Dispersion and persistence of synthetic detergents in ground water, San Bernardino and Riverside Counties : [a report to the State Water Quality Control Board, September 1964.

California. Department of Water Resources.

Sacramento] : State Water Quality Control Board, 1965.

STATE OF CALIFORNIA
THE RESOURCES AGENCY

STATE WATER QUALITY CONTROL BOARD

DISPERSION AND PERSISTENCE OF SYNTHETIC DETERGENTS IN GROUND WATER, SAN BERNARDINO AND RIVERSIDE COUNTIES

1965

Publication No. 30

STATE OF CALIFORNIA
EDMUND G. BROWN
Governor

THE RESOURCES AGENCY
HUGO FISHER
Administrator

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DISPERSION AND PERSISTENCE OF SYNTHETIC DETERGENTS IN GROUND WATER, SAN BERNARDINO AND RIVERSIDE COUNTIES

1965

Publication No. 30

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—January, 1965

FOREWORD

For many years detergents have been recognized as a problem in surface waters throughout the United States and in other countries. Until recently, synthetic detergents had not manifested themselves significantly in ground waters. Since 1958, however, synthetic detergents have been reported in well waters in concentrations sufficient to cause foaming.

In August 1960, operators of wells in the Colton Narrows area of the Santa Ana River of Southern California noticed foaming in their irrigation water. This situation led to investigations resulting in a research project and the report which follows. Further background information concerning the research project is given in Chapter I of the report. Findings, conclusions and recommendations presented in Chapter VII, are summarized in the report transmittal letter. The project was carried out by the State Department of Water Resources under contract with the State Board.

Printing and distribution of the report as Publication No. 30 was authorized by the State Board on January 27, 1965.

The investigations reported herein were conducted under the sponsorship of the State Water Quality Control Board (formerly the State Water Pollution Control Board). The investigations and their direction were under the responsibility of the State Department of Water Resources. The conclusions and recommendations are, therefore, those of the research contractor, and do not necessarily reflect opinions or policies of the State Water Quality Control Board.

State of California
THE RESOURCES AGENCY
Department of Water Resources

DISPERSION AND PERSISTENCE OF SYNTHETIC DETERGENTS IN GROUND WATER, SAN BERNARDINO AND RIVERSIDE COUNTIES

A Report to
the
State Water Quality Control Board

September 1964

HUGO FISHER
Administrator
The Resources Agency

EDMUND G. BROWN
Governor
State of California

WILLIAM E. WARNE
Director
Department of Water Resources

AUTHORIZATION

This investigation was conducted and the final report prepared in accordance with Interagency Agreement No. 12-25, dated January 22, 1962, Amendment No. 1 to Interagency Agreement No. 12-25, and Interagency Agreement 12-17, dated July 1, 1963, between the California State Water Quality Control Board (formerly the State Water Pollution Control Board) and the State Department of Water Resources. This investigation followed specifications submitted by the board in these agreements.

Statutory authority for conducting this investigation is given by Section 13024 of the State Water Code, which reads as follows:

> "13024. The state board shall administer any state-wide program of research in the technical phases of water pollution control which may be delegated to it by law and may accept funds from the United States or any person to that end. The state board may conduct such a program independently, or by contract or in cooperation with any federal or state agency, including any political subdivision of the State, or any person or public or private organization."

The objectives of this investigation, as noted in the Interagency Agreements, are those set forth on page 1 of this report.

In addition, the agreements called for the preparation by the department and submission to the board of quarterly progress reports and an annual report, as well as this final report.

ORGANIZATION

State of California
THE RESOURCES AGENCY
Department of Water Resources

EDMUND G. BROWN, Governor
HUGO FISHER, Administrator, The Resources Agency
WILLIAM E. WARNE, Director, Department of Water Resources
ALFRED R. GOLZÉ, Chief Engineer
JOHN M. HALEY, Assistant Chief Engineer

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Jack J. Coe *	Chief, Planning Branch

This investigation was conducted and report prepared under the direction of

Mitchell L. Gould **	Chief, Water Quality Section

under the supervision of

George P. Gribkoff	Senior Engineer, Water Resources

by

Robert J. Turney	Assistant Engineering Geologist
Joseph F. LoBue	Assistant Engineering Geologist
Gary G. Ford	Assistant Engineering Geologist
Diane Halstead	Junior Civil Engineer
Steven Gregg	Engineering Aide II

* Herbert W. Greydanus was Chief, Planning Branch, until July 1, 1964.

** David B. Willets was Chief, Water Quality Section, until May 20, 1964.

STATE OF CALIFORNIA—RESOURCES AGENCY
WILLIAM E. WARNE, Director

DEPARTMENT OF WATER RESOURCES
. O. BOX 388
ACRAMENTO

November 5, 1964

State Water Quality Control Board
Resources Building
Room 855
1416 Ninth Street
Sacramento, California 95814

Attention: Mr. Paul R. Bonderson
Executive Officer

Gentlemen:

I am pleased to transmit herewith the final report on "Dispersion and Persistence of Synthetic Detergents in Ground Water of San Bernardino and Riverside Counties". It incorporates the information contained in the progress reports and the annual report submitted earlier, and also includes material obtained during the latter part of the study.

This report traces the movement, both laterally and vertically, of ABS (the foam-producing constituent of synthetic detergents) through surface and ground waters of the affected area, thus giving valuable information on mixing and dispersion within a ground water basin.

In addition, the study shows that approximately 80 percent of the ABS entering the soil is degraded (broken down) as it percolates through the zone of aeration. Most of this degradation, about 66 percent, takes place within the first 10 feet of percolation.

The soap and detergent industry has announced plans to convert, by June 30, 1965, from the ABS-type detergent to one that is more easily broken down in normal sewage treatment. Because of the proposed conversion, this report recommends that the study be continued so that the effects of the new detergent on the basin can be evaluated, and the degradability of the new detergent in an actual ground water basin can be determined. Continuation of this study, utilizing the disappearance of the ABS detergent as a tracer, will add invaluable basic knowledge on ground water flows.

Sincerely yours,

William E. Warne

Director

ACKNOWLEDGMENT

To conduct an investigation such as this into the dispersion and persistence of synthetic detergents in ground water requires a coordinated effort by many governmental agencies (local, state, and federal), private companies, and individuals.

Because a list of everyone who aided in this study would be too long and laborious to compile, it will not be attempted here. However, we would especially like to thank the following agencies, committees, and companies for the great efforts that they extended in granting rights-of-way for drilling, furnishing crews and personnel, giving technical information, and performing many other services:

Advisory Committee on ABS
Santa Ana Regional Water Pollution Control Board (No. 8)
The San Bernardino County Flood Control District
The Riverside County Flood Control and Water Conservation District
La Sierra Water Company
Riverside Water Company
East San Bernardino County Water District
Gage Canal Company
Albert Webb and Associates
University of California at Riverside
City of San Bernardino
City of Riverside
City of Colton
City of Rialto
San Bernardino Water Conservation District
Salinity Laboratory, U.S. Department of Agriculture, Riverside
Soil Conservation Service, U.S. Department of Agriculture
Irrigation Engineering Corporation
Riverside Highland Water Company
Riverside Water Company
Twin Buttes Water Company
East San Bernardino County Water District
W. P. Rowe and Son
Intercity Mutual Company
Tippecanoe Water Company

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Water from well in Colton Narrows of Santa Ana River

"The problem... was first recognized when operators of two separate wells... noticed foaming in their irrigation water."

CHAPTER I

INTRODUCTION

The problem toward which this study is directed was first recognized in August 1960 when operators of two separate wells in the Colton Narrows area of the Santa Ana River of Southern California noticed foaming in their irrigation water. Their complaints to the Santa Ana Regional Water Pollution Control Board led to a sampling of other wells in the area, conducted by the board and the California State Department of Water Resources. As a result, the presence of foaming was also detected in other irrigation wells.

An analysis of the offending waters revealed that appreciable concentrations of alkyl benzene sulfonate (a constituent of most household detergents and commonly known as ABS) were responsible for the foaming. The origin was presumed to be the municipal wastes discharged at points upstream of the wells.

Armed with these facts, members of the board petitioned the State Water Quality Control Board for a comprehensive study to determine both the dispersion and persistence of synthetic detergents in the ground water producing area along the Santa Ana River. The Department of Water Resources was selected to conduct the investigation, and the report that follows summarizes the findings of that study.

Never before had the effects of ABS been studied on such a scale. Prior to this investigation, workers at a number of laboratories had made studies on degradation of ABS soil columns and lysimeters, using both artificial media and various natural soil types. ABS problems in restricted areas of ground water basins in the eastern United States had led to limited ground water investigations. Concentrations of ABS in the surface waters of major river systems had also been monitored for many years. In Germany and England, for example, extensive laboratory investigations had been undertaken to determine the causes of foaming along the Rhine and Dee Rivers.

All these studies provided many needed basic concepts on the nature of foaming, adsorption, and bacterial and soil action on ABS, but failed to answer the fundamental question of how does ABS mix, disperse or persist in an extensive ground water basin under natural conditions. Hence, the need for this investigation.

At first, the area of investigation appeared to be an ideal site because all the requisites for a study to determine the dispersion and mixing of ABS in a ground water basin were available, i.e., sources of ABS, confined river channel, abundant hydrologic data, and confined area downstream in which to monitor outflow. Soon after the start of the investigation, however, a number of complexities were revealed. These included the recognition that many—not just one or two—sewage sources are involved, the unusual structure of the ground water aquifers (they are circuitous, braided, and varied in permeability, thickness, and lithologic characteristics), and the fact that not all subsurface flows follow the river floodplain. Other problems encountered were the existence of structural barriers between the sources of ABS and monitoring wells, the long history of litigation in the area that hinders the obtaining of records, and the extensive pumping programs and exports from the area that lead to unnatural conditions by reversing hydraulic gradients and cause seasonal shifts in extent of areas of high concentrations of ABS. A study such as this had no precedent and thus these difficulties could not be foreseen but had to be overcome as the study progressed.

Area of Investigation

The area of investigation depicted on Plate 1, "Location Map" is a reach of the Santa Ana River between Loma Linda and the Riverside Narrows at Pedley and extending into a portion of both San Bernardino and Riverside Counties. Where the river passes between Slover Mountain and La Loma Hills, the area is known as Colton Narrows. The remaining portion of the river is a broad floodplain that narrows at a bedrock constriction known as the Riverside Narrows. The major area found to be affected by ABS roughly follows the floodplain and is approximately 10 miles in length. A less affected area also exists east of the La Loma Hills in the East Riverside Mesa. The affected areas occupy portions of three ground water basins: Bunker Hill Basin, Colton Basin, and Riverside Basin.

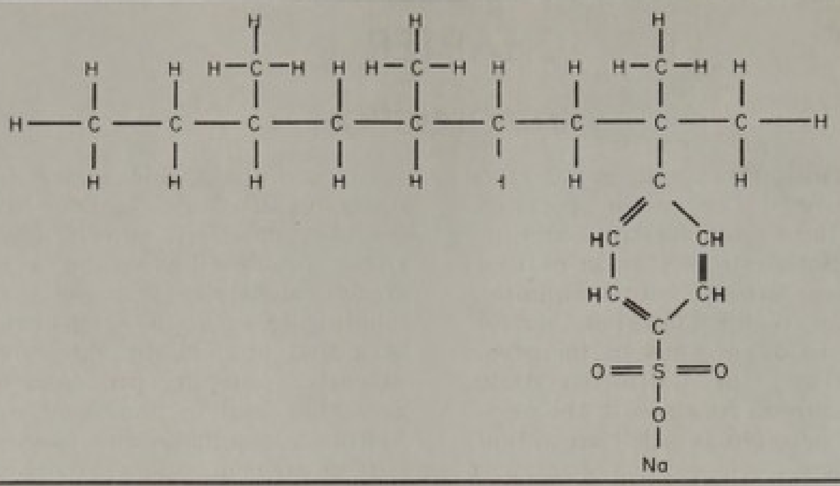
Three natural barriers to ground water movement are located in the area of investigation. All trend approximately northwest to southeast and all are located near the northern end of the area. One of the three—the Loma Linda fault—is actually north of the affected area. Therefore, only the San Jacinto fault and Rialto-Colton Barrier figure in the study.

Objectives of the Investigation

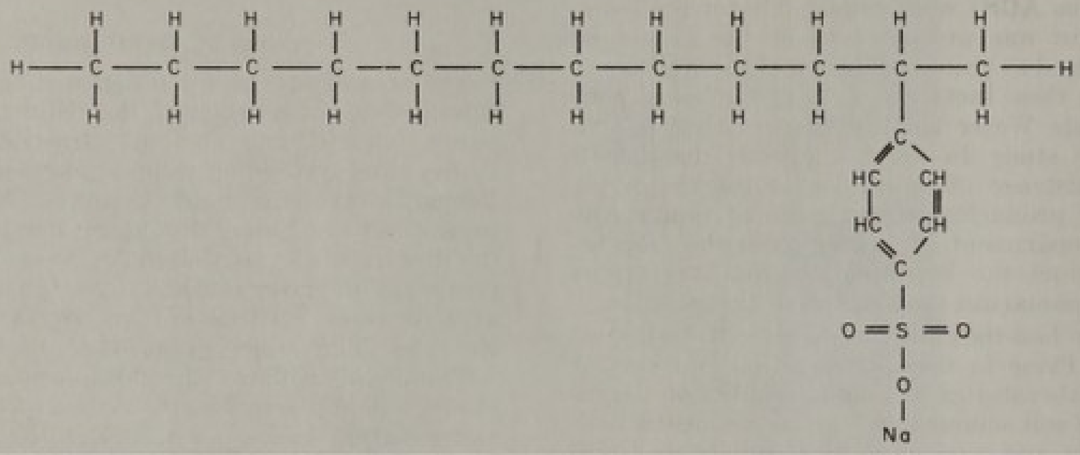
The general objectives of the investigation of dispersion and persistence of synthetic detergents in ground water in the Colton Narrows of San Bernardino and Riverside Counties are:

1. To assist the Santa Ana Regional Water Pollution Control Board in the conduct of its regulatory responsibilities.
2. To determine the fate of synthetic detergents percolating into ground waters.
3. To develop fundamental data that will aid in the evaluation of mixing and dispersion within a ground water basin.

FIGURE 1

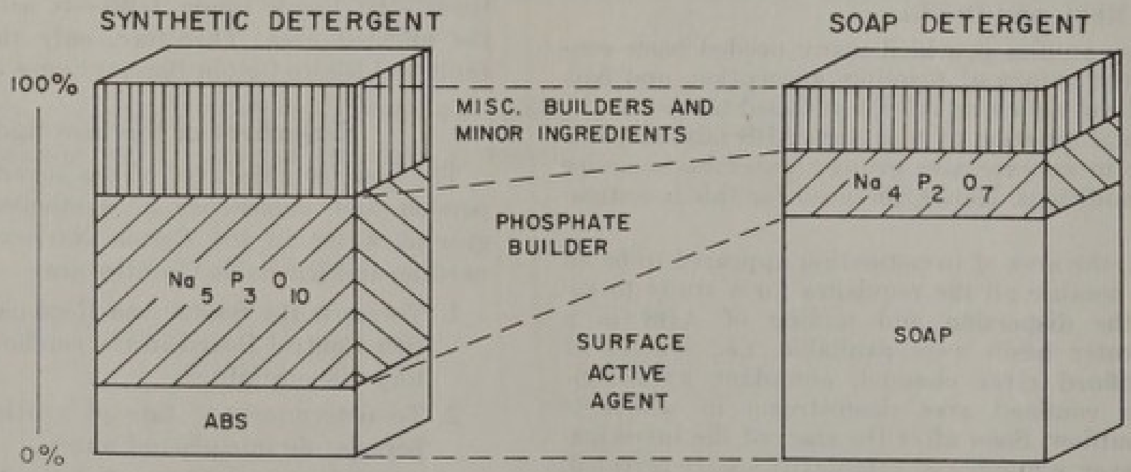


STRUCTURE OF A TYPICAL ALKYL BENZENE SULFONATE (ABS)



STRUCTURE OF A TYPICAL LINEAR ALKYLATE SULFONATE (LAS)

Source – "Review of Detergent Research Program"
D. J. Weaver, JWPCF, 32, 1960



PACKAGED HOUSEHOLD DETERGENTS

To attain these objectives the following determinations were made: the areal extent of ABS concentration in the Colton Narrows area and the changes occurring during the period of investigation, the concentrations of ABS reaching the ground water by percolation through the unsaturated zone, dispersion of synthetic detergents in the ground water body, extent of vertical mixing of ABS in the ground water body, and persistence of synthetic detergents in ground water.

Definitions and Properties of ABS

By definition, a detergent is anything that cleanses, including ordinary soap and the new "synthetics." The most widely used household synthetic detergents contain the anionic surfactant ABS.

A surfactant is an organic compound that is "surface active," which means it has the ability to act as a link between the water and dirt particles. Thus, dirt particles are "tied" to the water by the surfactant so that mechanical agitation in the washing process can pull the dirt from the soiled material and keep it in the wash water.

Every molecule of ABS does not have exactly the same structural arrangement, as the carbon chain may be branched or may be a single straight chain. Also, the molecule may contain from 9 to 15 carbon atoms.

Biological degradability (breakdown of complex organic compounds to simple forms by biological action) is determined by the molecular weight and arrangement of the side chain. Straight chains are more susceptible to bacterial and biological degradation than are those with side branching.

The predominant arrangement of the ABS molecule consists of the "alkyl" (noncyclic) side chain containing 12 carbon atoms in a branched arrangement and a cyclic-sulfonate benzene ring. Figure 1 shows such a molecular structure and contrasts it with the proposed new linear alkylate sulfonate known as LAS. LAS is biologically degradable under normal sewage treatment and is popularly termed a "soft type," as opposed to the "hard type" ABS.

In addition to the surfactant ABS, household synthetic detergents contain many other ingredients that act as wetting, dispersing, bleaching, stabilizing, and emulsifying agents. Table 1 gives the formation of a typical synthetic detergent and the function of each ingredient.

TABLE 1

Typical Synthetic Detergent Formulation

Ingredient	*Proportion by weight, in percent*	*Function*
Surface active agent	20	Reduces surface tension
Phosphate	35	Buffer—assists suspension, dispersion, and emulsification of soil
Sodium sulfate	20	Provides additional electrolyte to aid wetting and dispersion
Sodium silicate	10	Prevents metal corrosion
Methyl cellulose	1	Prevents redeposition of soil
Fatty acids	3	Stabilize foam
Sodium perborate	10	Acts as bleaching agent
Perfumes, antioxidants, fluorescent dyes, and impurities	1	Enhance appearance and aroma of product

ABS in even low concentrations causes sudsing or foaming in waters because of the lowering of surface tension at the air-water interface. Foaming occurs particularly during pumping or agitation of the water. This foaming property is what first attracted the public's attention to the presence of ABS in rivers, sewage effluents, and water supplies. In other words, aesthetic considerations have been responsible for the public reaction against ABS.

The real problem, however, lies in the ability of ABS to pollute ground waters. This is becoming increasingly undesirable because of the growing practice of reclaiming waste waters by recharge to ground water basins through spreading or injection. As little as 0.5 mg/l of ABS may cause foaming when the water is drawn from the household tap, particularly if the faucet has a screening device to agitate the water. Thus, ABS is the main "Villain" that stands in the way of successfully reclaiming waste waters, because the other organic contaminants are largely adsorbed or degraded as they pass through a sufficient amount of soil.(19)*

ABS has not proved to be toxic to man even in concentrations far in excess of 1 to 3 mg/l, such as those found in ground waters in the study area. However, copious foaming is noted at these concentrations during pumping of wells. The United States Public Health Service has set a recommended upper limit of 0.5 mg/l for ABS in drinking water supplies based on aesthetic consideration (foaming).

Because ABS is reported to be degradable only from 50 to 60 percent by conventional aerobic and biological treatment, a need for the development of a more degradable type of ABS molecule is urgent. The soap and detergent industry has spent millions of dollars in research to develop a more biodegradable detergent. Largely through these efforts, the industry has established a timetable for full-scale distribution of biodegradable LAS by the middle of 1965.

Impact of LAS on Detergent Problem

The physical properties and characteristics of LAS are essentially the same as those of ABS, with the major difference that this material is reported, by laboratory investigators, to be almost entirely biodegradable by conventional aerobic sewage treatment. It is anticipated that this additional biodegradability will be sufficient to reduce the LAS concentrations in the waste waters to a level that will prevent foaming. This biodegradability is attributed to the presence of only straight chain hydrocarbons in the molecule.

The soap and detergent industry anticipated that by the end of 1963, engineering and cost estimates and full-scale pilot plants would be completed, and samples made available for tests of biodegradability and for washing ability of the new LAS. By mid-1964, the industry expected to start full-scale production

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* Numbers refer to list of Selected References in Appendix A.

and regular tank car shipments to distributors. June 1965 is given as the target date for the depletion of the existing ABS inventories and the full conversion by the industry to the use of the new LAS detergent.

By the end of 1966, when the new type of detergent has been in use approximately 18 months, valuable information can be obtained on the rate of disappearance of ABS from a ground water basin. Continuation of the study in this area, where data on ABS concentrations in ground water are available and where test wells and facilities for monitoring are in existence, would make possible an evaluation of the degradability of LAS and the disappearance of ABS in a ground water basin under actual field conditions. Much valuable information could be obtained and added to the general knowledge of the dispersion and mixing of waters in this and similar ground water basins and on the rate of disappearance and fate of organic-type contaminants, some of which may not be known today. This ready-made opportunity to obtain such information at a reasonable cost and on such a large scale may never present itself again.

Scope and Conduct of the Investigation

The investigation reported here utilized the full- or part-time services of three technical persons over the three-year study period. It also required the part-time services of other department personnel for performing pumping tests, sampling, analyzing samples, and collecting data. Many cooperating agencies assisted with basic data collection.

During the investigation, the following items were accomplished:

1. A literature search for pertinent information on synthetic detergents, hydrology, and geology of the study area, and preparation of a bibliography, which is included in Appendix A of this report.
2. Formation of a committee, titled "Advisory Committee on Dispersion and Persistence of ABS in Ground Waters," in March 1962 to provide technical assistance and counsel for the investigation. Meetings were held during the course of the investigation to evaluate progress.
3. Delineation of problem area and selection of wells for monitoring. These were obtained from a compilation of previous data and new data gathered in the field.
4. A field canvass of wells in the problem area in July 1964 to provide a closing inventory of ABS concentrations.
5. A program of geologic field mapping to delineate the various unconsolidated and consolidated water-bearing deposits, as well as the non-water-bearing rocks. Geologic sections were prepared to better understand the subsurface relationships and interconnections of these water-bearing materials. Information from drillers' logs were used to contour the undulating and irregular buried surface of the bedrock. These data were used to indicate the thickness of the alluvium and estimate the depth to drill the test wells. Extensions of the aquifer materials indicated the most likely paths of subsurface flow and aided in the interpretation of hydrologic data.
6. Drilling of six test holes along the floodplain of the Santa Ana River. Samples were obtained at selected depths from these test holes and analyzed for ABS and selected chemical constituents.
7. Development, testing, and successful use of methods for obtaining subsurface samples from the unsaturated and saturated zones.
8. Determination of the apparent decrease in ABS concentrations of the waste waters during percolation through the zone of aeration to depths of 55 feet.
9. Evaluation of the analytical procedure used during this study for the determination of ABS. The evaluation included a determination of the standard deviations for several concentrations of ABS to determine the precision of the test. The method of analysis and its evaluation are given in Appendix D.
10. Analysis and evaluation of water quality data as a possible means of explaining the direction and quantities of subsurface flows and their effects upon the dispersion and mixing of ABS in ground waters. Water quality data were correlated with variations of surface flows, waste discharges, and seasonal extractions to determine the extent of mixing within the ground water basin.

Related Investigations and Reports

The first study of the hydrology of the San Bernardino Valley was made in 1888 by William Ham Hall, the first State Engineer of California. In 1905, W. C. Mendenhall made a comprehensive investigation of the hydrology and published the results (23, 24). These reports delineated the original artesian areas and the geologic setting for the valley. In 1945 the Division of Water Resources instigated an investigation of the "Geology and Ground Water Storage Capacity of Valley Fill" and published the results in Bulletin No. 45 (5). Bulletin No. 15, "Santa Ana River Investigation," (8) which was released in February 1959, reported on an extensive investigation encompassing the entire drainage system of the Santa Ana River and of the surface and underground water resources. The reports also gave estimates of ultimate water utilization, along with a list of flood control problems. In June 1962, the Santa Ana Regional Water Pollution Control Board staff members prepared a report entitled, "Report on Preliminary Investigation Occurrence of Apparent Alkyl Benzene Sulfonate Surface and Ground Waters of Santa Ana River Vicinity of Colton Narrows." (28) This report summarized the data obtained during a field reconnaissance study of apparent ABS concentrations in wells and waste waters in the immediate area along the Santa Ana River at Colton Narrows. These and related reports are listed in Appendix A.

Advisory Committee on Investigation

Soon after the agreement for the investigation reported here was drawn up, a committee of outstanding qualified personnel to provide additional technical assistance for the conduct of this investigation was formed. Such a plan was decided upon because of the highly technical field type of investigation required.

Members of the Advisory Committee on Dispersion and Persistence of Synthetic Detergents in Ground Waters were carefully chosen on the basis of their technical specialties and contributions in the fields of engineering, hydrology, chemistry, and public health.

Named to the committee were the following:

Warren T. Kaufman, Professor of Sanitary Engineering, University of California, Berkeley

J. E. McKee, Professor of Environmental Health Engineering, California Institute of Technology

John C. Merrell, Jr., United States Public Health Service

Raymond V. Stone, Jr., (Formerly Executive Officer, Santa Ana Regional Water Pollution Control Board)

Paul Ward, Supervising Sanitary Engineer, Department of Public Health, State of California

Mr. Stone was replaced by:

Richard A. Bueermann, Executive Officer, Santa Ana Regional Water Pollution Control Board

CHAPTER II

GEOLOGY AND HYDROLOGY

Fundamental to any study of ground water are the geology and hydrology of the area. This chapter is designed to give information on both subjects for the area of investigation.

First is included an abbreviated discussion of the water-bearing and nonwater-bearing sediments and rock masses occurring along a portion of the Santa Ana River. In addition, those structural faults that form barriers to subsurface flow and all other geologic features that affect the ground water movements in the area are discussed. A more detailed geologic description is included under Appendix E of this report.

Following the section on geology is a discussion of the various hydrologic factors that may affect the occurrence, movement, dispersion, and mixing of detergents in a ground water basin. The report is not intended to present the standard hydrological analysis, which normally includes items on supply, water utilization, and change in storage.

General Geology

Areal geology of the area is shown on Plate 2, "Areal Geology." Plates 3 through 6, "Geologic Sections A-A′, B-B′, C-C′, D-D′, E-E′, F-F,′ G-G′, J-J′, K-K′, L-L′, and M-M′," depict the subsurface geology along and across the Santa Ana River and adjacent plains. The surface and subsurface geology reported here is based upon field surveys and reconnaissance mapping, office studies, published reports, and exploratory drilling.

The Santa Ana River begins in the San Bernardino Mountains and flows in a general southern and southwestern direction and empties into the Pacific Ocean near Newport Beach, Orange County, California. In the study area, the river flows southwesterly and westerly across a broad floodplain in the reach from Loma Linda to Arlington. The floodplain at Colton Narrows constricts to 4,000 feet between Slover Mountain on the north and La Loma Hills on the south. Flanking both sides of the floodplain are the escarpments and terraces of the Riverside and Fontana Plains, which stand topographically higher than the floodplain itself. Crystalline rock masses protruding through the alluvial fans and plains rise above the surrounding alluvium. This crystalline complex is considered to be essentially nonwater-bearing.

Alluvium, derived from the San Gabriel, San Bernardino, and Box Springs Mountains, as well as the San Timoteo Badlands, comprises the material of the plains and floodplain. As is shown on Plate 2, the alluvial deposits have been separated into three divisions according to the superposition and degree of weathering. The river channel deposits (Qal) are composed of blue to black clays, silts, silty sand, and other fine-grained sediments. These have been referred to as River Channel Deposits (Qrc) in an earlier report by the United States Geologic Survey (USGS). These sediments occur to a depth of 25 to 30 feet below the river floodplain. In some parts of the floodplain, particularly over buried bedrock "highs," this member is missing. Younger alluvium (Qyal), the uppermost water-bearing zone, underlies this most recent alluvium and extends to a depth of approximately 90 to 100 feet. When water levels were high, these coarse-grained sediments acted as the main conduit for underflow across the San Jacinto fault, but they have decreased in importance with the lowering of the water table. Older alluvium (Qoal), which makes up the plains, terraces, and mesas, is composed of clay, silt, sand, and gravel. Three different types of older alluvium are discernible: Terrace deposits along the west side of Reche Canyon, resulting from downcutting processes of the Santa Ana River in its adjustment to sea level changes during glacial periods; alluvial fan material of the mesas and plains, which weathers to reddish brown clays and silts; and residual soils developing from the processes of weathering. This older alluvium, containing several aquifers, is the primary water-bearing zone. These deposits comprising the older alluvium also underlie both Recent alluvial deposits, Qal and Qyal, beneath the Santa Ana River floodplain. Aeolian deposits of sand overlie the older deposits, and although they are not important as waterbearing aquifer, they do serve as conduits to transport surface water as it percolates to the older alluvium.

Under that portion of the river between the Rialto-Colton Barrier and the San Jacinto fault, the older alluvium is underlain by Tertiary sediments known as the San Timoteo beds. The San Timoteo beds are not important as water-producing materials. These sediments also crop out in the San Timoteo Badlands, south of the Santa Ana River.

Downstream of the Rialto-Colton Barrier, the crystalline rock forms the floor upon which the alluvium of the Santa Ana River floodplain is laid. This basement complex also underlies the older alluvium and San Timoteo beds with a configuration that is undulating. The total thickness of all alluvial deposits in this area vary from 85 feet to possibly 400 feet. Subsurface "highs" of the bedrock occur beneath the Santa Ana River channel at Colton Narrows, at Rubidoux, and at Riverside Narrows. Upstream of the Rialto-Colton Barrier, few wells have reached a crystalline rock. Here the basement rock is broken into blocks, the first of which is an uplifted block between the Loma Linda and San Jacinto faults and the second is a downdropped block between the San Jacinto fault and Rialto-Colton Barrier.

The major structural feature in the vicinity is the San Jacinto fault that crosses the Santa Ana River about 2 miles northeast of Slover Mountain. This fault trends northwesterly-southeasterly and passes just to the east of Reche Canyon Road. The San Jacinto fault has a controlling influence on the movement of ground water from Bunker Hill Basin into Colton Basin, as well as possibly contributing thermal waters from deeper aquifers. Water level data indicate the existence of another subsurface barrier, referred to as the Rialto-Colton Barrier, which trends northwesterly from the general vicinity of the northern extent of Slover Mountain toward Rialto. Although little is known concerning the subsurface extent or characteristics of this barrier, an impedance to the movement of ground water from the Colton Basin is indicated. On the downstream side of this barrier, wells bottom in bedrock, while to the northeast no bedrock is encountered. Geoloigc sections A-A′ and B-B′ shown in Plate 3 depict the bedrock configuration.

General Hydrology

Ground waters in the immediate vicinity of the Santa Ana River downstream of the Loma Linda fault and upstream of Riverside Avenue are currently replenished by percolation of sewage effluents. To a lesser degree, they are replenished by deep percolation of rainfall, irrigation return water, occasional flood flows, and subsurface inflow. Subsurface inflow may consist of waters moving laterally or horizontally into the area. Thermal waters are added minor components of those waters, moving vertically upward along the San Jacinto and Loma Linda faults. These thermal waters may be meteoric waters which, through deep percolation, have contacted warm rock materials and moved toward the ground surface, or they may be magmatic, or connate, waters that find a release through the crushed materials along the faults. The source of these waters is indicated by their proximity to faults, by their high temperatures, and by their high concentrations of fluorides. Ground waters leave the Colton Basin by subsurface outflow, by being exported to land overlying other basins and, to a very minor extent, by evaporation and transpiration from consumptive use of riparian vegetation.

The area of investigation which lies along the Santa Ana River from Loma Linda to the Riverside Narrows at Pedley, is semiarid, with warm, dry summers and cool, wet winters. The mean average annual temperature is about 63° F, with variations from 18 ° to 118° F.

Precipitation

The rainfall season is in the winter with about 70 percent of the precipitation occurring during December, January, February, and March. Seasonal precipitation increases from south to north. Troxell attributes the precipitation in this area to three types of storms resulting from three different conditions: Pacific maritime air masses moving from the west and northwest upon the area form the principal source of winter precipitation; tropical Pacific maritime air masses moving in from the south and southwest provide a secondary source of winter rainfall; and tropical air masses originating over the warm waters of the Caribbean Sea and the Gulf of California infrequently lead to summer storms that move into the area from the south or southeast.(31) The unstable air from the three types of storms circulates because of the unequal temperatures existing among air masses. It is lifted over the mountains and there the water vapor in the clouds precipitates because of the lowered temperatures.

Two rainfall stations were selected for measuring precipitation, one at either end of the study area. The upstream location, at the U. S. Weather Bureau Station in the City of San Bernardino, shows a 50-year mean (1897 through 1947) of 17.35 inches. The downstream station, located in the City of Riverside, shows a mean seasonal precipitation of 10.65 inches (1930 through 1961). For the period of this study, the monthly rainfall is as shown in Table 2.

TABLE 2

Monthly Rainfall At Two Selected Stations

In inches

	San Bernardino station			*Riverside station*		
Month	*1962*	*1963*	*1964*	*1962*	*1963*	*1964*
January	2.32	0.77	1.65	1.65	0.17	1.20
February	5.58	3.12	0.32	4.02	2.41	0.24
March	1.74	1.61	--	.94	1.28	1.04
April	.02	2.42	--	.00	1.44	0.75
May	.67	0.00	0.39	.44	0.00	0.05
June	T	0.48	--	.04	0.09	--
July	.00	0.00	--	.00	0.00	--
August	.00	0.02	--	.00	0.11	--
September	.00	4.42	--	.00	3.91	--
October	.14	1.58	--	.01	0.32	--
November	T	2.66	--	.01	1.73	--
December	.04	0.27	--	.06	0.00	--
TOTAL		17.35		7.17	11.46	

For the 21-year period, 1927–1948 inclusive, calculations of the effect of rainfall indicate that, in the Colton Basin, 1,900 acre-feet of water has gone into deep penetration from rainfall and 1,100 acre-feet has gone into deep penetration from water artificially applied.(25) Dividing this 3,000 acre-feet by the 21-year period gives an annual mean of 143 acre-feet of deep percolation from rainfall and irrigation return waters exclusive of sewage. However, since 1948, this area has been experiencing a drought and, therefore, the amount of water available for deep penetration from rainfall is negligible.

Surface Flows

The natural surface flows of streams in the area of investigation occur only during times of moderate to heavy rainfall or infrequent flood flow. During periods of no rainfall, the flows that occur in both Warm Creek and the Santa Ana River consist mainly of effluent discharged from the City of San Bernardino Treatment Plants Nos. 1 and 2 located along these streams. The locations of these plants are shown on Plate 1. Santa Ana River and Warm Creek upstream of these plants have been dry since the beginning of this study. Presently, the percolating sewage effluent alone has contributed 12,261 acre-feet in the 1962-1963 fiscal year. Similarly, calculations of the amount of water removed by consumptive use of vegetation along the Santa Ana River show it to be less than 1 percent of the surface flow. Therefore, it will not be considered in this report.

Since 1961, the peak daily sewage discharges from the San Bernardino Plants Nos. 1 and 2 have occurred at noon, while the minimum daily releases were between 6 and 7 a.m. These flows are depicted in Figure 2. A smaller peak is indicated at 8 p.m. These fluctuations have held true for the three years of 1961–1963. Monthly variations of the sewage releases for the past five years as depicted in Figure 3 show that increasing quantities of effluent are being released yearly. Where the effluent releases exceeded the stream flow, the difference between the two is assumed to have percolated down through the soil in the reaches of the streams between the sewage treatment plants and the gaging stations.

To determine quantities of effluent percolating in the streambed and velocities of flow, discharge along the Santa Ana River at four locations downstream of San Bernardino Treatment Plants 1 and 2 was measured on July 23 and 24, 1963. The results of these measurements are shown on Figure 4 and the locations of the four measuring points are shown on Plate 1 as surface sampling stations. As the peak of the flow moved downstream, the quantity of flow diminished as it passed each station.

The maximum flow peak traveled downstream at approximate rates of 0.83 to 1.3 feet per second. Two hours were required to travel from Mt. Vernon Avenue to La Cadena Drive (from surface sampling stations A to B), a distance of 9,500 feet (1.3 feet per second); two hours from La Cadena Drive to the Duck Farm (from B to C), a distance of 6,000 feet (0.83 feet per second); and two hours from the Duck Farm to Riverside Avenue (from C to D), a distance of 8,700 feet (1.2 feet per second).

Of the total volume of waste water released by the two San Bernardino plants, 20 percent of the total had percolated by the time the flow reached Mt. Vernon Avenue gaging station, a distance of 7,200 feet; approximately 46 percent had percolated before the flow reached La Cadena Drive; 66 percent had percolated when the flow reached the Duck Farm; and 95 percent had percolated when the flow reached Riverside Avenue. These waters infiltrated into the zone of aeration and percolated downward to the ground water table.

Subsurface Flows

The USGS calculated subsurface flows across the San Jacinto fault through a section 5,800 feet wide in the upper 110 feet of alluvial material. However, no data could be found for other subsurface flows in other parts of the study area. For the years 1935 to 1949, the USGS determined that annual flows across the San Jacinto fault ranged from 23,700 acre-feet to 15,800 acre-feet.(33) Using the same thickness of alluvial materials and a cross section across the Santa Ana River approximately equal to that used by the USGS, the personnel of the Department of Water Resources updated these flow values from 1949 through 1962. The flows ranged from 10,500 acre-feet in 1950 to 3,000 acre-feet in 1962. From recent geological exploratory drilling, the thickness of the Recent alluvium was found to be 85 feet. Therefore, a revision of the previously mentioned figures was necessary. Revised subsurface flows range from 19,700 acre-feet in 1935 to a low of 2,500 acre-feet in 1962, a reduction of approximately 17 percent from the earlier USGS data.

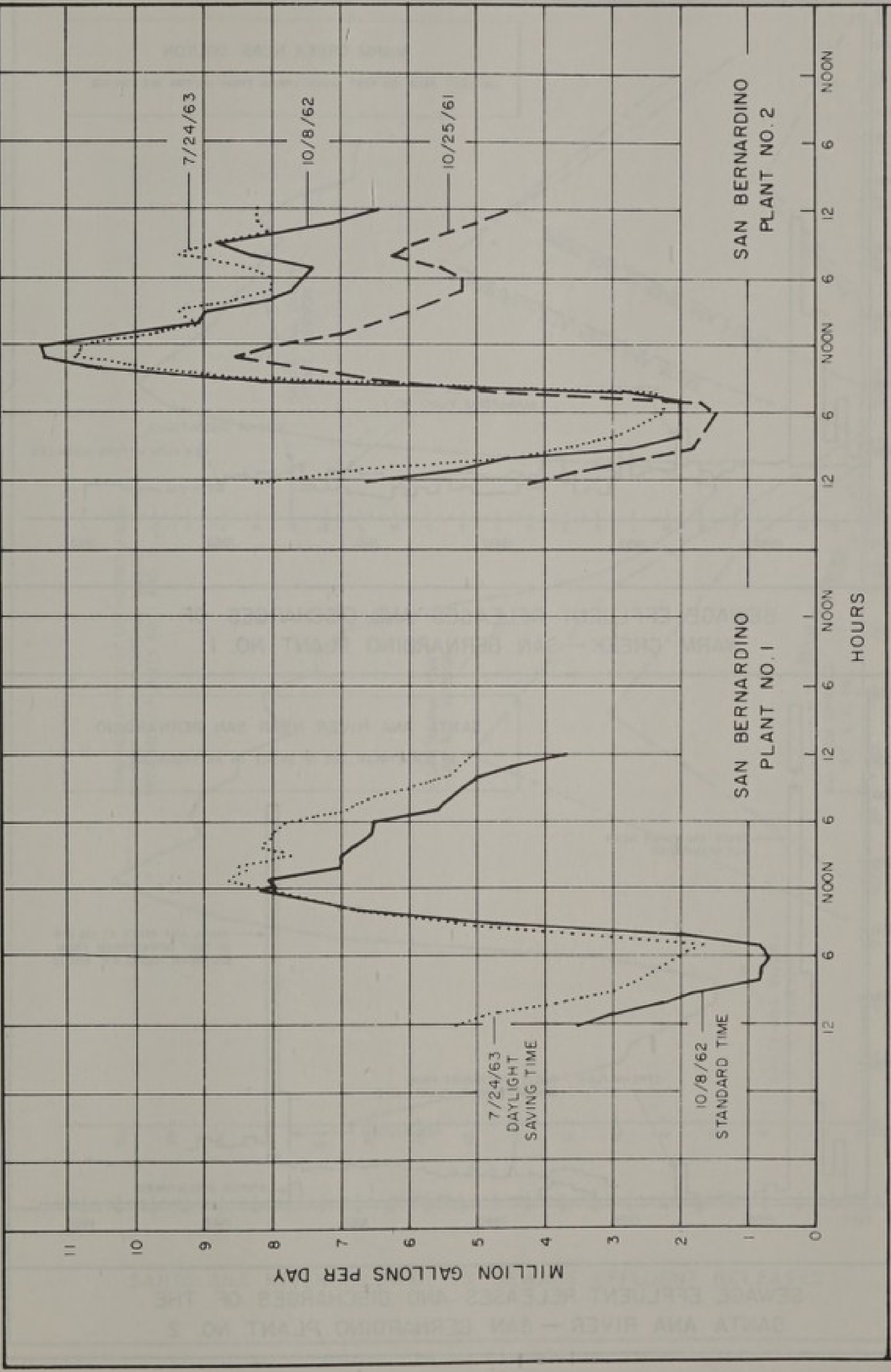
Results of a well canvass and sampling program carried out in July 1962 revealed an advancing ABS front that was not restricted to the river. This was an indication that subsurface materials were serving as conduits to divert ground water around areas of exposed basement complex. To determine the magnitude and direction of these subsurface flows, the formula $Q = TIW$ was used; where Q is the quantity of flow, T is the transmissibility, I is the water table gradient and W is the width of section taken for the calculation.

For this report subsurface flows, based on water levels as of winter 1961 and spring 1963, were then calculated at different places throughout the study area. Transmissibility values, based upon well pump tests, were assigned to various lithologic materials shown on drillers' well logs on file with this department. Plate 7, "Ground Water Flows, Winter 1961," and Plate 8, "Ground Water Flows, Spring 1963 and Ground Water Quality, 1962–1964," indicate the most probable paths of subsurface flow. The arrows serve as vectors to represent relative magnitude of the flow quantities. Apparent velocities of subsurface flows are listed at each cross section line directly beneath the value of the subsurface flow.

Subsurface Flows for Winter 1961.

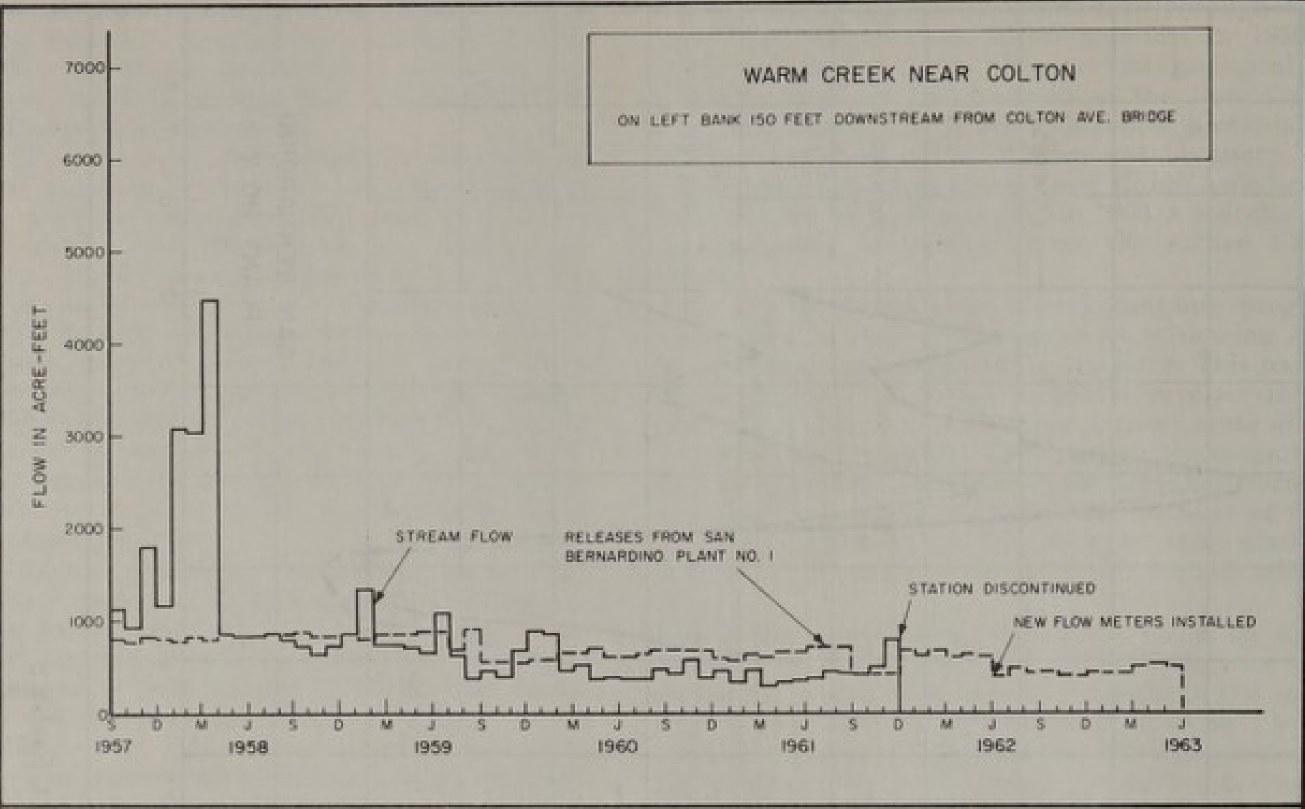
Plate 7 depicts the subsurface flows for the study area based on ground water elevations for the winter of 1961. During this period, subsurface flows in the amounts of 16,790 acre-feet per year (AFY) (Line B-B′) and 7,117 AFY (Line A-A′) were directed toward Section 32, T1S, R4W. This area was heavily pumped in the summer and fall of 1961 and the pumping depression that developed created gradients so that waters were drawn both from the vicinity of Slover Mountain and the East Riverside Mesa. That water drawn from the East Riverside Mesa to the Santa Ana River was probably derived from subsurface percolation of applied irrigation on the higher slopes of the mesa. Subsurface water leaving the East Riverside Mesa between La Loma Hills and Box Springs Mountains in the winter 1961 was 7,665 AFY (Line E-E′). Line D-D′ indicates that only 2,007 AFY flowed beneath the Santa Ana River north of the La Loma Hills and that 657 AFY of this amount (Line F-F′) passed north of Mount Rubidoux. Subsurface flow in a southwestern direction between Mount Rubidoux and Pachappa Hill amounted to 730 AFY (Line G-G′). Subsurface flow across Line C-C′ was not calculated for the winter 1961.

