EVALUATION OF THE POTENTIAL FOR ARTIFICIAL GROUND-WATER RECHARGE IN EASTERN SAN JOAQUIN COUNTY, CALIFORNIA--PHASE 2

By Richard L. Ireland

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CONVERSION FACTORS

The inch-pound system of units is used in this report. For readers who prefer metric (SI) units, the conversion factors for the terms used are listed below:

Multiply	By	To obtain
acres	4047	m^2 (square meters)
acre-ft (acre-feet)	1233	m^3 (cubic meters)
acre-ft/yr (acre-feet per year)	1233	m^3/a (cubic meters per annum)
ft (feet)	0.3048	m (meters)
ft^3/s (cubic feet per second)	0.02832	m^3/s (cubic meters per second)
inches	25.4	mm (millimeters)
mi (miles)	1.609	km (kilometers)
mi^2 (square miles)	2.590	km^2 (square kilometers)

ALTITUDE DATUM

National Geodetic Vertical Datum (NGVD) of 1929: A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level. NGVD of 1929 is referred to as sea level in this report.

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ABSTRACT

In response to increasing demand on water supplies and declining water levels, the U.S. Geological Survey, in cooperation with the San Joaquin County Flood Control and Water Conservation District, is evaluating the potential for artificially recharging the aquifer system in eastern San Joaquin County, California. The study is being done in three phases. This report on phase 2 summarizes data collected during test drilling and evaluates the suitability of the drilled areas for their potential for artificial recharge.

Data from 11 test holes, including electric, lithologic, and nuclear logs, indicated that all of the deposits underlying potential recharge areas are stream-deposited beds of gravel, sand, silt, and clay. None of the beds are continuous for more than a few tens of feet.

By ruling out those sites where fine-grained beds lie near land surface and where topographic conditions would interfere with recharge operations, two areas were identified as having potential for artificial recharge: (1) The flood-plain area along the Mokelumne River north of Lockeford, and (2) an area northeast of Linden along the Calaveras River.

INTRODUCTION

Problem

A lowering of the water table, which began between 1954 and 1964 in eastern San Joaquin County, and the eastward movement of poor quality ground water into the Stockton area (California Department of Water Resources, 1967), combined with projected increases in water needs are causes of concern to officials of San Joaquin County. Artificial recharge to the aquifer system in the eastern part of the county using the spreading basin method is being evaluated in an effort to resolve these ground-water problems. Surplus surface water available during the winter and spring months is a potential source of water to recharge the aquifer system.

Location and General Features

The study area (fig. 1) comprises about 250 mi^2 in the east-central part of California's Central Valley, east of the confluence of the San Joaquin and Sacramento Rivers, and west of the Sierra Nevada. The area is characterized by low hills in the east (western edge of the Sierra Nevada foothills), a gently rolling terrain in the central areas, and a nearly level valley floor in the west (Mitten, 1982).

The study area consists of two parts: the northern part (about 50 mi^2) along the Mokelumne River and the southern part (about 200 mi^2) along the Calaveras River, Mormon Slough, and Littlejohns Creek (Mitten, 1982, fig. 2).

Purpose and Scope

The overall purpose of the study is to evaluate the potential for artificially recharging the unconfined aquifer system in the eastern part of San Joaquin County by the spreading basin method. The study was divided into three phases. Continuation of each successive phase depends on an evaluation of the results from the previous phase. This is the second phase of the study with the purpose of drilling test holes at sites selected in phase 1 to define the characteristics of the sediments above the water table.

Phase 1 defined the areas most suitable for recharge. Phase 3 will consist of constructing and evaluating test-recharge ponds in the areas selected during phase 2.

This report summarizes the data collected in phase 2 and evaluates the suitability of the drilled areas for their potential for artificial recharge.

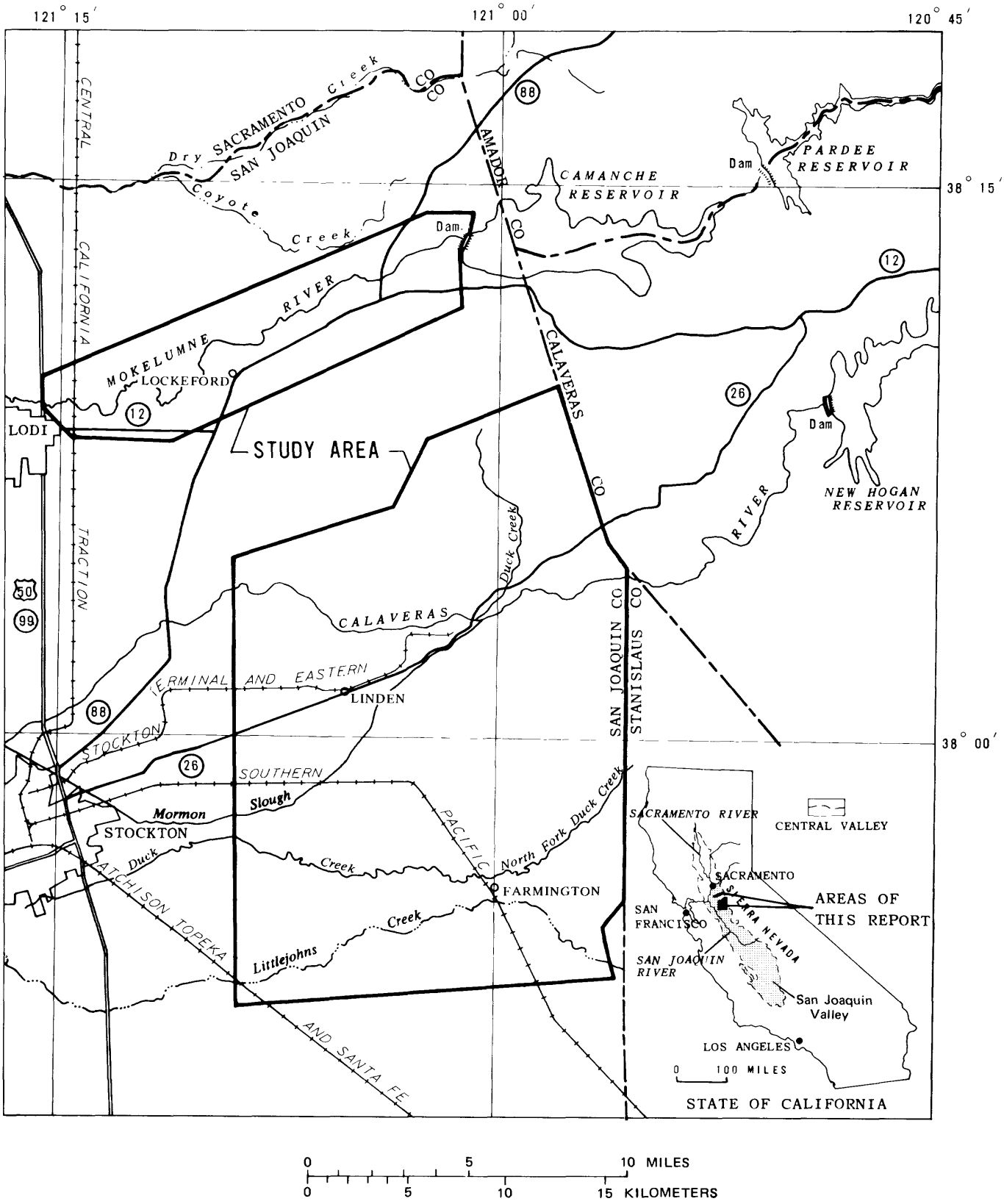

FIGURE 1. – Study area.

