CHAPTER 1

INTRODUCTION

1.01 *Authorization.*

The research work described in this report was originally authorized by Standard Agreement No. 12-28, dated 25 January 1962, and extended by Standard Agreement No. 12-16, dated 1 July 1962, both between the California Institute of Technology and the then-named California State Water Pollution Control Board. The latter agreement specified that an annual report of all work completed between 25 January 1962 and 30 June 1963 be submitted by 30 September 1963. In compliance, the first annual report (1) was prepared and 100 copies were submitted in September 1963.

The project was extended until 30 June 1964 and modified somewhat in its specific objectives by Standard Agreement No. 12-16, dated 1 July 1963. This agreement also called for an annual report to be submitted by 30 September 1964 and to contain not only the 1963–64 results but also all significant data and information obtained from the inception of the project in January 1962. The second annual report (2) was prepared and 100 copies were submitted in September 1964. A limited number of additional copies of both the first and second annual reports were reproduced and distributed upon request to interested parties.

The third and terminal year of the project was authorized by Standard Agreement No. 12-16, dated 1 July 1964. Although the general objective remained the same, the specific objectives were modified somewhat to comply with developments during the first two years of the project.

To supplement the project and to provide technical liaison with its other activities in wastewater reclamation, the Chief of the Division of Water Supply and Pollution Control of the U. S. Public Health Service agreed to assign one of the commissioned engineers to Caltech to serve as project engineer. The assignment of Dr. F. C. McMichael to this post became effective in February 1963, and terminated in August 1965.

The Los Angeles County Flood Control District (LACFCD) and the Los Angeles County Sanitation Districts also agreed informally to cooperate on this project. The LACFCD has assigned personnel to operate the test basins and the well-monitoring program, to take samples and deliver them to Caltech, and to make field analyses and observations. Furthermore, under contract with Caltech, LACFCD agreed to construct two test basins and drill three sampling wells. Personnel of LACSD have cooperated by providing analyses and data relative to operation of the Whittier Narrows Water Reclamation Plant and by participation in monthly coordinating conferences.

1.02 *Purpose.*

The general objective of this research has been to investigate the effects of percolation of highly treated activated-sludge effluent on the quality of water in subterranean aquifers. More specifically, the project was oriented toward the water-reclamation activities of the Los Angeles County Sanitation Districts (LACSD) and the Los Angeles County Flood Control District (LACFCD) in the area of Whittier Narrows. It was the broad intent of this project to determine how the reclamation of wastewater in this location might possibly influence the quality of ground water.

1.03 *Scope and Limitations.*

Each of the aforementioned Standard Agreements included an Exhibit "A" delineating the scope of the investigations to be undertaken that year. The detailed items differed somewhat from year to year, but for the most part embraced the following specific objectives:

a. To study the effects of intermittent percolation through soil or sand on the chemical and biological quality of wastewater, especially with respect to:

(1) mineral constituents such as total dissolved solids, chlorides, and nitrogen compounds,

(2) organic parameters such as chemical oxygen demand, biochemical oxygen demand, and volatile solids,

(3) synthetic detergents, including the new linear alkylate sulfonates (LAS) as well as the common alkyl benzene sulfonates (ABS),

(4) coliform bacteria, and

(5) enteroviruses.

b. To assay products from the degradation of organic substances and insofar as feasible to define pathways of decomposition and to identify the major organisms.

c. To study the reaction rates and other phenomena associated with adsorption and desorption, oxidation and reduction, and ion exchange in the soil column.

d. To relate respiratory parameters (i.e. the oxygen demand and the mechanisms for reaeration) in the soil column.

e. To investigate methods for evaluating the biodegradability of ABS, LAS, and other exotic organic substances in soil columns.

f. To develop improved means for accelerating or otherwise fostering biochemical stabilization in intermittent spreading operations.

g. To evaluate the rate and extent of travel of fecal organisms through the soil.

h. To measure the patterns of dispersion and diffusion of effluent under field conditions in the soil and underground strata insofar as possible.

i. To develop guidelines for the optimum operation of spreading basins for ground-water recharge with treated wastewater effluent.

The scope of the project as specified in the nine items above is very broad. Consequently, it was recognized that some aspects would probably develop rapidly while detailed investigation of other factors would have to be postponed or perhaps deleted. It was anticipated, moreover, that the direction of the project would change as developments in the field operations were altered. For that reason, the scope of the project has broadened in some aspects and contracted in others.

Within the limitations of time, personnel, and budget, it was not anticipated that this project would embrace a comprehensive ground-water survey or that complete chemical and biological analyses would be performed on all water samples. Instead, it was planned that the project staff would cooperate with the Los Angeles County Sanitation Districts, Los Angeles County Flood Control District, and other agencies in an interchange of analyses and other data. Such cooperation has been most effective to date.

1.04 *Organization of the Project.*

The work on this project was divided into two major categories, viz. field investigations and laboratory bench-scale studies. The field investigations, in turn, were separated into spreading operations and chemical analyses of wells in the general area of Whittier Narrows. Chapter 3 gives a general picture of water-reclamation activities and the relation of this research project to the over-all plan. The results of field investigations and concomitant laboratory analyses for the test spreading basins are presented in Chapter 4. The well-sampling program is summarized in Chapter 5. Special studies in laboratory soil columns are described in Chapter 6. Remaining chapters discuss special phases of these results.

Prior to July 1963, much of the laboratory bench-scale research was performed by or under the direction of Dr. K. R. Johansson and Dr. Ludwig Hartmann. The results of their investigations were described in Appendices A and B of the first annual report, and reviewed critically in Chapter V of that report. Subsequent to that work, however, further investigations revealed that the findings in Appendices A and B were no longer relevant. In the interest of clarity and brevity, therefore, these appendices have been omitted from this report. Much of the material in Chapter V of the first report is incorporated at various places in this final report.

1.05 *Personnel.*

The engineers, scientists, technicians, clerk typists, and others who have worked on this project under Caltech administration are listed in the following tabulation. Their contributions and assistance are gratefully acknowledged.

Name	Category	Approximate Dates of Participation
Melvin E. Holland	Associate Research Engineer	Feb. 1962–Sept. 1962
Robert B. Scott	Laboratory Aide (Student)	June 1962–Sept. 1962
David A. Mann	Laboratory Aide (Student)	Oct. 1962–May 1963
Ralph E. Pressman	Scientist	Mar. 1962–Nov. 1962
Ludwig Hartmann	Research Fellow	May 1962–Aug. 1963
Karl R. Johansson	Associate Professor	Mar. 1962–Feb. 1963
Ann P. Miller	Junior Chemist	Oct. 1963–Jan. 1964
Linda S. Keene	Research Assistant	June 1964–Sept. 1964
Jean E. Edens	Laboratory Aide	Jan. 1965–Aug. 1965
Joann Kiekover	Clerk Typist	Jan. 1963–Mar. 1964
Joy C. Smelser	Clerk Typist	April 1965–Sept. 1965
Jesse C. Watt	Laboratory Technician	May 1963–July 1965
Francis C. McMichael	Project Engineer (Caltech)	Sept. 1962–Feb. 1963
Jack E. McKee	Project Director	Feb. 1962–Sept. 1965

1.06 *Acknowledgements.*

In view of the many facets to wastewater reclamation and the large number of agencies and individuals interested in the Whittier Narrows project, it became evident early in the project that an advisory committee would be most helpful and indeed even essential to the successful completion of this work. Accordingly the Advisory Committee listed on the following page was established. It has met three times at the W. M. Keck Engineering Laboratories at Caltech on 7 September 1962, on 6 September 1963, and 24 September 1964. The Advisory Committee, functioning as a group and separately as individuals throughout the past 42 months, has been most helpful in its suggestions and review of progress. In addition, Dr. William R. Samples and Dr. Andrew L. Gram of Caltech have provided valuable technical advice with respect to analytical procedures and interpretation of results.

Personnel of the Los Angeles County Sanitation Districts and the Los Angeles County Flood Control District have contributed much to the detailed operation of the project. Gratitude is especially due to John D. Parkhurst, Walter E. Garrison, and Franklin D. Dryden of the LACSD and to Arthur E. Bruington, Howard H. Haile, A. A. Ingram, and C. Charles Evans of the LACFCD who served with the Caltech staff as an informal project coordinating committee. Appreciation is also expressed for the LACFCD personnel who operated the test spreading basins, gathered samples, and delivered them to Caltech.

The assistance of the Division of Water Supply and Pollution Control, U.S. Public Health Service, in assigning Dr. F. C. McMichael to this project is gratefully acknowledged.

ADVISORY COMMITTEE

WHITTIER NARROWS PROJECT

Mr. A. E. Bruington, Assistant Chief Deputy Engineer
Los Angeles County Flood Control District

Mr. John D. Parkhurst, Chief Engineer and General Manager
Los Angeles County Sanitation Districts

Mr. Arthur Reinhardt, Supervising Sanitary Engineer
State Department of Public Health

Mr. David B. Willets, Supervising Engineer
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Mr. Linne Larson, Executive Officer
Los Angeles Regional Water Pollution Control Board

Mr. F. B. Laverty, Consulting Engineer

Dr. H. F. Ludwig, Consulting Engineer
Engineering-Science, Inc.

Mr. Carl Fossette, General Manager
Central and West Basin Water Replenishment District

Mr. R. C. Merz, Professor of Civil Engineering
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Mr. Norman B. Hume, Director, Bureau of Sanitation
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Mr. Paul W. Eastman, Regional Program Director
Water Supply and Pollution Control, U.S. Public Health Service

Mr. Arthur V. Potter, Civil Engineer
Planning and Reports Branch, U.S. Army Engineer District. Los Angeles

Mr. Donald Suggs, Public Health Engineer
Los Angeles County Health Department

Mr. George M. Cook, Assistant to the President
Oronite Division, Chevron Chemical Co., San Francisco

Mr. Howard H. Haile, Division Engineer
Water Conservation Division, Los Angeles County Flood Control District

CHAPTER 2

A REVIEW OF PAST EXPERIENCE IN GROUND-WATER RECHARGE

The planned artificial recharge of ground-water basins for augmentation of potable water supplies has been practiced for over a century, especially in Europe. Much of the literature discussing this experience is summarized by Todd (23, 24) and by Rambow (25). This chapter will be a short résumé of some of the pertinent findings by various investigators.

2.01 *Surface Spreading.*

Many of the operational procedures used in ground-water recharge are based on experience with artificial filters, i.e., slow sand filters for water treatment and intermittent sand filters for sewage treatment. In principle, percolation through soil is very similar to percolation through a fine-grained biological filter. Purification is accomplished by mechanical, physical-chemical, and biological processes. Normally, artificial filters have some type of collection gallery as the terminal part of the filter, whereas a surface spreading operation normally permits the percolated water to reach the main body of ground water. This recharged water is not taken out of the ground by itself, but attempts are made to cause it to blend with other waters underground so that the pumped water has no distinct identity.

2.02 *European Practice.*

The artificial recharge of polluted river waters is widely practiced in Sweden, Germany, and the Netherlands and to a lesser extent in France, Great Britain, and Spain. Recharge in Europe is accomplished partially to conserve flood waters, but primarily as a mechanism for purification. Many European waterworks officials frown upon the direct use of surface waters for municipal water supply, even after modern treatment methods. Instead, they prefer to utilize ground-water supplies, relying upon natural phenomena associated with flow through soil to provide adequate treatment. At Wiesbaden, for example, polluted water from the Rhine River is spread and percolated intermittently through natural soil into infiltration galleries and wells.

At many locations in the Netherlands, the planned percolation of polluted surface waters into sand dunes augments the natural ground-water resources and also militates against salt-water intrusion (27). Polluted water from a branch of the Rhine River and from the Amsterdam-Rhine shipping canal is recharged through infiltration basins to augment the water supplies of Amsterdam, Haarlem, Leyden, and The Hague. According to Baars (28), the color is diminished by 50 percent, the permanganate consumption by two-thirds, and the suspended matter by 100 percent as a result of flow through soil. Nitrates are largely destroyed by denitrification. There is little change in chlorides, bicarbonates, and hardness. Dissolved oxygen is depleted by percolation and surprisingly the sulfates are decreased by 50 percent. There are slight increases in carbon dioxide, ferrous iron, and divalent manganese. Coliform organisms are absent in the filtrate.

In England, experiments on intermittent percolation through soil were conducted with biologically treated wastewater effluent and with water from the River Trent, of which as much as 36 percent of the normal summer flow at Nottingham originates as wastewater effluent (29). Results of percolation with river water showed no significant change in total dissolved solids, hardness, magnesium, calcium, sulfate, or chlorides, but almost complete removal of heavy metals (nickel, chromium, zinc, lead, and copper). For the wastewater effluent, BOD concentrations were diminished by 80–90 percent and almost all organic nitrogen and ammonia were converted to nitrates. In one or two feet of percolation, approximately 96.5 percent of the coliforms were removed.

2.03 *Israel.*

A project is being designed for the reclamation of wastewater from the Tel Aviv metropolitan area, estimated to process more than 72 million gallons per day by the year 1990. The wastewater will be stabilized first in lagoons and then percolated intermittently into sand dunes for subsequent recovery through wells. Preliminary investigations with experimental spreading basins indicated that vertical percolation and lateral ground-water travel over a distance of about 26 feet produced a potable water. Little change occurred in the concentrations of total solids, chlorides, sulfates, and pH. The 5-day, 20°C biochemical oxygen demand was decreased by over 75 percent to a mean of 5.8 mg/l and the chemical oxygen demand was reduced on the average from 172 to 85 mg/l. The iron increased from 0.28 to 0.57 mg/l and manganese from 0.08 to 0.19 mg/l. The total nitrogen in the percolating water was decreased by about 40 percent (30).

2.04 *Los Angeles County.*

The most extensive investigations of ground-water recharge by percolation of wastewaters have been conducted in California, especially in the Los Angeles metropolitan area. In addition to planned percolation, it should be recognized that the incidental recharge of ground-water basins by percolating effluents occurs at many inland locations where treatment plants discharge to dry river beds or to spreading basins. Incidental recharge also takes place from innumerable cess pools and subsurface drainage fields.

In 1949, the Los Angeles County Flood Control District (LACFCD) constructed test spreading basins to percolate effluents from the Azusa and Whittier wastewater treatment plants, both of which utilized trickling filters for conventional secondary treatment. The soil at Whittier was much finer than that at

Azusa. Sampling pans were installed at depths of 4, 5, 6, and 7 feet below the surface at each location. As reported by Stone and Garber (31), percolation of effluent at rates of about one foot per day produced water at the 7-foot pans free of coliform bacteria and with a BOD of less than 0.5 mg/l, provided that aerobic conditions were maintained. At Azusa, the total dissolved solids in the treatment-plant effluent were only 172 mg/l higher than those in the municipal water supply. Stone (32) further discusses the benefits of the intermittent spreading operation for wastewater stabilization and suggests some design criteria for the wastewaters. The merits of aerobic treatment are discussed with emphasis placed on reduction of odor and insect nuisance by employing an intermittent operation. Stone suggests a design load criteria of 45 lb./acre/day based on the 5-day biochemical oxygen demand.

Some of the activities of the LACFCD with respect to spreading of storm run-off as well as wastewaters are discussed by Baumann (33). Off-channel spreading has been carried out since 1960 in Los Angeles County. As late as 1944–45, there was no ocean disposal of wastes from the San Gabriel Valley, but in 1956 the wastewater flow to the ocean from the Valley was 35,000 acre-feet per year, thus reducing groundwater replenishment by a considerable amount in only 10 years.