FIGURE 2

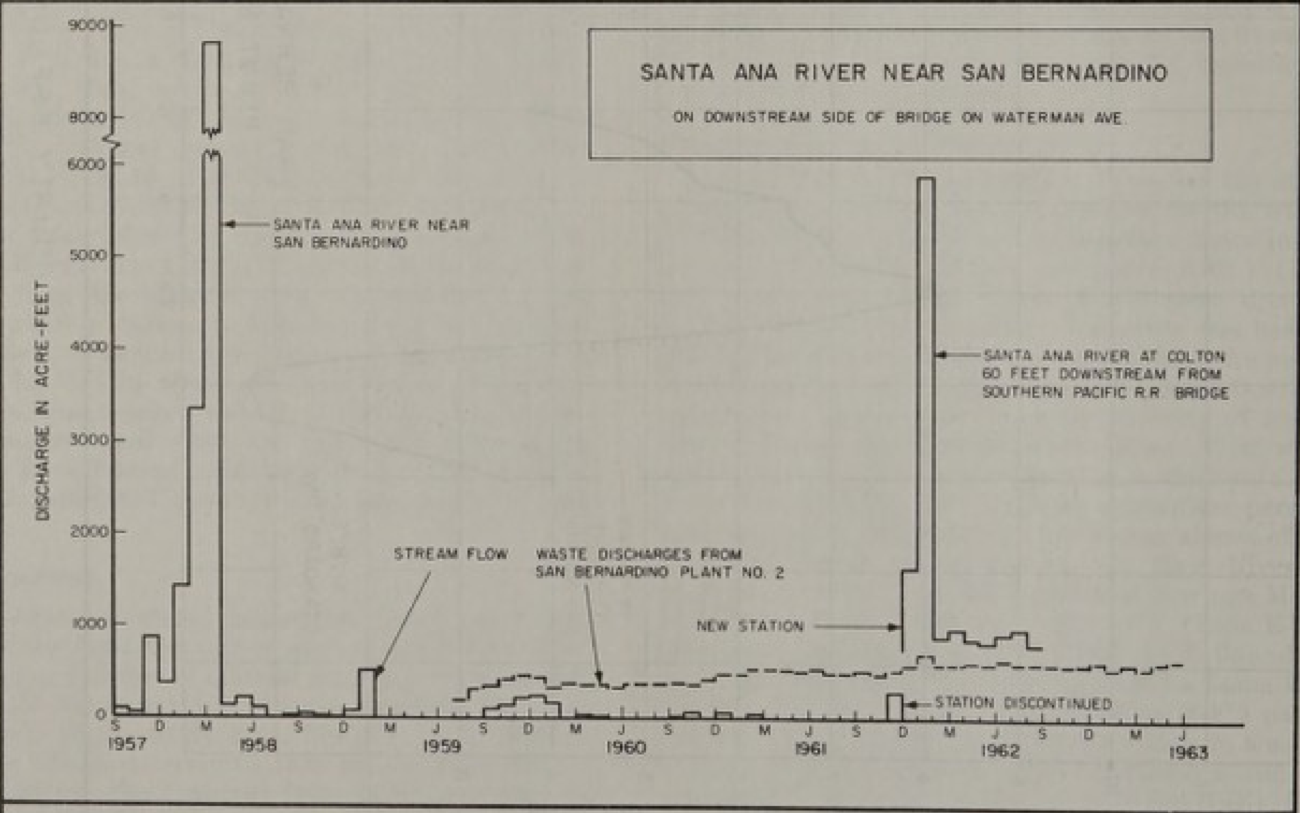


HOURLY EFFLUENT RELEASES

FIGURE 3

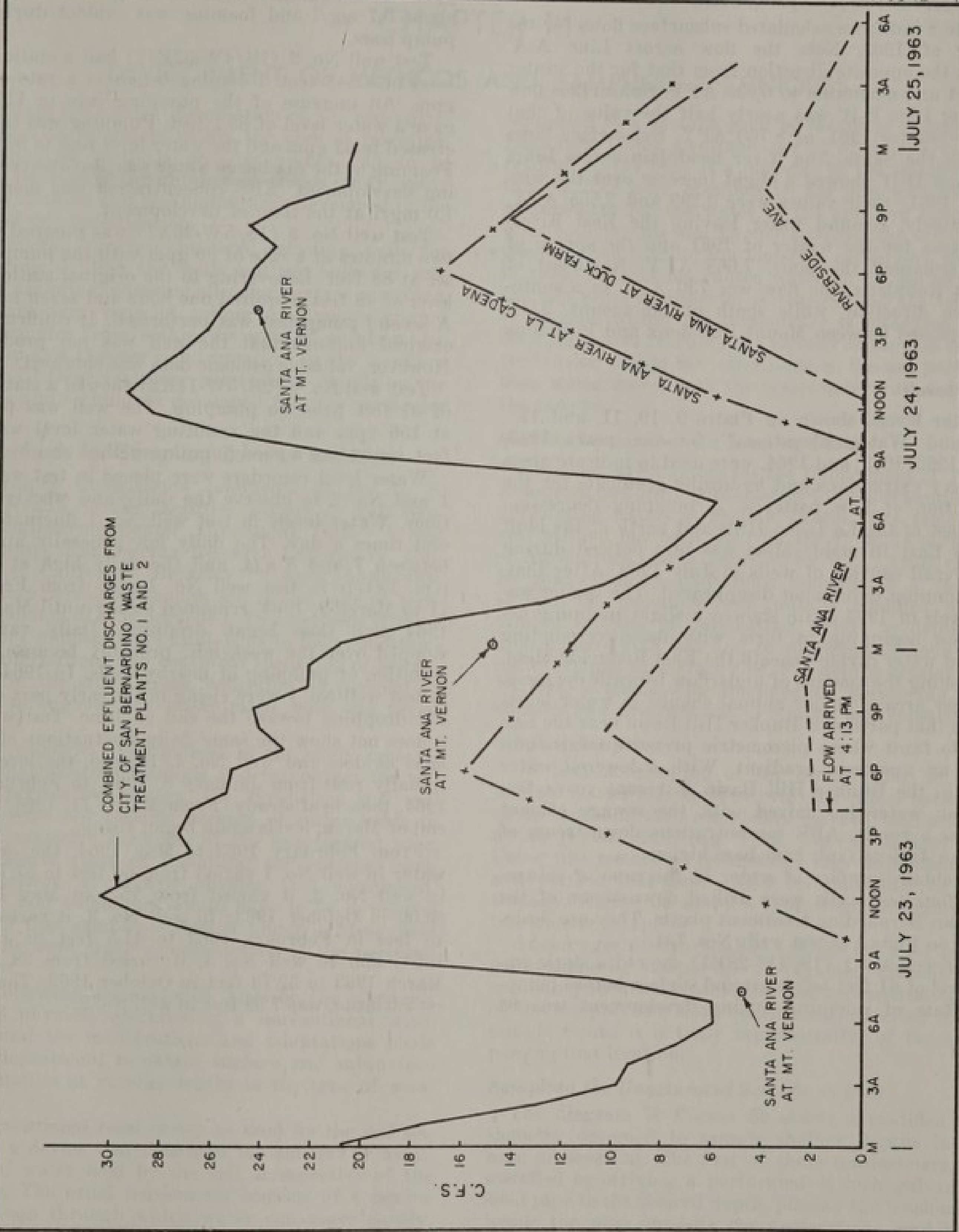


SEWAGE EFFLUENT RELEASES AND DISCHARGES OF WARM CREEK — SAN BERNARDINO PLANT NO. I



SEWAGE EFFLUENT RELEASES AND DISCHARGES OF THE SANTA ANA RIVER — SAN BERNARDINO PLANT NO. 2

FIGURE 4



SANTA ANA RIVER FLOWS VS. SEWAGE EFFLUENT RELEASES

Subsurface Flows for Spring 1963.

Plate 8 indicates calculated subsurface flows for the spring of 1963. Note the flow across Line A-A′ was in the opposite direction from that for the winter of 1961 and amounted to 6,935 AFY. Subsurface flow crossing Line B-B′ was nearly half the value of that for the winter 1961, or 8,760 AFY. Subsurface flows beneath the Santa Ana River floodplain across Lines C-C′ and D-D′ showed a slight increase over the winter of 1961; their values were 2,299 and 2,555 AFY, respectively. Ground water leaving the East Riverside Mesa for the winter of 1961 and the spring of 1963 remained the same, 7,665 AFY. Northeast of Mount Rubidoux, the flow was 730 AFY in a southwestern direction, while south of the mount, 2,007 AFY passed between Mount Rubidoux and Pachappa Hill.

Water Levels

Water levels, shown on Plates 9, 10, 11, and 12, "Ground Water Elevations" for the years 1945, 1961, 1962, 1963, and 1964, were used to indicate areas of heavy extractions and hydraulic gradients for the evaluation of flow patterns. A pumping depression just east of the La Loma Hills and north of the bluff of the East Riverside Mesa was first noticed during the overall canvass of wells in July 1962. After that, the pumping depression disappeared. The spring water levels of 1963 again showed a slight pumping depression beginning to form with its corresponding ground water divide beneath the East Riverside Mesa, controlling the amount of underflow beneath the mesa. Another area of major annual change in water levels was in that portion of Bunker Hill Basin near the San Jacinto fault where piezometric pressure levels indicated an upstream gradient. With a lowered water table in the Bunker Hill Basin in recent years, less dilution water has mixed with the sewage effluent and, as a result, ABS concentrations downstream of the San Jacinto fault have been higher.

To obtain samples of water in the zone of saturation, four test wells were drilled downstream of the two San Bernardino treatment plants. They are designated on Plate 1 as test wells Nos. 1–4.

Test well No. 1 (1S/4W-28E1) showed a static water level of 61 feet below ground surface before pumping. Rate of pumping during development was 94 gpm. ABS concentration in the ground water was about 0.7 mg/l and foaming was evident during the pump tests.

Test well No. 2 (1S/4W-32E12) had a static water level of 82.48 feet. Pumping began at a rate of 74.1 gpm. An increase of the pumping rate to 117 gpm gave a water level of 85.1 feet. Pumping was then decreased to 62 gpm and the water level rose to 83.0 feet. Foaming of the discharge water was also observed during development. ABS concentration was more than 1.0 mg/l at the time of development.

Test well No. 3 (1S/5W-36A1) was pumped dry in two minutes at a rate of 90 gpm with the pump bowls set at 88 feet. Recovering to the original static water level of 46 feet, required one hour and seven minutes. A second pump test was performed. It confirmed the original findings that the well was not productive. However, valuable geologic data was obtained.

Test well No. 4 (2S/5W-11K2) showed a static level of 31 feet prior to pumping. The well was pumped at 156 gpm and the resulting water level was 34.5 feet, indicating a good pumping well.

Water level recorders were placed in test wells No. 1 and No. 2 to observe the daily and weekly variations. Water levels in test well No. 1 fluctuated several times a day. The daily low generally appeared between 7 and 8 a.m. and the daily high at 1 to 4 p.m. Levels in test well No. 1 rose from February 11 to March 2, 1964, remained steady until March 11, 1964, and then began dropping. Daily variations stopped over the weekends, probably because of the cessation of pumping of nearby wells. In 1964, levels in test well No. 1 were rising in the early part of May but dropping toward the end of June. Test well No. 2 does not show the same daily fluctuations of water level as does test well No. 1. Instead, the levels continually rose from January 8, 1964, to February 24, 1964, then held steady. From March 11, 1964, till the end of March, levels again began rising.

From February 1963 to May 1964, the depth to water in well No. 1 varied from 64 feet to 57.75 feet; in well No. 2, it varied from 75.5 in May 1963 to 83.09 in October 1963; in well No. 3, it varied from 45 feet in February 1963 to 41.5 feet in January 1964; and in well No. 4, it varied from 28 feet in March 1963 to 32.73 feet in October 1963. The greatest variation was 7.59 feet in well No. 2.

CHAPTER III

DEVELOPMENT OF METHODS AND SAMPLING TECHNIQUES

To obtain the needed information on the concentrations of ABS in waters within the area of investigation, sampling methods and techniques had to be chosen. Because of the uniqueness of this study, many of these methods and techniques were developed in the course of this investigation.

The overall program involved selecting wells for monitoring, drilling test wells and test holes for subsurface sampling, choosing sites for surface sampling, and developing ways of taking continuous ground water samples from within the zone of aeration. Included in this chapter is information on the locations for each of these sampling points, plus details on the methods and techniques developed for this particular study.

Methods for Sampling Zone of Aeration

Laboratory experiments conducted at the U. S. Public Health Service facilities, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio (27), and the Sanitary Engineering Research Laboratory, University of California, Berkeley (16) have shown that when ABS percolates though soil in the zone of aeration, a portion of it is degraded. To determine if these laboratory findings were applicable to field conditions under intermittent and continual spreading of sewage effluent in the study areas, collection of percolating effluent throughout the unsaturated zone was necessary.

Early geologic investigations of the study area revealed that existing methods and techniques for collecting percolating waters, (i.e. lysimeters and well points) were not feasible because of unfavorable lithology, excessive thickness of the unsaturated zone, and excessive costs of installing conventional sampling devices. It became obvious that equipment, methods, and techniques would have to be developed to insure that samples collected under existing field conditions were truly representative of the percolating water.

The following sections will describe the construction and physical operation of a conventional tensiometer and the modifications and adaptations made by the department to obtain surface and subsurface water samples at various depths in the zone of aeration.

A conventional tensiometer as used by the soil scientist is a device that measures the amount or availability of water held by the soil, irrespective of the soil type. The usual tensiometer consists of a porous ceramic cup through which water can move slowly, a connecting tube, and a vacuum gage. The small pores of the cup, together with the surface tension of water make possible the development of 29 inches of vacuum within the cup. As used in soil science the ceramic cup is filled with water, placed in the soil, and connected to a vacuum gage by means of a copper or glass tube. After a suitable period of time, a vacuum reading on the gage is a measure of the soil-moisture tension. The pore openings in the cup wall provide passageways for the water in the cup and the water films covering the soil particles. When the soil is under less than equilibrium moisture conditions, tension in these water films causes water to be pulled from the cup until equilibrium is reached and the tension, or suction, within the tensiometer is measured. Percolating waters reaching the vicinity of the cup reduce the tension within the water films on the soil particles, thus water moves into the tensiometer cup reducing the vacuum.

Modified Tensiometer as a Sampling Device

Previous investigators for the Department of Water Resources had used tensiometers to obtain samples of percolating waters at shallow depths. The same general method has been used by the U. S. Department of Agriculture and is described by V. A. Aronovici.(1) Because of depth limitations inherent in a vacuum system, the technique was initially confined to obtaining samples of percolating waters to depths of approximately 18 feet and to obtaining 24-hour composite samples of surface flow. For depths greater than 18 feet, a tensiometer modification employing both vacuum and pressure was developed and constructed.

Surface Sampling

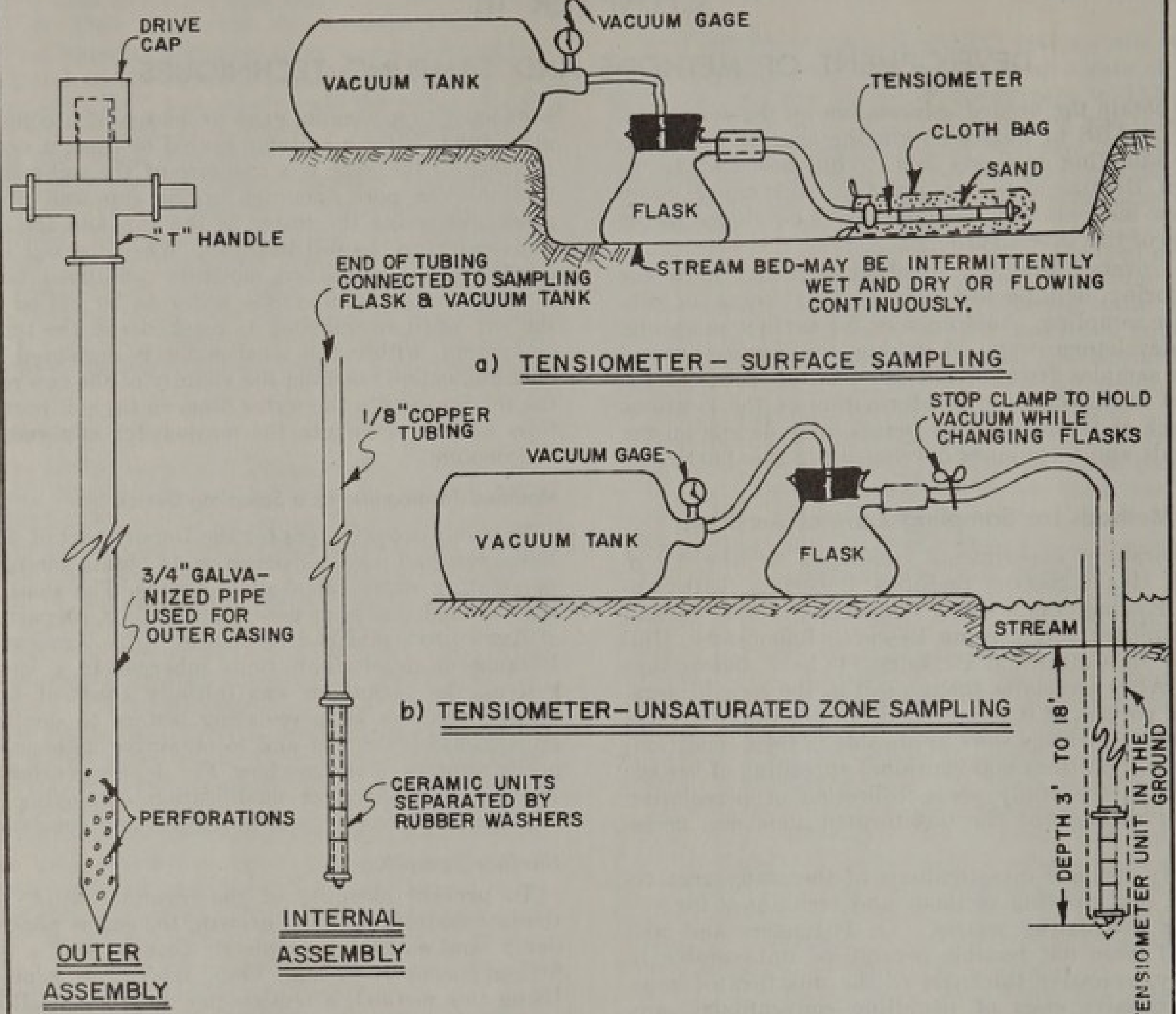
To prevent clogging of the ceramic cup by particulate matter and algal growth, the cup is packed in damp sand and then completely covered with a tight-fitting porous cloth bag. Thus, the cup is kept wet. Using this method, a tensiometer may be installed in a streambed that flows either intermittently or continually. Figure 5a shows a typical surface sampling tensiometer setup.

Advantages of this method are the low cost (a 24-hour composite sample can be obtained without anyone being in attendance) and the representativeness of the sample. The slow, continuous collecting of the sample means it is truly representative of the water passing that location.

Sampling the Unsaturated Zone to 18 Feet

The diagram in Figure 5b shows a modified tensiometer designed to sample shallow depths in the zone of aeration. The first of these tensiometers was installed by driving a perforated ¾-inch galvanized steel pipe to the desired depth, placing the tensiometer inside the pipe opposite the perforations, and backfilling with native soil. One installation of this type in good, homogeneous sandy soil was made to a depth of 18 feet. This method of installation did not prove satisfactory at other test sites. The pipe was bent when it was driven into cobble-boulder soils and the

FIGURE 5



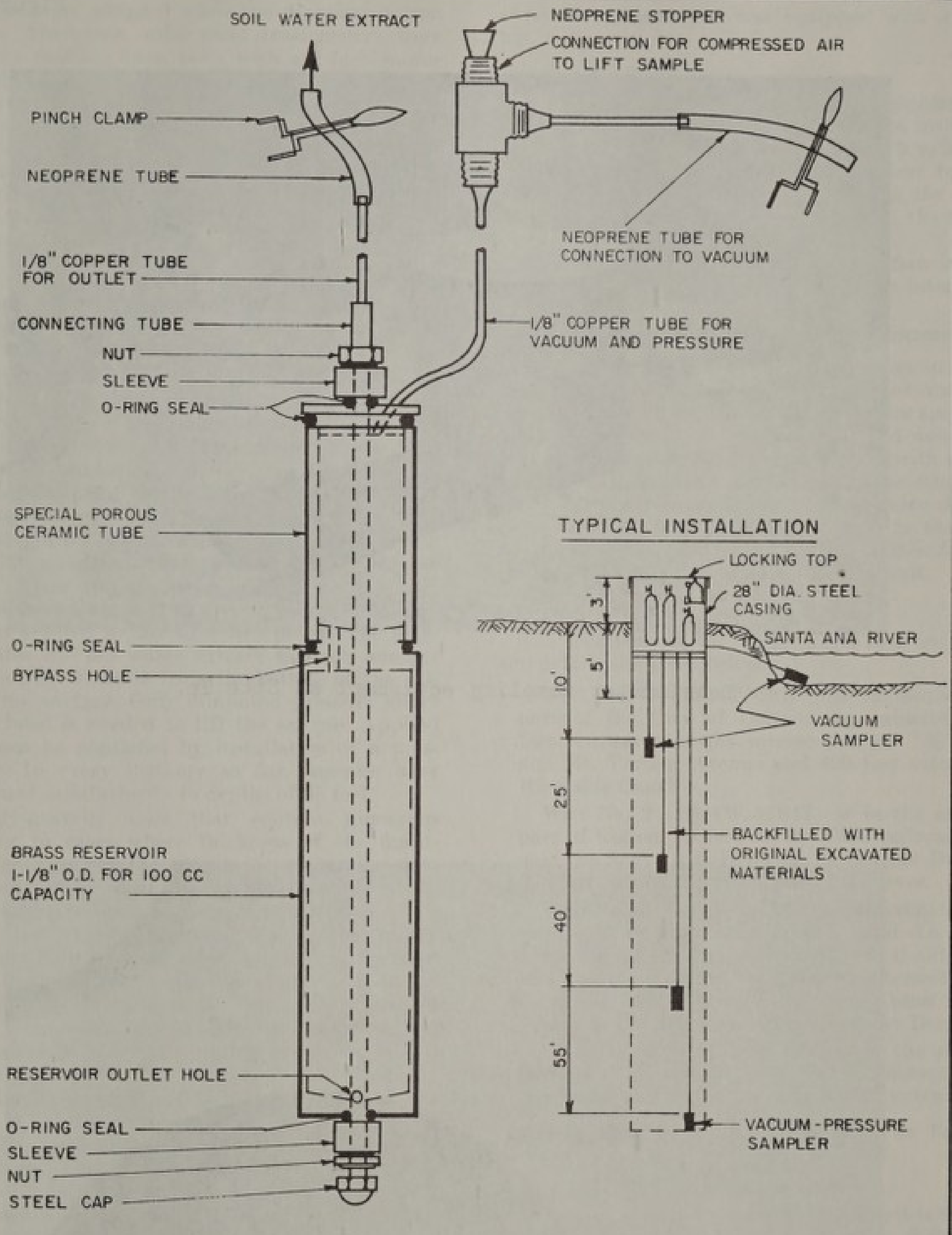
NOTE

THE UNIT CONSISTS OF TWO PARTS. THE OUTER ASSEMBLY IS A METAL PIPE THAT IS PERFORATED AT ITS LOWER END TO ALLOW SOIL MOISTURE TO ENTER. THE INTERNAL ASSEMBLY IS A SERIES OF POROUS CERAMIC UNITS CONNECTED TO A LENGTH OF COPPER TUBING. THIS UNIT IS PLACED INSIDE THE CASING. ANNULAR SPACE BETWEEN THE TWO ASSEMBLIES IS FILLED WITH SAND. THE END OF THE COPPER TUBING IS CONNECTED TO THE SAMPLING FLASK AND VACUUM TANK.

(NOT TO SCALE)

DIAGRAMMATIC SKETCH SHOWING USE OF TENSIOMETER

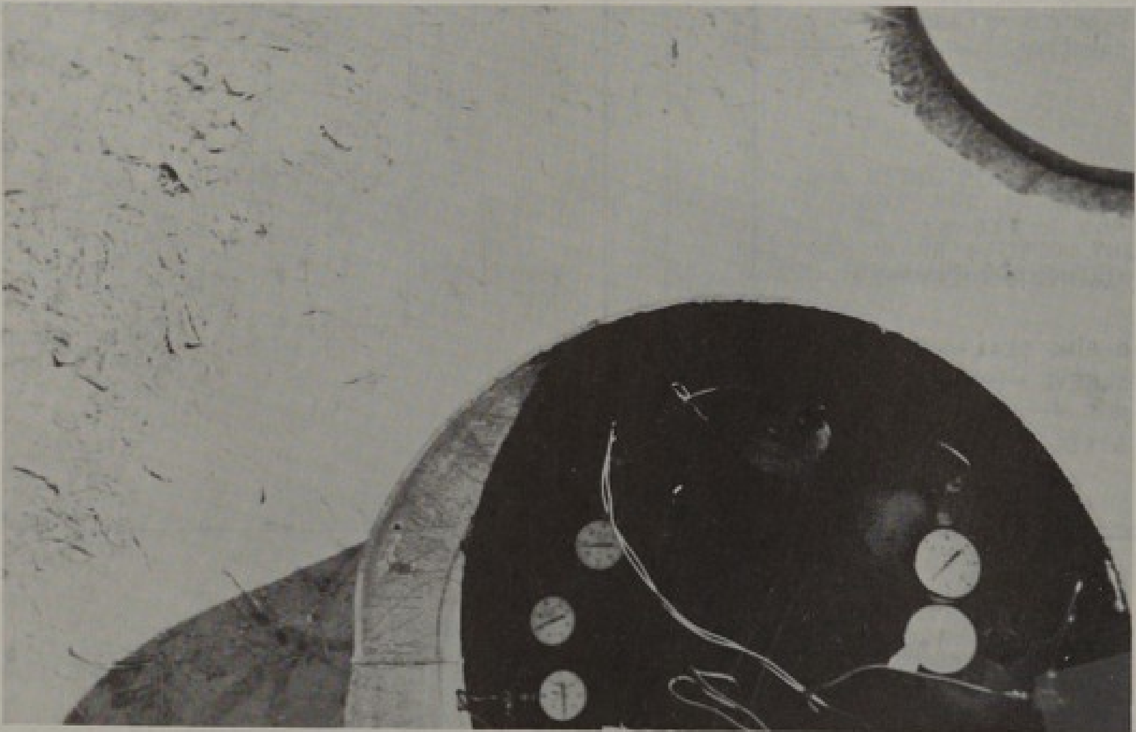
FIGURE 6



VACUUM-PRESSURE SAMPLER

Figure 7

Tensiometer sampling equipment at Site Te.



Interior of equipment at Site Te.

perforations were plugged when the pipe was driven into clays. Therefore, subsequent tensiometers were installed by drilling open holes with a 4-inch power auger and then backfilling with the excavated material. However, when unconsolidated dry sand and boulders were encountered, tensiometers could be installed to a maximum depth of only 10 feet. In sand, caving was experienced, and in soils containing large boulders the power auger failed. Attempts to use temporary casing and drilling mud to keep auger holes open in sand proved fruitless.

Sampling the Unsaturated Zone at Greater Depths

To sample percolating waters in the zone of aeration at depths exceeding 18 feet, modifications had to be made to overcome depth limitations of the vacuum system and to make satisfactory installations.

To overcome the depth limitations of the tensiometer described above, a pressure system was incorporated in it to lift samples from deeper zones. This system is described below.

Vacuum is applied to the sampling unit via a ¼-inch diameter copper tube. Soil water passes through the special porous ceramic unit and is stored in an attached 100 cc capacity reservoir, as can be seen in Figure 6. After the reservoir is filled to capacity, the tube is disconnected from the vacuum source, and pressure is applied by use of a tire pump. The pressure elevates the soil water extract through another ¼-inch tube that extends from the bottom of the reservoir to the surface. Only minimum pressure above the static head is needed to lift the sample. Applied pressure can be regulated by installation of a pressure gage. In every instance so far, samples have been obtained satisfactorily to depths of 55 feet.

In sandy-gravelly soils that contain numerous boulders or in cases where thickness of the unsaturated zone requires the placement of tensiometers deeper than can be done by driving or auger methods, a drilling type operation had to be adapted.

At the last tensiometer site chosen, the rotary bucket auger drilling method was selected as the most economically suitable for placing sampling units. A 28-inch hole was drilled to 55 feet without use of mud or temporary casing. Modified tensiometers were installed in this hole at depths of 55, 40, 25 and 10 feet.

Protective lightweight plastic pipe of sufficient size to enclose the sampling unit was set to the bottom of the hole. The tensiometer was lowered inside the pipe to the bottom. Then a small amount of clean, well-sorted sand was added through the pipe to provide a tight pack around the ceramic unit. Backfill was shoveled into the hole while the plastic pipe was being removed. Care was taken to keep at least 1 foot of the pipe buried in the fill while working it to the surface so as to protect the ceramic unit from crushing. Using the same method, other tensiometers were installed at successively more shallow depths.

To provide a convenient and pilfer-proof enclosure for vacuum bottles and connections, an 8-foot section of steel casing with a 28-inch diameter was installed as shown in Figure 7. The casing extended 3 feet above the ground and was equipped with a locking top.

Tensiometer Sites

The five sites chosen for installing tensiometers are shown on Plate 1. The instruments were installed on the surface and at depths ranging from 3 to 55 feet—all within the zone of aeration. The first four sites were confined to 18 feet or less, but with the development of the techniques described above, the depth at the last site was increased.

At sites Ta, Tb, and Te, the surface flow is continuous, but at sites Tc and Td, the flow is intermittent.

Methods for Studying Vertical Dispersion

To be able to study vertical dispersion in the saturated zone, four test wells were drilled and perforated to allow extractions of samples from specific elevations, and two test holes were drilled downstream of the San Jacinto fault and equipped with piezometers (two in one hole, and three in the other). The piezometers were installed also to determine the movement of ABS from the shallow zone to the deeper aquifers downstream from the San Jacinto fault and through the deeper aquifers across the fault.

Location of Test Wells

The locations of the wells are shown on Plate 1, and details are given below:

Well No. 1 (1S/4W-28E1) is in the southeast part of the City of Colton, approximately 1,300 feet southwest of the intersection of "M" Street and Mt. Vernon Avenue and 400 feet south of the Riverside Canal.

Well No. 2 (1S/4W-32E12) is in the southwest part of Colton, 75 feet south of the railroad bridge over the Santa Ana River on La Cadena Drive and 500 feet east on the south side of the levee.

Well No. 3 (1S/5W-36A1) is approximately halfway between Riverside Avenue and La Cadena Drive along the Santa Ana River, 1 mile northeast on Agua Mansa Road from its intersection with Riverside Avenue and 1,700 feet southeast of Agua Mansa Road. This area is known as the Duck Farm.

Well No. 4 (2S/5W-11K2) is in the northeast portion of Riverside, 600 feet northwest of the northwest end of Santa Ana Street extended.

The depth of each test well is shown in Table 3.

TABLE 3

Depth of Test Wells

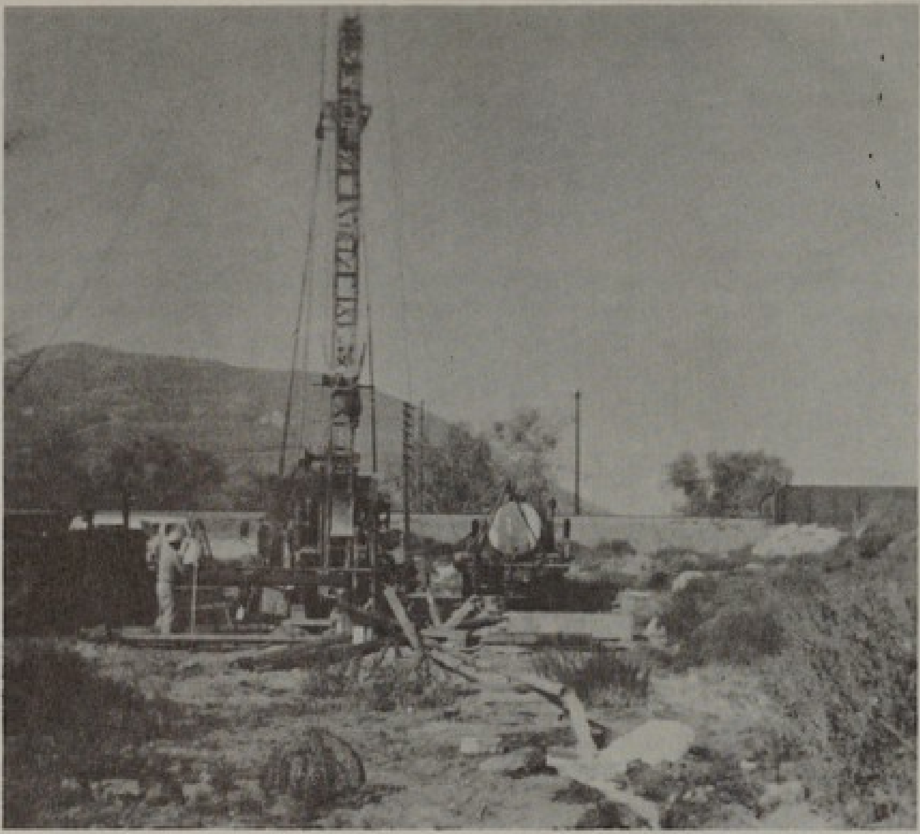
Well site	*Total depth, in feet*	*Depth to bedrock, in feet*
No. 1	200	600–700 *
No. 2	200	450 *
No. 3	100	90
No. 4	400	395

* Estimated

Drilling of Test Wells

On October 12, 1962, drilling was started on the first of the four test wells for the investigation. A cable tool rig was used to drill all wells, as may be

Figure 8



Construction of test well No. 2.

Foam from test well No. 2 during
development.

seen in Figure 8. In each hole, approximately 30 feet of 10-inch surface casing was installed prior to placing ¼-inch single wall steel casing of 8-inch diameter. The casing thickness and structural strength complied with American Water Works Association Specifications for Deep Wells (A100). All casing joints were circumferentially welded before driving. After placement, the casing was perforated at selected intervals using a Mills knife. The perforations were 2 inches in length and ¼ inch in width, with six perforations per row. The rows were generally spaced 4 feet or more apart, except in the interval between the historical "high" water levels and the water table where the perforations were cut on 2-foot centers.

Well development was accomplished by the installation and use of a temporary turbine test pump. The pump was operated at varying capacities with intermittent bailing until the discharge water was clear of silty and sandy material. Well No. 3 showed a very poor yield during development, in that it could not be pumped at a rate of more than two gallons per minute.

After development of the wells, the surface casing was pulled and a cement seal was poured. Construction was completed by equipping each well with a locking cap.

Drill hole logs were based on the classification and description of bailer samples. Samples were collected at each bailing and at other designated intervals. All logging was done by a geologist at the well site. Soil samples obtained from various depths were retained for reference and possible future analyses.

Description of Packer Pump

To obtain selected depth samples from test wells, the Department of Water Resources designed and constructed a portable, self-contained pumping unit. The pump consisted of a one horsepower, submersible pump that had inflatable rubber packers banded above and below the pump intake at 18-inch centers. The packers were inflated by air pressure through an airline. A minimum pressure of 6 to 9 pounds per square inch above the the static head of water was required to inflate the packers. These packers sealed the casing at the desired depth. The pump is shown in Figures 9 and 10.

Wells were sampled with the packer pump at selected perforation depths to determine the vertical profile of ABS concentrations in the ground water. The pumping was started as soon as the wells were completed so as to have as long a pumping record as possible.

Prior to the next pumping of the test wells, tests were conducted to determine the optimum rate and time of pumping required to assure that samples were collected from the chosen depths and that no leakage was occurring between the casing wall and the inflated rubber packers.

The packers were tested against leakage by pressure tests and chloride conductivity tests as described below. These tests indicated that no leakage was taking place between the packers inside the casing. As a result of these tests, pumping at a rate of 5 gallons per minute for 20 minutes was found to be the best rate to assure that samples were obtained from the desired aquifer. It was also determined from chloride conductivity tests that some leakage occurred outside the casing between the adjoining 4-foot perforations during the pumping of the well. This resulted in an actual 5- to 10-foot thickness of the aquifer being sampled.

Horizontal and Vertical Velocities

A point dilution technique, using chloride as a tracer, was conducted on well No. 1 to determine horizontal flow-through velocity. This test is made by introducing sodium chloride into a well. After mixing, the chloride concentrations in the well water are measured at suitable time intervals. Because the natural horizontal flow of ground water through the well will dilute the tracer, the reduction in chloride concentrations is proportional to the average water velocity along the aquifer intercepted by the well. These tests showed considerable horizontal movement of water through the well, with velocities that varied with depth. These velocities ranged from 5.0 feet per day to as little as 0.1 foot per day. The lowest velocity occurred at the 180-foot depth where the well log showed the presence of soils of lower permeability. Well No. 2 also showed considerable horizontal flow-through, as indicated by the rate of disappearance of chloride under nonpumping conditions.

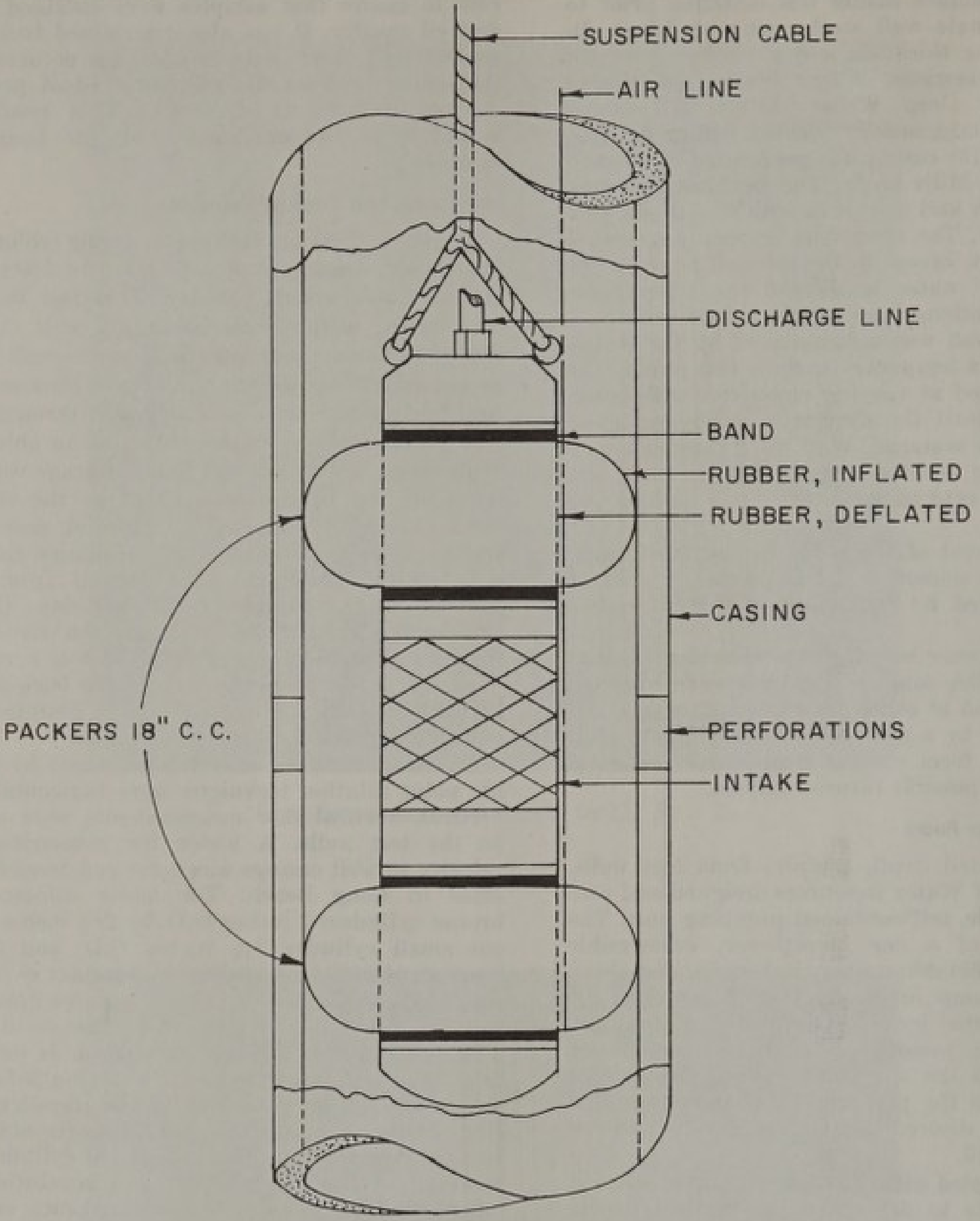
To assure that the velocities measured by the chloride point dilution technique were horizontal and not vertical, vertical flow measurements were conducted on the test wells. A meter for measuring vertical velocity in well casings was borrowed from the USGS office in Long Beach. The meter consists of two bronze cylinders 3 inches O.D. by 26½ inches long and one small cylinder $2\frac{1}{16}$ inches O.D. and 5⅝ inches long, an aluminum impeller and contact switch in the small cylinder, a 6-volt battery and headphones, and 400 feet of double electric wire. The small cylinder with the impeller and contact switch is inserted between the two larger cylinders, leaving 2 feet of the long cylinders on each end of the impeller, thereby eliminating any interference from horizontal flow. If vertical flow is occurring through the cylinder, a click is heard at the headset per each revolution of the impeller. Vertical velocity measurements were made at 20-foot intervals from just below the standing water level in the casing, and they were continued to the bottom of the well. No measurable vertical velocities were obtained in any of the wells, as indicated by lack of any revolutions of the impeller.

Location of Test Holes

Plate 1 shows the location of the two test holes containing five piezometers which are designated as test wells 5P and 6P. They were adjacent to the San Jacinto fault and downstream of it. They were designed to ascertain ABS concentrations and movement at selected depths down to 400 feet.

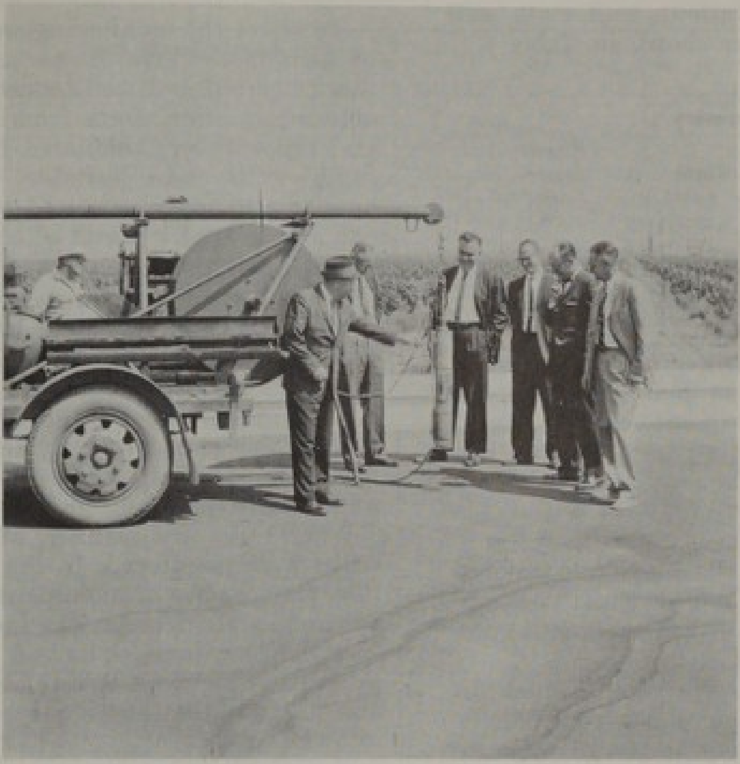
Piezometer 5P is at the apex of the area bounded by the flood control barrier and the western off-ramp

FIGURE 9

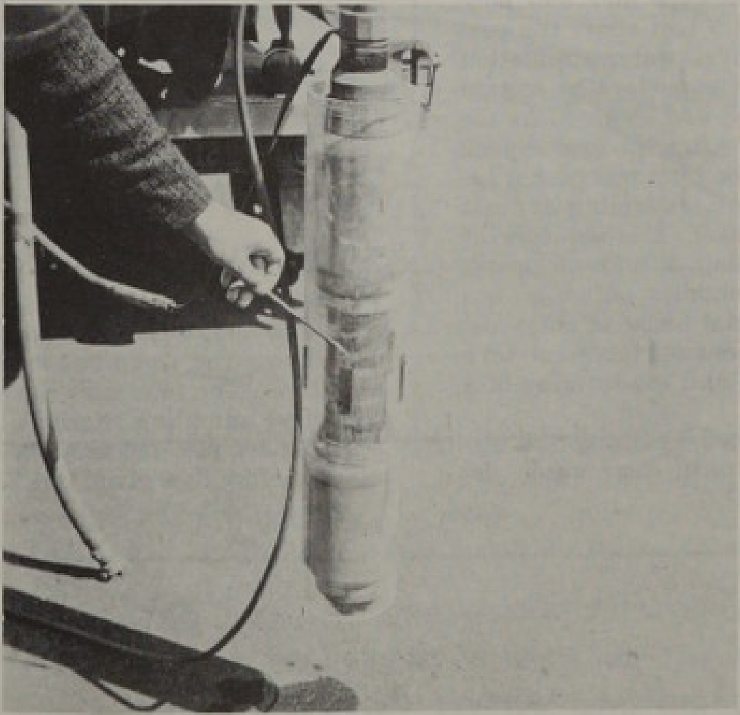


DEPTH SAMPLING PUMP

Figure 10



Portable, self-contained pumping unit.



Submersible pump with rubber packers
inflated inside a plastic casing.

from the Barstow Freeway to the San Bernardino Freeway.

Piezometer 6P is immediately west of piezometer 5P.

The perforated depths, elevations, and state well numbers of each piezometer are shown in Table 4.

TABLE 4

Depth of Piezometers

Piezometer site	*Perforated depth, in feet*	*State well number*	*Elevation at top of pipe, in feet*
5P–A	378–398	1S/4W–21R3	965.5
B	286–306	–21R4	965.9
C	172–192	–21R5	966.1
6P–A	136–156	–21R6	965.8
B	100–120	–21R7	967.2

The two 7¾ inch holes were drilled by the hydraulic rotary method. A geologist was present during all drilling operations to log the sequence and nature of sediments encountered in the well bore. At the end of each drill rod penetration, the mud was circulated until all formation cuttings were brought to the surface.

Immediately after reaching the maximum desired depth, the hole 5P was electric logged. Final positioning of piezometers was determined from examination of the lithology and electric logs.

Schedule 40, galvanized-steel pipe of 1.315-inch diameter was used for the piezometers. Each piezometer contained 20 feet of perforated pipe placed opposite the desired sampling depth. The perforated sections of pipe had two ⅛-inch diameter holes per round with each round set 90 degrees from the previous round and eight rounds per foot.

The bottom piezometer pipe was placed at the selected depth and clear water was circulated through the pipe. After the mud was thinned back enough to prevent "bridging," clean, rounded pea gravel was added. The annulus between the pipe and well bore was filled with gravel to at least 5 feet above the perforations. After placing the gravel, water circulation was continued opposite the entire perforated section until the gravel was consolidated and cleaned. As the gravel settled, more was added. After the gravel pack had been installed, a cement grout plug was placed between the pipe and the well bore, extending at least 10 feet above the top of the gravel. This sequence of placing piezometers, gravel-packing, and grouting was continued until the required number of pipes was placed in each drill hole. The final phase of construction was the pouring of a cement surface seal to a point 35 feet below ground level and the forming of a cement pedestal at each site.

The piezometers were developed by using the airlift method. Each was pumped until clear water, devoid of sand and silt, was obtained. The airlift method is also used for periodic sampling of the piezometers.