Approach

Twenty sites were selected in phase 1 for drilling. In phase 2, 11 test holes were drilled in three potential recharge areas to or below the water table. Two other holes were drilled, but drilling equipment was unable to reach the desired depth. Samples of the borehole cuttings were collected and geophysical logs were run at each borehole. These were evaluated to determine the feasibility of recharging the unconfined aquifer system. Lithologic logs were prepared from the sample descriptions.

Drilling was completed by Geological Survey personnel using rotary drilling equipment. Bentonitic drilling mud was used in all holes. Geophysical logs were run by Geological Survey Borehole Geophysical Unit equipment and personnel.

Each test hole was evaluated using the descriptions (test-hole logs) of sediments found in the ditch samples taken at the time of drilling. Each test hole was rated as a poor, fair, or good recharge site using the suite of geophysical logs to determine the amount of permeable coarse-grained sediments and the amount of impermeable fine-grained sediments.

The test holes were destroyed in accordance with the San Joaquin County Health Department code. All holes were filled with bentonitic drilling mud to within 8 to 10 ft of the land surface, then 3 to 4 ft of cement, and local surface material to land surface.

Well-Numbering System

The well-numbering system used in California by the Geological Survey indicates the location of wells according to the rectangular system for the subdivision of public lands. For example, in the number 2N/8E-11H1, the part of the number preceding the slash indicates the township (T. 2 N.), the part after the slash the range (R. 8 E.), the digits after the hyphen the section (sec. 11), and the letter after the section number the 40-acre subdivision of the section as indicated in the lettered diagram below. Within each 40-acre tract, the wells are numbered serially as indicated by the final digit of the well number. Thus, well 2N/8E-11H1 was the first well to be listed in the SE¼NE¼ of sec. 11. For wells not located in the field by the Geological Survey, the final digit has been omitted. The entire study area is north and east of the Mount Diablo base line and meridian.

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

Acknowledgments

The data collection for this study was made possible by the cooperation of many local land owners and public agencies. Mr. Tom Iwamiya and others of the San Joaquin County Flood Control and Water Conservation District, and Mr. Lee Hall and others of the San Joaquin Local Health District were helpful and cooperative.

SELECTION OF DRILLING SITES

On the basis of a well canvass and analyses of existing data on geology, soils, drillers' logs, and land use, Mitten (1982) selected 20 sites for exploratory test drilling in areas potentially favorable for artificial recharge of the aquifer system. The areas selected for possible artificial recharge were divided into areas of relatively high and low potential (Mitten, 1982, fig. 10). Areas were selected where the hydraulic conductivity was highest and where no hardpan or claypan were found to hinder percolation (Mitten, 1982, fig. 5). In some areas, selection was based on geologic units exposed in the area, but in most areas was based on the classification of soils. Infiltration rates are controlled mostly near the surface by factors such as topography, soil permeability, the presence of shallow hardpan or claypan, and at depth by hydrologic characteristics of the aquifer. Areas of high potential were mostly adjacent to the Mokelumne River, Calaveras River, and Mormon Slough. An additional favorable area was in the southeast part of the study area north of Littlejohns Creek (fig. 1). The most probable parts within areas were considered to be those where the computed average specific yields were largest (Mitten, 1982, fig. 10). The final criterion for drill-site selection was land use, which was obtained from a 1976 California Department of Water Resources land-use survey.

The selected sites are in the river channel deposits of Holocene age, alluvium of Holocene and Pleistocene age, or Mehrten Formation of Miocene to late Pliocene age, all of which are stream-deposited, lenticular beds of gravel, sand, silt, and clay. None of the lenticular beds are continuous for more than a few tens of feet. These formations are characterized by their heterogeneity, but they transmit water fairly well both in the horizontal and vertical directions.

TEST DRILLING

Of the 20 sites selected for drilling, 13 were drilled---8 along or adjacent to the Mokelumne River, 3 adjacent to the Calaveras River or Mormon Slough, and 2 in the easternmost part of the area north of Littlejohns Creek (fig. 2). Two holes, one south of the Mokelumne River north of the town of Lockeford and one south of the Calaveras River northeast of Linden, were not completed because of difficult drilling. Coarse gravels were found near the land surface in both boreholes. Both sites were in flood-plain areas where the topography suggests the streams meandered through the area in the recent past. Local land owners, familiar with the areas, confirmed this. Two proposed sites in the Littlejohns Creek area were not drilled owing to the prominence of fine-grained deposits in the test holes completed in the area. Five proposed sites in the Linden area were not drilled because owners would not permit drilling on their land.

The test holes were drilled by conventional rotary methods to 5-10 ft below the water table. Drill cuttings were sampled and examined for changes in lithology. Table 1 gives a general description of the test holes. Geophysical logs, including caliper, natural-gamma, gamma-gamma, neutron, spontaneous-potential, single-point resistance, and two resistivity (16-inch short normal and 64-inch long normal), were run in each completed borehole. A lithologic log was prepared using the samples collected and the suite of nuclear and electric logs. The geophysical and lithologic logs are shown on plates 1 and 2. Table 2 gives a brief summary of applications that can be made using geophysical logs.

TABLE 1. - Description of test holes

Test hole No.	Date drilled	Location	Depth (ft)	Owner
Mokelumne River				
4N/7E-25E1	5-04-82	SW¼NW¼ sec. 25	102	U.S. Soil Conservation Service
4N/8E-30E1	5-05-82	SW¼NW¼ sec. 30	[1]37	Manuel Machado
4N/8E-30M1	5-06-82	NW¼SW¼ sec. 30	138	Manuel Machado
4N/7E-24Q1	5-07-82	SW¼SE¼ sec. 24	98	Joseph W. Hull
4N/8E-18R1	5-10-82	SE¼SE¼ sec. 18	157	Ruben and F. M. Baeza
4N/8E-19H1	5-11-82	SE¼NE¼ sec. 19	108	Louis DeLuca
3N/7E-05N1	5-12-82	SW¼SW¼ sec. 5	98	D. K. Lane
4N/7E-32M1	5-13-82	NW¼SW¼ sec. 32	97	John Graffigna
Calaveras River				
2N/8E-28H1	6-02-82	SE¼NE¼ sec. 28	163	M. B. Amer
2N/8E-01Q1	6-04-82	SW¼SE¼ sec. 1	[1]31	Raymond Ramsey
2N/8E-11H1	6-09-82	SE¼NE¼ sec. 11	149	John W. Eilers
Littlejohns Creek				
2N/9E-36Q1	6-07-82	SW¼SE¼ sec. 36	189	Cook Land and Cattle Co.
1N/9E-12R1	6-08-82	SW¼SW¼ sec. 12	159	Cook Land and Cattle Co.

[1]No geophysical logs.