Starting in 1955, LACFCD conducted tests near the Hyperion treatment plant of the City of Los Angeles to determine the effectiveness of percolation through dune sand to polish the high-rate activated-sludge effluent for subsequent pressurized injection into a confined aquifer. The results were reported by Van der Goot (34) and by Laverty et al. (35). When intermittent operation was employed, percolation rates of one foot per day were obtained through a 13-foot depth of dune sand. With effluents from the high-rate activated-sludge process, percolates averaged only 3.5 mg/l of BOD and 7.5 mg/l of suspended solids. With standard-rate activated-sludge effluents, the results were even better. Detergents were reduced to an average of 1.1 mg/l. Tests at a collecting pan seven feet below the surface showed reductions in coliform concentrations of 98.0 to 99.9 percent. With intermittent spreading almost all of the nitrogen compounds were converted to nitrates. The percolate was well-stabilized, of sparkling clarity, and odorfree.

The wastewater reclamation research at the Hyperion site was reactivated in 1961 by LACFCD and Caltech. In these experiments, however, the effluent was prepared for well injection by rapid-sand or diatomite filtration rather than by intermittent spreading on soil or sand.

2.05 *Experiments at Lodi, California.*

In 1949–1952, the University of California conducted extensive field experiments on the spreading of wastewater at Lodi, California, utilizing activated-sludge effluent with a BOD of about 10 mg/l and settled sewage with a BOD of about 100 mg/l. This work was sponsored by the California Department of Public Health and the California State Water Pollution Control Board. Samples were collected after percolation through 1, 2, 4, 7, 10, and 13 feet of a fine sandy loam (4, 37). Basins were generally flooded for 7 or 14 days and then rested for 7 days. Some basins were flooded continuously. It was concluded that:

a. A bacteriologically safe water can be produced from settled sewage or from final effluent if the liquid percolates vertically through at least four feet of soil.

b. A water of satisfactory chemical quality can be produced from settled sewage or from final effluent, providing high concentrations of undesirable industrial wastes are not included in the raw sewage.

c. In order to obtain good rates of percolation, a highly treated wastewater effluent must be used. With such an effluent, percolation rates of 0.5 feet per day or better can be achieved with this soil.

The University of California has also conducted extensive investigations at Richmond, California, on percolation through lysimeters (37) and for direct injection into a confined aquifer (38, 39).

2.06 *Santee, California.*

A wastewater reclamation scheme using the effluent from a small (about 1 MGD) activated-sludge treatment plant which is stabilized in an oxidation pond and then spread in a dry river channel has been the subject of study at Santee (40). The spreading basins are operated intermittently and presently the percolated water travels about 1000 feet through sands and gravels before being collected and diverted into recreational lakes. Three lakes with between 6 and 11 surface acres each are used for recreational boating and fishing. In the summer of 1965 a swimming area was created using percolated effluent that was chlorinated. Primary emphasis on Santee was on the determination of the fate of viruses and bacterial indicators throughout the treatment process. The microbiological and virological work (41) indicates that samples of raw sewage, settled sewage, and final effluent were 100 percent positive for enteric viruses, yielding 13 distinct viruses. The percent of samples positive after about 30 days detention in an oxidation pond dropped to 25 percent, and the percolated waters and recreational lake waters have been consistently negative for virus. A special study (42) subjected the filtration zone to a massive dose of attenuated polio Type III virus (about 3.5×10^5 PFU per liter in the applied percolate) in November 1964. Samples of percolate at distances of 200, 400, and 1500 feet were found to be completely free of virus.

2.07 *Illinois Experience.*

At Peoria, Illinois, considerable success has been achieved in the replenishment of ground water by artificial recharge with Illinois River water (43, 44). This source of supply includes all of the sewage from the City of Chicago, but fortunately this wastewater now receives a high degree of treatment and conseqently the Illinois River at Peoria is in relatively good condition. Originally small test pits were used for experimental purposes, but in 1959 the Peoria Water complished at the University of Illinois on the adsorption and retention of alkylbenzenesulfonates (ABS) on granular media.

2.08 *U. S. Public Health Service, R. A. Taft Sanitary Engineering Center.*

Considerable laboratory research on percolation through soil systems has been conducted at the Robert A. Taft Sanitary Engineering Center of the USPHS in Cincinnati, Ohio. Much of this work has been summarized by Robeck et al. (45). On the basis of pilot-plant studies using septic-tank effluents and soil lysimeters, the following seven design parameters were suggested:

1. Start with a soil that has 0.5-1 percent organic matter, or at least an adsorptive additive to provide retention at an early stage.
2. Use a soil that has an effective size of about 0.1 to 0.3 mm to have low enough permeability.
3. Make the depth to ground water be at least 10 ft. (3 m).
4. Start with a 1 gallon per day per sq. ft. (0.04 cu. m./day/sq.m) loading, but increase a month later to 3 gallons per day per sq. ft. (0.1 cu. m./day/sq.m).
5. Apply wastewater three to six times per day.
6. Mix in a ½-inch (1.3 cm) transplant from another biologically active bed to insure early treatment.
7. Avoid starting at or under 40°F (4°C) unless an adsorptive additive is used on top of sand.

Robeck et al. feel that the above design factors will help effect a 90 to 95 percent reduction of ABS and other COD components as well as nearly complete removal of coliforms and polio virus from septic-tank effluents and protect the pollution of the receiving ground waters.

2.09 *Intermittent Sand Filter Practice Applicable to Surface Spreading.*

The design and application of intermittent sand filtration for sewage and industrial waste treatment are discussed extensively in sanitary engineering textbooks (46, 47, 48, 49). Presently the intermittent sand filter has been abandoned as a method of normal municipal sewage treatment because of the large areas occupied by the filters. However, when used properly the intermittent sand filter has been known to give consistently an extremely high-quality effluent of sparkling clarity.

0.04 cu.m./day/sq.m.) for septic tank effluents, 2 to 4 gpd/sq.ft. for settled sewage, and 10 gpd/sq.ft. for secondary effluents. Application at the rate of two doses per day is preferred.

Furman et al. (51) demonstrated quite dramatically the capabiltiy of obtaining better than 95 percent BOD removal through 18 and 30-inch sand beds of 0.25 and 0.31 mm sands when a loading increment was increased from once to twice per day. The improved performance was found over a range of loadings from 100 to 300 thousand gallons per acre per day (100,000 gallons per acre per day = 0.307 ft/day = 0.101 cu.m./day/sq.m.) for a settled sewage.

Calaway (52, 53) examined in detail the biology of a 30-inch experimental filter bed of the type used by Furman. Core samples from the surface and the 6-, 12-, 18-, 24-, and 30-inch depths were assayed. Zoogleal bacterial predominated at the surface and 6-inch levels with plate counts on the order of 10^{11} zoogleal bacteria per gram of sand. Below the 12-inch level zoogleal bacteria were appreciably reduced in number possibly owing to a lack of sufficient oxygen and reduced amounts of nutrient. Of the general heterotrophic bacteria at the heavier dosing rates, *Flavobacterium* was the most prevalent at the surface, 12- and 18-inch levels and the second most numerous bacterium at the 6-inch level. Its presence was not detected below the 18-inch depth. The genus *Bacillus* was most numerous at the 6- and 30-inch levels. At least one member of the genus *Alcaligenes* was found in all levels except the 6- and 30-inch depths. *Alcaligenes bookeri* was the most numerous organism of the 24-inch level and the second most numerous at the 18-inch level. Whereas total plate counts were of the order of 10^{11} organisms per gram of sand at the surface and 6-inch levels, the total counts became less than 10^7 organisms per gram of sand at greater filter depths. A 95-percent reduction in coliforms was observed in the percolate with the final filter effluent having about 10^4 presumptive coliforms per milliliter. The coliform content of the sand samples showed geometric mean concentrations of about 10^5 coliforms per gram of sand at the surface diminishing with depth to less than 10^3 coliforms per gram of sand at the 24-inch level. Fecal streptococci showed little change (only a 20-percent reduction) between the influent and effluent, having a geometric mean of about 2×10^3 organisms per milliliter. Sand extracts showed concentrations of 2×10^3 fecal streptococci per gram at the surface and less than 50 fecal streptococci per gram at the 30-inch level.

In general, Calaway concluded that increases in dosing rates resulted in increases in the bacterial population of the filter. Fourteen species of general heterotrophic bacteria were isolated from various levels of the filter with *Flavobacterium* and *Bacillus* predominating. At high rates *Flavobacterium* predominated, but at low dosing rates (150,000 gallons per acre per day) *Bacillus* exceeded *Flavobacterium*. Zoogleal bacteria exceeded in number the general heterotrophic bacteria. There was a decrease in count of all species of bacteria with depth, but the rates of decrease were not equal for all species. No relationship between the decreasing numbers of coliforms and fecal streptococci extracted from the sand at increasing filter depths and the decrease of organisms in the filtrate was established. Coliform organisms and fecal streptococci may play an important part in the rapid decomposition of carbohydrates found in sewage, owing to their continuous presence in the filter and great activity in carbohydrates under laboratory conditions.

2.10 *Whittier Narrows Study.*

In January 1963 a field study was initiated at Whittier Narrows, California, to study the quality changes in an activated-sludge effluent recharged into the ground by intermittent surface spreading. The results of the 27-month study are reported in detail in subsequent chapters of this report.

the topography called the Whittier Narrows. The Whittier Narrows separates the La Merced Hills from the Puente Hills. To the west, the La Merced Hills rise to over 600 feet above sea level, while on the east, the Puente Hills rise more sharply to about 1400 feet above sea level. Topographic relief is not extreme, however, since the ground-surface elevation at the Narrows is about 200 feet above sea level.

In addition to the surface drainage which is focused at Whittier Narrows, the subsurface ground-water flow from the San Gabriel Valley also passes through Whittier Narrows. To the north in the San Gabriel Valley, the depth to ground water may be several hundred feet below the ground surface. Because of normal faulting and the presence of impermeable igneous rocks, the ground-water flow is forced laterally and vertically to come near the surface at the Narrows where the depth to ground water may be only 10 feet below the ground surface. In fact, a condition of "rising water" is not uncommon adjacent to the lined Rio Hondo channel. A special unlined canal is maintained to direct this water south to the Rio Hondo Spreading Grounds.

A broad floodplain has been formed to the south where the Rio Hondo and San Gabriel rivers emerge from the Whittier Narrows. This area is known as the Montebello forebay. It forms the connection between the ground water in the San Gabriel Valley and the two large ground-water basins to the south, namely the Central Basin and the West Basin. Located in the Montebello forebay are the Rio Hondo and San Gabriel Spreading Grounds which are operated by the Los Angeles Flood Control District (see Figure 4-1. For many years water has been spread at these areas for the purpose of recharging ground-water aquifers in the Central and West Basins. Until the opening of the Whittier Narrows Water Reclamation Plant, the water used for recharge has been exclusively storm run-off and purchased Colorado River water. Recharge has been necessary in these basins because for many years the pumping of the ground water has exceeded the safe yield. This overdraft has resulted in a lowering of the ground-water table to such a degree that there has been sea-water intrusion into the formerly fresh-water aquifers for many miles along the Los Angeles coast.

3.02 *The Rio Hondo and San Gabriel Spreading Grounds.*

On both sides of the Rio Hondo channel are located spreading basins. The total available area at Rio dikes and an earth dam, water is ponded in the San Gabriel River channel and recharged into the groundwater system. During 1964 over 88,000 acre feet of Colorado River water were spread in the Montebello forebay. Similar or larger quantities of water have been spread each year since 1957 by the Los Angeles County Flood Control District. However, with increased demands for imported water it is not likely that such quantities of Colorado River water will continue to be available for ground-water recharge.

The Rio Hondo Spreading Grounds are divided into modules of about 10 acres each. These smaller basins are operated in a pattern of rotation such that a basin may be flooded for four days and then allowed to rest for eight to ten days. This method of intermittent loading has proved to be very satisfactory for the recharge of storm run-off and Colorado River water.

3.03 *The Whittier Narrows Water Reclamation Plant.*

In August 1962 the Los Angeles County Sanitation Districts released the first waters from its Whittier Narrows Water Reclamation Plant. This reclaimed water provides an additional source of supply for ground-water recharge in the Montebello forebay.

The Whittier Narrows Water Reclamation Plant and the plans of the Los Angeles County Sanitation Districts for additional water-reclamation plants are described in their recent report (3). The Whittier Narrows Water Reclamation Plant is located about one mile north of the Whittier Narrows Dam in the dam reservoir area (see Figure 4-1). Wastewater is directed into the plant from a trunk sewer which runs through the plant site parallel to Rosemead Boulevard. This sewer is the principal artery for wastewater disposal for the western half of the San Gabriel Valley. The wastewater is primarily of domestic origin and comes from an area where nearly 86 percent of the water supply is taken from ground water.

The plant was designed as a 10-million gallon per day (MGD) activated-sludge treatment plant but it has been operated successfully at rates of 14 MGD. There are no sludge-processing facilities at the plant, and all sludge from the plant is returned to the trunk sewer. In addition to the conventional secondary treatment, the Los Angeles County Sanitation Districts added a tertiary foam-fractionation or foam-separation unit in April 1963. This additional treatment was introduced in order to reduce the concentration of the synthetic detergent, alkyl benzene sulfonate (ABS), to less than 2 mg/l in the final plant effluent. By producing such an effluent, the

Sanitation Districts were able to satisfy the detergent criteria of the Regional Water Pollution Control Board without necessitating the purchase of natural water for dilution purposes.

Tables 3-1 and 3-2 summarize the chemical quality of the effluent from the Whittier Narrows Water Reclamation Plant as reported by the LACSD. The effluent is highly stabilized organically and it is lower than Colorado River Water in terms of its total dissolved solids. The requirements of the Regional Water Pollution Control Board No. 4 are also shown. Hexavalent chromium was a problem for a short period of time, but arrangements for treating or hauling away the strong chromium wastes of the isolated industrial sources have eliminated this problem.

Because of the successful operation of the plant at its current capacity, plans have been formulated for expanding the capacity. These plans have been described by Parkhurst (3).

Table 3-1—Summary of analyses of final effluent from Whittier Narrows Water Reclamation Plant * (17 April 1963–20 November 1963)

Determination	R.W.P.C.B. No. 4 requirement	Mean	Maximum	Minimum	No. of tests
General					
pH	--	7.4	7.9	7.1	14
Biochemical oxygen demand, mg/l					
Final effluent	--	3.5	6.2	1.6	6
Secondary effluent	--	18	25	11	7
Alkylbenzenesulfonate, mg/l	2.0	1.6	1.9	1.0	14
Ammonia, as N, mg/l	--	15.8	21.0	11.6	14
Total nitrogen, as N, mg/l	--	17.4	23.1	14.2	14
Total carbon, as C, mg/l	--	78	133	58	14
Total solids, mg/l	--	635	674	523	14
Suspended solids, mg/l	--	5	11	1	14
Dissolved solids, mg/l	1000	630	668	522	14
Electrical conductivity, micromhos/cm	--	990	1129	800	13
Major mineral analyses					
Total hardness, as $CaCO_3$, mg/l	--	190	208	155	14
Sodium, mg/l	--	136	148	112	14
Potassium, mg/l	--	19	23	12	14
Sodium equivalent ratio, %	60	58.0	62.9	54.2	14
Total alkalinity, as $CaCO_3$, mg/l	--	236	263	217	14
Chlorides, mg/l	--	110	124	52	14
Sulfates, mg/l	--	112	126	82	14
Chlorides plus sulfates, mg/l	500	222	248	171	14
Trace mineral analyses					
Arsenic, mg/l	0.05	0.01	0.03	0.00	14
Boron, mg/l	2.0	0.65	0.80	0.45	14
Chromium, hexavalent, mg/l	0.05	0.03	0.18	0.00	14
Copper, mg/l	3.0	0.10	0.20	0.04	14
Fluorides, mg/l	1.5	0.82	1.08	0.65	14
Lead, mg/l	0.1	0.04	0.32	0.00	14
Iron, mg/l	--	0.025	0.10	0.00	14
Iron plus manganese, mg/l	0.3	0.032	0.16	0.00	14
Manganese, mg/l	--	0.00	0.10	0.00	14
Phenols, mg/l	--	0.025	0.30	0.00	14
Selenium, mg/l	0.05	0.00	0.00	0.00	--
Zinc, mg/l	15	0.036	0.32	0.00	14

* From data supplied by Los Angeles County Sanitation Districts.

