EVALUATION

OF

RECHARGE POTENTIAL

NEAR

INDIO, CALIFORNIA

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 33-74

PREPARED IN COOPERATION WITH THE

VALLEY SANITARY DISTRICT

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The feasibility of recharging 8,000 acre-ft (9.9 hm^3) of sewage effluent per year in an area northwest of Indio, Calif., was evaluated. Driller's logs, water-level data, and water-quality data indicate that the area most suitable for recharge through surface spreading is west of Washington Street and north of the Whitewater River stormwater channel. Using three spreading grounds on a rotating basis and assuming long-term infiltration rates of 2 ft/d (0.6 m/d), an area of 33 acres (13 ha) would be required to infiltrate 8,000 acre-ft (9.9 hm^3) per year. Water-level rise due to recharge is anticipated to be about 36 ft (11 m) at the site of recharge.

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By Joe A. Moreland

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Prepared in cooperation with

the Valley Sanitary District

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February 1975

UNITED STATES DEPARTMENT OF THE INTERIOR

Rogers C. B. Morton, Secretary

GEOLOGICAL SURVEY

V. E. McKelvey, Director

CONTENTS

ILLUSTRATIONS

IV   CONTENTS

TABLES

CONVERSION FACTORS

Factors for converting English units to the International System of Units (SI)
are given below to four significant figures. However, in the text the
metric equivalents are shown only to the number of significant figures
consistent with the values for the English units.

English	Multiply by	Metric (SI)
acres	4.047×10^{-1}	ha (hectares)
acre-ft (acre-feet)	1.233×10^{-3}	hm^3 (cubic hectometres)
acre-ft/d (acre-feet per day)	1.233×10^{-3}	hm^3/d (cubic hectometres per day)
acre-ft/yr (acre-feet per year)	1.233×10^{-3}	hm^3/yr (cubic hectometres per year)
ft (feet)	3.048×10^{-1}	m (metres)
ft/d (feet per day)	3.048×10^{-1}	m/d (metres per day)
ft^3/s (cubic feet per second)	2.832×10^{-2}	m^3/s (cubic metres per second)
in (inches)	2.540×10^1	mm (millimetres)
mi (miles)	1.609	km (kilometres)
mi^2 (square miles)	2.590	km^2 (square kilometres)

EVALUATION OF RECHARGE POTENTIAL NEAR INDIO, CALIFORNIA

By Joe A. Moreland

ABSTRACT

The U.S. Geological Survey evaluated the feasibility of utilizing 8,000 acre-feet (9.9 cubic hectometres) of sewage effluent per year to recharge the ground water in a 25-square mile (65-square kilometre) area northwest of Indio, Calif. The depth to water in the area studied ranged from about 50 feet (15 metres) to more than 200 feet (61 metres). Dissolved-solids concentrations greater than 500 milligrams per litre exist in the shallow aquifers in the eastern and southern parts of the study area. The permeability of the shallow sediments ranges from 15 to 50 feet per day (5 to 15 metres per day). The eastern part of the area is underlain by fine-grained sediments that effectively separate the deep and shallow aquifers and would not be conducive to artificial recharge. In the western part of the area, sediments in the upper 100 feet (30 metres) are primarily sand. Considering all but economic factors, the most hydrologically favorable area for recharge is west of Washington Street and north of the Whitewater River.

Using three spreading pits on a rotating basis and assuming long-term infiltration rates of 2 feet per day (0.6 metre per day), an area of 33 acres (13 hectares) would be required to infiltrate 8,000 acre-feet (9.9 cubic hectometres) per year. At the recharge site, a water-level rise of about 36 feet (11 metres) due to recharge is expected.

INTRODUCTION

Valley Sanitary District (VSD), which serves the city of Indio, Calif. (fig. 1), has been prohibited by the California Water Resources Control Board (CWRCB) from discharging sewage effluent to water courses that flow to the Salton Sea. CWRCB's order requires that 25 percent of the sewage effluent from the VSD's Indio plant be used beneficially by January 1973, 40 percent by January 1974, 70 percent by January 1975, and 99 percent by January 1976.

1
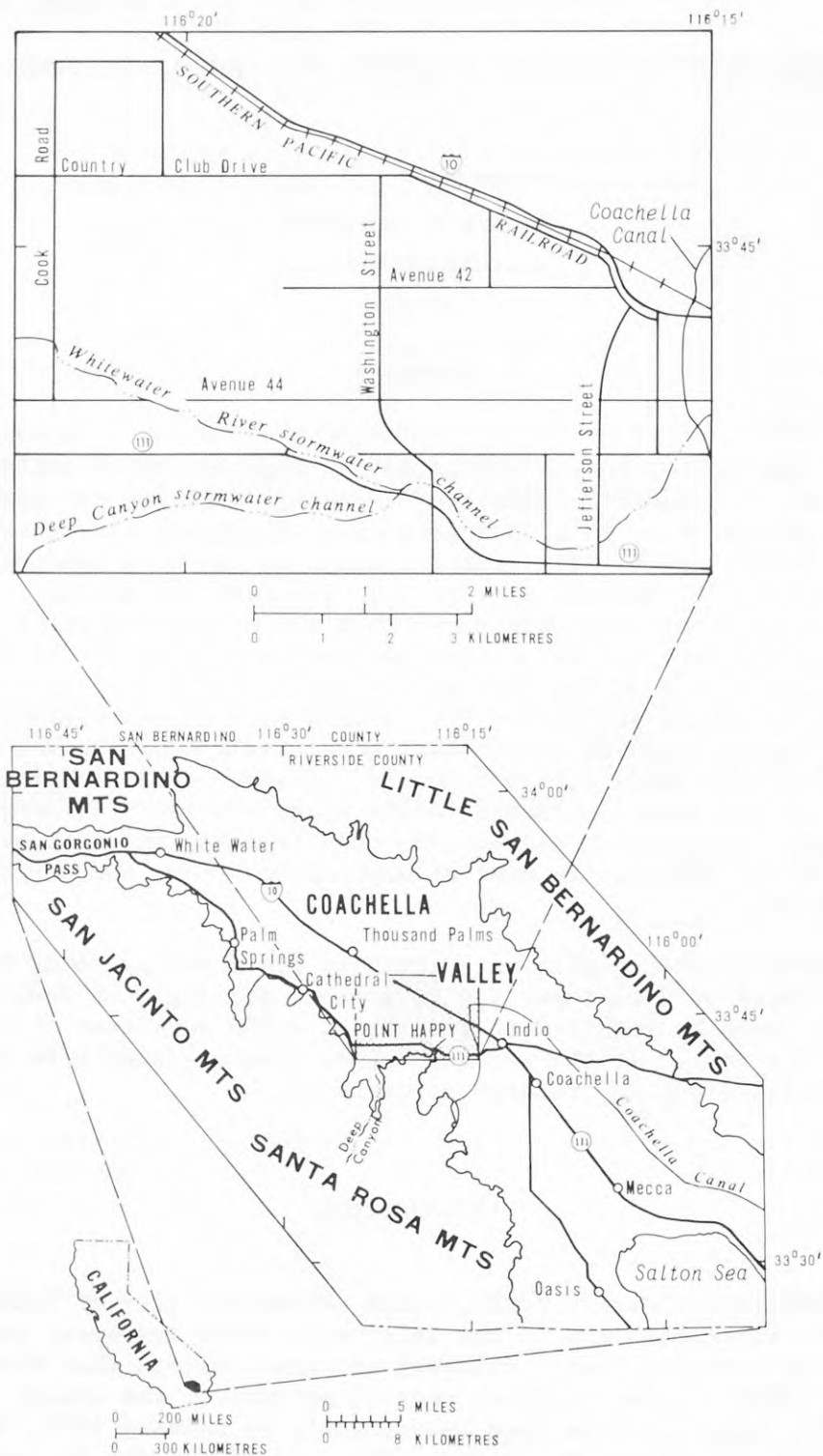
FIGURE 1.--Index map of study area.

Currently (1973) the VSD uses about 25 percent of its total annual sewage effluent for irrigation of adjacent pasture lands and discharges the remaining 75 percent to the Whitewater River stormwater channel, which drains to the Salton Sea. The VSD currently treats about 3,000 acre-ft (3.7 hm^3) of sewage per year and expects an increase of sewage to about 8,000 acre-ft (9.9 hm^3) per year by 1980.

Irrigation of adjacent agricultural land cannot accommodate the projected quantities of sewage effluent. Therefore, the VSD must develop alternative beneficial means for disposing of their effluent if the timetable set forth by CWRCB is to be met.

Purpose

One of the many methods considered by VSD for disposing of its sewage effluent is to use the effluent to artificially recharge the aquifers underlying the district. The VSD requested that the U.S. Geological Survey evaluate the feasibility of this method. Specifically, the VSD requested that the Geological Survey:

1. Determine depth to water in the area of primary interest.

2. Determine the existence, extent, and effectiveness of any subsurface geologic units that might tend to retard or restrict infiltration of the effluent.

3. Determine the most hydrologically favorable sites for recharge.

4. Determine the permeability of sediments underlying hydrologically favorable sites.

5. Estimate expected infiltration rates at potential recharge sites.

6. Estimate the spreading area required to infiltrate 8,000 acre-ft (9.9 hm^3) of treated effluent per year.

7. Analyze the general effects of algal growth on recharge operation and determine possible control measures.

8. Prepare a report describing the study and the results obtained.

Scope

The scope of this investigation included:

1. Collection and analysis of nearly 150 drillers' logs of wells.

2. Collection and analysis of existing ground-water quality data from nearly 100 wells.

3. Collection and analysis of existing water-level measurements from more than 40 wells.

4. Augering 11 test holes to depths ranging from 64 to 109 ft (20 to 33 m) below land surface.

5. Collection and particle-size analysis of 19 sediment samples from the augered test holes.

6. Collection and analysis of six ground-water samples from the augered test holes.

7. Compilation and evaluation of data pertaining to algal-growth problems in recharge of sewage effluent.

For economic and hydrologic reasons, the study was confined to a 25-mi^2 (65-km^2) area north and west of Indio (fig. 1) and is bounded by Interstate Highway 10 on the north, California Highway 111 on the south, Coachella Canal on the east, and Cook Road on the west. Data from wells outside the area were also considered in evaluating the geology and hydrology of the study area.

Acknowledgments

This study was done in cooperation with the Valley Sanitary District. Members of the VSD's Board of Directors supplied helpful background information concerning historic ground-water development.

Personnel of the Coachella Valley County Water District supplied drillers' logs, water-level measurements, and ground-water quality analyses. In addition, they made chemical analyses of ground-water samples collected during this investigation.

Local land owners and the Riverside County Road Department were helpful in granting permission to auger test holes on their property.

