

Shallow Ground Water and Tile Drainage in the Oxnard Plain

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Abstract—A study of the hydrology of the shallow ground waters of the Oxnard Plain, Ventura County, California, was made using a network of piezometers at 10 and 20 ft below the surface. Mean depth to water is 6.8 ft and shows little difference between January and June readings during the years 1953–1956. The perched water table slopes to the south and southwest. It is only slightly above sea level near the coast. Piezometric head differences established the presence of a downward gradient over most of the area. The shape and rate of recession of the water table in tile-drained land and tile effluent rate were measured at various sites. Twenty-two per cent of water applied is discharged from tile lines as waste. Equipment and technique for hydraulic conductivity measurement in unstable soils is described.

Introduction—Field investigations were carried out on the Oxnard Plain, in the southwest portion of Ventura County, California. This is a rather low-lying area adjacent to the coast, originally saline, reclaimed by drainage with subsequent leaching. (It is understood that a large measure of the success of drainage in this area belongs to Walter W. Weir, Drainage Engineer, Emeritus, of the University of California, who gave considerable expert advice to local people planning the works.) It now supports a highly productive agriculture, notable products being lemons, lima beans, and off-season vegetables. Studies were confined to the area south of the Santa Clara River and west of Calleguas Creek. These are the two main drainage channels of the plain, and run approximately west and south respectively. They discharge into the Pacific Ocean which forms the western boundary.

Annual rainfall averages about 14 inches but was below normal during two years of this investigation. Drainage from the area is accomplished by means of an extensive system of tile drains and a relatively small number of open ditches (Fig. 1). Farm ditches are being replaced gradually by collector lines. Ditch maintenance, weed control, and the loss of valuable land are thus eliminated. The lateral tile lines usually discharge into collection lines from which the water flows to the district ditch system, thence to the ocean via one of the main drainage channels. Very few individual laterals suitable for effluent measurement were found discharging directly into ditches.

Objectives of the investigation were (a) to make a general survey of the area to determine the facilities that had been required to create a highly productive agriculture on land previously almost worthless; (b) to evaluate the shallow semi-

perched ground-water levels resulting from the drainage measures utilized; and (c) to study the mechanics of the movement of ground water to the tile drains to provide more rational design criteria.

Soils and stratigraphy—Soils in the Oxnard area are recent alluvium from sedimentary rocks and old valley fill material which have been transported and deposited by the Santa Clara River. The majority are classified as Yolo with a few areas in the Dublin series. The surface soils are generally fairly homogeneous to a depth of six to eight feet and generally overlie much less permeable silts and clays. This subsoil material was laid down on the flood plain by the Santa Clara River and there is little continuity to the strata. Deposits typical of flood plain deposition are found ranging from fine gravel through sands, silts, and clays, at depths between 10 and 20 ft below the surface. Auger-hole samples were taken down to 16 ft at the three major tile-line investigation sites, but mechanical analyses did not indicate the presence of a true clay. From information gathered from local farmers, it appears that an impermeable barrier does underlie parts of the plain. The shallowest depth reported was 14 ft below the surface. Stratigraphic information obtained while jetting in piezometers to 20 ft below the ground surface indicated no continuous clay layer, but rather a series of clay and silt lenses of low permeability which were interspersed with lenticular deposits of fine sand, coarse sand, and fine gravel of high permeability. South of Highway 101 between Rice and Las Posas Roads, a series of piezometers jetted to 30 ft indicated that similar conditions prevailed between 20 and 30 ft with sand layers constituting in some cases more than half of that 10-ft interval. No thick clay layers were present down to 60 ft at field Site 3.

