (D.G. Swain, 1990). A variation of this option would be to intercept shallow, salty ground water moving to the river and pump it into surface-water storage ponds used as wildlife habitat. A possible drawback to this measure is that the average concentration of selenium in the intercepted moderately deep ground water may exceed the selenium water-quality objectives in the river (5 ppb). The ponds could be drained to the river during high flows and refilled during low-flow periods.

Figure 31
NORTHERN SUBAREA



Grasslands Subarea

Figure 32 shows the shallow ground-water quality zones. Agricultural components of the recommended plan for the subarea are listed in Table 29. Selected facilities and flows are shown on Figure 33.

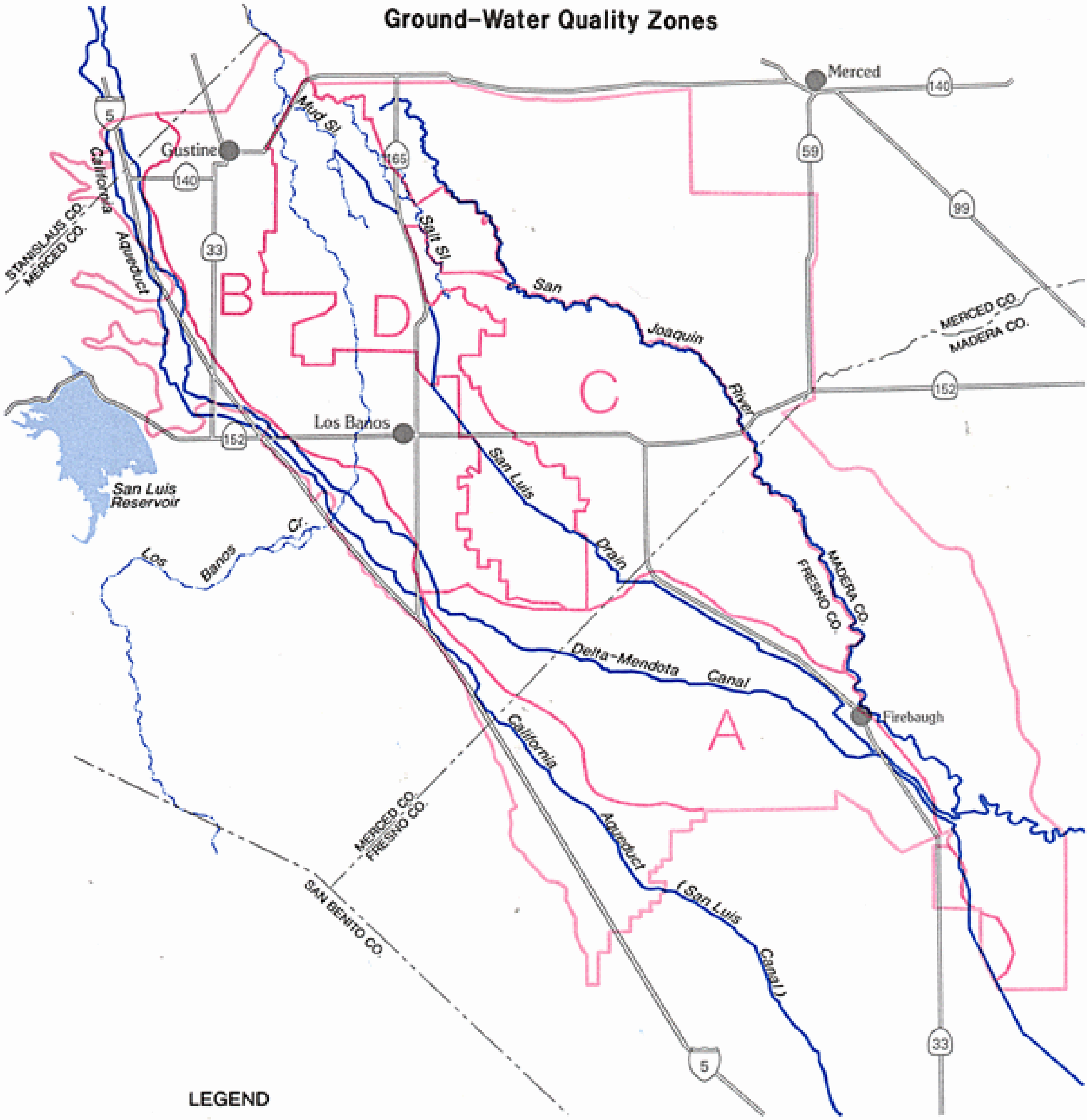
The agricultural components of the recommended plan for 2040 are:

- **Practicing source control on 93,600 acres of irrigated land.** The amount of water applied to irrigate drainage problem areas would be reduced, on the average, by 0.35 acre-foot per acre per year (a total of 32,700 acre-feet) by improving methods of irrigation water application, by improving scheduling of irrigation water application, and by tiered water pricing.
- **Reusing drainage water to irrigate 2,600 acres of salt-tolerant trees and halophytes.** Through installation of on-farm tile drains and conveyance facilities, drainage water would be collected and supplied to trees to reduce the total drainage volume by 10,900 acre-feet. Drains would be installed beneath the trees to collect the brackish water drained for subsequent use by halophytes. This would reduce the drainage volume by another 2,700 acre-feet, for a total reduction of 13,600 acre-feet. These reuse plantations could serve individual farms or an entire water or drainage district and would be located on the least productive soils. Most sites would be located on Storie Index class 4, 5, or 6 soils on the Panoche and Little Panoche Creek fan rim in the eastern part of water-quality Zone A.
- **Operating 120 acres of evaporation ponds and 130 acres of solar ponds.** Pond design and operation criteria would be consistent with State guidelines, and ponds would be located near tree and halophyte plantations. The volume of influent water evaporated annually would be about 700 acre-feet.
- **Pumping the semiconfined aquifer under about 10,000 acres of land.** Due to natural features, this option is most feasible in the southeastern and northwestern portions of the subarea. The design average annual yield would be 0.4 acre–foot per acre of land affected, for a total management of 4,000 acre-feet of problem water. To exert this effect at the land surface, 8,000 acre-feet would have to be pumped from the aquifer. These lands would also have received source control (0.35 acre-foot per acre), but they would not be artificially drained. Pumped ground water of initial good quality could be used for agriculture, or fish and wildlife, or a variety of other uses. If, in future years, influent water to a well should contain dissolved salt in excess of 2,500 ppm TDS, that water would be used for trees and halophytes, or as top water in solar ponds. This component would be applicable only in water-quality Zones A and B.
- **Retiring 3,000 acres of irrigated agricultural lands.** Lands having the combined characteristics of poor drainability, high salinity levels, and high levels of dissolved selenium (greater than 50 ppb) in shallow ground water would be retired. Only lands in water-quality Zone A met this criterion.

Figure 32

GRASSLANDS SUBAREA

Ground-Water Quality Zones



LEGEND

Subarea Boundary

A — Ground Water Quality Zone

N

LOCATION MAP

Table 29. RECOMMENDED DRAINAGE MANAGEMENT PLAN GRASSLANDS SUBAREA (In 1000s)

PLAN COMPONENT	YEAR 2000			YEAR 2040		
	AREAL APPLICATION OF COMPONENT	PROBLEM WATER REDUCTION		AREAL APPLICATION OF COMPONENT	PROBLEM WATER REDUCTION	
	Acres	AF	%	Acres	AF	%
ZONE A						
SOURCE CONTROL	68.9	24.0	44.4	72.0	25.1	44.3
LAND RETIREMENT	0.0	0.0	0.0	3.0	2.3	4.0
GROUND-WATER MGM'T	5.0	2.0	3.7	10.0	4.0	7.1
DRAINAGE REUSE[a]	3.1	16.5	30.6	0.8	4.1	7.2
EVAPORATION SYSTEM	0.18	0.8	1.5	0.12	0.2	0.4
DISCHARGE TO SJ RIVER	26.8	10.7	19.8	52.5	21.0	37.0
Total		**54.0**	**100.0**		**56.7**	**100.0**
ZONE B						
SOURCE CONTROL	6.8	2.4	22.8	21.6	7.6	21.6
LAND RETIREMENT	0.0	0.0	0.0	0.0	0.0	0.0
GROUND-WATER MGM'T	0.0	0.0	0.0	0.0	0.0	0.0
DRAINAGE REUSE	0.4	1.1	10.0	1.8	9.5	27.0
EVAPORATION SYSTEM	0.01	0.1	0.6	0.12	0.5	1.4
DISCHARGE TO SJ RIVER AND OR WETLANDS	9.3	7.0	66.6	23.5	17.6	50.0
Total		**10.6**	**100.0**		**35.2**	**100.0**
ZONE C						
SOURCE CONTROL	0.0	0.0	0.0	0.0	0.0	0.0
LAND RETIREMENT	0.0	0.0	0.0	0.0	0.0	0.0
GROUND-WATER MGM'T	0.0	0.0	0.0	0.0	0.0	0.0
DRAINAGE REUSE[a]	0.0	0.0	0.0	0.0	0.0	0.0
EVAPORATION SYSTEM	0.0	0.0	0.0	0.00	0.0	0.0
DISCHARGE TO SJ RIVER AND OR WETLANDS	29.3	22.0	100.0	84.7	63.5	100.0
Total		**22.0**	**100.0**		**63.5**	**100.0**
TOTAL						
SOURCE CONTROL	75.7	26.4	30.5	93.6	32.7	21.0
LAND RETIREMENT	0.0	0.0	0.0	3.0	2.3	1.4
GROUND-WATER MGM'T	5.0	2.0	2.3	10.0	4.0	2.6
DRAINAGE REUSE[a]	3.5	17.6	20.3	2.6	13.6	8.8
EVAPORATION SYSTEM	0.2	0.9	1.0	0.2	0.7	0.5
DISCHARGE TO SJ RIVER AND OR WETLANDS	65.4	39.7	45.9	160.6	102.1[b]	65.7
Total		**86.6**	**100.0**		**155.4**	**100.0**

[a] Includes potential drainage from irrigated agricultural land used to grow salt tolerant crops.

[b] Increases in volume from year 2000 to year 2040 are due largely to improvements forecasted to occur over time in the quality of shallow ground water drained from irrigated lands. For data and interpretation supporting this concept, see Gilliom, et al., (1989a) and Deverel and Gallathine (1988).

- **Discharging about 102,000 acre-feet of drainage water[3] to wetlands and/or the San Joaquin River (while meeting river water-quality standards).** About 63,500 acre-feet of subsurface drainage water of adequate quality[4] for fish and wildlife uses would be discharged from water-quality Zone C into Salt Slough, from which diversions could be made to adjacent public and private wetland management areas. About 17,500 acre-feet of subsurface drainage water from west of the wetland area (water-quality Zone B) would also be of adequate quality for use in wetland habitat areas. About 21,000 acre-feet of subsurface drainage water from irrigated land (water-quality Zone A) south of the Grasslands wetland area would be unsuitable for reuse in wetlands and, therefore, would be discharged into the San Luis Drain for delivery to the San Joaquin River below its confluence with the Merced River. The sediments removed from the drain would be placed within the Kesterson Reservoir disposal area and treated as the Kesterson sediments were managed in that cleanup effort. The amount of drainage water discharged is limited by the river criteria near Newman (Table 7). The San Luis Drain would be cleaned of sediments and modified structurally to receive drainage from water quality Zone A at a point near South Dos Palos, and the drain would be extended to the San Joaquin River, below the confluence of the Merced River. The Main, Panoche, Hamburg, and Charleston drains would be interconnected and routed to the San Luis Drain near South Dos Palos. The San Luis Drain thus would become the means by which a portion of the contaminated subsurface drainage now entering the South Grasslands area would be re-routed around the wetlands.