Well-Numbering System

Wells are numbered according to their location in the rectangular system for the subdivision of public land. That part of the number preceding the slash (as in 5S/6E-27A2) indicates the township (T. 5 S.); the number following the slash indicates the range (R. 6 E.); the letter (A) following the section number (27) indicates the 40-acre (16-ha) subdivision of the section according to the lettered diagram. The final digit (2) is a serial number for wells in each 40-acre (16-ha) subdivision. The area covered by the report lies entirely south and east of the San Bernardino base line and meridian.
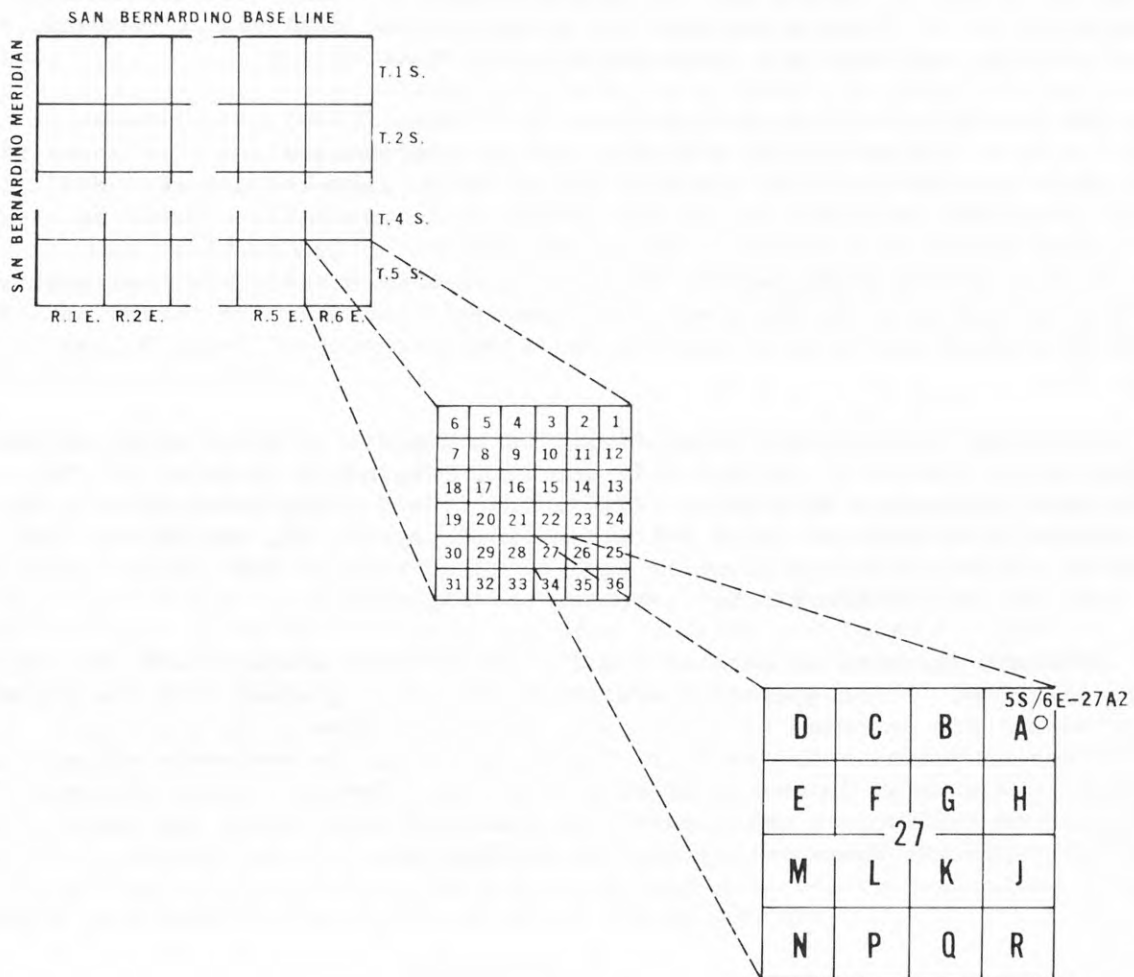
GEOLOGY

The area studied lies within a structural basin and is bordered and underlain at considerable depth by pre-Tertiary igneous and metamorphic rocks. Filling the structural basin is a thick sequence of consolidated, semiconsolidated, and unconsolidated marine and alluvial sediments of Tertiary and Quaternary age. A discussion of geology and the various sediments in the basin is given in California Department of Water Resources (1964) Bulletin 108, "Coachella Valley Investigation."

The stratigraphic units of significance to this investigation are the Ocotillo Conglomerate as redefined by the California Department of Water Resources (1964, p. 28), a unit of late Pliocene or early Pleistocene age, older alluvium of Pleistocene age, and river-channel deposits, dune sand, alluvial fans, and lake and playa deposits of Holocene age.

The Ocotillo Conglomerate, defined by Dibblee (1954), consists of interfingered coarse-grained granitic-pebble conglomerate and thin zones of reddish-brown silt and clay probably deposited as lake-bed material during times of inundation. The top of the formation is generally 300–400 ft (90–120 m) below land surface. The upper 100–200 ft (30–60 m) of the formation consists predominantly of fine-grained lake sediments that partly confine ground water in the lower, more permeable part of the formation. The upper section seems to be missing in the area northwest of Point Happy (fig. 1).

Overlying the Ocotillo Conglomerate is a deposit of older alluvium that is 150–300 ft (45–90 m) thick. This deposit, originally included in the Ocotillo Conglomerate by Dibblee (1954), has been distinguished from it by the California Department of Water Resources (1964, p. 22, 28, and 29) on the basis of resistivity from electric logs of water wells. The latter usage of the name is used herein for the purposes of this report.

Holocene deposits as much as 100 ft (30 m) thick overlie much of the older alluvium. These sediments are generally finer grained than the older alluvium and are composed of clay, silt, fine to medium sand, and minor quantities of gravel. Southeast of Indio, the Holocene sediments effectively confine ground water in the underlying aquifers. However, north and west of Indio, these sediments consist mainly of sand and silty sand, and their ability to prevent downward percolation is limited.

HYDROLOGY

Occurrence and Movement of Ground Water

Ground water occurs in the Ocotillo Conglomerate and the older alluvium (herein called the deep aquifers), and the Holocene sediments (herein called the shallow aquifers). Most wells within the study area are perforated in the Ocotillo Conglomerate and the older alluvium. Because the shallow Holocene sediments are subject to recharge from irrigation-return water of poor quality, most wells are not open to these deposits.

Recharge to the deep aquifers occurs mainly upstream from the study area where streams issuing from the bordering mountains flow onto coarse-grained alluvial fans. Within the study area, percolation of streamflow in the Whitewater River stormwater channel is relatively small, primarily because flows passing through the area are infrequent and short lived. Some recharge occurs as underflow from the Deep Canyon area, but this quantity is also small. The only significant source of recharge within the area is by the downward percolation of excess irrigation water to the shallow aquifers. Water used for irrigation is obtained primarily from wells, although some water imported from the Colorado River is used in the southeastern part of the area. Recharge by rainfall is considered to be insignificant because the total annual rainfall averages about 5 in (130 mm) (California Department of Water Resources, 1964).

Ground-water levels in the entire Coachella Valley began to decline in the early 1900's as a result of pumping for irrigation. In the study area, the decline continued until the late 1940's when the Coachella Canal was completed and began delivering imported Colorado River water to the valley. Shortly after the arrival of the imported Colorado River water, water levels in wells in the eastern part of the study area began to rise (fig. 2). As shown in figure 2, water levels in the deep aquifers continued to rise through the 1950's and early 1960's. Since about 1966, water levels have shown a gradual decline--due partly to increased pumpage.

A water-level contour map (fig. 3) was constructed for the deep and shallow aquifers to illustrate current (1973) ground-water conditions. Data used to construct the contours for the shallow aquifer were obtained from 26 wells or potentiometer tubes perforated only in the upper few feet of the shallow ground-water aquifer. Data for the deep aquifers were obtained from 16 wells perforated below depths of about 100 ft (30 m).
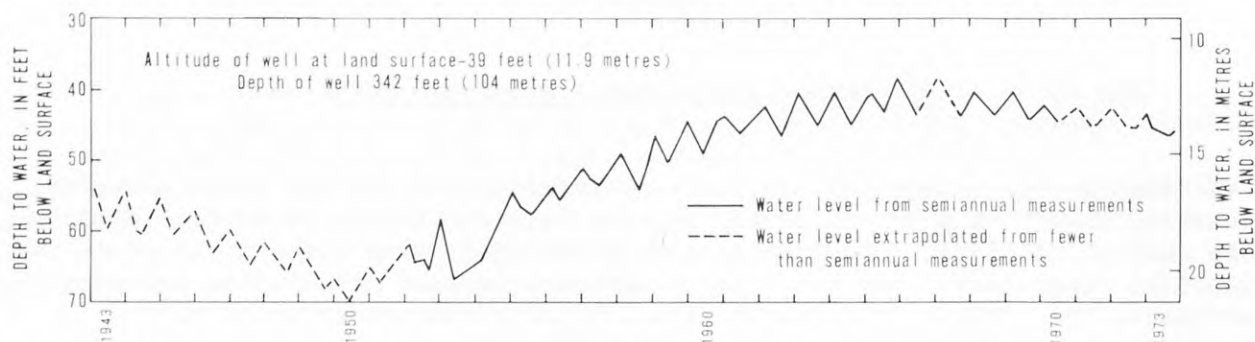
FIGURE 2.--Hydrograph of well 5S/7E-21F2.

West of Washington Street, the water levels in the shallow aquifer are about 20 ft (6 m) higher than in the deep aquifers and contours for the two zones are nearly parallel. East of Washington Street, however, the water-level contours for the two zones are quite divergent, probably because of pumping from the deeper aquifers. A relatively effective hydrologic separation of the shallow and deep aquifers by interbedded fine-grained sediments undoubtedly also contributes substantially to the divergent flow patterns.

The water-level contour map (fig. 3) was used in conjunction with topographic maps to develop a depth-to-water map (fig. 4) for the deep and shallow aquifers.

Quality of Ground Water

Three distinct types of ground-water quality are identifiable within the study area:

1. A calcium sodium bicarbonate type water that contains 150-250 mg/l (milligrams per litre) dissolved solids. This water occurs in the deep aquifers throughout the study area and has its source in the recharge area to the northwest. Examples of this type of ground-water quality are illustrated by chemical analyses of water from wells 5S/6E-16M1 and 5S/7E-17E1 (table 1).

116°15'

— 10 — WATER-LEVEL CONTOUR-- Shows altitude of water level in deep aquifer in 1973; dashed where approx- imately located. Contour interval 10 feet (3m); datum is mean sea level

— 20 — WATER-LEVEL CONTOUR-- Shows altitude of water level in shallow aquifer, 1972-73. Contour interval 10 feet (3m); datum is mean sea level

● DEEP WELL--Water-level measurement, 1973

○ SHALLOW WELL--Water- level measurement, 1972 and 1973

SOUTHERN PACIFIC RR

Country Club Drive

Cook Road

33° 45'

60

50

40

30

20

10

0

Washington Street

Avenue 42

Avenue 44

Whitewater

River

111

Deep Canyon

stormwater channel

Miles Avenue

Stormwater Channel

Jefferson Street

Coachella Canal

10

0

10

20

30

0   1   2 MILES

0   1   2   3 KILOMETRES

FIGURE 3.--Water-level contours for deep and shallow aquifers, 1973.

FIGURE 4.--Depth to water for deep and shallow aquifers, 1973.