Methods for Selecting Monitoring Wells

To select the monitoring wells, a canvass was made of wells in the area of investigation, a base well map was prepared and wells coded according to the available information. Data from well logs and well drillers' reports were tabulated for the selection of sampling wells most suitable for monitoring. Water quality data were reviewed to determine which wells had the longest records of chemical data.

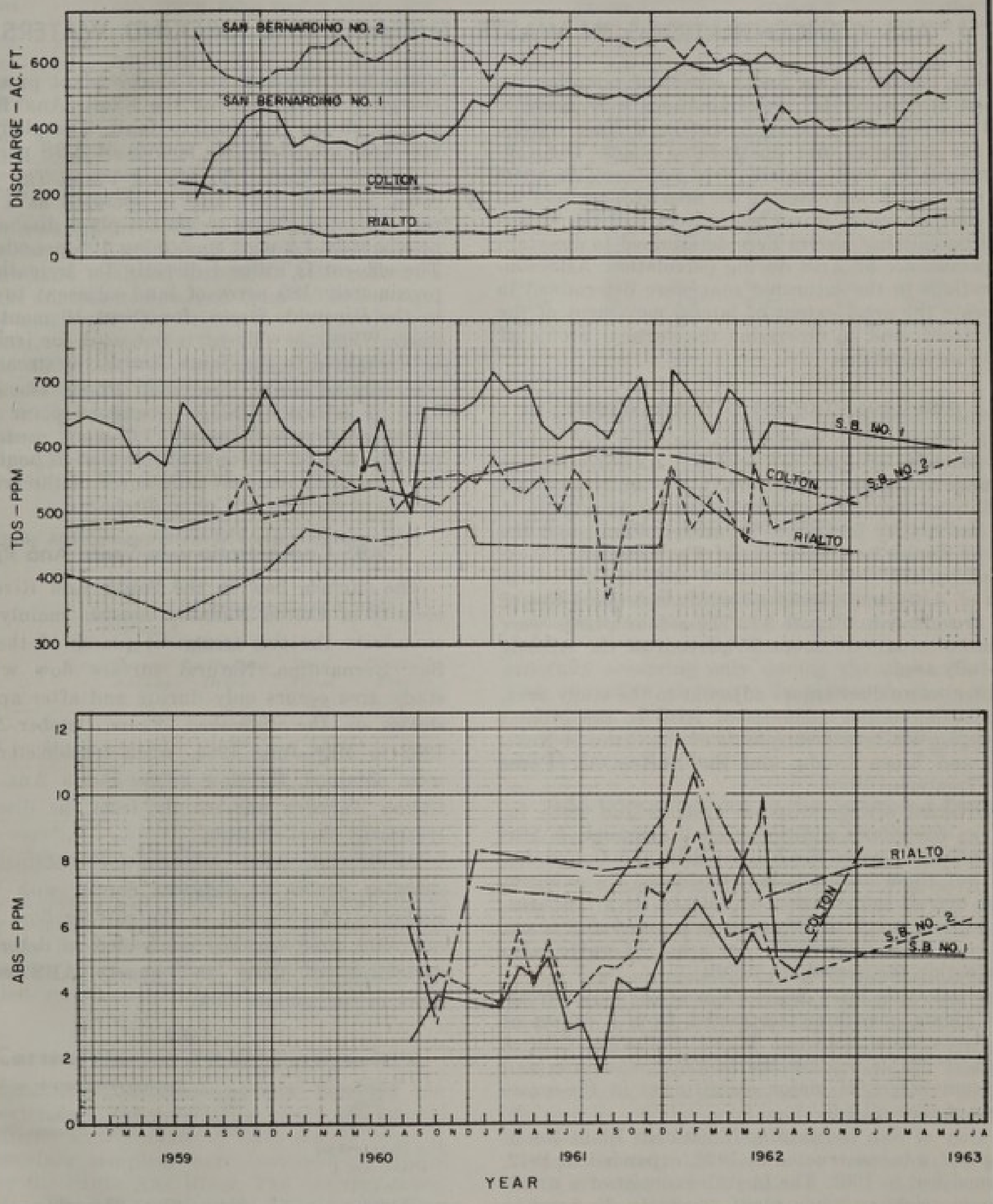
Based on the above information and the original field testing, 50 wells were chosen for quarterly sampling of ABS and selected chemical constituents. Care was exercised to select some wells around the periphery of the ABS problem area so that a constant check could be maintained on its lateral migration. Vertical control was maintained by the selection of wells perforated in the shallow zone (0–100 feet), intermediate, zone (100–350 feet) and deep zone (greater than 350 feet). In this manner, all major subsurface flow paths were monitored. In the course of the investigation, the number of monitoring wells was increased to approximately 60. As was inevitable in a three-year investigation, some wells had to be dropped from the program. New wells were chosen to replace these and also monitor the lateral movement of the ABS front into new areas.

Quarterly samples were analyzed for ABS, phosphates, electrical conductivity, pH, chlorides, sulfates, and nitrates. The anions were chosen rather than the cations because they were less likely to interact with the soil during subsurface flow. Earlier samples were analyzed for nitrites but after these samples showed that nitrites were absent in most of the ground waters, the nitrite analyses were discontinued. Plate 13, "Well Location Map," shows the location of the quarterly sampling wells, which are indicated by solid circles. The hollow circles indicate the general canvass wells used to delineate the area of apparent ABS presence in ground water at the start and end of the study. The results of the analyses of the quarterly sampling are given in Table C-1 of Appendix C.

Methods for Surface Sampling

In addition to the tensiometer sites, test wells, test holes, and monitoring wells described above, sites were also chosen for sampling surface flow in the Santa Ana River. The four sites chosen are shown on Plate 1 as surface sampling Stations A, B, C, and D. Their locations are also the same as those used for the gaging of surface flow given in Chapter II.

FIGURE 11



DISCHARGES, TDS, AND ABS CONCENTRATIONS OF WASTE WATERS FROM SEWAGE TREATMENT PLANTS AT THE CITIES OF SAN BERNARDINO, COLTON, AND RIALTO

CHAPTER IV

ABS CONCENTRATIONS IN WASTE, SURFACE, AND GROUND WATERS

Using the techniques and methods of sampling described in Chapter III, determinations were made of ABS concentrations in waste waters, surface waters, and the saturated and unsaturated zones. The concentrations in waste waters were necessary to know how much ABS was entering the area of investigation. The concentrations in surface waters and the underlying percolating waters were determined to ascertain the persistence of ABS during percolation. ABS concentrations in the saturated zone were determined to delineate the areal extent of lateral movement of the ABS front, and to determine the vertical profile of ABS concentrations.

ABS Concentrations in Waste Waters

The major waste dischargers contributing significant amounts of ABS to the Santa Ana River or to the underlying ground waters in the study area are the City of San Bernardino Treatment Plants No. 1 and No. 2, City of Colton Treatment Plant, and the City of Rialto Treatment Plant. The location of these discharges are shown on Plate 1 and the concentrations of ABS, total dissolved solids and quantities of flow are given in Figure 11. These four plants were found to contribute about 95 percent of the ABS to the study area.

Other waste dischargers adjacent to the study area, contributing minor amounts of ABS to the ground waters, are the treatment plants of the Cities of Rubidoux and Loma Linda, and the Norton Air Force Base Treatment Plant.

Individual sewage disposal systems and some industries contribute additional small amounts of ABS in localized areas in the Bunker Hill and Colton Basins, but these amounts are considered insignificant to the overall contribution of ABS in the study area. In addition, much of this area is sewered and therefore very little recirculation, or reuse, of water takes place within the immediate vicinity.

The following brief descriptions of the major treatment plants have been abstracted from a report of the Santa Ana Regional Water Pollution Control Board.(28) Table 5 gives the average, maximum and minimum values of major constituents in the waste waters of these plants.

1. City of San Bernardino Treatment Plant No. 1. The plant was constructed in 1928, expanded in 1942, and modified in 1962. The facilities consist of a standard rate trickling filter plant presently discharging approximately 4.2 mgd of mixed domestic and industrial wastes to Warm Creek, a tributary of the Santa Ana River. The plant contributes approximately 220 pounds of ABS per day.

2. City of San Bernardino Treatment Plant No. 2. The plant was constructed in 1959 and is operated as a standard rate-activated sludge plant presently discharging to the bed of the Santa Ana River, upstream of the San Jacinto fault. The plant contributes approximately 205 pounds of ABS per day.

3. City of Colton Treatment Plant. The plant was constructed in 1950 and is operated as a standard rate-activated sludge treatment plant discharging approximately 1.8 mgd containing 105 pounds of ABS. The effluent is utilized directly for irrigation of approximately 180 acres of land adjacent to the river in the Riverside Basin, for about 10 months of the year. When the effluent is not used for irrigation, it is discharged to the Santa Ana River streambed.

4. City of Rialto Treatment Plant. The city operates an activated sludge treatment plant presently discharging approximately 1.0 mgd, containing 70 pounds of ABS per day, to percolation ponds located approximately one-half mile north of the river downstream of the City of Colton discharge.

ABS Concentrations in Santa Ana River

The surface flow in the Santa Ana River in the vicinity of Colton Narrows consists mainly of effluents from the two treatment plants of the City of San Bernardino. Natural surface flow within the study area occurs only during and after appreciable storms on the watershed. From October–November 1962 to May–June 1964, when tensiometer samples were obtained, the flow in the Santa Ana River at Colton Narrows was mainly from the discharge of treatment plant effluents.

To correlate ABS concentrations obtained by tensiometer probes at different depths with the ABS concentrations present in the surface flow, a special sampling program was conducted to determine the variability of daily and hourly ABS concentrations in the surface flow.

TABLE 5

Chemical Constituents in Treatment Plant Effluents

Treatment plant and period of record	Chemical constituents in mg/l					
	Total dissolved solids	Chloride	Sulfate	Ortho-phosphate	Nitrate	ABS 1960–1963
San Bernardino Plant No. 1 8/45–7/63						
Average	574	97	65	26	56	4.7
Maximum	910	170	100	51	118	12.0
Minimum	411	28	40	0.2	1	1.5
San Bernardino Plant No. 2 11/59–7/63						
Average	524	76	103	33	19	5.4
Maximum	585	92	434	54	75	8.8
Minimum	365	53	57	9	1	3.6

TABLE 5—Continued

Chemical Constituents in Treatment Plant Effluents

Treatment plant and period of record	Chemical constituents in mg/l					
	Total dissolved solids	Chloride	Sulfate	Ortho-phosphate	Nitrate	ABS 1960–1963
Colton Plant 9/47–1/63						
Average	549	89	60	29	21	6.9
Maximum	1,012	175	86	48	98	10.7
Minimum	406	50	31	0.4	0	2.2
Rialto Plant 2/48–7/63						
Average	483	61	45	34	39	8.6
Maximum	890	152	111	62	143	11.8
Minimum	119	38	21	7	0	6.8

Surface samples were taken at 8 a.m., noon, and 4 p.m. at Stations A, B, C and D, composited according to flow, and analyzed for ABS. ABS concentrations in the surface flow ranged from 4.0 to 5.4 mg/l. The daily and hourly variations of ABS at the sampling stations are shown in Tables 6 and 7. The data show that daily ABS concentrations in the surface flow of the Santa Ana River did not vary appreciably from day to day and that ABS generally decreased with distance from the point of discharge. However, the hourly ABS concentrations at Station A showed as much as 40 percent variation.

TABLE 6

Daily ABS Concentrations in Surface Waters of the Santa Ana River

October 8–14, 1962

Day	*ABS concentrations in mg/l*			
	Station A Mt. Vernon Avenue	*Station B La Cadena Drive*	*Station C Duck Farm*	*Station D Riverside Avenue*
Monday	4.6	4.9	3.8	
Tuesday	5.0	5.0	4.2	2.8*
Wednesday	4.8	4.3	4.1	
Thursday	4.3	4.0	4.0	
Friday	4.3	4.3	4.0	
Saturday	5.1	4.9	4.4	
Sunday	5.2	5.4	4.8	
Weekly Average	4.7	4.7	4.2	

* Station D: Grab sample taken at 2 a.m.; no flow during daylight hours.

Data in Tables 6 and 7 indicate the desirability of obtaining surface samples over a 24-hour period. Thus, hourly fluctuations in surface flow ABS concentration can be averaged out and a meaningful interpretation on the degradability of ABS can be made.

ABS Concentrations in the Unsaturated Zone

To determine ABS concentrations reaching the ground water from the percolating waste effluent and the persistence and decrease in ABS during percolation, subsurface samplers were installed at several sites along the Santa Ana River. The descriptions of the sampling devices are given in Chapter III. This section presents data, obtained with these devices, on the concentrations of ABS at various depths in the unsaturated zone and on those reaching the ground water table.

TABLE 7

Hourly ABS Concentrations in Surface Waters of the Santa Ana River

October 8, 1962

Station A Mt. Vernon Avenue			*Station B La Cadena Drive*		*Station C Duck Farm*	
Time	*Flow* cfs*	*ABS mg/l*	*Time*	*ABS mg/l*	*Time*	*ABS mg/l*
7:00 a.m.	6.5	4.7	7:10 a.m.	4.4	7:22 a.m.	3.8
8:00	6.5	4.5	8:10	4.5	8:20	4.0
9:00	8.0	4.9	9:27	4.7	9:37	3.9
10:00	27.0	6.0	10:12	4.8	10:30	3.9
11:00	30.0	4.9	11:10	4.9	11:20	3.5
12:00 noon	34.0	4.4	12:00 noon	5.1	12:25 p.m.	4.2
1:00 p.m.	32.0	4.5	1:20 p.m.	4.8	1:30	4.2
2:00	32.0	–	2:10	5.1	2:22	4.2
3:00	27.0	3.5	3:20	4.7	3:35	3.6
4:00	27.0	3.6	4:10	4.9	4:25	4.2
5:00	27.0	4.7	5:20	5.2	5:25	3.5
6:00	26.0	5.2	6:10	4.9	6:23	3.3
7:00	23.5	4.9	7:15	4.2	7:25	4.0
2:00 a.m.	8.0	5.1	2:15 a.m.	4.7	–	–
4:15	7.0	5.7	4:25	4.2	–	–
Average** (mg/l)		4.9		4.6		3.7

* Flows from USGS gaging station at Mt. Vernon Avenue Bridge.
** Weighted average according to flow.

Samples of percolating water in the zone of aeration were obtained at depths ranging from 3 to 55 feet at sites Ta, Tb, Tc, Td, and Te. The sites are shown on Plate 1. The size of the samples obtained at site Tc was very limited because of the tight clayey soil encountered. This clay plugged the perforations in the outer casing while it was being driven into the soil. Subsequently, tensiometers at other sites were placed without the outer perforated casing.

At Stations Ta, Tb, and Te, the riverflow is continuous. At station Td the riverflow is intermittent, generally occurring only during the night. To eliminate the effect of hourly fluctations in surface concentrations, 24-hour samples were obtained of both the surface and percolating waters. Tables 8, 9, 10, and 11 summarize these data.

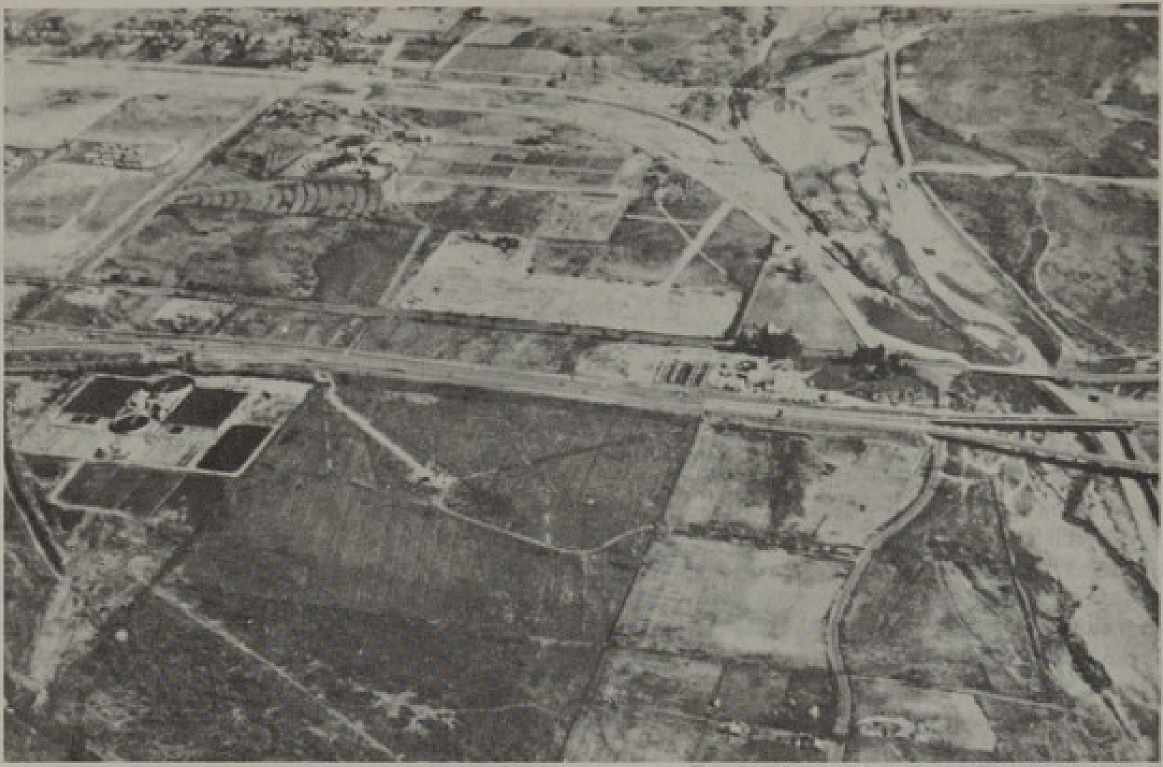
ABS Concentrations in the Saturated Zone

A comprehensive testing program utilizing an ABS field testing kit was conducted at the start of the study to delineate and define the study area. A final comprehensive sampling run was made at the end of the field investigation to determine the changes in the affected area during the study period.

The vertical distribution of ABS concentrations was determined at six selected sites in the study area. This was done by sampling four test wells, perforated at 4-foot intervals, with the specially designed packer pump described previously and by sampling two test holes with piezometers by the airlift method. The results of the areal and vertical sampling are discussed in the following sections.

Approximately 125 wells were sampled at the start of the investigation. In addition, 50 wells were chosen as monitoring wells on the basis of areal distribution, anticipated underground flow patterns, and problem areas. The number of monitoring wells was increased to approximately 60 during the course of the study.

The method of determining ABS concentrations in the laboratory is described in Appendix D under "Taft Method" Analytical Procedure. The field



Treatment plants Nos. 1 and 2 (from left)

The flows consist mainly of effluent discharged from City of San Bernardino plants

Looking east from La Loma Hills

The river flows southwesterly and westerly across a broad flood plain methods are basically the same as this laboratory method, with the exception that colors were determined in the field by comparison with standards of known concentrations of ABS. The final field determinations for ABS were made with the Helige ABS field kit, which utilizes a color disc to determine concentrations. The principle of the method is the same as that of the field kit prepared by the laboratory, except that greater precision could be obtained with the use of the color disc.

A value of 0.10 mg/l was taken as the lowest limit of meaningful ABS concentrations that could be determined by the ABS field method. Checks were made in the laboratory on the ABS field values as determined by the field kit. In about half the 50 samples checked, the agreement between the field kit and the laboratory analyses was within ±0.05 mg/l of ABS. In a large percentage of the samples where zero values of apparent ABS were shown by the field kit, these values were confirmed by laboratory determinations. The field kit method, when used on good quality ground waters, has proved very reliable on low ABS concentrations when compared with the Taft method in the laboratory. The advantages of determining ABS in the field are that costs are lower, time is saved, and investigators can screen for the absence or presence of ABS at the time of sampling.

The concentrations of apparent ABS found in the monitoring wells are shown on Plates 14, 15, 16, and 17, "Areal Extent of ABS Concentration — October 1962, May 1963, August 1963, and June–July 1964," which depict areas of ABS concentrations from ground water samples obtained without regard to depth.

TABLE 8

ABS Concentrations at Station Ta

In mg/l

Date Sampled 1962	*Surface Samples*	*3-foot Depth*	*8-foot Depth*	*13-foot Depth*
October 3	--	1.9	--	--
October 8 *	--	--	--	--
October 9	5.0	--	--	--
October 10	4.8	--	--	--
October 11	4.3	--	--	--
October 12	4.3	--	--	--
October 13	5.1	--	--	--
October 14	5.2	--	--	3.0
October 17	--	--	--	2.7
October 18	--	--	1.8	3.4
October 19	--	2.2	--	1.2
October 31	4.0	--	--	--
November 1	4.5	--	--	--
November 7	4.5	--	--	--
November 8	5.0	--	--	--
November 9	5.3	--	--	--
November 13	4.5	1.6	2.0	--
Average	4.7	1.9	1.9	2.5
Percent decrease in ABS	--	59.5	59.5	46.8

* October 8–14 are composite surface grab samples. Remainder of surface samples were obtained by means of tensiometers suspended in the riverflow which gave a continuous 24-hour sampling period.

TABLE 9

ABS Concentrations at Station Tb

In mg/l

Date Sampled 1963	*Surface Samples*	*3-foot Depth*	*5-foot Depth*	*8-foot Depth*
May 2	4.5	4.5	3.8	1.7
May 6	4.8	3.9	--	--
May 7	4.7	3.7	--	--
May 8	3.8	4.3	4.0	2.2
May 10	4.9	4.8	4.2	2.2
May 15	--	2.9	2.6	2.6
May 20 *	--	--	--	--
Average	4.5	4.0	3.6	2.4
Percent decrease in ABS	--	11.1	20.0	47.0

* Tensiometers destroyed and equipment stolen by vandals.

TABLE 10

ABS Concentrations at Station Td

In mg/l

Date Sampled 1962	*Surface Samples*	*3-foot Depth*	*8-foot Depth*	*13-foot Depth*	*18-foot Depth*
October 3	--	1.9	--	--	--
October 4	--	2.0	1.6	1.1	--
October 8	--	--	--	--	1.7
October 9 *	2.8	3.1	--	1.0	--
October 11	--	3.9	1.9	1.3	--
October 14	--	--	1.8	--	--
October 19**	--	1.4	2.0	--	0.8
October 31	4.6	--	--	--	--
November 2	4.3	--	2.0	3.2	--
November 6	3.4	--	--	--	--
November 7	3.8	--	2.7	--	--
November 8	3.3	--	--	--	--
November 9	4.2	--	--	--	--
November 20	4.1	--	--	--	1.7
Average	3.8	2.5	2.0	1.6	1.4
Percent decrease in ABS	--	34.2	47.4	57.9	63.2

* Three-foot tensiometer destroyed by vandals after October 19.
** October 9 surface sample was a single grab sample.

TABLE 11

ABS Concentrations at Station Te

In mg/l

Date Sampled 1964	*Surface Samples*	*10-foot Depth*	*25-foot Depth*	*40-foot Depth*	*55-foot Depth*
May 7	5.00	--	1.44*	2.62*	1.40*
May 12	4.60	1.60	1.20	--	0.68
May 15	5.60	1.20	0.72	--	0.64
May 18	--	0.92	0.98	2.40	0.68
May 20	--	1.50	0.64	1.60	0.56
May 22	--	0.80	0.80	1.20	0.32
May 25	--	0.84	1.05	1.10	0.45
May 28	--	1.15	0.80	2.00	0.76
June 3	4.40	--	1.30	1.25	0.70
June 8	4.60	0.65	0.65	0.94	0.80
June 12	4.70	0.72	0.80	1.04	0.64
June 17	4.60	0.64	0.56	0.80	0.72
June 24	4.40	0.60	0.48	0.80	0.92
Average	4.74	0.97	0.87	1.31	0.66
Percent decrease in ABS	--	79.7	80.6	72.0	86.0

* Values when first installed—not to be used.

Areal Extent of ABS Concentrations in Ground Water (1962–1964)

The overall area affected by ABS has not changed appreciably since the start of the study. However, considerable variation has been found in the concentrations of ABS in ground waters of specific areas. Plates 18 and 19, "Change in ABS Concentrations," depict areas of increase or decrease in ABS concentrations October 1962 to May 1963 and October 1962 to June 1964. The areal extent of ground waters containing different ranges of ABS concentrations were determined by planimetering from plates showing areal extent of ABS concentrations. Table 12 shows the ranges of ABS concentrations in mg/l and the areal extent in acres.

TABLE 12

Areal Extent and Range of ABS Concentrations

Area in acres—ABS in mg/l

Month sampled	*Range ABS concentrations*			*Total acreage*
	(trace) 0.0 to 0.10	*0.10 to 0.50*	*Greater than 0.50*	
October 1962	8,440	5,200	1,000	15,300
May 1963	8,900	3,680	1,590	14,260
August 1963	7,900	5,200	1,000	13,100
June 1964	8,190	3,400	1,015	12,606

The fall and late summer sampling programs showed the areas that had concentrations of ABS in the 0.10 to 0.50 range were greater than those in the spring and early summer programs. Also, according to the findings the size of areas with ground water containing ABS greater than 0.05 mg/l and the total affected acreage have decreased since the start of the study. The table also shows a seasonal variation in areas having ABS concentrations in the range of 0.00 to 0.50 mg/l. Plates 14–17, which depict the areal concentrations of ABS, again point out this cyclic shifting of ABS, with the greater than 0.5 mg/l area showing similar configurations in May 1963 and June 1964 and in October 1962 and August 1963.

From October 1962 to May 1963, the general trend was a slight decrease of ABS concentrations in the Bunker Hill Basin northeast of the San Jacinto fault and an increase in the Colton Basin between the San Jacinto fault and the Rialto-Colton Barrier along the floodplain of the Santa Ana River. The area containing ABS greater than 0.5 mg/l in the Colton Basin increased since the start of the study from 0.05 square mile to 0.49 square mile in July 1964. This could be attributed either to heavier pumping in the area or to the effects of the added discharge by the City of San Bernardino Treatment Plant No. 2 to the Santa Ana River, starting in 1959.

The final sampling in June 1964 indicates that since the start of the study, the area showing ABS ranging from 0.10 to 0.50 and greater than 0.50 mg/l increased considerably in the Colton Basin, perhaps reflecting the influence of plant No. 2 discharge. The ABS front also showed slightly increased concentrations in Riverside Basin southwest of La Loma Hills at the Riverside and San Bernardino county lines and in the Riverside Basin southwest of La Loma Hills. The trend of a slight decrease in ABS concentrations in Bunker Hill Basin, in the vicinity of Loma Linda and in the East Riverside Mesa, southeast of La Loma Hills, continued during the period of study.

In spite of increased discharge flows, the area affected remained essentially the same, and the heaviest pollution of ground waters followed the floodplain along the Santa Ana River beginning at the San Jacinto fault and extending downstream to Riverside Avenue, a distance of approximately 6 miles. With the present discharges and heavy pumping extractions in the area, it is doubtful that the pollution area will expand to any considerable amount in the foreseeable future.

Vertical Profile of ABS Concentrations

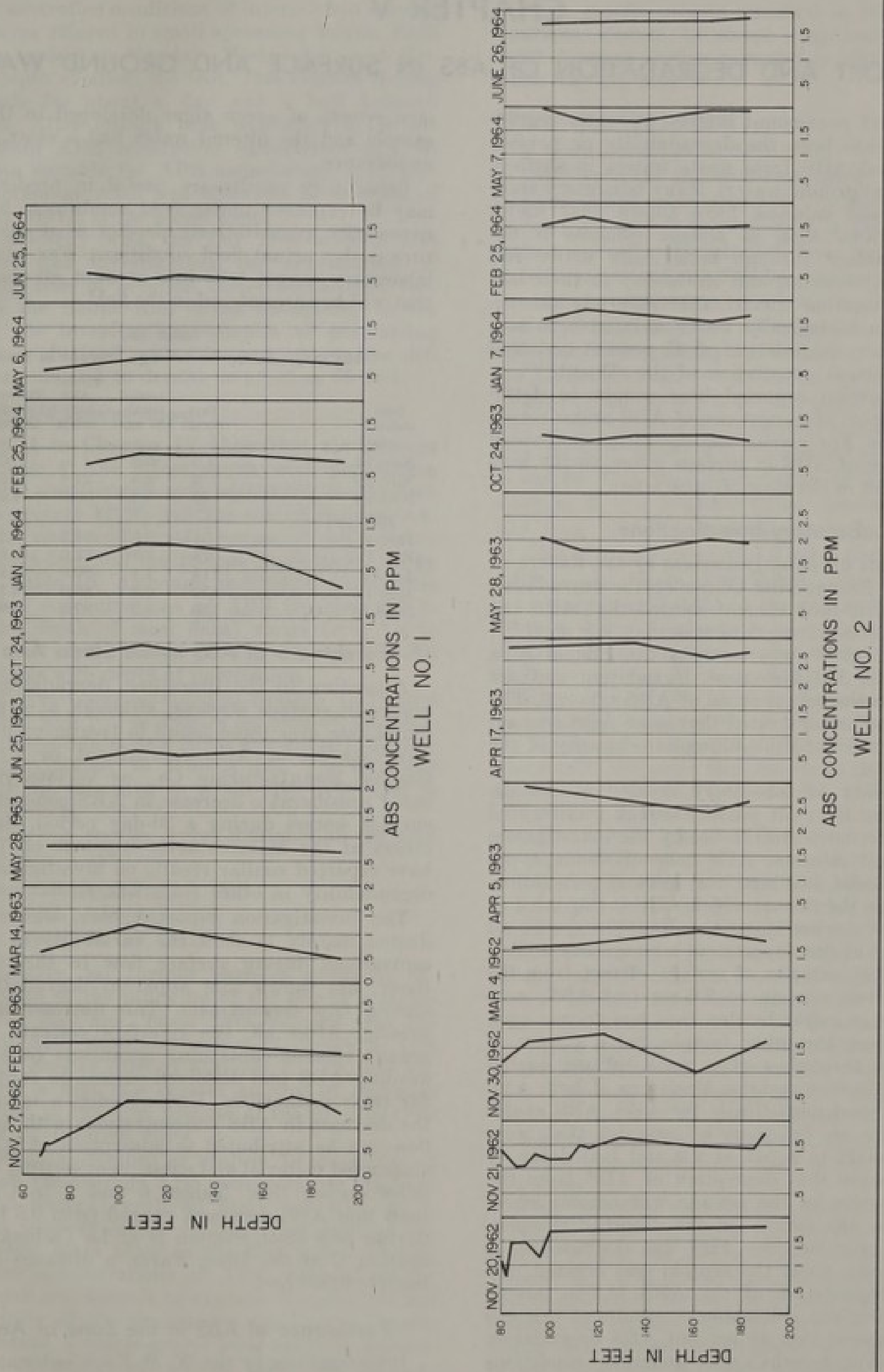
To determine the vertical profile of ABS concentrations in the ground water, the four 8-inch test wells and two test holes for piezometers, described previously, were drilled.

Figure 12 shows the variation of ABS concentrations with depth in ground water from test wells No. 1 and No. 2. Graphs were not prepared for test wells No. 3 and 4 because no variation of ABS with depth was exhibited in these wells and ABS concentrations were too low (0.10 to 0.20 mg/l) to indicate any significant trends.

In well No. 1 ABS concentrations in the winter and spring showed considerable variation among depths and registered the highest values of the year. In the summer, they showed the least variation among depths and recorded the lowest values. ABS concentrations with depth in well No. 2 showed a reversed pattern, with the high concentrations occurring in the summer and lower values in the winter. These trends may be attributed in part to two factors: ABS adsorption on soil varies with concentration and velocity of flow and pumping well fields in the vicinity create pumping depressions and ground water divides that alter the inflow velocities and amounts of dilution water available.

Plate 20 shows the average ABS concentration of three samplings of the piezometers installed by the department. No significant trend of ABS variation with depth was shown, and the low concentrations indicate that little or no percolation of ABS-laden waters from the shallow to the deeper zones takes place near the San Jacinto fault.

FIGURE 12



ABS CONCENTRATIONS WITH DEPTH OF TEST WELLS 1 AND 2

CHAPTER V

TRANSPORT AND DEGRADATION OF ABS IN SURFACE AND GROUND WATERS

A question of paramount interest to water regulatory agencies has been the degradability or persistence of residual ABS from waste waters in surface, percolating, and ground waters. Many laboratory studies utilizing soil columns have shown that under proper conditions ABS in sewage effluents is degraded by passage through biologically active soil columns. Klein, Jenkins, and McGauhey in their laboratory investigation found that degradation occurred only in biologically active aerated soils and that a maximum degradation of 35 percent occurred during intermittent percolation of the effluent.(16)

The investigation reported here sought to determine this question of persistence of ABS under actual field conditions. For clarity the discussion is divided into persistence of ABS in surface water, in the zone of aeration, and in the zone of saturation.

Laboratory Investigations

Investigations utilizing lysimeters by the Robert A. Taft Sanitary Engineering Center on the degradation of ABS in septic tank effluent showed that ABS can be degraded from 35 mg/l to less than 0.5 mg/l (27) Radioactive ABS (35) was used in the effluent as a tracer to prove that biological degradation and not adsorption was the actual cause of ABS removal. The experiment also demonstrated that some ABS was adsorbed on the soil until the adsorptive capacity of the soil was reached.

The variability of laboratory results on the degradability of ABS as it passes through unsaturated soils can be attributed to the use by the investigators of different soil columns, ABS concentrations, types of biological media, loadings, and rates of percolation.

To determine the rate at which ABS is degraded in sewage effluent during storage, a limited experiment was performed at the department's laboratory at San Bernardino. Two samples of sewage effluent from the Santa Ana River, containing 5.6 mg/l of ABS, were allowed to age in gallon bottles. One sample was aged without aeration, the other sample had a stream of air introduced through a glass wool diffuser during its shelf life of seven months. Fractions of both samples were analyzed periodically for ABS. ABS analyses were made on fractions of samples that were treated by NaOH to a pH of 9.0 and boiled for 10 minutes to assure that desorption of ABS from the particulate matter in the sewage was accomplished. Table 13 gives the results on the desorbed samples. As could be expected, the ABS was degraded at a much faster rate when the sample was aerated. Although the degradation of the ABS in the sample without aeration was much slower, results of this one experiment showed that 48 percent ABS degradation occurred in seven months under anaerobic conditions and 87.5 percent under aerobic conditions. An extensive growth of green algae developed in the aerated sample and the filtered water had a clear, sparkling appearance.

Laboratory results are useful in predicting what may be expected under field conditions, but do not necessarily quantitatively predict what occurs in nature under actual field conditions. For example, the laboratory cannot take into account all the variables that will be encountered in the field.

TABLE 13

ABS Degradation in Sewage Effluent in Storage

Date analyzed	Days storage	Aerated sample ABS mg/l	Percent ABS degradation	Unaerated sample ABS mg/l	Percent ABS degradation
1962					
Nov. 14	0	5.6	–	5.6	–
Nov. 16	2	4.4	21.4	5.5	1.8
Nov. 24	10	3.4	39.3	4.6	17.8
1963					
Jan. 4	51	2.0	64.5	3.2	43.0
Feb. 1	78	1.3	77.0	2.8	50.0
April 5	114	1.1	80.0	2.4	57.0
May 13	152	0.6	89.0	3.1	45.0
June 10	180	0.7	87.5	2.9	48.0

Persistence of ABS in the Santa Ana River

According to the literature, degradation of ABS occurs in surface streams, although at a greatly reduced rate over those found in treatment plants. Die-away studies of ABS carried out by Proctor and Gamble Manufacturing Co., on various rivers indicated considerable decrease in ABS concentrations in surface waters during a 30-day period. Sawyer and others at the Massachusetts Institute of Technology have reported similar results on investigations of biodegradability in other river waters.(29)

The investigation reported here, which was conducted mainly to show the variability of ABS concentrations during surface flow in the Santa Ana River, has shown that apparent degradation occurs during flow downstream. This decrease is not surprising. After all, the riverflow consists mainly of sewage effluent containing organisms capable of degrading ABS and dissolved oxygen to supply energy for their metabolism. Undoubtedly, a minor part of the decrease in ABS concentrations with downstream flow can be attributed to adsorption of ABS on the suspended material and subsequent settling of the particles during flow. Tables 6 and 7 in Chapter IV show that ABS decreases ranged from 0.5 to 0.9 mg/l during flow from Station B at La Cadena Drive to Station C at the Duck Farm, a distance of approximately 6,000 feet.

Persistence of ABS in the Zone of Aeration

Investigations by the W. M. Keck Laboratory of Environmental Health Engineering at the California Institute of Technology (Cal Tech) have shown significant removals of ABS during percolation through the zone of aeration.(20) These experiments were carried out under controlled conditions of intermittent spreading of sewage effluent in small spreading basins. Each basin was loaded on Monday, Wednesday, and Friday to a depth of about 0.6 foot. This allowed drying of the beds for about a day and a half between spreadings. After enough time was allowed for the soil to attain ABS adsorption equilibrium and attain a biota suitable for ABS assimilation, a 75 percent reduction in ABS was observed in samples of percolating waters at the 6-foot depth.

Simultaneously with the Cal Tech studies, this department was investigating the degradation of ABS in the zone of aeration under actual field conditions in the Santa Ana River floodplain. In the course of the investigation, samples of percolating waters were obtained with tensiometers at five different locations and to depths as great as 55 feet.

Analyses of Field Determinations

Tables 8-11 in Chapter IV show that the average ABS decrease at the 8-foot depth with percolation through the unsaturated zone amounted to approximately 58 percent of the surface concentrations. Apparently, a small additional decrease of ABS occurs between the 8-foot and the 18-foot depth as shown by values in Table 10. Although individual results are variable and concentrations of ABS reaching the 8-foot depth (depth of most data) range from 1.6 to 3.2 mg/l, most of the values show a decrease in ABS concentrations with depth of percolation.

One test result was obtained at Station Tc located opposite test well No. 3. This is an area of intermittent flow in the Santa Ana River streambed; the flow occurs approximately 16 hours a day. The soil near the surface in this area is a silt-clay type and is fairly impervious.

The following results were obtained on 24-hour samples on May 2, 1963:

Surface sample: 3.0 mg/l ABS
3-foot depth: 1.0 mg/l ABS
5-foot depth: 0.4 mg/l ABS

Unfortunately, no further samples could be obtained because of the plugging of the casing perforations by the clay soil. These data indicate that the decrease in ABS concentrations with depths at this site is much greater than at Stations Ta, Tb, and Td. The opinion is that this greater amount of degradation occurred in this area because of the silt-clay type of soil and intermittent flows.

The 1964 data obtained at Station Te show that at this location the average ABS concentration reaching the ground water (depth 60 feet) was 0.66 mg/l. These data support earlier findings that most of the ABS decrease takes place in the first 8 feet of soil. The greater concentrations of ABS obtained at the 40-foot depth are difficult to explain. Because the soil in the vicinity of the tensiometer site is of a heterogeneous nature, a coarse-gravel lense could be permitting short-circuiting of waters from the surface, which contain higher concentrations of ABS. These results again point up the anomolies that will be encountered under natural conditions as opposed to uniform results usually obtained in laboratory investigations. Figure 13 shows graphically the rate of ABS decrease during percolation with depth at Stations Tb, Td, and Te.

Adsorption or Degradation

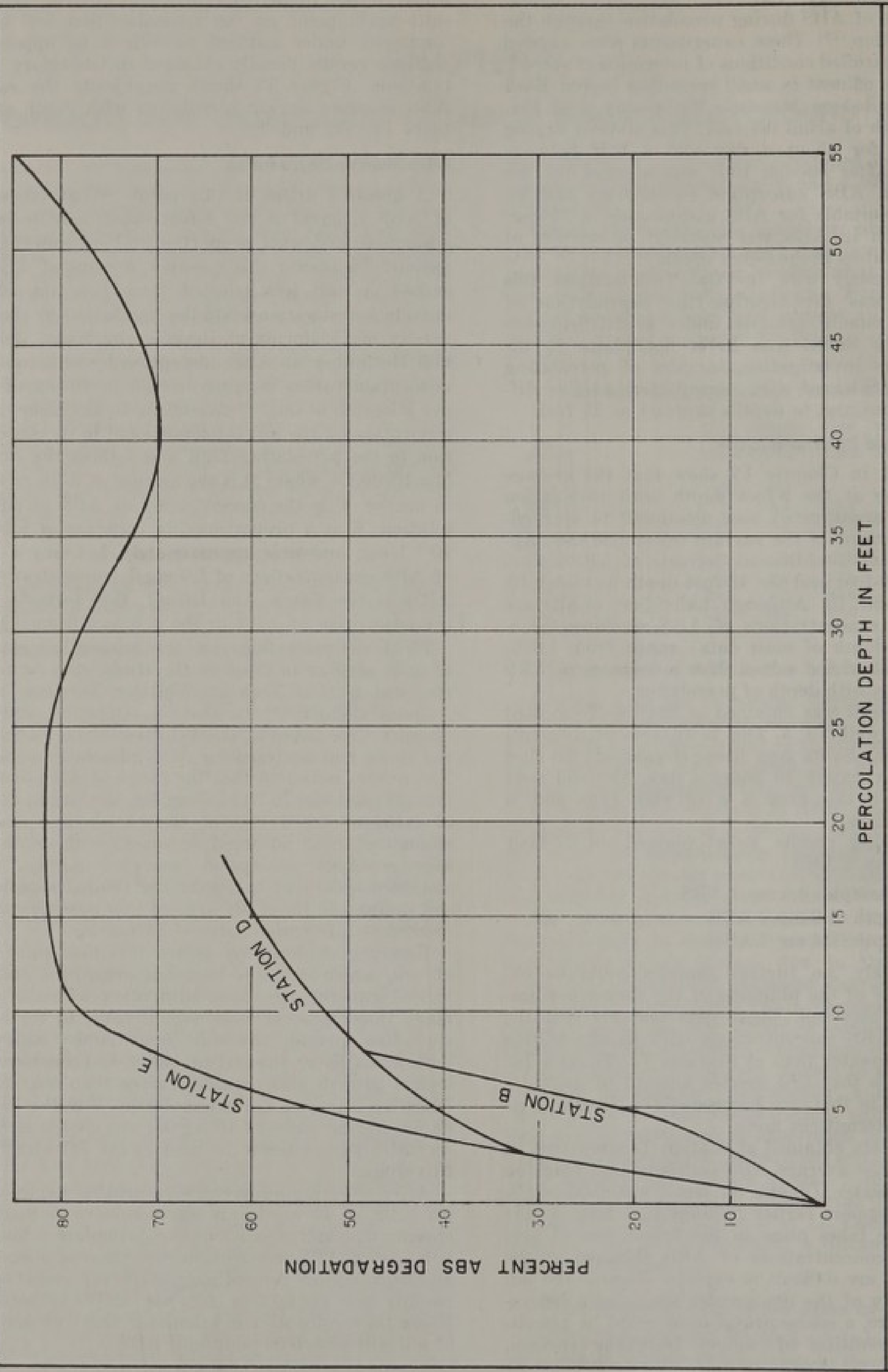
A question arises at this point: What proportion of ABS removal at the 8-foot depth can be laid to adsorption and what proportion to biochemical degradation? To answer this question, a value of ABS adsorbed on soil was selected from two independent outside investigations. Studies conducted at the University of California at Berkeley by Klein, Jenkins, and McGauhey on ABS adsorption by soils indicated adsorption values ranging from 5 to 10 mg of ABS per kilogram of soil.(15) According to McGauhey, ABS adsorption on the soil is proportional to its concentration in the percolating fluid and follows the formula $M=1000KC^n$, where M is the amount of ABS adsorbed in mg/kg, C is the concentration of ABS in mg/l of solution, K is a proportionality constant of 5.188×10^{-4} l/mg, and n is approximately 1. Using a value of ABS concentrations of 5.0 mg/l (concentrations of ABS in the Santa Ana River), this formula gives the adsorption of ABS in the soil as 3.0 mg/kg.

Field determinations on the adsorption capacity of soils, similar to those in the study area, were carried out by Cal Tech at Whittier Narrows in Los Angeles County.(10) In that investigation, soil core samples were taken at the Whittier Narrows Spreading Basin and analyzed for ABS adsorbed on the soil. The results indicated that the range of ABS desorbed from the soil was 16.2 to 1.0 mg/kg, the largest amount of ABS adsorbed was in the top layers, and the amount of ABS adsorbed decreased with depth. The average ABS adsorption was 6.0 mg/kg, when weighted according to depth. The limited analyses on soil samples in the study area of this investigation indicated an adsorption value of 5.0 mg/kg.

However, studies have shown that the upper layer of soil, which contains bacterial organisms and biological growths, can have adsorption values of ABS many times those of clean soil. Because of the longer spreading period, the soil immediately under the Santa Ana River channel probably contains more biological growth and organic matter than that at the Whittier Narrows Spreading Basin. For this reason, an adsorption value of 10 mg/kg was chosen as a conservative parameter to be used in the calculation for this study.

After selecting an average adsorption value of soil for ABS of 10 mg/kg, it was necessary to assume a specific weight for soil and then calculate a material balance for ABS to ascertain the extent of adsorption and degradation. Accordingly, a specific weight of 115 pounds per cubic foot for wet soil was assumed. Using these values, it is calculated that one acre-foot of soil will adsorb 50 pounds of ABS.

FIGURE 13



PERCENT ABS DECREASE WITH PERCOLATION DEPTH

A volume of land selected underneath the Santa Ana River for the ABS balance, extending from Mt. Vernon Avenue to La Cadena Drive, had a depth of 10 feet, a width of 40 feet, and a length of 9,500 feet. This volume of land contains 3,800,000 cubic feet, or 87.2 acre-feet. Using a previously calculated value of 50 pounds of ABS adsorbed per acre-foot of soil, it is calculated that this volume of soil can adsorb 4,360 pounds of ABS.

The total amount of ABS discharged from both San Bernardino plants was 155,000 pounds during the 1962–1963 fiscal year. Of this amount, 24 percent, or a total of 37,200 pounds, percolated in the reach of the Santa Ana River between Mt. Vernon Avenue and La Cadena Drive, as determined by a stream gaging program discussed earlier.

ABS concentrations in the surface waters are about 5.0 mg/l and those reaching the 10-foot depth average approximately 1.5 mg/l. Therefore, 12,400 pounds of ABS, out of the original 37,200, pass the 10-foot zone. As has been shown, this stretch of the riverbed to a depth of 10 feet can at most adsorb only 4,360 pounds of ABS. This leaves an unexplained balance of 20,440 pounds, which can only be accounted as degradation of ABS.

Table 14 summarizes the ABS balance under conditions of full ABS adsorption and no ABS adsorption by the soil. Assuming that the soil was not saturated with ABS and the full credit of the adsorptive capacity of the soil of 4,360 pounds was used, 55 percent of the ABS was degraded. On the other hand, a more reasonable assumption is that during the 15 years of effluent percolation containing 120,000 pounds of ABS, the soil has reached full saturation.

TABLE 14

ABS Material Balance in Santa Ana River Between Mt. Vernon Avenue and La Cadena Drive

	Soil condition			
	Full ABS adsorption		*No ABS adsorption*	
ABS balance entry	*ABS in pounds per year*	*Percent of total*	*ABS in pounds per year*	*Percent of total*
ABS contribution 1962–1963	37,200	100.0	37,200	100
ABS adsorbed in 10 feet of soil	4,360	11.7	0.00	0.0
ABS available	32,840	88.3	37,200	100
ABS leaving 10-foot zone	12,400	33.3	12,400	33.3
ABS degraded	20,440	55.0	24,800	66.7

Under these conditions the degradation is shown as 66.7 percent. This calculated value agrees closely with experimental results obtained in field investigations for this study, which show an average ABS decrease of 75 percent at the 10-foot depth. The above material balance and the results of tensiometer tests show conclusively that degradation and not adsorption is the explanation of the decrease in ABS during percolation in the zone of aeration.