Management of agricultural drainage problems and protection, restoration, and substitute water supplies for fish and wildlife are planned as complementary activities. The interception of contaminated subsurface drainage water currently discharged into waterways of the Grasslands wetland area would make available nontoxic tailwater, operational spills, and nontoxic subsurface drainage for use in the wetlands.

Plan components for protection, restoration, and substitute water supplies for fish and wildlife in the Grasslands Subarea are shown on Figure 33 and discussed in the following subsections.

- Providing, on a firm basis, 129,000 acre-feet per year of adequate-quality water from existing sloughs, ditches, and canals that serve the Grasslands area. This volume is the average amount of surface and subsurface drainage water diverted to the wetlands before 1985, when use of the contaminated drainage water for wetland management was discontinued. It is assumed that the quantity and quality of tailwater, operational spills, and local runoff will continue to be suitable for fish and wildlife water supplies throughout the period of the plan. The 129,000 acre-feet of water could be obtained by:

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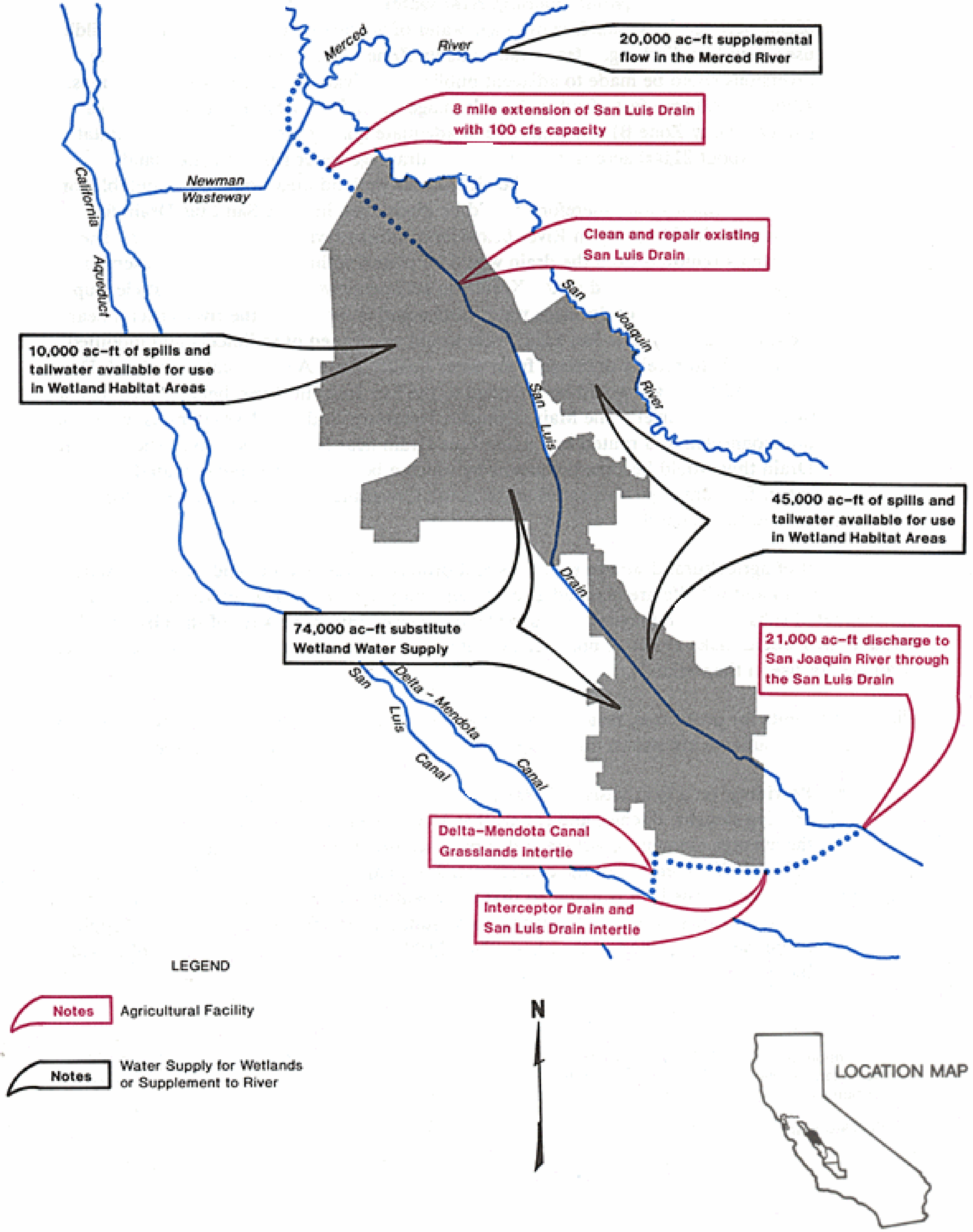
[3] Assumption used to calculate the volume of drainage water discharged: (a) Dry-year hydrology similar to the 1986-87 water year, (b) existing 150 ppb selenium in subsurface drainage water, decreased to 75 ppm by 2040, and (c) 5 ppb selenium criteria in the San Joaquin River near Newman.

[4] TDS less than 1,250 ppm, boron less than 1 ppm, and selenium less than 2 ppb.

Figure 33

FACILITIES AND FLOWS INCLUDED IN THE RECOMMENDED PLAN

Grasslands Subarea



SJVDP

- Providing up to about 74,000 acre-feet from the Central Valley Project through the Delta-Mendota Canal for diversion into wetland areas.
- Delivering an average of 45,000 acre-feet of tailwater, operational spills, and local runoff of adequate quality from water-quality Zone C to Salt Slough for use in wetlands.
- Delivering up to 10,000 acre-feet of tailwater, operational spills, and local runoff from water-quality Zone B to Los Banos Creek and vicinity.

- Providing the facilities necessary to deliver 74,000 acre-feet of substitute water, including a Delta-Mendota Canal Turnout with a capacity of 200 cubic feet per second and 1.75 miles of 200-cfs canal and siphons, to the wetlands of South Grasslands.
- Providing facilities to intercept all subsurface drainage water now being discharged from water-quality zone A into open channels in the Grasslands; facilities would also be provided to convey this water to the San Luis Drain near South Dos Palos.
- Using an estimated 63,500 acre-feet of subsurface drainage water from water-quality Zone C, and 17,500 acre-feet of subsurface drainage water from Zone B, by 2040, in wetlands. Most of this water would flow by gravity to Salt and Mud sloughs, where it would be conveyed to public and private wetlands.
- Providing, on a firm basis, an additional 20,000 acre-feet of fresh water to supplement October flows in the Merced River. This would minimize the straying of migrating adult salmon into the Grasslands instead of into the natural spawning grounds in the Merced River. This water must be obtained by purchasing surface or ground water from water-rights holders in the Merced River drainage or by extending the northern end of the Friant-Madera Canal into the Merced River watershed so that water stored behind Friant Dam could be delivered to the Merced River. Purchasing water in the Merced River drainage appears to be the most economical approach.
- Providing alternative wetland habitat near evaporation ponds. Because the selenium concentrations in the evaporation ponds would exceed 2 ppb, a hazing program would be required to discourage bird use. In addition, wetland habitat (one acre for each acre of evaporation ponds) would be developed close to the evaporation ponds to offer alternative clean habitat for hazed birds. Each acre of alternative habitat would require about 10 acre–feet of water per year.

Assessment of Plan Features and Their Effects

The plan for the Grasslands Subarea relies on the continued discharge of subsurface drainage water to the San Joaquin River, either directly to the river or through sloughs and wetlands. The opportunity for the discharge of contaminated subsurface drainage water depends on the flows in the San Joaquin River, the concentrations of contaminants in the subsurface drainage water, and the limiting water-quality objective at the point of discharge. Interception of contaminated subsurface drainage water south of the Grasslands Subarea and delivery to the San Luis Drain near South Dos Palos for conveyance to the San Joaquin River below the Merced River are key features of the plan. The removal and disposal of sediments within the San Luis Drain are necessary conditions for use of the drain as a plan component.

About half the subsurface drainage water would be suitable as a fish and wildlife water supply. Under conditions of the recommended plan, the quality of water delivered to the wetlands would be the best-quality water delivered since subsurface drainage was first introduced to the marsh area, and the volume (more than 129,000 acre-feet) would approximate the optimal water requirement for wildlife habitat in the subarea. Construction of the proposed wetland water-supply intertie facilities would provide the flexibility needed to ensure that the water would be delivered on an optimal schedule, assuming sufficient water is available in the Delta and sufficient capacity in the Delta-Mendota Canal to deliver the substitute water.

Table 30 compares the recommended plan features with those of the present and projected future-without conditions. The recommended plan would keep about 36,000 more acres of existing irrigated agricultural lands in production than under future-without conditions.

The annualized costs of the components of the recommended plan for the Grasslands Subarea are presented in Table 31. The category "Agricultural Drainage" comprises all drainage-related components of the recommended plan, except on-farm drainage systems. "On-Farm Drains"

Table 30. COMPARISON OF PLAN WITH PRESENT AND FUTURE-WITHOUT CONDITIONS, GRASSLANDS SUBAREA
In 1,000s

Item	Present (1990)	Future-Without (2040)	Recommended Plan (2040)
Agricultural Land Area (acres)			
Irrigable agricultural Land	365	303	339
Drainage reuse	0	2	3
Abandoned and/or retired agricultural land	0	40	3
Evaporation System			
Nontoxic evaporation pond	0.00	0.00	0.00
Toxic evaporation pond	0.10	0.20	0.12
Accelerated evaporation pond	0.00	0.00	0.02
Solar pond	0.00	0.00	0.13
Evaporation pond alternative habitat	0.00	0.00	0.12
Urban expansion	0	20	20
TOTAL [a]	**365**	**365**	**365**
Wildlife Areas (acres) [b]			
Wetlands	68.0	24.0	55.0
Other	29.0	72.4	41.4
Abandoned wildlife areas	0.0	0.6	0.6
TOTAL	**97.0**	**97.0**	**97.0**
Water Freed in Addressing Drainage Problems (acre-feet)	0	122[c]	55[d]
Firm Water Supply for Wildlife Areas (acre-feet)	97	97	226
Water Supply for Evaporation Pond Alternative Habitat (acre-feet)	0	0	1

[a] Evaporation systems are located on existing pond sites or on retired or nonirrigable lands, so are not included in "Total."
[b] Federal and State wildlife areas, private duck clubs, and other private wildlife areas.
[c] Includes increased conserved water through source control on problem water lands and firm water supply freed by land abandonment and conversion of crop land to salt-tolerant crops.
[d] Includes increased conserved water through source control on problem water lands; firm water supply freed by land retirement and conversion of cropland to salt-tolerant crops; and ground water pumped to control water levels within problem water areas.

includes the installation of new on–farm drainage systems from 1991 to 2040 and the annual operation from 1991 to 2040 of the newly installed drains and those already operating in 1990. "Fish and Wildlife" comprises the costs of constructing and operating facilities and purchasing water to deliver clean replacement water to waterfowl habitat formerly supplied with contaminated drainage water.