2. A calcium sodium mixed anion type water that contains 300–600 mg/l dissolved solids. This water is present in aquifers along the south edge of the study area near the Deep Canyon stormwater channel. The source of this water is apparently runoff from Deep Canyon. An example of this type of ground-water quality is illustrated by chemical analysis of water from well 5S/6E-27A2 (table 1).
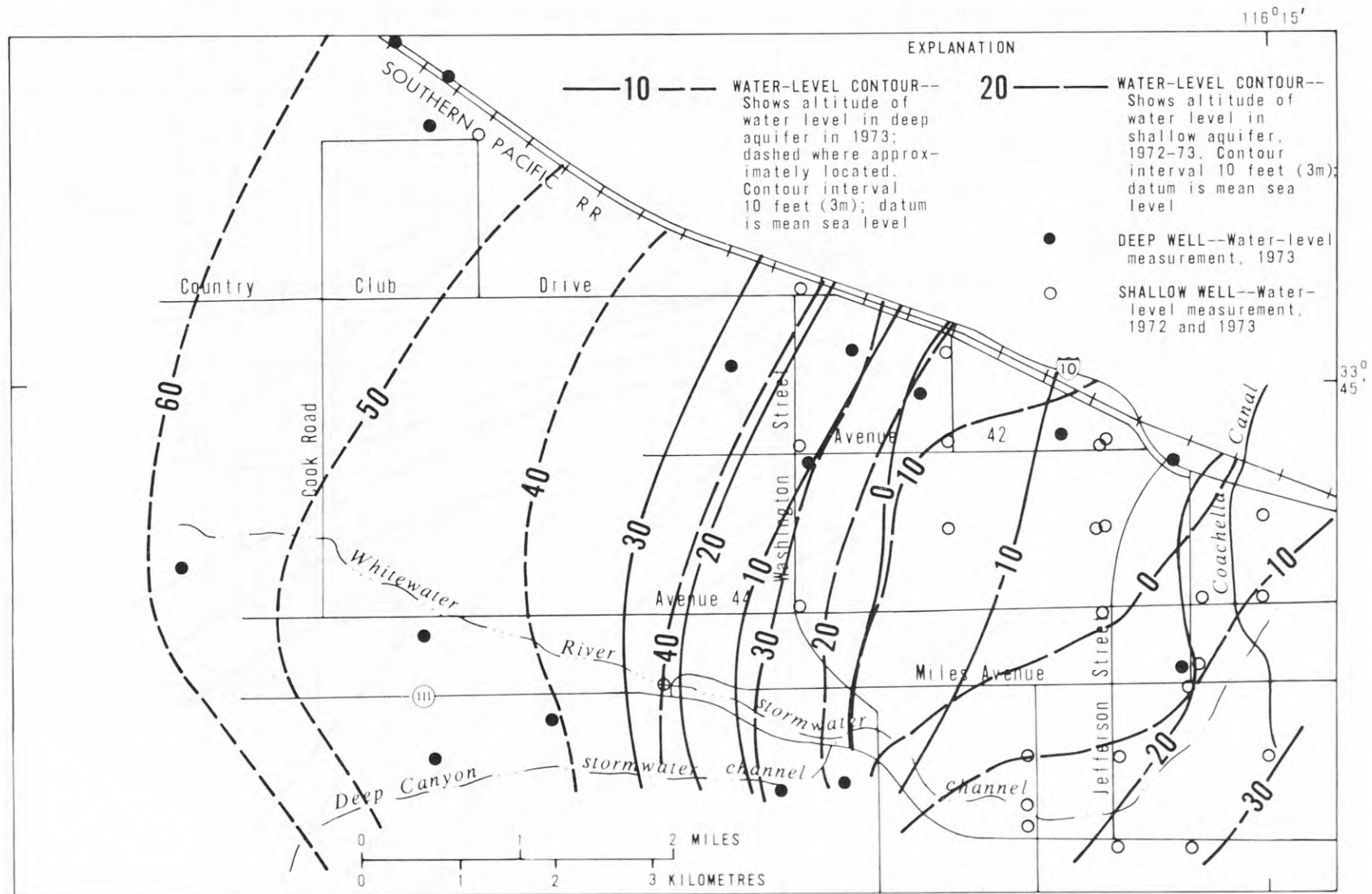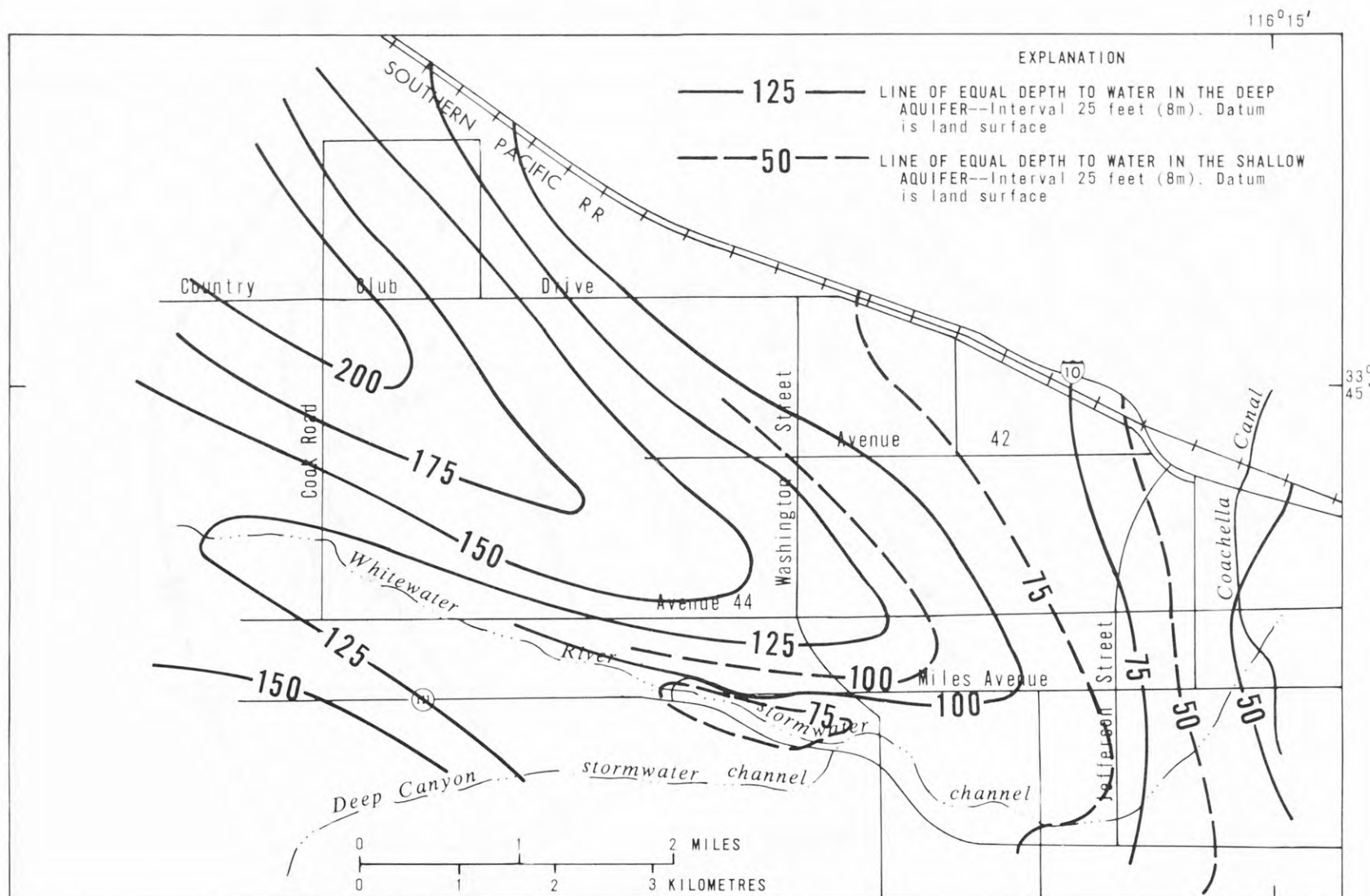
3. A water whose quality varies from a calcium to sodium sulfate type that contains 500–3,000 mg/l dissolved solids. This water is present in the shallow aquifer where overlying land has been irrigated and its varying quality is probably a result of the infiltration of irrigation-return water. Examples of this type of ground-water quality are illustrated by chemical analyses of water samples from the Whitewater River stormwater channel and test holes 2 and 3 (fig. 5 and table 1).

Compared to water from the deep aquifers, the water in the shallow aquifer is of poor quality. This is probably due to the infiltration of irrigation-waste water to the shallow aquifer. The presence of this relatively poor-quality water is important when considering artificial recharge. First, poor-quality water overlying good-quality water suggests that under existing conditions hydrologic connection is poor between the two zones. Second, if artificial recharge is started in areas underlain by poor-quality water, downward percolation through the fine-grained sediments might be induced because of the increased head differential thus created. The downward movement of shallow, poor-quality water into the deep aquifers where it could be extracted by wells is obviously undesirable.

Although much ground-water quality data are available from existing production wells, many of the wells are perforated only in the deep aquifers. Generally, the wells that are perforated at depths of less than 150 ft (45 m) below land surface are also open to the deep aquifers. Thus, few data were available on the water quality of the shallow aquifer. However, by comparing water-quality data from wells perforated in both zones with data from wells perforated in only the deep aquifers, some indication of water quality in the shallow aquifer is obtained.

To define more accurately the extent of poor-quality water in the shallow aquifer, water samples were collected from six test holes augered during the study. These test holes were cased and perforated in the uppermost part of the shallow aquifer, and water samples collected from them are, therefore, representative of water in the shallow aquifer. Table 1 lists the results of chemical analyses of water samples collected from the test holes.

The analyses of water samples from test holes 2, 3, and 9, and to a lesser extent, test holes 4 and 5, suggest the presence of irrigation-return water in the shallow aquifer. The higher concentrations of calcium, sulfate, nitrate, and dissolved solids in the water samples are characteristic of water from irrigated and fertilized lands.

TABLE 1.--*Selected*

Source	Date	Major constituents in				
		Calcium	Magnesium	Sodium	Potassium	Bicarbonate
Filtered effluent Valley Sanitary District	11-20-73	31	4.0	84	12	120
Well 5S/6E-16M1, perforated 350-500 ft	2-14-69	27	5.0	16	4	110
Well 5S/7E-17E1, perforated 459-603 ft	3-24-65	34	4.0	23	4	150
Well 5S/6E-27A2, perforated 322-482 ft	3- 2-70	40	5.0	56	5	92
Colorado River water (Coachella canal)	8-12-58	79	28	110	4.3	140
Whitewater River stormwater channel	7-16-59	180	45	750	15	350
Test hole 1,[4] perforated 62-64 ft	12-27-73	40	5.4	32	4.4	200
Test hole 2,[4] perforated 67-69 ft	12-27-73	120	10	62	7.7	160
Test hole 3,[4] perforated 82-84 ft	12-27-73	150	16	63	7.2	170

water-quality analyses

milligrams per litre				Specific conductance (micromhos per centimetre)	pH	Laboratory	Remarks
Sulfate	Chloride	Nitrate	Dissolved solids				
59	63	13	392	642	7.5	(1)	Potential recharge water.
15	11	4	174	260	8.1	(2)	Deep aquifers.
14	9	2	210	310	7.9	(2)	Deep aquifers.
82	57	9	334	510	7.8	(2)	Deep Canyon area.
130	210	--	727	1,080	8.1	(3)	Irrigation.
1,200	570	--	2,980	4,230	--	(3)	Tile-drain system draining shallow ground water.
25	8	4	222	347	7.8	(3)	Shallow aquifer.
200	58	33	572	959	7.6	(3)	Shallow aquifer.
210	140	13	690	1,120	7.6	(3)	Shallow aquifer.