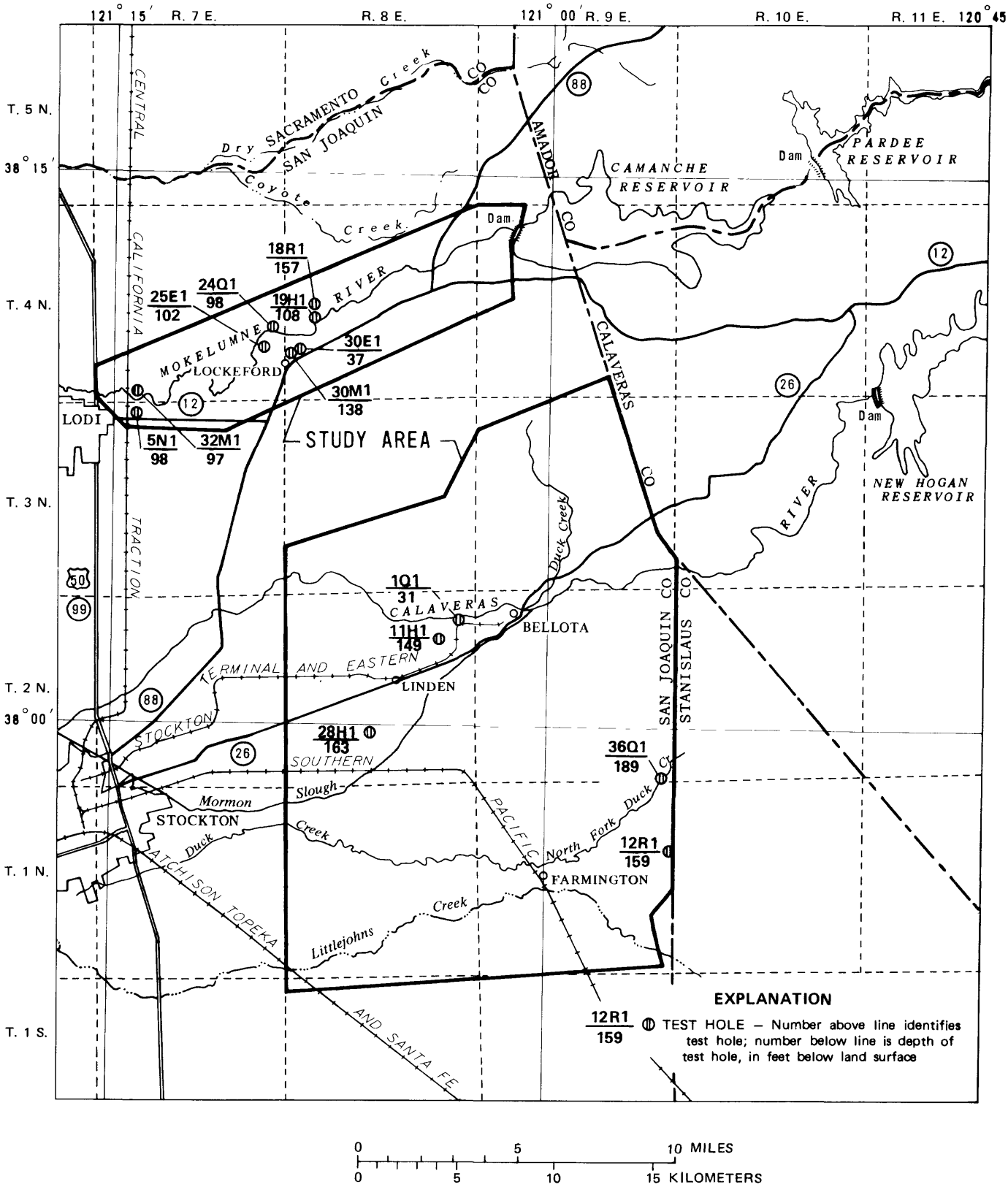

FIGURE 2. – Location of test holes.

TABLE 2. - Simplified description of geophysical logs made for this study

(From Keys and MacCary, 1981)

Type of log	Parameters measured and direction of log deflection	Parameters inferred and direction of log deflection
Caliper	Hole diameter (increases to right)	Cementation and effect of drilling
Natural-gamma	Natural-gamma radiation (increases to right)	Clay content (increases to right)
Gamma-gamma	Scattered and attenuated gamma photons (radiation decreases to right)	Bulk density (decreases to right) and hole diameter (increases to right)
Neutron	Neutrons slowed and scattered by hydrogen (radiation increases to right)	Saturated porosity (decreases to right)
Spontaneous-potential	Natural electrical potentials (positive to right)	Clay or shale content
Single-point resistance	Electrical resistance of hole and adjacent rocks (increases to right)	Hole diameter and water salinity (decreases to right), effective porosity (increases to right)
Resistivity (Short and long normal)	Electrical resistivity of hole and adjacent rocks (increases to right)	Formation resistivity (increases to right), fluid resistivity, and field formation factor

Lithologic Logs and Correlation With Geophysical Logs

The lithologic logs illustrated on plates 1 and 2 indicate many alternating beds of fine- and coarse-grained sediments. The natural-gamma log, which was the primary log used in correlating the samples, also shows many alternating thin beds of fine- and coarse-grained sediments, which were generally silty. Samples taken during drilling were difficult to describe because many of the fine-grained sediments were lost in the drill mud and the coarse-grained sediments were broken up owing to the method of drilling. The spontaneous-potential and single-point resistance logs also show alternating beds of fine- and coarse-grained sediments but were not as definitive as the natural-gamma log.

Mokelumne River Near Lockeford

Five test holes were drilled to depths below the water table adjacent to the Mokelumne River north of Lockeford and one test hole, 4N/8E-30E1, was not completed because of difficult drilling.

The holes (fig. 2) were drilled from 0.1 to 0.6 mi north or south of the river. Samples collected and the geophysical logs (pl. 1) indicate that the material drilled was chiefly alluvial stream-channel deposits consisting of alternating beds of sand, gravel, and clay to a depth below the water table.

4N/7E-25E1. U.S. Department of Agriculture, Soil Conservation Service, test hole on alluvial plain about 1 mi northwest of Lockeford and 0.3 mi southeast of the Mokelumne River. Altitude 60 ft.

Material	Thickness (ft)	Depth (ft)
Topsoil; clay, light tan; sand, coarse to very coarse; gravel, small, subangular, fair sorting	18	18
Sand, coarse to very coarse; gravel, small, subangular, fair sorting	7	25
Sand, medium to coarse; clay, tan, sandy, fair sorting	3	28
Clay, tan	2	30
Sand, medium to coarse; gravel, light and dark, subrounded, subangular, fair sorting; clay, sandy	8	38
Sand, coarse to very coarse; gravel, subrounded, and subangular, good sorting; clay, silty	6	44
Clay, tan to brown, silty	9	53
Sand, very coarse; gravel, subrounded, fair sorting	2	55
Clay, brown, sandy, silty	2	57
Sand, very coarse; gravel, subrounded, fair sorting	2	59
Clay, brown, silty	3	62
Sand, medium to coarse; clay, brown, sandy	8	70
Sand, coarse to very coarse; gravel, small to coarse, fair sorting	4	74
Clay, brown, silty	8	82
Sand, coarse to very coarse; gravel, coarse, subrounded, fair sorting	6	88
Clay, brown, sandy	3	91
Sand, medium to coarse; clay, brown, silty	3	94
Sand, medium to coarse; gravel, coarse	2	96
Clay, brown	2	98
Sand, medium to coarse; gravel, coarse	2	100
Clay, brown	1	101
Sand, medium to coarse; gravel, coarse	1	102

(Test hole drilled to 102 ft)
(Test hole destroyed 5-4-82)

Fine-grained sediments lensed with some coarse-grained sediments from the land surface to the first major coarse-grained bed at about 18 ft and the amount of coarse-grained sediments above the water table suggest fair vertical hydraulic conductivity at this site. The thin intermittent clays and the two thick clay beds at 44 to 53 ft and 74 to 82 ft may impede the vertical permeability and slow the infiltration rates. This site is rated as a fair to good recharge site.

The water table is shown on the neutron log (pl. 1) at about 80 ft below land surface.

4N/8E-30E1. Manuel Machado, test hole on alluvial plain about 0.5 mi northeast of Lockeford and about 0.25 mi south of the Mokelumne River. (Did not reach water table in this test hole). Altitude 68 ft.