One-time costs include those for installation of facilities and purchase of land retired from irrigated agriculture. Costs were annualized, using an interest rate of 10 percent to reflect opportunities available to growers and a 50-year planning period. The grand total cost for the Grasslands Subarea would amount to about $107 per acre of problem farmland served by components of the recommended plan. This includes the cost of the fish and wildlife components. If these costs were separated, the per-acre cost to farmland served would be $81.

Included in the total cost is a provision necessary to minimize the risks to wildlife from evaporation ponds. The ponds in which the selenium level exceeded 2 ppb (the level assumed to be safe for wildlife) would include special features, such as steep side slopes, increased depth, hazing, and alternative habitat.

Table 31. ANNUALIZED COSTS OF THE RECOMMENDED PLAN FOR THE GRASSLANDS SUBAREA

AGRICULTURAL DRAINAGE		
One–time:		
Source control	$ 622,000	
Reuse	845,000	
Evaporation	224,000	
Ground-water management	193,000	
Land retirement	55,000	
San Luis Drain	2,300,000	
Subtotal	$4,239,000	
Operation, maintenance, and replacement:		
Source control	$1,232,000	
Reuse	145,000	
Evaporation	239,000	
Ground-water management	549,000	
Land retirement	6,000	
San Luis Drain	390,000	
Subtotal	$2,561,000	
Total		$ 6,800,000
ON–FARM DRAINS		
Installation	$2,653,000	
Operation, maintenance, and replacement	584,000	
Total		$ 3,237,000
FISH AND WILDLIFE		
Installation	$ 153,000	
Operation, maintenance, and replacement	18,000	
Water supply	2,548,000	
Total		$ 2,719,000
GRAND TOTAL		$12,756,000

Westlands Subarea

Figure 34 shows the location of the ground–water quality zones within the subarea. Agricultural components of the recommended plan for the subarea are shown on Table 32.

The agricultural components of the recommended plan for 2040 are:

- **Practicing source control on 159,300 acres of irrigated land.** The amount of applied irrigation water would be reduced by 0.35 acre–foot per acre per year (a total of 55,800 acre–feet) by improving methods of irrigation water application, improving scheduling of irrigation water application, and tiered water pricing.

- **Reusing drainage water to irrigate about 12,100 acres of salt-tolerant trees and halophytes.** Through installation of on-farm tile drains and conveyance facilities, drainage water would be collected and supplied to trees to reduce the total drainage volume by 45,700 acre-feet. Drains would be installed beneath the trees to collect the brackish water for direct use by halophytes. This would reduce the drainage volume by another 15,300 acre–feet, for a total reduction of about 61,000 acre-feet. These reuse plantations could serve individual farms or an entire water or drainage district. They would be located on the least productive soils, with most sites on class 4 soils on the alluvial fan rims. These soils occur in the eastern part of the subarea near the San Luis Drain. Existing collector drains and the San Luis Drain would be used to convey drainage water to reuse plantations.

- **Operating 400 acres of evaporation ponds and about 1,500 acres of solar ponds.** Pond design and operation criteria would be consistent with State guidelines, and the ponds would be located close to tree and halophyte plantations. About 200 acres of additional land would be used for accelerated-rate evaporation facilities.

- **Pumping the semiconfined aquifer under about 19,000 acres of land.** Due to natural features, this option is most feasible in the southeastern portion of the subarea. The design average annual yield would be 0.4 acre-foot per acre of land affected, for a total management of 7,600 acre-feet of problem water. To exert this effect at the land surface, 16,000 acre-feet would have to be pumped from the aquifer. These lands would also have received source control (0.35 acre–foot per acre), but they would not be artificially drained. Pumped ground water of initial good quality (some 16,000 acre–feet) could be used for agriculture, or fish and wildlife, or a variety of other uses. If, in future years, influent water to a well should contain dissolved salt in excess of 2,500 ppm, that water would be used as a supply for trees and halophytes, or as top water in solar ponds.

- **Retiring 33,000 acres of irrigated agricultural lands.** Lands having the combined characteristics of low productivity, poor drainability (USBR class 4 lands), and high levels of dissolved selenium (greater than 50 ppb) in shallow ground water would be retired. A part of water-quality Zones A, B, and C would be retired.

Figure 34

WESTLANDS SUBAREA

Ground-Water Quality Zones

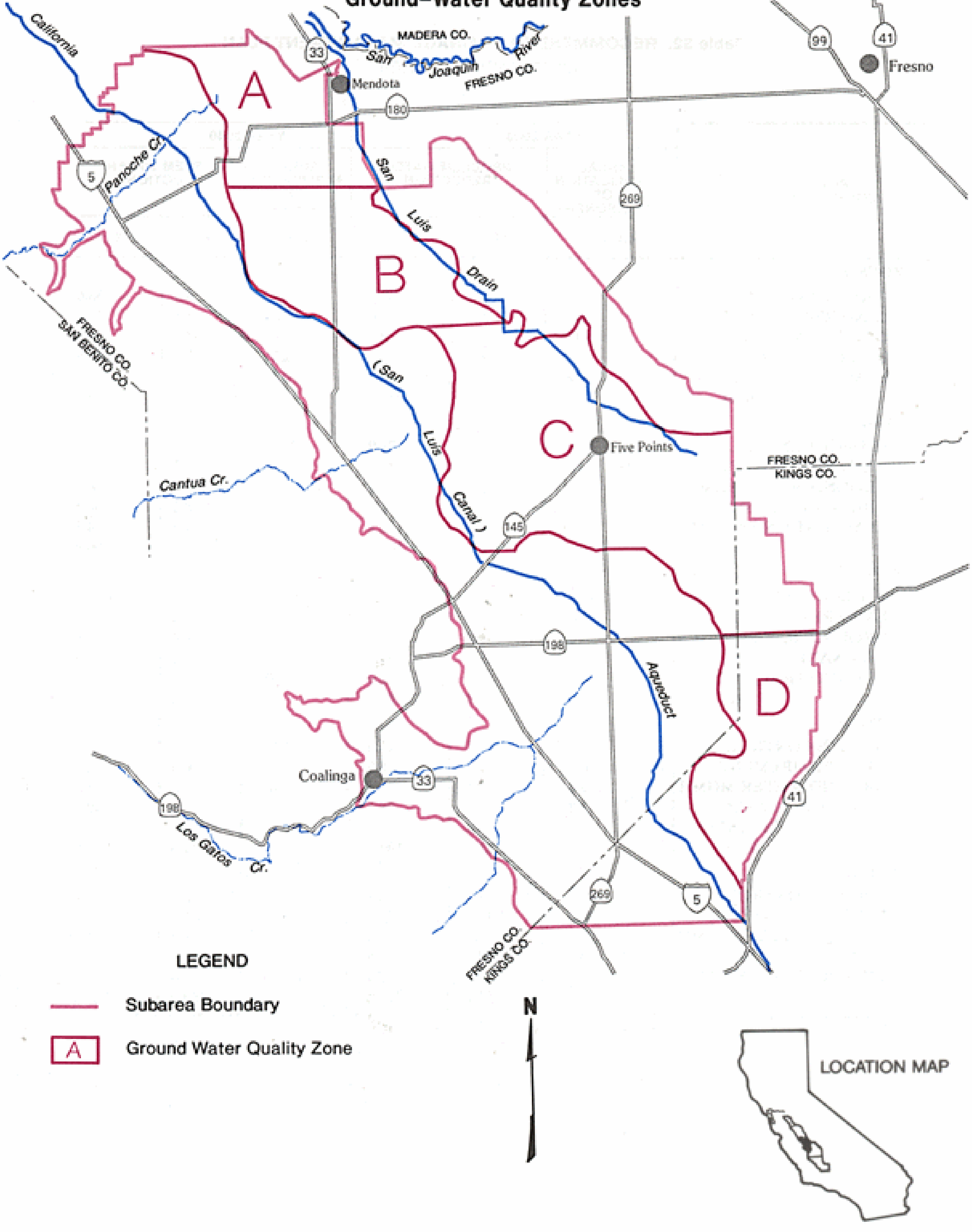


Table 32. RECOMMENDED DRAINAGE MANAGEMENT PLAN WESTLANDS SUBAREA (In 1000s)

PLAN COMPONENT	YEAR 2000			YEAR 2040		
	AREAL APPLICATION OF COMPONENT	PROBLEM WATER REDUCTION		AREAL APPLICATION OF COMPONENT	PROBLEM WATER REDUCTION	
	Acres	AF	%	Acres	AF	%
ZONE A						
SOURCE CONTROL	11.2	3.9	30.2	25.3	8.9	36.6
LAND RETIREMENT	5.0	3.8	29.4	5.0	3.8	15.4
GROUND-WATER MGM'T	0.0	0.0	0.0	0.0	0.0	0.0
DRAINAGE REUSE[a]	1.0	4.9	38.1	2.2	11.1	45.5
EVAPORATION SYSTEM	0.06	0.3	2.3	0.27	0.6	2.5
Total		**12.9**	**100.0**		**24.4**	**100.0**
ZONE B						
SOURCE CONTROL	12.3	4.3	28.0	21.7	7.6	26.3
LAND RETIREMENT	7.0	5.3	34.1	15.0	11.2	38.8
GROUND-WATER MGM'T	0.0	0.0	0.0	0.0	0.0	0.0
DRAINAGE REUSE[a]	1.2	5.0	32.7	2.0	8.8	30.4
EVAPORATION SYSTEM	0.07	0.8	5.2	0.94	1.3	4.5
Total		**15.4**	**100.0**		**28.89**	**100.0**
ZONE C						
SOURCE CONTROL	44.4	15.5	38.9	81.8	28.6	37.9
LAND RETIREMENT	6.0	4.5	11.3	13.0	9.8	12.9
GROUND-WATER MGM'T	10.0	4.0	10.0	11.0	4.4	5.8
DRAINAGE REUSE[a]	2.7	15.1	37.8	6.0	31.2	41.3
EVAPORATION SYSTEM	0.18	0.8	2.0	0.78	1.6	2.1
Total		**39.9**	**100.0**		**75.6**	**100.0**
ZONE D						
SOURCE CONTROL	16.2	5.7	44.0	30.5	10.7	44.0
LAND RETIREMENT	0.0	0.0	0.0	0.0	0.0	0.0
GROUND-WATER MGM'T	5.0	2.0	15.4	8.0	3.2	13.2
DRAINAGE REUSE[a]	1.0	5.0	38.3	1.9	9.9	40.7
EVAPORATION SYSTEM	0.06	0.3	2.3	0.13	0.5	1.3
Total		**13.0**	**100.0**		**24.3**	**100.0**
TOTAL						
SOURCE CONTROL	84.1	29.4	36.3	159.3	55.8	36.4
LAND RETIREMENT	18.0	13.6	16.7	33.0	24.8	16.1
GROUND-WATER MGM'T	15.0	6.0	7.4	19.0	7.6	5.0
DRAINAGE REUSE[a]	5.9	30.0	36.9	12.1	61.0	39.9
EVAPORATION SYSTEM	0.4	2.2	2.7	1.0	4.0	2.6
Total		**81.2**	**100.0**		**153.2**	**100.0**

[a] Includes drainage from irrigated agricultural land used to grow salt tolerant crops.