3.04 *Ground Water Recharge with Reclaimed Water.*

The effluent from the Whittier Narrows Water Reclamation Plant is spread in the Montebello forebay by the Los Angeles County Flood Control District. This water is purchased by the Central and West Basin Water Replenishment District from the Los Angeles County Sanitation Districts. Although the mineral quality of the effluent is excellent, the presence of residual organic solids, color, pin-point floc, and some microorganisms precludes direct reutilization. One of the objectives of the surface spreading operations of the Flood Control District is to provide a form of tertiary treatment. It has long been known that vertical percolation through the zone of aeration in soil and lateral movement beneath the ground-water table or in confined aquifers serve to purify water and stabilize it. Ground-water basins can be used effectively for water purification, trans-

Table 3-2—Summary of analyses of final effluent from Whittier Narrows Water Reclamation Plant * (8 January 1964–April 1965)

Determination	R.W.P.C.B. No. 4 requirement	Mean	Maximum	Minimum	No. of tests
General					
pH	--	7.85	8.05	7.20	17
Biochemical oxygen demand, mg/l					
Final effluent	--	5	10	1	18
Secondary effluent	--	27	46	7	2
Alkylbenzenesulfonate, mg/l	2.0	1.9	3.0	0.8	20
Ammonia, as N, mg/l	--	16.0	21.4	12.2	17
Total nitrogen, as N, mg/l	--	19.3	24.0	13.8	8
Total carbon, as C, mg/l	--	60	126	26	15
Total solids, mg/l	--	665	757	596	17
Suspended solids, mg/l	--	9	25	1	20
Dissolved solids, mg/l	1000	654	756	594	20
Electrical conductivity, micromhos/cm	--	1070	1243	908	17
Chemical oxygen demand, mg/l	--	45	66	30	9
Major mineral analyses					
Total hardness, as $CaCO_3$, mg/l	--	218	254	179	17
Sodium, mg/l	--	140	160	118	17
Potassium, mg/l	--	20.5	23.0	18.0	17
Sodium equivalent ratio, %	60	55.2	58.6	51.9	20
Total alkalinity, as $CaCO_3$, mg/l	--	238	273	200	15
Chlorides, mg/l	--	118	151	96	20
Sulfates, mg/l	--	139	156	111	20
Chlorides plus sulfates, mg/l	500	257	285	207	20
Trace mineral analyses					
Arsenic, mg/l	0.05	0.00	0.05	0.00	18
Boron, mg/l	2.0	0.70	0.95	0.46	20
Chromium, hexavalent, mg/l	0.05	0.05	0.14	0.00	17
Copper, mg/l	3.0	0.11	0.30	0.00	18
Fluoride, mg/l	1.5	1.0	1.54	0.60	18
Lead, mg/l	0.1	0.02	0.04	0.00	18
Iron, mg/l	--	0.06	0.32	0.00	17
Iron plus manganese, mg/l	0.3	0.08	0.32	0.00	17
Manganese, mg/l	--	0.02	0.20	0.00	18
Phenols, mg/l	--	0.005	0.009	0.001	20
Selenium, mg/l	0.05	0.00	0.00	0.00	--
Zinc, mg/l	15	0.08	0.21	0.00	18

* From data supplied by Los Angeles County Sanitation Districts.

portation, and storage; but they must not be polluted.

trict, the time may come when imported water is no longer available, and wastewater may constitute a major portion of the water available for spreading. At that time, knowledge obtained by test-basin studies will aid the spreading operations in getting good tertiary treatment as well as optimum hydraulic acceptance.

Table 3-3 is a summary of the volumes of Colorado River water, local water, and reclaimed water spread by the Los Angeles County Flood Control District in the Montebello forebay since the inception of this project.

Table 3-3—Summary of water spread in the Montebello forebay area * (January 1963–February 1965)

October	10,780	957	1,102	12,839
November	9,830	2,947	1,111	13,888
December	17,800	459	1,130	19,389
Totals for 1963	74,069	18,450	12,673	105,192
1964				
January	12,030	3,267	1,000	16,297
February	6,260	612	800	7,672
March	7,260	2,993	1,070	11,323
April	11,520	1,354	1,080	13,954
May	10,340	329	1,120	11,789
June	227	352	1,143	1,722
July	0	221	1,158	1,379
August	0	190	1,152	1,342
September	0	140	1,395	1,535
October	10,530	602	1,346	12,478
November	15,840	1,892	1,237	18,969
December	14,110	1,861	1,095	17,066
Totals for 1964	88,117	13,813	13,596	115,526
1965				
January	20,239	800	1,082	22,121
February	11,090	577	1,022	12,689
Grand totals	193,515	33,640	28,373	255,528

* Information supplied by the Los Angeles County Flood Control District.

CHAPTER 4

FIELD SPREADING BASIN INVESTIGATIONS

4.01 *Sites for the Field Spreading Basins.*

Two sites were selected by Caltech and the Los Angeles County Flood Control District for the construction of small spreading basins. The first site, herein called the Whittier Narrows Test Basin, is located north of the Whittier Narrows Dam in the dam reservoir area. This test basin is situated south of Durfee Road about 250 feet west of the outlet pipe from the Whittier Narrows Reclamation Plant. In November 1963 the pipeline from the plant was extended from Durfee Road to the San Gabriel River channel. At the Durfee Road outlet it is possible to divert the flow from the pipeline into an open ditch in which it may flow to the Zone-1 bypass ditch. The Zone-1 bypass ditch connects the San Gabriel River channel with the Rio Hondo River channel and permits the diversion of surface water from the San Gabriel River to the Rio Hondo River. A second test basin site was chosen within the Rio Hondo Spreading Grounds of the Los Angeles Flood Control District. This test basin is called the Rio Hondo Test Basin.

The selection of the site for the Whittier Narrows Test Basin was predicated on its closeness to the point of discharge of undiluted plant effluent. The spreading areas downstream from the Whittier Narrows Dam receive other waters in addition to the plant effluent, namely collected storm runoff water and Colorado River water purchased for ground-water basin recharge. Except for rainfall, the only water introduced into the Whittier Narrows Test Basin has been effluent from the Whittier Narrows Water Reclamation Plant.

The site within the Rio Hondo Spreading Grounds was chosen as being representative of the soil in the spreading grounds. It is also an isolated area to which regulated amounts of water can easily be diverted without interference with the main operation of the Rio Hondo Spreading Grounds. The water introduced into the Rio Hondo Test Basin is representative of the water in the main spreading grounds. Over the first nineteen months of the operation of the basin, the waters diverted into the site varied from almost undiluted effluent to effluent diluted nearly ten times with Colorado River water and collected storm runoff.

Figure 4-1 shows the location of the Whittier Narrows Test Basin and the Rio Hondo Test Basin. Figures 4-2 and 4-3 are photographs of the test basin sites. A soil profile for each of the test basins is given in Figures 4-4 and 4-5. This information was obtained from the Los Angeles County Flood Control District. The soil profiles at each location are quite different. Up to the date of installation of the spreading basin at the Whittier Narrows site, the land was used for farming. Consequently there was an abundance of organic material in the soil to a depth of nearly 2 feet at Whittier Narrows. There are also thin, discontinuous layers of silt and micaceous material at the Whittier Narrows site which indicate the non-homogeneity of the soil and a probable anisotropic condition for the hydraulic permeability. At Whittier Narrows the water table is quite shallow, being only about 9 feet below the ground surface. The soil profile at the Rio Hondo site presented in Figure 4-5 shows the soil to be very homogeneous and to be composed mainly of a fine to medium sand. Sieve analyses on three samples taken from the Rio Hondo site indicate the uniformity of the soil with depth as shown in the following tabulation:

Depth Below Ground Surface (ft.)	D_{50}(mm)	σg	D_{10}(mm)	U.C.
10	0.275	1.68	0.135	2.29
14.5	0.310	1.84	0.142	2.40
16	0.290	1.70	0.140	2.38

D_{50} is the geometric mean sieve diameter by weight; σg is the geometric standard deviation of the sieve diameters; D_{10} is the effective size; and U.C. is the uniformity coefficient.

Figure 4-5 shows that the depth to the water table at the Rio Hondo test basin site is about 16 feet below the ground surface. This depth is nearly twice the depth to the water table at Whittier Narrows.

4.02 *Construction of the Basins*

The construction of the two test basins was done by the Los Angeles Flood Control District with funds provided by Caltech under this project grant. Each of the basins is similar in that there is a central well with four sampling pans located at depths of 2, 4, 6, and 8 feet below the ground surface. Figure 4-6 shows the design of these wells.

a. *Whittier Narrows Test Basin:* Construction began on 6 December 1962 at a site near the mid-point of the ditch which connects the outlet pipe from the Whittier Narrows Reclamation Plant to the Zone-1 bypass ditch. Ground water was reached at a depth of about 6.5 feet below the basin bottom. Because this high water table would interfere with the operation of the sampling pans, the construction site was restored and abandoned. A new location was chosen about 200 feet west of the ditch and construction of the Whittier Narrows Test Basin was begun again on 14 December 1962.

The basin is 50 feet by 70 feet with 2-foot high levees and a basin bottom grade of 210.50 feet. The ditch was connected to the basin by 186.5 feet of 10-foot wide canal. However, on 26 March 1963 this inlet canal was replaced with an 18-inch diameter corrugated metal pipe.

The sampling well is located at the center of the basin and access is provided from the levee to the well by a 2-foot high and 4-foot wide wooden foot bridge. A Caldwell drilling rig was used to excavate a 60-inch diameter hole into which was placed a 48-inch diameter corrugated metal pipe which is the sampling well.

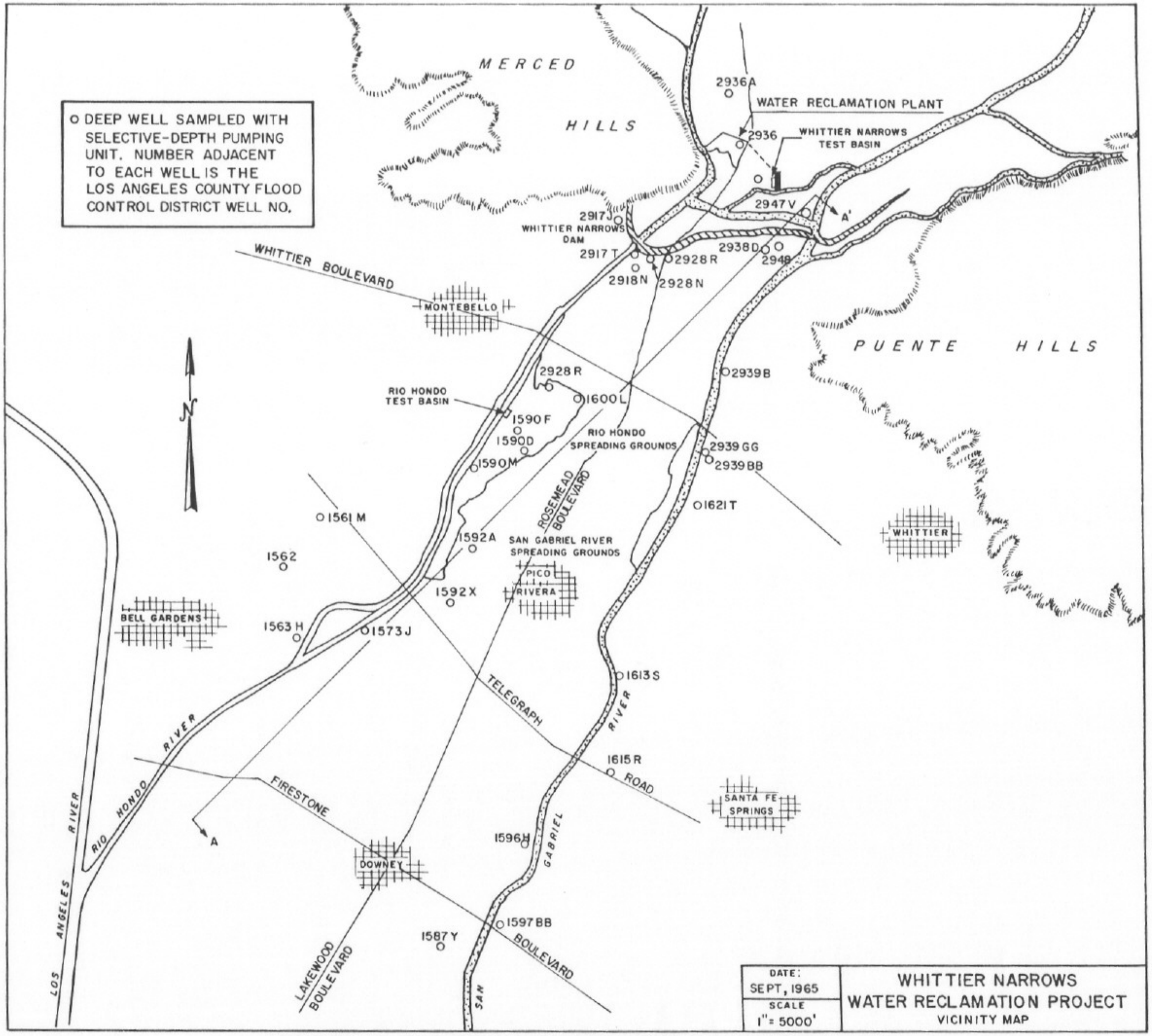

Fig. 4-1—Vicinity Map for the Whittier Narrows Water Reclamation Project

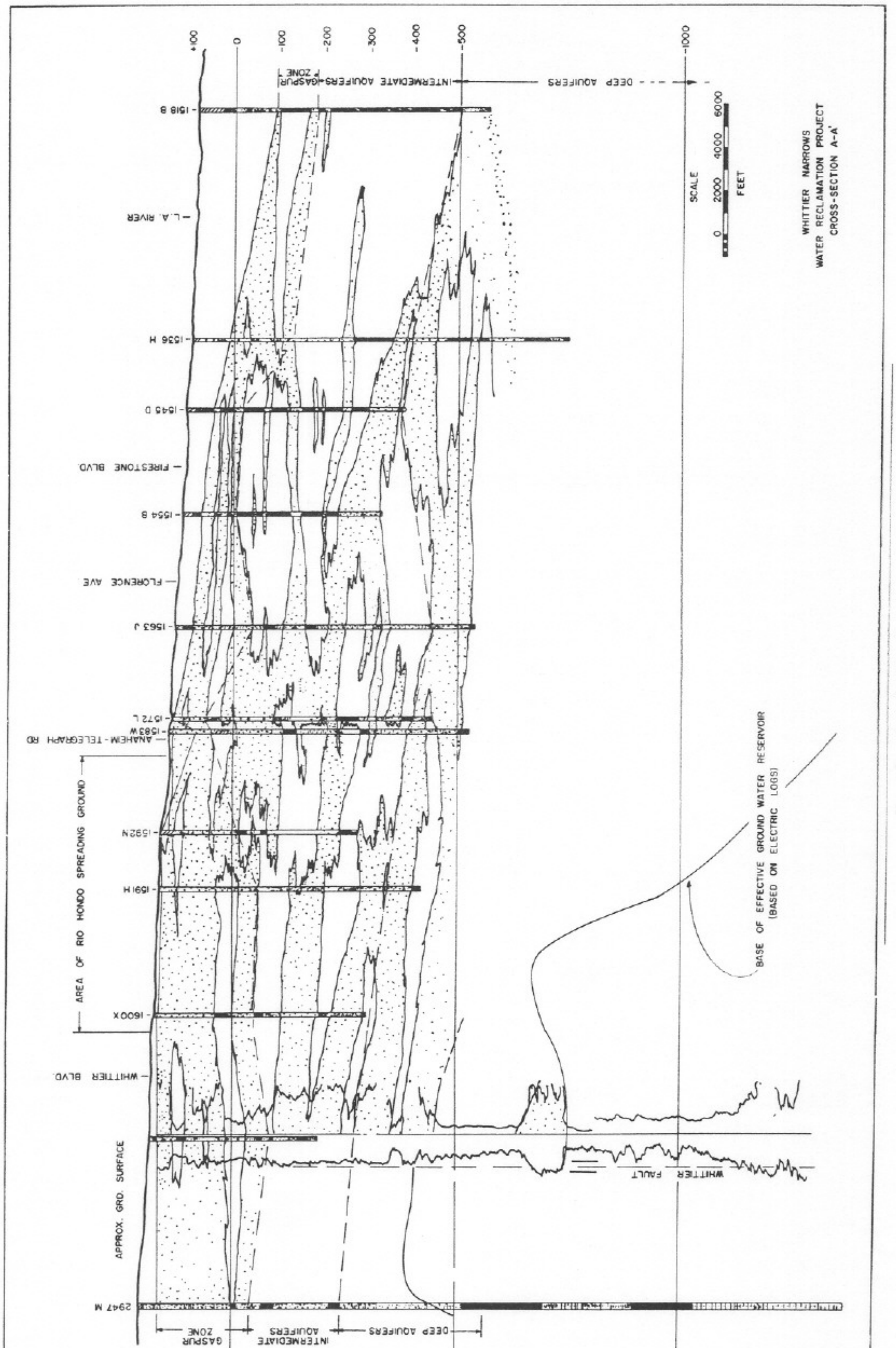

Fig. 4-1a—Cross-Section A-A'