Persistence in the Saturated Zone

Degradation of ABS proceeds most readily in the presence of the proper biological organisms and a supply of oxygen. Ground waters contain little or no dissolved oxygen or bacterial organisms conducive to ABS degradation. Furthermore, by the time the percolative waters reach a ground water table, most of the easily biodegradable ABS molecules are degraded. In comparison to ABS degradation in surface waters and in the zone of aeration, the breakdown in ground waters must be very slow, if at all. A literature search on the biodegradability of ABS in ground waters disclosed one study on behavior of ABS in water-saturated soils.(15) This study on soil columns indicated that under saturated flow conditions, ABS was not materially degraded after 90 days of flow.

In the field investigations reported here, it was impossible to clearly determine if further degradation of ABS occurred in ground waters. Laboratory studies by other investigators had shown that under conditions of saturated flow and absence of biological life, very little if any biodegradations of ABS occurred. The fact that concentrations of 1.5 to 2.5 mg/l ABS were obtained in wells at considerable distances and depths from the sources indicates that little ABS biodegradation occurs after the percolating waters reach the saturated zone.

CHAPTER VI

MIXING AND DISPERSION IN A GROUND WATER BASIN

Mixing and dispersion of ABS-laden water within a ground water basin depend on a large number of different and variable conditions. The rate of its dispersion from the surface to the zone of aeration is determined by surface conditions such as lithology of materials, static head, plant cover, temperature, biological environment, and additional minor influences. While moving through the zone of aeration, the water is forced to take devious paths to reach the water table because of lithologic differences and permeabilities. Movement of water in this zone is primarily vertically downward, although capillary rise near the water table may supply ABS to the zone of aeration from the underlying saturated materials. Upon reaching the water table, the water follows typical laminar flow patterns in moving through the aquifers. Cones of depression that develop around pumping wells increase the velocity of flow, thus causing local turbulent conditions that aid in the mixing and dispersion of ground waters.

In the area of investigation, the aquifer materials through which the ABS-laden water flows consist of layer upon layer of gravels, sand, silts, and clays in varying proportion, order, and thicknesses. At the time each stratum was being deposited, the stream channels were subjected to much braiding and meandering, and thus developed many alternate channels. This complex of possible flow paths makes detailed determination of ground water flow directions nearly impossible.

The use of radioactive tracers to determine ground water velocities and directions was considered, but their many disadvantages precluded their use. Objections were raised as to the health hazards, costs of such a study, and administrative difficulties that must be met in arranging for their use. Also, the time required for ground water to travel the distances encountered in the study are too long for tracers to provide the answers in a three-year study. Similarly, the use of other possible tracers such as sugars, salts, and dyes were considered and rejected. Tritiated water was also deemed undesirable as a tracer for this study.

After rejecting the insertion of possible tracers, consideration was given to the study of mineral concentrations as a means of tracing the relative direction and magnitude of subsurface flows. Therefore, a survey was made of the quality of ground water that existed prior to the release of large discharges of effluent to determine the lateral and vertical patterns of the mineral concentration values.

Conventional Concepts of Ground Water Flows and ABS Travel

According to laboratory studies at the Sanitary Engineering Research Laboratory of the University of California at Berkeley (15), dispersion in porous media occurs in both longitudinal and lateral directions. Also, the effect of molecular diffusion in the range of ground water flows encountered during the study reported here is insignificant. On the other hand, the average velocity of flow greatly affects the geometric pattern of the transitional front and the amount of dispersion. The University of California studies were performed with sodium chloride solutions in which the chloride ion was used as the tracer and, therefore, did not exhibit the same adsorption and desorption phenomena for the soil as do the synthetic detergents. Another complicating factor in the determination of mixing and dispersion under field conditions as compared to the laboratory studies is the heterogeneous nature of the porous media in the study area.

Apparently, dispersion and mixing of synthetic detergents in solution follow the classic pattern of laminar flow in porous media, with the exception that adsorption and desorption of synthetic detergents from soil particles is influenced by the type of soil, rate of flow, and concentration of detergent in solution. (15) Probably the main factors causing dispersion and mixing in localized areas are the complex and varying lithology and the pumping patterns. When a solution under laminar flow travels from a coarse gravel of sand to a fine silty material, dispersion and extension of the lateral flow take place rapidly. It is not surprising that under such consitions ABS concentrations vary greatly, and mixing and dispersion of the ABS front cannot be precisely defined.

Mixing within the ground water basins depends upon: (1) the geologic conditions and features (i.e., the thickness, areal extension and degree of homogeneity of the sediments, subsurface barriers, and presence or absence of aquicludes); (2) the median depth to which wells are drilled; and (3) the concentration of wells and amount of pumping.

Water Quality as a Tracer for Mixing and Dispersion

Studies of water quality changes and ABS variations were carried on during this investigation. ABS variations and concentrations were used to define the problem area and the particular water-bearing horizons affected, and to delineate the advances and retreats of the pollution front. Water quality was studied to establish the historical water quality "base" upon which to compare quality changes with time, depth, and areal extent of ground water. Plate 21, "Ground Water Quality Changes of Representative Wells in Study Area," shows that total dissolved solids and bicarbonates have varied with time, while very little change of the other constituents was noted in these wells. Thus, water quality may be used as an aid in determining the degree of mixing and dispersion taking place and in establishing flow paths of ground water or dilution water from lateral sources. This may be facilitated by the use of modified Stiff diagrams, which graphically depict the chemical characteristics of water.⁽³⁰⁾

Quality of Surface Water

Rainwater, the prime source of surface water in the area of investigation, was analyzed for total dissolved solids (TDS) to establish a reference upon which to illustrate mineral pickup. Total dissolved solids of the rain samples ranged from 0 to 15 ppm. This surface water, or near-surface water, generally had increased in total dissolved solids to more than 150 ppm by the time it was discharged as surface water from the mountain front. As it traveled across the alluvial fan deposits, the surface water infiltrated and became a part of the ground water of the basin.

However, during times of normal and subnormal rainfall, such as occurred during the study period, the largest portion of the flow in Warm Creek and the Santa Ana River in the area of investigation consisted of sewage effluent. ABS and TDS values for waste waters of treatment plants affecting this area are shown in Figure 11.

Reclaimed waste waters of the treatment plants of the Cities of San Bernardino, Loma Linda, Colton, and Rialto contain sodium as the predominant cation, and bicarbonate as the predominant anion. Analyses of surface waters taken at four stations along the Santa Ana River also indicate a sodium bicarbonate character to the water not unlike that of the waste waters. Figure 14 shows the geochemical classification of sewage effluent waters and analyses of surface waters in the Santa Ana River and of ground water in the four test wells and in the two monitoring wells in East Riverside Mesa. Water from test wells No. 1 and No. 2, which were situated closer to the waste discharge plants than any of the others, showed a striking resemblance in quality to the sewage effluent. Water from test wells No. 3 and No. 4 and the mesa wells, which were further away, did not.

Quality of Ground Water

To determine the water quality variations in the ground water basins and to determine vertical mixing, if any, a search of water quality records was made. Not enough analyses were available for any one year to give a complete sampling of the historical water quality. Therefore, the mineral constituents of the available analyses, which extended over a 21-year period, were grouped into three 7-year average values and were classified into three depth zones: shallow zone, surface to 100 feet; intermediate zone, 100 to 350 feet; and deep zone, below 350 feet. Table 15 gives the seven-year averages for total dissolved solids at different depth zones.

TABLE 15

Seven-year Values * of Total Dissolved Solids

In mg/l

Area	Depth zones	1941–1947		1948–1954		1955–1961	
		Values	Number of analyses	Values	Number of analyses	Values	Number of analyses
Bunker Hill Basin upstream of San Jacinto fault	Shallow	--	--	295	10	448	6
	Intermediate	305	3	320	22	372	69
	Deep	171	4	231	91	256	25
Floodplain portion of Colton Basin	Shallow	--	--	--	--	--	--
	Intermediate	122	1	450	1	322	3
	Deep	--	--	--	--	--	--
East Riverside Mesa area	Shallow	584	1	--	--	--	--
	Intermediate	--	--	486	12	680	25
	Deep	--	--	--	--	--	--
Colton Narrows area	Shallow	270	1	365	2	734	7
	Intermediate	214	1	304	11	448	17
	Deep	--	--	--	--	--	--
Slover Mountain to Crestmore	Shallow	697	1	600	11	703	24
	Intermediate	--	--	294	1	--	--
	Deep	--	--	--	--	--	--
Mount Rubidoux to Riverside Narrows	Shallow	629	3	760	3	637	22
	Intermediate	--	--	--	--	--	--
	Deep	--	--	--	--	--	--

* Average values, except when only one analysis available.

Shallow wells generally produced water of the poorest quality, while intermediate wells and deep wells, in that order, produced increasingly better quality water. These averages include the effects of local disturbances such as proximity to sources of pollution, i.e., sewage disposal plants, industrial plants, dump sites, faults, agricultural plots that are fertilized, and areas of heavy extractions of ground water.

Effects of Waste Discharges on Water Quality

Generally the chloride-sulfate ratios in the ground water were found to parallel the ABS values, although in a few areas of high chloride-sulfate ratios, no ABS was evident. This is presumed to be caused by the application of sulfate fertilizers and irrigation return waters that have been recycled.

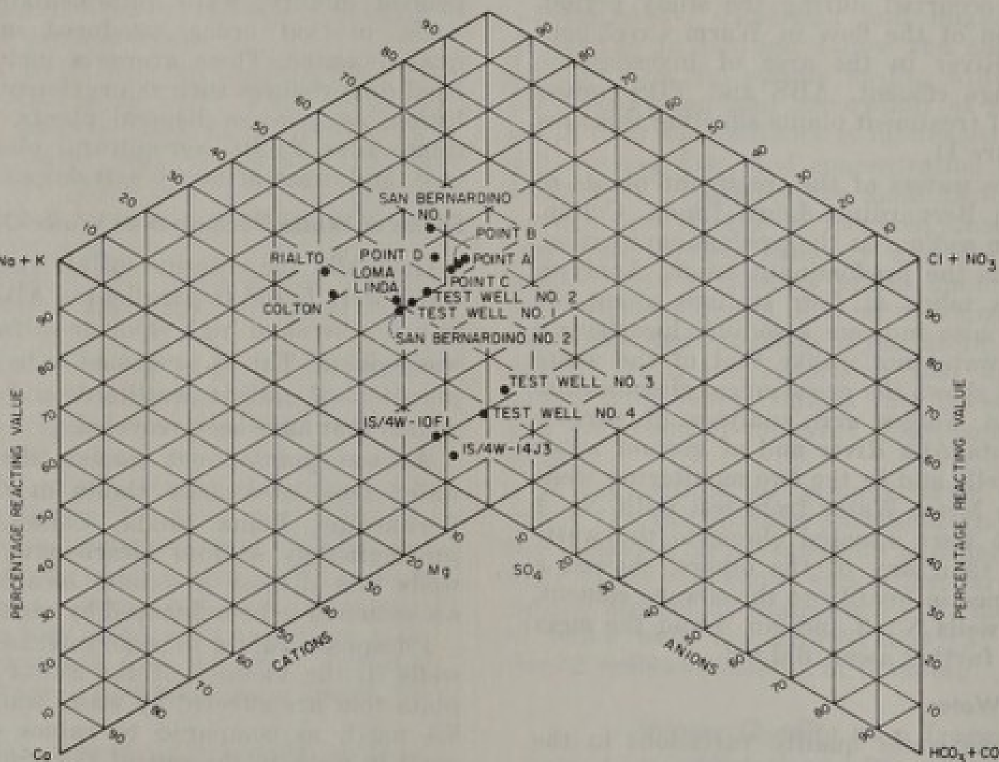
As was pointed out earlier, the reclaimed waste water from treatment plants in the Cities of San Bernardino, Loma Linda, Colton, and Rialto are predominately sodium bicarbonate. Therefore, those wells that display a sodium bicarbonate type water are assumed to be influenced by sewage effluent.

Phosphate values in some intermediate and shallow wells in the vicinity of the Santa Ana River floodplain that are affected by waste waters are as high as 8.4 mg/l, as compared to values of less than 0.05 mg/l in wells in the rest of the study area. The same correlation was found for pH values. Sewage effluent pH averaged approximately 6.5. The pH of wells in the area determined to be influenced by the percolating effluent, as shown by ABS and Cl/SO_4 ratios, generally had pH values of the same order. Wells in the rest of the study area had pH values of 7.6–8.0. Nitrate concentrations in ground water exhibited the same areal distribution as ABS, pH, and Cl/SO_4 ratios.

Industrial waste waters have been monitored once or twice yearly in the Colton Narrows area and ap-

FIGURE 14

NOTE: WELLS 10F1 AND 14J3 WERE USED TO SHOW THE TYPICAL GROUND WATER QUALITY UPSTREAM OF CITY OF SAN BERNARDINO PLANTS 1 AND 2



QUALITY OF EFFLUENT WASTE WATER, SURFACE WATER IN THE SANTA ANA RIVER, AND GROUND WATER FROM FOUR TEST WELLS
JULY-AUGUST, 1962

parently the quality of these waters has generally improved.

Irrigation return waters have caused increases in certain mineral constituents of the ground water, such as sulfates, phosphates, and nitrates. This is especially true in areas where these waters pass over recently fertilized lands.

Most of the study area is sewered and therefore little recycling of the raw waste waters occurs. Home cesspool units are not a problem in this area as the population density is low and the water table is deep enough (i.e., 45 to 100 feet in the Colton Narrows) to allow some purification and degradation to take place in the percolating wastes before they reach the saturated zone. Upstream of the large treatment plants, only a few isolated and unexplained occurrences of ABS have been found. Possibly these islands of ABS are the result of percolation from individual disposal units and commercial wastes.

The ABS concentrations that formed the basis for the problem dealt with in this study were located downstream of the large treatment plants. Therefore, details are given on the way in which these ABS-laden waters reached the aquifers, as is shown in Plate 20.

Upstream of the San Jacinto fault and underlying the Santa Ana River floodplain is a fine blue to black silt of low permeability, which thickens upstream. In the vicinity of the fault, it is approximately 35 feet deep. The active stream channel containing fine to coarse sand has cut partially through the silts and provided the most probable conduit for infiltration, although some percolation also occurs through the remaining fines. Many abandoned channels, caused by lateral movement of the Santa Ana River back and forth across the floodplain, are also backfilled with fine to coarse sand deposits. Beneath the fine material lies an aquifer that consists primarily of sands, gravels, and cobbles. This aquifer is about 75 to 100 feet thick and is continuous beneath the floodplain in an upstream and downstream direction but thins or is absent laterally away from the Santa Ana River. Although this aquifer is highly permeable, water levels have been drawn down near its base. Next in vertical succession is a silty clay aquiclude containing stringers of sand and gravel. This is the main restricting member to percolating ABS-laden waters.

Two conditions indicate an upward rather than a downward flow of the ground water in this part of the area. Fluoride concentrations in ground water are high in the vicinity of the San Jacinto and Loma Linda faults. Ground water temperatures are also high between the San Jacinto and Loma Linda faults and temperatures increase with depth. Because ground water flow is from areas of high temperatures to areas of low temperatures, this indicates the existence of an upward flow. These waters rise toward the surface in the crushed zone to mix with and dilute shallow waters. Also, piezometric levels of upstream wells indicate a pressure head of approximately 60 feet. Thus, geologic conditions, temperature gradients, and piezometric levels all tend to prevent downward percolation. Therefore, ABS percolation is limited to the uppermost strata.

The investigation indicated that lateral flow on the surface and in the shallow aquifer move water containing ABS laterally across the San Jacinto fault. Downstream from the fault, percolation is known to occur to a depth of 400 feet. The piezometers indicate ABS in all zones down to nearly that depth. Because wells immediately upstream of the fault indicate a very slight amount of ABS, the ABS downstream apparently comes from percolation and not from passing across the fault at depth.

Effects of Well Depths on ABS Concentrations

Downstream of the Rialto-Colton Barrier, a deep well, 1S/4W-28N5, showed low ABS concentrations because fine sediments and cemented zones prevent much percolation or replenishment of ABS from the shallow zone. Farther downstream at test well No. 2 heavy concentrations again appear to a depth of 200 feet. The values at well No. 2 again demonstrate the lack of overlying impermeable zones and the resulting appreciable percolation from the shallow zone.

The study reported in Bulletin 78, which was conducted by the Department of Water Resources in this area, showed that the most active zone of mixing for a ground water basin is slightly deeper than the median depth of the wells.(7)

The area of Bunker Hill Basin just upstream from the San Jacinto fault has mostly deep wells and virtually no shallow wells. This absence of shallow wells is because of the low water table and, therefore, the best water-producing zones occur at 220 and 250 feet.

Downstream of the San Jacinto fault, wells are primarily of intermediate depth (100 to 350 feet).

Mixing and Dispersion of Ground Water in Specific Areas

Dispersion of ABS throughout the area downstream of the sewage treatment plants depends on geologic and hydrologic conditions, and dilution. Because wells upstream of the City of San Bernardino Treatment Plants No. 1 and No. 2 show little or no ABS, the assumption is that the upstream discharges of ABS-laden waste waters have no effect on the area of study. From the points of discharge above the San Jacinto fault to points downstream of the fault, many complex conditions are involved in the dispersion of ABS-carrying waters. For one thing, each area has a hydrologic connective influence over every other area and cannot be separated, except for the purpose of simplified explanation of mixing.

Vicinity of San Jacinto Fault

Earlier in this chapter, information was given on the upper deposits that form the floodplain in the vicinity of the San Jacinto fault and underlie it to depths up to 120 feet. Therefore, it will not be repeated here.

Directly beneath the Santa Ana River, two deeper aquifers appear on both sides of the San Jacinto fault. The uppermost is approximately 200 feet thick while the lower is about 50 to 60 feet thick. Lithology of penetrated materials for wells 1S/4W-22E1 and

1S/4W-21Q1 show that the physical condition for possible hydraulic continuity exists in these deeper aquifers across the fault as the quality of water in these two wells are similar. However, ABS concentrations in the upstream wells are negligible while those in the downstream wells are heavy. A zone of fine, clay-like material (at the surface) overlies the area of the upstream well, preventing downward percolation of sewage effluent.

Modified Stiff diagrams using various proportions of well water and effluent waters indicate a possible dilution ratio of three parts of ground water to one part of sewage. When three parts of water from well 1S/4W-22L5 were blended with one part composite effluent from San Bernardino Plants No. 1 and No. 2, a water with a quality similar to that in well 1S/4W-28L2 was produced. Mixing one part composite effluent from the two plants and one part water from well 22L5 produced a quality of water similar to that from well 1S/4W-29H1, downstream of the Rialto-Colton Barrier. See Figure 15 for method of using Stiff diagrams to determine mixing ratios. Apparently, the dilution ratio on the downstream side of the San Jacinto fault is higher than that on the downstream side of the Rialto-Colton Barrier.

Beneath East Riverside Mesa

A geologic appraisal of the East Riverside Mesa indicates a buried channel of coarse sands, gravels, and boulders passing beneath the mesa in an alignment roughly parallel to the eastern edge of the La Loma Hills and the Riverside Freeway.

Geologic Section M-M′ in Plate 6 shows that, physically, the aquifers beneath the East Riverside Mesa are in hydraulic continuity with Santa Ana River floodplain deposits both upstream and downstream of the La Loma Hills. Water quality similarities of mesa wells with those in the floodplain bear out this hydraulic continuity. This easy path of flow for ground water is regulated by pumping conditions of the well field at the northern edge of the mesa. During the summer, water is drawn in a northerly direction from beneath the northern portion of the mesa.

ABS concentrations of ground water beneath the mesa were increasing at the beginning of the study but appeared to reach a point of equilibrium. The quantity of ABS discharged is apparently balanced by the quantity of ABS degraded and adsorbed by the sediments through which the water passes, and by extractions. As the distance traveled by the water increases, the volume of sediments through which it travels also increases. Thus, this distance is important in establishing the equilibrium. Also, at times of heavy pumping, the removal of ABS-laden water and its replacement with ABS-free water is stepped up. Infiltration of ABS-free irrigation return water applied on the upper slopes of the mesa is another thing that aids in the dilution of ground water in this area. Very little infiltration into surface materials of the mesa's lower slopes occurs because here the aquifers are overlain by 60 to 75 feet of highly weathered clays, silts, and silty sands.

At Colton Narrows

At the Colton Narrows, that area of the Santa Ana River floodplain and Fontana Plain that lies between Slover Mountain and La Loma Hills, the subsurface geology indicates a lack of good quality materials to transmit ground water downstream. The area where the most suitable aquifers exist is north of the present river floodplain approximately beneath the property of the Colton Cement Company, south and southwest of Slover Mountain.

The concentration of ABS at Colton Narrows is higher than that anywhere else in the area of investigation. The distribution of this high ABS concentration depends upon the degree and times of heavy pumping in the well field in Section 32, T1S, R4W. Although heavy extractions change the direction of flow and may even draw dilution water from the surrounding sections, little actual vertical mixing takes place in the Colton Narrows. This is because most of the flows are contained within the aquifer material and flow is laminar. Deep waters in this area are ABS-free, also indicating little mixing of the waters above 200 feet with those below this depth. This is evidenced by ABS concentrations in wells 1S/4W-32E2 and 1S/4W-32E7. Well 1S/4W-32E7, which is perforated between 202 and 368 feet, shows very little ABS, while adjacent well 1S/4W-32E2, perforated from 30 to 191 feet, shows ABS as high as 2.0 mg/l. This is also borne out by phosphate analyses, which show 10 to 13 mg/l for the shallow well and 0.00 for the deeper well.

Downstream of the Colton Narrows the sedimentary section is more uniform, with less effective aquitards. Therefore, the ABS concentrations are nearly the same from the surface to bedrock at a depth of nearly 400 feet. Because ground water contours for this area indicate a western direction of ground water movement, paralleling the Santa Ana River, it is believed that little ABS is brought in from the Chino Basin north of the Santa Ana River or from the East Riverside Mesa. Even though a physical connection exists between the aquifers of the mesa and the Santa Ana River downstream of the La Loma Hills, water level contours indicate that water is being conducted southwesterly through the Riverside area and southeasterly of Mount Rubidoux. ABS values in test well No. 4, (2S/5W-11K2) show little variation throughout the depth of the well indicating that mixing among the shallow, intermediate, and deep zones does exist here.

Mount Rubidoux to Riverside Narrows

In the area from Mount Rubidoux to Riverside Narrows, geologic data is lacking below 110 feet, although projected bedrock contours through this area show a depth of 290 feet. Ground water contours indicate that ground water is brought into this area from both northwest and southeast of Mount Rubidoux. This is further borne out by the high ground water levels in the area. Plate 8, showing modified Stiff diagrams of water quality for this area, depicts the similarity of these waters with those entering the area both from upstream along the floodplain and from the Riverside Plain. Because of the high bedrock, ground water rises and becomes surface water which passes through the Riverside Narrows.

Relationship of Ground Water Elevations, ABS Concentrations, and Total Pumpage

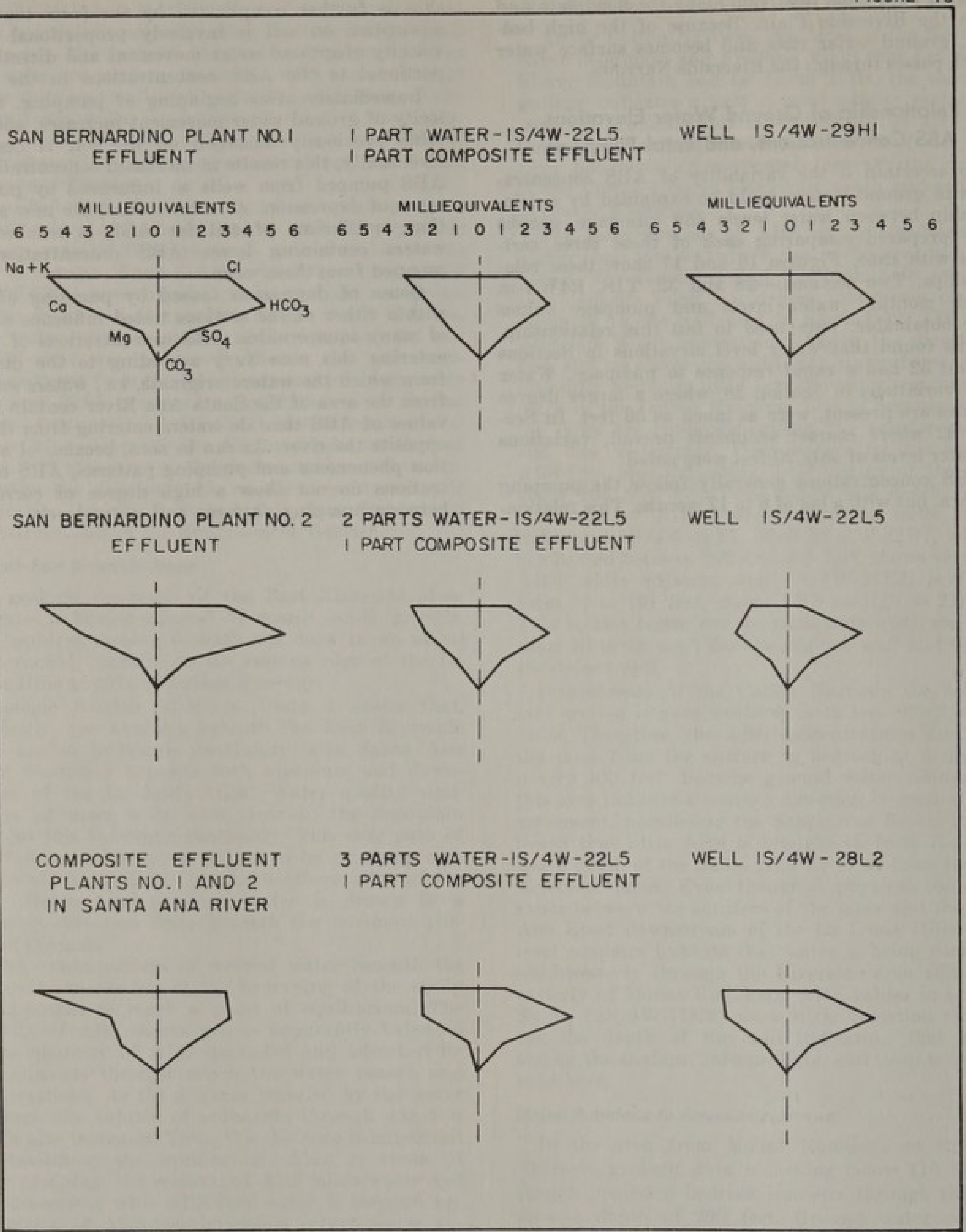
To ascertain if the variability of ABS concentrations in ground waters could be explained by a relationship between water levels and pumpage, graphs were prepared comparing each of these three variables with time. Figures 16 and 17 show these relationships. Two sections,—28 and 32, T1S, R4W—in which monthly water levels and pumpage values were obtainable, were used to test this relationship. It was found that water level elevations in Sections 28 and 32 had a rapid response to pumpage. Water level variations in Section 28, where a larger degree of fines are present, were as much as 30 feet. In Section 32 where coarser sediments prevail, variations in water levels of only 20 feet were noted.

ABS concentrations generally follow the pumping pattern, but with a lag of 6 to 12 months. This relationship is further complicated by the facts that ABS adsorption on soil is inversely proportional to the velocity of ground water movement and directly proportional to the ABS concentrations in the water.

Immediately after beginning of pumping, the velocity of ground water movement increases, and some ABS previously adsorbed on the soil is desorbed. Eventually, this results in increased concentrations of ABS pumped from wells so influenced by pumping cones of depression. At a later time, the new adsorption equilibrium of soil for ABS is reached, and waters containing lower ABS concentrations are pumped from these wells.

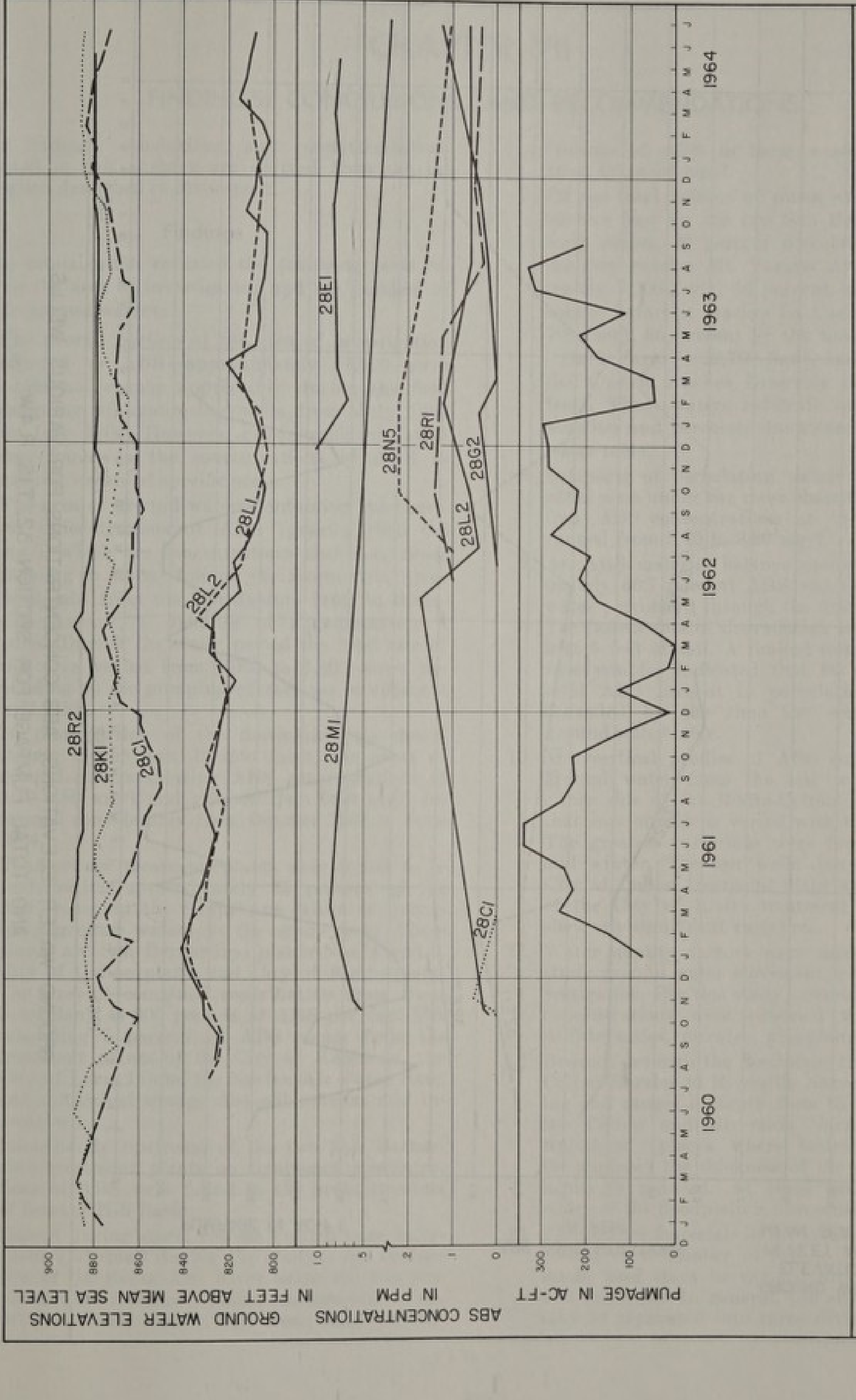
Cones of depression caused by pumping of wells within either of the sections tested influence an area of many square miles. ABS concentrations of waters entering this cone vary according to the direction from which the waters originate, i.e., waters entering from the area of the Santa Ana River contain higher values of ABS than do waters entering from the side opposite the river. As can be seen, because of adsorption phenomena and pumping patterns, ABS concentrations do not show a high degree of correlation between pumping patterns and water levels.

FIGURE 15



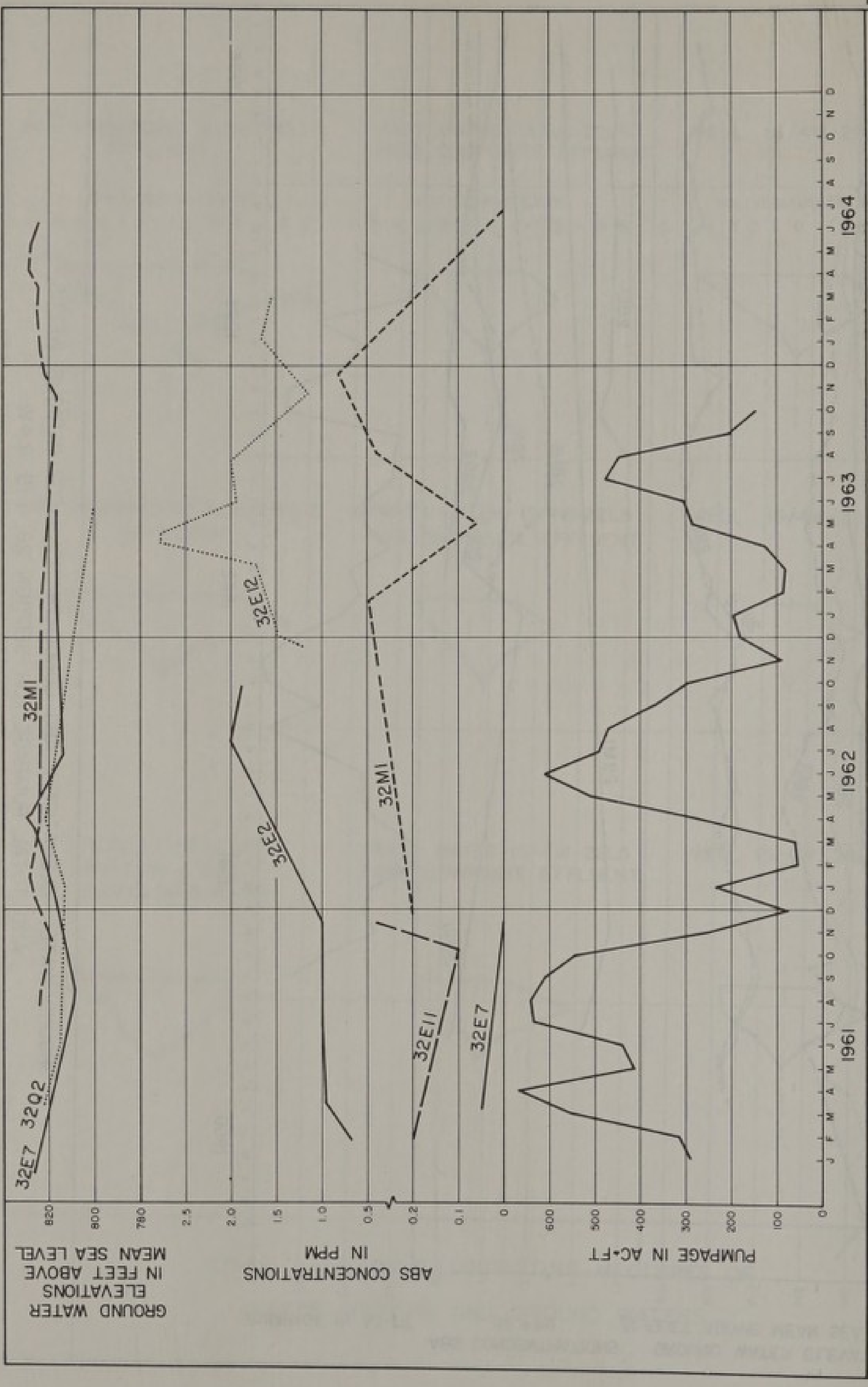
STIFF DIAGRAMS ILLUSTRATING MIXTURES OF WASTE WATERS AND GROUND WATERS

FIGURE 16



GROUND WATER ELEVATIONS, ABS CONCENTRATIONS FOR VARIOUS WELLS, AND TOTAL PUMPAGE FOR SECTION 28, T.1S. R.4W.

FIGURE 17



GROUND WATER ELEVATIONS, ABS CONCENTRATIONS FOR VARIOUS WELLS, AND TOTAL PUMPAGE FOR SECTION 32, T.1S. R.4W.

CHAPTER VII

FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

The findings, conclusions, and recommendations presented in this chapter are derived from the investigation described in this report.

Findings

This investigation revealed the following facts regarding the area of investigation and the problem of ABS in ground waters:

1. The overall portion of the area of investigation affected by ABS—approximately 14,000 acres—did not change appreciably during the field sampling of monitoring wells from July 1962 to July 1964. However, considerable variation was found in the concentrations of ABS in ground waters of specific areas.
2. The area of ground waters containing the heaviest concentrations of ABS (greater than 0.5 mg/l, which are concentrations that may cause foaming in wells) follows the Santa Ana River floodplain from the San Jacinto fault to Riverside Avenue, a distance of approximately 6 miles. During the study period the total size of this area varied from 1,000 to 1,600 acres, depending on the pumping extractions in adjacent well fields.
3. In that portion of the floodplain just downstream of the San Jacinto fault, the areas of ground waters showing ABS concentrations of 0.10–0.50 mg/l and greater than 0.50 mg/l increased considerably from October 1962 to June 1964.
4. Four sewage treatment plants were found to be contributing approximately 95 percent of the ABS reaching the Santa Ana River or underlying ground waters in the study area. These plants are San Bernardino plants Nos. 1 and 2, City of Colton plant, and City of Rialto plant. The present combined contribution from these four plants is 600 pounds of ABS per day. The remaining 5 percent of ABS comes from the treatment plants of the City of Rubidoux, the City of Loma Linda, the Norton Air Force Base, and individual sewage disposal systems and industries.
5. Immediately upstream of the two San Bernardino treatment plants no significant concentrations of ABS were found in the ground waters of Bunker Hill Basin.
6. Except during storm runoffs (which were infrequent and small during the study), the surface flow of the Santa Ana River below the two San Bernardino treatment plants consists almost entirely of waste waters. The mean daily concentrations of ABS in these waste waters range from 4.0 to 5.4 mg/l.
7. Of the total volume of waste water released as surface flow by the two San Bernardino treatment plants, 20 percent percolates by the time the flow reaches Mt. Vernon Avenue (approximately 7,200 feet), 46 percent of the total percolates before it reaches La Cadena Drive (16,700 feet), 66 percent by the time it reaches the "Duck Farm" (22,700 feet), and 95 percent by the time it reaches Riverside Avenue (31,400 feet). These waters infiltrate into the zone of aeration and percolate downward to the ground water table.
8. Sampling of percolating waters in the unsaturated zone under the river channel demonstrated that ABS concentrations at the 8-foot depth ranged from 0.80 to 2.60 mg/l.
9. An ABS material balance showed that approximately 66.7 percent ABS was degraded as the water percolated through the first 10 feet of soil. The fastest rate of degradation took place in the first 5 feet of soil. A limited number of subsurface samples indicated that 80 percent of the total ABS present in percolating waters was degraded by the time the waters reach the ground water table.
10. The vertical profiles of ABS concentrations in ground water from the test wells located on either side of the Rialto-Colton Barrier showed that concentrations varied with time and depth. The greatest variations were found in the fall and winter. The test wells downstream of the City of Colton treatment plant and downstream of the City of Rialto treatment plant did not show any significant variation.
11. Water quality factors were used as tracers to study ground water movement in the area of investigation. For this study, correlation with ABS concentrations were obtained with chloride—sulfate ratios, nitrates, phosphates, and pH.
12. Bedrock beneath the floodplain from the Rialto-Colton Barrier to Riverside Narrows is undulating and ranges in depth from 85 to 400 feet. In the Colton and Riverside Narrows and near Rubidoux (places where bedrock approaches the surface) the thickness of the overlying sediments is reduced. At these same points, the width of the floodplain is also constricted.
13. The aquifer materials in the area of investigation consist of a number of layers of gravels, silts, sands, and clays in various proportions, order and thickness. In general, the alluvium deposits may be separated into three divisions, with the

lowest of them containing the principal water-bearing zones.

14. Although three faults exist in the area of investigation, only two play a significant role in the distribution of ABS in ground waters. These two are the San Jacinto fault and the Rialto-Colton Barrier. Upstream of the San Jacinto fault, sampling of wells perforated in the intermediate and deep zones revealed only a trace of ABS. Measureable amounts were found in the surface and near surface waters. Downstream of the fault, samples obtained by means of piezometers showed significant concentrations to a depth of 400 feet. Immediately downstream of the Rialto-Colton Barrier, percolation was limited by fine sediments and cemented zones.
15. In the East Riverside Mesa, southeast of La Loma Hills, a fine silt-clayey mantle exists at 200 feet below ground surface and acts as a barrier to downward percolation of ABS-laden waters. Wells perforated above 200 feet show significant concentrations of ABS, while those perforated only at depths greater than 200 feet show merely traces.

Conclusions

On the basis of the findings reported above, the following conclusions are drawn:

1. The present quantity of waste water discharges and pumping extractions from the ground waters along the Santa Ana River floodplain will probably prevent further increase of the total area affected by ABS. However, variations may be expected in the concentrations within specific portions of the area.
2. Between October 1962 and June 1964, the considerable increase in size of area containing concentrations of ABS greater than 0.5 mg/l, located just downstream of the San Jacinto fault, is accounted for, in part, by the increase in pumping upstream of the fault and by the addition of effluent from San Bernardino Treatment Plant No. 2. (The plant started operations in 1959.)
3. Extraction of ground waters for irrigation from well fields adjacent to the San Jacinto fault and Rialto-Colton Barrier reduces the flow of diluting waters to Colton Narrows. This, along with the narrow and shallow constriction of the Colton Narrows, results in the highest ABS concentrations found in the study area.
4. Pumping depresssions in various sections of the study area, caused by extractions of ground water, are responsible for local changes in ground water elevations. These lead to changes in velocity of ground water flows and local reversals in direction of flow. Consequently, ABS concentrations vary with the changes in pumping depressions.
5. The vertical distribution of ABS in test wells on either side of the Rialto-Colton Barrier is influenced by the pumping extractions in adjacent well fields.
6. Individual sewage disposal systems and industries in the area of investigation are contributing only insignificant amounts of ABS as compared to the waste discharges of the four major treatment plants.
7. No significant amount of ABS is being contributed to the ground waters of the area of investigation from Bunker Hill Basin, upstream of the Loma Linda fault.
8. The constant lateral migration of the Santa Ana River during the development of its floodplain, and the backfilling of these channels with sediments of higher permeability than the floodplain itself, has produced a complex of subsurface flow paths. This multiplicity of possible flow paths makes detailed determination and monitoring of ground water flows extremely difficult.
9. Discontinuous confining clay members occur in the area of the investigation which prevent the mixing of waste waters containing ABS between aquifers. Such clay members are found in the vicinity of the San Jacinto fault, beneath Colton Narrows, and beneath the East Riverside Mesa.

Recommendations

Based on the findings and conclusions of the investigation as reported here, the following recommendations are made:

1. It is recommended that the California State Water Quality Control Board continue to encourage the soap and detergent industry to meet its timetable for the proposed switchover from manufacturing ABS-type detergent to new types which are degradable by conventional methods of sewage treatment to a degree that will prevent pollution of receiving ground waters.
2. It is recommended that the sampling of monitoring wells, test wells, piezometers, and percolating waters be continued, on a limited basis in the 1964–1965 and 1965–1966 fiscal years, to determine the hydrologic and synthetic detergent concentration changes that may occur in the affected area. At the end of each fiscal year, a summary report should be prepared.
3. It is recommended that, with the anticipated replacement of ABS-type detergents with the LAS-type by mid-1965, a detailed study of the affected area be initiated in the 1966–1967 fiscal year. It would be designed to show the recovery of the basins from the high ABS concentrations and the impact of the new type detergents on the ground waters of the study area. Such a study would also add to the general information on the hydrology of the area.

A continuation of the study in this area will enable the full utilization of the geologic, hydrologic and water quality data secured thus far. Test equipment is already in place, and suitable methods and procedures have been developed for this work. Such a ready-made opportunity to obtain the desired information on such a large scale may never present itself again.

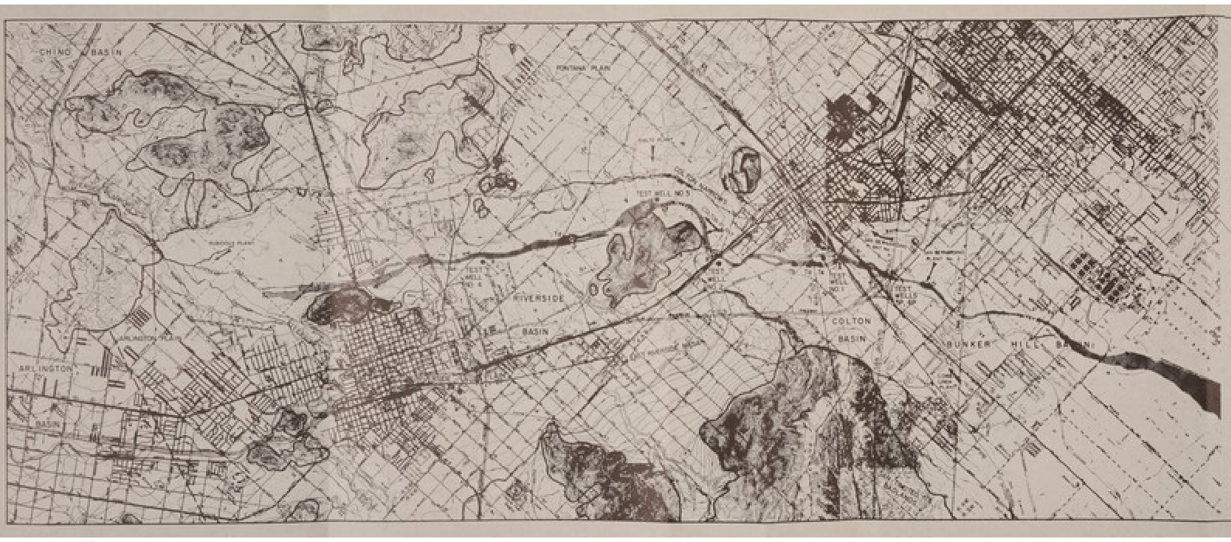
a. The study should include the determination of the biodegradability of the LAS-type detergent under actual field conditions. This determination should be made by sampling percolating waters in the zone of aeration through use of existing test facilities.

b. The study should also include determination of the proportions of ABS or LAS found in ground and surface waters.

c. At the conclusion of the study, results should be summarized and evaluated in a report. It should not only present new data, but it should also be directly related to the current report through its identification of findings that agree or disagree with all prior determinations.

4. It is recommended that the Advisory Committee on Dispersion and Persistence of Synthetic Detergents in Ground Waters be retained, and that the advice and counsel of its members be used in planning and conducting the above investigations.