The lenticular silts and clays provide an ef-

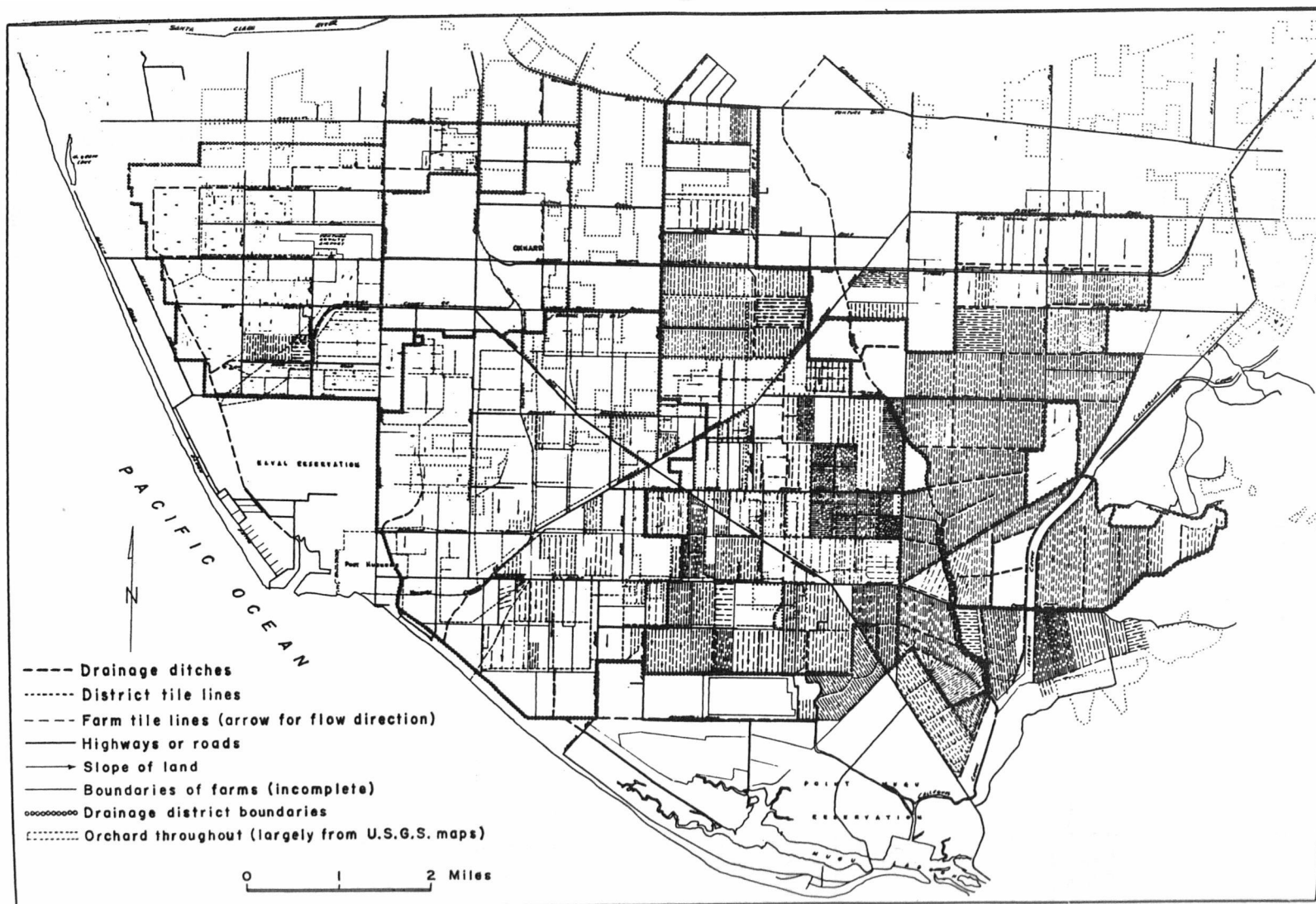


FIG. 1 — The drainage facilities of the Oxnard Plain, Ventura Co., California, 1952