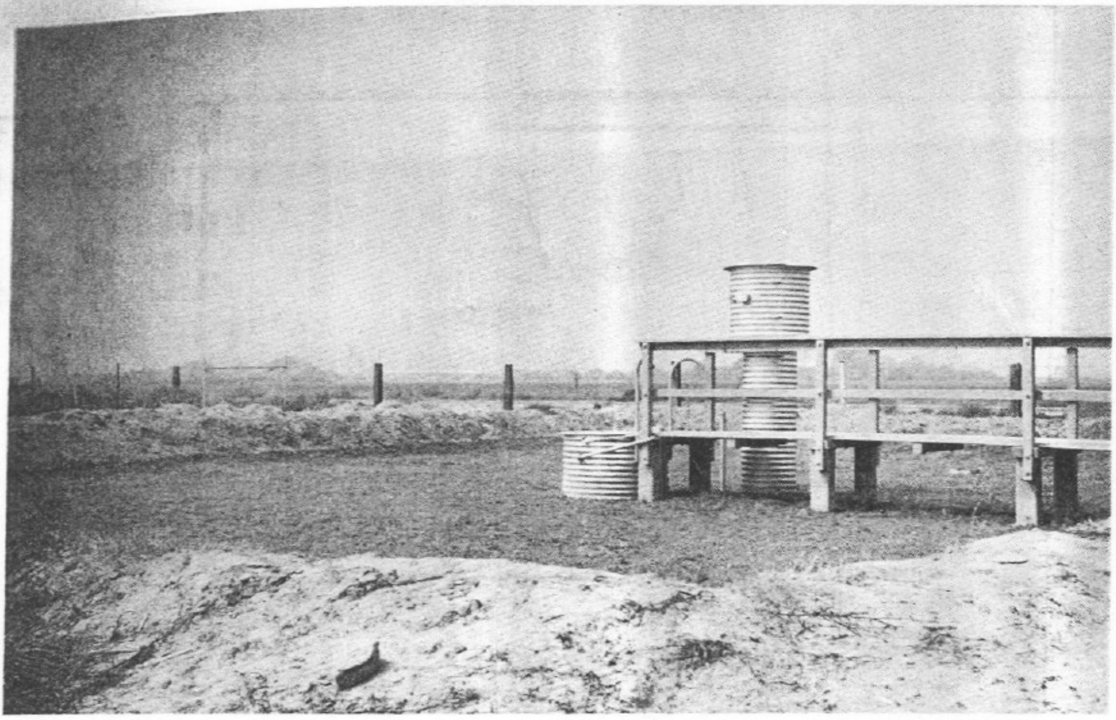

Fig. 4-2—Photograph of the Whittier Narrows Test Basin

Fig. 4-3—Photograph of the Rio Hondo Test Basin

The water table was at 9.5 feet below the ground surface at the time of installation of the well. A 2-foot concrete slab footing was poured inside the well below the water table, and a 12-inch concrete collar was placed around the central well at a depth of 4 feet below the basin bottom. To stop leakage into the well, a thin luminate cement coating was placed on the concrete floor. Airplane matting was used for flooring.

A separate excavation was made for each of the sampling pans using the Caldwell drilling rig. The trenches in which the pipes connecting the sampling pans to the central well were placed also were dug with the Caldwell rig. The sampling pans have a conical shape, being 24-inches in diameter at the top and 9 inches deep. They are made of 12-gauge sheet metal and are coated with an epoxy resin paint. The tops of the sampling pans are located at 2, 4, 6, and 8 feet below the basin bottom. For the 2, 6, and 8-foot pans, a 42-inch diameter hole was drilled. A ¼-inch to ¾-inch gravel packing was provided below and around the sides of these pans with the gravel filled to the extremities of the 42-inch diameter excavation. The gravel fill extends slightly above the sides of each pan and to a depth of about one foot below the pan bottom. The excavation for the 4-foot sampling pan was a 36-inch diameter hole drilled with the Caldwell rig. This pan was also surrounded with a gravel fill. Each of the sampling pans was selectively filled with sand and gravel starting at the bottom of the cone with a 3-inch layer of ¼-inch to ¾-inch gravel, then a 3-inch layer of #30 sand and ¼-inch gravel, and a final 3-inch layer of Ottawa sand. Backfill over the pans was placed by hand and compacted by foot. The fill over the trenches was placed and compacted with a skip loader. After backfilling, the basin bottom was scarified.

The four sampling pans were placed 60 degrees apart on a semi-circle with a radius of 15 feet from the center of the central well. A ¾-inch I. D. Tygon tubing was drawn through 1¼-inch galvanized iron pipe and a seal provided at the pan between the pipe and tubing with Johns-Manville Mastic. The pipe protrudes 7 inches inside the central well and has a 90-degree elbow at its end. All seams and connections at the central well were made watertight.

A ladder provides access up and down the central well.

b. *Rio Hondo Test Basin:* Construction of this basin began on 9 January 1963 at the site of an old intake canal to the Los Angeles County Flood Control District Rio Hondo Spreading Grounds. The sides of the canal form two sides of the basin, but two additional levees were constructed to close the basin on four sides. This basin is 109 feet by 32 feet and the basin is graded so that the bottom has an elevation of 160.5 feet.

The Caldwell drilling rig was used for the 60-inch diameter excavation for the central well. Because of the greater depth to ground water at this site, the central well was provided with a drain in the floor to make the well self-draining. At the bottom of the well 12 inches of ¼-inch to ¾-inch gravel bedding was placed leaving 6 inches of clear distance between the gravel and the well bottom. A concrete floor with collar was placed at the bottom of the well and airplane matting was used for flooring.

The excavation and trenching for the 8-foot sampling pan was done with the Caldwell drilling rig. Excavation for the other sampling pans was done with the Caldwell unit but the trenching for these pans was done by hand. The same type of sampling pans, pipe, and tubing was used at this site as was used at the Whittier Narrows Test Basin. A 3-foot diameter gravel packing was used for all four pans. Seals at both ends of the pipe connecting the pans with the well were made by packing with plumber's

Geologic Soil Profile at the Whittier Narrows Test Basin *

Depth below surface (feet)	Unit thickness (ft.-in.)	From (ft.-in.)	To (ft.-in.)	At (ft.-in.)	Description
0–	1′ 10″	0	1′ 10″	0	Dark brown very fine to medium silty sand and soil.
2–	2′ 2″	1′ 10″	4′	1′ 10″	Light brown to tan fine to medium sand with lenses of gray fine sand. Moist, oxidized, orange fine sand streaks are common in tan portion.
4–	1′ 6″	4′	5′ 6″	4′	Wood fragments up to 3 in. long in dark brown to black medium to fine sand. Sand is highly micaceous.
6–	2′ 2″	5′ 6″	7′ 8″	5′ 6″	Tan fine to medium soft, micaceous sand, with gray fine sand lenses. Tan portions commonly show orange streaks of oxidized fine sand.
8–	4″	7′ 8″	8′	7′ 8″	Dark brown to black micaceous fine sandy silt stringer.
10–	1′ 6″	8′	9′ 6″	8′	Gray medium to coarse sand.
				8′ 6″	Gray medium to coarse sand and "pea gravel" with occasional gravels to ⅜ in.

* Soil profile taken on 27 December 1962. Information supplied by the Los Angeles County Flood Control District.

Fig. 4-4—Soil Profile at Whittier Narrows Test Basin

Geologic Soil Profile at the Rio Hondo Test Basin *

Depth below surface (feet)	Unit thickness (feet)	From (feet)	To (feet)	At (feet)	Description
0–					
	11	0	11		Tan fine to medium sand.
2–					
				3	Gray fine sand.
				3.5	Gray to tan medium sand.
4–					
				4	Occasional pebble.
6–					
				7	Trace of orange streaks.
8–					
				8.5	Micaceous material.
10–					
12–	3.5	11	14.5		Tan medium to coarse sand with ½ inch pebbles.
				12	Light orange color with pebbles.
				12.5	A few gravels to 2 inches.
				13.5	Occasional clay ball.
16–	2	14.5	16.5		Tan-gray medium sand. Water level at 16 feet.

* Soil profile taken on 11 December 1962. Information supplied by the Los Angeles County Flood Control District.

Fig. 4-5—Soil Profile at the Rio Hondo Test Basin

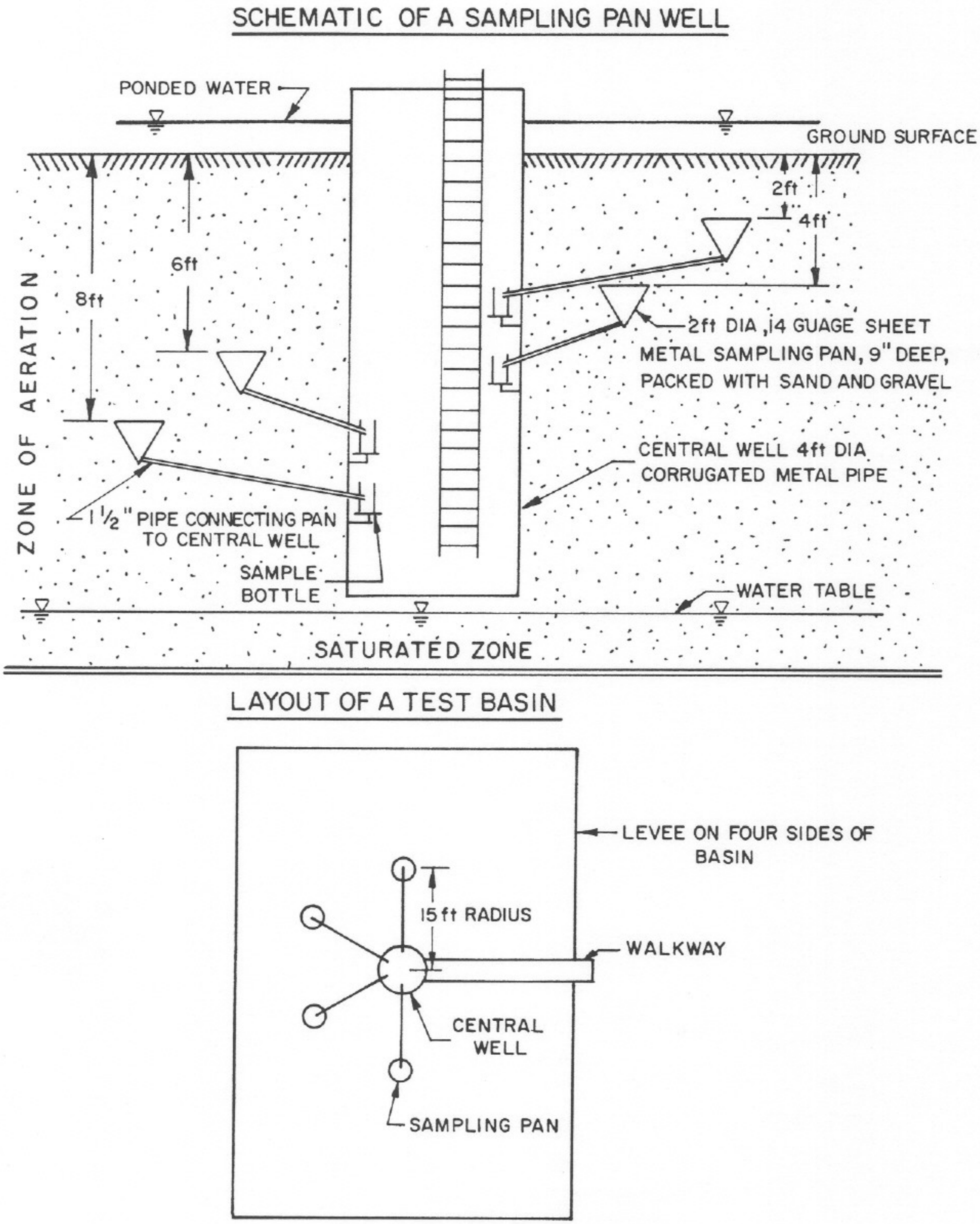

Fig. 4-6—Schematic of a Sampling Pan Well

rope oakum and sheet metal putty and then caulking with bathroom tile plastic caulking compound.

Backfill over the pans was placed in 3-foot lifts and compacted by jetting and tamping. Each lift was tested for proper compaction. The backfill over the trenches was compacted by jetting and normal travel of equipment, but was not tested for compaction.

A ladder was provided within the central well for access to the pipes connecting the pans to the central well. A wooden walkway provides access from the levee to the well.

In March 1963 stage recorders were installed at each of the test basin sites thus permitting a more accurate measurement of the volume inflow to the basins and the infiltration rate of the ponded water into the soil. At the Whittier Narrows Test Basin site seven 2-inch diameter piezometer wells were installed in the neighborhood of the test site when the basin was constructed. These wells enable one to determine any change in the level of the ground water table in the vicinity of the test site. A 2-inch diameter piezometer well is also located in the central well at the Rio Hondo Test Basin.

4.03 *Operation of the Test Basins.*

The first water was diverted into the Whittier Narrows Test Basin on 27 December 1962 and into the Rio Hondo Test Basin on 22 January 1963. Initially, the method of operation of each basin was intended to be identical with only the quality of the water received at each basin and the soil being different. The basins were to be flooded intermittently so that the soil would alternate between being wet and dry and so that air could enter the interstices of the soil. It is generally believed that the hydraulic acceptance for ponded water is better for a spreading basin which is flooded intermittently compared to one which is flooded continuously. Besides being concerned with basin hydraulics, it is the primary intention of this project to operate the test basins in the manner of a tertiary treatment operation. With this goal in mind, it is desired that the soil between the ground surface and the water table remain aerobic. This condition is best maintained if this soil system is not allowed to become saturated with water for an extended period of time. Maintaining an aerobic condition in the soil permits a rapid stabilization of the organic compounds present in the reclaimed water and furthermore an aerobic condition has been found to be mandatory for the removal and degradation of such refractory compounds as the synthetic detergents.