PLATES 1 TO 21



LOCATION MAP

LEGEND

● ABS TEST WELLS

▲ TENSIOMETER SITES

⊠ SURFACE SAMPLING STATIONS

GROUND WATER BASIN BOUNDARY (COINCIDES WITH FAULTS AND BARRIERS WHERE LABELED)

SEWAGE PLANT DISCHARGE

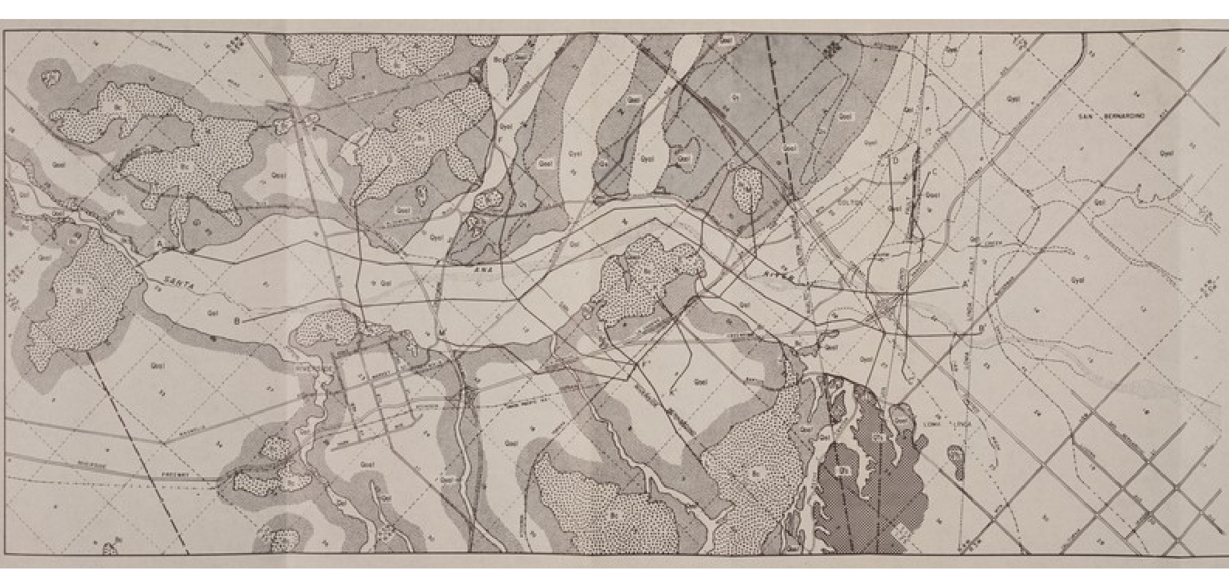
STATE OF CALIFORNIA
THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

DISPERSION AND PERSISTENCE OF SYNTHETIC DETERGENTS
IN GROUND WATER, SAN BERNARDINO AND RIVERSIDE COUNTIES

LOCATION MAP

SCALE OF FEET

1964



LEGEND

RECENT
PLEISTOCENE
QUATERNARY
PLEISTOCENE (?) TO PLIOCENE (?)
MESOZOIC

Qal ALLUVIUM - FINE GRAINED SANDS, SILTS, AND CLAYS. WATER BEARING.

Qyal YOUNGER ALLUVIUM - ALTERNATING COARSE TO FINE GRAVEL, SAND, SILTS, AND CLAYS. WATER BEARING.

Qs DUNE SAND - RELATIVELY UNIFORM IN SIZE, ROUNDED TO SEMI-ROUNDED GRAINS. RECENT TO UPPER PLEISTOCENE IN AGE. TRANSMITS WATER TO UNDERLYING AQUIFERS.

Qoal OLDER ALLUVIUM - COMPRISES THREE WATER-BEARING UNITS: TERRACE DEPOSITS OF ALLUVIUM SITUATED ABOVE FLOOD PLAINS; MESA AND PLAIN DEPOSITS - WEATHERED SURFACE OVERLYING WATER-BEARING MATERIALS; RESIDUUM - WEATHERED SURFACE GRADING VERTICALLY DOWNWARD INTO IN-PLACE ROCK.

QTs SAN TIMOTEO BEDS - GRAVEL CAPPING OVER SHALES AND CLAYS, FOUND IN SAN TIMOTEO BADLANDS. CONTAINS MINOR AMOUNTS OF WATER BUT NOT EXTENSIVELY USED FOR PRODUCTION.

Bc BASEMENT COMPLEX - GABBROS, TONALITES, GRANODIORITES, AND GRANITES. NOT GENERALLY USED FOR WATER PRODUCTION.

GROUND WATER BASIN BOUNDARY. COINCIDES WITH FAULTS AND BARRIERS WHERE LABELED, DOTTED WHERE CONCEALED.

A A' LINE OF SECTION

GEOLOGIC CONTACT

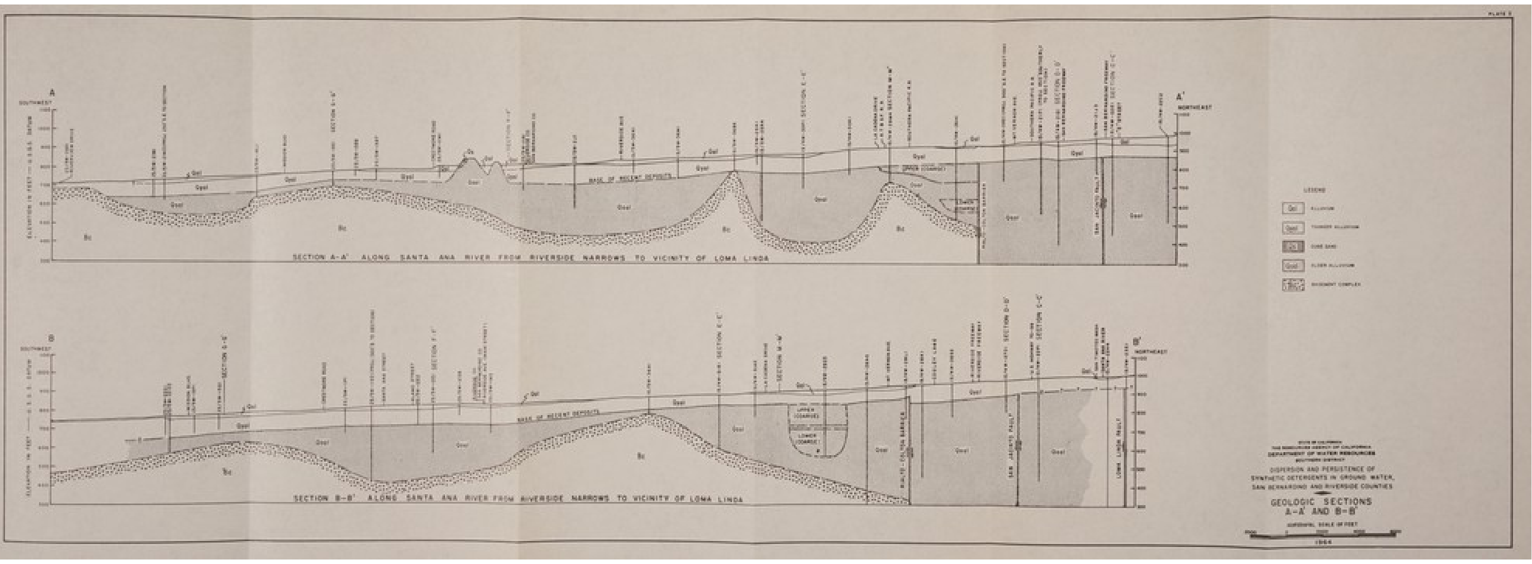
STATE OF CALIFORNIA
THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

DISPERSION AND PERSISTENCE OF
SYNTHETIC DETERGENTS IN GROUND WATER,
SAN BERNARDINO AND RIVERSIDE COUNTIES

AREAL GEOLOGY

SCALE OF FEET

1964



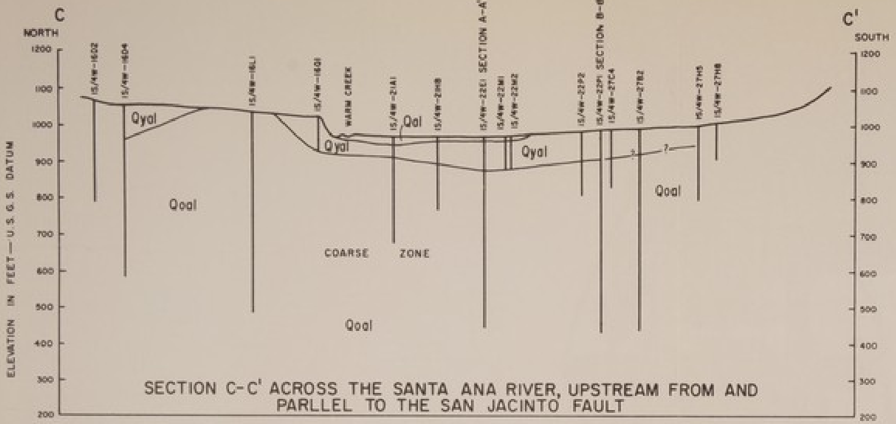
STATE OF CALIFORNIA
THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

DISPERSION AND PERSISTENCE OF
SYNTHETIC DETERGENTS IN GROUND WATER,
SAN BERNARDINO AND RIVERSIDE COUNTIES

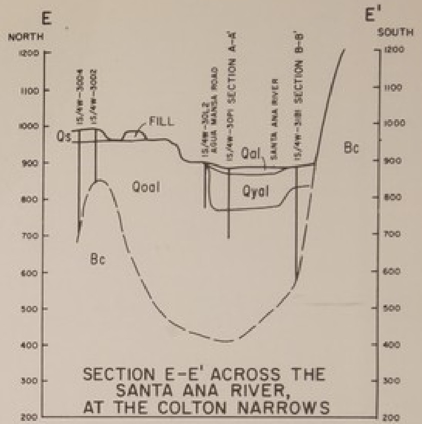
GEOLOGIC SECTIONS
A-A' AND B-B'

HORIZONTAL SCALE IN FEET

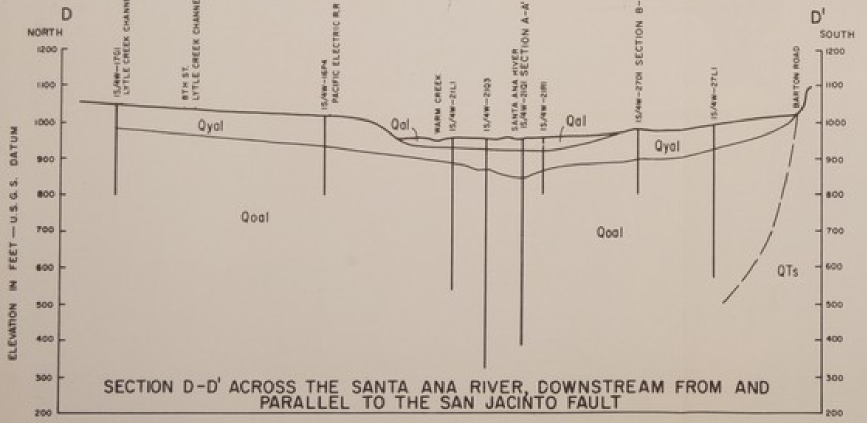
1964



SECTION C-C' ACROSS THE SANTA ANA RIVER, UPSTREAM FROM AND PARLLEL TO THE SAN JACINTO FAULT



SECTION E-E' ACROSS THE SANTA ANA RIVER, AT THE COLTON NARROWS



SECTION D-D' ACROSS THE SANTA ANA RIVER, DOWNSTREAM FROM AND PARALLEL TO THE SAN JACINTO FAULT

LEGEND

Qal	ALLUVIUM
Qs	DUNE SAND
Qyal	YOUNGER ALLUVIUM
Qoal	OLDER ALLUVIUM
QTs	QUATERNARY-TERTIARY SEDIMENTS
Bc	BASEMENT COMPLEX

STATE OF CALIFORNIA
THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

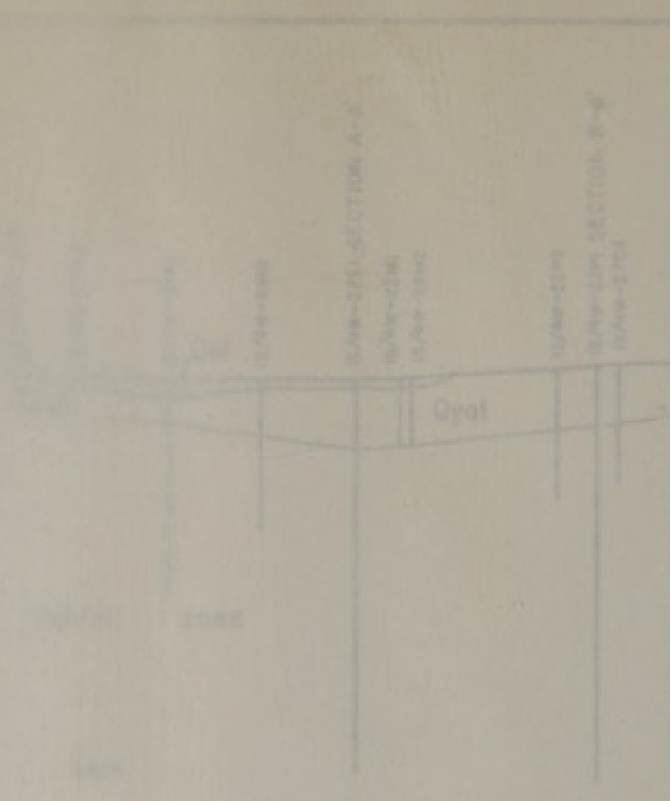
DISPERSION AND PERSISTENCE OF
SYNTHETIC DETERGENTS IN GROUND WATER,
SAN BERNARDINO AND RIVERSIDE COUNTIES

◆

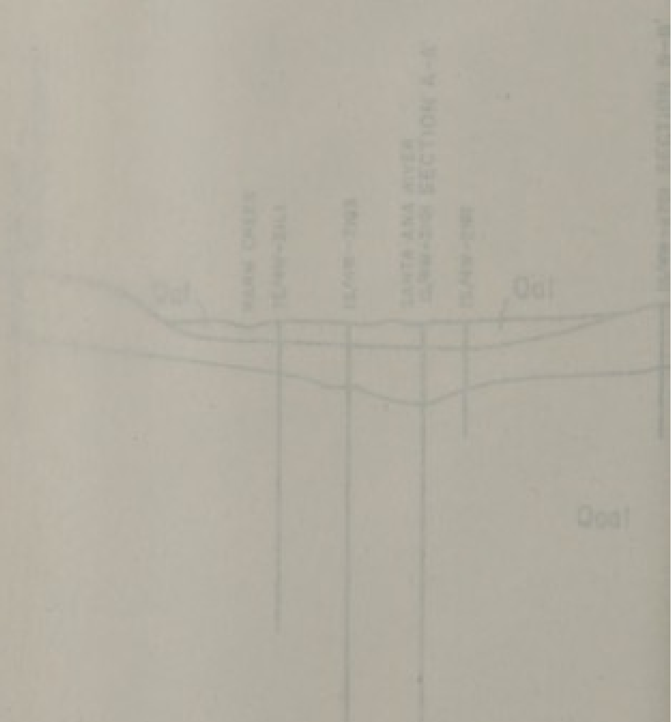
GEOLOGIC SECTIONS
C-C', D-D' AND E-E'

HORIZONTAL SCALE OF FEET
2000 0 2000 4000 6000

1964

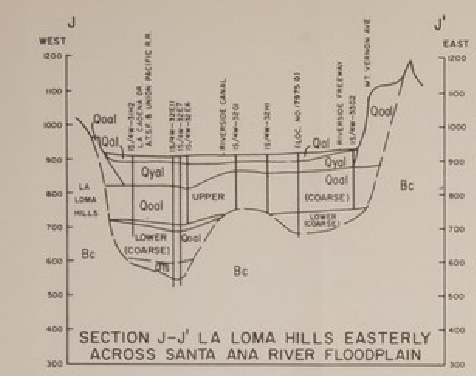


THE SANTA ANA RIVER, UPSTRE
TO THE SAN JACINTO FAULT

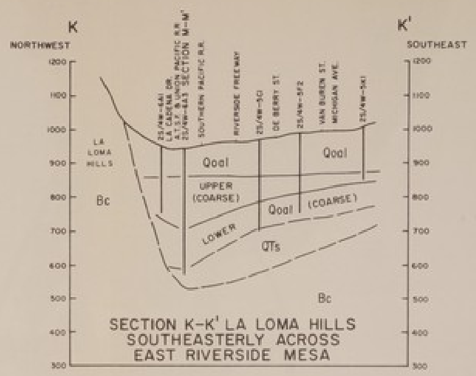


THE SANTA ANA RIVER, DOWNSTRE
PARALLEL TO THE SAN JACINTO FAULT

PLATE 5



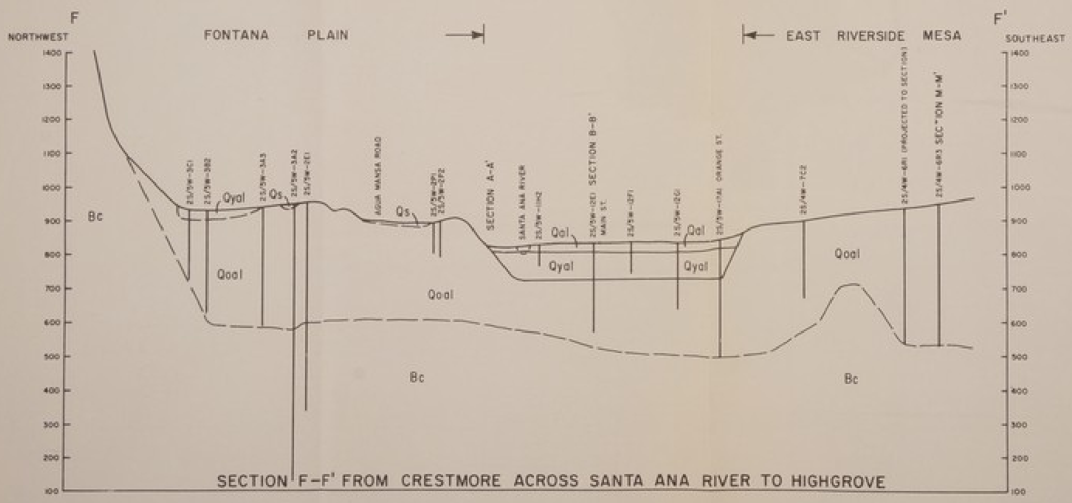
SECTION J-J' LA LOMA HILLS EASTERLY ACROSS SANTA ANA RIVER FLOODPLAIN



SECTION K-K' LA LOMA HILLS SOUTHEASTERLY ACROSS EAST RIVERSIDE MESA

LEGEND

Qal	ALLUVIUM
Qs	DUNE SAND
Qyal	YOUNGER ALLUVIUM
Qoal	OLDER ALLUVIUM
QTs	QUATERNARY–TERTIARY SEDIMENTS
Bc	BASEMENT COMPLEX



SECTION F-F' FROM CRESTMORE ACROSS SANTA ANA RIVER TO HIGHGROVE

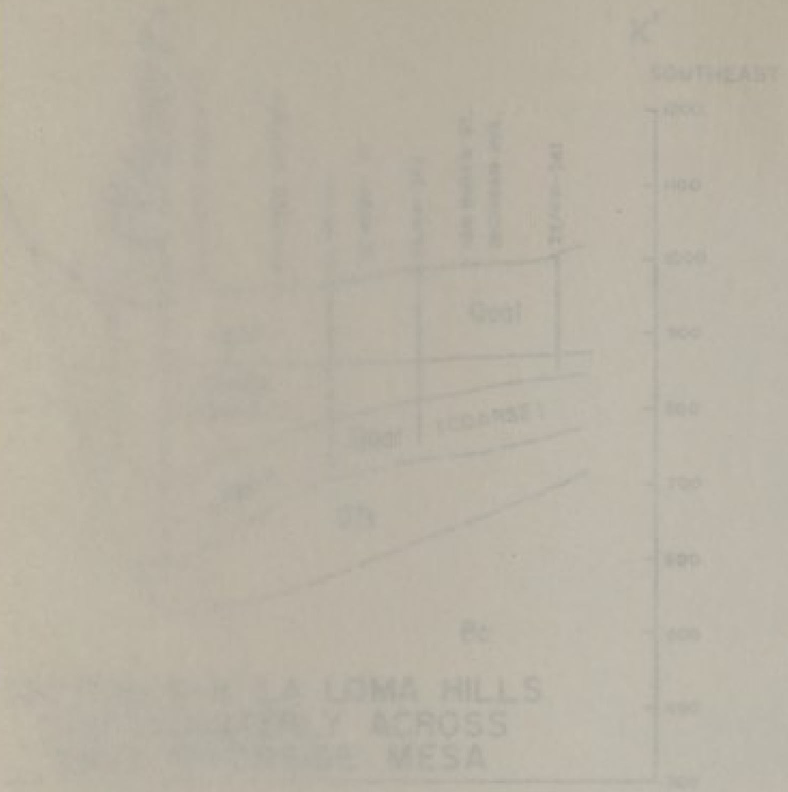
STATE OF CALIFORNIA
THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

DISPERSION AND PERSISTENCE OF
SYNTHETIC DETERGENTS IN GROUND WATER,
SAN BERNARDINO AND RIVERSIDE COUNTIES

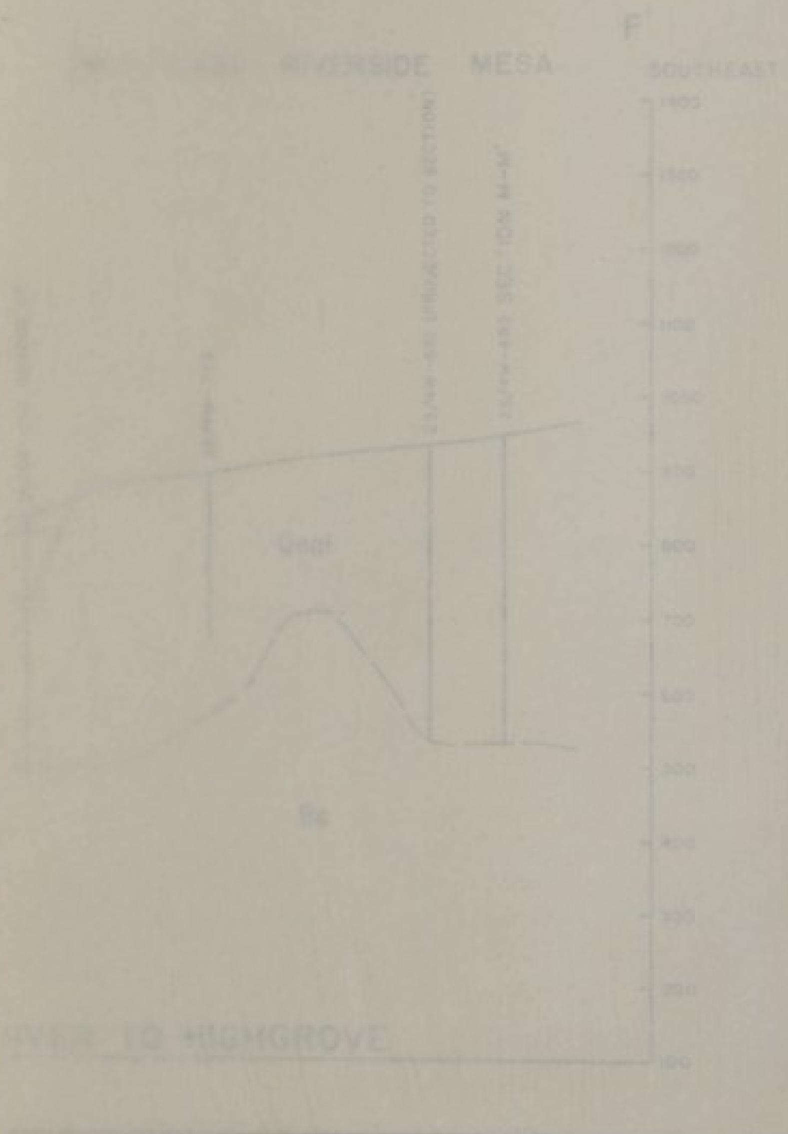
◆

GEOLOGIC SECTIONS
F-F', J-J' AND K-K'

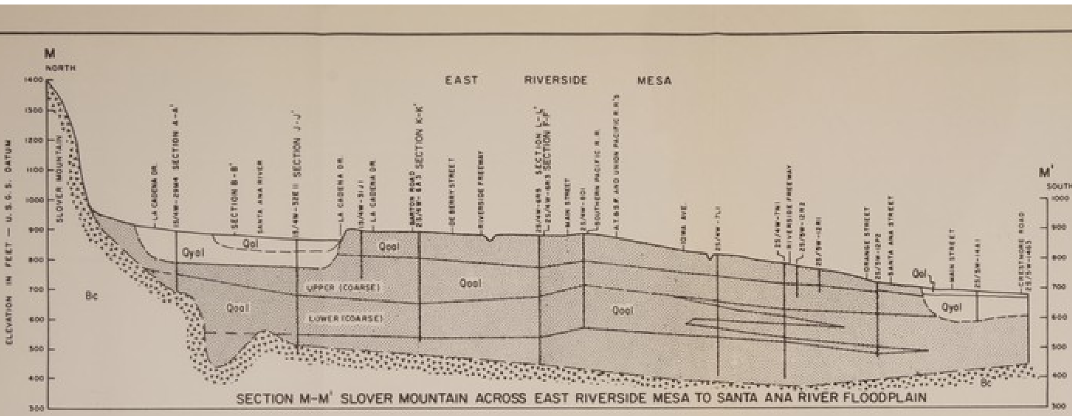
HORIZONTAL SCALE OF FEET
2000 0 2000 4000 6000
1964



LA LOMA HILLS
ACROSS
RIVERSIDE MESA



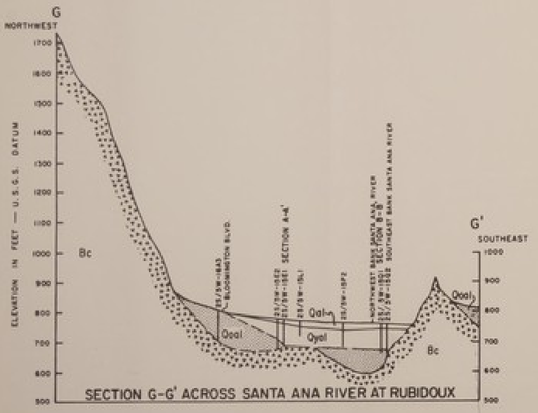
TO HIGHGROVE



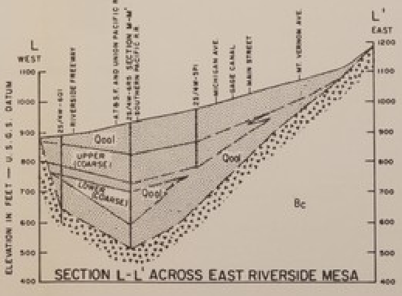
SECTION M-M' SLOVER MOUNTAIN ACROSS EAST RIVERSIDE MESA TO SANTA ANA RIVER FLOODPLAIN

LEGEND

Qal	ALLUVIUM
Qyal	YOUNGER ALLUVIUM
Qoal	OLDER ALLUVIUM
Bc	BASEMENT COMPLEX



SECTION G-G' ACROSS SANTA ANA RIVER AT RUBIDOUX



SECTION L-L' ACROSS EAST RIVERSIDE MESA

STATE OF CALIFORNIA
THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

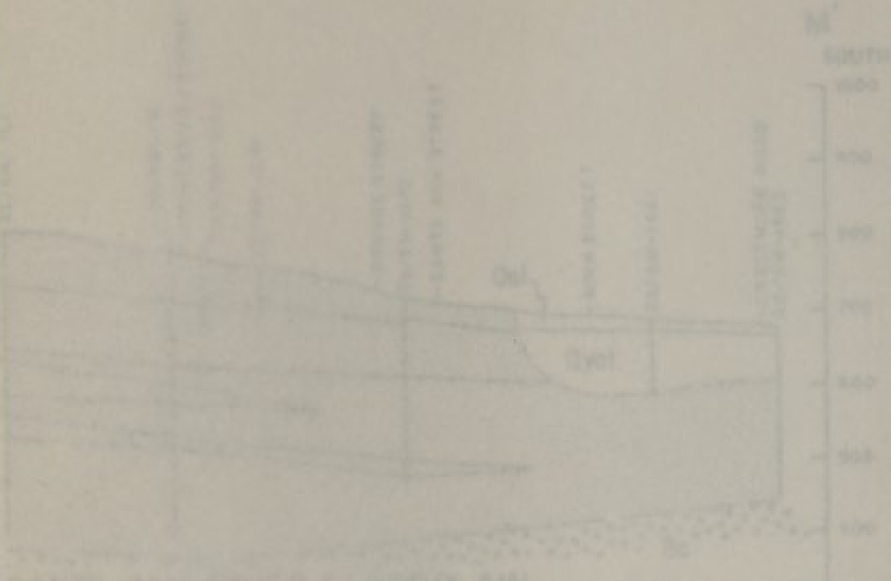
DISPERSION AND PERSISTENCE OF
SYNTHETIC DETERGENTS IN GROUND WATER,
SAN BERNARDINO AND RIVERSIDE COUNTIES

◆

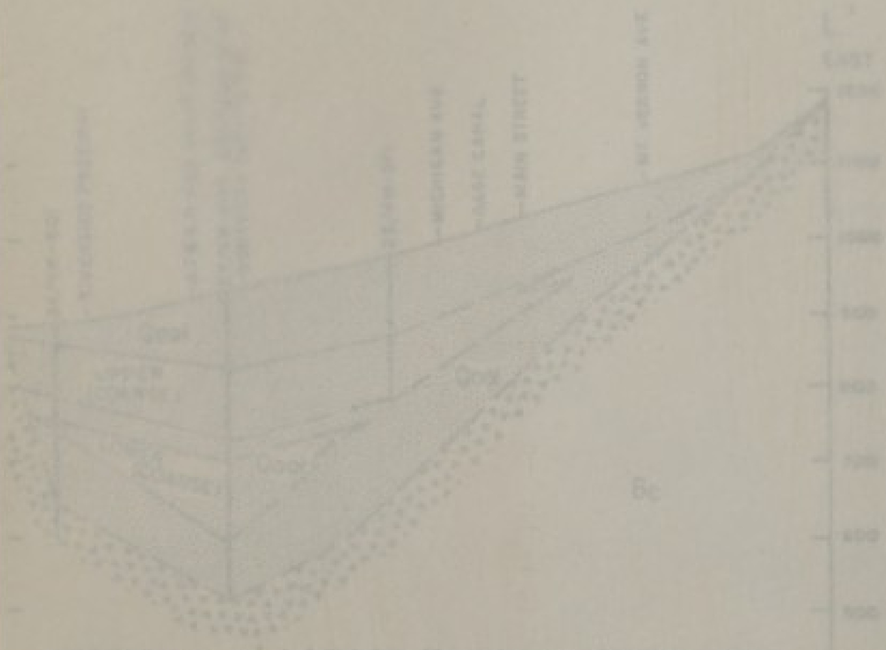
GEOLOGIC SECTIONS
M-M', G-G' AND L-L'

HORIZONTAL SCALE OF FEET
2000 0 2000 4000 6000

1964

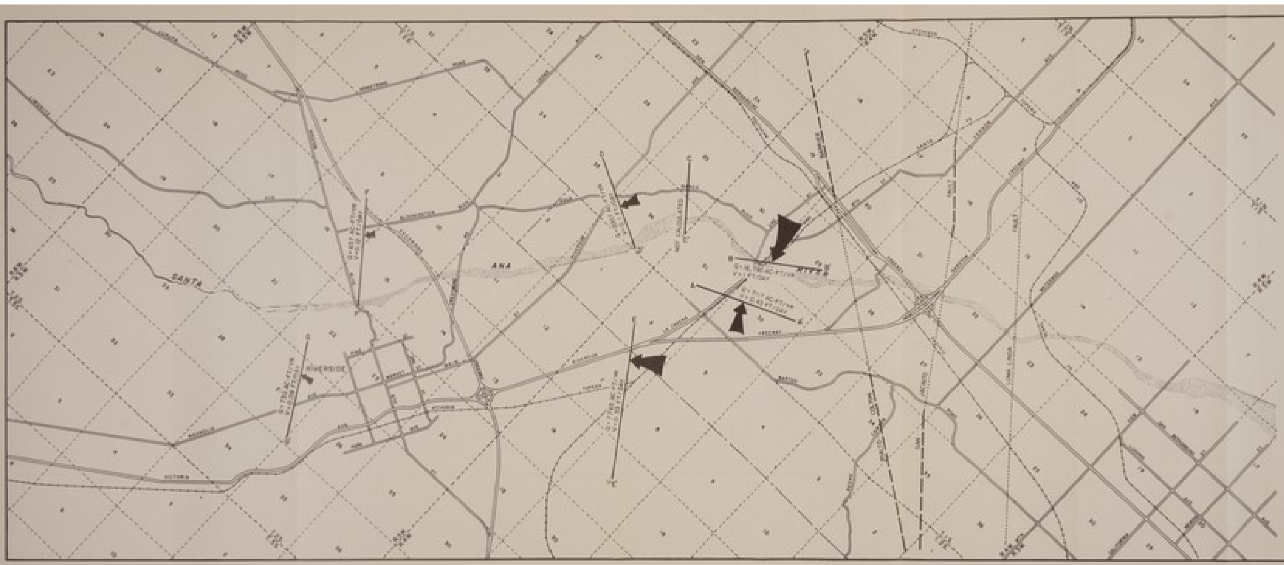


SANTA ANA RIVER FLOODPLAIN



SECTION L-L' ACROSS EAST RIVERSIDE MESA

PLATE 7



LEGEND

FAULT, DOTTED WHERE CONCEALED

STATE OF CALIFORNIA
THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

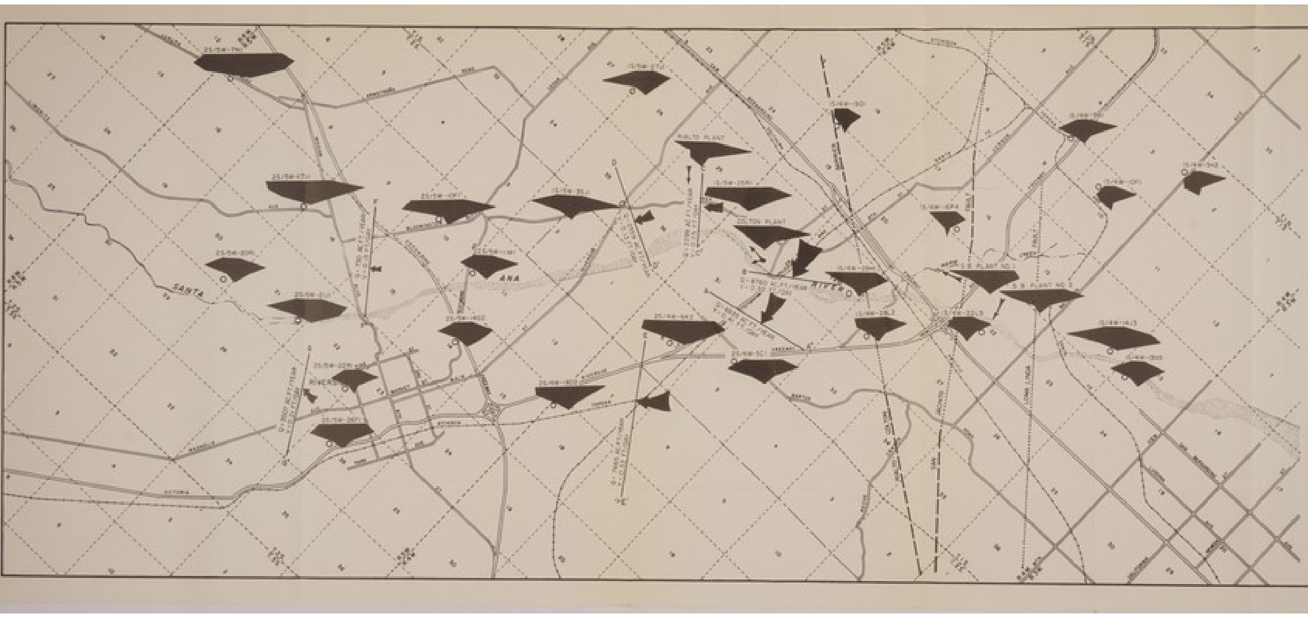
DISPERSION AND PERSISTENCE OF SYNTHETIC DETERGENTS
IN GROUND WATER, SAN BERNARDINO AND RIVERSIDE COUNTIES

GROUND WATER FLOWS
APPROXIMATE QUANTITIES, VELOCITIES AND DIRECTIONS,
WINTER 1961

SCALE OF FEET

1964

PLATE 8



LEGEND

○ SAMPLING WELL

⟵ SEWAGE PLANT DISCHARGE

— — ···· FAULT, DOTTED WHERE CONCEALED

EPM

TYPICAL DIAGRAM

STATE OF CALIFORNIA
THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

DISPERSION AND PERSISTENCE OF SYNTHETIC DETERGENTS
IN GROUND WATER, SAN BERNARDINO AND RIVERSIDE COUNTIES

GROUND WATER FLOWS

APPROXIMATE QUANTITIES, VELOCITIES AND DIRECTIONS,
SPRING 1963

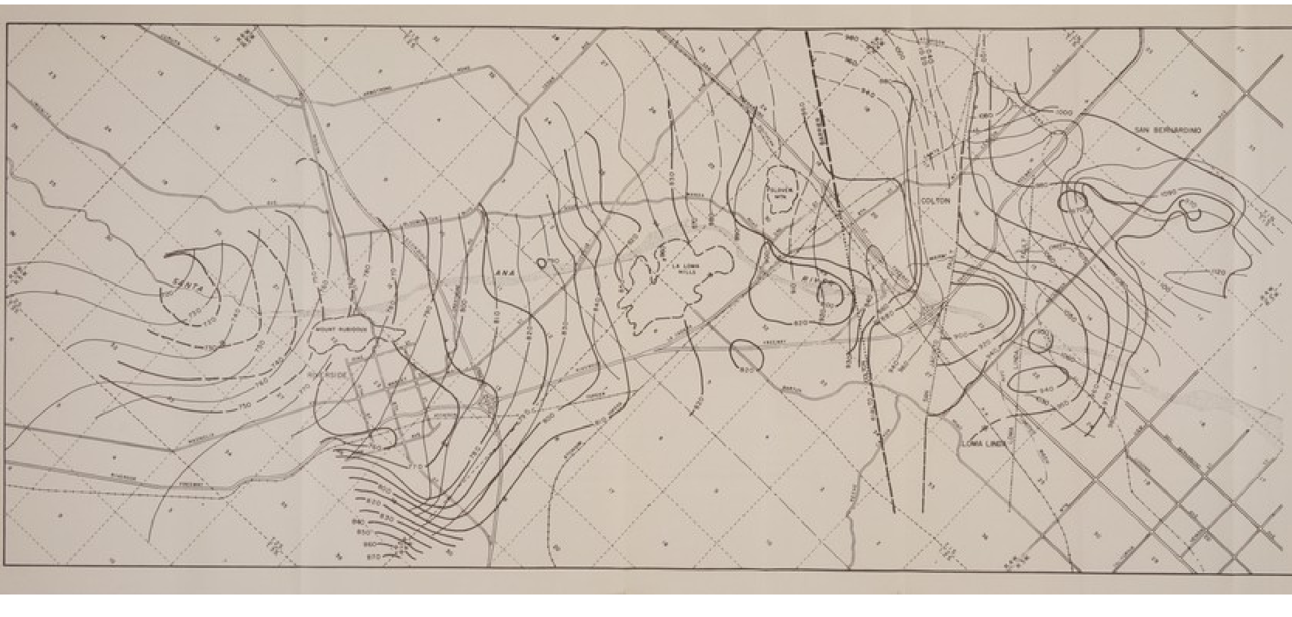
AND

GROUND WATER QUALITY

1962-64 DATA

SCALE OF FEET

1964



LEGEND

—980— GROUND WATER ELEVATION SUMMER 1961

—980— GROUND WATER ELEVATION SPRING 1945

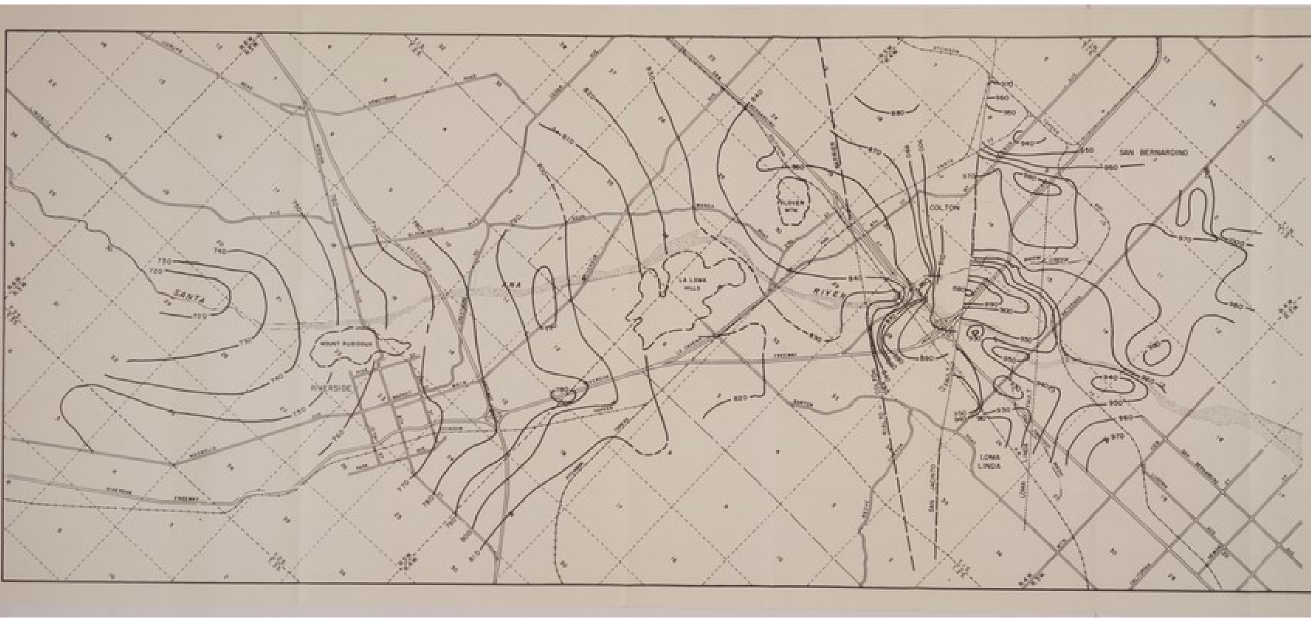
STATE OF CALIFORNIA
THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

DISPERSION AND PERSISTENCE OF SYNTHETIC DETERGENTS
IN GROUND WATER, SAN BERNARDINO AND RIVERSIDE COUNTIES

GROUND WATER ELEVATIONS
SPRING 1945 AND SUMMER 1961

SCALE OF FEET
2000 0 2000 4000 6000

1964



LEGEND

—— 970 —— GROUND WATER ELEVATION

STATE OF CALIFORNIA
THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

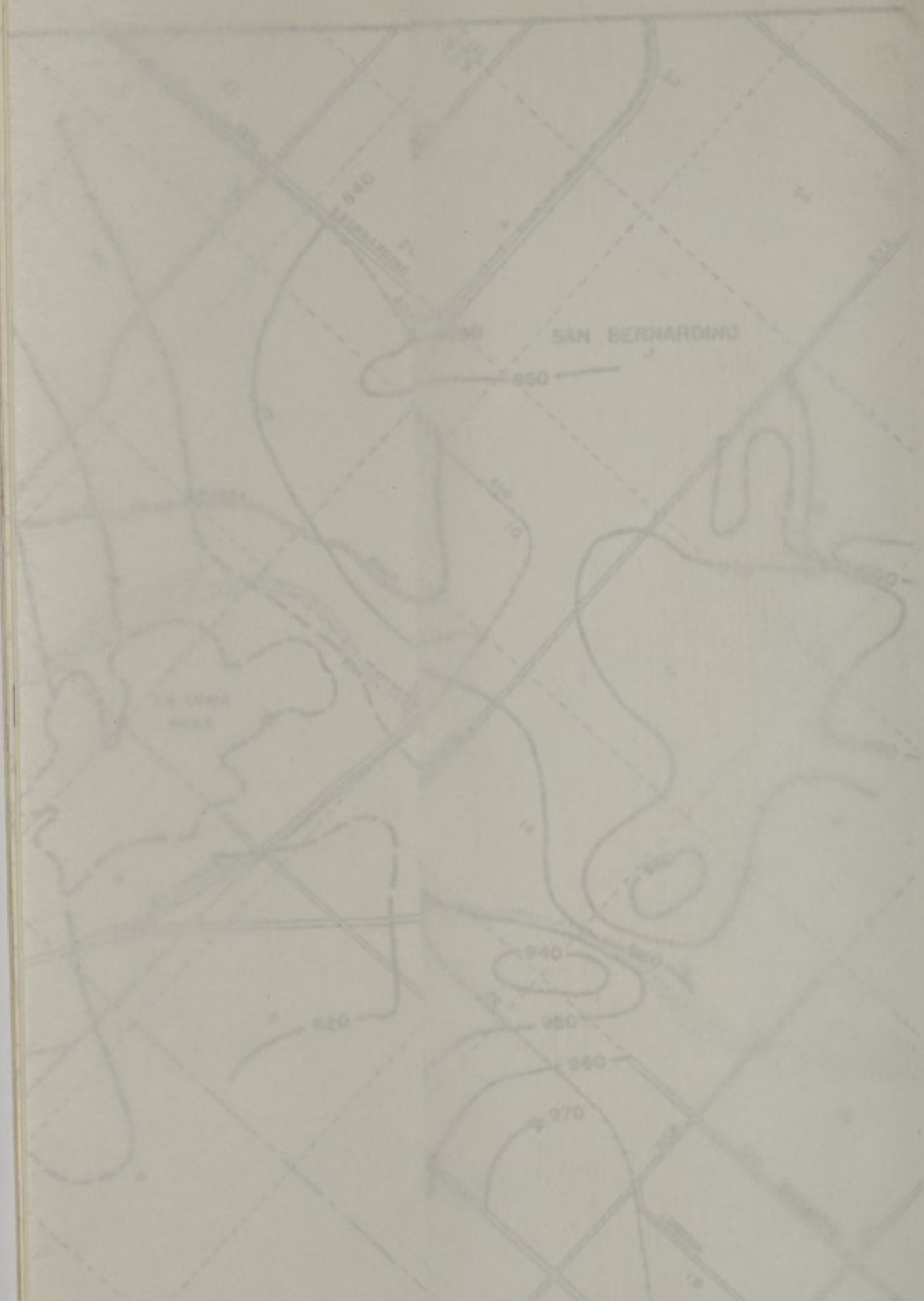
DISPERSION AND PERSISTENCE OF SYNTHETIC DETERGENTS
IN GROUND WATER, SAN BERNARDINO AND RIVERSIDE COUNTIES