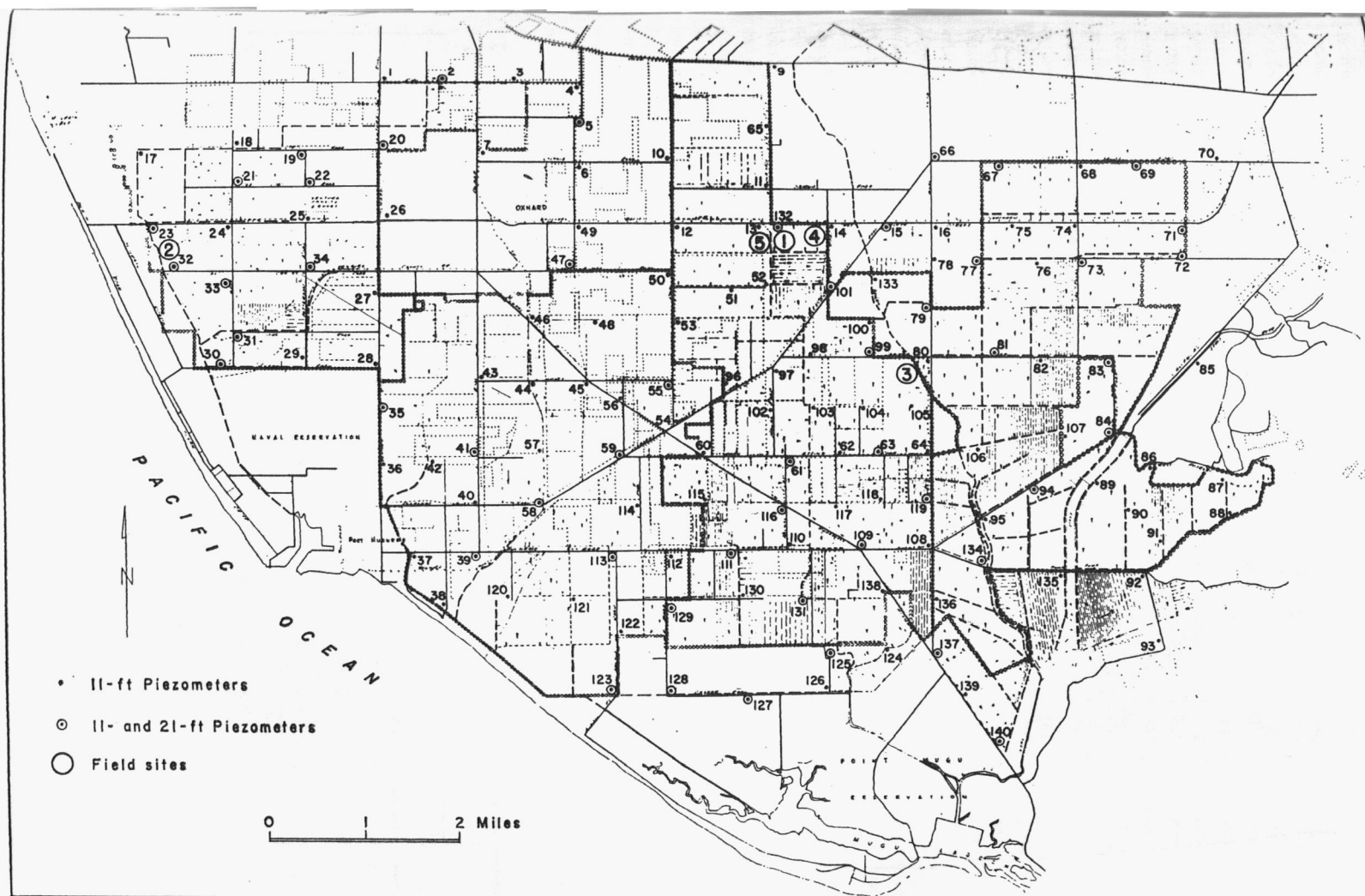
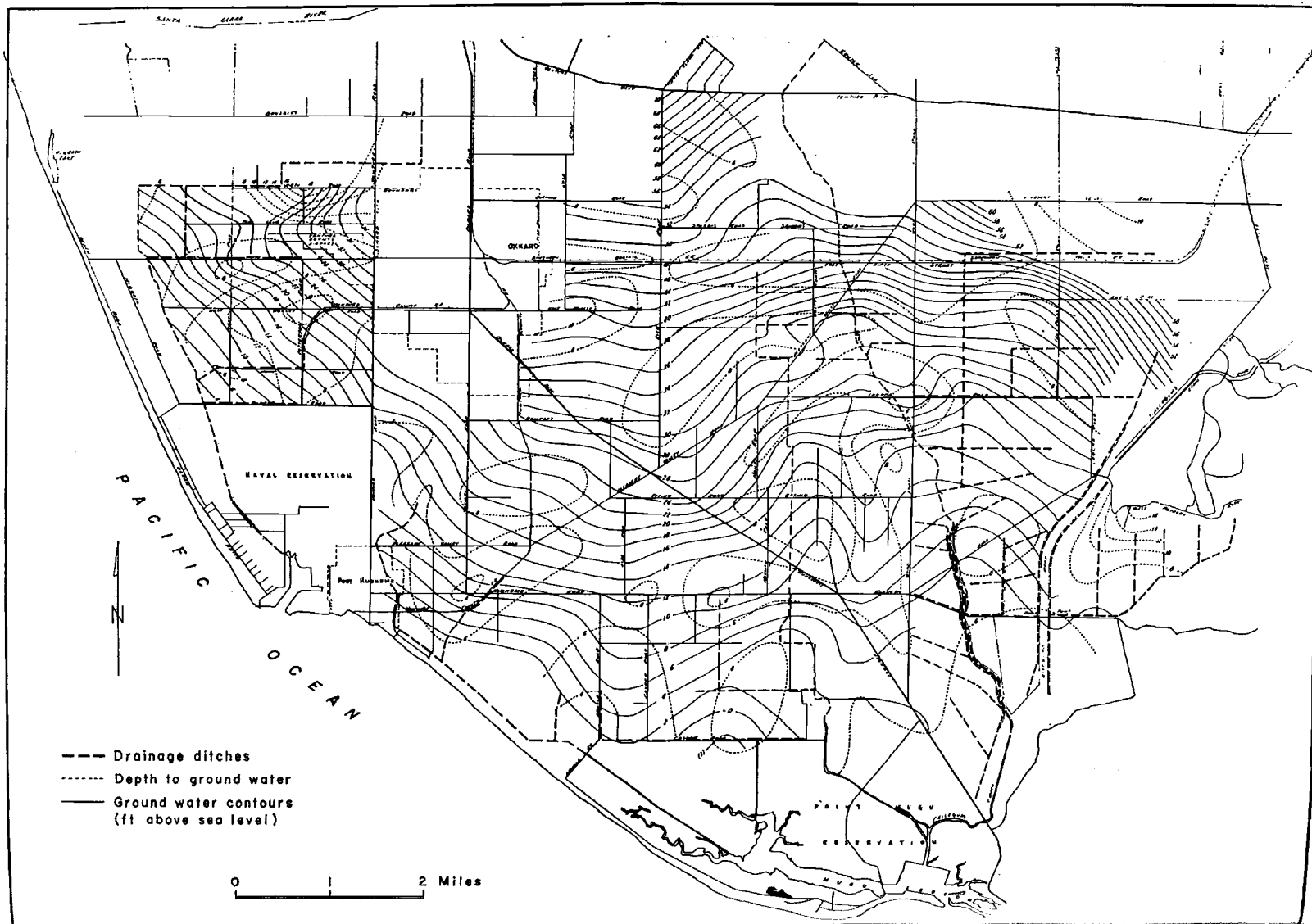