Tables 4-1 and 4-2 show the volumes of water applied to each test basin. The amounts of water are reported in units of cubic feet and cubic meters and were obtained from weir height or pump discharge measurements. Stage recorders were installed at the test basin sites in March 1963. Before that time measured volumes of water applied to the basins were not as accurately known. For each month, the total volume of water spread is reported as well as the average hydraulic load which is simply the total volume of water divided by the number of calendar days divided by the basin area. Also included in the tables are the average measured infiltration rates. These rates are based on the measured change in the water surface elevation for the ponded water in each basin and were determined either from readings on a staff gauge or from the chart of a stage recorder.

Tables 4-3 and 4-4 list the methods of operation carried out at the test basins. The nominal depth of flooding is the intended depth of the ponded water for each flooding, namely, the total volume of water diverted into the test basin divided by the basin area. The nominal frequency of flooding is also an intended value rather than the actual frequency of basin loading, that is, it represents the intended or strived for loading pattern. The number of days flooded represents the actual number of times in a month that water was diverted into the basin. Also reported is the average basin drying time. This number is the average of the measured times for the basin surface to become free of ponded water. It is measured from the time the discharge to the basin is stopped. Normally at the loadings reported it takes about a half hour to flood a basin to its nominal depth.

For the first four months of operation, January–April 1963, it was intended to flood the basins to a nominal depth of one foot each day. However, numerous problems were encountered, the principal one being the failure of the basin bottom to dry out and be free of ponded water in the interval between floodings. Near the end of February 1963, the nominal loading was cut back to 0.5 foot daily. Some experimenting with operations at the Whittier Narrows Treatment

Table 4-1—Hydraulic data for operation of Whittier Narrows Test Basin

Date	Volume of water applied		Average hydraulic load[1]	Average rate of infiltration[2]	
	Cu. ft.	Cu. m.	[1]M/day	[2]M/day	[2]Ft./day
January 1963*	100,450	2,844.7	0.244	0.424	1.45
February	65,170	1,845.6	0.204	0.381	1.25
March	34,810	985.8	0.098	0.320	1.05
April	25,528	723.0	0.074	0.223	0.73
May	22,229	629.5	0.063	0.180	0.59
June	15,026	425.5	0.044	0.375	1.23
July	28,369	803.4	0.080	0.467	1.53
August	27,211	770.6	0.077	0.543	1.78
September	16,979	480.8	0.049	0.665	2.18
October	19,637	556.1	0.055	0.525	1.72
November	19,175	543.0	0.056	0.503	1.65
December	24,001	679.7	0.068	0.522	1.71
January 1964	25,376	718.6	0.072	0.485	1.59
February	23,902	676.9	0.072	0.866	2.84
March	34,792	985.3	0.098	0.872	2.86
April	35,142	995.2	0.012	0.961	3.15
May	41,759	1,182.6	0.117	1.034	3.39
June	61,055	1,729.1	0.178	1.211	3.98
July	87,913	2,489.7	0.248	1.470	4.82
August	101,516	2,874.9	0.286	1.585	5.20
September	97,207	2,752.9	0.283	1.512	4.96
October	105,341	2,983.2	0.297	1.491	4.89
November	100,456	2,844.9	0.293	1.375	4.51
December	109,462	3,100.1	0.308	1.293	4.24
January 1965	111,496	3,157.6	0.314	1.308	4.29
February	122,328	3,464.3	0.382	1.323	4.34
March	135,556	3,838.9	0.382	1.418	4.65
Totals	1,591,886	45,081.9			
Means	58,959	1,669.7	0.168	0.865	2.84

[1] Average hydraulic load equals total volume of water applied during the month divided by number of days in the month divided by the surface area of the basin. Basin area = 3,500 sq.ft. = 324.1 sq.m.

[2] Average infiltration rate is the arithmetic mean of measured rates of decline of the water surface of the ponded water in the test basin.

* January 1963 includes data since 27 December 1962, so this month is considered to have 36 days.

Plant resulted in an increase in discharge to greater than 13.5 million gallons per day. The suspended solids in the effluent rose to as high as 30 mg/l, and a sludge covering about one-sixteenth of an inch thick was formed on the basin bottom at Whittier Narrows. Flooding operations were stopped at Whittier Narrows and the basin allowed to dry between 27 February and 12 March 1963. The basin was releveled and disked. Spreading operations began again on 12 March 1963 at the Whittier Narrows Test Basin at the nominal loading of 0.5 foot each day. Anticipating the change at Whittier Narrows, the flooding of the Rio Hondo Test Basin was cut back on 23 February 1963.

During the month of March 1963, flow from the sampling pans at Whittier Narrows was quite erratic. Leaks developed between the ¾-inch tubing and the 1¼-inch pipes which connect the pans to the well. From 30 March to 8 April 1963, 2, 4, and 6-foot sampling pans were exposed for repairs. These pans were repainted with an epoxy paint, the leaks sealed, and the pans filled again with graded material. When flooding was started again on 9 April 1963, it was apparent that the upper one-foot of soil was excessively compacted. The soil was excavated and recompacted to a depth of about one foot over the area of the sampling pans and pan flow began to improve by the end of April 1963.

From the middle of April to the middle of May 1963, the flooding schedule of loading the beds each afternoon was maintained, but the volume of water for each loading was again reduced. Some problems of weed growth, algae growth, and a general decline in infiltration rates caused a change in basin operation. After disking the surfaces of each basin to a depth of several inches, the schedule of basin flooding was changed to loading each basin on only three days each week, namely on Monday, Wednesday, and Friday, to a nominal depth of 0.6 foot. This allowed a basin to dry for about a day and a half between floodings. This schedule permitted nearly continuous operation without stoppage from 17 May 1963 through January 1964. Infiltration rates increased, and the volume of flow from the 2, 4, and 6-foot sampling pans at each basin was satisfactory for analyses. Flow from the 8-foot sampling pan remained erratic and was frequently too small to provide an adequate sample for analysis.

Table 4-2—Hydraulic data for operation of Rio Hondo Test Basin

Date	Volume of water applied		Average hydraulic load[1]	Average rate of infiltration[2]	
	Cu. ft.	Cu. m.	[1]M/day	[2]M/day	[2]Ft./day
January 1963*	29,600	838.3	0.260	0.580	1.90
February	44,439	1,258.5	0.139	0.592	1.94
March	47,770	1,352.8	0.135	0.561	1.84
April	43,585	1,234.3	0.127	0.265	0.87
May	30,045	850.9	0.085	0.217	0.71
June	26,803	759.1	0.078	0.430	1.41
July	29,929	847.6	0.085	0.586	1.92
August	28,704	812.9	0.081	0.604	1.98
September	15,120	428.2	0.044	0.454	1.49
October	21,666	613.6	0.061	0.302	0.99
November	23,523	666.2	0.069	0.278	0.91
December	26,478	749.9	0.075	0.186	0.61
January 1964	29,180	826.4	0.083	0.140	0.46
February	66,914	1,895.0	0.202	0.702	2.30
March	158,571	4,490.7	0.448	0.726	2.38
April	161,851	4,583.6	0.473	1.513	4.96
May	114,818	3,251.6	0.325	0.586	1.92
June	31,902	903.5	0.093	0.387	1.27
July	80,243	2,272.5	0.226	0.326	1.07
August	33,500	948.7	0.095	0.393	1.29
September	87,608	2,481.0	0.256	0.604	1.98
October	40,162	1,137.4	0.116	0.497	1.63
November	64,943	1,839.2	0.190	0.351	1.15
December	29,643	839.5	0.084	0.393	1.29
January 1965	8,421	238.5	0.024	0.389	1.27
February	19,886	563.2	0.062	0.617	2.03
March	59,255	1,678.1	0.168	0.616	2.02
Totals	1,354,559	38,361.2			
Means	50,169	1,420.8	0.111	0.492	1.61

[1] Average hydraulic load equals total volume of water applied during the month divided by the number of days in the month divided by the surface area of the basin. Basin area = 3,488 sq.ft. = 323.0 sq.m.

[2] Average infiltration rate is the arithmetic average of measured rates of decline of the water surface of the ponded water in the test basin.

* Basin operation began on 22 January 1963, so this month has only 10 days.

The period of operation of three floodings per week was maintained fairly continuously. There were some shut-downs for weed removal and scarifying of the basin bottoms, but generally the pattern worked quite well. Because of the regularity of the changes in water quality observed with depth at each basin (these results will be presented later in this chapter), it was decided in January 1964 to increase the hydraulic load on each of the test basins. At the Whittier Narrows Basin the loading was maintained at three floodings per week, but the nominal flooded depth was gradually increased 0.6 to 1.4 feet. The limit of 1.4 feet reached in June 1964 was due to the low height of the levees surrounding the basin.

In July 1964, it was decided to increase the loading of the Whittier Narrows Test Basin. The new pattern was chosen at five days per week, each Monday through Friday with the weekend idle. To start, a nominal depth of flooding of 1.0 foot was chosen. The nominal depth of flooding has been increased

Table 4-3—Method of operation of Whittier Narrows Test Basin

Date	Nominal depth of flooding (feet)	Nominal frequency of flooding	Number of days flooded	Average drying time† (hours)
January 1963*	1.0	Every day	36	▴
February	1.0	Every day	19	▴
March	0.5	Every day	15	▴
April	0.25–0.5	Every day	21	▴
May	0.6	Mon., Wed., Fri.	17	▴
June	0.6	Mon., Wed., Fri.	8	12.5
July	0.6	Mon., Wed., Fri.	14	11.8
August	0.6	Mon., Wed., Fri.	13	9.5
September	0.6	Mon., Wed., Fri.	8	8.3
October	0.6	Mon., Wed., Fri.	9	10.3
November	0.6	Mon., Wed., Fri.	9	10.0
December	0.6	Mon., Wed., Fri.	12	9.0
January 1964	0.6	Mon., Wed., Fri.	12	11.0
February	0.6–0.8	Mon., Wed., Fri.	10	▴
March	0.8	Mon., Wed., Fri.	13	▴
April	0.8	Mon., Wed., Fri.	13	6.5
May	0.8–1.2	Mon., Wed., Fri.	13	6.5
June	1.4	Mon., Wed., Fri.	13	8.0
July	1.0	Mon., Tu., Wed., Th., Fri.	21	6.2
August	1.0–1.2	Mon., Tu., Wed., Th., Fri.	20	4.9
September	1.2–1.4	Mon., Tu., Wed., Th., Fri.	22	5.8
October	1.4–1.6	Mon., Tu., Wed., Th., Fri.	21	6.9
November	1.6	Mon., Tu., Wed., Th., Fri.	20	8.1
December	1.6	Mon., Tu., Wed., Th., Fri.	20	8.8
January 1965	1.6–1.8	Mon., Tu., Wed., Th., Fri.	20	9.1
February	1.8	Mon., Tu., Wed., Th., Fri.	20	10.1
March	1.8	Mon., Tu., Wed., Th., Fri.	22	9.2

* January 1963 includes data since 27 December 1962.

† Drying time is time for the basin surface to become free of ponded water after each flooding.

▴ No measurements made.

gradually (after an increase in levee height in November 1964) to the maximum allowable height to avoid overtopping the new levee at 1.8 feet.

A significant improvement in basin maintenance and operation was caused at Whittier Narrows in February 1964 with the application of a six-inch layer of pea gravel to the basin bottom. Weed growth which has become a monthly maintenance problem was reduced to a minor problem with only an occasional plant to be removed.

When the increased loading was started at Whittier Narrows in February 1964, it was decided to change the pattern at the Rio Hondo Basin to the schedule of continuous flooding at a constant depth of about 2 feet for a period of 6 to 8 days and then to let the basin dry out and be idle for about 14 days. This pattern of a 2 to 1, dry-to-wet cycle is currently practiced for the operation of the main spreading basins at the Rio Hondo Spreading Grounds. It is a good pattern for the operation of the large 10-acre basins which receive predominantly Colorado River water with some storm flow and reclaimed water. An error in the flooding depth occurred during the months of April and May 1964. The nominal depth reached 3.0 feet and a significant increase in the volume of water spread was observed. However, the main observation for this site was that the infiltration began to decrease with time so that the accumulative hydraulic load to the basin was not being maintained at its previous rate. In January 1965, it was decided to change the loading at the Rio Hondo site to the pattern used at Whittier Narrows, namely five days per week with the weekend idle. After three months of operation, apparently the basin is begining to regain its capacity for hydraulic acceptance.

Table 4-4—Method of operation of Rio Hondo Test Basin

Date	Nominal depth of flooding (feet)	Nominal frequency of flooding	Number of days flooded	Average drying time† (hours)
January 1963*	1.0	Every day	8	[a]
February	1.0	Every day	16	[a]
March	0.5	Every day	26	[a]
April	0.25–0.5	Every day	28	[a]
May	0.6	Mon., Wed., Fri.	21	[a]
June	0.6	Mon., Wed., Fri.	12	14.0
July	0.6	Mon., Wed., Fri.	13	8.5
August	0.6	Mon., Wed., Fri.	13	6.8
September	0.6	Mon., Wed., Fri.	8	11.5
October	0.6	Mon., Wed., Fri.	10	14.8
November	0.6	Mon., Wed., Fri.	11	18.0
December	0.6	Mon., Wed., Fri.	12	[a]
January 1964	0.6	Mon., Wed., Fri.	13	[a]
February	2.0	Continuous flooding for about 6 days with water depth held constant, then basin allowed to dry out for about 14 days	10	--
March	2.0		10	--
April	2.0–3.0		10	--
May	2.0		12	--
June	2.0		7	--
July	2.0		14	--
August	2.0		7	--
September	2.0		14	--
October	2.0		7	--
November	2.0		13	--
December	2.0		7	--
January 1965	0.1–0.5	Mon., Wed., Fri.	12	10.7
February	0.3–0.5	Mon., Tu., Wed., Th., Fri.	19	6.0
March	0.5–0.9	Mon., Tu., Wed., Th., Fri.	22	12.0

* Basin operation began 22 January 1963.

† Drying time is time for the basin surface to become free of ponded water after each flooding.

[a] No measurements made.

4.04 *Collection of Samples.*

All samples were collected by personnel of the Los Angeles County Flood Control District. Samples for chemical and bacteriological analyses were taken from all sampling points about once a week. Each time a basin was flooded, a surface grab sample was collected. These daily surface grab samples were composited. A separate surface grab sample was taken on the afternoon prior to the delivery of the samples to Caltech. At this time at each sampling point in the central well a one-gallon PVC bottle was placed. The water received from each sampling pan would fill the PVC bottle and overflow out the top. On the following morning, if there was enough water in a bottle, a one-liter sample was poured into another one-gallon PVC bottle and acidified with about 0.8 ml of concentrated sulfuric acid. This acidified sample was the sample to be analyzed for the nitrogen components.

If the sampling pipes were still flowing water in the morning, a sample for coliform analysis was also collected in a sterilized 100-ml bottle containing sodium thiosulfate as the dechlorinating agent. Samples at this time were also taken for analysis for dissolved oxygen. The dissolved oxygen samples were analyzed immediately by the Los Angeles County Flood District. Measurements of pH and water temperature were also made at this time.