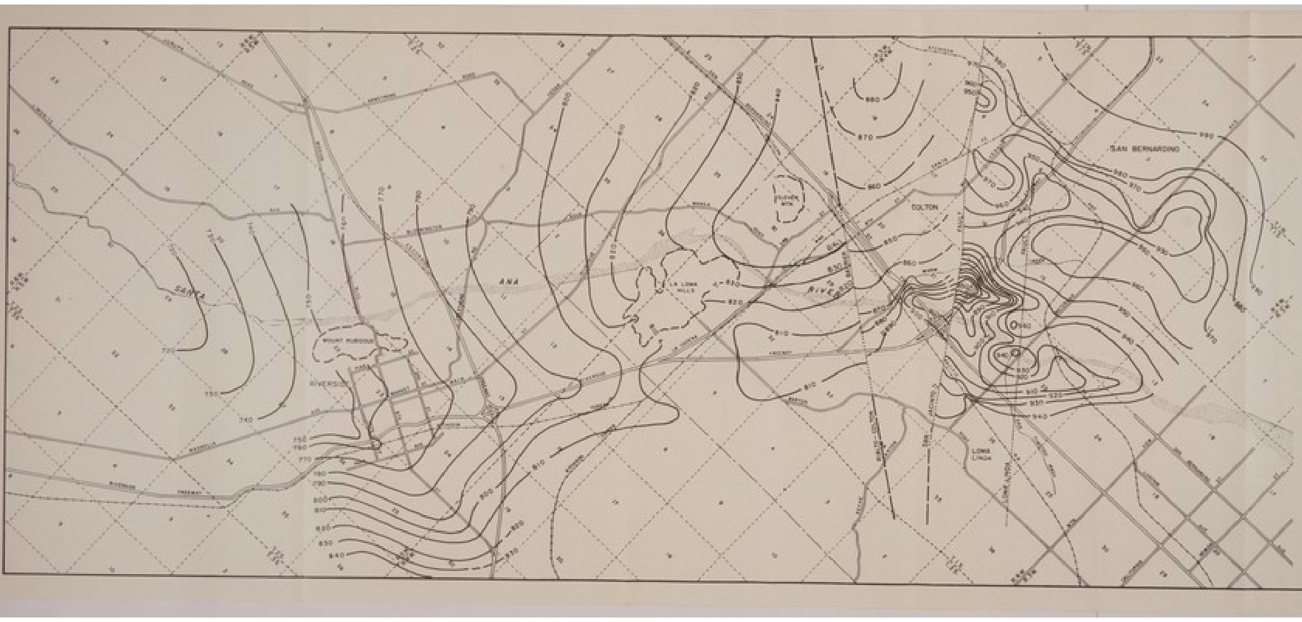
GROUND WATER ELEVATIONS

SUMMER 1962

SCALE OF FEET
2000 0 2000 4000 6000

1964


SAN BERNARDINO
940
950
960
970
920



LEGEND

—— 950 —— GROUND WATER ELEVATION

STATE OF CALIFORNIA
THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

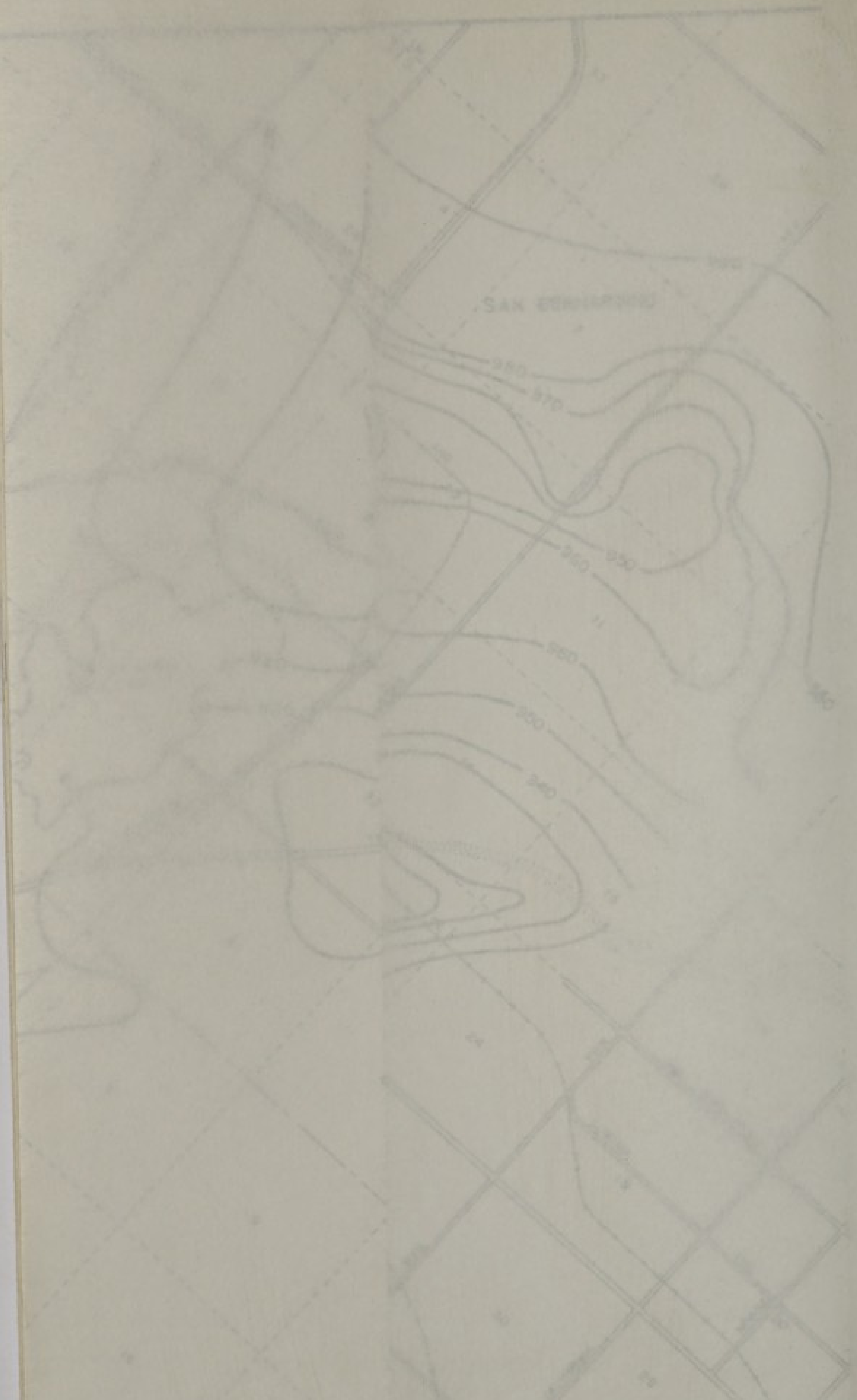
DISPERSION AND PERSISTENCE OF SYNTHETIC DETERGENTS
IN GROUND WATER, SAN BERNARDINO AND RIVERSIDE COUNTIES

GROUND WATER ELEVATIONS

SPRING 1963

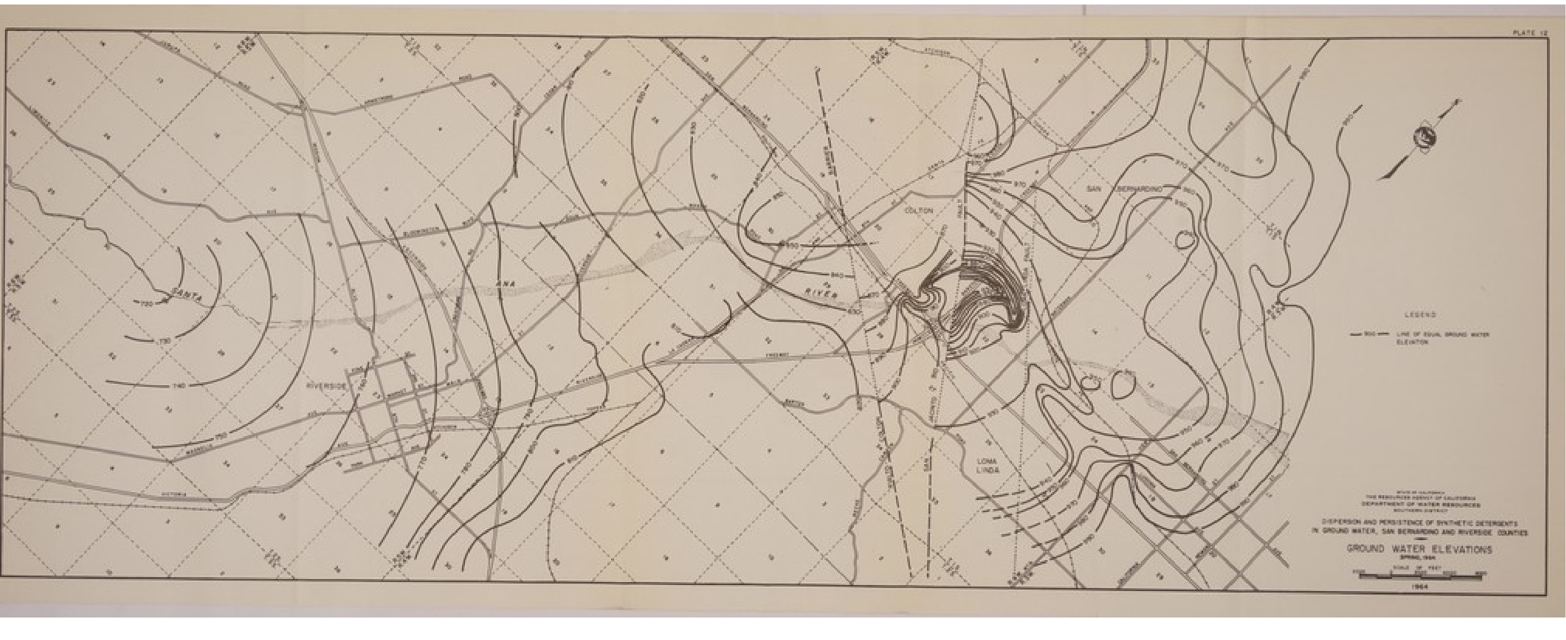
SCALE OF FEET
2000 0 2000 4000 6000

1964



SAN BERNARDINO
980
970
960
950
960
950
940
950

PLATE 12



LEGEND

900 LINE OF EQUAL GROUND WATER ELEVATION

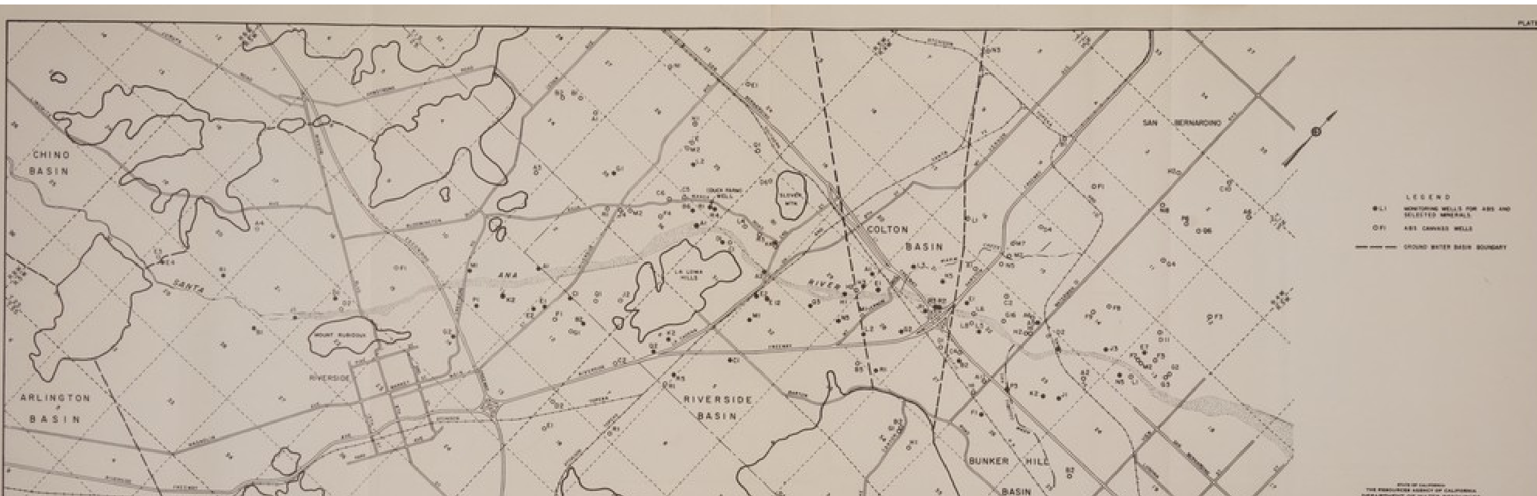
STATE OF CALIFORNIA
THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

DISPERSION AND PERSISTENCE OF SYNTHETIC DETERGENTS
IN GROUND WATER, SAN BERNARDINO AND RIVERSIDE COUNTIES

GROUND WATER ELEVATIONS
SPRING, 1964

SCALE OF FEET

1964



STATE OF CALIFORNIA
THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

DISPERSION AND PERSISTENCE OF SYNTHETIC DETERGENTS,
SAN BERNARDINO AND RIVERSIDE COUNTIES

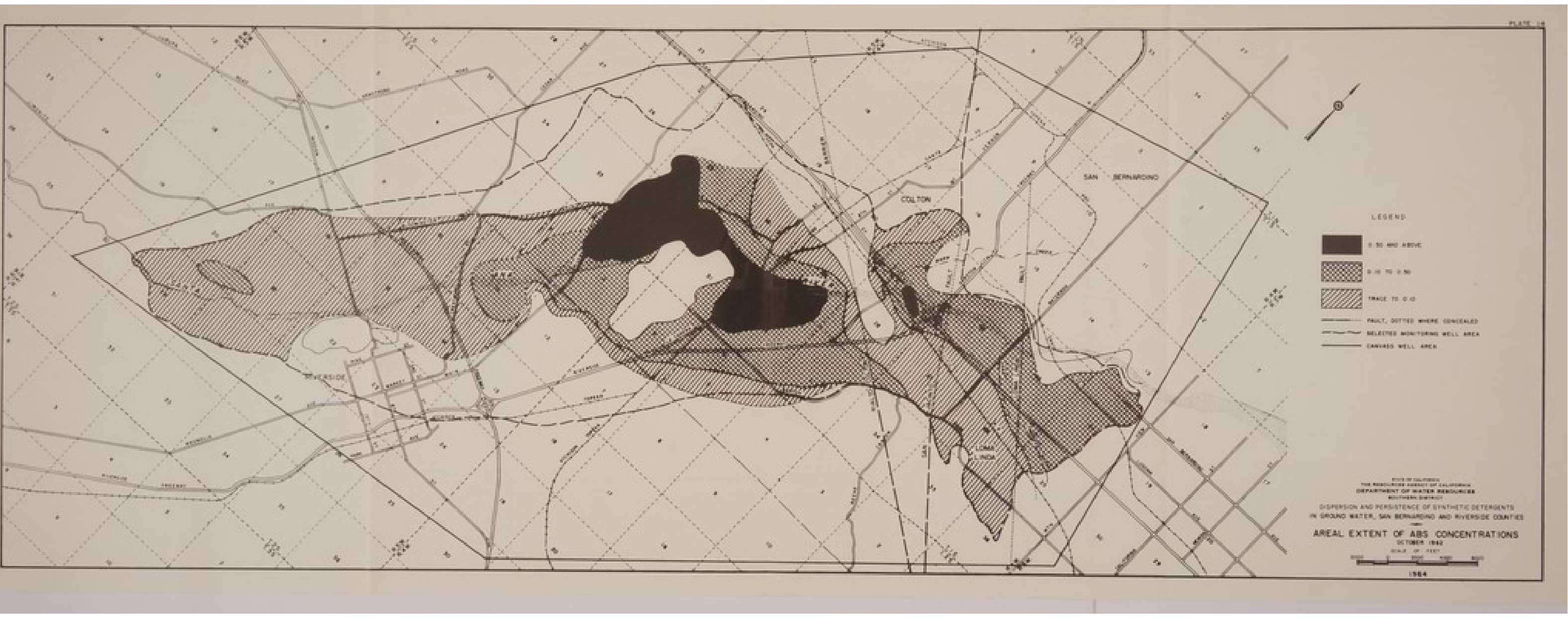
WELL LOCATION MAP

SCALE OF FEET
2000 0 2000 4000 6000

1964


D1
D2
MOUNT RUBIDOUX
RIVERSIDE
AVE.
AVE.

PLATE 14



STATE OF CALIFORNIA
THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

DISPERSION AND PERSISTENCE OF SYNTHETIC DETERGENTS
IN GROUND WATER, SAN BERNARDINO AND RIVERSIDE COUNTIES

AREAL EXTENT OF ABS CONCENTRATIONS
OCTOBER 1962

SCALE OF FEET

1964

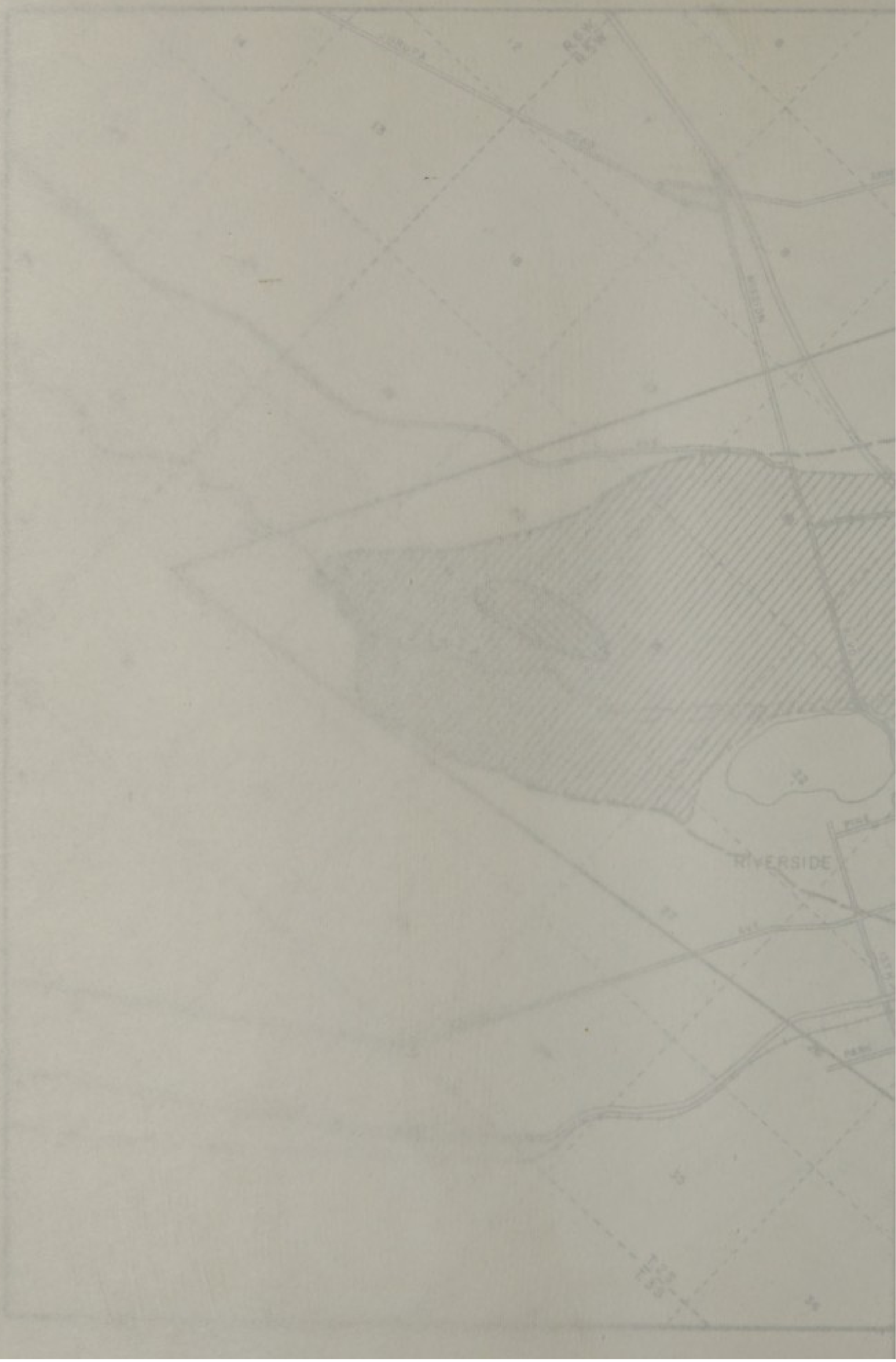
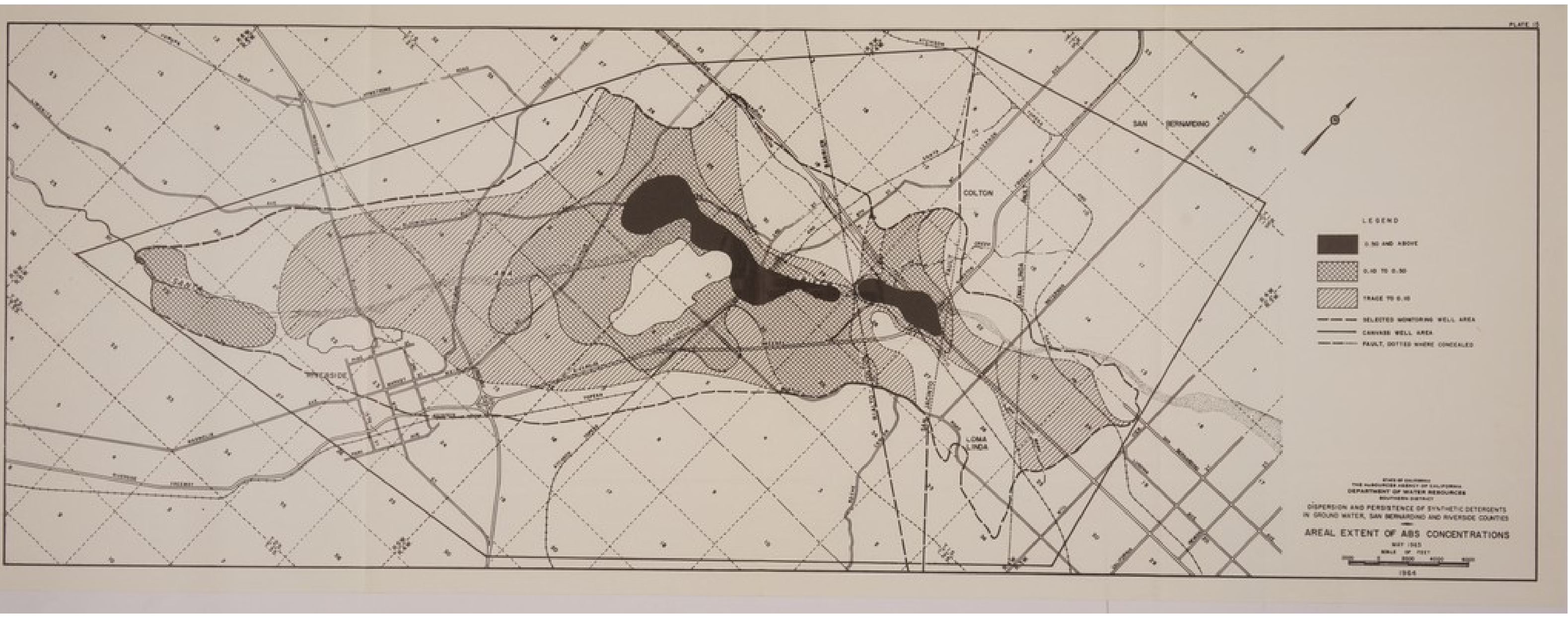

R.6W.
R.5W.
RIVERSIDE
T.2S.
T.3S.

PLATE 15



STATE OF CALIFORNIA
THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

DISPERSION AND PERSISTENCE OF SYNTHETIC DETERGENTS
IN GROUND WATER, SAN BERNARDINO AND RIVERSIDE COUNTIES

AREAL EXTENT OF ABS CONCENTRATIONS

MAY 1963

1964

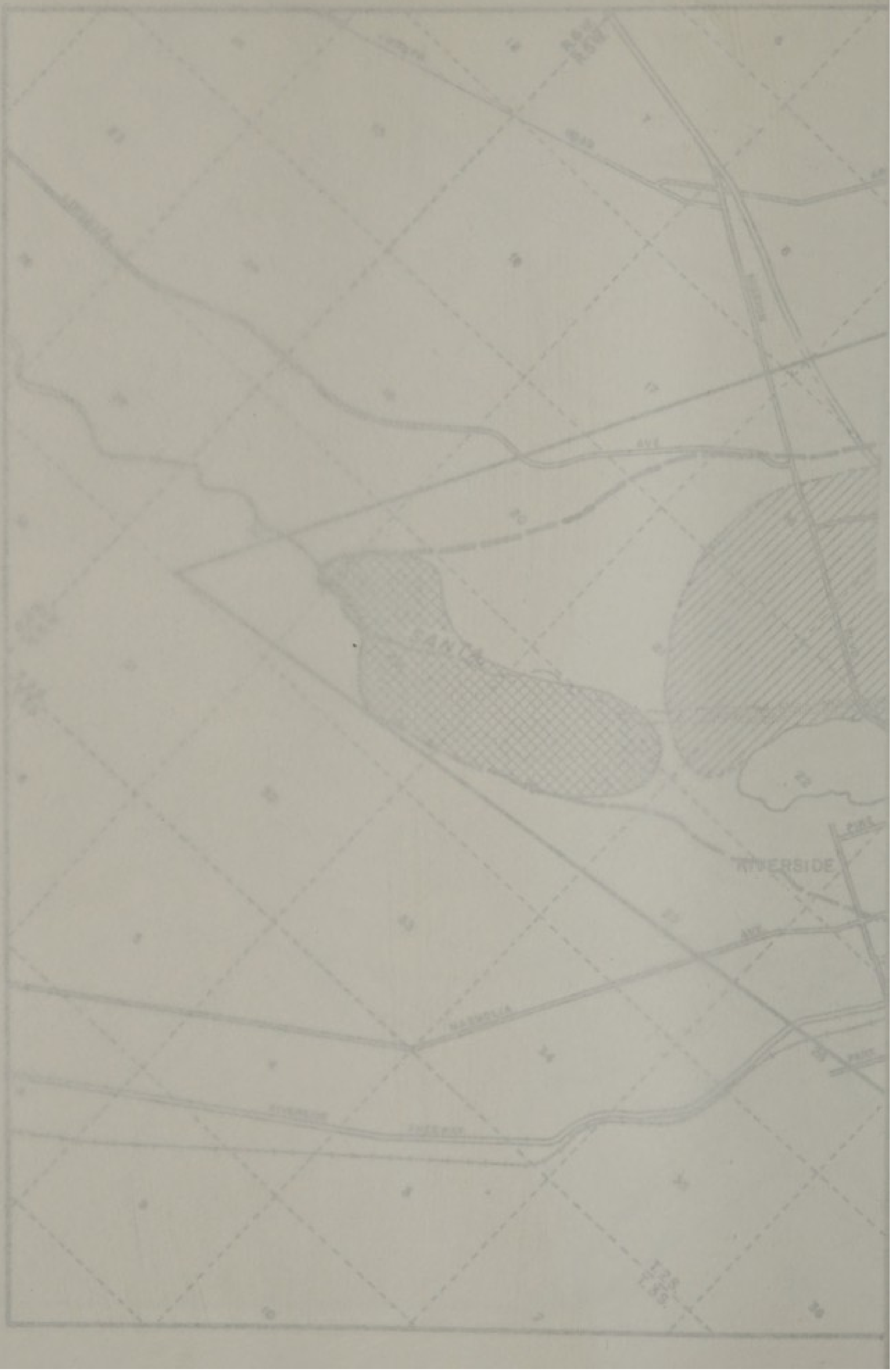
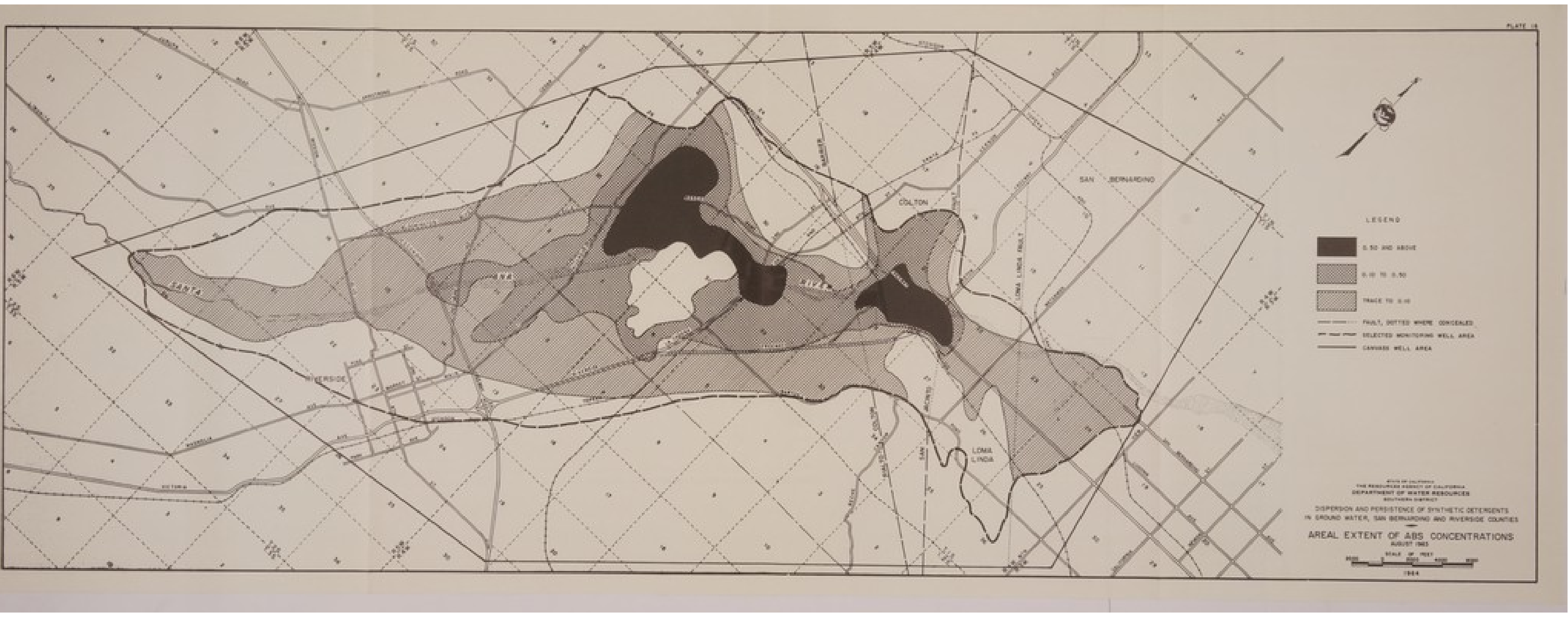

AVE
SANTA
RIVERSIDE
AVE
MAGNOLIA
RIVERSIDE
FREEWAY
T.2S.
T.3S.

PLATE 16



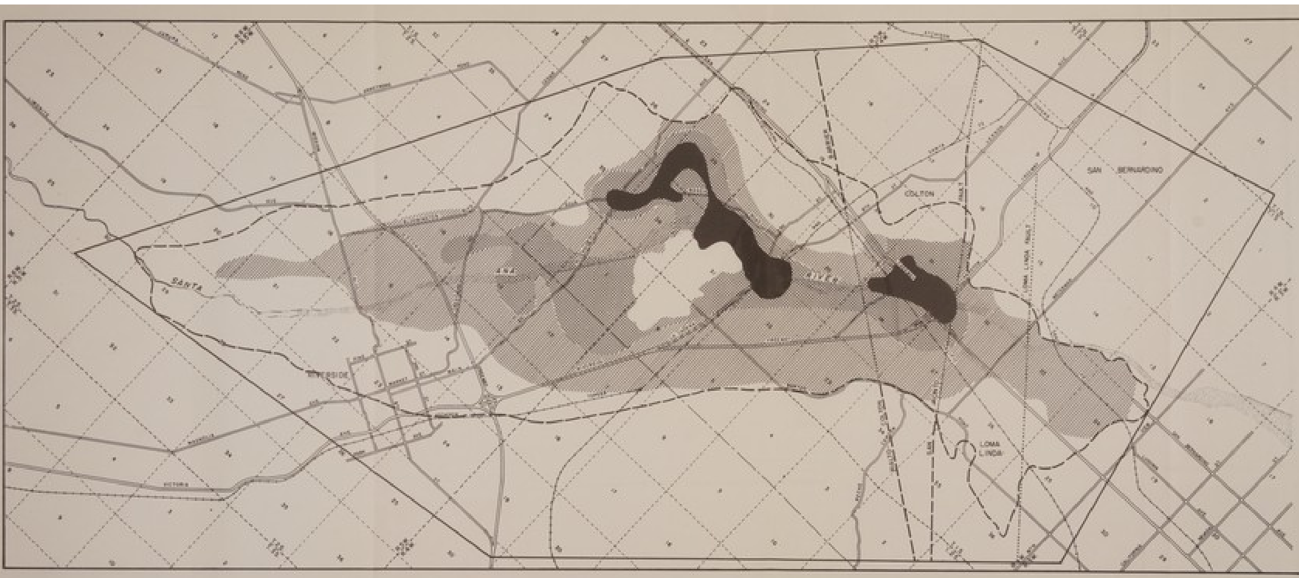
STATE OF CALIFORNIA
THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

DISPERSION AND PERSISTENCE OF SYNTHETIC DETERGENTS
IN GROUND WATER, SAN BERNARDINO AND RIVERSIDE COUNTIES

AREAL EXTENT OF ABS CONCENTRATIONS
AUGUST 1963

1964


RIVERSIDE



LEGEND

■	0.50 AND ABOVE
▩	0.10 TO 0.50
▨	TRACE TO 0.10
— — —	SELECTED MONITORING WELL AREA
———	CANVASS WELL AREA
— - —	FAULT, DOTTED WHERE CONCEALED

STATE OF CALIFORNIA
THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

DISPERSION AND PERSISTENCE OF SYNTHETIC DETERGENTS
IN GROUND WATER, SAN BERNARDINO AND RIVERSIDE COUNTIES

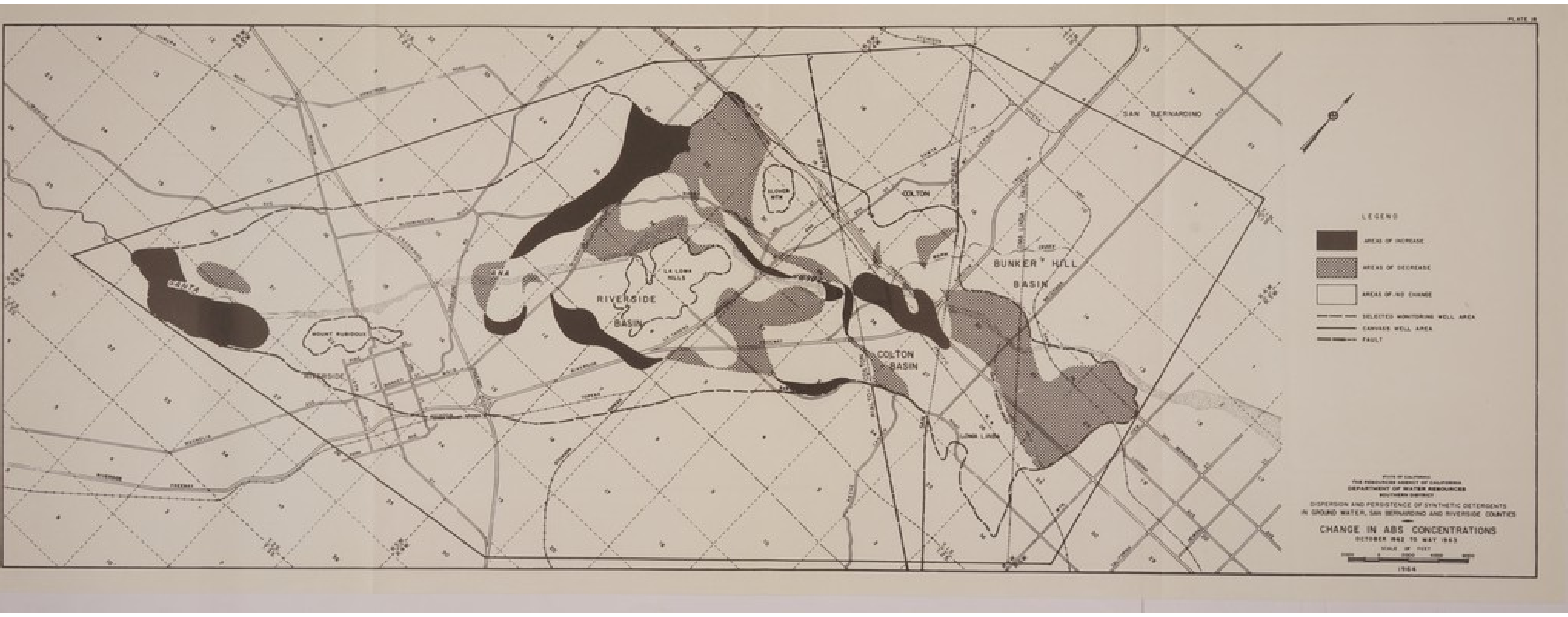
AREAL EXTENT OF ABS CONCENTRATIONS

JUNE - JULY, 1964

SCALE OF FEET
2000 0 2000 4000 6000

1964


SANTA
RIVERSIDE
MAGNOLIA
AVE
PARK
VICTORIA

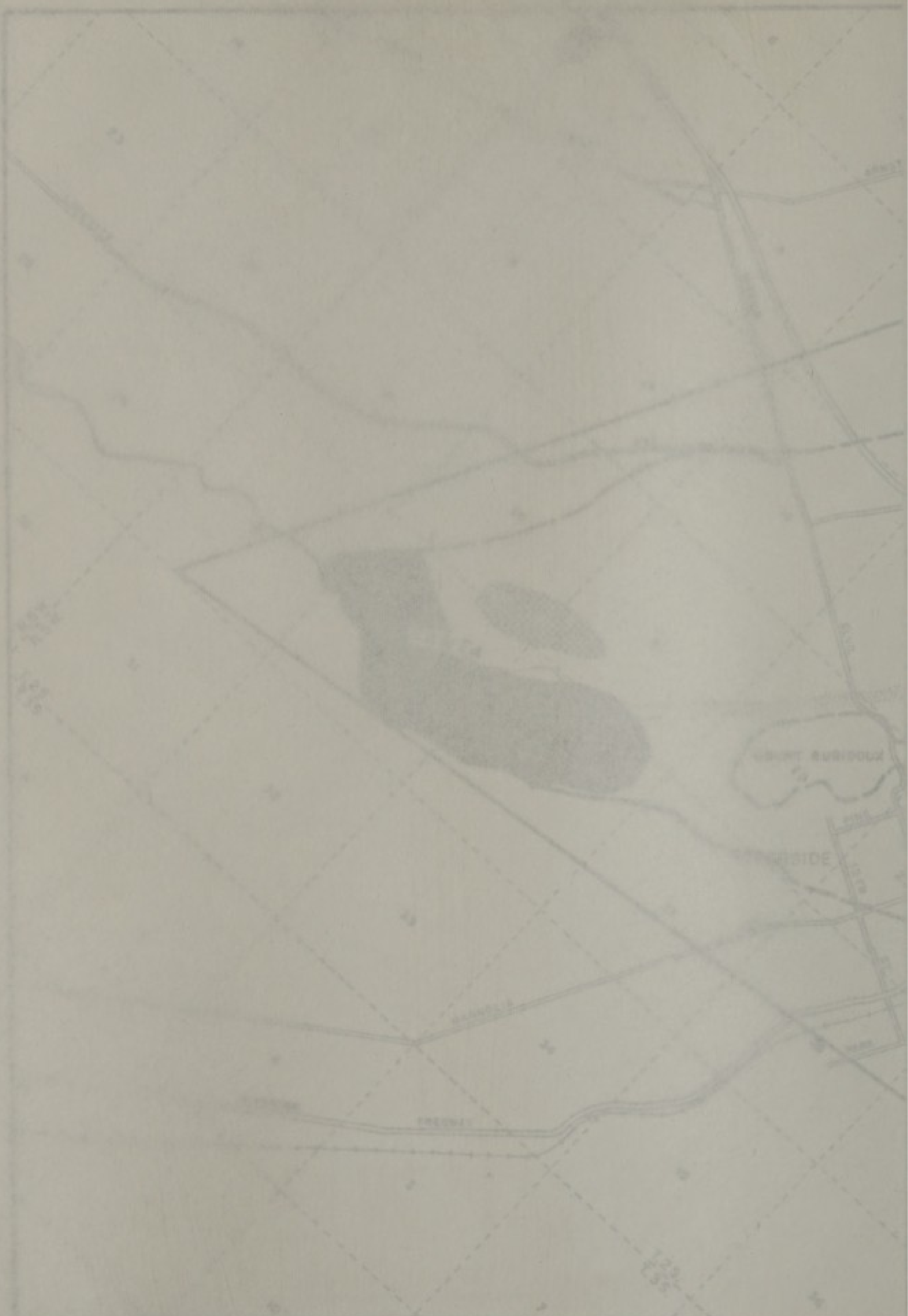


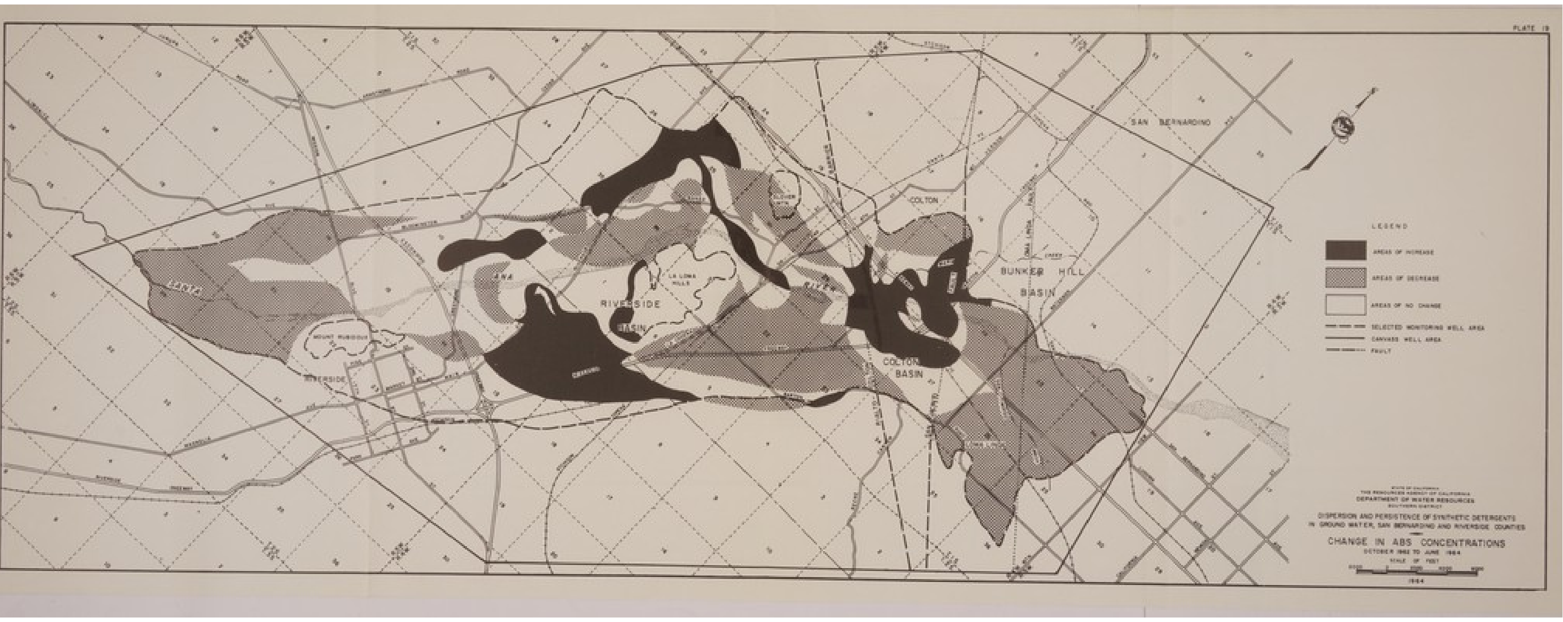
STATE OF CALIFORNIA
THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

DISPERSION AND PERSISTENCE OF SYNTHETIC DETERGENTS
IN GROUND WATER, SAN BERNARDINO AND RIVERSIDE COUNTIES

CHANGE IN ABS CONCENTRATIONS
OCTOBER 1962 TO MAY 1963

1964


MOUNT RUBIDOUX



LEGEND

■	AREAS OF INCREASE
▨	AREAS OF DECREASE
□	AREAS OF NO CHANGE
— — —	SELECTED MONITORING WELL AREA
———	CANVASS WELL AREA
—·—·—	FAULT

STATE OF CALIFORNIA
THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

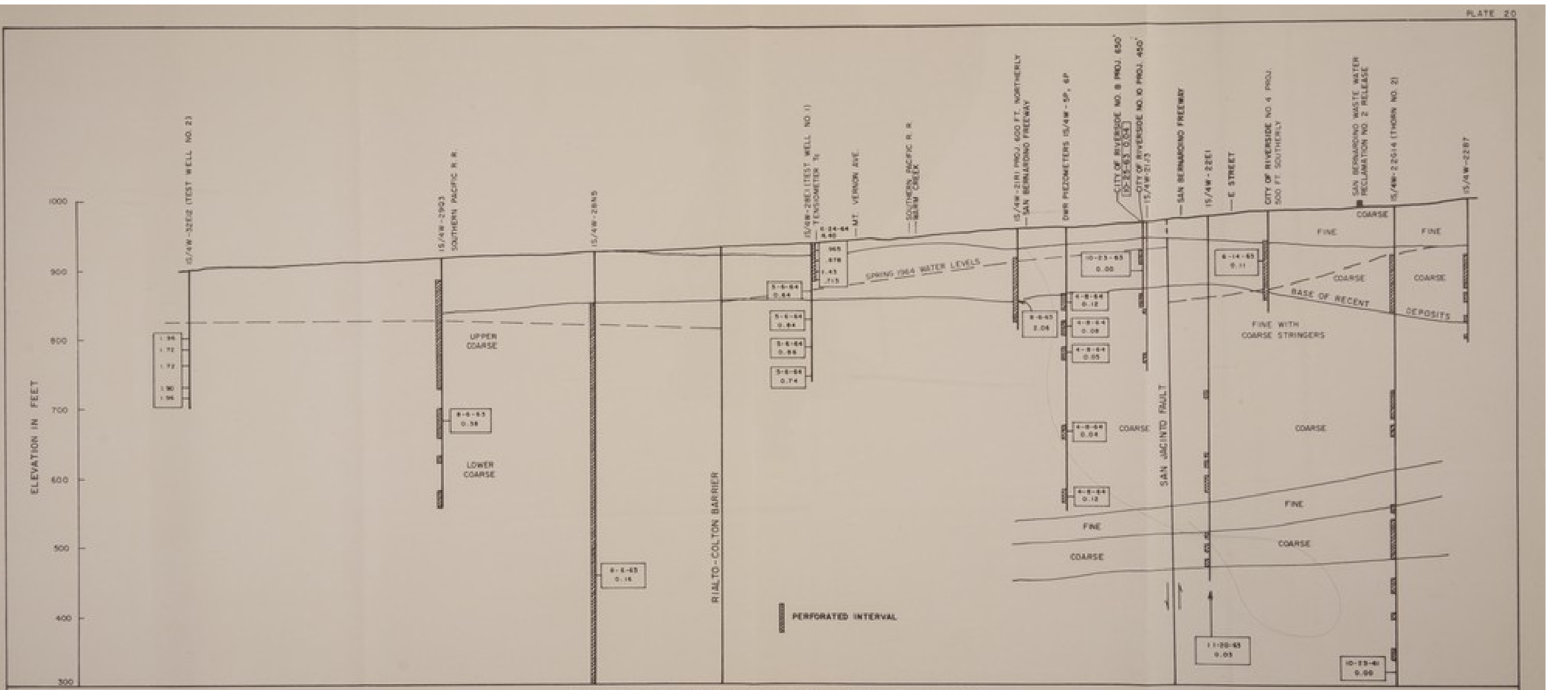
DISPERSION AND PERSISTENCE OF SYNTHETIC DETERGENTS
IN GROUND WATER, SAN BERNARDINO AND RIVERSIDE COUNTIES

CHANGE IN ABS CONCENTRATIONS

OCTOBER 1962 TO JUNE 1964

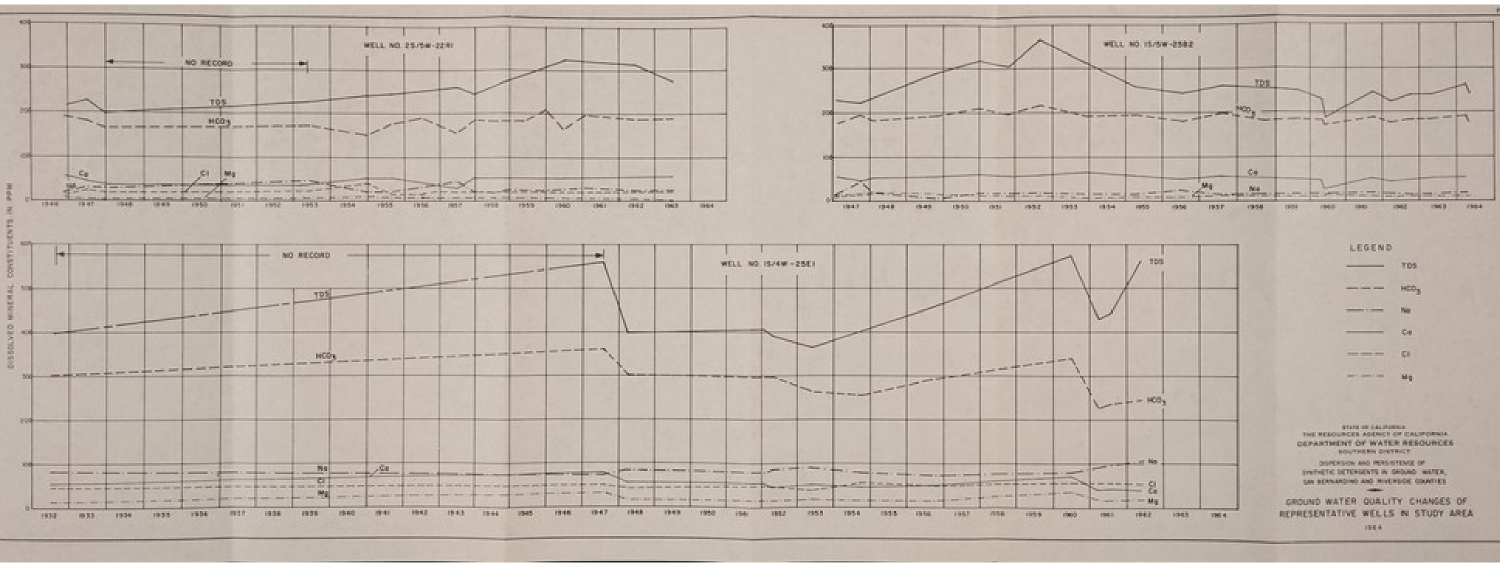
SCALE OF FEET

1964



PROFILE OF ABS CONCENTRATIONS ALONG THE SANTA ANA RIVER

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1964



STATE OF CALIFORNIA
THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

DISPERSION AND PERSISTENCE OF
SYNTHETIC DETERGENTS IN GROUND WATER,
SAN BERNARDINO AND RIVERSIDE COUNTIES

GROUND WATER QUALITY CHANGES OF REPRESENTATIVE WELLS IN STUDY AREA

1964

APPENDIX A

LIST OF SELECTED REFERENCES
AND
BIBLIOGRAPHY

APPENDIX A

LIST OF SELECTED REFERENCES

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APPENDIX B

WELL NUMBERING SYSTEM

Locations and well numbers used in this report are referenced by use of the United States Public Land Survey System, and to the San Bernardino Base and Meridian. The well numbers consist of township, range, section number, a letter which indicates the 40-acre lot in which the well is located, and a final number which indicated the identity of the particular well within the lot. The subdivision of a section is shown below:

23

D	C	B	A
E	F	G	H
M	L	K	J
N	P	Q	R

For example, 3S/14W-23A2, S.B.B. & M., is the second well to be identified in Lot A of Section 23 of Township 3 South, Range 14 West, San Bernardino Base and Meridian.