Material	Thickness (ft)	Depth (ft)
Clay, dark brown, silty with a few pieces of gravel; sand, some very coarse, fair sorting----------	17	17
Gravel, mostly subrounded; sand, very coarse with some lenses of silty clay, fair sorting----------	5	22
Gravel, probably subrounded, some are angular due to drilling; sand, very coarse, fair sorting----------	15	37

NOTE: Test hole stopped at 37 ft because of difficult drilling, moved 10 ft to the north and hit same coarse-grained material.

(Test hole destroyed 5-5-82)

The logs show fine-grained sediments with some gravel and very coarse sand from the land surface to about 17 ft, which may impede the near surface vertical hydraulic conductivity. This site is rated as a fair to good recharge site because of (1) the coarse to very coarse sediments from about 17 ft to at least 37 ft, some of which drilled like large cobbles, (2) the land-surface topography suggesting an old ancestral stream-channel location, and (3) the logs of test hole 4N/8E-30M1, located about 0.25 mi southwest, which suggests fair to good vertical hydraulic conductivity below 26 ft.

The water table at this site would be about 100 ft, the same as at test hole 4N/8E-30M1.

The drill site was abandoned because of the difficult drilling.

4N/8E-30M1. Manuel Machado, test hole on alluvial plain about 0.5 mi north of Lockeford and about 0.5 mi south of the Mokelumne River. Altitude 65 ft.

Material	Thickness (ft)	Depth (ft)
Clay, dark brown; sand, silty, alternating lenses	26	26
Gravel and sand, coarse, subrounded, fair sorting; lenses of silty brown clay	10	36
Clay, dark brown, silty	6	42
Sand, coarse, fair sorting; clay, green, silty	5	47
Clay, dark brown, silty	3	50
Sand, coarse, fair sorting; clay, brown	2	52
Clay, brown; sand, coarse, subangular	4	56
Sand, silty; clay, brown	6	62
Sand, coarse, subangular; gravel, fine, subrounded; lenses of brown clay	12	74
Sand, coarse; clay, brown, silty	16	90
Sand, coarse, fair sorting; gravel, pea size; lenses of brown clay	10	100
Clay, brown; sand, silty	6	106
Sand, coarse; gravel, pea size; lenses of brown clay	6	112
Sand, coarse; clay, brown, silty, some gravel	23	135
Clay, brown, silty; sand, coarse	3	138

(Test hole drilled to 138 ft)
(Test hole destroyed 5-6-82)

Fine-grained sediments from the land surface to about 26 ft suggest low vertical hydraulic conductivity from the land surface to the first major coarse-grained bed at about 26 ft. The logs show three thick coarse-grained beds, totaling about 32 ft, and three thin fine-grained beds, totaling about 13 ft, from 26 ft to the water table suggesting fair vertical hydraulic conductivity below 26 ft. This site is rated as a poor recharge site owing to the presence of the fine-grained sediments from the land surface to 26 ft.

The water table is shown on the neutron log (pl. 1) at about 100 ft below land surface.

4N/7E-24Q1. Joseph W. Hull, test hole on alluvial plain about 1.4 mi northwest of Lockeford and about 0.1 mi north of the Mokelumne River. Altitude 65 ft.

Material	Thickness (ft)	Depth (ft)
Topsoil; clay, dark brown, silty	10	10
Sand, medium, subangular, fair sorting; clay, dark green	7	17
Clay, dark green	2	19
Sand, medium subangular, fair sorting; clay, dark green, silty	4	23
Clay, dark brown and greenish, silty	6	29
Sand, medium to coarse, subrounded; some gravel, fair sorting	2	31
Clay, light tan, silty; sand, medium to coarse	5	36
Sand, medium to coarse, subrounded; some gravel, fair sorting	3	39
Clay, light tan, silty; sand, medium to coarse	2	41
Sand, medium to coarse, subrounded; some gravel, fair sorting	2	43
Clay, light tan, silty; sand, medium to coarse	2	45
Sand, very coarse, subrounded; gravel, small, subrounded, fair sorting; clay, light tan to gray, silty	2	47
Clay, light tan, silty; sand, medium to coarse	2	49
Sand, very coarse, subrounded; gravel, small, subrounded, fair sorting; clay, light tan to gray, silty	2	51
Clay, light tan, silty; sand, medium to coarse	4	55
Sand, fine to very coarse; clay, brown, sandy, silty	3	58
Clay, brown, silty, sandy	3	61
Sand, fine to very coarse; clay, brown, sandy, silty	4	65
Clay, brown and tan, silty	6	71
Sand, fine to very coarse subrounded and angular; gravel, subrounded, poor sorting	4	75
Clay, brown and tan, silty	3	78
Sand, medium to very coarse, subrounded and angular; some gravel, poor sorting; clay, brown, silty	7	85
Clay, brown and tan, silty	2	87
Sand, medium to very coarse, subrounded and angular; some gravel, poor sorting; clay, brown, silty	2	89
Clay, brown and tan, silty	2	91
Sand, medium to very coarse, subrounded and angular; some gravel, poor sorting; clay, brown, silty	3	94
Clay, brown and tan, silty	4	98

(Test hole drilled to 98 ft)
(Test hole destroyed 5-7-82)

This site is rated as a poor recharge site because of its topographic location below high river stage and the absence of major permeable coarse-grained beds. The logs show fine-grained sediments from the land surface to about 10 ft, then 7 ft of coarse-grained sediments and alternating thin beds of fine- and coarse-grained sediments to the water table suggesting probable low vertical hydraulic conductivity.

The water table was not identified at this drill site. Mitten (1982) showed the water table at about 100 ft below and surface in autumn 1979. This site is subject to flooding when the river is at high stage.

4N/8E-18R1. Ruben and F. M. Baeza, test hole on alluvial plain about 2 mi northeast of Lockeford and about 0.6 mi north of the Mokelumne River. Altitude 112 ft.

Material	Thickness (ft)	Depth (ft)
Topsoil; clay, brown and greenish; sand, coarse to very coarse, fair sorting	16	16
Sand, coarse to very coarse; clay, brown and greenish, fair sorting	2	18
Clay, brown and greenish, sandy	3	21
Clay, light tan, silty	6	27
Sand, coarse; some gravel, fair sorting	2	29
Clay, brownish, silty; sand, coarse, subangular, fair sorting	7	36
Sand, coarse; some gravel; clay, brownish, silty, fair sorting	7	43
Clay, brown, sandy	7	50
Sand and clay, brown, silty	6	56
Clay, brown, sandy	2	58
Sand and clay, brown, silty	3	61
Clay, brown	3	64
Sand and clay, brown, silty	3	67
Clay, brown, silty	6	73
Sand and clay, brown, silty	9	82
Clay, brown	2	84
Sand and clay, brown, silty	7	91
Clay, brown, silty	7	98
Sand, coarse, subangular	5	103
Clay, brown, sandy and silty	11	114
Clay, brown, sandy	12	126
Sand, coarse to very coarse, subangular	4	130
Clay, brown	3	133
Sand, fine to very coarse	5	138
Clay, brown	4	142
Sand, fine to very coarse	4	146
Clay, brown, sandy	6	152
Sand, fine to very coarse	3	155
Clay, brown, sandy	2	157

(Test hole drilled to 157 ft)
(Test hole destroyed 5-10-82)

This site is rated as only a moderately fair recharge site because of its topographic location, elevation differential of about 40 ft above river level. The logs show 16 ft of fine-grained sediments with some coarse sand, then alternating beds of fine- and coarse-grained sediments to the water table suggesting moderately fair vertical hydraulic conductivity. The drill site is adjacent to a small natural drainage which was dammed and ponded at the time of drilling suggesting poor near-surface hydraulic conductivity.