FIG. 2 - Piezometer locations and field sites



fective local barrier, however. Piezometric head measured at points 14 and 20 ft below the surface often showed a high downward gradient (up to five feet of difference in piezometric head at the two points or a gradient of more than 0.8). Such data substantiate the existence of low vertical permeability between the 14- and the 20-ft level at those locations. On the other hand differences of piezometric head were small in areas where sands occurred between the depths at which the head was measured.

The ground surface slopes gently and uniformly to the southwest, with elevations ranging from 100 ft inland to almost sea level along the coast.

Water-table survey—Little information was available on the hydrology of the shallow ground water. Previous surveys [*California Division of Water Resources*, 1933, and 1953; *U. S. Department of Agriculture*, 1920] have shown that the Oxnard Plain overlies pressure aquifers which were still flowing from water-supply wells some 20 years ago. The presence of artesian water clearly indicates a flow barrier between the deeper aquifer and the surface, which is borne out by the existence of a shallow perched water table a few feet below the ground surface. Water levels in wells penetrating the Oxnard aquifer have now dropped to below sea level. Figure 2 shows the locations of 140 $\frac{3}{8}$ -inch diameter piezometers 11 ft long which were installed on roughly a half-mile grid over the area, to obtain shallow ground-water elevations.

The network was read in January and June of each year beginning in January 1953. Readings were taken using an electrical sounder [*Donnan and Bradshaw*, 1952] and plotted on a map showing water-table elevations above sea level and depth to water below ground surface (Fig. 3). Water-table elevations determined in this manner show a positive seaward gradient at all points. At no time since the beginning of the survey has the ground-water level fallen below sea level although piezometers near the coast show only a slight positive elevation. Ground-water movement, in general, follows the main surface drains, Revlon Slough and Calleguas Creek, and flows in a southerly direction to the coast.

Deep percolation—The usefulness of piezometers to different lengths at the same location to determine vertical gradients has been firmly established in other areas [*Reger and others*, 1950]. A network of 21-ft piezometers on approximately a one-mile grid was installed by jetting as described by *Pillsbury and Christiansen* [1947]. These piezometers were located within a foot or two of

the 11-ft piezometers already installed (Fig. 2). To penetrate some of the coarse sands encountered, a commercial drilling mud preparation (Aquagel) was added to the jetting water at a rate of 10 lb per 100 gallons of water. Without the Aquagel these sands are so highly permeable that none of the flow of water from the jetting pipe returns to the surface, and progress is impossible. After flushing with clean water, piezometers installed in this manner responded normally to changes in the piezometric head.