APPENDIX C

ANALYSES OF SELECTED CONSTITUENTS IN GROUND WATER FROM MONITORING WELLS IN BUNKER HILL, COLTON, AND RIVERSIDE BASINS

TABLE C-1

Analyses of Selected Constituents in Ground Water From Monitoring Wells in Portions of Bunker Hill, Colton, and Riverside Basins

State well number	Date sampled	Well depth, in feet	Perforated interval, in feet	pH	EC × 10^6 at 25° C	Constituents, in parts per million					
						SO_4	Cl	NO_3	NO_2	ABS	PO_4
1S/4W-13E7	7- 2-62	148	102–145	8.0	456	57	15	6.0	0.00	0.00	0.05
	9-27-62			7.7	464	56	14	4.8	0.00	0.05	0.10
	1-17-63			7.5	486	64	15	6.0	--	0.00	0.02
	4-26-63			7.5	491	69	13	5.6	--	0.00	0.08
	8- 5-63			7.3	491	72	13	4.0	--	0.02	0.02
	11-19-63			7.8	471	83	18	1.5	--	0.03	--
	6-24-64			7.4	510	84	15	2.3	--	0.00	0.02
-13F3	7- 2-62	123	102–120	7.9	349	36	12	9.5	0.00	0.00	0.04
	9-25-62			7.8	351	38	9	8	0.00	0.03	0.09
-13N5	9-27-62	1126	467–1104	7.6	546	64	14	36	0.00	0.12	0.11
	1-16-63			7.9	546	64	14	42	--	0.08	0.02
	4-26-63			7.5	548	68	13	40	--	0.04	0.08
	6-24-64			7.6	533	67	13	45	--	0.07	0.02
-14J3	7- 2-62	183	119–180	7.9	766	203	1	1.0	0.02	0.00	0.00
	9-28-62			7.9	790	206	18	1.2	0.14	0.02	0.11
	1-17-63			7.4	824	234	20	2.0	--	0.02	0.02
	5- 8-63			7.3	840	225	18	4.2	--	0.04	0.00
	11-22-63			7.4	898	250	27	3.7	--	0.04	--
	6-24-64			7.9	872	262	21	2.6	--	0.06	0.02
-21K5	7- 6-62	150	135–148	7.4	593	107	27	0	0.00	0.00	0.00
	9-27-62			7.2	588	95	26	0.5	0.013	0.08	0.10
	1-17-63			7.3	609	96	27	0.8	--	0.05	0.00
	4-30-63			6.5	2590	1419	94	45	--	0.12	0.04
	8- 5-63			6.1	2037	1014	90	14	--	0.08	0.00
	11-20-63			7.8	1491	634	100	18	--	0.19	--
	6-25-64			7.9	649	79	40	6.4	--	0.40	0.00
-21L3	6-20-62	245	165–240	8.2	610	72	32	55	--	0.50	0.00
	8- 9-62			7.8	612	--	32	--	0.00	0.52	0.00
	9-27-62			7.5	613	81	35	6.4	0.00	0.46	0.04
	1-17-63			7.5	607	73	33	5.5	--	0.04	0.02
	4-30-63			7.4	619	79	34	5.5	--	0.26	0.00
	8- 7-63			7.3	645	76	38	8.0	--	0.50	0.04
	11-20-63			7.5	625	77	36	7.0	--	0.30	--
-21R1	7- 3-62	150	42–137	8.1	603	79	25	8.0	0.16	0.35	0.00
	9-27-62			8.1	624	82	34	9.5	0.26	0.55	0.00
	1-17-63			7.5	673	79	39	12	--	0.72	0.02
	5- 1-63			7.5	734	66	55	5.0	--	1.48	0.06
	8- 6-63			7.3	820	72	56	23	--	2.06	0.00
	11-19-63			7.4	890	64	65	33	--	1.46	--
	6-24-64			7.3	840	86	64	16	--	2.20	0.02
-22A5	7- 2-62	108	85–108	7.7	884	283	16	3.0	0.01	0.00	0.00
	9-27-62			7.5	921	294	17	2.8	0.11	0.10	0.08
	1-17-63			7.5	823	225	12	2.5	--	0.02	0.00
-22E1	1-24-63	525	252–266 346–508	8.0	513	28	49	1.5	--	0.04	0.00
	4-26-63			7.8	501	32	46	1.8	--	0.00	0.08
	8- 6-63			8.1	505	29	49	1.0	--	0.00	0.28
	11-20-63			7.9	503	28	52	4.4	--	0.03	--
	6-24-64			8.0	478	29	44	1.0	--	0.02	0.04
-22L5	1-24-63	243		7.7	449	53	16	8.8	--	0.06	0.05
	4-29-63			7.7	457	44	17	11	--	0.05	0.16
	8- 5-63			7.6	462	44	19	11	--	0.03	0.04
	11-19-63			7.8	442	40	23	10	--	0.00	--
	8- 6-64			7.9	447	50	18	9	--	0.00	0.02
-23C2	6- 7-62	1192	536–1166	8.0	398	37	25	2.5	--	0.02	0.06
	7- 9-62			8.3	362	31	18	2.0	--	0.00	0.04
	9-28-62			8.3	446	46	32	2.6	0.00	0.00	0.05
	1-16-63			8.0	394	36	23	2.4	0.00	0.00	0.02
	4-30-63			8.0	373	32	20	2.2	--	0.04	0.04
	8- 6-63			7.9	364	30	20	3.0	--	0.00	0.03
	6-24-64			7.7	365	33	18	2.4	--	0.03	0.06
-23D2	7- 2-62	744	595–714	8.4	381	14	27	2.0	0.00	0.00	0.04
-23J1	7- 2-62	303	84–279	8.0	595	66	30	32	0.00	0.00	0.08
	9-27-62			7.8	623	59	29	31	0.00	0.12	0.14
	1-16-63			7.9	619	68	27	32	--	0.04	0.04
	5- 1-63			7.6	665	66	34	32	--	0.09	0.06
	8- 6-63			7.5	611	68	29	33	--	0.06	0.03
	6-24-64			7.6	599	70	27	27	--	0.03	0.00

TABLE C-1—Continued

Analyses of Selected Constituents in Ground Water From Monitoring Wells in Portions of Bunker Hill, Colton, and Riverside Basins

State well number	Date sampled	Well depth, in feet	Perforated interval, in feet	pH	EC × 10^6 at 25° C	Constituents, in parts per million					
						SO_4	Cl	NO_3	NO_2	ABS	PO_4
1S/4W-23K2—Continued	7- 2-62			8.1	805	74	37	16	0.01	0.00	0.08
	9-27-62			7.7	807	68	40	44	0.00	0.14	0.12
	1-16-63			7.7	782	71	39	45	--	0.08	0.05
	4-26-63			7.5	791	73	38	40	--	0.09	0.15
	8- 6-63			7.4	779	71	40	45	--	0.06	0.04
	6-24-64			7.5	788	77	41	43	--	0.08	0.00
-23P3	1-24-63			7.8	445	24	28	9.0	--	0.08	0.05
	8- 6-63			7.9	411	25	22	7.0	--	0.00	0.05
-26F1	8- 7-62	510	405-490	8.0	565	45	39	2.1	--	0.04	0.00
	9-27-62			8.1	564	45	41	3.5	0.00	0.06	0.00
	1- 8-63			8.0	579	45	41	2.0	--	0.06	0.02
	4-30-63			7.9	575	43	39	2.5	--	0.00	0.05
	8- 7-63			7.7	562	41	40	2.0	--	0.02	0.02
	11- 9-63			7.5	555	40	42	5.0	--	0.00	--
	6-24-64			8.0	539	45	37	2.0	--	0.00	0.18
-27B2	1-25-63	555		7.6	658	46	50	13	--	0.08	0.00
	4-26-63			7.6	650	49	51	15	--	0.00	0.08
	8- 6-63			7.6	672	53	50	9.4	--	0.01	0.07
	11-19-63			7.6	679	45	59	10	--	0.05	--
	6-24-64			7.6	644	54	48	9.5	--	0.02	0.10
-28G2	6-20-62	180	62-130	7.4	814	97	40	11	--	0.00	0.00
	9-26-62			7.6	810	96	41	13	0.00	0.02	0.04
	1- 5-63			7.8	824	96	42	12	--	0.04	0.02
	5- 1-63			7.4	824	97	43	12	--	0.00	0.04
	8- 6-63			7.4	825	97	42	9.6	--	0.02	0.05
	11-19-63			7.2	887	83	50	12	--	0.04	--
	6-25-64			7.6	918	123	56	20	--	0.12	0.02
-28L2	7-13-62	280	60-280	7.9	650	53	47	19	0.00	0.06	0.04
	9-26-62			8.1	575	44	43	13	0.00	0.06	0.02
	1-24-63			7.5	597	45	44	14	--	0.12	0.04
	5- 1-63			7.4	730	58	50	34	--	0.09	0.00
	8- 6-63			7.5	595	45	43	15	--	0.06	0.02
	6-25-64			8.0	600	49	42	18	--	0.06	0.00
-28N5	7- 2-62	701	40-701	8.0	797	77	66	36	0.00	0.10	0.02
	9-26-62			7.7	826	81	67	36	0.01	0.22	0.14
	1-24-63			7.4	790	68	64	28	--	0.22	0.14
	5- 1-63			7.4	813	72	70	25	--	0.19	0.09
	8- 6-63			7.4	764	72	62	24	--	0.16	0.02
	6-25-64			8.1	700	80	56	25	--	0.10	0.00
-28R1	5-31-62	272	106-193	7.4	998	91	60	82	--	0.10	0.00
	9-26-62			8.0	956	92	61	91	0.05	0.14	0.12
	1-16-63			7.9	925	84	58	80	--	0.14	0.05
	4-30-63			7.6	890	76	59	80	--	0.12	0.08
	8- 8-63			7.8	853	68	58	62	--	0.03	0.13
	11-19-63			7.6	800	48	57	51	--	0.05	--
	6-25-64			7.8	673	38	53	37	--	0.03	0.04
-29A1	7- 6-62	326	185-314	8.3	390	30	17	5.5	0.00	0.00	0.00
	9-27-62			8.2	387	31	16	6.0	0.00	0.00	0.00
	1-16-63			8.0	389	25	14	5.3	--	0.04	0.02
	5- 8-63			7.7	397	32	15	8.8	--	0.05	0.00
	8- 5-63			7.7	389	24	15	6.5	--	0.02	0.00
	11-20-63			8.0	406	36	20	8.3	--	0.06	--
	6-25-64			7.6	428	36	17	9.8	--	0.03	0.00
-29H1	3-26-62			8.1	781	74	76	14	--	0.76	11
	9-25-63			7.5	703	71	52	15	0.00	0.08	0.74
-29H3	7- 6-62	214	104-160	7.8	780	69	71	12	0.00	0.04	0.04
	9-27-62			8.0	732	74	55	14	0.00	0.05	0.00
	1-16-63			7.7	734	72	50	14	--	0.06	0.03
	5- 1-63			7.6	778	69	70	12	--	0.00	0.04
	3-26-63			8.5	782	68	93	12	--	0.02	0.08
	8- 5-63			7.4	743	72	61	14	--	0.06	0.02
	11-20-63			8.0	752	71	68	15	--	0.04	--
	6-23-64			7.3	673	79	44	11	--	0.04	0.04
-29Q3	8- 6-62			7.4	671	59	52	20	--	0.04	0.04
	9-25-62			7.4	824	71	85	10	0.01	1.30	0.25
	5-10-63			7.5	678	63	44	31	--	0.36	0.22
	8- 6-63			7.3	646	59	44	18	--	0.38	0.10

TABLE C-1—Continued

Analyses of Selected Constituents in Ground Water From Monitoring Wells in Portions of Bunker Hill, Colton, and Riverside Basins

State well number	Date sampled	Well depth, in feet	Perforated interval, in feet	pH	EC × 10^6 at 25° C	Constituents, in parts per million					
						SO_4	Cl	NO_3	NO_2	ABS	PO_4
1S/4W-30K4—Continued	9-26-62	104	22-84	7.3	937	92	50	4.5	0.01	0.06	0.00
	1-16-63			7.8	998	92	64	22	--	0.10	0.02
	5- 1-63			7.3	1047	93	69	42	--	0.04	0.00
-31A2	7- 3-62	130	70-130	7.8	909	74	87	33	0.01	0.78	3.1
	9-26-62			7.2	908	71	81	47	0.03	0.55	1.1
	1-16-63			7.1	940	84	92	50	--	0.70	3.1
	3-26-63			6.9	937	82	94	43	--	0.64	3.3
	5- 1-63			7.1	945	84	102	13	--	0.54	2.0
	8- 5-63			6.8	971	86	94	60	--	0.70	1.2
	11-20-63			7.1	986	81	93	66	--	0.57	--
	6-25-64			7.5	840	79	82	32	--	0.78	2.9
-31D1	7- 3-62	200		7.3	860	74	72	32	0.00	0.32	12
	9-25-62			7.3	839	74	76	25	0.01	1.08	10.8
	1-16-63			7.1	896	84	86	50	--	0.70	11
	3-25-63			7.3	909	83	85	41	--	0.81	14
	5- 3-63			6.9	863	79	83	35	--	0.74	12
	8- 6-63			6.9	814	76	75	46	--	0.76	12
	11-22-63			7.0	808	81	86	31	--	0.74	--
-32E2	7-13-62	200	30-191	7.5	820	72	87	25	0.01	2.00	10
	9-26-62			7.4	826	81	90	36	0.86	1.88	13
-32E7	2-21-63	363	202-211 217-257 307-368	7.5	675	51	44	17	--	0.28	0.00
-32E11	7- 3-64			7.8	734	69	59	25	--	0.40	0.08
-32M1	7- 3-62			8.0	833	65	73	33	0.00	0.25	0.10
	1-15-63			7.7	874	69	79	37	--	0.48	0.02
	5- 1-63			7.7	432	33	6	14	--	0.06	0.08
	8- 6-63			7.2	845	71	77	32	--	0.40	0.04
	11-20-63			7.7	867	74	89	32	--	0.82	--
	6-25-64			7.3	401	30	8	10	--	0.00	0.36
1S/5W-25L2	7-11-62	250	130-200	7.9	606	30	27	24	0.05	0.58	2.5
	9-25-62			7.3	567	33	25	24	0.03	0.56	2.3
	1-14-63			7.3	540	29	19	28	--	0.44	1.4
	5- 6-63			7.3	514	31	17	29	--	0.17	1.5
	8- 7-63			7.0	761	47	36	47	--	1.24	3.2
	11-19-63			7.1	649	15	33	26	--	0.80	--
	6-23-64			7.6	604	31	27	22	--	0.52	3.2
-25R1	7-11-62	74	64-74	8.0	1391	168	140	82	0.02	0.30	0.00
	9-25-62			7.3	1550	174	190	94	0.00	0.25	0.05
	1-24-63			7.1	1565	180	194	78	--	0.28	0.00
	5- 8-63			7.1	1500	170	198	84	--	0.34	0.00
	9-24-63			7.6	1406	165	155	75	--	0.36	0.00
	11-22-63			7.4	1244	118	100	83	--	0.55	--
	6-25-64			7.5	1373	182	184	62	--	0.11	0.02
-25R4	7- 6-62	364		7.6	1126	136	105	59	0.01	0.52	0.00
	7-10-62			7.6	1127	--	99	--	--	0.00	0.05
	10- 1-62			7.7	1311	155	155	72	0.01	0.50	0.00
	5- 8-63			7.2	1278	133	150	69	--	0.31	0.00
	8- 8-63			7.2	1070	111	118	53	--	0.39	0.09
	6-26-64			7.7	969	104	97	56	--	0.53	0.02
-35G1	7-11-62	148		8.4	425	24	10	19	0.00	0.08	0.08
	9-25-62			7.8	423	24	11	22	0.00	0.04	0.08
	1-14-63			7.7	433	24	10	22	--	0.08	0.10
	5- 6-63			7.7	429	24	10	22	--	0.06	0.10
	8- 7-63			7.6	431	27	9	22	--	0.02	0.08
	11-19-63			7.8	446	26	13	27	--	0.12	--
	6-23-64			8.1	412	26	8	20	--	0.00	0.08
-35J1	7- 7-64			8.1	773	44	50	21	--	0.84	0.00
-35J4	7- 7-64			8.1	769	41	47	22	--	0.92	0.14
-35R1	7- 7-64			7.9	648	39	31	31	--	0.16	0.10
-36B6	7- 6-62	103		8.0	1019	150	111	18	0.02	2.00	0.00
	9-25-62			7.5	954	128	99	13	0.01	1.73	0.03
	1-14-63			7.4	944	107	94	12	--	1.96	0.04
	5- 3-63			7.4	951	96	90	26	--	1.40	0.02
	8- 7-63			7.3	971	113	90	33	--	1.00	0.02
	11-20-63			7.7	899	112	76	36	--	0.90	0.00
	6-23-64			7.4	1079	136	95	44	--	0.46	0.00

TABLE C-1—Continued

Analyses of Selected Constituents in Ground Water From Monitoring Wells in Portions of Bunker Hill, Colton, and Riverside Basins

State well number	Date sampled	Well depth, in feet	Perforated interval, in feet	pH	EC × 10⁶ at 25° C	Constituents, in parts per million					
						SO_4	Cl	NO_3	NO_2	ABS	PO_4
1S/5W-36C6—Continued	7- 7-64			8.3	472	38	13	33	--	0.10	0.08
-36F4	7- 7-64			7.9	937	132	105	39	--	0.08	0.00
-36M2	7- 7-64			7.7	703	53	53	29	--	0.34	0.00
-36N1	7- 9-64			7.9	602	82	30	34	--	0.02	0.00
2S/4W-5C1	7- 3-62	266	152-258	8.1	937	71	91	65	0.00	0.04	0.08
	10- 1-62			7.8	987	70	101	80	0.00	0.14	0.00
	1-18-63			7.4	977	70	94	75	--	0.14	0.04
	5- 6-63			7.4	908	68	84	58	--	0.11	0.08
	8- 7-63			7.3	937	88	87	63	--	0.08	0.04
	6-26-64			7.5	888	67	85	64	--	0.05	0.04
-6K2	7- 3-62	149		8.1	1285	166	121	91	0.00	0.04	0.08
	9-26-62			7.7	1302	136	139	75	0.00	0.15	0.04
	1-14-63			7.3	1340	156	134	90	--	0.18	0.06
	5- 6-63			7.4	1341	152	131	94	--	0.14	0.09
	8- 7-63			7.3	1340	148	134	90	--	0.10	0.00
	11-20-63			7.7	1341	135	143	104	--	0.26	--
	6-26-64			8.0	1291	146	139	94	--	0.09	0.00
-6Q2	8- 6-62	289		7.2	1798	465	166	62	--	0.10	0.00
	9-26-62			7.8	1833	510	175	64	0.00	0.16	0.00
	1-14-63			7.2	2371	551	185	72	--	0.16	0.04
	5- 6-63			7.3	1933	541	179	66	--	0.17	0.10
	8- 7-63			7.2	1852	516	167	63	--	0.14	0.02
	11-19-63			7.2	1848	504	150	67	--	0.12	--
	6-26-64			7.4	1542	372	136	52	--	0.07	0.04
-6R5	8- 2-62	427	130-204	7.7	805	79	62	27	0.02	0.08	0.00
	9-26-62		216-222	7.7	816	89	63	30	0.00	0.06	0.06
	1-24-63		302-342	7.4	867	79	73	40	--	0.12	0.06
	5- 8-63			7.4	832	76	68	32	--	0.05	0.05
	11-20-63			7.5	853	65	85	48	--	0.09	--
	6-26-64			7.8	842	81	74	42	--	0.08	0.04
2S/5W-11A1	7- 5-62	140		8.1	750	119	44	28	0.00	0.04	0.04
	9-25-62			7.3	759	115	47	33	0.00	0.17	0.06
	1-14-63			7.6	882	141	71	40	--	0.14	0.04
	5- 6-63			7.6	778	133	74	36	--	0.12	0.05
	8- 7-63			7.4	817	104	62	38	--	0.14	0.05
	6-23-64			7.7	791	113	60	34	--	0.15	0.12
-11M1	7- 5-62	67	36-66	8.2	665	87	25	28	0.00	0.08	0.08
	9-25-62			7.6	765	89	26	27	0.00	0.09	0.09
	1-14-63			7.3	695	89	27	34	--	0.12	0.06
	4-23-63			7.3	657	77	22	34	--	0.07	0.20
	8- 8-63			7.3	628	70	21	35	--	0.13	0.10
	11-20-63			7.7	627	66	23	41	--	0.09	--
	6-23-64			7.8	579	59	17	35	--	0.06	0.14
-11P1	7- 5-62	131	23-131	7.7	1767	623	108	4.5	0.06	0.02	0.00
-12B2	7- 5-62	75	60-75	7.5	1670	420	180	34	0.00	0.06	0.00
	9-25-62			7.4	1585	377	179	36	0.01	0.00	0.11
	1-15-63			7.3	1667	395	186	40	--	0.06	0.00
	5- 6-63			7.2	1713	413	174	45	--	0.11	0.00
	8- 7-63			7.3	1585	378	156	35	--	0.03	0.07
	11-20-63			7.5	1499	322	181	43	--	0.11	--
-12C1	9-26-62	60	43-58	7.4	1175	191	118	40	0.49	0.15	0.02
	1-24-63			7.2	1101	157	107	40	--	0.20	0.04
	3-25-63			8.3	1066	154	106	40	--	0.20	0.15
	5- 8-63			7.2	1078	148	105	44	--	0.23	0.05
	8- 7-63			7.3	1040	131	105	40	--	0.26	0.00
	9-24-63			7.3	1022	130	102	40	--	0.28	0.06
	11-20-63			7.5	999	113	100	19	--	0.37	--
-12D6	7- 9-64			7.4	1036	176	113	37	--	0.18	0.00
-12E1	7- 5-62	266	150-208	8.2	316	13	8	45	0.00	0.00	0.08
	9-25-62		214-256	7.9	461	39	28	10	0.01	0.00	0.16
	1-15-63			7.9	323	11	5	3.5	--	0.00	0.10
	5- 6-63			7.6	325	12	5	5.8	--	0.04	0.05
	8- 8-63			7.8	316	12	4	6.3	--	0.11	0.15
	11-20-63			8.0	318	10	9	6.3	--	0.04	--
	6-23-64			7.7	304	11	5	3.2	--	0.00	0.00

TABLE C-1—Continued

Analyses of Selected Constituents in Ground Water From Monitoring Wells in Portions of Bunker Hill, Colton, and Riverside Basins

State well number	Date sampled	Well depth, in feet	Perforated interval, in feet	pH	EC $\times 10^6$ at 25° C	Constituents, in parts per million					
						SO_4	Cl	NO_3	NO_2	ABS	PO_4
2S/5W-12E2—Continued	7- 5-62	100	55-84	7.4	1245	288	121	32	0.18	0.06	0.04
	9-25-62			7.4	1251	285	120	33	0.24	0.11	0.02
	1-15-63			7.2	1242	269	124	36	--	0.08	0.00
	5- 6-63			7.1	1249	259	122	43	--	0.11	0.00
	8- 8-63			6.9	1294	269	121	48	--	0.20	0.10
	11-19-63			7.2	1339	268	131	58	--	0.15	--
	6-23-64			7.1	1215	247	119	41	--	0.14	0.08
-12F1	7- 9-64			7.8	1034	182	116	39	--	0.10	0.04
-14G2	7- 5-62		210-228	8.0	486	62	22	3.5	0.00	0.00	0.00
	9-28-62			7.8	472	56	22	2.5	0.00	0.08	0.16
	4-23-63			7.4	527	69	24	5.8	--	0.06	0.08
	11-19-63			7.6	499	57	29	6.4	--	0.10	--
	6-23-64			7.7	575	99	28	3.8	--	0.00	0.04
-20R1	7-12-62	72	48-58	7.8	609	56	26	20	0.00	0.08	0.08
	9-25-62			7.6	614	59	25	20	0.00	0.11	0.07
	1-15-63			7.5	606	58	21	24	--	0.02	0.10
	4-23-63			7.4	586	58	21	25	--	0.00	0.36
	6- 5-63			7.7	575	37	21	25	--	--	--
	8- 7-63			7.6	609	63	23	23	--	0.00	0.13
	11-22-63			7.7	612	60	28	19	--	0.07	--
	6-23-64			8.0	578	76	19	23	--	0.03	0.00
-21J1	7-12-62			7.8	840	165	45	5.4	0.00	0.00	0.04
	9-28-62			7.8	574	80	20	5.2	0.00	0.08	0.10
	1-15-63			7.5	907	176	50	5.5	--	0.04	0.08
	4-23-63			7.2	893	171	48	6.6	--	0.06	0.10
	8- 7-63			7.4	911	178	51	3.2	--	0.02	0.05
	7-10-64			7.4	858	176	48	3.5	--	0.00	0.02
-22D1	7-12-62	100	40-95	7.7	975	201	56	6.3	0.00	0.00	0.04
	9-28-62			7.8	939	188	53	6.2	0.00	0.06	0.10
	1-15-63			7.6	1017	96	57	4.8	--	0.02	0.04
	4-23-63			7.2	1052	230	58	5.6	--	0.06	0.20
	8- 7-63			7.5	1031	215	59	4.4	--	0.02	0.07
	7-10-64			7.6	982	235	57	5.0	--	0.00	0.04
-28B1	7-12-62	65	14-65	7.5	1574	161	286	8.7	0.058	0.12	0.00
	1-15-63			7.9	1449	--	184	1.7	--	0.32	0.00
	6- 4-63			7.1	1410	--	201	--	--	0.20	--
-29E4	7-12-62	40		7.3	903	18	45	46	0.20	0.10	0.18
	9-25-62			7.4	887	4.8	46	32	0.15	0.08	0.22
	1-15-63			8.1	940	--	87	1.5	--	0.20	0.18
	6- 4-63			7.6	829	--	75	--	--	0.13	--
	8- 6-63			7.2	784	108	64	1.5	--	0.04	0.00
	11-22-63			7.4	666	54	56	23	--	0.15	--
	7-10-64			7.5	672	59	57	1.0	--	0.00	0.12

APPENDIX D

"TAFT METHOD" ANALYTICAL PROCEDURE ALKYL BENZENE SULFONATE DETERMINATION

REAGENTS

Methylene blue solution-dissolve 0.35 gms methylene blue (total amount in small vial) in one liter of .01 N sulfuric acid.

Chloroform, C. P.

Sulfuric Acid, 5N

STOCK STANDARD ABS, 1.00 mg/ml

WORKING STANDARD ABS, 0.011 mg/ml

GLASSWARE:

Separatory funnels, 250 or 125 ml
Volumetric flasks, 50 ml
Filtering funnels
Pipettes, assorted sizes
Preparation of Standard Benzene Sulfonate Solutions

Stock Standard: Weigh out 1.460 grams of the Primary Standard ABS powder, transfer quantitatively to a 1.0 liter volumetric flask and add 500 ml of distilled water. Swirl gently until all of the powder is dissolved, let stand for one half hour or until most of foam breaks and then make up to mark with distilled water. This solution contains 1.00 mg/ml of ABS.

Working Standard: Pipette 10.0 ml of the stock standard into a 1.0 liter Volumetric flask and make up to mark. This solution contains 0.010 mgs/ml of ABS. Prepare fresh daily.

PROCEDURE

1. Add 1, 1.0, 2.0, 5.0, 10.0, and 25.0 ml of WORKING STANDARD ABS to separatory funnels and make up to 100 ml with distilled water. These standards contain 1, .01, .02, .05, .10, .20, and .25 mg of ABS.
2. Add 100 ml of each sample to a separatory funnel.
3. Add 1.0 ml of 5 N sulfuric acid and 5.0 ml of methylene blue solution to each separatory funnel and mix.
4. Add 10 ml of chloroform to each funnel, invert and shake once a second for 25 seconds. Allow the chloroform layer to separate.
5. Draw off the chloroform layer and filter through a plug of absorbent cotton into a 50 ml volumetric flask. Repeat the extraction twice more, using 10 ml portions of chloroform, collecting the extracts in the same flask.
6. Rinse the cotton plugs with chloroform into the 50 ml volumetric flask, make up to mark with chloroform, mix well and let stand for 5-10 minutes.
7. Read the optical density of the Reagent Blank and Standards against chloroform as a reference blank at 650 mu in a suitable photometer or spectrophotometer and prepare a standard curve.
8. Read the optical density of each sample in a similar manner and calculate mg/l of ABS in each portion. Report all results to the second decimal place.

EVALUATION OF TAFT PROCEDURE

The procedure chosen for the determination of the anionic surfactant alkyl-benzene sulfonate is a modification of the methylene blue method (tentative) given in Standard Methods for the Examination of Water and Waste Water, Eleventh Edition, 1960, as modified by the Taft Sanitary Engineering Center of the United States Public Health Service.

Briefly, the basis of this method depends on the formation of a blue-colored salt when the methylene blue dye reacts with the anionic surfactants, which includes the alkyl-benzene sulfonates and the alkyl sulfates. The blue colored salt is soluble in the chloroform layer and the intensity of color is proportional to the concentration of ABS. The blue color intensity is measured by a spectrophotometer at a wave length of 650 mu.

The Taft method was chosen for this study because of its simplicity with the resultant saving in time and cost of analyses. It has been found by comparative analyses performed for the United States Public Health Service Analytical Reference Section by a large number of cooperating laboratories that the Taft method agrees substantially with the (tentative) methylene blue method given in Standard Methods.

Comparative study of the two methods performed in our San Bernardino laboratory based on 36 samples containing ABS in concentration range of 0.03–4.0 mg/l showed that the deviation by the Taft method averaged only +4.7 per cent from the Standard Method. Following is Table showing range of concentrations and per cent deviation from Standard Method.

TABLE

	Average Value		Range Concentrations mg/l		% Deviation From
No. Samples	Standard Method	Taft Method	Standard Method	Taft Method	Standard Method
12	0.086	0.088	0.03–0.16	0.03–0.16	+2.33
24	2.76	2.90	0.90–4.1	0.12–3.7	+5.1

This method was developed by the Analytical Reference Service, Taft Sanitary Engineering Center United States Public Health Service, Cincinnati, Ohio.

Eight samples out of the twenty-four compared were higher by the Standard Method showing a variability both on the low and high side, but generally speaking the Taft values tended to be from 2 to 5 per cent higher than the values obtained by Standard Methods. Since our basic interest in this study was to obtain comparative ABS data over a long period of time as economically and as reliably as possible a further study on the reproducibility of results by our chemist at the San Bernardino Laboratory of ABS determination by the Taft method was conducted.

Following is a tabulation of the analyses on samples prepared by addition of different amounts of ABS to a detergent free water. Samples were analyzed on different days:

Reproducibility of ABS Analyses by Taft Method
Added ABS mg/l

	0.05	0.12	0.75
Analysis Results			
Chemist A			
1	0.05	0.14	0.80
2	0.04	0.11	0.75
3	0.02	0.10	0.75
4	0.03	0.11	0.75
5	0.04	0.15	0.74
Chemist B			
1	0.05	0.12	0.76
2	0.06	0.12	0.78
3	0.06	0.11	0.78
4	0.06	0.11	0.80
5	0.05	0.12	0.78
Average mg/l	0.046	0.119	0.769
Standard Deviation mg/l	±0.013	±0.015	±0.023

Standard Methods quotes that forty-six analysts using the methylene blue method were able to reproduce their own results within ±0.01 mg/l on a sample containing 0.40 mg/l in distilled water and to ±0.03 mg/l on a sample containing 0.25 mg/l in tap water. These values bear out the findings tabulated above that ABS analyses on ground water samples are reproducible to ±0.02 mg/l when the samples are analyzed by the same chemists using the Taft Method.

APPENDIX E

GEOLOGY
AND
LOGS OF TEST WELLS AND TEST HOLES

APPENDIX E

TABLE OF CONTENTS

Following the above are given logs of test wells and test holes constructed during the investigation.

GEOLOGY

Detailed geologic information was not readily available for the area of investigation and it became evident from the inception of this study that this deficiency had to be met in order to complete the geologic mapping.

Although geology is not a primary objective of this investigation, it is required in order to understand the physical limitations of the aquifers and basins and to permit easy interpretation of the flow characteristics of the ground waters contained therein. This chapter has been kept as brief as possible without detracting from pertinent geologic facts. It has been divided to give information on geologic history, physiography, stratigraphy, and structure.

Geologic History

The geologic history of the area of investigation is closely dependent upon: (1) the emplacement of the bedrock masses of igneous and metamorphic character; (2) structural movements of these masses or the earth blocks in which they occur; (3) erosion of these masses with subsequent deposition of sediments in alluvial plains, fans, and floodplains; (4) worldwide sea level changes with their effects upon the stream regimen, thus, downcutting through the floodplain, removing some material and leaving the remainder as terraces along the streams; (5) weathering processes that produce residual soils or regoliths or transported soils; (6) aeolian processes that deposit sand in the form of dunes; and (7) changes in stream courses that lead to braiding and interlacing of the channels, backfilling with sediments, and eventual abandonment of the channels.

As presented here, the geologic history begins with pre-Tertiary, discusses Tertiary, and concludes with Quaternary events.

Pre-Tertiary History

The reach of the Santa Ana River from Loma Linda to the Riverside Narrows lies in the most northwestern extreme of the rock mass known as the Southern California batholith. This continuous mass of rocks extends from the Jurupa Mountains to the tip of Baja California in Mexico. It is approximately 1,000 miles long and covers approximately 50,000 square miles. Each of the many rock types of which it is composed was injected separately, but uniformly, along its length.

Prebatholithic rocks were folded and metamorphosed, possibly by compressive forces from off the coast of California or from the south. A magmatic body, which was uniform in composition throughout its length, was created and raised, by virtue of this structural activity, to a position near or at the surface. Many separate injections, caused by the same diastrophic forces that led to the original folding, were made from this magmatic reservoir to or near the ground surface along zones of structural weakness. Subsequently, erosional processes exposed these injections for a time only to be covered later by depositional processes. In some of these injections, the parent rock, or wall rock, was shattered and carried along with the molten material as inclusions. Contact metamorphism occurred between the molten material and parent rock in which recrystallization and deposition of minerals occurred. Each injection changed the remaining magma by removing the least volatile matter first, leaving behind the more volatile for later injections to follow. This magmatic differentiation (or crystal fractionation) led to the following order of rock types: gabbros, tonalites, granodiorites, and finally, granites. Few gradational contacts occurred between the various rock types. This indicates that cooling and crystallization of each type occurred before each succeeding injection was placed. The age of this batholith has been placed as early Upper Cretaceous.

Following emplacement of these bedrock masses, peneplanation leveled the area. This is evidenced by the level skyline of the San Bernardino Mountains. In contrast, the San Gabriel Mountains have sharp angular crests and an irregular profile. This peneplanation set the stage for the Tertiary history.

Tertiary History

Much of the geological record, from the time of emplacement of the Southern California batholith until the Tertiary period began, either is buried beneath a heavy sedimentary cover or is missing. The tilted sandstones and shales in Mill Creek Canyon and the Cajon sandstone in Cajon Pass, and the Potato sandstone (Vaughn), which is east of the area of investigation, are believed to be of Miocene age.

Tertiary sediments were deposited in the areas of the San Timoteo Badlands and Mill Creek before the San Jacinto block had dropped to its present level. These partly consolidated lacustrine clays and silts, which crop out in the badlands, probably accumulated in fresh water lakes. The area around these fresh water lakes was rejuvenated, and folding occurred in late Pliocene time. Coarse fluviatile sediments were deposited unconformably over the early Pliocene fine sediments. Uplift of the San Bernardino and San Gabriel Mountains possibly began in late Pliocene time. Most streams flowed to the northeast, with some depositional material derived from the Santa Ana Mountains to the south and southwest during late Pliocene time.

Quaternary History

Quaternary history, because it is of younger origin, is given in detail under Pleistocene and Recent.

Pleistocene

Early Pleistocene history shows continued sedimentation by materials from the south. Because the only probable early Pleistocene sediments occur as part of the San Timoteo beds in the badlands, little can be inferred from these sediments as to the early Pleistocene history.

Mid-Pleistocene was a time of major diastrophism in which there was further uplift of the San Bernardino Mountains and San Gabriel Mountains, major movements along the faults, and folding and faulting of the sediments in the badlands area. From these orogenic forces, the area was broken into four rigid earth blocks: the San Gabriel Mountains, San Bernardino Mountains, San Jacinto fault block, and Perris fault block. Some of these blocks were uplifted and eroded, while others were depressed and covered with sediments and detritus from the surrounding positive areas.

Middle to late Pleistocene history shows that deposition was widespread throughout the area as evidenced by widely scattered depositional remnants still standing above the alluvial plain. During the Wisconsin glacial period, sea level dropped with resulting downcutting action by streams, leaving remnants of these alluvial fan materials as terraces and mesas. The depth of this downcutting was controlled by resistant rocks in the stream channels. Drainage patterns were very different from those existing today. Abandoned channels were cut, possibly by Cajon Creek or Lytle Creek across the Rialto Bench to the Santa Ana River. One of these channels continues under the East Riverside Mesa and provides a flow path for subsurface movement east of the La Loma Hills. It has been reported that the Santa Ana River flowed directly westward, north of the Jurupa Mountains, and that the alluvial fan building southward from the San Gabriel Mountains forced its path southerly to its present location (USGS—''Underflow Across the San Jacinto fault''). Near the close of the Pleistocene epoch the streams were in their present positions.

Recent

Deposition of alluvium occurred in the downcut trenches, which were scoured during the most recent or Wisconsin glacial stage. Winds brought in sand from the north and west to build dunes. Alternating periods of deposition and erosion have altered the surface of this Younger alluvium with the deposition of a highly permeable material in the channels. Recent sand dunes continue to develop on top of the older weathered dunes.

Physiography

This description of the physiography of the area of investigation gives details on bordering mountains and highlands; plains, mesas, terraces, and deposits; and valleys and floodplains.

Bordering Mountains and Highlands

South of Loma Linda lie the San Timoteo Badlands, a series of folded, highly eroded sediments that end abruptly at Reche Canyon on the west. On the western side of Reche Canyon lies Blue Mountain, a steep peak that has a maximum elevation 2,423 feet above sea level.

At the Colton Narrows, two rock masses form the constriction of the Santa Ana River; north of the river is Slover Mountain, a limestone roof pendant rising to an elevation greater than 1,400 feet; south of the river are the La Loma Hills, bedrock masses that appear to be related to the Box Springs Mountains in rock type and have a connection with them continuing beneath the East Riverside Mesa.

At Riverside, many isolated bedrock masses project through the alluvium. Of these, three are located immediately along the southern bank of the Santa Ana floodplain. These are Mount Rubidoux, a mass of leucogranite rising to an elevation of 1,339 feet, a hill sometimes referred to as Indian Hill, and North Hill to the northeast. A series of lower hills extend southerly in a curved line from Mount Rubidoux. These are Pachappa Hill, one unnamed hill, and Quarry Hill. This line of hills forms a natural barrier for water movement and may represent a separate earth block. Evidence of this is seen in water levels and depths to bedrock on either side of the row of hills.

South of the Santa Ana River and northeast of Arlanza Village a highland area rises to an elevation of 894 feet. This unnamed hill is underlain by bedrock and forms part of the constriction known as Riverside Narrows. Directly across the Santa Ana River, to the north, the Pedley Hills form the other part of the constriction of the Riverside Narrows. Maximum elevation of the Pedley Hills is 424 feet above sea level. Several spurs or extensions of the Pedley Hills radiate outward toward the river. These are covered by regolith (residuum) and crop out again along the river as outliers. To the north of the Pedley Hills lie the Jurupa Mountains. The Jurupa Mountains rise to 2,235 feet and consist of a complex series of prebatholith metasedimentary rocks, and batholithic rocks that range from gabbro and leucogranodiorite in composition.(18) These mountains exert little effect on the area of study except for some intermittent streamflow and wind control.

East of the Jurupa Mountains lies an unnamed hill, which rises to a maximum elevation of 1,739 feet. A small extension extends eastward toward the Crestmore Quarry. At the Crestmore Quarry, twin hills—Chino Hill and Sky Blue Hill, are mined for the production of cement.

Plains, Mesas, Terraces, and Dikes

Within the report area is a prominent unnamed terrace on the western side of Reche Canyon. This physiographic remnant of older alluvium was left standing against the slope of Blue Mountain after downcutting by Reche Creek as it adjusted to a change in base level of the Santa Ana River. A drop in sea level affected the Santa Ana River and its tributaries in the upper Santa Ana Valley, causing them to downcut through their floodplains and alluvial fans nearby.

South of the Santa Ana River between Blue Mountain and the La Loma Hills is a physiographic feature referred to as the ''East Riverside Mesa.'' This alluvial fan surface has been abruptly truncated, leaving a scarp approximately 19 to 210 feet above the river floodplain.

Along the south side of the Santa Ana River between the La Loma Hills and the Riverside Narrows and extending easterly and southeasterly for 2 to 5 miles lies a relatively flat area, which is referred to in this report as the Riverside Plain. Alluvial fans developing from the Box Springs Mountains give a slight westward slope to this feature. Immediately adjacent to the river, this physiographic feature is approximately 5 feet above the floodplain near the La Loma Hills and increases in height to 60 feet near North Hill.

Extending along the south side of the Santa Ana River to the Riverside Narrows and southerly to the mountains lies a sloping surface referred to in this report as the Arlington Plain. Alluvial fans extending from the mountains to the valley flat are primarily responsible for the slope to the northwest. Beneath the alluvial fans, the original surface of the Riverside and Arlington Plains would be either flat or tilted in the opposite direction (i.e., to the southeast). Immediately along the Santa Ana River, this surface lies approximately 60 feet above the floodplain. It is entirely possible that the Riverside and Arlington Plains may represent depressed blocks of the original Perris peneplain.

North of the Santa Ana River from Riverside Narrows to Colton Narrows, the Fontana Plain forms the bluff above the floodplain. It is not a continuous surface, however, as local interruptions of bedrock and abandoned stream channels do occur. From Crestmore to Colton Narrows, sand dunes form the surface topography, locally interrupted by floodplains of backfilled channels that end at the Santa Ana River.

The Bunker Hill dike is a series of low, elongated hills that parallel the San Jacinto fault, and are evidently uplifted by movement along the fault. Beneath the Santa Ana River, these hills have been eroded away.

Valleys and Floodplains

The San Bernardino Valley is that area between the San Jacinto and San Andreas faults, the San Gabriel Mountains, the Crafton Hills, and the San Timoteo Badlands. It is formed by coalescing alluvial fans of the Santa Ana River, Mill Creek, Lytle Creek, Cajon Creek, and smaller tributaries to the Santa Ana River.

The San Bernardino Valley surface continues across the San Jacinto fault and downstream as the Santa Ana River floodplain. Connecting with the Santa Ana River floodplain from the Fontana Plain and the Riverside and Arlington Plains are floodplains of minor tributaries and abandoned, backfilled channels.

Stratigraphy

In discussing the stratigraphy of the area, the sediments are considered from youngest to oldest, with the Quaternary system first, followed by the Tertiary and the pre-Tertiary systems.

Quaternary System

Quaternary sediments are the most important sediments, from a ground water-producing aspect and therefore, the youngest unit is discussed first with each succeeding unit increasing in geologic age (see Plate 2, Areal Geology).

Recent Series

The Recent series consists of the three units: Recent alluvium (Qal); Younger alluvium (Qyal); and active dune sand (Qs).