The water table was not identified at this drill site. Mitten (1982) showed the water table at about 120 ft below land surface in autumn 1979.

4N/8E-19H1. Louis DeLuca, test hole in alluvial plain about 1.7 mi northeast of Lockeford and about 0.15 mi north of the Mokelumne River. Altitude 75 ft.

Material	Thickness (ft)	Depth (ft)
Topsoil; clay, tan, silty; sand, coarse to very coarse, subrounded, and angular; gravel, subrounded, fair sorting----	9	9
Sand, coarse to very coarse, subrounded and angular; gravel, pea size, subrounded; clay, light tan, silty, fair sorting---	5	14
Clay, light tan, silty; sand, coarse to very coarse, subrounded and angular, fair sorting----------	6	20
Sand, coarse to very coarse, subrounded and angular; gravel, pea size, subrounded, fair sorting----------	4	24
Clay, tan to greenish----------	3	27
Sand, coarse to very coarse, subangular, fair sorting; gravel, subrounded, angular, fair sorting; clay, silty-------	10	37
Clay, brown to yellow (adobe-like), light purple----------	4	41
Sand, and gravel, very coarse, subrounded, fair sorting--------	2	43
Clay, brown to yellow (adobe-like)----------	2	45
Sand and gravel, very coarse, subrounded, fair sorting---------	3	48
Clay, brown-tan, sandy, silty; some gravel----------	8	56
Sand and gravel, coarse to very coarse, subrounded, angular, fair sorting----------	6	62
Clay, brown-tan, sandy, silty; some gravel----------	5	67
Clay, brown, sandy; some gravel----------	11	78
Clay, brown-tan, sandy, silty; sand ranges from fine to very coarse; some gravel, poor sorting----------	6	84
Sand and gravel, coarse to very coarse, with lenses of light brown silty clay----------	5	89
Clay, light brown, silty----------	5	94
Sand and gravel, coarse to very coarse, with lenses of light brown silty clay----------	5	99
Clay, light brown----------	4	103
Sand and gravel, coarse to very coarse----------	2	105
Clay, brown, silty----------	3	108

(Test hole drilled to 108 ft)
(Test hole destroyed 5-11-82)

This site is rated as a fair recharge site because of its topographic location on the perimeter of the flood plain near the river and, the presence of only 9 ft of fine-grained sediments lensed with some coarse-grained sediments near the land surface. The remainder of the deposits were typical alternating beds of fine- and coarse-grained sediments to the water table suggesting fair to good vertical hydraulic conductivity.

The water table was not identified at this drill site. Mitten (1982) showed the water table at about 110 ft below land surface in autumn 1979.

Mokelumne River Near Lodi

Two test holes (fig. 2) were drilled to depths below the water table north and south of the Mokelumne River east of Lodi.

The samples collected and the geophysical logs (pl. 1) indicate the material drilled was chiefly alluvial stream-channel deposits consisting of alternating beds of sand, gravel, and clay to a depth below the water table.

3N/7E-5N1. D. K. Lane, test hole in alluvial plain about 0.75 mi east of Lodi and about 1 mi south of the Mokelumne River. Altitude 62 ft.

Material	Thickness (ft)	Depth (ft)
Topsoil; clay, brown, sandy, silty; gravel, subrounded, fair sorting	15	15
Sand, fine to very coarse, subrounded and angular; gravel, subrounded, poor sorting	5	20
Clay, brown, sandy, fine in size	2	22
Clay, light brown to gray-green, silty; sand, coarse to very coarse, subrounded, poor sorting	6	28
Sand, coarse to very coarse; gravel, subrounded, poor sorting-	4	32
Clay, light tan-gray, silty; sand, coarse to very coarse, subrounded and angular, fair sorting	7	39
Clay, light tan-gray, sandy	10	49
Sand, coarse to very coarse, subrounded and angular, fair sorting	4	53
Clay, light tan-gray	3	56
Sand, coarse to very coarse, subrounded and angular, fair sorting	2	58
Clay, light tan to gray, silty	7	65
Sand, coarse to very coarse, subrounded and angular, fair sorting	2	67
Clay, light tan to gray	4	71
Sand, coarse to very coarse, subrounded, angular, fair sorting; gravel, medium to large, subrounded, fair sorting--	4	75
Clay, light tan to gray	3	78
Clay, gray-green, sandy, silty; sand, coarse to very coarse, subangular, fair sorting	7	85
Clay, gray-green, silty	4	89
Sand, medium to very coarse, subrounded and angular; gravel, subrounded, poor sorting; clay, gray-green, silty	9	98

(Test hole drilled to 98 ft)
(Test hole destroyed 5-12-82)

The logs show predominantly more fine-grained beds than coarse-grained beds again suggesting low vertical hydraulic conductivity. The site is rated as a poor recharge site.

The water table was not identified at this drill site. Mitten (1982) showed the water table at about 50 ft below land surface in autumn 1979.

4N/7E-32M1. John Graffigna, test hole in alluvial plain about 1 mi northeast of Lodi and about 0.35 mi north of the Mokelumne River. Altitude 50 ft.

Material	Thickness (ft)	Depth (ft)
Topsoil; clay, silty, poor sorting	9	9
Clay, brown, sandy, fair sorting	5	14
Sand, clayey, fair sorting	7	21
Clay, brown, sandy	2	23
Sand and gravel, medium to coarse, fair sorting	3	26
Sand, clayey, fair sorting	5	31
Clay, brown, silty, with lenses of sand, medium to coarse, good sorting	23	54
Sand, coarse, clayey	3	57
Clay, brown	4	61
Sand and gravel, coarse, fair sorting with lenses of brown clay	9	70
Clay, brown, sandy	5	75
Clay, brown	4	79
Sand and gravel, coarse, fair sorting	5	84
Clay, brown, silty	3	87
Clay, brown, sandy	3	90
Sand and gravel, fair sorting	3	93
Clay, brown, silty	2	95
Sand and gravel, medium to coarse, fair sorting	2	97

(Test hole drilled to 97 ft)
(Test hole destroyed 5-13-82)

The logs show more fine-grained beds than permeable-coarse-grained beds, suggesting low vertical hydraulic conductivity. This site is rated as a poor recharge site because of its topographic location and amount of fine-grained sediments from the land surface to about 23 ft.

The water table was not identified at this drill site. Mitten (1982) showed the water table at about 50 ft below land surface in autumn 1979. This site is subject to flooding when the river is at high stage.

Calaveras River Near Linden and Mormon Slough Area

Two test holes (fig. 2) were drilled to depths below the water table adjacent to the Calaveras River and Mormon Slough. A third test hole, 2N/8E-1Q1, was abandoned because of difficult drilling.

Samples collected and the geophysical logs (pl. 2) indicate the material drilled is chiefly alluvial stream-channel deposits and consists of alternating beds of sand, gravel, and clay to a depth below the water table.

Five proposed sites were not drilled because owners would not permit drilling on their land.

2N/8E-28H1. M. B. Amer, test hole in alluvial plain about 2 mi southwest of Linden, 3.75 mi south of the Calaveras River and about 1 mi northwest of Mormon Slough. Altitude 79 ft.