The one-gallon samples for general chemical analysis, the one-liter samples for analysis of the nitrogen components, and the samples for coliform analysis were delivered to Caltech where they arrived by 10 or 11 o'clock that morning.

4.05 *Chemical Analysis.*

The samples of surface water and percolated water from the sampling-pan wells were analyzed at Caltech for alkyl benzene sulfonate (ABS), the nitrogen components (nitrite, nitrate, ammonia and organic nitrogen), total dissolved solids (TDS), total volatile solids (TVS), chemical oxygen demand (COD), biochemical oxygen demand (BOD), and chlorides.

The tests for the nitrogen components, COD, and BOD were set up immediately upon receiving the samples. The other chemical tests were completed as soon as possible thereafter.

The methods of analysis used for TDS, TVS, chlorides (mercuric nitrate), BOD, nitrite, and nitrate (brucine) are those given in the Eleventh Edition of "Standard Methods for the Examination of Water and Wastewater." The method of analysis for the chemical oxygen demand is the Standard Methods technique without the use of the silver sulfate catalyst. Prior to May 1964, the chloride correction applied to the COD was on the basis of the measured chloride concentration. After May 1964 a mercury sulfate catalyst was added to the COD test reagents and no chloride correction was made. The method of analysis for organic nitrogen and ammonia (total minus three oxidation number nitrogen) is a microanalytical Kjeldahl method utilizing a copper sulfate catalyst with final ammonia determination by Nesslerization. No determination of either component is made separately. The determination of the ABS is done by the methylene-blue procedure recommended by the United States Public Health Service Analytical Research Service.

4.06 *Summary of the Hydraulic Measurements.*

A summary of the hydraulic data collected over the 27 months of this test is presented in tabular and graphical form in Tables 4-5 and 4-6 and Figures 4-7 to 4-10.

On the basis of the hydraulic operation and other factors, it is convenient to divide the history of the test basins into four periods. The nature of these divisions is presented in Table 4-5. For the first two periods both test sites were operated in identical fashion. Period I is the time of "break in" during which many of the operational problems described in the previous sections of this chapter were encountered. During this period, the test basins were nominally flooded for part of each day. Period II is characterized by a nominal flooding pattern of three loads per week. This schedule was maintained with a good deal of regularity for nine months. Also at the end of Period I, the Whittier Narrows Treatment Plant introduced a foam separation unit as a form of tertiary treatment. Either foaming or the addition of a foam suppressor has been utilized since then until the present.

Period III represents two distinct and different operational patterns for the test basins. At the Whittier Narrows Test Basin, the nominal frequency of three loads per week was maintained, but the loading was gradually increased from 0.6 to 1.4 feet per load. In August 1964, it was recognized that the hydraulic capacity of this site had not been reached, so that Period IV was initiated and the hydraulic load was further increased to five days per week. This is the present pattern at Whittier Narrows with the nominal flooding depth limited by levee height to 1.8 feet. Also it should be noted that in February 1964 the six-inch pea-gravel blanket was placed on the Whittier Narrows Basin. Period III at the Rio Hondo Basin is characterized by flooding to a nearly constant depth for about one week and then allowing the basin to drain and dry for about two weeks. This pattern was practiced at Rio Hondo for eleven months. Because of a general decline in the infiltration rate, it was decided to halt this pattern of operation at the end of the year 1964. Period IV for the Rio Hondo site began in January 1965. Since then the loading pattern has been increased from three loads per week to five loadings with a gradual increase in depth of flooding.

Table 4-5—Test basin loading schedules

Whittier Narrows Test Basin

Period	Dates	Calendar days	Loading pattern
I	Jan.*-Apr. 1963	125	Every day—variable depth
II	May 1963-Jan. 1964	276	Mon., Wed., Fri.—constant depth
III	Feb.-June 1964	151	Mon., Wed., Fri.—increasing depth
IV	July 1964-Mar. 1965	274	M., T., W., Th., F.—increasing depth

* Jan. 1963 includes data since 27 Dec. 1962, so this month is considered to have 36 days.

Rio Hondo Test Basin

Period	Dates	Calendar days	Loading pattern
I	Jan.†-Apr. 1963	99	Every day—variable depth
II	May 1963-Jan. 1964	276	Mon., Wed., Fri.—constant depth
III	Feb.-Dec. 1964	335	One week wet, two weeks dry—constant depth
IV	Jan.-Mar. 1965	90	M., W., F., and M., T., W., Th., F.—increasing depth

† Operation began 22 Jan. 1963, so this month has only 10 days.

The contrasting behavior of the two test basins is quite evident from the graphed data in Figures 4-7 to 4-10. The gradual increase in the hydraulic loading at the Whittier Narrows site has been accompanied by an increase in the infiltration rate or rate of hydraulic acceptance by the basin. After the "break in" period (Period I) the rate of application at Whitttier Narrows increased nearly five times from 0.063 meter/day to 0.310 meter/day. This hydraulic load is the total volume of water applied in a time interval divided by the basin area and the total calendar days in the period. It includes all days whether the basin was flooded or not. At the Rio Hondo Basin, the average hydraulic load was increased to more than three times its value at the end of the "break in" period, but this rate could not be maintained under the system of flooding for one week and two weeks idle. Over the entire 27-month test, by hydraulic considerations only, the Whittier Narrows site has performed in a truly outstanding manner.

4.07 *Summary of the Chemical Analyses.*

The results of the chemical analyses performed on the surface waters and the percolated waters received

Table 4-6—Summary of hydraulic data

Whittier Narrows Test Basin

Period	Calendar days	Total applied water		Average hydraulic load	Average rate of infiltration	
		cu. ft.	cu. m.	m/day	m/day	ft/day
I	125	225,958	6,399.1	0.130	0.342	1.12
II	276	198,003	5,607.2	0.063	0.474	1.55
III	151	196,650	5,569.1	0.113	0.905	2.70
IV	274	971,275	27,506.5	0.310	1.420	4.66
Totals	826	1,591,886	45,081.9			

Rio Hondo Test Basin

Period	Calendar days	Total applied water		Average hydraulic load	Average rate of infiltration	
		cu. ft.	cu. m.	m/day	m/day	ft/day
I	99	165,394	4,683.9	0.165	0.500	1.64
II	276	231,448	6,554.8	0.073	0.355	1.16
III	335	870,155	24,642.7	0.228	0.589	1.93
IV	90	87,562	2,479.8	0.085	0.541	1.77
Totals	800	1,354,559	38,361.2			