Assessment of Plan Features and Their Effects

Table 33 compares the recommended plan features with those of present and projected future conditions without a plan. Compared to future-without conditions, the recommended plan would maintain about 100,000 more acres of existing irrigated agricultural lands in production. By 2040, the plan would result in the conservation or development of 181,000 acre-feet of water through implementation of plan components (such as source control, conversion of land to reuse drainage water, land retirement, and ground-water pumping) on drainage problem areas.

Table 33. COMPARISON OF PLAN WITH PRESENT AND FUTURE-WITHOUT CONDITIONS WESTLANDS SUBAREA In 1,000s

Item	Present (1990)	Future-Without (2040)	Recommended Plan (2040)
Agricultural Land Area (acres)			
Irrigable agricultural land	640	489	590
Drainage reuse	0	6	12
Abandoned and/or retired agricultural land	0	140	33
Evaporation System			
Nontoxic evaporation pond	0.00	0.00	0.00
Toxic evaporation pond	0.50	0.20	0.40
Accelerated evaporation pond	0.00	0.00	0.20
Solar pond	0.00	0.00	1.52
Evaporation pond alternative habitat	0.00	0.00	0.40
Urban expansion	0	5	5
TOTAL [a]	**640**	**640**	**640**
Wildlife Areas (acres) [b]			
Wetlands	0.1	0.1	0.1
Other	0.4	0.4	0.4
Abandoned wildlife areas	0.0	0.0	0.0
TOTAL	**0.5**	**0.5**	**0.5**
Water Freed in Addressing Drainage Problems (acre-feet)	0	390[c]	189[d]
Firm Water Supply for Wildlife Areas (acre-feet)	0	0	0
Water Supply for Evaporation Pond Alternative Habitat (acre-feet)	0	0	4

[a] Evaporation systems are located on existing pond sites or on retired or nonirrigable lands, so are not included in "Total."
[b] Federal and State wildlife areas, private duck clubs, and other private wildlife areas.
[c] Includes increased conserved water through source control on problem water lands and firm water supply freed by land abandonment and conversion of crop land to salt-tolerant crops.
[d] Includes increased conserved water through source control on problem water lands; firm water supply freed by land retirement and conversion of cropland to salt-tolerant crops; and ground water pumped to control water levels within problem water areas.

The annualized costs of the components of the recommended plan for the Westlands Subarea are presented in Table 34. The category "Agricultural Drainage" comprises all drainage-related components of the recommended plan, except on-farm drainage systems. "On-Farm Drains" includes the installation of new on-farm drainage systems from 1991 to 2040 and the annual operation from 1991 to 2040 of the newly installed drains and those already operating in 1990.

One-time costs include those for installation of facilities and purchase of land retired from irrigated agriculture. Costs were annualized, using an interest rate of 10 percent to reflect opportunities available to growers and a 50-year planning period.

The grand total cost for the Westlands Subarea amounts to about $136 per acre of problem farmland served through the components stipulated in the recommended plan.

Included in the cost is a provision necessary to minimize the risk to wildlife from evaporation ponds. The ponds in which the influent selenium level exceeded 2 ppb (the level assumed to be safe for wildlife) would include special features, such as steep side slopes, increased depth, hazing, and alternative habitat.

Table 34. ANNUALIZED COSTS OF THE RECOMMENDED PLAN FOR THE WESTLANDS SUBAREA

AGRICULTURAL DRAINAGE		
One-time:		
Source control	$ 829,000	
Reuse	1,801,000	
Evaporation	702,000	
Ground-water management	319,000	
Land retirement	1,930,000	
Subtotal	$5,581,000	
Operation, maintenance, and replacement:		
Source control	$1,588,000	
Reuse	626,000	
Evaporation	596,000	
Ground-water management	903,000	
Land retirement	208,000	
Subtotal	$3,921,000	
Total		$ 9,502,000
ON-FARM DRAINS		
Installation	$3,008,000	
Operation, maintenance, and replacement	355,000	
Total		$ 3,363,000
GRAND TOTAL		$12,865,000

Tulare Subarea

Figure 35 shows the location of the ground-water quality zones within the subarea. Agricultural components of the recommended plan for the subarea are listed in Table 35.

The agricultural components of the recommended plan for 2040 are:

- **Practicing source control on 316,700 acres of irrigated land.** The amount of applied irrigation water will be reduced by 0.20 acre-foot per acre per year (a total of 63,200 acre-feet) by improving methods of irrigation water application, improving scheduling of irrigation water application, and tiered water pricing.

- **Reusing drainage water to irrigate 24,500 acres of salt-tolerant trees and halophytes.** Through installation of on-farm tile drains, drainage water would be collected and supplied to trees to reduce the total drainage volume by 68,900 acre-feet. Drains would be installed beneath the trees to collect the brackish water for direct use by halophytes. This would reduce the drainage volume by another 44,400 acre-feet, for a total reduction of 113,300 acre-feet. These reuse plantations could serve individual farms or an entire water or drainage district. They would be located on the least productive soils, with most sites on class 4, 5, and 6 soils (Storie Index) on the basin rim.

- **Operating 3,000 acres of evaporation ponds.**[5] Pond design and operation criteria would be consistent with State guidelines, and the ponds would be located close to tree and halophyte plantations.

- **Pumping the semiconfined aquifer under about 40,000 acres of land.** Due to natural features, this option is most feasible in the northern part of water-quality Zones D and E. The design average annual yield would be 0.4 acre-foot per acre of land affected, for a total management of 16,000 acre-feet of problem water. To exert this effect at the land surface, 32,000 acre-feet would have to be pumped from the aquifer. These lands would also have received source control (0.20 acre-foot per acre), but they would not be artificially drained. Pumped ground water of initial good quality could be used for agriculture, or fish and wildlife, or a variety of other uses. If, in future years, influent water to a well should contain dissolved salt in excess of 2,500 ppm, that water would be used for trees and halophytes.

- **Retiring 7,000 acres of irrigated agricultural lands.** Lands having the combined characteristics of low productivity, poor drainability (Storie Index 4, 5, and 6 lands), and overlying high selenium (greater than 50 ppb) in shallow ground water would be retired. All the lands lie within water-quality Zone B.

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[5] No solar ponds are included because salinity levels would probably be too low to support them.

Figure 35

TULARE SUBAREA

Ground-Water Quality Zones

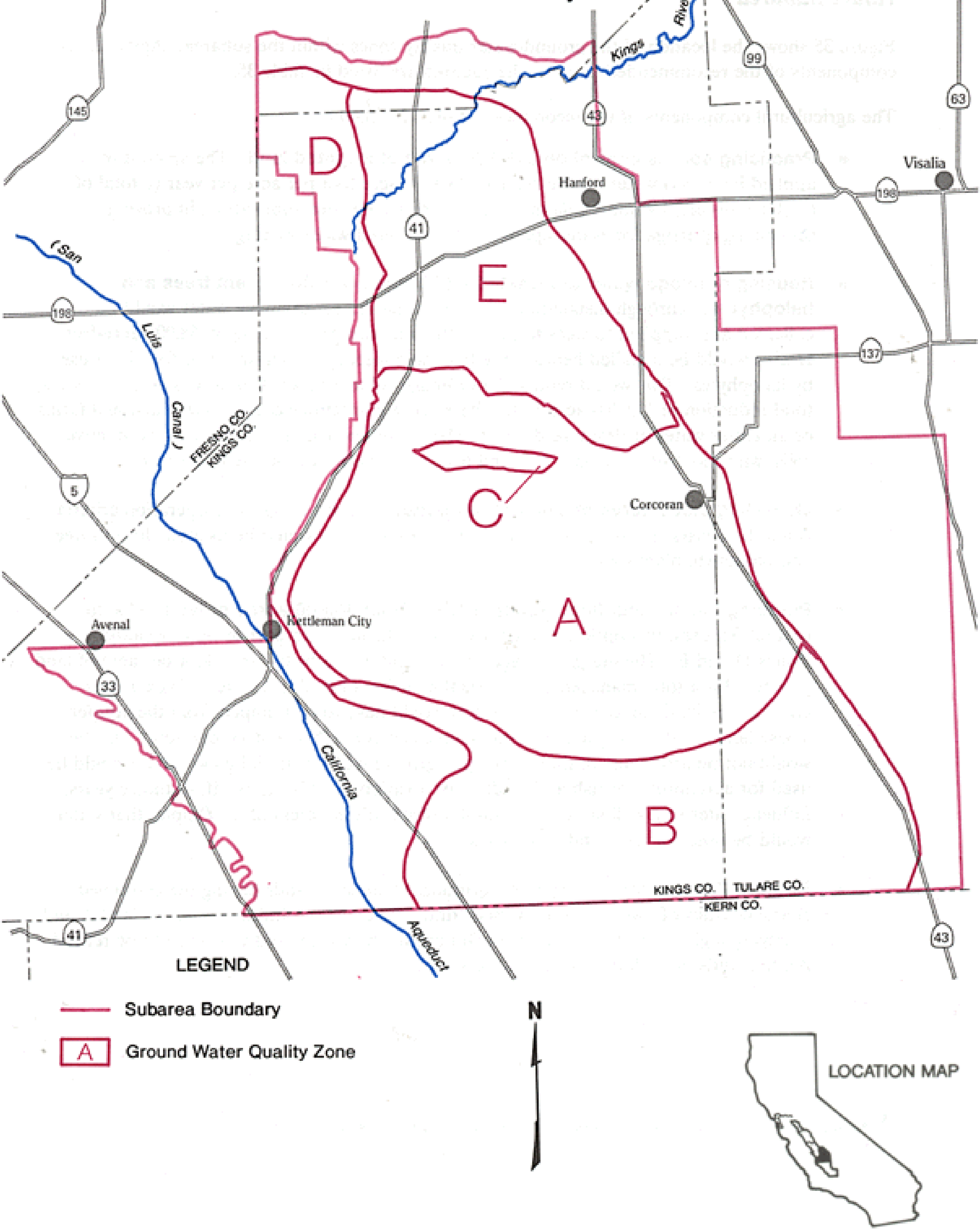

Table 35. RECOMMENDED DRAINAGE MANAGEMENT PLAN TULARE SUBAREA (In 1000s)