TABLE 1.--*Selected*

Source	Date	Calcium	Magnesium	Sodium	Potassium	Bicarbonate
						Major constituents in
Test hole 4,[4] perforated 67-69 ft	12-27-73	77	9.5	47	5.2	260
Test hole 5,[4] perforated 78-80 ft	12-27-73	54	8.6	36	5.8	180
Test hole 9,[4] perforated 87-89 ft	12-27-73	320	4.0	250	12	170

[1]U.S. Geological Survey, Central Laboratory, Salt Lake City, Utah.
[2]Edward S. Babcock and Sons, Riverside, Calif.

The dissolved-solids concentrations of water from three groups of wells were plotted in figure 6. The groups are: (1) 6 test holes perforated only in the shallow aquifer, (2) 25 wells perforated in both deep and shallow aquifers (highest perforations less than 150 ft or 45 m below land surface); and (3) 24 wells perforated only in the deep aquifer (highest perforations more than 300 ft or 90 m below land surface). From these data the areas where water in the shallow aquifer is known or suspected to contain greater than 500 mg/l dissolved solids were delineated.

DESCRIPTION OF NEAR-SURFACE SEDIMENTS

Distribution

A heterogeneous mixture of dune sand, playa and lake deposits, and river-channel deposits occurs in the upper 100 ft (30 m) of sediments underlying this area. Attempts to correlate specific lithologic units using drillers' logs of water wells were unsuccessful, generally because individual sedimentary units could not be traced from well to well.

water-quality analyses--Continued

Sulfate	Chloride	Nitrate	Dissolved solids	Specific conductance (micromhos per centimetre)	pH	Laboratory	Remarks
milligrams per litre							
96	13	15	394	648	7.6	(3)	Shallow aquifer.
66	31	3	298	500	8.1	(3)	Shallow aquifer.
600	330	120	1,730	2,520	7.6	(3)	Shallow aquifer.

[3]Coachella Valley County Water District, Coachella, Calif.
[4]Test holes located in figure 5.

The upper 100 ft (30 m) of the driller's log for each well in the study area was divided into four 25-ft (8-m) intervals. For each lithologic unit, the driller's description of the sediment penetrated was used to estimate the percentage of fine-grained sediments present. For example, clay was assigned a value of 100 percent, silt was assigned a value of 50 percent, and sand was assigned a value of 0 percent. A considerable amount of subjective judgment in assigning percentages was required because of the extreme variability of descriptive terms used by different drillers to describe the materials penetrated. Sand and clay, for example, were assigned a value of 50 percent, but clay with streaks of sand was assigned a value of 80 percent, and sand with streaks of clay was assigned a value of 20 percent.

After each lithologic unit had been reduced to a number representing the probable percentage of fine-grained sediments, the total percentage for each 25-ft (8-m) interval was calculated.

To aid in defining the distribution of sediments, 11 test holes were drilled within the study area (fig. 5) to depths ranging from 64 to 109 ft (19.5 to 33.2 m). Driller's logs were kept of the sediments penetrated (table 2), and 19 samples of the material penetrated were collected for analysis.
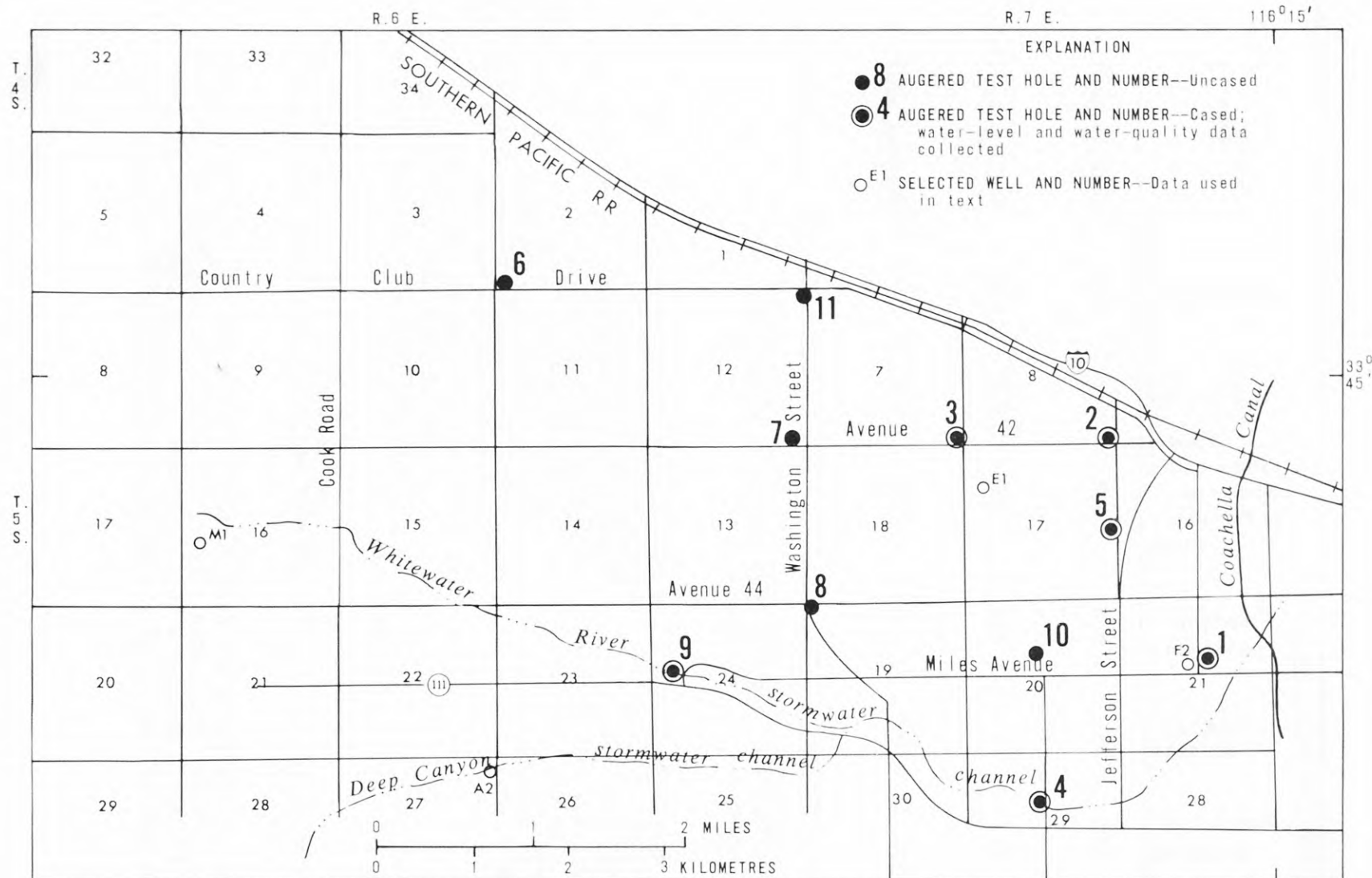
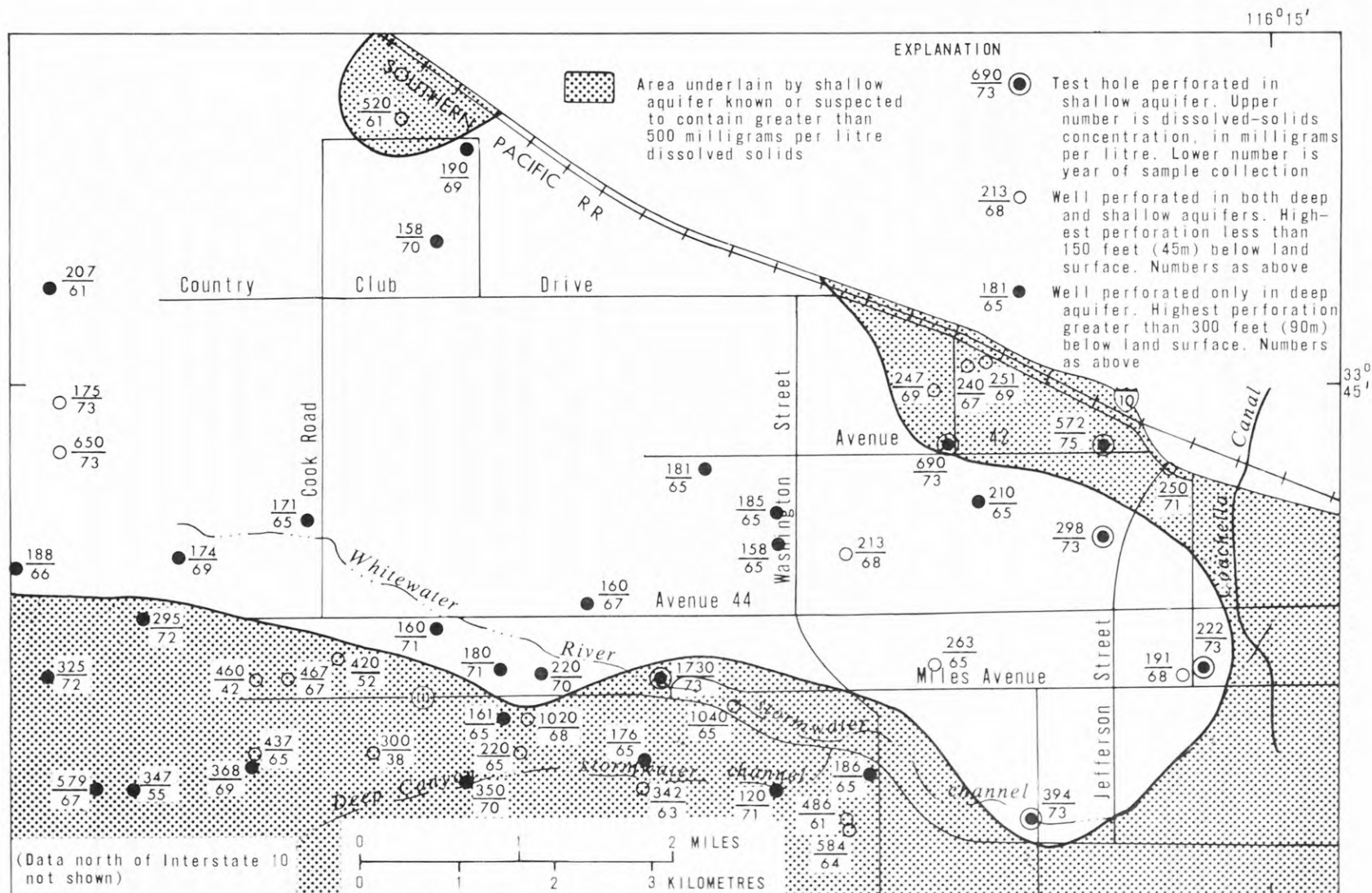FIGURE 5.--Location of test holes and wells used in this study.

FIGURE 6.--Area where shallow ground water contains greater than
500 milligrams per litre dissolved solids.

Lithologic data from the 11 test holes and the calculated percentages of
fine-grained sediments from nearly 150 drillers' logs were used to construct
four maps (figs. 7-10) showing the distribution of sediments in the four depth
intervals: 0-25 ft (0-8 m), 25-50 ft (8-15 m), 50-75 ft (15-23 m), and
75-100 ft (23-30 m).