ALLUVIUM. Recent alluvium is primarily stream-deposited gravel, sand, silt, and clay with some debris added locally by slope wash or flood deposits. These deposits, which lie relatively horizontal form the floodplain of the Santa Ana River and some of its tributaries. This unit has been separated from the Younger alluvium in this report because it forms a mappable unit of finer materials stratigraphically above the coarse-grained Younger alluvium, and it lies horizontally as opposed to the rolling, tilted surfaces where Younger alluvium is exposed. In areas of bedrock structural ''highs'' along the river, this alluvium is missing, thus, exposing the Younger alluvium. This is clearly evident in geologic Sections A-A′ and B-B′. The thickness of this unit reaches a maximum of 30 feet. Black and blue silts are very common in these alluvial deposits, indicating much included carbonaceous matter and dark minerals. The deposits of silt-size particles may result because of the location of the Colton Narrows near the distal portions of several coalescing alluvial fans from Cajon Creek, Santa Ana River, Mill Creek, Reche Canyon, and Lytle Creek. Also, the period of low rainfall, that this area has experienced in the past 17 years, has led to deposition of fine-grained sediments. Thus, surface infiltration from rainfall over those parts of the floodplain where fine materials predominate is slower than percolation in other parts where coarse sediments are found.

Channels of the Santa Ana River have been incised into the alluvial material of the floodplain and backfilled with a coarse sand and fine gravel to a maximum depth of 30 feet. These channels meander across the floodplain and, at times, cut across previously developed meanders to straighten out the channel. The gradient at the base of these sediments is approximately 12 feet per mile. Those streams debouching from the East Riverside Mesa and the Riverside Plain show little river wash in their channels. The little river wash that is present occurs in discontinuous patches in these tributary channels. Stretches of the stream where the river wash is absent may have been slightly folded or uplifted very recently and, thus, erosion removed the material over the structural ''highs''. Quantities of this material depend on the rate of erosion and weathering, the stream gradient and the resistance of the bedrock source.

YOUNGER ALLUVIUM. Lying stratigraphically beneath the alluvium listed above is the Younger alluvium. Two phases are identified: an upper fine-grained phase which crops out on the surface, upstream of the Colton Narrows, on both sides of the Santa Ana River floodplain, and a lower coarse-grained phase which is continuous within this area. Beneath the Santa Ana River floodplain, only the coarse phase is present. This coarse phase may be correlative with the Talbert aquifer in the Orange County portion of the Santa Ana River. The thickness of Younger alluvium beneath the Santa Ana River floodplain is approximately 100 feet, except over uplifted high areas where a thickness of 75 to 80 feet is encountered. The base of the Younger alluvium coincides with the beginning of the Recent epoch.

ACTIVE DUNE SAND. Active dune sand occurs on the northern side of the Santa Ana River. Primarily developed from winds from the west and northwest, these dunes mask the Older alluvium of the Fontana Plain near the river. Although some of the dune sand may be older than Recent, because some of the dunes are well stabilized and show a soil development, they are included under this unit in this report.

Pleistocene Series (Older Alluvium).

Only the Upper Pleistocene deposits occur as sediments in the immediate area, because Lower Pleistocene sediments appear to have been removed. Older alluvium (Qoal) includes all the Upper Pleistocene deposits.

The generalized term, Older alluvium, has been used in this report to include three types of sediments: (1) those alluvial deposits comprising Older alluvial fans, such as those that occur on the East Riverside Mesa and Fontana Plain; (2) remnants of floodplains along the Santa Ana River which, after downcutting, now stand as terraces about the present floodplain; and (3) deeply weathered residuum or regolith, which occurs around the La Sierra and Pedley Hills and the Jurupa Mountains. Along the Santa Ana River, these deposits lie beneath the Younger alluvium and include both coarse and fine deposits. Although occurring to a depth of 400 feet beneath the floodplain, these sediments are locally interrupted by higher bedrock subsurface elevations.

Beneath the East Riverside Mesa, Older alluvium comprises the excellent aquifer materials that allow passage of subsurface flow from the Santa Ana River beneath the mesa when water level gradients are favorable for such flow. (See Sections J-J′, K-K′, L-L′, M-M′, Plates 5 and 6.)

Tertiary System

Downstream from the San Jacinto fault, within the area of investigation, well logs and test drilling indicate that the Older alluvium lies directly on the bedrock surface; no evidence of Tertiary sedimentary materials was encountered. Upstream from the fault, the Tertiary deposits occur as the San Timoteo beds, which begin at Reche Canyon and continue easterly to the Beaumont area as a large anticlinal structure. The Tertiary sediments are not pertinent to this report and, therefore, will be treated lightly.

Pre-Tertiary System

All pre-Tertiary rocks have been included under the symbol Bc (Basement complex). Many types of bedrock occur in this area, from quartz diorites, tonalities, gabbros, granites, and recrystallized limestones. Because these consolidated rocks form the basement for the ground water materials, and because they yield little water for productive use, a grouping of the many types was made for convenience.

Structure

The following discussion of geologic structures treats the regional structures as well as the specific faults and barriers which affect the movement of ground water.

Regional Earth Blocks

Four major structural units make up the area surrounding the San Bernardino-Riverside area. These are the San Bernardino Mountain block, the San Jacinto block, the San Gabriel Mountain block, and the Perris block. The earth blocks that affect the area of investigation are the last two named, therefore, they will be discussed first.

Perris Block

The limits of the Perris block have been defined in several studies. In general, they define the boundaries as: the northeastern boundary at the San Jacinto fault zone, the southern boundary at the Aguanga fault zone in San Diego County, the southwestern limit at the Elsinore fault system, and the northwestern boundary as a somewhat arbitrary line joining Prado Dam to the City of San Bernardino. This block also forms the northern extension of the Southern California batholith and appears to have moved downward relative to neighboring blocks.

San Jacinto Block

Lying between the San Jacinto and San Andreas fault systems is the wedge or pie-shaped San Jacinto block. It includes the San Bernardino Valley and the San Timoteo Badlands area. This block has moved vertically downward relative to the San Bernardino Mountain and Perris blocks.

San Bernardino Mountain Block

The San Bernardino Mountain block lies to the north of the San Jacinto block and rises to an elevation of 11,502 feet above sea level. The smooth crest along its length and the many uneroded Pleistocene terraces still remaining near Big Bear Lake indicate the recency of the uplift. Several authors suggest that the movement took place at mid-Pleistocene time and is continuing.

San Gabriel Mountain Block

Lying west of the San Bernardino block from which it is separated by Cajon Pass is the San Gabriel block. This mass of crystalline rocks has a very rugged and jagged crestline. This shows the heavy erosion that has taken place either by glacial and stream action or weathering.

Faults

Three faults cross the Santa Ana River in the study area: the Loma Linda fault, San Jacinto fault, and the Rialto-Colton Barrier. All three of these faults trend northwest to southwest and are roughly parallel.

Loma Linda Fault

The Loma Linda fault is located farther upstream than the other two faults just named. It offsets Pleistocene and Tertiary sediments in the Colton Narrows area. The earth block upstream from the fault is the San Bernardino Valley with its 1,500 or more feet of sediments. Downstream of the fault is an uplifted block in which Tertiary sediments are brought to approximately 600–700 feet below the surface. The Younger alluvium apparently is not affected by this fault. Vertical offset is plainly evident on the three geologic sections that parallel the Santa Ana River.

San Jacinto Fault

The San Jacinto fault extends from the San Andreas fault zone across the San Bernardino Valley, through the San Timoteo Badlands, and continues on into the San Jacinto and Imperial Valleys. Although it is termed a right lateral fault, because of the amount of horizontal movement, the vertical movement where it crosses the Santa Ana River probably has more effect upon ground water levels, ground water movement, and ground water quality. This fault separates the San Jacinto earth block from the Perris earth block. The block upstream of the fault has been uplifted, while that on the downstream side of the fault has been downdropped. Movement along the fault probably took place during Tertiary time and has been continuing to the present time. Earthquake epicenters have been associated with the San Jacinto fault in recent times.

Rialto-Colton Barrier

The Rialto-Colton Barrier has little effect upon the ground water in the Colton area. Wells downstream of the fault encountered bedrock at approximately 600 to 650 feet below the surface, while those upstream, between the San Jacinto fault and the Rialto-Colton Barrier, do not extend to bedrock. To the north, vertical displacement becomes greater, and offset in the water levels on both sides of the fault are as much as 250 feet.

Test well logs

LEGEND

▥	Silt and clay
░	Fine sand
⁘	Medium sand
∴	Coarse sand
●	Granules
○	Gravel
▓	Boulders/cobbles
▒	Decomposed granite
∠	Granite

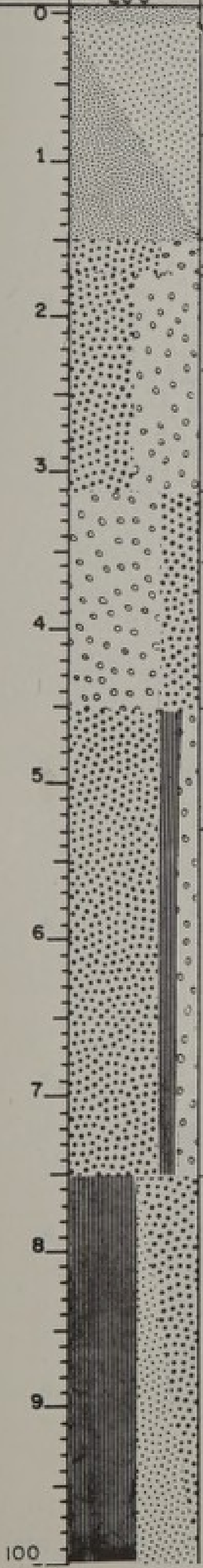
DATE STARTED Nov. 5, 1962
DATE COMP. Nov. 19, 1962
GEOLOGIST R. Turney - G. Ford
ELEV. 938.34 top of casing
TOTAL DEPTH 200'

STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
SOUTHERN CALIFORNIA DISTRICT
DRILL HOLE LOG

CONTRACTOR K. KIRKLAND
DRILLER K. KIRKLAND
TYPE DRILL RIG CABLE TOOL
SIZE OF HOLE 8"
DEPTH TO WATER 64'

PROJECT ABS Study Colton Narrows HOLE No. 1 SHEET 1 OF 2

DEPTH	GRAPHIC LOG	CLASSIFICATION AND DESCRIPTION



SAND; fine grain, well sorted and angular, brown.

SAND; fine-medium grain, angular-subangular.

SAND; 70% coarse grain, arkosic sand, subangular, light brown.
30% rock fragments, very angular, maximum size 1/2-inch, granite/granodiorite composition.

SAND AND GRAVEL; 30% - 65% coarse grain, arkosic sand, subangular, light brown.
35% - 65% pea gravel with mafic minerals.

GRAVEL AND SAND; 50% - 80% pea gravel to 3/4-inch maximum, angular/subangular.
20% - 50% coarse grain, arkosic sand, subangular, light brown.

SAND; 70% - 75% coarse grain, arkosic sand, subangular, light brown.
10% - 25% brown silt.
15% - 30% pea gravel, angular.

SILT AND SAND; 50% - 60% brown silt.
40% - 50% medium-coarse grain, arkosic sand, subangular, light brown with dark minerals.

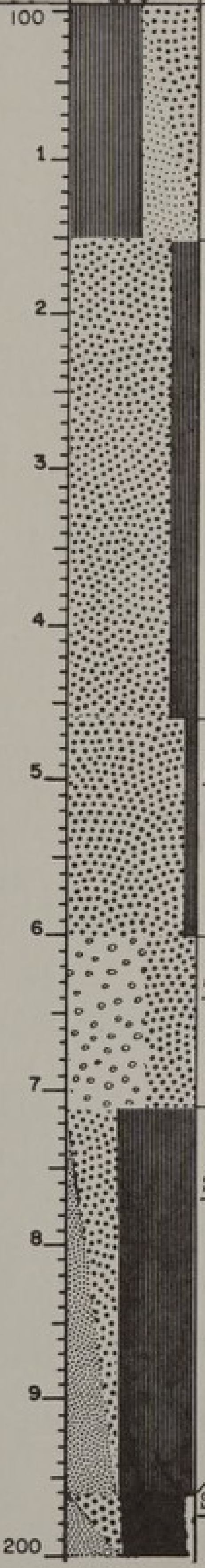
DATE STARTED
DATE COMP.
GEOLOGIST
ELEV.
TOTAL DEPTH

STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
SOUTHERN CALIFORNIA DISTRICT
DRILL HOLE LOG

CONTRACTOR
DRILLER
TYPE DRILL RIG
SIZE OF HOLE
DEPTH TO WATER

PROJECT HOLE No. 1 SHEET 2 OF 2

DEPTH | GRAPHIC LOG | CLASSIFICATION AND DESCRIPTION



SAND; 70% - 90% coarse grain, arkosic sand, subangular, light brown with dark minerals.
10% - 25% brown silt.

SAND; 90% very coarse grain, arkosic sand, subangular, light brown.
10% brown silty clay

GRAVEL; 50% - 60% pea gravel, angular.
30% - 40% coarse grain, arkosic sand, subangular, light brown.

SAND AND SILT; 40% - 60% fine-coarse grain, arkosic sand, subangular, light brown with dark minerals.
60% - 40% brown silt.

SAND AND SILT; 40% - 50% fine-coarse grain, arkosic sand.
40% - 50% brown silt.
10% pea gravel.

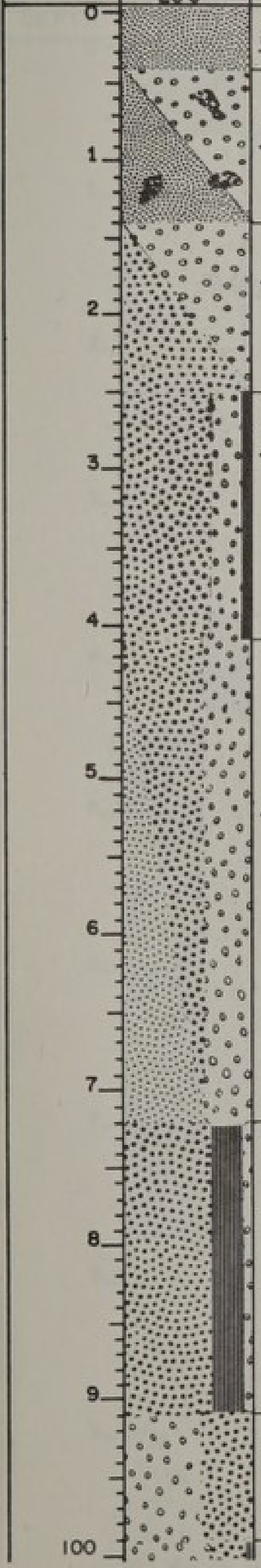
DATE STARTED Oct. 12, 1962
DATE COMP. Nov. 1, 1962
GEOLOGIST R. Turney - G. Ford
ELEV. 903.30 top of casing
TOTAL DEPTH 200'

STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
SOUTHERN CALIFORNIA DISTRICT
DRILL HOLE LOG

CONTRACTOR K. KIRKLAND
DRILLER K. KIRKLAND
TYPE DRILL RIG CABLE TOOL
SIZE OF HOLE 8"
DEPTH TO WATER 78.8

PROJECT ABS Study Colton Narrows HOLE No. 2 SHEET 1 OF 2

DEPTH | GRAPHIC LOG | CLASSIFICATION AND DESCRIPTION



SAND; fine grain, angular with debris.

SAND; fine grain, with gravel (cobbles to 4-inches).

SAND; course grain, arkosic, subangular with fine gravel to 1/4-inch.

SAND; 60% - 70% coarse, arkosic sand, subangular with dark minerals.
25% - 30% gravel.
10% silt.

SAND AND GRAVEL; 50% - 65% medium-coarse grain, quartzose sand, subangular.
35% - 50% pea size gravel, granodiorite composition.

SAND; 65% coarse grain, quartzose sand, subangular.
25% silt.
10% gravel of granodiorite composition.

GRAVEL; 60% fine gravel.
40% coarse grain, quartzose sand, subangular-very clean.

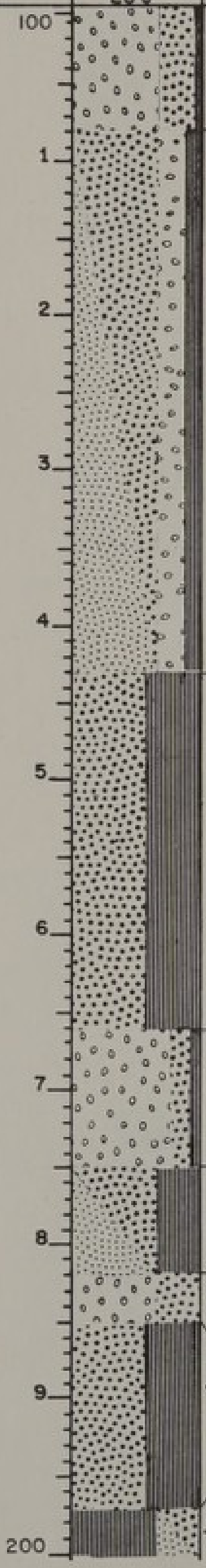
DATE STARTED
DATE COMP.
GEOLOGIST
ELEV.
TOTAL DEPTH

STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
SOUTHERN CALIFORNIA DISTRICT
DRILL HOLE LOG

CONTRACTOR
DRILLER
TYPE DRILL RIG
SIZE OF HOLE
DEPTH TO WATER

PROJECT HOLE No. 2 SHEET 2 OF 2

DEPTH | GRAPHIC LOG | CLASSIFICATION AND DESCRIPTION



GRAVEL; 65% 1/4 - 3/8 inch gravel.
30% coarse grain, arkosic sand.
5% brown clay.

SAND; 60% - 80% medium-coarse grain, arkosic sand, subangular with dark minerals.
15% - 20% pea gravel.
10% - 20% brown silt.

SAND AND CLAY; 50% - 60% coarse grain, arkosic sand.
40% - 50% brown silty clay.

GRAVEL; 75% fine gravel
20% coarse grain, arkosic sand, subangular.
5% brown silt.

SAND; 65% medium-coarse grain, arkosic sand, subangular.
35% brown silty clay.

GRAVEL; 65% pea gravel.
35% coarse grain, arkosic sand, subangular.

SAND; 60% coarse grain, arkosic sand, subangular with dark minerals.
35% brown silt.
5% clay.

SILT; 60% - 70% brown silt.
30% - 40% medium-coarse grain, arkosic sand.

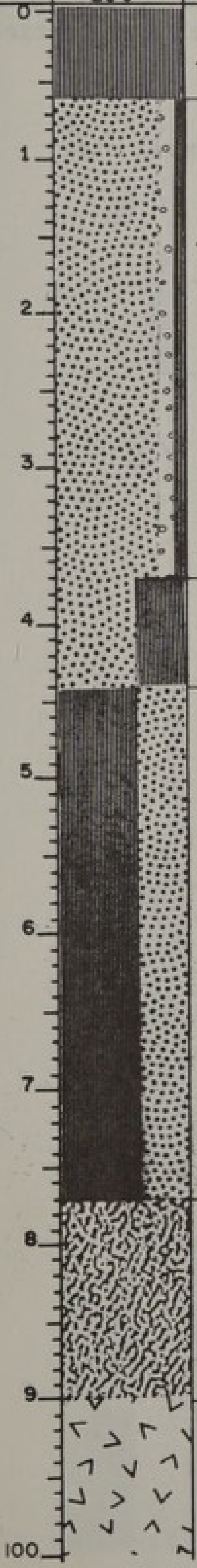
DATE STARTED Dec. 18, 1962
DATE COMP. Dec. 27, 1962
GEOLOGIST R. Turney - G. Ford
ELEV. 871.36 top of casing
TOTAL DEPTH 100'

STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
SOUTHERN CALIFORNIA DISTRICT
DRILL HOLE LOG

CONTRACTOR K. KIRKLAND
DRILLER K. KIRKLAND
TYPE DRILL RIG CABLE TOOL
SIZE OF HOLE 8"
DEPTH TO WATER 42.5'

PROJECT ABS Study Colton Narrows HOLE No. 3 SHEET 1 OF 1

DEPTH | GRAPHIC LOG | CLASSIFICATION AND DESCRIPTION



SILT; brown with fine dark minerals.

SAND; 80% - 90% coarse grain, arkosic sand, subangular with dark minerals.
5% - 15% pea gravel, angular.
5% - 10% brown micaceous silt.

SAND; 60% coarse grain, arkosic sand, subangular with dark minerals.
40% brown micaceous silt.

SILT; 40% - 65% brown micaceous silt
35% - 40% coarse grain, arkosic sand, subangular with dark minerals.

DECOMPOSED GRANITE-GRANODIORITE

GRANITE-GRANODIORITE

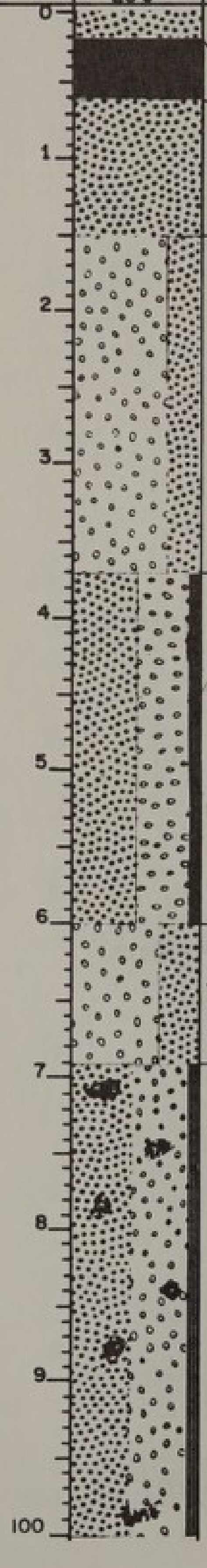
DATE STARTED Nov. 21, 1962
DATE COMP. Dec. 17, 1962
GEOLOGIST R. Turney - G. Ford
ELEV. 817.00 top of pedestal
TOTAL DEPTH 398'

STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
SOUTHERN CALIFORNIA DISTRICT
DRILL HOLE LOG

CONTRACTOR K. KIRKLAND
DRILLER K. KIRKLAND
TYPE DRILL RIG CABLE TOOL
SIZE OF HOLE 8"
DEPTH TO WATER 31'

PROJECT ABS Study Colton Narrows HOLE No. 4 SHEET 1 OF 4

DEPTH | GRAPHIC LOG | CLASSIFICATION AND DESCRIPTION



SAND; coarse grain, arkosic sand, angular with some gravel size particules.

SILT; brown silty soil horizon.

SAND; coarse grain, arkosic sand, subangular with some gravel size particules.

GRAVEL; 75% pea gravel, subangular-angular.
25% coarse grain, arkosic sand.

SAND; 50% coarse grain, arkosic sand, light brown, subangular with dark minerals.
40% pea gravel.
10% brown silt.

GRAVEL; 70% pea size to 3/4-inch gravel, subangular.
30% coarse grain, arkosic sand, subangular.

SAND AND GRAVEL; 40% - 50% coarse grain arkosic sand, light brown, subangular.
40% - 50% gravel, angular/subangular, granitic composition.
10% brown silt.
This section contains boulders/cobbles of granitic composition throughout.

DATE STARTED

DATE COMP.

GEOLOGIST

ELEV.

TOTAL DEPTH

STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
SOUTHERN CALIFORNIA DISTRICT
DRILL HOLE LOG

CONTRACTOR

DRILLER

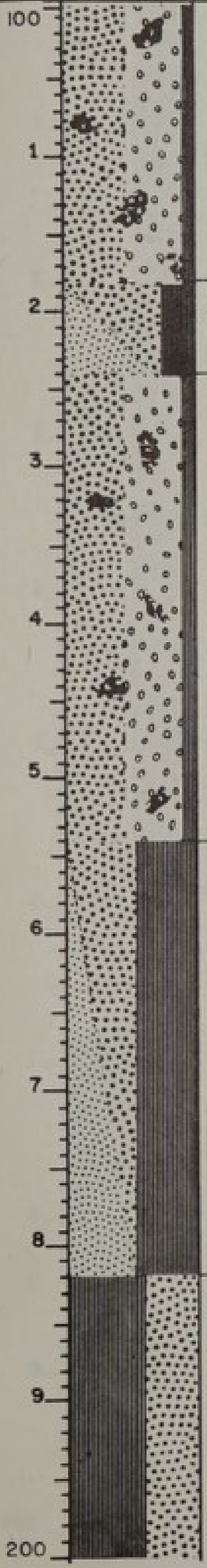
TYPE DRILL RIG

SIZE OF HOLE

DEPTH TO WATER

PROJECT HOLE No. 4 SHEET 2 OF 4

DEPTH	GRAPHIC LOG	CLASSIFICATION AND DESCRIPTION



SAND; 65% - 85% medium-coarse grain, arkosic sand, subangular with dark minerals.
15% - 35% brown silt.

SAND AND GRAVEL; 40% - 50% coarse grain arkosic sand, light brown, subangular.

40% - 50% gravel, angular/subangular, granitic composition.

10% brown silt.

This section contains boulders/cobbles of granitic composition throughout.

SAND AND SILT; 45% - 60% medium-coarse grain, arkosic sand, subangular with dark minerals.

40% - 55% brown silt.

SILT; 60% brown silty clay.

40% coarse grain, arkosic sand, subangular with dark minerals.

10% brown clay.

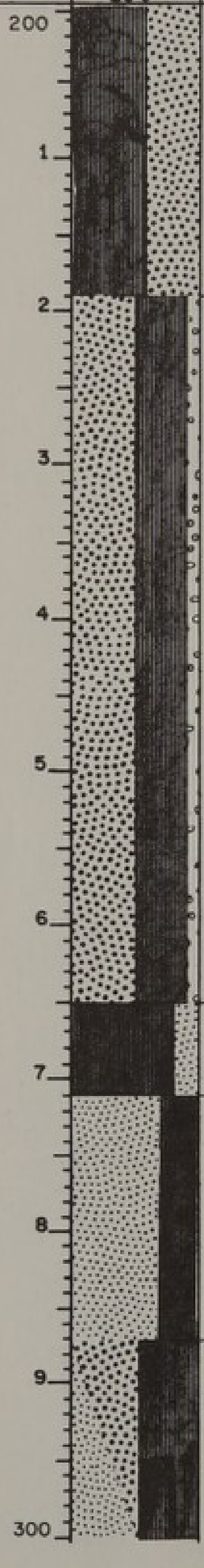
DATE STARTED
DATE COMP.
GEOLOGIST
ELEV.
TOTAL DEPTH

STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
SOUTHERN CALIFORNIA DISTRICT
DRILL HOLE LOG

CONTRACTOR
DRILLER
TYPE DRILL RIG
SIZE OF HOLE
DEPTH TO WATER

PROJECT HOLE No. 4 SHEET 3 OF 4

DEPTH | GRAPHIC LOG | CLASSIFICATION AND DESCRIPTION



SAND AND SILT; 50% - 60% coarse grain, arkosic sand, subangular/angular with dark minerals.
30% - 50% brown silt.
5% - 10% pea gravel.

CLAY; 80% brown silty clay.
20% medium grain, arkosic sand, subangular.

SAND; 70% medium grain, arkosic sand.
30% sandy silt.

DATE STARTED ____________

DATE COMP. ____________

GEOLOGIST ____________

ELEV. ____________

TOTAL DEPTH ____________

STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
SOUTHERN CALIFORNIA DISTRICT
DRILL HOLE LOG

CONTRACTOR ____________

DRILLER ____________

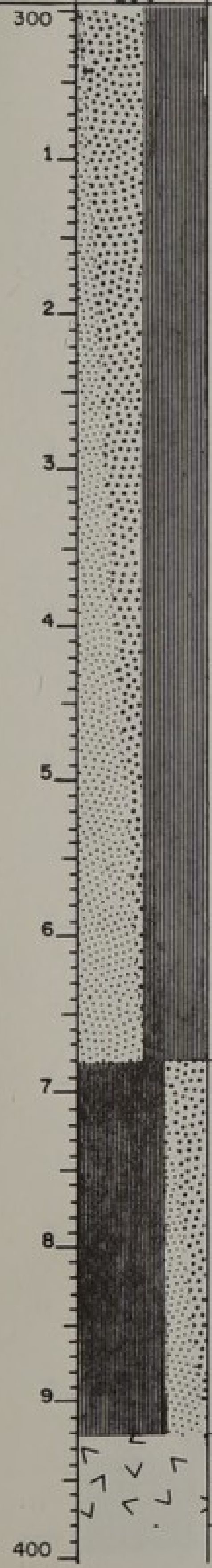
TYPE DRILL RIG ____________

SIZE OF HOLE ____________

DEPTH TO WATER ____________

PROJECT ____________ HOLE No. 4 SHEET 4 OF 4

DEPTH | GRAPHIC LOG | CLASSIFICATION AND DESCRIPTION



SAND AND SILT; 65% - 40% medium-coarse grain, arkosic sand,
angular/subangular with dark minerals.
35% - 60% brown silt with clay.

SILT; 65% brown silt with clay.
35% medium-coarse grain, sand, angular/subangular with
dark minerals.

NOTE: lower portion contains decomposed granite.

GRANITE-GRANODIORITE

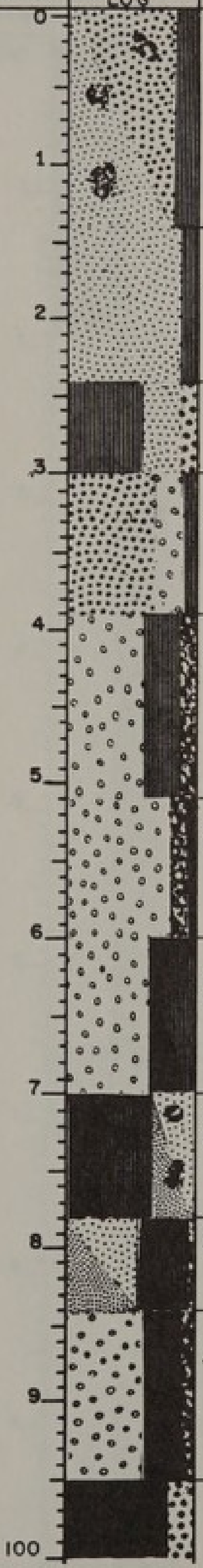
DATE STARTED March 9, 1964
DATE COMP. March 19, 1964
GEOLOGIST G. Ford
ELEV. 964.67 top of pedestal
TOTAL DEPTH 410'

STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
SOUTHERN CALIFORNIA DISTRICT
DRILL HOLE LOG

CONTRACTOR W. H. BULLINGTON
DRILLER LARRY HIMES
TYPE DRILL RIG ROTARY
SIZE OF HOLE 7-3/4
DEPTH TO WATER 31.0 ft.

PROJECT ABS PIEZOMETERS HOLE No. 5P SHEET 1 OF 5

DEPTH | GRAPHIC LOG | CLASSIFICATION AND DESCRIPTION



SAND; 85% medium-coarse grain, arkosic sand, angular subangular
15% brown micaceous silt
indication of boulders/cobbles

SAND; 90% medium grain, arkosic sand, subangular.
10% brown micaceous silt.

SILT; 60% brown micaceous silt.
30% medium grain angular/subangular sand.
10% angular granitic granules.

SAND; 70% coarse grain, arkosic sand, angular.
20% gravel, angular.
10% brown micaceous silt.

GRAVEL; 60% gravel, angular and granitic in composition.
30% brown silty clay.
10% cobbles/boulders, granitic.

GRAVEL; 85% fine granitic gravel, angular.
10% cobbles/boulders, granitic.
5% brown micaceous silt.

GRAVEL; 60% fine gravel, angular.
40% sandy silt, brown-black.

SILT; 65% sandy silt, micaceous, brown.
35% fine-medium grain, arkosic sand, subangular
indication of cobbles/boulders.

SAND; 55% fine-medium grain, arkosic sand, subangular.
40% sandy silt, micaceous, brown.
5% cobbles/boulders, granitic.

GRAVEL; 60% fine gravel, angular, granitic composition.
30% sandy silt, micaceous, brown.
10% cobbles/boulders, granitic.

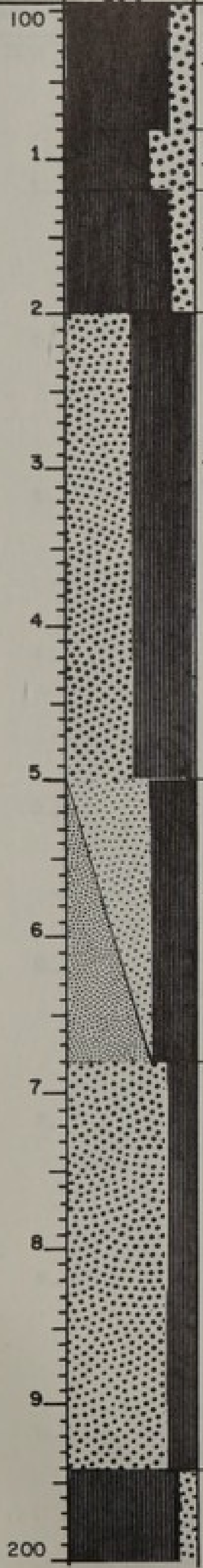
DATE STARTED
DATE COMP.
GEOLOGIST
ELEV.
TOTAL DEPTH

STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
SOUTHERN CALIFORNIA DISTRICT
DRILL HOLE LOG

CONTRACTOR
DRILLER
TYPE DRILL RIG
SIZE OF HOLE
DEPTH TO WATER

PROJECT HOLE No. 5P SHEET 2 OF 5

DEPTH	GRAPHIC LOG	CLASSIFICATION AND DESCRIPTION



SILT; 80% sandy silt, micaceous, brown.
20% granules, angular and granitic.

SILT; 60% sandy silt, micaceous, brown
40% granules, angular and granitic.

SILT; 80% sandy silt, micaceous, brown.
20% granules, angular and granitic.

SAND AND SILT; 50% coarse grain, arkosic sand, angular.
50% greenish silty clay (alternating layers).

SAND; 60% fine-medium grain, arkosic sand, angular.
40% greenish sandy silt.

SAND; 75% coarse grain, arkosic sand, angular.
25% greenish sandy silt.

CLAY; 80% greenish silty clay.

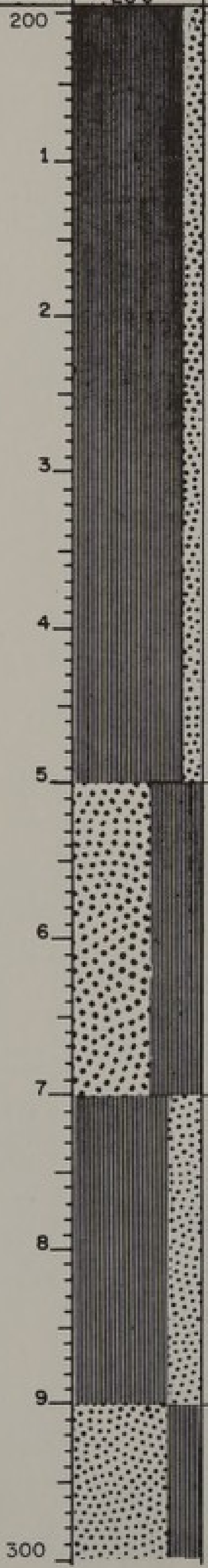
DATE STARTED
DATE COMP.
GEOLOGIST
ELEV.
TOTAL DEPTH

STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
SOUTHERN CALIFORNIA DISTRICT
DRILL HOLE LOG

CONTRACTOR
DRILLER
TYPE DRILL RIG
SIZE OF HOLE
DEPTH TO WATER

PROJECT HOLE No. 5P SHEET 3 OF 5

DEPTH | GRAPHIC LOG | CLASSIFICATION AND DESCRIPTION



15% coarse grain, arkosic sand, angular.
5% brown micaceous silt.

GRANULES; 60% granitic granules, angular.
30% greenish silty clay.
10% brown micaceous silt.

CLAY; 75% greenish silty clay.
25% coarse grain, arkosic sand, angular.

SAND; 75% very coarse grain, arkosic sand, angular.

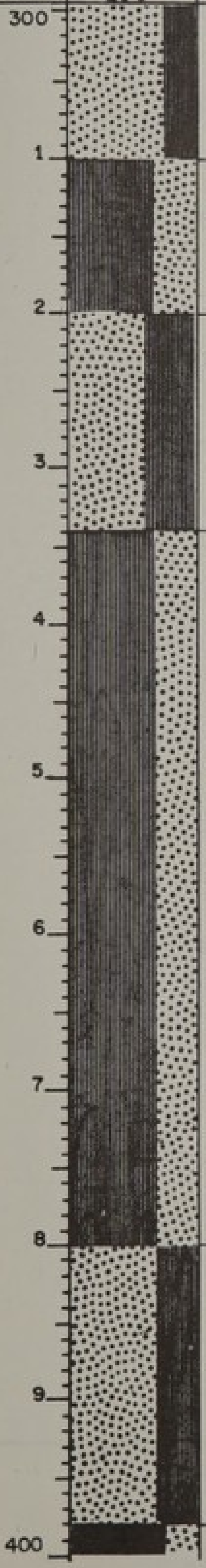
DATE STARTED
DATE COMP.
GEOLOGIST
ELEV.
TOTAL DEPTH

STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
SOUTHERN CALIFORNIA DISTRICT
DRILL HOLE LOG

CONTRACTOR
DRILLER
TYPE DRILL RIG
SIZE OF HOLE
DEPTH TO WATER

PROJECT HOLE No. 5P SHEET 4 OF 5

DEPTH | GRAPHIC LOG | CLASSIFICATION AND DESCRIPTION



25% greenish silty clay.

SILT; 65% greenish sandy silt.
35% coarse grain, arkosic sand, angular.

SAND; 60% coarse grain, arkosic sand, angular.
40% greenish sandy silt.

SILT; 70% greenish sandy silt.
30% coarse grain, arkosic sand, angular.

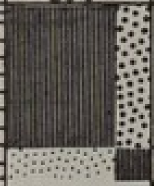
SAND; 70% coarse grain, arkosic sand, angular.
30% greenish sandy silt.

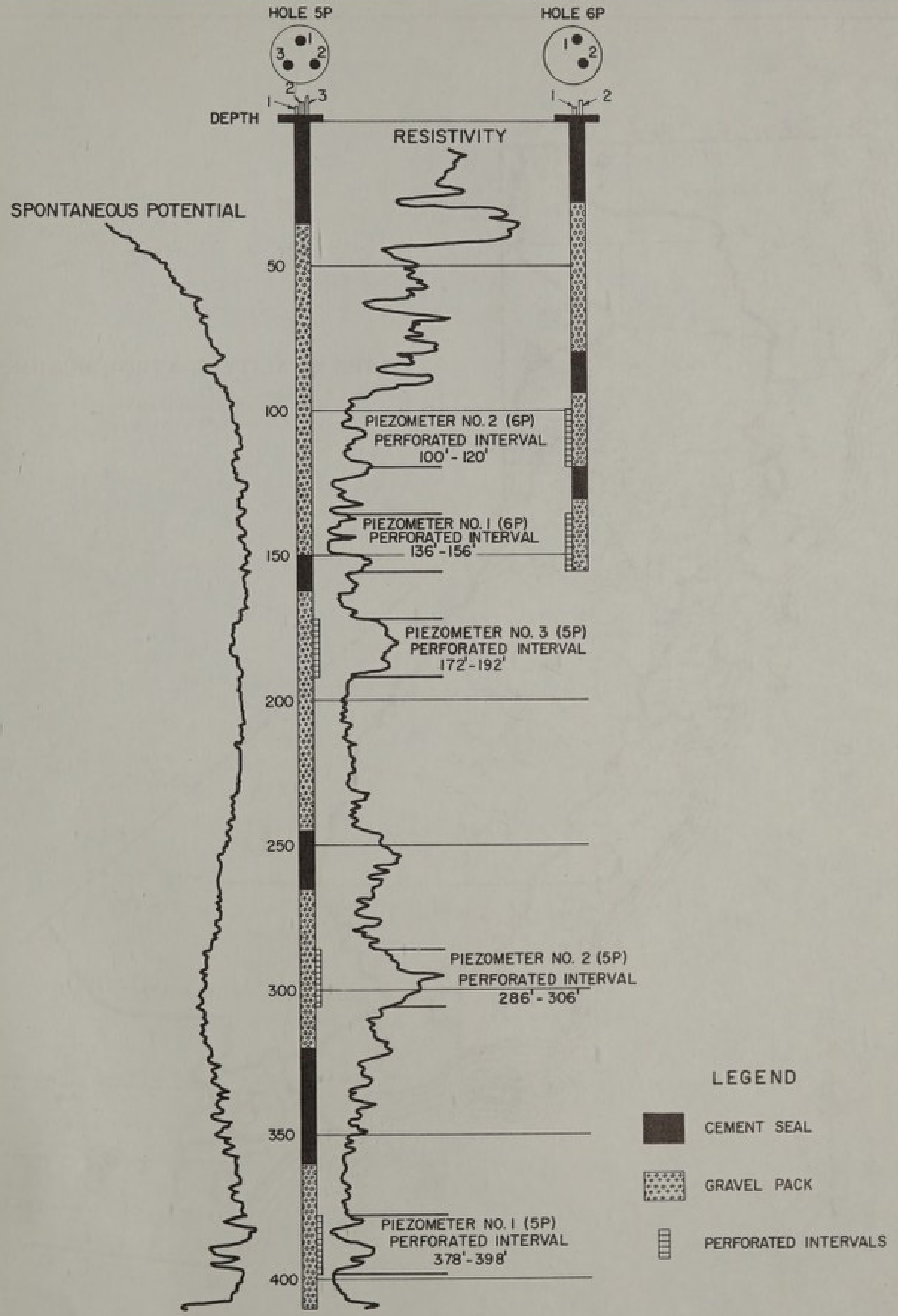
DATE STARTED ______
DATE COMP. ______
GEOLOGIST ______
ELEV. ______
TOTAL DEPTH ______

STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
SOUTHERN CALIFORNIA DISTRICT
DRILL HOLE LOG

CONTRACTOR ______
DRILLER ______
TYPE DRILL RIG ______
SIZE OF HOLE ______
DEPTH TO WATER ______

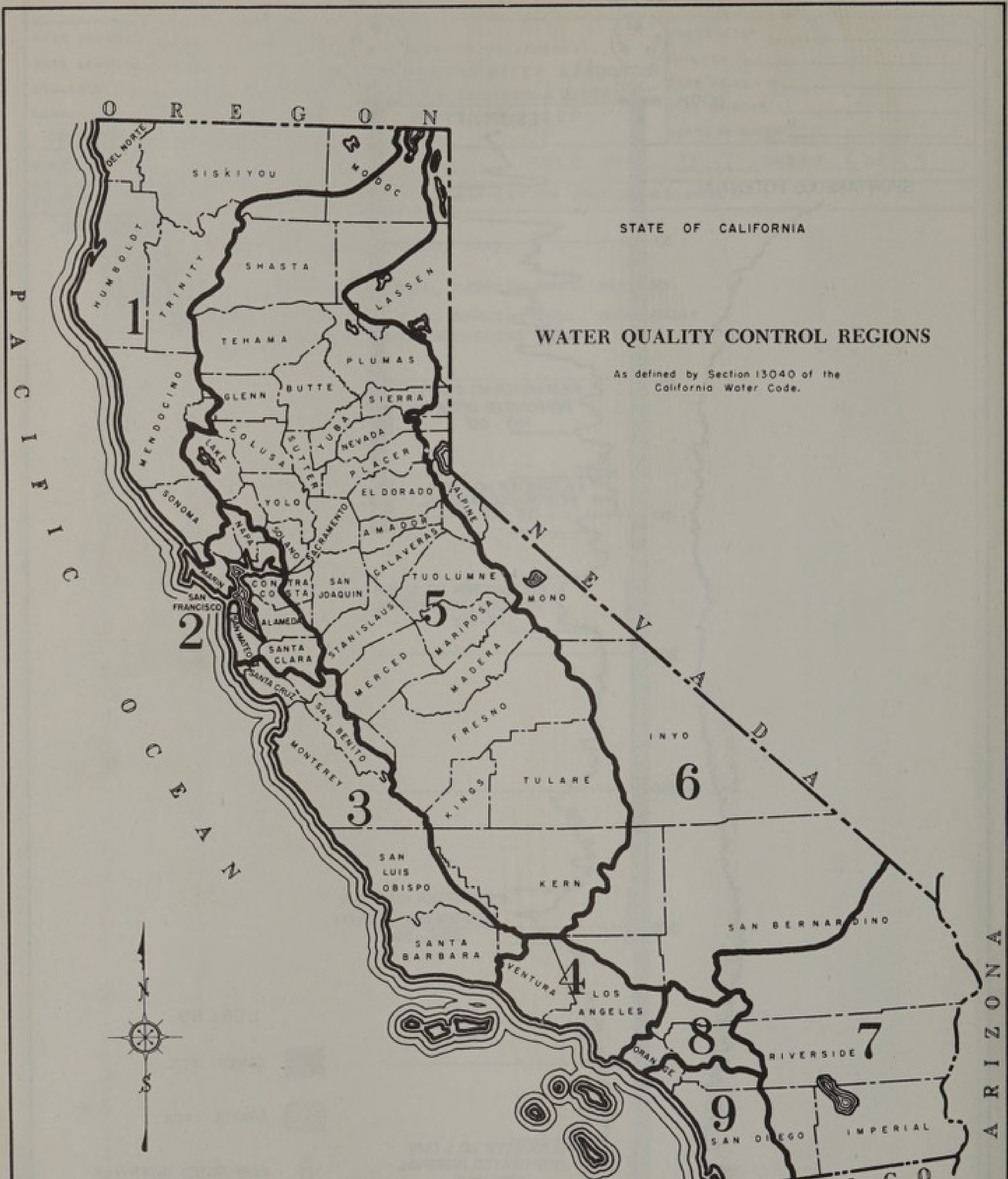
PROJECT ______ HOLE No. 5P SHEET 5 OF 5

DEPTH	GRAPHIC LOG	CLASSIFICATION AND DESCRIPTION
400		<u>CLAY</u>; 75% greenish silty clay. 25% coarse grain, arkosic sand, angular.
1		<u>SAND</u>; 75% medium grain, arkosic sand, subangular. 25% brown sandy micaceous silt.
2		
3		
4		
5		
6		
7		
8		
9		
500		



ELECTRIC LOG AND
CONSTRUCTION DETAIL OF PIEZOMETERS

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1964



STATE OF CALIFORNIA

WATER QUALITY CONTROL REGIONS

As defined by Section 13040 of the California Water Code.

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△39676—956 2-65 2M

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STATE OF CALIFORNIA

REGIONAL WATER QUALITY CONTROL BOARDS

NORTH COASTAL REGIONAL WATER QUALITY CONTROL BOARD (NO. 1)
1739 Fourth Street (P.O. Box 1436), Santa Rosa, California 95404

SAN FRANCISCO BAY REGIONAL WATER QUALITY CONTROL BOARD (NO. 2)
1111 Jackson Street, Oakland, California 94607

CENTRAL COASTAL REGIONAL WATER QUALITY CONTROL BOARD (NO. 3)
1108 Garden Street, San Luis Obispo, California 93401

LOS ANGELES REGIONAL WATER QUALITY CONTROL BOARD (NO. 4)
217 West First Street, Los Angeles, California 90012

CENTRAL VALLEY REGIONAL WATER QUALITY CONTROL BOARD (NO. 5)
1416 Ninth Street (Room 1354), Sacramento, California 95814

LAHONTAN REGIONAL WATER QUALITY CONTROL BOARD (NO. 6)
407 West Line Street, Bishop, California 93514

COLORADO RIVER BASIN REGIONAL WATER QUALITY CONTROL BOARD (NO. 7)
82-380 Miles Avenue (P.O. Box 277), Indio, California 92202

SANTA ANA REGIONAL WATER QUALITY CONTROL BOARD (NO. 8)
3691 Main Street, Riverside, California 92501

SAN DIEGO REGIONAL WATER QUALITY CONTROL BOARD (NO. 9)
1350 Front Street, San Diego, California 92101