Material	Thickness (ft)	Depth (ft)
Topsoil, clay, dark brown; sand, lensed with brown silty clay, fair sorting	15	15
Clay, brown, silty	6	21
Sand, medium; gravel, small, lensed with brown clay	9	30
Sand, medium to coarse; gravel, small to medium, with lenses of brown clay, fair sorting	19	49
Gravel, large; sand, coarse	4	53
Sand, coarse, with lenses of brown clay, fair sorting	6	59
Clay, brown, silty	7	66
Sand, coarse, with lenses of brown clay	4	70
Clay, brown, silty	3	73
Sand, clayey	3	76
Clay, brown, silty	2	78
Sand, clayey	3	81
Clay, brown, silty	4	85
Sand, medium to coarse, with lenses of brown clay	11	96
Gravel, medium to large; sand, coarse to medium, with lenses of brown clay	24	120
Sand, medium, with lenses of brown clay	7	127
Clay, brown, silty	6	133
Sand, medium, clayey	5	138
Clay, brown, silty; sand, medium	9	147
Sand, clayey	3	150
Clay, brown, silty	6	156
Sand, medium, clayey	5	161
Clay, brown	2	163
(Test hole drilled to 163 ft)		
(Test hole destroyed 6-2-83)		

The logs show fine-grained sediments from the land surface to about 21 ft. Below this depth, the sediments were predominantly coarse grained. Because of the thickness of the near-surface fine-grained sediments, which would probably slow the hydraulic conductivity rates, this site was rated as a moderately poor to fair recharge site.

The water table was at about 126 ft below land surface.

2N/8E-1Q1. Raymond Ramsey, test hole in alluvial plain about 2.75 mi northeast of Linden and about 0.3 mi south of the Calaveras River. (Did not reach water table in this test hole). Altitude 117 ft.

	Material	Thickness (ft)	Depth (ft)
	Topsoil; sand, very coarse; gravel, subangular, fair sorting----------	15	15
	Note: Caving and circulation problems at 18 ft, very hard drilling, probably cobbles. Very coarse-grained material, probably saturated, can't stop caving.		
6-5-82	Hole open to 13-15 ft, rock bit to 23 ft, still caving, reamed hole with 8-inch drag bit, set 19 ft of 6½-inch steel casing. Gravel, very coarse (probably some cobbles); sand, very coarse--	8	23
6-6-82	Drilling with 4-inch casing with cutting edge.		
	Gravel, coarse (probably cobbles)----------	4	27
	Clay, silty----------	1	28
	Gravel, coarse----------	3	31
	Note: Drill tools hung-up, salvaged tools and abandoned site.		
	(Total depth drilled: 31 ft)		
	(Test hole destroyed 6-6-82)		

The logs show fine-grained sediments with some sand and gravel from the land surface to about 15 ft, then at least 15 ft of coarse-grained sediments. Although this clay may impede the near-surface hydraulic conductivity, this site was rated as a fair to good recharge site because of (1) the thinner section of fine-grained sediments near the surface, (2) the coarse- to very coarse-grained sediments from about 15 ft to at least 30 ft, some of which drilled like large cobbles, and (3) the log of test hole 2N/8E-11H1 showing the same bed of thick coarse-grained sediments near the land surface.

Mitten (1982) showed the water table at about 120 ft below land surface.

2N/8E-11H1. John W. Eilers, test hole on alluvial plain about 2 mi northeast of Linden and 0.7 mi south of the Calaveras River and about 1 mi northwest of Mormon Slough. Water level, when drilled, was about 100 ft below land surface. Altitude 103 ft.

Material	Thickness (ft)	Depth (ft)
Clay, brown, sandy	12	12
Sand, medium to coarse with lenses of sandy brown clay	17	29
Gravel, large; sand, coarse with lenses of sandy brown clay	15	44
Clay, brown, sandy, with small gravel	16	60
Sand, coarse; gravel, small, lensed with sandy brown clay	8	68
Clay, brown, silty; gravel, small	13	81
Sand, coarse; gravel, small	2	83
Clay, brown, silty	3	86
Clay, brown, sandy	14	100
Sand, coarse; gravel, small, lensed with brown clay	5	105
Clay, brown, silty	5	110
Clay, brown, silty, lensed with fine to medium sand; gravel, small	37	147
Clay, brown, silty	2	149

(Test hole drilled to 149 ft)
(Test hole destroyed 6-9-82)

The logs show only about 12 ft of fine-grained sediments from the land surface to the first major coarse-grained beds from about 12 to 44 ft. Thick fine-grained beds at 44 to 60 ft, 68 to 81 ft, and 86 to 100 ft may impede the vertical hydraulic conductivity, but near-surface conditions and the approximately 32 ft of permeable coarse-grained sediments to 44 ft make this a moderately fair to good recharge site.

Littlejohns Creek Area

Two test holes (fig. 2) were drilled east and north of Farmington, one along the North Fork of Duck Creek in the SW¼ of the SE¼ of sec. 36, T. 2 N., R. 9 E., and one in the SE¼ of the SE¼ of sec. 12, T. 1 N., R. 9 E. along Duck Creek.

Samples collected and the geophysical logs (pl. 2) indicate that the material drilled is chiefly alluvial stream channel deposits consisting of alternating beds of sand, gravel, and clay to a depth below the water table.

Two additional sites proposed for drilling in this area were not completed owing to the abundance of fine-grained sediments and lack of coarse-grained sediments found in the two completed test holes.

2N/9E-36Q1. Cook Land and Cattle Co., test hole in alluvial plain about 3 mi north and about 3.5 mi east of Farmington. Altitude 160 ft.

Material	Thickness (ft)	Depth (ft)
Clay, dark brown; clay, gray, lensed with medium sand	28	28
Clay, gray, sandy	5	33
Sand, medium, lensed with gray clay	4	37
Clay, brown, sandy	6	43
Sand, medium, lensed with brown clay	8	51
Sand, coarse to medium	4	55
Clay, brown, sandy	2	57
Sand, coarse to medium, lensed with brown clay	5	62
Clay, brown, sandy	5	67
Sand, medium to fine, lensed with brown clay	8	75
Clay, brown, lensed with fine sand	7	82
Sand, medium to fine, lensed with brown clay	15	97
Gravel; sand, coarse	3	100
Clay, brown, sandy	4	104
Sand, medium to coarse; gravel, small, lensed with brown clay	8	112
Clay, dark brown, sandy	10	122
Sand, coarse, lensed with silty brown clay	8	130
Clay, brown, silty	4	134
Sand, coarse; gravel, medium, lensed with brown clay	6	140
Clay, brown, silty	2	142
Sand, medium; gravel, small	2	144
Clay, brown, silty	2	146
Sand, clayey; gravel	4	150
Clay, brown, sandy	3	153
Sand, medium, clayey	3	156
Clay, brown	2	158
Sand, fine to medium, clayey	5	163
Clay, brown, sandy	4	167
Sand, medium, clayey	5	172
Clay, brown, sandy	5	177
Sand, fine to medium, clayey	3	180
Clay, brown, sandy	3	183
Sand, fine to medium, clayey	5	188
Clay, brown, sandy	1	189

(Test hole drilled to 189 ft)
(Test hole destroyed 6-7-82)

The logs show predominantly fine-grained sediments from the land surface to about 33 ft and only a few thin coarse-grained beds to the water table at about 126 ft. Because of the thick fine-grained sediments near the land surface, which would probably slow hydraulic conductivity rates and absence of major coarse-grained sediments, this site was rated as a poor recharge site.

The depth to the water table was at about 126 ft below land surface.

1N/9E-12R1. Cook Land and Cattle Co., test hole in alluvial plain about 4 mi east and about 1 mi north of Farmington. Altitude 152 ft.