PLAN COMPONENT	YEAR 2000			YEAR 2040		
	AREAL APPLICATION OF COMPONENT	PROBLEM WATER REDUCTION		AREAL APPLICATION OF COMPONENT	PROBLEM WATER REDUCTION	
	Acres	AF	%	Acres	AF	%
ZONE A						
SOURCE CONTROL	60.9	12.2	30.8	169.5	33.9	30.8
LAND RETIREMENT	0.0	0.0	0.0	0.0	0.0	0.0
GROUND-WATER MGM'T	2.0	0.8	2.0	3.0	1.2	1.1
DRAINAGE REUSE	5.0	25.2	63.7	14.0	71.3	64.7
EVAPORATION SYSTEM	0.34	1.4	3.5	0.96	3.8	3.4
Total		**39.6**	**100.0**		**110.2**	**100.0**
ZONE B						
SOURCE CONTROL	25.0	5.0	30.3	63.2	12.6	27.4
LAND RETIREMENT	0.0	0.0	0.0	7.0	4.2	9.2
GROUND-WATER MGM'T	0.0	0.0	0.0	0.0	0.0	0.0
DRAINAGE REUSE	2.5	9.0	54.5	6.3	22.8	49.7
EVAPORATION SYSTEM	0.62	2.5	15.2	1.58	6.3	13.7
Total		**16.5**	**100.0**		**45.9**	**100.0**
ZONE C						
SOURCE CONTROL	1.5	0.3	27.3	4.1	0.8	29.6
LAND RETIREMENT	0.0	0.0	0.0	0.0	0.0	0.0
GROUND-WATER MGM'T	0.0	0.0	0.0	0.0	0.0	0.0
DRAINAGE REUSE	0.2	0.6	54.5	0.4	1.5	55.6
EVAPORATION SYSTEM	0.04	0.2	18.2	0.10	0.4	14.8
Total		**1.1**	**100.0**		**2.7**	**100.0**
ZONE D						
SOURCE CONTROL	6.9	1.4	31.1	19.7	3.9	31.4
LAND RETIREMENT	0.0	0.0	0.0	0.0	0.0	0.0
GROUND-WATER MGM'T	2.0	0.8	17.8	10.0	4.0	32.3
DRAINAGE REUSE	0.5	1.8	40.0	1.0	3.5	28.2
EVAPORATION SYSTEM	0.12	0.5	11.1	0.24	1.0	8.1
Total		**4.5**	**100.0**		**12.4**	**100.0**
ZONE E						
SOURCE CONTROL	22.1	4.4	32.6	60.2	12.0	31.8
LAND RETIREMENT	0.0	0.0	0.0	0.0	0.0	0.0
GROUND-WATER MGM'T	16.0	6.4	47.4	27.0	10.8	28.6
DRAINAGE REUSE	0.5	2.6	19.3	2.8	14.2	37.5
EVAPORATION SYSTEM	0.04	0.1	0.7	0.15	0.8	2.1
Total		**13.5**	**100.0**		**37.8**	**100.0**
TOTAL						
SOURCE CONTROL	116.4	23.3	31.0	316.7	63.2	30.2
LAND RETIREMENT	0.0	0.0	0.0	7.0	4.2	2.0
GROUND-WATER MGM'T	20.0	8.0	10.6	40.0	16.0	7.7
DRAINAGE REUSE	8.7	39.2	52.1	24.5	113.3	54.2
EVAPORATION SYSTEM	1.2	4.7	6.3	3.0	12.3	5.9
Total		**75.2**	**100.0**		**209.0**	**100.0**

Assessment of Plan Features and Their Effects

Table 36 compares the plan features with those of present and projected future conditions without the plan. Compared to future-without conditions, the recommended plan would maintain 166,000 more acres of existing irrigated agricultural lands in production. By 2040, the plan would result in the conservation or development of about 164,000 acre-feet of water through implementation of plan components (such as source control, conversion of land to reuse of drainage water, land retirement, and ground-water pumping) on drainage problem areas.

The annualized costs of the components of the recommended plan for the Tulare Subarea are presented in Table 37. The category "Agricultural Drainage" comprises all drainage-related components of the recommended plan, except on-farm drainage systems. "On-Farm Drains" includes the installation of new on-farm drainage systems from 1991 to 2040 and the annual operation from 1991 to 2040 of the newly installed drains and those already operating in 1990.

One-time costs include those for installation of facilities and purchase of land retired from irrigated agriculture. Costs were annualized, using an interest rate of 10 percent to reflect opportunities available to growers and a 50-year planning period.

Table 36. COMPARISON OF PLAN WITH PRESENT AND FUTURE-WITHOUT CONDITIONS TULARE SUBAREA In 1,000s

Item	Present (1990)	Future-Without (2040)	Recommended Plan (2040)
Agricultural Land Area (acres)			
Irrigable agricultural land	612	406	572
Drainage Reuse	0	11	25
Abandoned and/or retired agricultural land	0	190	7
Evaporation system			
Nontoxic evaporation pond	0.80	0.50	0.20
Toxic evaporation pond	4.10	0.90	2.90
Accelerated Evaporation pond	0.00	0.00	0.00
Solar pond	0.00	0.00	0.00
Evaporation pond alternative habitat	0.00	0.00	2.90
Urban expansion	0	5	5
TOTAL[a]	**612**	**612**	**612**
Wildlife Areas (acres)[b]			
Wetlands	1.7	0.0	0.0
Other	7.7	9.3	9.3
Abandoned wildlife areas	0.0	0.1	0.1
TOTAL	**9.4**	**9.4**	**9.4**
Water Freed in Addressing Drainage Problems (acre-feet)	0	454[c]	164[d]
Firm Water Supply for Wildlife Areas (acre-feet)	0	0	0
Water Supply for Evaporation Pond Alternative Habitat (acre-feet)	0	0	29

[a] Evaporation systems are located on existing pond sites or on retired or nonirrigable lands, so are not included in "Total."
[b] Federal and State wildlife areas, private duck clubs, and other private wildlife areas.
[c] Includes increased conserved water through source control on problem water lands and firm water supply freed by land abandonment and conversion of crop land to salt-tolerant crops.
[d] Includes increased conserved water through source control on problem water lands; firm water supply freed by land retirement and conversion of cropland to salt-tolerant crops; and ground water pumped to control water levels within problem water areas.

Table 37. ANNUALIZED COSTS OF THE RECOMMENDED PLAN FOR THE TULARE SUBAREA

AGRICULTURAL DRAINAGE			
One-time:			
Source control		$1,312,000	
Reuse		3,111,000	
Evaporation		396,000	
Ground-water management		513,000	
Land retirement		112,000	
Subtotal		$5,444,000	
Operation, maintenance, and replacement:			
Source control		$2,450,000	
Reuse		992,000	
Evaporation		241,000	
Ground-water management		1,441,000	
Land retirement		112,000	
Subtotal		$5,135,000	
	Total		$10,579,000
ON-FARM DRAINS			
Installation		$3,144,000	
Operation, maintenance, and replacement		589,000	
	Total		$ 3,733,000
	GRAND TOTAL		$14,312,000

The grand total cost for the Tulare Subarea amounts to about $104 per acre of problem farmland served through components included in the recommended plan.

Included in the cost is a provision necessary to minimize the risk to wildlife from evaporation ponds. The ponds in which the influent selenium level exceeded 2 ppb (the level assumed to be safe for wildlife) would include special features, such as steep side slopes, increased depth, hazing, and alternative habitat.

Kern Subarea

Figure 36 shows the location of the ground-water quality zones within the subarea. Agricultural components of the recommended plan for the subarea are shown on Table 38.

The agricultural components of the recommended plan for 2040 are:

- **Practicing source control on 105,900 acres of irrigated land.** The amount of applied irrigation water will be reduced by 0.35 acre-foot per acre per year (a total of 37,100 acre-feet) by improving methods of irrigation water application, improving scheduling of irrigation water application, and tiered water pricing.

Figure 36

KERN SUBAREA

Ground-Water Quality Zones

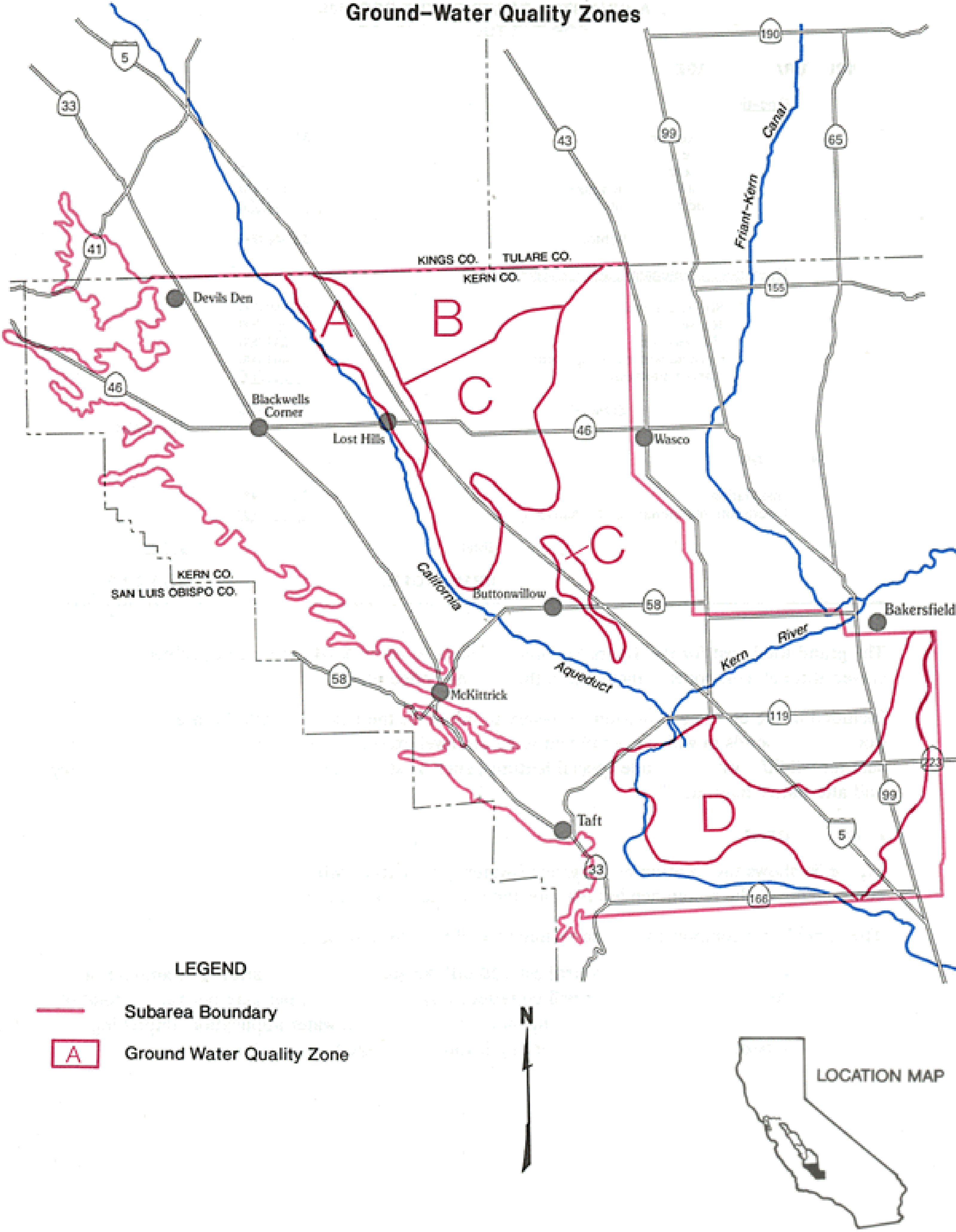

Table 38. RECOMMENDED DRAINAGE MANAGEMENT PLAN KERN SUBAREA (In 1000s)