Figures 7, 8, 9, and 10 show the areal distribution of three principal
groups of sediments: (1) Sand containing less than 20 percent silt and clay,
(2) silt and sand containing 20-50 percent silt and clay, and (3) silt and
clay containing less than 50 percent sand.

TABLE 2.--*Driller's logs of test holes*

	Thickness (feet)	Depth (feet)

Test hole 1. Drilled by U.S. Geological Survey in 1973. Cased with
2-inch polyvinyl chloride pipe. Perforated 62-64 feet.

	Thickness (feet)	Depth (feet)
Sand, fine to medium, brown, silty-----------------------------	9	9
Sand, fine to medium, brown, silty, damp----------------------	15	24
Sand, fine to medium, brown, damp, some silt----------------	5	29
Sand, silty---	5	34
Sand, medium to coarse, silty, moist------------------------	5	39
Sand, silty and clayey, moist-------------------------------	5	44
Clay, silty, moist--	5	49
Sand, silty, and clay, water--------------------------------	5	54
Sand, silty, saturated--------------------------------------	10	64

Test hole 2. Drilled by U.S. Geological Survey in 1973. Cased with
2-inch polyvinyl chloride pipe. Perforated 67-69 feet.

	Thickness (feet)	Depth (feet)
Sand, silty, moist--	9	9
Clay---	2	11
Sand, fine to medium, moist--------------------------------	18	29
Sand, fine, moist, with clay streaks-----------------------	7	36
Silt, clayey--	3	39
Sand, fine, silty---	3	42
Gravel--	1	43
Sand, clayey, moist---------------------------------------	3	46
Clay, silty---	3	49
Sand, very fine, silty, moist-----------------------------	1	50
Sand, medium, water---------------------------------------	4	54
Sand, fine, silty, saturated------------------------------	15	69

TABLE 2.--*Driller's logs of test holes*--Continued

	Thickness (feet)	Depth (feet)

Test hole 3. Drilled by U.S. Geological Survey in 1973. Cased with 2-inch polyvinyl chloride pipe. Perforated 82-84 feet.

	Thickness (feet)	Depth (feet)
Sand, medium to coarse, silty, moist-------------------------	9	9
Sand, fine to medium, silty, moist---------------------------	5	14
Clay, silty--	1	15
Sand, fine to medium, silty, moist---------------------------	9	24
Sand, medium, moist--	5	29
Sand, fine to medium, silty, moist---------------------------	5	34
Sand, silty, with clay streaks-------------------------------	5	39
Sand, fine to medium---	5	44
Sand, fine, silty, with clay streaks-------------------------	5	49
Sand, fine, silty--	20	69
Clay, silty, with sand, water--------------------------------	5	74
Sand, coarse, silty, saturated-------------------------------	10	84

Test hole 4. Drilled by U.S. Geological Survey in 1973. Cased with 2-inch polyvinyl chloride pipe. Perforated 67-69 feet.

	Thickness (feet)	Depth (feet)
Sand, fine to medium, dry------------------------------------	4	4
Sand, fine to medium, silty, moist---------------------------	8	12
Sand, very fine, silty, moist--------------------------------	2	14
Silt, sandy, and clay streaks, moist-------------------------	5	19
Sand, fine, silty, moist-------------------------------------	5	24
Clay, silty, and sand, moist---------------------------------	6	30
Sand, fine to medium, red, and silt streaks-----------------	4	34
Silt, sandy, light-brown, and clay streaks, moist-----------	5	39
Sand, fine, moist--	5	44
Sand, very fine, silty---------------------------------------	5	49
Sand, fine---	5	54
Clay, silty--	10	64
Clay, silty, water---	5	69

TABLE 2.--*Driller's logs of test holes*--Continued

	Thickness (feet)	Depth (feet)

Test hole 5.   Drilled by U.S. Geological Survey in 1973.   Cased with 2-inch polyvinyl chloride pipe.   Perforated 78-80 feet.

	Thickness (feet)	Depth (feet)
Sand, fine, dry	4	4
Sand, fine, moist	10	14
Sand, fine to coarse, some silt, moist	5	19
Sand, medium, moist	11	30
Clay, silty	4	34
Sand, fine, some silt, moist	10	44
Sand, fine to medium, some silt, moist	5	49
Sand, medium to coarse, moist	10	59
Silt	2	61
Sand, medium to coarse, moist	2	63
Sand, silty, moist	1	64
Clay, silty, water	5	69
Clay, silty, saturated	5	74
Sand, silty, saturated	10	84
Silt, clayey, organic matter, sticky	10	94

Test hole 6.   Drilled by U.S. Geological Survey in 1973.   Backfilled test hole.

	Thickness (feet)	Depth (feet)
Sand, medium to coarse, some silt, dry	14	14
Sand, medium, some silt, dry	21	35
Sand, medium, moist	4	39
Sand, coarse, moist, occasional pebble	5	44
Sand, medium to coarse, some silt, moist	20	64
Sand, medium to coarse, moist	45	109

Test hole 7.   Drilled by U.S. Geological Survey in 1973.   Backfilled test hole.

	Thickness (feet)	Depth (feet)
Sand, fine, silty, moist	9	9
Sand, fine to medium, silty, moist	5	14
Sand, fine to medium, some silt, dry	65	79
Sand, silty, moist	20	99

TABLE 2.--*Driller's logs of test holes*--Continued

	Thickness (feet)	Depth (feet)
Test hole 8. Drilled by U.S. Geological Survey in 1973. Backfilled test hole.		
Sand, fine to medium, some silt, moist-----------------------	14	14
Sand, medium to coarse, some silt, moist--------------------	10	24
Sand, fine to medium, some silt, dry-------------------------	75	99
Test hole 9. Drilled by U.S. Geological Survey in 1973, cased with 2-inch polyvinyl chloride pipe. Perforated 87-89 feet.		
Silt, moist---	6	6
Silt, sandy, light-brown, moist-----------------------------	8	14
Clay, silty, dark-brown, moist------------------------------	5	19
Silt, clayey, brown, moist----------------------------------	5	24
Silt, sandy, light-brown, moist-----------------------------	2	26
Clay, silty, moist--	3	29
Clay, silty, light-brown, moist-----------------------------	3	32
Clay, light-brown, saturated--------------------------------	2	34
Silt, sandy, clayey, moist----------------------------------	5	39
Sand and gravel, to 1-inch, moist---------------------------	15	54
Sand, coarse, silty, moist----------------------------------	3	57
Sand, medium to coarse, moist-------------------------------	22	79
Sand, coarse, water---	1	80
Silt--	9	89
Test hole 10. Drilled by U.S. Geological Survey in 1973. Backfilled test hole.		
Sand, fine, silty, dry--------------------------------------	9	9
Sand, fine to medium, silty, slightly moist----------------	20	29
Sand, some silt--	5	34
Sand, fine to medium, silty, slightly moist---------------	15	49
Sand, medium to coarse, slightly moist---------------------	20	69
Sand, fine, silty, moist-----------------------------------	10	79
Sand, silty, moist---	5	84
Sand, fine to medium, saturated----------------------------	15	99

TABLE 2.--*Driller's logs of test holes*--Continued

	Thickness (feet)	Depth (feet)
Test hole 11. Drilled by U.S. Geological Survey in 1973. Backfilled test hole.		
Sand, silty, dry---	4	4
Sand, fine to medium, slightly moist-------------------------	5	9
Sand, medium--	5	14
Sand, silty, dry---	15	29
Sand, silty, slightly moist--	22	51
Silt and sand, fine, moist---	28	79

Permeability

Although attempts to collect undisturbed drive-core samples for laboratory analysis were unsuccessful, some quantitative estimates of probable infiltration rates and permeability are possible from analysis of the samples collected. Permeability of a material is related to the size and the uniformity of sorting of the particles composing the material.

Moreland (1972) related two factors to measured infiltration rates for 25 sediment samples collected at infiltrometer test sites throughout the upper Santa Ana Valley. D_{20} (particle size in micrometres, corresponding to 20 percent finer on the particle-size distribution curve) was found to be directly related to the infiltration rate; S_O or sorting coefficient (square root of the ratio of the 75-percent finer particle size and the 25-percent finer particle size) was found to be inversely related to the infiltration rate. A log-log plot of infiltration rate versus the ratio of D_{20} to S_O (Moreland, 1972, fig. 9) was used to illustrate the relation.

In this investigation, particle-size distributions were determined for 19 samples collected from the augered test holes (table 3). Most of the samples were composed of sand or silty sand of the type found at the surface of nearby sand-dune deposits. The ratios of D_{20} to S_O for all the samples ranged from 49 to 143 and averaged 92. The investigation by Moreland (1972, fig. 9) indicated that infiltration rates of 15 to 50 ft/d (5 to 15 m/d) could be expected through soils whose ratio of D_{20} to S_O ranged from 50 to 150.

Moreland (1972) obtained infiltration rates from ring infiltrometers under a driving force of 1 ft (0.3 m) of water, which are approximately equivalent to laboratory permeabilities measured at unit hydraulic gradient. Therefore, from particle-size analyses, the 19 samples listed in table 3 probably have permeabilities ranging from 15 to 50 ft/d (110 to 370 gallons per day per foot squared or 5 to 15 m/d).

TABLE 3.--*Particle-size distributions of sediment samples*

Sample		Percent finer by weight						D_{20} (micro- metres)	S_o $\sqrt{D_{75}/D_{25}}$	D_{20}/S_o
Test hole	Depth (feet)	Screen size, millimetres								
		0.061	0.124	0.246	0.495	0.991	1.981			
1	10	9	20	72	93	99	100	140	1.27	110
2	20	1	10	63	97	100	100	160	1.31	122
3	10	1	7	65	95	100	100	145	1.41	103
3	40	1	7	51	94	98	100	160	1.40	114
3	75	7	15	44	72	87	97	150	1.79	84
4	5	2	5	46	91	99	100	165	1.43	115
5	15	3	11	32	65	99	100	180	1.63	110
5	45	5	14	60	92	98	100	150	1.43	105
6	10	6	23	43	66	95	100	110	2.18	50
6	30	4	19	45	71	96	100	130	2.00	65
6	50	4	19	44	70	97	100	130	2.00	65
7	15	2	13	65	97	100	100	145	1.39	104
7	45	6	21	58	92	99	100	120	1.56	77
8	15	4	17	49	94	100	100	135	1.52	89
8	50	4	17	61	93	99	100	130	1.54	84
8	80	9	20	65	92	99	100	120	1.44	83
10	90	1	6	52	92	98	99	180	1.26	143
11	20	6	19	52	88	99	100	130	1.59	82
11	75	18	43	93	98	100	100	70	1.44	49
Average										92