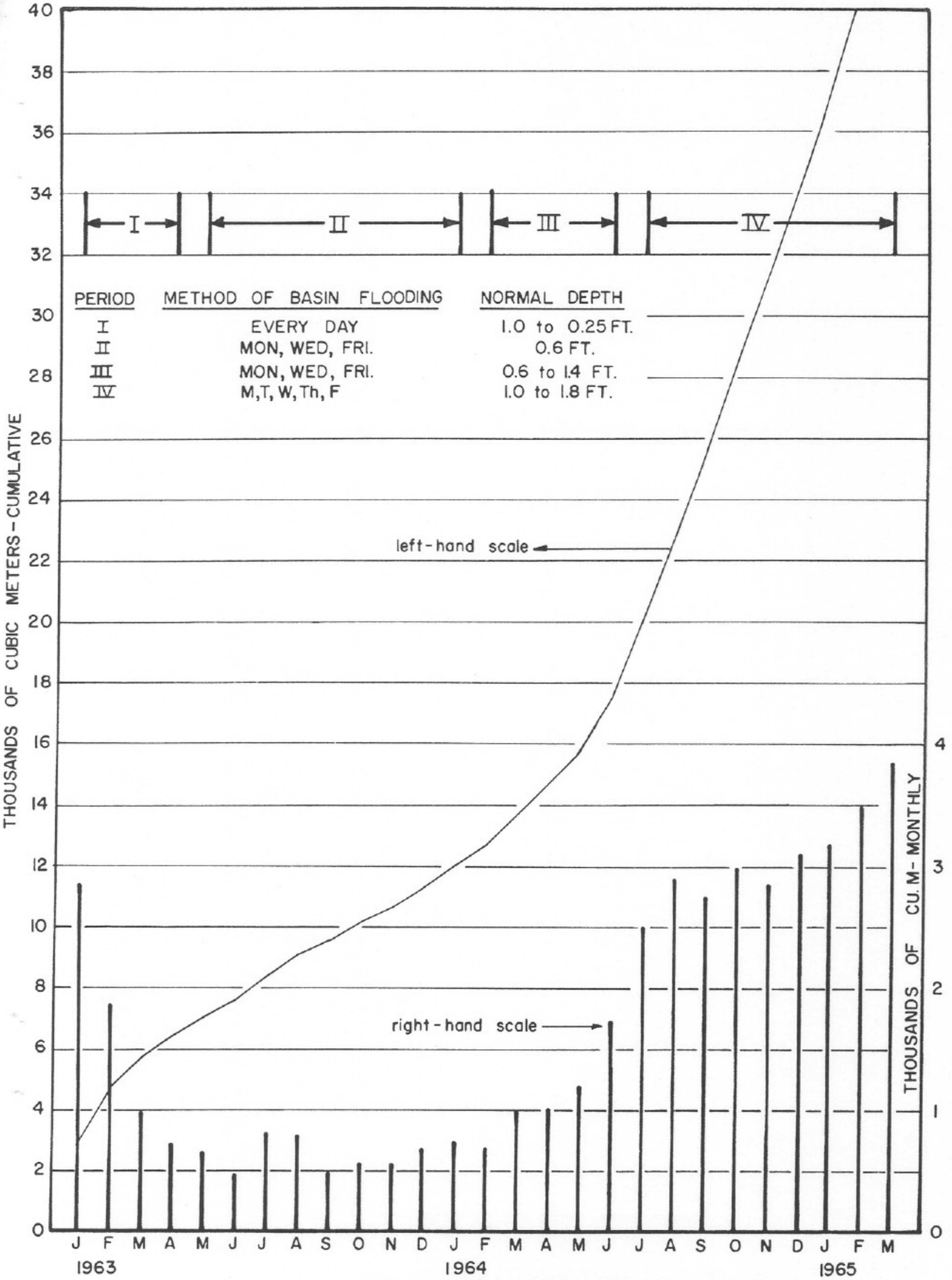

Fig. 4-7—Hydraulic Loads at Whittier Narrows Test Basin

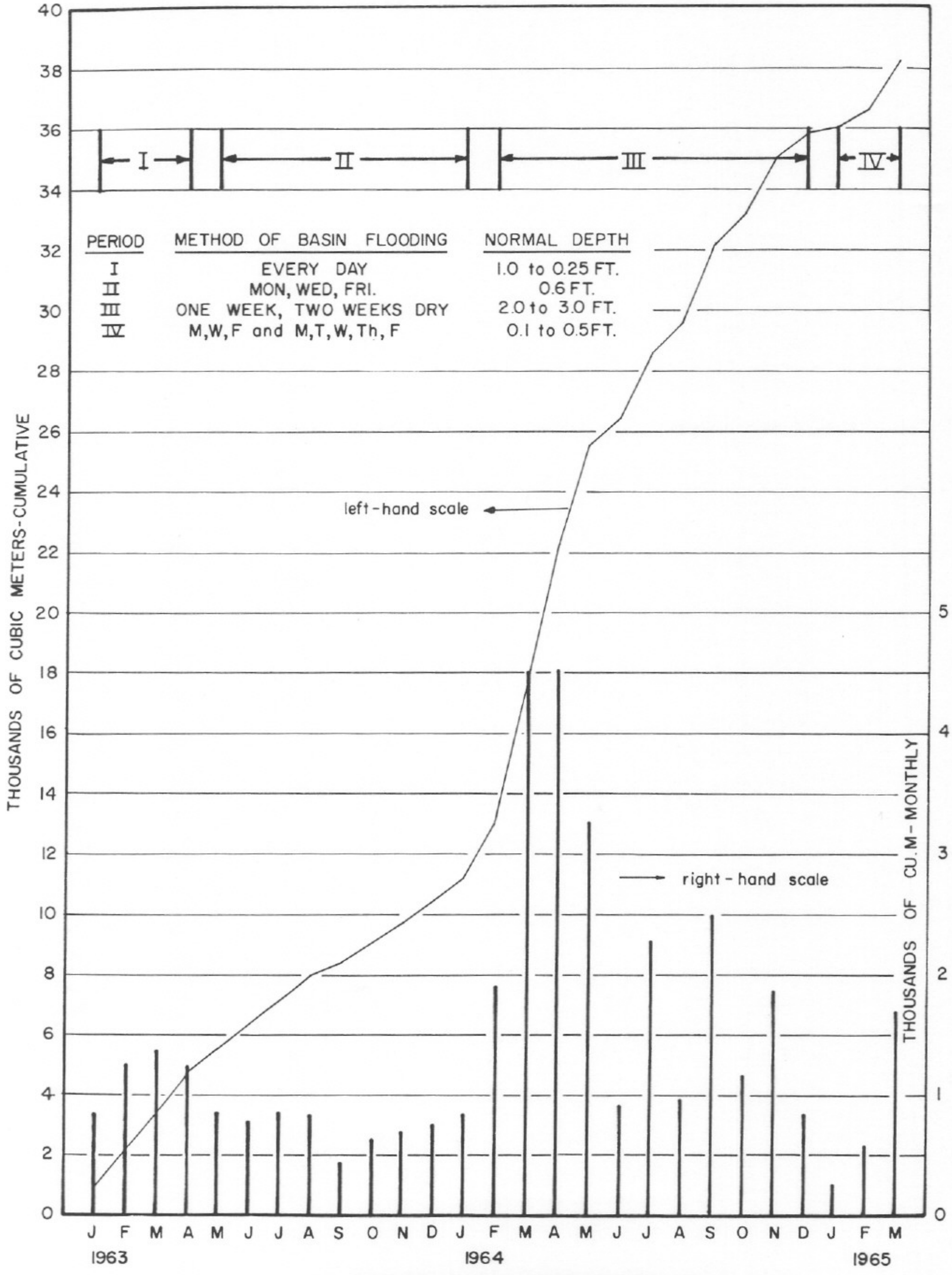

Fig. 4-8—Hydraulic Loads at Rio Hondo Test Basin

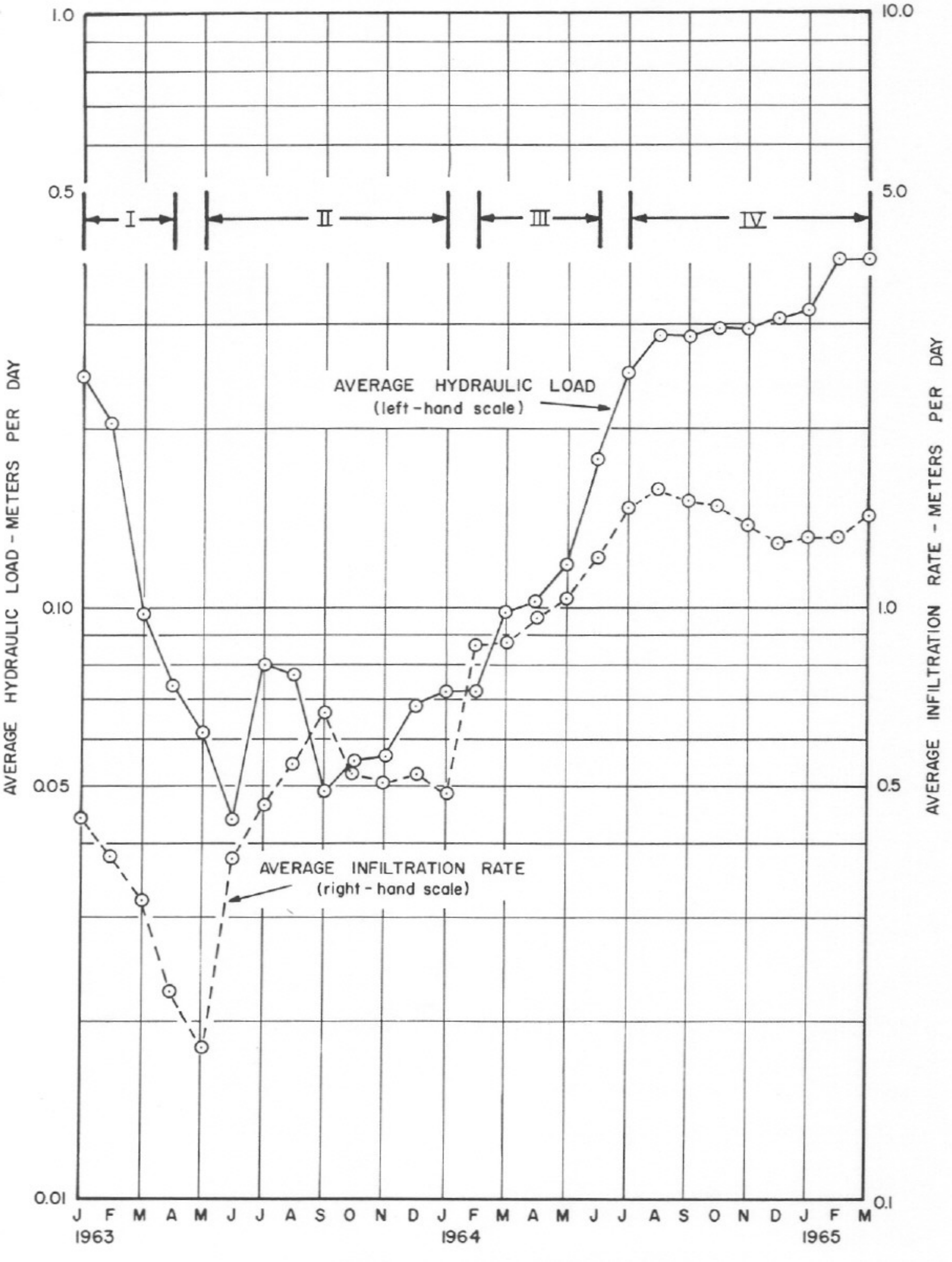

Fig. 4-9—Infiltration Rates at Whittier Narrows Test Basin

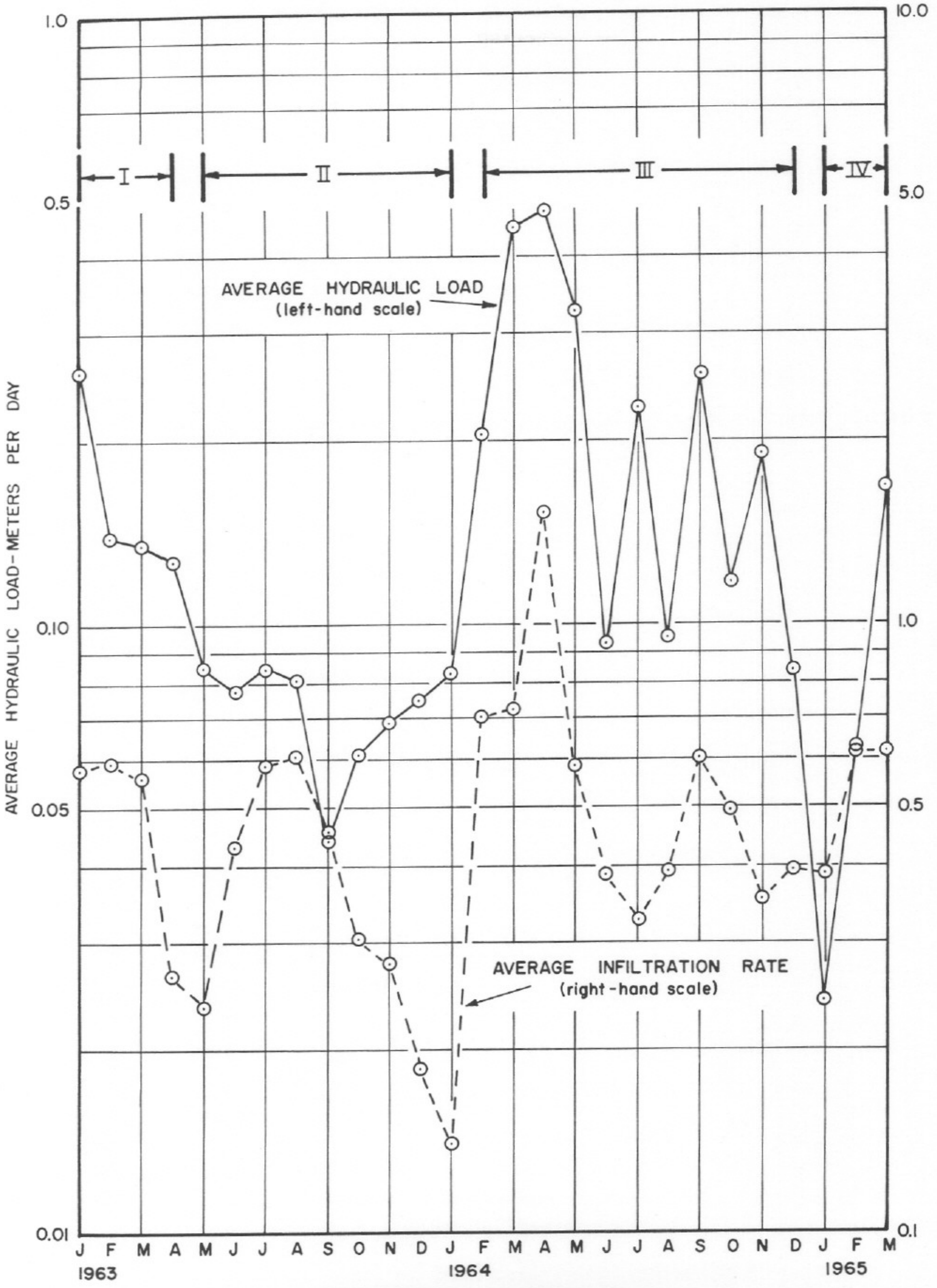

Fig. 4-10—Infiltration Rates at Rio Hondo Test Basin

from the sampling pans at the Whittier Narrows and Rio Hondo Test Basins are presented in tabular form in this section. Data are given for 27 months of operation covering the period from January 1963 through March 1965. The data are reasonably complete. Some gaps in the tables are due to the fact that the sampling pans did not always flow over periods of time long enough for the adequate collection of samples. There are no chemical data for the month of April 1964 at the Rio Hondo Test Basin because of a mixup in communications between Caltech and the LACFCD. This is the only major gap in the analytical data. No sample was received from the sampling pan at the 8-feet depth after March 1964. For an unknown reason the pan became inoperable. There were periods of a rising water table under the basin resulting from the spreading operations at adjacent basins, which caused this pan to be flooded out on several occasions.

Tables 4-7 through 4-26 present a summary of the data showing monthly averages for total solids, total volatile solids, chemical oxygen demand (COD), alkylbenzenesulfonates (ABS), chlorides, nitrates, nitrites, organic nitrogen and ammonia, total nitrogen, and turbidity. Each tabulated value is the arithmetic mean of all the measured data for the month. Samples were routinely collected and analyzed on a weekly basis.

A general presentation of the results for the operational periods defined in the previous section (see also Table 4-5) is given in tabular and graphical form. Tables 4-27 and 4-28 show the period averages for total solids, fixed solids, volatile solids, chemical oxygen demand, alkylbenzenesulfonates, nitrates, and total nitrogen. These data are also presented graphically for the two test basin sites in Figures 4-11 through 4-14. Detailed discussions of the data will be given in later chapters.

4.08 *Summary of Field Measurements of Dissolved Oxygen and Temperature.*

Measurements of water temperature and dissolved oxygen were made periodically at the test site by field personnel of LACFCD. These data are summarized in Tables 4-29 to 4-32, inclusive. Because the data are so sparse, arithmetic means were not computed, and only the ranges of the high and low values are given. The dissolved-oxygen measurements were made under varying conditions. Many times the samples were obtained by placing a dissolved-oxygen bottle at the sampling point within the test well with the hose from the sampling pan discharging inside the bottle. The bottle was left to fill and overflow. When the field man returned, the oxygen determination was performed. Admittedly such observations are open to question, but nevertheless they showed a definite diminution of oxygen as a result of percolation.

4.09 *Dissolved Solids and Related Data.*

A general measure of the quality of a water is given by the residue of solids remaining after evaporating off the water at 105°C. At the Whittier Narrows Test Basin, the data presented in Table 4-7 show that this residue, total dissolved solids, is reasonably uniform over the entire 27-month period. Analyses of the percolate show a substantial increase in dissolved solids with depth that continued for the entire duration of this study. Such an increase might be attributed to leaching, evaporation from the soil body, and mineralization from the biological activity. During the first four months of the basin operation, the increase in dissolved solids followed a classic leaching pattern. This effect was expected inasmuch as the area occupied by the test basin had been covered with a standing alfalfa crop prior to basin excavation. Farming by irrigation with highly mineralized Colorado River water (700 mg/l TDS) was practiced for many years in this area, and a build-up of salts in the soil was a common occurrence. It is somewhat surprising to observe the magnitude of the solids increase that persisted in the percolate over a 27-month period. Tables 4-27 and 4-28 which summarize the field data by significant periods show that the increase in dissolved solids was in part due to an increase in fixed solids (the fraction not lost from the residue upon heating to 600°C) and in part due to volatile solids (the fraction of the original residue lost at 600°C). Volatile solids are sometimes taken as representing only the organic portion of the residue. This is not always true since a part of the inorganic carbonate and bicarbonate may become volatile at the 600°C ignition temperature.

The increase in dissolved solids as a result of the recharge operation is believed to be somewhat incidental to the soil conditions at the Whittier Narrows site. By comparison, the solids increase at the Rio Hondo site has been much smaller. A check of the chloride data shows about a two-percent increase in the percolate over the applied water at Whittier Narrows, with almost no change in the percolate at Rio Hondo. Leaching was not expected at Rio Hondo since

Table 4-7—Average total solids as a function of depth at the Whittier Narrows Test Basin

Date	Average concentration in milligrams per liter at				
	Surface	2 ft.	4 ft.	6 ft.	8 ft.
January 1963	678	916	1186	1965	3112
February	725	912	860	1194	2079
March	678	1071	1330	1030	1016
April	670	939	859	1059	1616
May	581	671	691	580	723
June	688	1059	1292	1164	[a]
July	698	975	996	[a]	[a]
August	696	1000	1020	1137	[a]
September	688	1012	945	945	[a]
October	640	877	933	964	[a]
November	640	938	948	948	1129
December	639	903	934	948	977
January 1964	734	1003	992	1030	1173
February	800	968	1006	1028	1140
March	795	1055	1028	1057	1116
April	790	1071	1058	1099	1076
May	780	1157	1021	1115	1186
June	895	1034	994	1148	1350
July	808	1066	1008	1016	1181
August	885	1124	1093	1120	1228
September	835	1143	1057	1099	1274
October	816	1186	1066	1109	1249
November	746	954	962	1038	1172
December	773	999	1032	1014	1156
January 1965	798	931	1006	959	1057
February	745	995	1036	1011	1184
March	762	1033	949	952	1145

[a] No samples available for analysis, i.e., pan was not flowing.

the area has been used for recharge of the ground water basin by suface spreading for the last eight years. Biological activity seems to be the principal factor affecting solids increase in the test basins. For example, a pH reduction caused by carbon-dioxide production and/or nitrification could lead to dissolution of the soil matrix, causing a significant solids increase.

A complete mineral analysis of the percolate at each of the test basins was not part of the normal analytical routine. The Los Angeles County Flood Control Laboratory, however, ran mineral analyses on composite samples taken from the surface and the percolate at each of the test basins during the period 12–21 August 1964. These results are included herewith as Tables 4-33 and 4-34.

On 18 August 1964 a special sampling of the waters at the Whittier Narrows Test Basin was made for bacteriological purposes. The results of these tests are presented in a later chapter of this report. At the same time, chemical analyses were run on the percolate samples. Figure 4-15 shows the results of the analyses for alkalinity, dissolved oxygen, pH, and COD.

Table 4-8—Average total volatile solids as a function of depth at the Whittier Narrows Test Basin

Date	Average concentration in milligrams per liter at				
	Surface	2 ft.	4 ft.	6 ft.	8 ft.
January 1963	210	215	323	431	544
February	247	420	306	470	660
March	306	569	706	530	515
April	219	287	286	571	566
May	190	212	228	214	275
June	170	332	527	427	[a]
July	204	273	313	[a]	[a]
August	208	292	337	398	[a]
September	208	323	314	286	[a]
October	219	295	301	345	[a]
November	230	363	377	371	458
December	202	348	384	405	342
January 1964	214	371	390	398	457
February	248	378	386	387	461
March	280	492	406	419	483
April	229	405	383	405	454
May	311	520	416	470	507
June	331	400	400	505	611
July	250	392	374	342	456
August	312	451	411	443	497
September	278	486	410	429	539
October	300	516	454	419	537
November	244	349	389	507	557
December	263	375	501	362	468
January 1965	319	391	432	367	410
Februry	234	411	463	449	545
March	230	426	360	358	517

[a] No samples available for analysis, i.e., pan was not flowing.

Table 4-9—Average chemical oxygen demand (COD) as a function of depth at the Whittier Narrows Test Basin

Date	Average concentration in milligrams per liter at				
	Surface	2 ft.	4 ft.	6 ft.	8 ft.
January 1963	[a]	73.0	66.0	97.0	10.0
February	66.0	36.7	38.0	26.0	52.0
March	45.8	23.7	[b]	35.0	29.0
April	31.0	31.0	32.0	51.0	[b]
May	45.3	37.0	27.3	42.3	32.5
June	33.2	43.8	21.4	231.6	[b]
July	30.8	33.6	31.5	[b]	[b]
August	33.2	30.8	56.2	84.7	[b]
September	30.7	24.8	16.4	79.9	[b]
October	27.5	17.2	15.0	79.2	[b]
November	32.1	14.2	10.2	95.9	48.6
December	34.0	9.2	7.0	14.6	82.8
January 1964	36.1	10.2	8.0	7.2	47.8
February	37.7	8.1	8.8	7.5	33.6
March	38.8	8.7	9.6	6.8	36.1
April	37.8	8.3	8.8	11.4	51.4
May	36.4	9.8	9.1	14.4	54.6
June	32.9	9.0	9.2	22.9	18.2
July	32.9	11.3	10.2	25.7	21.1
August	39.1	11.2	9.2	17.3	22.4
September	34.9	10.2	8.5	26.3	14.5
October	33.8	9.8	8.6	21.1	13.1
November	35.0	8.9	8.6	13.3	18.2
December	50.0	17.4	17.1	20.0	19.8
January 1965	48.2	9.2	8.2	9.7	7.9
February	46.6	7.6	8.2	10.4	7.4
March	33.6	7.7	8.7	9.3	6.9

[a] No samples taken for analysis.
[b] No samples available for analysis, i.e., pan was not flowing.