PLAN COMPONENTS	YEAR 2000			YEAR 2040		
	AREAL APPLICATION OF COMPONENT	PROBLEM WATER REDUCTION		AREAL APPLICATION OF COMPONENT	PROBLEM WATER REDUCTION	
	Acres	AF	%	Acres	AF	%
ZONE A						
SOURCE CONTROL	7.5	2.6	32.5	1.1	0.4	2.1
LAND RETIREMENT	2.2	1.7	21.2	24.0	18.0	95.4
GROUND-WATER MGM'T	0.0	0.0	0.0	0.0	0.0	0.0
DRAINAGE REUSE	0.8	2.9	36.3	0.1	0.4	2.0
EVAPORATION SYSTEM	0.15	0.8	10.0	0.08	0.1	0.5
Total		**8.0**	**100.0**		**18.9**	**100.0**
ZONE B						
SOURCE CONTROL	7.8	2.7	42.2	18.8	6.6	42.6
LAND RETIREMENT	0.0	0.0	0.0	0.0	0.0	0.0
GROUND-WATER MGM'T	0.0	0.0	0.0	0.0	0.0	0.0
DRAINAGE REUSE	0.8	2.9	45.3	1.9	7.0	45.3
EVAPORATION SYSTEM	0.19	0.8	12.5	0.47	1.9	12.1
Total		**6.4**	**100.0**		**15.5**	**100.0**
ZONE C						
SOURCE CONTROL	13.4	4.7	43.1	32.4	11.3	43.1
LAND RETIREMENT	0.0	0.0	0.0	0.0	0.0	0.0
GROUND-WATER MGM'T	0.0	0.0	0.0	0.0	0.0	0.0
DRAINAGE REUSE	1.1	5.9	54.2	2.7	14.2	54.2
EVAPORATION SYSTEM	0.08	0.3	2.7	0.19	0.7	2.7
Total		**10.9**	**100.0**		**26.2**	**100.0**
ZONE D						
SOURCE CONTROL	24.4	8.5	41.0	53.6	18.8	37.5
LAND RETIREMENT	0.9	0.7	3.4	8.0	6.0	12.0
GROUND-WATER MGM'T	0.0	0.0	0.0	0.0	0.0	0.0
DRAINAGE REUSE	2.3	10.0	48.4	5.0	22.0	43.9
EVAPORATION SYSTEM	0.34	1.5	7.2	1.57	3.3	6.6
Total		**20.7**	**100.0**		**50.1**	**100.0**
TOTAL						
SOURCE CONTROL	53.1	18.5	40.2	105.9	37.1	33.5
LAND RETIREMENT	3.1	2.4	5.1	32.0	24.0	21.7
GROUND-WATER MGM'T	0.0	0.0	0.0	0.0	0.0	0.0
DRAINAGE REUSE	5.0	21.7	47.3	9.7	43.6	39.4
EVAPORATION SYSTEM	0.8	3.4	7.4	2.3	6.0	5.4
Total		**46.0**	**100.0**		**110.7**	**100.0**

- **Reusing drainage water to irrigate 9,700 acres of salt-tolerant trees and halophytes.** Through installation of on-farm tile drains, drainage water will be collected and supplied to trees to reduce the total drainage volume by 20,900 acre-feet. Drains would be installed beneath the trees to supply the water to halophytes. This would reduce the drainage volume by another 22,700 acre-feet, for a total reduction of 43,600 acre-feet. These reuse plantations could serve individual farms or an entire water or drainage district. They would be located on the least productive soils, with most sites on class 5 and 6 soils (Storie Index) on the alluvial fans in water-quality Zones A and D.
- **Operating 1,100 acres of evaporation ponds and 1,100 acres of solar ponds.** Pond design and operation criteria would be consistent with State guidelines, and the ponds would be located close to tree and halophyte plantations. An additional 100 acres of land would be required for accelerated-rate evaporation systems.
- **Retiring 32,000 acres of irrigated agricultural lands.** Lands having the combined characteristics of low productivity, poor drainability (Storie Index 4, 5, and 6 lands), and overlying high selenium (greater than 50 ppb) in shallow ground water would be retired. These lands lie within water-quality Zones A and D.

Assessment of Plan Features and Their Effects

Table 39 compares the plan features with those of present and projected future conditions without the plan. Compared to future-without conditions, the recommended plan would maintain about 52,000 more acres of existing irrigated agricultural lands in production. By 2040, the plan would create an opportunity to free at least 753,600 acre-feet of irrigation water for other uses.

The annualized costs of the components of the recommended plan for the Kern Subarea are presented in Table 40. The category "Agricultural Drainage" comprises all drainage-related components of the recommended plan, except on-farm drainage systems. "On-Farm Drains" includes the installation of new on-farm drainage systems from 1991 to 2040 and the annual operation from 1991 to 2040 of the newly installed drains and those already operating in 1990.

One-time costs include those for installation of facilities and purchase of land retired from irrigated agriculture. Costs were annualized, using an interest rate of 10 percent to reflect opportunities available to growers and a 50-year planning period.

The grand total cost for the Kern Subarea amounts to about $137 per acre of problem farmland served through the components stipulated in the recommended plan.

Included in the cost is a provision necessary to minimize the risk to wildlife from evaporation ponds. The ponds in which the influent selenium level exceeded 2 ppb (the level assumed to be safe for wildlife) would include special features, such as steep side slopes, increased depth, hazing, and alternative habitat.

Table 39. COMPARISON OF PLAN WITH PRESENT AND FUTURE-WITHOUT CONDITIONS KERN SUBAREA

In 1,000s

Item	Present (1990)	Future-Without (2040)	Recommended Plan (2040)
Agricultural Land Area (acres)			
Irrigable agricultural land	762	632	684
Drainage Reuse	0	5	10
Abandoned and/or retired agricultural land	0	90	32
Evaporation system			
Nontoxic evaporation pond	0.00	0.00	0.00
Toxic evaporation pond	1.70	0.70	1.07
Accelerated Evaporation pond	0.00	0.00	0.14
Solar pond	0.00	0.00	1.10
Evaporation pond alternative habitat	0.00	0.00	1.07
Urban expansion	0	35	35
TOTAL[a]	762	762	762
Wildlife Areas (acres)[b]			
Wetlands	6.1	0.0	0.0
Other	10.9	13.6	13.6
Abandoned wildlife areas	0.0	3.4	3.4
TOTAL	17.0	17.0	17.0
Water Freed In Addressing Drainage Problems (ac-ft)	0	268[c]	154[d]
Firm Water Supply for Wildlife Areas (acre-feet)	0	0	0
Water Supply for Evaporation Pond Alternative Habitat (acre-feet)	0	0	11

[a] Evaporation systems are located on existing pond sites or on retired or nonirrigable lands, so are not included in "Total."
[b] Federal and State wildlife areas, private duck clubs, and other private wildlife areas.
[c] Includes increased conserved water through source control on problem water lands and firm water supply freed by land abandonment and conversion of crop land to salt-tolerant crops.
[d] Includes increased conserved water through source control on problem water lands; firm water supply freed by land retirement and conversion of cropland to salt-tolerant crops; and ground water pumped to control water levels in problem water areas.

Table 40. ANNUALIZED COSTS OF THE RECOMMENDED PLAN FOR THE KERN SUBAREA

AGRICULTURAL DRAINAGE			
<u>One-time</u>:			
Source control		$ 551,000	
Reuse		1,391,000	
Evaporation		542,000	
Land retirement		<u>652,000</u>	
Subtotal		$3,136,000	
<u>Operation, maintenance, and replacement</u>:			
Source control		$1,051,000	
Reuse		637,000	
Evaporation		489,000	
Land retirement		<u>68,000</u>	
Subtotal		$2,245,000	
	Total		$5,381,000
ON-FARM DRAINS			
Installation		$2,051,000	
Operation, maintenance, and replacement		<u>288,000</u>	
	Total		<u>$2,339,000</u>
	GRAND TOTAL		<u>$7,720,000</u>

Evaluation of Plan and Comparison to Future-Without

The actions included in the recommended plan for each subarea would reduce the amount of irrigation water used on the lands overlying problem water. The volume would be reduced through: (1) Water conserved through source control measures, (2) water not applied to retired land, and (3) water not applied to lands being supplied through reuse of drainage water (for example, eucalyptus trees replacing a cotton field). In addition, a relatively small volume of water, some 56,000 acre-feet per year, would be pumped from the semiconfined aquifer.

The estimated water potentially available through recommended plan actions to reduce irrigation water application is given in Table 41. Although the water is potentially available with the plan, the water may not be physically available for any given use. That is because of restrictions due to water law (including contracts), economics, or private property rights (for example, pumped ground water). In the Westlands Subarea, for instance, 189,000 acre-feet annually would be conserved or developed in implementing the recommended plan. However, there is currently a shortage of irrigation water for some lands in the Westlands Water District. Consequently, water made available by reduced demand in the drainage problem area would probably be transferred to the area of shortage. Considerations of service area boundaries, priority of rights, availability of funds, and the full array of alternative uses for such water should be examined in more detail.

The water needs for fish and wildlife are shown in Table 42. Comparison of Tables 41 and 42 shows that a possible source of the water needed for fish and wildlife to offset the effects of drainage could be found in the water made available under the plan. It is assumed that 189,000 acre-feet of water freed in the Grasslands Subarea may be used to satisfy the 158,000-acre-foot shortage in the current firm water supply of the Grassland Water District. Additional investigation is required to determine the means of making the needed water available. The investigation should include consideration of marketing part of the available water to help pay for costs of solving drainage problems, including protecting fish and wildlife.

Table 41. WATER POTENTIALLY AVAILABLE THROUGH RECOMMENDED PLAN ACTIONS
In 1,000 acre-feet annually

Subarea	Source Control and Reuse		Ground-Water Management		Land Retirement		Total Water Available	
	2000	2040	2000	2040	2000	2040	2000	2040
Northern	0	0	0	0	0	0	0	0
Grasslands	35	39	4	8	0	8	39	55
Westlands	45	87	12	16	47	86	104	189
Tulare	42	117	16	32	0	15	58	164
Kern	32	64	0	0	9	90	41	154
TOTAL	154	307	32	56	56	199	242	562

Table 43 shows the area of wetlands, evaporation ponds, and solar ponds included in the recommended plan. The new year-round wetlands have been created to provide alternative habitat to unsafe evaporation ponds, and they are necessary for successful hazing. The wetlands would require fresh water at the rate of about 10 acre-feet per acre per year.

Comparison of the recommended plan to the future-without conditions provides a scale for further evaluation of the recommended plan. Selected features of the two courses of action are displayed in Tables 44 and 45. Table 44 shows that the recommended plan, which emphasizes more planned regional control of drainage water (beginning with intensive drainage water source control measures), provides water that could be made available for other uses, including fish and wildlife. However, by far the largest volume of water would be made available under future-without conditions, in which 1,140,000 acre-feet of water annually would not be used on 460,000 acres of presently irrigated lands because of salinization and abandonment of those lands.