ARTIFICIAL RECHARGE

Long-Term Infiltration Rates

After several days or weeks of submergence, intake rates in spreading facilities are considerably lower than the initial infiltration rates. The primary cause of the reduced rates is clogging of the surficial soil by silt and clay particles and microscopic organisms. The degree of reduction of infiltration rates is dependent on the quality of water recharged, the biological activity in the recharge facility, the wave-action on the sides and bottom of the facility, and the soil underlying the facility.
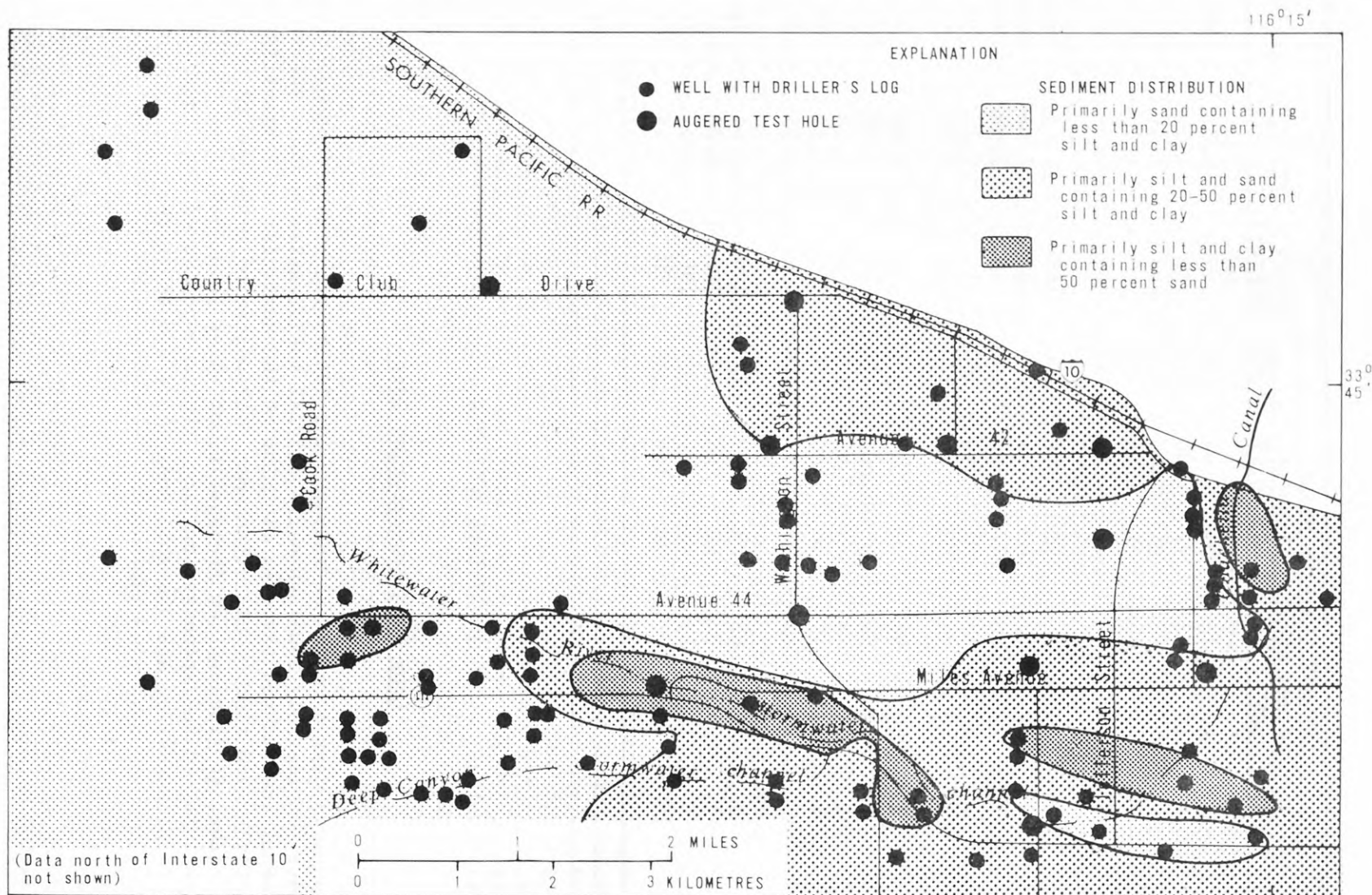
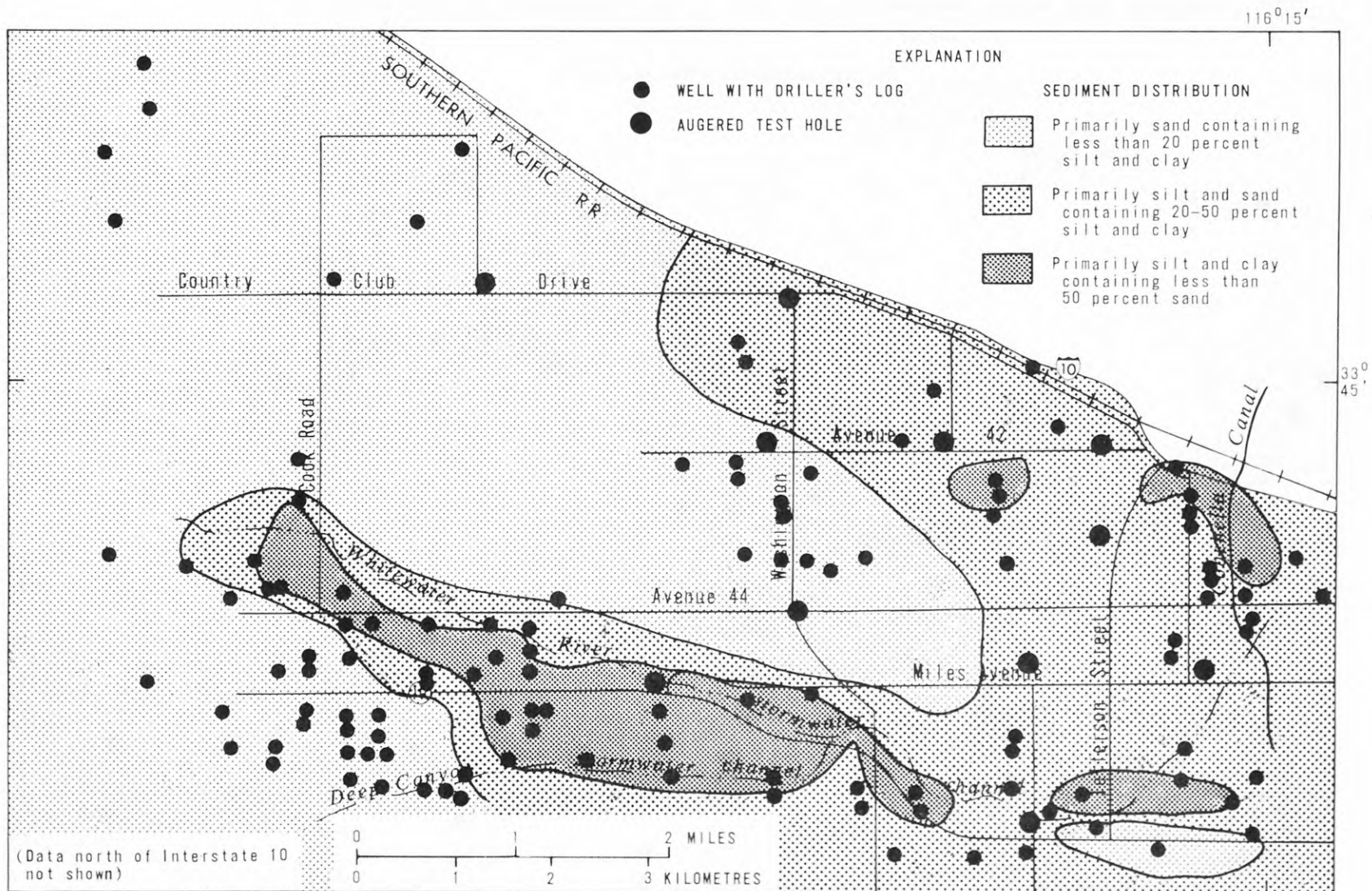FIGURE 7.--Distribution of sediments, 0-25 feet (0-8 metres) below land surface.

EXPLANATION

● WELL WITH DRILLER'S LOG

● AUGERED TEST HOLE

SEDIMENT DISTRIBUTION

Primarily sand containing
less than 20 percent
silt and clay

Primarily silt and sand
containing 20-50 percent
silt and clay

Primarily silt and clay
containing less than
50 percent sand

116°15'

33°
45'

(Data north of Interstate 10
not shown)

0   1   2 MILES

0   1   2   3 KILOMETRES

FIGURE 8.--Distribution of sediments, 25-50 feet (8-15 metres) below land surface.

FIGURE 9.--Distribution of sediments, 50-75 feet (15-23 metres) below land surface.
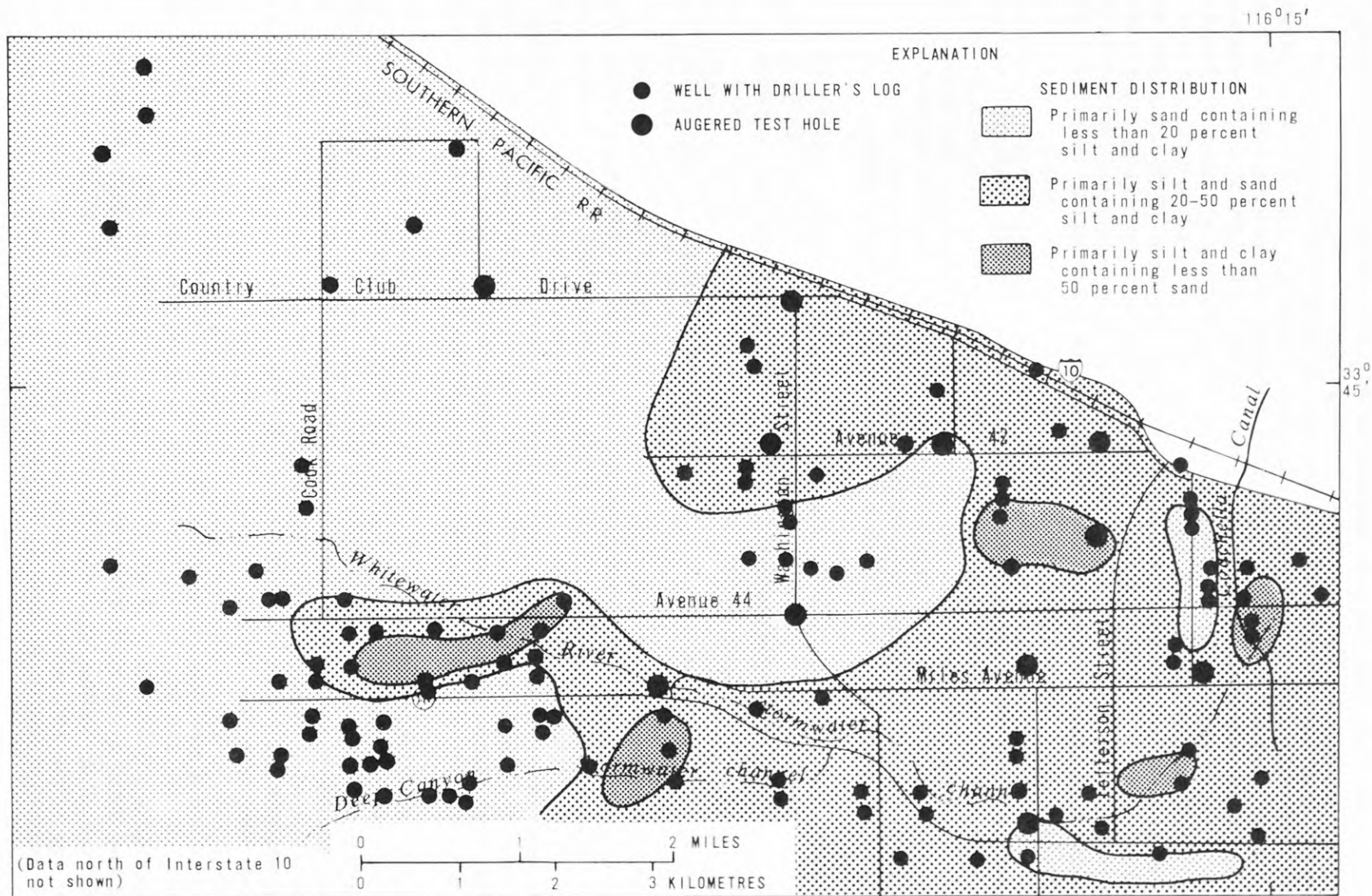
FIGURE 10.--Distribution of sediments, 75-100 feet (23-30 metres) below land surface.