4.10 *Phosphate Determinations.*

At the beginning of 1965, routine analyses were undertaken for orthophosphate and total phosphate in the surface water and percolates from the test basins. Determinations were made following the procedures described in the Eleventh Edition of "Stand-

Table 4-10—Average surfactant (ABS) concentration as a function of depth at the Whittier Narrows Test Basin

Date	Average concentration in milligrams per liter at				
	Surface	2 ft.	4 ft.	6 ft.	8 ft.
January 1963	4.13	2.94	2.16	1.26	1.32
February	4.13	1.92	2.40	0.63	0.55
March	2.95	2.20	0.70	0.80	0.40
April	1.70	2.45	1.60	0.65	[a]
May	1.64	2.45	2.08	1.88	1.23
June	1.85	1.43	1.00	0.70	[a]
July	2.31	1.20	0.42	[a]	[a]
August	1.99	1.05	0.55	0.47	[a]
September	1.96	0.97	0.37	0.40	[a]
October	1.96	0.83	0.20	0.33	[a]
November	1.96	0.62	0.18	0.27	0.20
December	1.98	0.65	0.25	0.32	0.20
January 1964	2.01	0.48	0.22	0.20	0.17
February	1.80	0.40	0.15	0.18	0.13
March	1.99	0.33	0.18	0.15	0.13
April	2.10	0.32	0.20	0.18	0.16
May	2.15	0.40	0.23	0.20	0.20
June	2.30	0.30	0.20	0.20	0.20
July	2.48	0.31	0.20	0.25	0.30
August	2.45	0.40	0.30	0.20	0.25
September	2.58	0.30	0.30	0.25	0.25
October	2.62	0.40	0.30	0.40	0.35
November	2.36	0.37	0.33	0.40	0.35
December	2.65	0.36	0.33	0.43	0.30
January 1965	2.51	0.30	0.35	0.35	0.25
February	2.73	0.35	0.40	0.42	0.25
March	2.43	0.30	0.43	0.50	0.30

[a] No sample available for analysis, i.e. pan was not flowing.

Table 4-11—Average chloride concentration as a function of depth at the Whittier Narrows Test Basin

Date	Average concentration in milligrams per liter at				
	Surface	2 ft.	4 ft.	6 ft.	8 ft.
January 1963	86	81	80	83	119
February	93	86	84	83	89
March	96	98	100	94	93
April	118	114	121	130	115
May	114	104	115	115	124
June	98	123	116	122	[a]
July	100	122	114	[a]	[a]
August	108	128	121	124	[a]
September	102	126	118	125	[a]
October	92	110	108	110	[a]
November	87	99	98	98	132
December	94	96	98	96	114
January 1964	91	99	100	101	101
February	108	99	106	104	101
March	104	110	108	112	108
April	117	112	105	118	110
May	114	115	112	112	105

[a] No samples available for analysis, i.e. pan was not flowing.

ard Methods for the Examination of Water and Wastewater," using the amino-naphthol-sulfonic-acid method. The results are presented in Table 4-35.

The concentrations of total phosphate were fairly uniform in the surface waters at each basin. The Whittier Narrows Basin had about ten times the surface concentration found at Rio Hondo. Practically all of the phosphate was in the ortho form at each basin. There was an anomalous behavior in the phosphate concentration at Whittier Narrows with a decrease in concentration after two feet of percolation, a build-up to four feet, and finally almost complete removal in the percolate at eight feet. No explanation for this behavior is available. The Rio Hondo Basin showed no significant change in phosphate concentration with depth.

Table 4-12—Average nitrate concentration as a function of depth at the Whittier Narrows Test Basin

Date	Average concentration in milligrams of N per liter at				
	Surface	2 ft.	4 ft.	6 ft.	8 ft.
January 1963	0.2	0.9	2.2	3.8	4.6
February	[a]	3.3	>13.0	>11.7	5.7
March	[a]	8.5	9.3	>24.0	>18.5
April	[a]	0.5	2.5	>25.7	25.0
May	[a]	0.0	4.0	1.0	[b]
June	3.9	4.9	>10.0	>10.0	[b]
July	5.5	0.0	>8.1	[b]	[b]
August	12.4	0.2	>10.0	10.0	[b]
September	8.5	0.1	>13.2	4.9	[b]
October	8.5	3.8	21.8	>10.8	[b]
November	5.7	20.4	27.8	17.5	[b]
December	2.4	20.2	25.8	23.2	[b]
January 1964	3.0	18.7	20.5	19.8	15.0
February	5.4	24.0	24.0	24.5	22.7
March	6.0	28.3	28.0	27.0	22.3
April	1.2	23.0	26.2	23.2	26.3
May	4.4	26.0	27.0	22.0	25.2
June	6.6	12.0	18.0	17.0	28.0
July	5.4	19.4	22.2	16.2	26.8
August	7.1	20.8	26.5	19.5	25.8
September	3.9	19.0	25.5	13.3	27.3
October	3.5	24.0	22.4	13.8	28.2
November	6.1	26.7	26.7	16.0	28.7
December	2.8	30.7	26.0	26.7	31.5
January 1965	4.1	26.5	23.8	25.5	29.3
February	3.3	27.8	23.0	22.7	30.3
March	6.2	26.3	25.0	26.3	30.7

[a] No sample taken for analysis.
[b] No samples available for analysis, i.e., pan was not flowing.

Table 4-13—Average nitrite concentration as a function of depth at the Whittier Narrows Test Basin

Date	Average concentration in milligrams of N per liter-at				
	Surface	2 ft.	4 ft.	6 ft.	8 ft.
January 1963	0.02	0.12	0.51	0.01	0.04
February	[a]	1.50	2.82	0.88	0.17
March	[a]	0.56	0.87	0.08	0.34
April	[a]	0.16	0.55	4.44	0.07
May	[a]	0.10	1.22	0.38	[b]
June	>1.46	>0.15	>0.83	0.02	[b]
July	0.40	>0.00	0.40	[b]	[b]
August	0.08	0.02	0.21	0.09	[b]
September	0.03	>0.00	0.19	0.18	[b]
October	0.32	0.53	0.26	0.72	[b]
November	0.24	0.25	0.18	0.34	[b]
December	0.38	0.25	0.08	0.59	[b]
January 1964	0.57	0.38	0.03	0.08	0.48
February	0.02	0.06	0.02	0.06	0.26
March	0.05	0.13	0.02	0.01	0.02
April	0.08	0.54	0.01	0.03	0.29
May	1.40	0.44	0.03	0.08	0.13
June	0.27	0.22	0.06	0.29	0.18
July	0.20	0.30	0.03	0.34	0.10
August	0.04	0.17	0.04	0.48	0.17
September	0.30	0.22	0.03	0.29	0.12
October	0.28	0.06	0.02	0.26	0.23
November	0.31	0.04	0.01	0.29	0.26
December	0.04	0.02	0.01	0.08	0.16
January 1965	1.20	0.05	0.04	0.01	0.09
February	1.15	0.02	0.01	0.05	0.04
March	0.48	0.03	0.01	0.03	0.07

[a] No samples taken for analysis.
[b] No samples available for analysis, i.e., pan was not running.

Table 4-14—Average ammonia plus organic nitrogen as a function of depth at the Whittier Narrows Test Basin

Date	Average concentration in milligrams of N per liter at				
	Surface	2 ft.	4 ft.	6 ft.	8 ft.
January 1963	21.1	9.6	1.6	0.5	1.0
February	[a]	>9.5	0.9	1.2	0.8
March	[a]	0.9	3.5	0.5	0.1
April	[a]	2.1	1.6	0.9	0.4
May	[a]	2.4	4.0	1.2	[b]
June	12.8	1.9	2.2	1.9	[b]
July	>10.0	2.9	1.6	[b]	[b]
August	13.8	2.0	>5.5	1.7	[b]
September	14.8	5.5	2.8	3.1	[b]
October	14.0	3.2	2.1	1.7	[b]
November	17.9	2.3	2.1	2.2	[b]
December	22.4	1.8	1.2	1.0	[b]
January 1964	18.9	1.2	1.0	0.9	0.5
February	19.8	0.8	0.6	0.7	0.6
March	17.7	1.0	1.0	0.5	0.6
April	24.7	0.8	0.6	0.8	0.5
May	18.3	0.6	0.8	0.6	0.9
June	20.7	0.7	0.5	0.6	1.0
July	17.2	0.6	1.1	1.2	1.0
August	16.8	1.0	0.7	0.9	0.7
September	21.5	1.0	0.8	0.7	1.0
October	24.9	0.9	0.7	0.9	1.2
November	22.2	0.8	0.7	0.6	0.8
December	25.9	1.2	1.3	0.8	1.2
January 1965	22.3	1.1	0.8	0.8	0.8
February	25.5	0.9	1.1	0.9	1.4
March	19.8	0.6	0.3	1.0	0.6

[a] No samples taken for analysis.
[b] No samples available for analysis, i.e., pan was not running.

Table 4-15—Average total nitrogen as a function of depth at the Whittier Narrows Test Basin

Date	Average concentration in milligrams of N per liter at				
	Surface	2 ft.	4 ft.	6 ft.	8 ft.
January 1963	21.3	10.7	3.2	4.3	5.6
February	[a]	>14.3	>17.0	>13.8	6.7
March	[a]	10.0	10.6	>24.6	19.0
April	[a]	2.8	3.9	>31.0	25.4
May	[a]	2.6	6.4	2.6	[b]
June	>18.2	>7.0	>12.7	>11.9	[b]
July	>15.4	>2.9	>8.5	[b]	[b]
August	26.3	2.2	>11.9	11.8	[b]
September	23.3	>5.6	>16.5	8.2	[b]
October	22.8	7.5	23.8	>13.2	[b]
November	23.8	22.4	30.2	20.0	[b]
December	25.2	22.2	26.7	24.8	[b]
January 1964	22.5	20.3	21.4	20.8	16.0
February	25.2	24.8	24.7	25.3	23.5
March	23.8	29.5	28.5	27.5	22.9
April	26.0	24.3	27.0	24.0	27.1
May	24.1	27.1	27.7	22.7	26.2
June	27.6	12.9	18.6	17.8	29.1
July	23.0	20.3	23.5	17.8	27.8
August	23.9	22.0	27.2	20.9	26.7
September	25.7	20.2	26.3	14.3	28.4
October	28.7	25.0	23.1	15.0	29.6
November	28.6	27.5	27.4	16.9	29.8
December	28.7	31.9	27.3	27.6	32.9
January 1965	27.6	27.6	24.6	26.3	30.2
February	30.0	28.7	24.1	23.6	31.7
March	26.5	26.9	25.3	27.3	31.4

[a] No samples taken for analysis.
[b] No samples available for analysis, i.e., pan was not flowing.

Table 4-16—Average turbidity as a function of depth at the Whittier Narrows Test Basin

Date	Average concentration in units of turbidity at				
	Surface	2 ft.	4 ft.	6 ft.	8 ft.
January 1963	6.2	0.9	1.2	0.3	0.4
February	6.0	0.6	0.4	0.3	0.4
March	9.0	1.6	6.7	1.0	1.3
April	4.8	1.4	1.0	0.9	0.7
May	2.1	0.5	0.6	0.3	0.3
June	2.6	0.7	0.9	4.0	[a]
July	2.7	1.0	1.8	[a]	[a]
August	2.9	1.0	1.2	1.8	[a]
September	2.7	1.3	1.2	2.1	[a]
October	3.1	1.3	1.6	1.3	[a]
November	3.2	1.5	1.3	1.6	1.3
December	2.7	1.2	1.2	1.5	1.8
January 1964	3.1	1.2	1.5	1.5	2.2
February	3.6	1.6	1.5	1.5	2.0
March	4.1	1.8	1.5	1.3	1.7
April	3.7	1.9	1.8	1.7	2.3
May	3.2	1.6	2.0	2.0	1.8
June	3.3	1.4	1.6	1.8	1.4
July	2.2	1.3	1.4	1.8	1.4
August	3.2	1.1	1.1	1.1	1.0
September	3.0	1.1	1.4	1.1	1.1

[a] No samples available for analysis, i.e. pan was not flowing.

Table 4-17—Average total solids as a function of depth at the Rio Hondo Test Basin

Date	Average concentration in milligrams per liter at				
	Surface	2 ft.	4 ft.	6 ft.	8 ft.
January 1963	867	970	902	756	762
February	573	491	612	694	894
March	1,084	728	777	901	872
April	605	664	666	724	610
May	636	558	566	486	521
June	635	711	821	931	[a]
July	715	745	808	982	[a]
August	754	790	843	935	[a]
September	515	600	695	911	778
October	494	421	441	742	[a]
November	548	570	847	919	787
December	895	815	827	835	828
January 1964	746	775	789	904	720
February	783	805	790	759	812
March	671	564	911	942	944
April	[a]	[a]	[a]	[a]	[a]
May	847	838	706	930	[a]
June	814	723	730	[a]	[a]
July	799	849	855	930	[a]
August	889	819	867	935	[a]
September	784	823	789	944	[a]
October	825	819	816	950	[a]
November	525	635	867	923	[a]
December	620	662	915	1,022	[a]
January 1965	894	810	952	988	[a]
February	838	931	965	952	[a]
March	871	906	999	993	[a]

[a] No samples available for analysis.

Table 4-18—Average total volatile solids as a function of depth at the Rio Hondo Test Basin

Date	Average concentration in milligrams per liter at				
	Surface	2 ft.	4 ft.	6 ft.	8 ft.
January 1963	300	440	284	174	190
February	207	188	307	245	310
March	439	326	276	307	340
April	224	224	207	185	178
May	241	217	196	181	192
June	158	179	226	289	[a]
July	208	223	249	335	[a]
August	210	227	250	268	[a]
September	204	244	248	281	278
October	159	151	159	308	[a]
November	218	157	243	329	273
December	217	232	217	254	238
January 1964	227	216	246	262	181
February	226	192	200	198	230
March	209	212	297	324	310
April	[a]	[a]	[a]	[a]	[a]
May	302	297	239	381	[a]
June	334	224	213	[a]	[a]
July	218	274	280	292	[a]
August	329	275	318	355	[a]
September	272	338	296	373	[a]
October	262	259	254	330	[a]
November	350	341	295	268	[a]
December	203	212	258	323	[a]
January 1965	249	164	332	373	[a]
February	206	239	261	238	[a]
March	226	234	325	252	[a]

[a] No samples available for analysis.

Table 4-19—Average chemical oxygen demand (COD) as a function of depth at the Rio Hondo Test Basin

Date	Average concentration in milligrams O_4 per liter at				
	Surface	2 ft.	4 ft.	6 ft.	8 ft.
January 1963	27.0	53.0	30.0	14.0	28.0
February	[a]	26.0	25.0	32.0	[b]
March	[a]	11.8	9.5	8.8	9.2
April	27.7	11.0	9.0	8.4	13.6
May	36.0	24.0	44.9	20.5	24.0
June	32.9	10.1	31.1	18.9	[b]
July	49.5	16.5	17.0	14.0	[b]
August	41.8	15.7	17.2	18.1	[b]
September	52.0	18.4	15.2	9.0	137.0
October	30.0	13.9	17.4	12.3	[b]
November	37.4	13.4	7.7	7.6	50.2
December	10.5	4.3	6.3	6.4	10.2
January 1964	20.3	5.2	5.8	5.0	6.2
February	11.1	6.2	7.8	5.0	5.2
March	29.7	17.0	7.2	9.7	9.5
April	[b]	[b]	[b]	[b]	[b]
May	43.1	28.9	12.4	8.6	[b]
June	42.1	12.1	9.5	[b]	[b]
July	27.2	16.0	9.7	7.4	[b]
August	47.2	15.3	9.8	8.7	[b]
September	33.3	17.4	10.3	7.4	[b]
October	36.5	17.3	9.2	6.2	[b]
November	51.0	17.0	6.9	8.7	[b]
December	28.3	12.5	5.8	7.8	[b]
January 1965	9.1	6.7	6.0	6.6	[b]
February	18.5	11.4	8.7	12.5	[b]
March	9.8	4.4	5.0	3.8	[b]

[a] No samples taken for analysis.
[b] No samples available for analysis.