Table 42. SUMMARY OF ANNUAL WATER NEEDS FOR FISH PROTECTION, SUBSTITUTE WATER SUPPLY FOR WILDLIFE AREAS, AND ALTERNATIVE HABITAT FOR EVAPORATION PONDS (As Related to Drainage Problem)
In acre-feet

Subarea	2000	2040
Grasslands[a]	149,300	150,200
Westlands[b]	2,300	4,000
Tulare[b]	11,200	29,000
Kern[b]	4,600	10,700
TOTAL	**167,400**	**193,900**

[a] Includes 20,000 acre-feet per year for Merced River fisheries, 129,000 acre-feet per year for substitute water supply, and 300 acre-feet per year (2000) / 1,200 acre-feet per year (2040) for alternative habitat for evaporation ponds. Some substitute water supply needs can be met with existing water-district spills and tailwater of adequate quality (about 55,000 acre-feet per year is estimated under the recommended plan on a firm basis).

[b] All needs are for alternative habitat to evaporation ponds.

Table 43. AREA OF EVAPORATION AND SOLAR PONDS AND WETLANDS IN THE RECOMMENDED PLAN
In acres

	Evaporation Ponds						Solar Ponds[a]		New Year-Round Wetlands[b]	
	Nontoxic Ponds (≤2 ppb selenium)		Standard Ponds (2-50 ppb selenium)		Accelerated Rate Ponds[a]					
Subarea	2000	2040	2000	2040	2000	2040	2000	2040	2000	2040
Northern	0	0	0	0	0	0	0	0	0	0
Grasslands	0	0	10	120	0	70	0	110	10	120
Westlands	0	0	230	410	20	200	140	1,520	230	410
Tulare	40	200	1,120	2,900	0	0	0	0	1,120	2,900
Kern	0	0	460	1,070	120	140	190	1,100	460	1,070
TOTAL	40	200	1,820	4,500	140	410	330	2,730	1,820	4,500

[a] These ponds must be evaluated to determine their effect on wildlife and shallow ground water.
[b] Provided as alternative habitat to standard evaporation ponds (new wetlands require 10 acre-feet per acre per year).

Table 44. COMPARISON OF SELECTED WATER FEATURES AND EFFECTS OF THE RECOMMENDED PLAN AND FUTURE-WITHOUT CONDITIONS, 2040

In acre-feet

	Future-Without Conditions	Recommended Plan
Water supplied to wetland areas	97,000	271,000[a]
Supplementation of Merced River	0	20,000
Water made available by land abandonment	1,140,000	0
Water made available through land retirement	0	195,000
Water pumped from the semiconfined aquifer	0	56,000
Water conserved through source control and reuse of drainage water	54,000[b]	308,000[c]

a Includes, approximately: 97,000 acre-feet per year of existing firm supply; 129,000 acre-feet per year of substitute water supply; and 45,000 acre-feet of water to create a wetland habitat that is an alternative to toxic evaporation ponds.

b Conservation rate of 0.2 acre-foot per acre of drained land.

c Conservation rate of 0.35 acre-foot per acre of drained land (except Tulare, which is 0.20 acre-foot); includes freeing of irrigation water supply supplanted by using drainage water on salt-tolerant plants.

Table 45. COMPARISON OF SELECTED LAND FEATURES AND EFFECTS OF THE RECOMMENDED PLAN AND FUTURE-WITHOUT CONDITIONS, 2040

In acres

	Future-Without Conditions	Recommended Plan
Seasonal and permanent wetlands	24,000	55,000[a]
Reuse areas (salt-tolerant plants)	28,000	49,000
Irrigated land area	1,965,000	2,325,000
Crop land drained [b]	345,000	783,000
Land abandoned [c]	460,000	0
Land retired from irrigation	0	75,000

a Does not include new wetlands created as alternative habitat for evaporation ponds because such lands are an adjunct of the drainage management system, not lands dedicated to wetlands.

b Does not include tile drains that would be installed under salt-tolerant plants.

c Salinization of formerly irrigated lands.

Estimates of the economic benefits of fish and wildlife resources in the San Joaquin Valley have been based on both market (user) and nonmarket (nonuser) values (Loomis et al., 1990). The combined annual market and nonmarket values of fish and wildlife for the recommended plan exceed those values associated with the future-without alternative by a ratio of almost 2 to 1.

Conditions that are expected to prevail with the recommended plan have been analyzed for 2040, and the agriculturally related economic impacts of plan conditions and future-without conditions for 2040 are compared in Table 46. The recommended plan would maintain more land in agricultural production and higher levels of retail sales, employment, and income. About 360,000 more acres would be kept in irrigated agriculture, with an associated crop value of $285 million. The positive impact on retail sales in neighboring communities would be nearly $41 million, and personal income would be about $78 million higher than in the future-without.

Total direct agricultural employment in the four subareas would be about 2,500 jobs higher with the recommended plan than without it. Additional employment of more than 3,200 person-years would occur both in industries that serve agriculture and in the general economies of nearby communities. The overall improvement in employment would exceed 5,700 jobs.

Table 46. INCREASE IN RETAIL SALES, INCOME, AND EMPLOYMENT FROM FUTURE-WITHOUT CONDITIONS TO THE RECOMMENDED PLAN FOR SELECTED SUBAREAS, 2040

Item	Grasslands	Westlands	Tulare	Kern	Total
Increase in irrigated crop area (1,000 acres)	36	101	170	53	360
Crop value maintained	23,788	85,862	139,332	35,877	284,859
Direct retail sales	865	3,125	5,071	1,305	10,366
Indirect and induced retail sales	2,529	9,158	14,932	3,836	30,455
TOTAL RETAIL SALES	**3,394**	**12,283**	**20,003**	**5,141**	**40,821**
Direct personal income	2,984	10,888	17,975	4,590	36,437
Indirect and induced personal income	4,054	19,635	11,417	5,975	10,565
TOTAL PERSONAL INCOME	**7,038**	**30,523**	**29,392**	**10,565**	**77,518**
Direct employment	223	780	1,206	319	2,528
Indirect and induced employment	568	1,423	812	414	3,217
TOTAL EMPLOYMENT	**791**	**2,203**	**2,018**	**733**	**5,745**

Note: Crop value, retail sales, and income are in 1,000s (1990) of dollars per year, and employment is in person-years per year.

REFERENCES CITED

The following abbreviations identify organizations that are cited in the text of this report.

AWMS	Agricultural Water Management Subcommittee, Interagency Technical Advisory Committee
CDFA	California Department of Food and Agriculture
CVRWQCB	California Regional Water Quality Control Board, Central Valley Region
DWR	California Department of Water Resources
IDP	Interagency Drainage Program
NRC	National Research Council
RMI	Resources Management International, Inc.
SJVDP	San Joaquin Valley Drainage Program
SWRCB	State Water Resources Control Board
UCCC	University of California Committee of Consultants on Drainage Water Reduction
USBR	U.S. Bureau of Reclamation
USEPA	U.S. Environmental Protection Agency

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No. 4 – July 1986	No. 10 – February 1988	No. 16 – March 1990
No. 5 – September 1986	No. 11 – September 1988	No. 17 – June 1990
No. 6 – January 1987	No. 12 – January 1989	

SUMMARIES OF PUBLIC INFORMATION MEETINGS

September 25 – October 3, 1989 (Bakersfield, Lost Hills, Corcoran, Fresno, Mendota, Los Banos, Patterson, and Oakland).

July 23–27, 1990 (Sacramento, San Francisco, Los Banos, Fresno, and Bakersfield).

CITIZENS ADVISORY COMMITTEE MEETING MINUTES

March 5, 1987 – Stockton
April 10, 1987 – Santa Nella
May 22, 1987 – Pleasanton
June 22, 1987 – Patterson
July 27, 1987 – Livermore
September 28–29 1987 – Coalinga
January 11, 1988 – Oakland
February 11, 1988 – Santa Nella
March 28,, 1988 – Tracy
April 25, 1988 – Livermore
May 23, 1988 – Stockton
June 28, 1988 – Coalinga
August 29, 1988 – Stockton
September 26, 1988 – Stockton
February 13, 1989 – Stockton
April 3, 1989 – Stockton
April 3, 1989 – Stockton
July 31, 1989 – Byron
September 11, 1989 – Stockton
November 13, 1989 – Los Banos
January 17, 1990 – Sausalito
April 18, 1990 – Coalinga
May 30, 1990 – Stockton
July 16, 1990 – Stockton
August 13, 1990 – Stockton

POLICY AND MANAGEMENT COMMITTEE MEETING MINUTES

1985

August 19
October 21
November 12
November 25
December 9
December 16

1986

January 8
January 21
February 13
March 6
April 2
April 29
May 26
June 26
August 28
October 8
November 12

1987

February 23
April 2
June 15
August 17
October 21

1988

January 4
March 11
May 9
May 23
December 5

1989

March 24
July 7
December 18
August 1

1990

May 7
June 13
August 15
September 22

CONTRACTORS' REPORTS PREPARED FOR OR IN COOPERATION WITH THE SAN JOAQUIN VALLEY DRAINAGE PROGRAM

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ABBREVIATIONS

Ac: acre

Acre-ft: acre-feet

AF: acre-feet

CCC: Commodity Credit Corporation

CSWRCB: California State Water Resources Control Board

CVP: Central Valley Project

CVRWQCB: California Regional Water Quality Control Board, Central Valley Region

DFG: California Department of Fish and Game

DWR: California Department of Water Resources

EC: electrical conductivity

EPA: U.S. Environmental Protection Agency

EPOC AG: EPOC Agricultural Corporation

gpm: gallons per minute

GW: ground water

ITAC: Interagency Technical Advisory Committee, San Joaquin Valley Drainage Program

k: thousand

mgd: million gallons per day

NWR: National Wildlife Refuge

ppb: parts per billion

ppm: parts per million

SJVDP: San Joaquin Valley Drainage Program (1984–1990)

SWP: State Water Project

SWRCB: California State Water Resources Control Board

TDS: total dissolved solids

UC: University of California

USBR: U.S. Bureau of Reclamation

USFWS: U.S. Fish and Wildlife Service

USGS: U.S. Geological Survey

WA: wildlife area managed by the State of California

yd^3: cubic yards

$>$: greater than

$\geq$: greater than or equal to

$<$: less than

$\leq$: less than or equal to

GLOSSARY

Acre-foot: The quantity of water required to cover 1 acre to a depth of 1 foot. Equal to 325,851 gallons or 43,560 cubic feet.

Adsorption: The surface retention of solid, liquid, or gas molecules, ions, or atoms by a solid or liquid.

Aerobic: Referring to a condition requiring the presence of oxygen. Aerobic bacteria require free oxygen for the metabolic breakdown of materials.

Agroforestry: As used in this report, it is the practice of growing certain types of trees with drainage water. The trees act to dispose of applied drainage and shallow ground water through foliar evapotranspiration and at the same time produce a marketable commodity.

Alluvium: A general term for clay, silt, sand, gravel, or similar unconsolidated material deposited during comparatively recent geologic time by a body of running water.

Alluvial fan: A low, outspread, relatively flat to gently sloping mass of stream deposits, shaped like an open fan or a segment of a cone deposited by a stream, especially in a semiarid region at the place where it issues from a narrow mountain valley upon a plain or broad valley.

Anaerobic: Referring to the condition of existing in the absence of oxygen. Anaerobic bacteria can survive in the partial or complete absence of air.