Because of the many variables involved, it is difficult to predict accurately long-term infiltration rates unless pilot recharge tests are conducted. Even then, results are meaningful only if the test is conducted under conditions very similar to actual recharge conditions. However, a prediction of long-term infiltration rates can be made by comparing the hydrologic, geologic, and general environmental conditions in the study area with investigations and spreading facilities in other areas with similar conditions. Moreland (1970) and Tyley (1973) found that infiltration rates decreased 50 to 75 percent after several days of submergence. They obtained long-term infiltration rates of 5 to 15 ft/d (2 to 5 m/d) in controlled test pits in Yucaipa and in the upper Coachella Valley. Brodie (1968) obtained an infiltration rate of 2 ft/d (0.6 m/d) after 147 days of submergence in a pit in San Bernardino County. Spreading facilities in Los Angeles County commonly have long-term infiltration rates of 1 to 5 ft/d (0.3 to 2 m/d) (McMichael and McKee, 1966).

From this, long-term infiltration rates of 1 to 15 ft/d (0.3 to 5 m/d) could be expected in recharge facilities in the study area. If the size of the facility is an important consideration because of limits on the amount of land available, pilot recharge tests would be beneficial in more accurately determining long-term infiltration rates. For planning purposes, a conservative estimate of 2 ft/d (0.6 m/d) appears to be reasonable.

Operation and Maintenance of Recharge Facilities

Reduction of infiltration rates during extended periods of recharge can be significantly controlled by proper operation and maintenance of recharge facilities. Because the most important factor in decreasing infiltration rates is clogging of the surficial soil matrix, steps to prevent, lessen, or correct clogging are imperative in any recharge operation.

The factors which contribute to clogging include: (1) Suspended solids carried into the facility by the recharge water, (2) biological growth in the ponded recharge water, (3) fine-grained sediments agitated and redistributed by wave action, and (4) fine-grained material blown into the facility by wind.

Treatment of recharge water to remove or greatly reduce suspended solids and to minimize biological growth will lessen the likelihood of clogging. Removal of solids can be accomplished by inducing settlement in holding ponds prior to admittance of waste water to the recharge facility. Several chemical additives such as alum are available that precipitate particularly slow-settling material. Controls of biological growth are discussed in a later section of this report.

Fine-grained sediments which are agitated by wave action from the sides and bottom of the basins, or are carried in by wind, can be partly controlled by constructing windbreaks. Also, wind-driven waves can be minimized by reducing the surface area of recharge ponds either by recharging in deep basins (pits) or by using several small ponds separated by berms.

Despite these preventive measures, clogging will eventually occur in any recharge basin. Corrective maintenance must therefore be practiced periodically to restore infiltration rates to acceptable levels.

The simplest method of maintenance is by rotation of use of recharge basins to allow for periods of drying. These drying periods permit clay and silt deposits to shrink and crack, thereby partly restoring surface permeability. Also, they allow time for biological growth, accumulated during submergence, to dry and be removed.

When clogging has developed to the point where drying is ineffective in restoring infiltration rates, disking or tilling the surface of the basin may be required. In extreme cases where the accumulation of dead organisms and silt and clay is thick, or where these materials have penetrated the soil matrix to a depth of several inches, scraping and removal of the upper few inches of material at the base of the infiltration basin may be necessary to restore reasonable infiltration rates.

Growth and Control of Algae

Artificial recharge by surface spreading is a particularly attractive method of beneficially using sewage effluent because of the natural filtration of microorganisms that occurs as the infiltrating water percolates through the soil. However, the process of filtration, though beneficial in removing bacteria, serves to decrease infiltration rates as the filtered bacteria clog the soil (Bianchi and Muckel, 1970).

Reduction of infiltration rates is only one of the many problems created in surface spreading facilities by microorganisms. Biochemical activity can effectively change the chemical quality of the recharge water, produce noxious odors, and cause hazards to public health. The type and severity of problems that develop depend upon the quality of the recharge water, the temperature of the air and water, the nature of the soil, the availability of nutrients, and the presence of bacteria. Obviously, biological growth should be controlled to minimize the associated problems.

One of the most widely used methods of biological growth control is chlorination or similar chemical treatment. This method can have disadvantages however. For example, if a large population of algae has developed in a recharge basin, chlorination may cause a drastic reduction in infiltration rates because of virtual sealing of the soil surface by dead organisms (Richard Aldrich, city of Oceanside Water and Sewer Department, oral commun., 1974). Subsequent decay of the organic material can produce significant water-quality and esthetic problems such as odors and unsightly conditions.

Chlorination of effluent prior to introduction into the spreading facilities to reduce the population of microorganisms would retard initial growth rates in the recharge basins. Although this method is less effective than later chlorination as a long-term control, it has the advantage of not causing precipitation of large quantities of dead or dying organisms in the facilities.

A comprehensive research program conducted at Whittier Narrows in Los Angeles County (McMichael and McKee, 1966) indicated that algal growth can be effectively controlled by rotating the use of spreading basins to allow complete drying at least once a week and preferably three times a week. The frequent drying not only reduces the amount of time available for biological growth but it also allows air to reenter the soil periodically thereby reducing the likelihood of developing anaerobic conditions and the associated odor problems. Although frequent rotation of basins would be required for this method of control, the benefits of maintaining high infiltration rates and aerobic conditions offset the added expense of operation.

Area Required for Recharge

The area required to recharge 8,000 acre-ft (9.9 hm³) of sewage effluent per year depends largely on the time schedule of delivery, method of operation, and infiltration rates. For the purpose of this investigation it is assumed that the reclaimed sewage will be delivered at a constant rate of 22 acre-ft/d (0.027 hm³/d) or 11 ft³/s (0.31 m³/s) and that a system of three separate basins would be used on a rotation basis--one basin being operated, one basin being dryed, and one basin being reconditioned. It is also assumed that an average long-term infiltration rate of 2 ft/d (0.6 m/d) can be maintained at each of the basins.

Minimum area required for the predicted volume of sewage effluent would then be:

$$A = \frac{Q}{IR}$$

where A = total area required, in acres
     Q = rate of delivery, in acre-feet per day
     IR = long-term infiltration rate, in feet per day.

Thus

$$A = \frac{Q}{IR}$$

$$= \frac{22 \text{ acre-feet per day}}{2 \text{ feet per day}}$$

$$= 11 \text{ acres (4.4 ha)}.$$

If three separate basins are used in rotation, the complete recharge facility would require 33 acres (13 ha) not including access roads, berms, and other peripheral areas.

Effects of Recharge

The hydrologic effects of recharging 8,000 acre-ft (9.9 hm^3) of water per year within the study area are nearly impossible to define because of the heterogeneous nature of the underlying sediments. However, some indication of the water-level rise resulting from the application of recharge is required when considering the feasibility of the use of a particular site.

A method of estimating the rise of water levels due to recharge developed by Baumann (1952) can be applied if several assumptions are made. However, in applying this method, it should be realized that because the assumptions made are so broad, the results obtained can be used only as a general approximation. The assumptions to be made are:

1. The aquifer is homogeneous and isotropic;
2. The underlying ground-water body is unconfined;
3. The base of the aquifer and the water table are horizontal;
4. Flow occurs radially from the recharge area; and
5. Recharge occurs at a constant rate and is applied evenly over a circular area.

To lessen the error introduced by assuming that the aquifer system is isotropic and unconfined, it is further assumed that, because of the effectiveness of fine-grained sediments in retarding vertical movement, only the upper 100 ft (30 m) of the aquifer is initially affected by the recharge.

Baumann's theory (1952, p. 1047) is expressed by his equation 109, which is:

$$h = -m + \sqrt{m^2 - \frac{Q}{\pi K}\left[\ln\frac{R}{L} + \frac{1 \text{ (one)}}{L-R}\left(Le^{(L-R)/L} - 2L + R\right)\right]}$$

where h = height of the mound, in feet, beneath the outside edge of recharge
       area
      m = thickness of the aquifer, in feet
      Q = rate of recharge, in cubic feet per day
      K = permeability, in feet per day
      R = radius of recharge area, in feet
      L = extent of the recharge mound, in feet.

If the recharge area is assumed to be in the area underlain by sand, a horizontal permeability of 50 ft/d (15.2 m/d) is reasonable. Assuming a long-term infiltration rate of 2 ft/d (0.6 m/d) in each of three basins whose use is rotated periodically, a recharge facility with a radius of about 700 ft (213 m) would be required to infiltrate 8,000 acre-ft/yr (9.9 hm^3/yr). Further assuming that the recharge mound would extend for a radial distance of 5,000 ft (1,524 m), the following values would apply:

      m = 100 ft (30.5 m)
      Q = 8,000 acre-ft/yr (9.9 hm^3/yr) = 955,000 ft^3/d (2.7 x 10^4 m^3/d)
      K = 50 ft/d (15.2 m/d)
      R = 700 ft (213 m)
      L = 5,000 ft (1,524 m).

Substituting these values into the equation:

$$h = -100 + \sqrt{(100)^2 - \frac{955,000}{157}\left[\ln\frac{700}{5,000} + \frac{1}{4,300}\left(5,000 \times e^{0.86} - 10,000 + 700\right)\right]}$$

h = 36 ft (11 m) of water-level rise beneath the recharge perimeter.

Thus, with the very general assumptions made, a recharge mound 36 ft (11 m) high would develop owing to recharging 8,000 acre-ft/yr (9.9 hm^3/yr) in a 33-acre (13-ha) recharge facility about 700 ft (213 m) in radius. Although this calculation is a gross approximation at best, it gives some indication of the magnitude of water-level rise that could occur at the recharge site.

SELECTION OF SITES HYDROLOGICALLY FAVORABLE FOR RECHARGE

Criteria for Evaluating Recharge Sites

In selecting sites hydrologically favorable for artificial recharge through surface spreading, several questions must be considered. They include:

1. Are surface infiltration rates sufficiently high?
2. Are subsurface strata relatively free of fine-grained horizons that might retard downward percolation of recharged water?
3. Is depth to water great enough to preclude saturation directly beneath the recharge site?
4. Is underlying ground water of good quality or will recharge encourage the movement of poor-quality water into areas of extraction?
5. Will recharge at the site benefit users by increasing ground water in storage in areas of use?
6. Will recharge at the site have detrimental effects, such as increasing ground-water discharge or adversely affecting water levels in other parts of the basin?
7. Is the operation of the recharge site economically feasible?

These questions, with the exception of number 7, can be answered using the information presented earlier in this report. The answer to question number 7 can best be answered by the Valley Sanitary District.