Material	Thickness (ft)	Depth (ft)
Topsoil; clay, brown; some small gravel	8	8
Clay, brown, sandy	6	14
Clay, brown	3	17
Sand, fine, silty	4	21
Clay, brown, silty	13	34
Sand, fine, silty	3	37
Clay, brown, sandy	11	48
Clay, brown	4	52
Sand, fine, silty	6	58
Clay, brown, silty	9	67
Clay, brown, sandy	10	77
Sand, fine; gravel, fine	5	82
Clay, brown, sandy	6	88
Clay, brown, sandy, silty; some red gravel	28	116
Clay, brown and gray	5	121
Sand, coarse; clay, gray, sandy	7	128
Clay, gray, silty	4	132
Sand, coarse	3	135
Clay, gray, silty	5	140
Sand, coarse; small gravel	10	150
Clay, gray, silty	5	155
Clay, gray, sandy	4	159

(Test hole drilled to 159 ft)
(Test hole destroyed 6-8-82)

The logs show predominantly fine-grained sediments with some silty sands and very few coarse-grained sediments from the land surface to the water table at about 125 ft. Because of the prominence of fine-grained sediments, which would slow the hydraulic conductivity, this site was rated as a poor recharge site.

The water table was at about 125 ft below land surface.

FEASIBILITY FOR ARTIFICIAL RECHARGE

The feasibility of artificially recharging the unconfined aquifer system using the spreading basin method in eastern San Joaquin County is dependent on the permeability of the deposits above the water table and the availability of surface water.

Streamflow in the rivers flowing into the area depends on precipitation and melting snowpack in the Sierra Nevada. Flow in the Mokelumne and Calaveras Rivers is regulated by dams so that water is available for irrigation during the summer months. Average discharge in the Mokelumne River below Camanche Dam is 804 ft^3/s, based on 50 years of record, and in the Calaveras River below New Hogan Dam is 211 ft^3/s, based on 17 years of record (U.S. Geological Survey, 1979, p. 263, 382).

> Piper (1939, p. 3) stated, "In the eastern part of the central district, between Clements and the vicinity of Lockeford, it is inferred that (1) the [Mokelumne] river and the water in the alluvium of the flood plain are not insulated from the water in the sediments that form the adjacent Victor plain (2) locally, if not generally, however, there are discontinuities in pervious strata along the outer margin of the flood plain, where the water table passes from the alluvium into the enclosing sediments, so that percolation of ground water is impeded materially at that margin; (3) rising river stages set up ground-water waves that store relatively large volumes of water in the alluvium close to the river, whereas falling stages cause much of that stored water to percolate back into the river, weeks and even months lapsing before the ground-water stage becomes steady within the flood plain; and (4) seepage loss from the river into the alluvium tends to be intermittent and to alternate with seepage gain, the rate of loss or gain lagging weeks or months behind the fluctuations of river stage and lagging more for moderate changes at low stage. However, in the succeeding reach downstream as far as Woodbridge [west of project area], it is inferred that percolation of ground water is not impeded generally along the outer margin of the flood plain and that the river tends to lose almost continuously by seepage rather than intermittently, although the rate of loss fluctuates somewhat in response to changing river stage."

Seepage loss to the aquifer system from the river is probably greatest during the flood season when flood-plain deposits some distance from the river become saturated, although recharge near the river to the unconfined aquifer system is continuous.

The California Department of Water Resources (1980, table 19, p. 63) estimated annual seepage losses to ground water from the Mokelumne River from Camanche Reservoir (fig. 2) to Woodbridge for the period 1929 through 1973. The quantities of seepage loss ranged from 1,200 acre-ft in 1943 to a high of 109,000 acre-ft in 1969. This same report (p. 63) shows that the quantity of annual recharge in this reach from seepage losses is increasing. Data obtained by the Geological Survey during regional aquifer studies in the San Joaquin Valley indicate that from 1961 through 1967, the average annual seepage loss was about 41,400 acre-ft and from 1968 through 1977 was about 52,500 acre-ft (Paul Nady and A. K. Williamson, U.S. Geological Survey, written commun., 1982). The increased seepage loss probably was due to lowering ground-water levels, which increases the head difference between the river and the ground-water table. The water table along this reach of the Mokelumne River was about 50 to 60 ft below land surface near Lodi and about 100 to 110 ft below land surface near Lockeford (San Joaquin County Flood Control and Water Conservation District, 1981), indicating about 50 to 100 ft of unsaturated deposits between the water level in the river and the ground-water table.

The trend of increasing loss is not apparent along the Calaveras River. However, studies of the San Joaquin Valley (Paul Nady and A. K. Williamson, U.S. Geological Survey, written commun., 1982) indicate that losses between the Calaveras River at Bellota and the Calaveras River near Stockton (fig. 2) averaged 17,700 acre-ft/yr for the period 1961-77. These losses, which become recharge to the aquifers along the losing reaches, suggest that recharge, through ponds in the permeable river channel deposits, could be affected. Also, controlled releases from the reservoir to optimize recharge along the natural channels might be affected. Studies would be needed to determine the optimum release required.

Piper (1939, p. 3) and the California Department of Water Resources (1980, p. 63) confirmed that the Mokelumne River is a losing stream. Furthermore, the results of phase 2 test drilling along the Mokelumne River show that the deposits above the water table are permeable. Most of the test holes drilled adjacent to the Mokelumne River contained coarse-grained sediments near land surface. All the test holes intercepted lenticular clay beds, many of them silty, but no hardpan or claypan that would slow or prevent percolation.

A three-dimensional geologic model, based on water well logs in an east-west strip of the ground-water basin approximately 2 mi on either side of the Mokelumne River, showed buried ancestral channels of the Mokelumne River at different depths trending generally southwesterly from the course of the present channel (California Department of Water Resources, 1980, p. 63).

AREAS SELECTED FOR POSSIBLE ARTIFICIAL GROUND-WATER RECHARGE

Areas along the Mokelumne and Calaveras Rivers selected for artificial ground-water recharge tests to the unconfined aquifer system by the spreading basin method are delineated in figures 3 and 4.

Mokelumne River

Area A was selected as the primary recharge site along the Mokelumne River (fig. 3). The site, which encompasses about 160 acres, is farmed in row crops and orchards.

Area B, also about 160 acres and the location of test hole 4N/7E-25E1, is a U.S. Soil Conservation Service experimental farm and is an alternative site.

Calaveras River

Area C was selected as the primary recharge site along the Calaveras River (fig. 4). This area encompasses about 30 acres and is farmed in row crops surrounded by orchards on the east, south, and west.

Area D is about 70 acres and is planted mostly in young orchard type crops. This site, surrounded mostly by mature orchards, is an alternative site.

Littlejohns Creek Area

No recharge areas were selected in the Littlejohns Creek area owing to the abundance of fine-grained sediments and the lack of coarse-grained sediments found in the two test holes drilled in the area.

CONCLUSIONS

The Mokelumne and Calaveras Rivers are losing streams, as indicated by the hydraulic gradients which, in general, slope away from the rivers and toward areas of water-level decline. Thus, the rivers contribute to the recharge of the aquifer system.

Results of the test drilling completed in phase 2 suggest that artificial recharge to the unconfined aquifer system by the spreading basin method in areas adjacent to the Mokelumne and Calaveras Rivers is feasible. The test holes penetrated coarse-grained sediments near land surface but no hardpan or claypan to prohibit water infiltration. The samples and logs, however, do show numerous clay beds; these are mostly silty and lenticular.

Favorable sites for testing recharge operations lie in an area north of the town of Lockeford and south of the Mokelumne River near test hole 4N/8E-30E1 or 4N/7S-25E1 and in an area northeast of the town of Linden and south of the Calaveras River near test hole 2N/8E-1Q1 or 2N/8E-11H1.