Aquaculture: As used in this report, refers to the potential use of drainage water for growth of aquatic organisms (fish, etc.) that could have product marketability.

Aquifer: An underground geologic formation that stores and transmits water and yields significant quantities of water to wells and springs.

Attenuation: In the context of this report, refers to the reduction of the amount of metal species transmitted through a soil column. Research has been conducted on the attenuation of selenium.

Basin trough: A long, sediment-filled depression at the center of the valley.

Bioaccumulation: The uptake and accumulation of a chemical by plants and animals directly from the environment (that is, from water, sediment, soil, or air) or through the diet. See **Bioconcentration** and **Biomagnification**.

Bioconcentration: The uptake and accumulation of a chemical by plants and animals directly from the environment, resulting in whole-body concentrations greater than those found in the environment. See **Bioaccumulation** and **Biomagnification**.

Biomagnification: The uptake and accumulation of a chemical by plants and animals through their diet, resulting in whole-body concentrations that increase at successively higher trophic levels of the food chain. See **Bioaccumulation** and **Bioconcentration**.

Biomass: As used in this report, refers to plant material that has been grown in drainage water and is suitable for use as a fuel, such as in cogeneration processes.

Cogeneration: A process using waste heat from the thermal generation of energy to evaporate drainage water.

Confined aquifer: An aquifer bounded above and below by impermeable beds or beds of distinctly lower permeability than the aquifer itself.

Conjunctive use: A resource use or management plan in which surface and ground water supplies are used in a manner to maximize use from both without degradation of either.

Contamination: The addition to a given medium, such as water, of substances that adversely affect its beneficial use.

Critical year: A year is classified as critical when unimpaired runoff to the San Joaquin River and key tributaries, as described in Department of Water Resources' Bulletin 120, is less than 3.37 million acre-feet. However, if the previous year was classified as critical, a year is rated as critical when unimpaired runoff is less than 4.13 million acre-feet.

Deep percolation: The downward percolation of water past the lower limit of the root zone of plants, usually more than 5 feet below the surface.

Delta: A low, nearly flat alluvial tract of land formed by deposits at or near the mouth of a river. In this report, Delta usually refers to the delta formed by the Sacramento and San Joaquin Rivers.

Drainage problem area: A land area characterized by waterlogging and related water-quality problems. Includes land areas now drained or land areas that likely will require drainage.

Drainage water: See **Subsurface drainage water.**

Endangered species: Any species or subspecies of bird, mammal, fish, amphibian, reptile, or plant which is in serious danger of becoming extinct throughout all, or a significant portion of, its range.

Electrical conductivity (EC): The ability of a particular parcel of water to conduct electricity. The EC of a water sample is an indirect measure of the total dissolved solids (TDS) or salinity of the sample. Units of reporting are siemens, which are equivalent to the older units, *mhos*. Microsiemens per centimeter are abbreviated as µS/cm.

Evaporation: The change of a substance from the solid or liquid phase to the gaseous (vapor) phase.

Evapotranspiration: Water lost as vapor through the combined processes of evaporation from soil surface and transpiration from plants.

Facultative bacteria: Microorganisms capable of adaptive response to varying environments (for example, adaptive to aerobic or anaerobic conditions).

Furrow: A long, narrow, shallow trench made in the ground by a plow or other implement.

Halophytes: Plants that are well adapted to growing in a saline soil environment.

Hydraulic connections: The situation existing between two aquifers whereby the openings allow water to go from one aquifer to the other.

Immobilization: In the context of this report, the application of processes and procedures to retain toxic elements, especially selenium, in a given (soil) area. This is done to limit the movement and availability of those metal species which may make them environmental hazards.

Ion exchange: A reversible chemical reaction between a solid (ion exchanger) and a fluid (usually a water solution), by means of which ions may be interchanged from one substance to another.

Irrigation efficiency: The ratio of the average depth of water infiltrated and stored in the root zone to the average depth of water applied to the field. Application efficiency of an irrigation system is estimated by dividing the crop water use between irrigations by the amount of water applied during the last irrigation.

Leaching: The dissolution and flushing of salts from the soils by the downward percolation of water.

Methylation: The chemical attachment of one or more methyl (CH_3) groups to an element or compound.

Mitigation: One or all of the following: (a) Avoiding an impact altogether by not taking a certain action or parts of an action; (b) minimizing impacts by limiting the degree or magnitude of an action and its implementation; (c) rectifying an impact by repairing, rehabilitating, or restoring the affected environment; (d) reducing or eliminating an impact over time by preservation and maintenance operations during the life of an action; and (e) compensating for an impact by replacing or providing substitute resources or environments.

Oxidation: A chemical reaction taking place by loss of electrons or addition of oxygen.

Oxidation state: In chemical terms, it is the number of electrons that can be added or subtracted from a chemical atom in a combined state to convert it to elemental form. Also known as the oxidation number or valence and could be positive or negative.

Part per billion (ppb): One part by weight per 1 billion (10^9) parts. In water, nearly equivalent to 1 microgram per liter (μg/L), or 1 microgram per kilogram (μg/kg) in solids.

Part per million (ppm): One part by weight per 1 million (10^6) parts. In water, nearly equivalent to 1 milligram per liter (mg/L), or 1 milligram per kilogram (mg/kg), also 1 microgram per gram (μg/g).

Percolation: In the context of this report, the downward movement of water through the soil or alluvium to the ground-water table.

Potential problem water: Shallow ground water within 5 feet of the surface of irrigated lands during at least part of the year that has chemical characteristics adversely affecting agriculture and, if the water were to be drained, fish and wildlife, public health, or attainment of State surface–water quality objectives.

Principal study area: Primarily the western side of the San Joaquin Valley, comprising lands, waters, and related resources currently affected by problems related to agricultural drainage, as well as lands likely to be affected in the future.

Problem water: That part of potential problem water that, because of its adverse impact on crops, soils, or off–site areas, and water and land uses, requires drainage and associated management.

Recharge: The processes of water filling the voids in an aquifer, which causes the piezometric head or water table to rise in elevation.

Reduction: A chemical reaction taking place by acceptance of electrons, removal of oxygen, or addition of hydrogen.

Riparian: Pertaining to the banks and other terrestrial environs adjacent to water bodies, watercourses, and surface-emergent aquifers (for example, springs, seeps, and oases), whose waters provide soil moisture significantly in excess of that otherwise available through local precipitation. Vegetation typical of this environment depends on the availability of excess water.

Root-zone storage: Water present in the first few feet, usually within 5 feet of the ground surface in field crops and vegetables; within 10 feet for some fruit and nut trees.

Salinity: The salt content of dissolved mineral salts in water or soil. Salinity in water is measured by determining the amount of total dissolved solids (TDS) or by the electrical conductivity (EC); 1,000 μS/cm is approximately equal to 650 ppm as TDS.

Salts: In chemistry, the compound formed when the hydrogen of an acid is replaced by a metal or its equivalent. Examples are sodium chloride, calcium sulfate, and magnesium carbonate. In this report, it generally refers to chemical salts as they are dissolved in water or present in soils. The major components of drainage water salts are sodium, sulfate, and chloride.

Salt balance: The equilibrium established between salts imported to an area and the salts exported from the same area. When used in a regional sense, imported salts are those contained in surface-applied water and may include other inputs such as fertilizer, soil amendments, and precipitation; exported salts are those conveyed from the area through surface and subsurface flows. The term "salt balance" can also be applied to the crop root zone. In this sense, it refers to an equilibrium state of soil salinity where there is no net salt accumulation in the root zone. Net accumulation of salt in the crop root zone can reduce crop yields.

Salt load: The total amount of salts contained in a given volume of water entering or leaving an area.

Seepage: Water escaping from a channel or an impoundment by percolation.

Selenate: Ionized selenium, usually present as a salt, existing in a valence (or oxidation) state of +6. The chemical symbol is SeO_4^{-2}.

Selenite: Ionized selenium, usually present as a salt, existing in a valence (or oxidation) state of +4. The chemical symbol is SeO_3^{-2}.

Semiconfined aquifer: As used in this report, it includes all aquifers above the Corcoran Clay, including the so-called unconfined aquifer.

Shallow ground water: Ground water within 20 feet of the land surface.

Sierran sand: A term referring to a distinct subsurface body of water-bearing material underlying the San Joaquin Valley. These deposits originated from the Sierra Nevada. Term is equivalent to "Sierran sediment" and "Sierra Nevada sediment."

Soil salinization: The accumulation of soluble salts in the soil by the evaporation of water from the soil zone.

Solar ponds: Nonconvective, salt-gradient solar ponds discussed in this report are about 6.5 to 16.5 feet deep with three distinct water salinity/density zones. Short-wave solar radiation penetrates the upper zones into the lower, denser, heat storage zone and raises its temperature. The stored heat can be used as a low-temperature energy source.

Subsidence: A local mass movement that involves principally the gradual downward settling or sinking of the earth's surface with little or no horizontal motion. It may be due to natural geologic processes or mass activity such as removal of subsurface solids, liquids, or gases, and wetting of some types of moisture-deficient loose or porous deposits.

Substance of concern: One of a group of toxic or potentially toxic chemical elements or constituents present in agricultural drainage water.

Substitute water supply: An adequate nontoxic and reliable freshwater supply equal in volume to the agricultural drainage water previously used by wildlife and/or wildlife habitat. In practical application, it is water to replace a supply on which biological dependence has developed.

Subsurface drainage water: Surplus water removed from within the soil by natural or artificial means, such as by drains placed below the surface to lower the water table below the root zone. In this report, unless otherwise qualified, drainage water refers to subsurface drainage water.

Tailwater: Irrigation water that flows over an irrigated field without infiltrating the soil. Synonymous with "surface drainage water" and "irrigation return flow."

Tile drain: An on-farm subsurface drain made of flexible plastic pipe (formerly made of clay tile).

Total dissolved solids: A measure of the amount of dissolved material in a liquid (usually water). It is used to determine salinity. The procedure requires measuring (weighing) the amount of solid remaining after evaporation of the liquid for a given time period and at a specified temperature.

Trace elements: Those elements present in the environment at small but measurable concentrations, usually less than 1 part per million.

Transpiration: The passage of water through the stomata of plant leaves into the atmosphere.

Upland: Generally means a land zone sufficiently above and/or away from freshwater bodies, watercourses, and surface-emergent aquifers to be largely dependent on precipitation for its water supplies. As used in this report, *upland* also refers to lands other than those which are seasonally or permanently wet.

Volatilization: The conversion of a chemical substance from a liquid or solid state to the gaseous (vapor) state.

Waterlogged: Soaked or saturated; said of an area affected by a high water table; that is, where water stands near, at, or above the land surface.

Water table: The area in unconfined subsurface material where hydrostatic pressure equals atmospheric pressure. Generally, the boundary between the saturated and unsaturated subsurface soil zones.

Wetland: A zone periodically or continuously submerged or having high soil moisture, which has aquatic and/or riparian vegetation components, and is maintained by water supplies significantly in excess of those otherwise available through local precipitation.

Wildlife habitat: An area that provides a water supply and vegetative habitat for wildlife.

Department of Water Resources

Travis Latham	Editing
Gayle Dowd Chuck Lano	Delineation
Teresa Chaney	Design