1. Surface infiltration rates--Figure 7 delineates the areas which primarily are underlain by sand from 0 to 25 ft (0 to 8 m) below land surface. Initial infiltration rates ranging from 15 to 50 ft/d (5 to 15 m/d) can be expected at any site selected within those areas underlain by sandy material containing less than 20 percent silt and clay. Long-term rates (1 to 6 weeks) of 2 to 10 ft/d (0.6 to 3 m/d) should be possible with proper precautions to minimize siltation and with reasonable rotation of basins to allow for drying and maintenance.

Areas underlain by materials containing 20-50 percent silt and clay would have limited use as recharge sites. In these areas surface infiltration rates of less than 1 ft/d (0.3 m/d) are probable. Those areas with less than 50 percent sand are unsuitable for recharge because of the high percentage of fine-grained material and consequent low infiltration rates.

2. Subsurface strata--Figures 8, 9, and 10 illustrate the character of sediments in the three 25-ft (8-m) intervals from 25 to 100 ft (8 to 30 m) below land surface. The probability of lingering perched water bodies developing in areas underlain by materials containing less than 20 percent silt and clay is low. Those areas underlain by materials containing 20-50 percent silt and clay could potentially retard downward percolation of water. In areas underlain by materials containing less than 50 percent sand, the sediments are of sufficient thickness, extent, and low permeability to seriously retard downward percolation of water.

3. Depth to water--Depth to water below a recharge site can be critical if the recharge results in complete saturation of the underlying sediments. Estimations made in a previous section of this report indicate that a recharge mound could develop to a height of 36 ft (11 m) above the water table.

Because of the heterogeneous nature of the sediments underlying the study area, a substantial margin for error in estimating the rise of the water table due to recharge is important to insure against unforeseen problems. A minimum depth to water of 75 ft (23 m) would probably provide an adequate margin of safety. Depth to water is considerably greater than 75 ft (23 m) everywhere west of Washington Street except along the Whitewater River channel from Point Happy to about 1 mi (1.6 km) west.

4. Quality of water--The dissolved-solids concentration of the sewage effluent to be applied to the recharge facility is less than 500 mg/l (table 1). Areas underlain by shallow ground water containing dissolved-solids concentrations greater than 500 mg/l are outlined in figure 6. Recharge within these areas could encourage movement of water which is high in dissolved solids into deep aquifers by increasing hydraulic gradients. The likelihood of degradation of water in the deeper aquifers can be lessened by selecting recharge sites in areas where dissolved-solids concentrations are less than 500 mg/l in the shallow aquifers. Areas where the shallow ground water is known or suspected to exceed 500 mg/l dissolved solids include most of the study area south of the Whitewater River channel, an area north of Avenue 42 and east of Washington Street, and most of the area east of Jefferson Street (fig. 6).

To guard against degradation of water in the deep aquifers, water samples could be collected for chemical analysis from nearby wells on a periodic basis. Information from the monitored wells would indicate if water of poor quality were migrating into the deep aquifers owing to increased hydraulic gradients from the recharge operation.

5. Benefits--Recharge at any site within the study area will increase the quantity of ground water in storage even in those areas dominated by fine-grained sediments. However, fine-grained sediments in the eastern and southern parts of the area would retard or even prevent percolation to the deeper aquifers. Although an increase in the quantity of ground water in storage would occur in the areas underlain by fine-grained sediments, this ground water could not be extracted using existing wells because they are generally perforated only in the deeper aquifers.

6. Detrimental effects--The discharge of ground water at the surface does not presently occur within the study area. However, tile drain lines drain shallow ground-water bodies in much of the area to the east. Therefore, artificial recharge to the shallow aquifer in the easternmost part of the area studied could result in a consequent rise of the water table and increased discharges through the tile drains. If the water were not removed by the drains, waterlogging might result.

Adverse conditions associated with raising water levels in other parts of the ground-water basin could also result from artificial recharge. These conditions could arise because of the relation between the unconfined aquifers underlying areas west of Washington Street and the effectively confined deeper aquifers southeast of the study area. Water levels in the confined aquifers represent pressure head rather than water-level conditions in the deep aquifers. Because pressure is transmitted readily in a confined system, a water-level rise at the margin of the confined system can cause rises in water levels throughout the rest of the confined system. Therefore, the effects of recharge at a site may be noted in wells several miles distant even though the recharged water has not physically moved to the wells. If sufficient quantities of water are recharged at sites near the margins of the confined aquifers, water-level rises might be sufficient to cause artesian wells to flow.

Several steps can be taken to protect against water-level rises within the areas of confined aquifers. Most importantly, the recharge site selected could be located as far upgradient from the fine-grained confining deposits as possible. By monitoring the water levels in wells near the recharge site and in selected wells within the confined system, effects of increased pressure heads could be detected before problems of flowing wells develop. Should the wells being monitored indicate that a problem is beginning to develop, remedial steps such as curtailment or relocation of recharge, and an adjustment of pumping patterns could be implemented.

Sites Hydrologically Favorable for Artificial Recharge

The sites hydrologically favorable for artificial recharge, taking into account each of the previously mentioned hydrologic factors, are delineated in figure 11. Any location selected within the area delineated as favorable should be hydrologically suitable as a potential recharge site. Economic considerations may be the deciding factor in final selection of specific sites for artificial recharge.
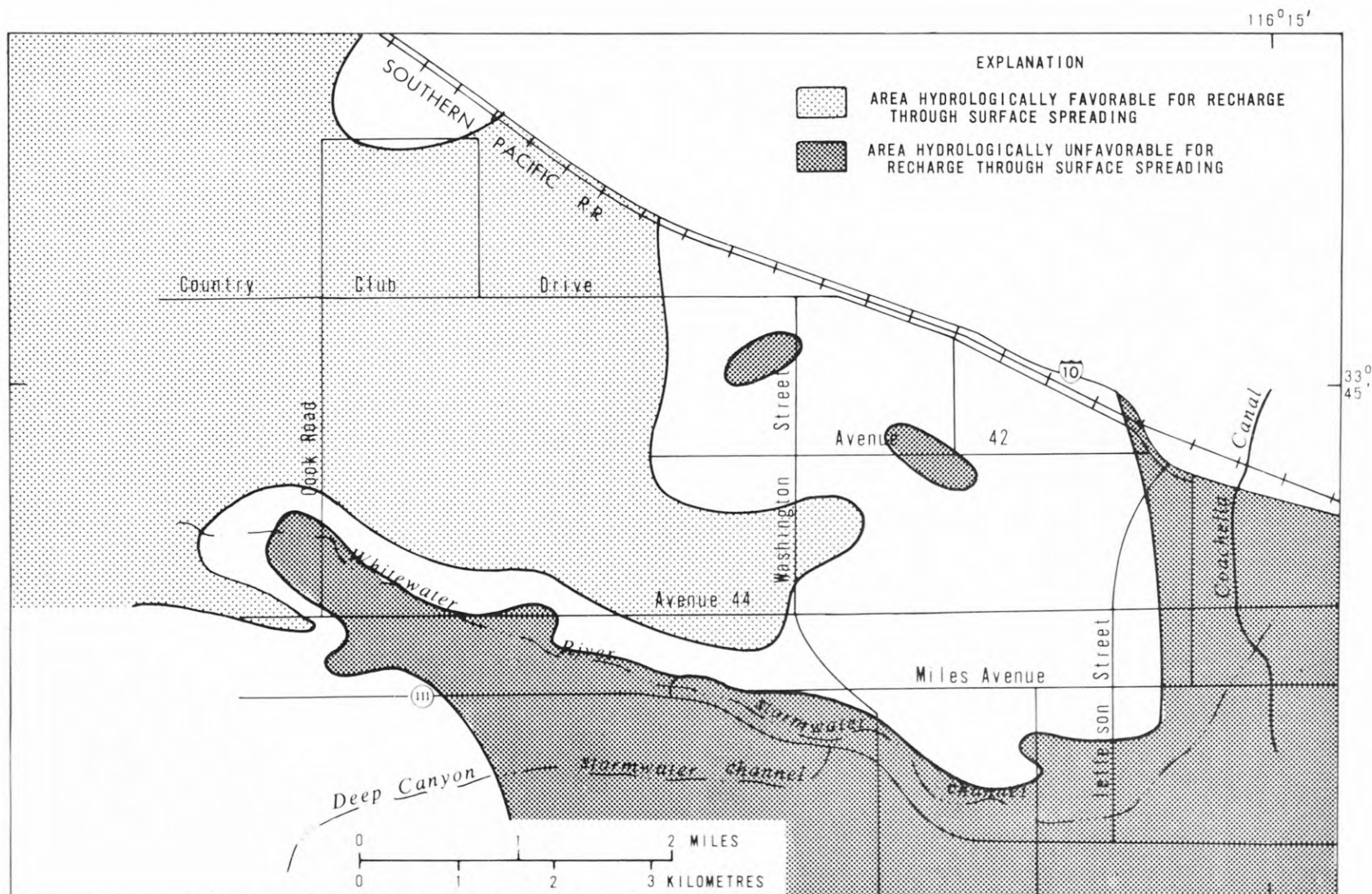
FIGURE 11.--Hydrologically favorable and unfavorable areas for recharge.

Also outlined in figure 11 are those areas which, for one or more reasons, would be hydrologically undesirable as recharge sites. The presence of significant percentages of fine-grained sediments (more than 50 percent) was the primary factor used to delineate unacceptable areas. Any area underlain by less than 50 ft (15 m) of unsaturated sediments was also considered to be unacceptable. Although quality of water contained in the shallow aquifers was considered in delineating favorable areas, no areas were deemed unacceptable solely because of high dissolved-solids concentration in the water in shallow aquifers.

In general, the areas determined to be the most hydrologically favorable sites for artificial recharge through surface spreading lie west of Washington Street and north of Whitewater River stormwater channel. However, an area of about 1 mi^2 (2.6 km^2) south of Country Club Drive and west of Washington Street, because of high percentages of fine-grained material reported in drillers' logs, is considered to be unacceptable as a potential recharge site.

REFERENCES CITED

Baumann, Paul, 1952, Ground-water movement controlled through spreading: Am. Soc. Civil Engineers trans. v. 117, paper no. 2525, p. 1024–1060.

Bianchi, W. C., and Muckel, D. C., 1970, Ground-water recharge hydrology: U.S. Dept. Agriculture, ARS 41-161, 62 p.

Brodie, O. H., 1968, Comprehensive plan of water resources conservation, Chino Basin, California: Eng. rept. to the Board of Directors, Chino Basin Water Conserv. Dist., 49 p.

California Department of Water Resources, 1964, Coachella Valley investigation: California Dept. Water Resources Bull. 108, 145 p.

Dibblee, T. W., Jr., 1954, Geology of the Imperial Valley region, California, Pt.2 *in* Chap. 2 of R. H. Jahns, ed., Geology of southern California: California Dept. Mines Bull. 170, p. 21–28.

McMichael, F. C., and McKee, J. E., 1966, Wastewater reclamation at Whittier Narrows: California State Water Quality Control Board, pub. 33, 100 p.

Moreland, J. A., 1970, Artificial recharge, Yucaipa, California: U.S. Geol. Survey open-file rept., 44 p.

_____1972, Artificial recharge in the upper Santa Ana Valley, southern California: U.S. Geol. Survey open-file rept., 51 p.

Tyley, S. J., 1973, Artificial recharge in the Whitewater River area, Palm Springs, California: U.S. Geol. Survey open-file rept., 51 p.

Moreland—EVALUATION OF RECHARGE POTENTIAL NEAR INDIO, CALIFORNIA