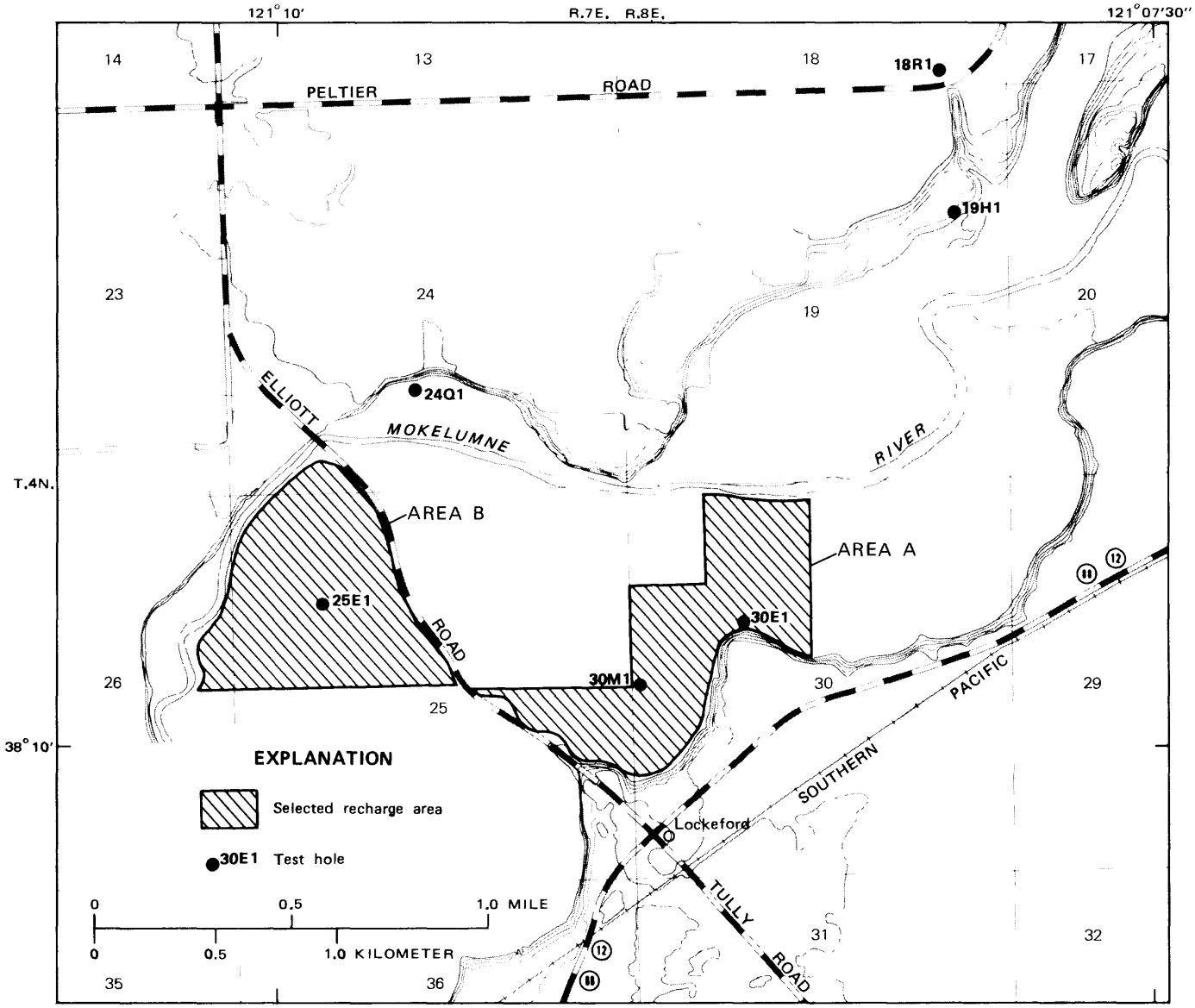

FIGURE 3. – Areas along the Mokelumne River where recharge is most feasible.

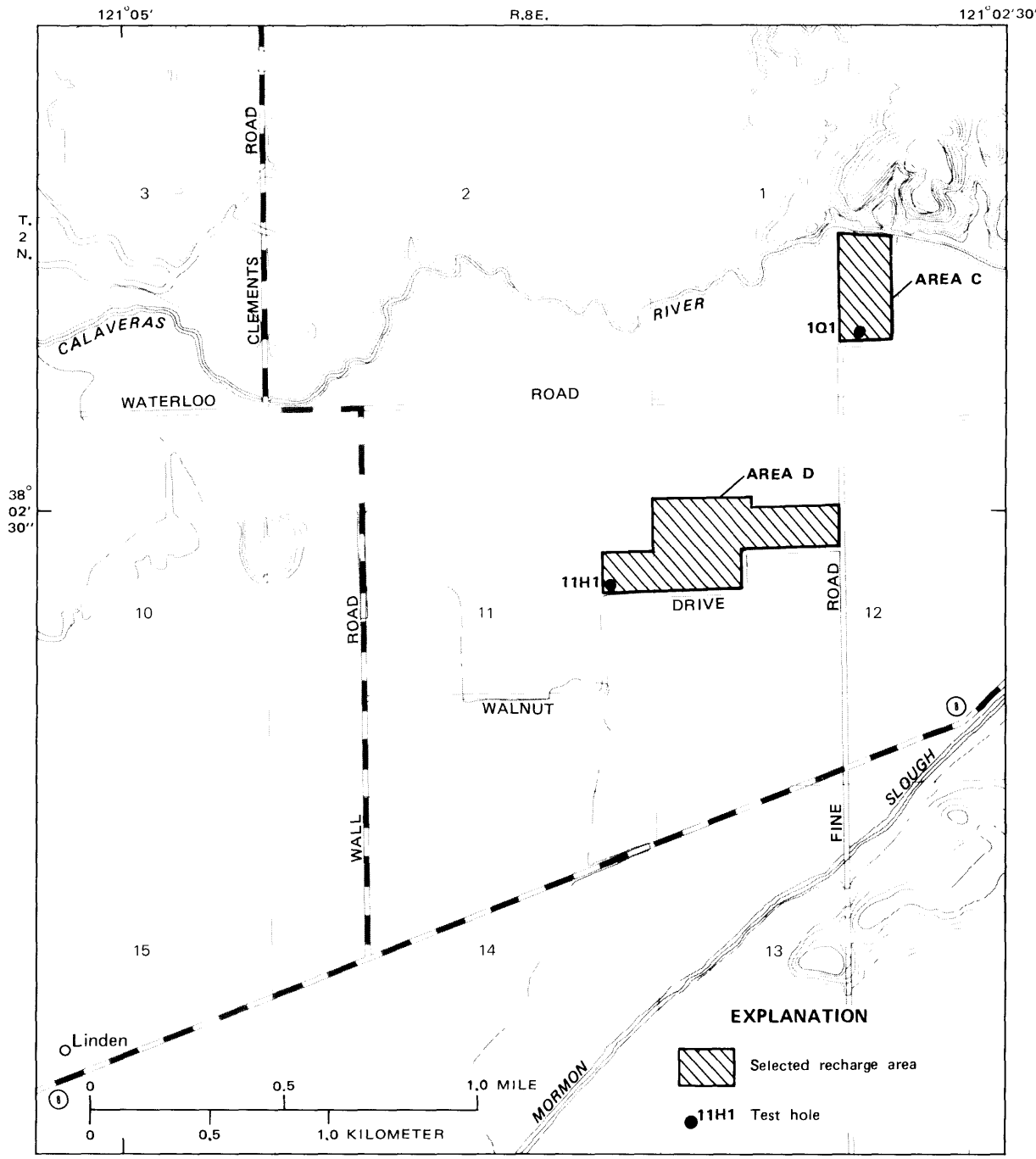

FIGURE 4. – Areas along the Calaveras River where recharge is most feasible.

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