Readings of both 21-ft and 11-ft piezometers were taken at six-month intervals in 1953, 1954, and 1955. These data show a definite downward gradient over the entire plain with a mean value of 0.05. Site 3 showed mean downward gradients during 1954 of 0.11, 0.1, 0.1, 0.14, and 0.18 over the intervals 7-12, 12-15, 15-21, 21-27, and 27-63 ft respectively. Time did not allow a complete water balance to estimate deep percolation losses over the plain but a very rough approximation was made by measuring the change in water level in two piezometers during a summer period when no irrigation water was applied in the vicinity. The water levels were well below the neighboring tile drains and slightly above the bottom of the nearest ditch ($\frac{1}{4}$ mile distant). If no lateral movement occurs, the drop in water level may be attributed to downward movement into deeper zones. Below the fairly non-stratified surface soil the particular nature of the profile makes it unlikely that the mean hydraulic conductivity in a horizontal direction will be any greater than in a vertical direction. In any case the influence of a drainage ditch is somewhat localized, so that the rate of water-table recession at a point $\frac{1}{4}$ mile from a ditch is likely to be low. The horizontal gradient is extremely small. In one case the piezometer water level was two feet above the ditch water surface $\frac{1}{4}$ mile distant; in the second case seven feet in $\frac{3}{4}$ mile which are gradients of 0.0015 and 0.0018. Vertical gradients vary from 0.15 to 0.30 depending on the elevation of the perched surface (assuming the mean depth of the Oxnard aquifer to be 200 ft.).

The assumption made above regarding the likely equality of horizontal and vertical hydraulic conductivity may be incorrect; but even if the horizontal conductivity exceeds the vertical by 100:1, the horizontal gradient would still hardly exceed the vertical gradient.

To interpret the change in water level in the soil in terms of true water quantity the specific yield was determined from 36 core samples taken

from a depth of five feet. Moisture content at $\frac{1}{2}$ atmosphere (assumed equivalent to field capacity) and bulk density were determined. The mean specific yield of 16.1 pct shows remarkable agreement with the 16 pct found by the State Division of Water Resources for the deeper aquifer.

The two piezometers observed both gave, perhaps fortuitously, a change in level equivalent to 0.9 ft of water per year. At the very least one-half of this or 0.45 ft/yr may be attributed to deep percolation and it is possible that all 0.9 ft percolates through to the deeper zones. The total extent of the area covered by this study is around 32,000 ac, which means an annual recharge to the deeper zones of 14,000 ac ft of water (using the conservative figure of 0.45 ft). This is a significant amount when the annual pumping draft is considered to average $1\frac{1}{2}$ to 2 ft, or at maximum 64,000 ac ft per annum. Almost one-quarter of the annual draft may actually be replenished by deep percolation. The quality of the shallow water is poor. Mean electrical conductivity (EC) from 20 samples was six millimhos/cm. To give some idea of the original salinity status of this area note that on land that was tiled during the course of the investigation, the EC of the tile effluent was 46 millimhos/cm after the third leaching.

Tile-drain performance—Three locations were chosen for tile-drain investigation (Sites 1, 2, and 3, Fig. 2) and measurements of effluent rate, cumulative discharge, hydraulic conductivity, and water-table recession following irrigation were

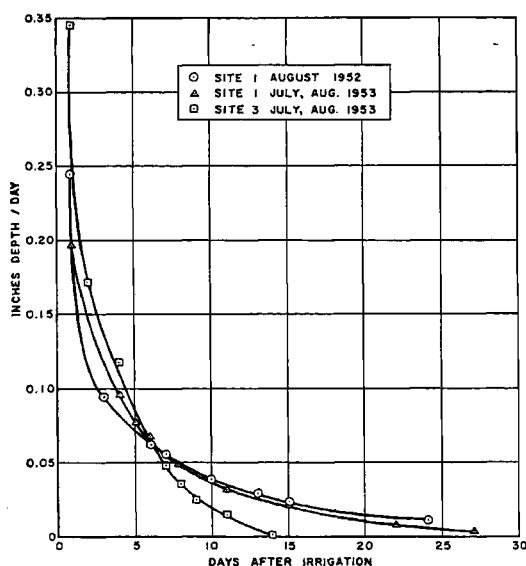


FIG. 4—Tile discharge rates

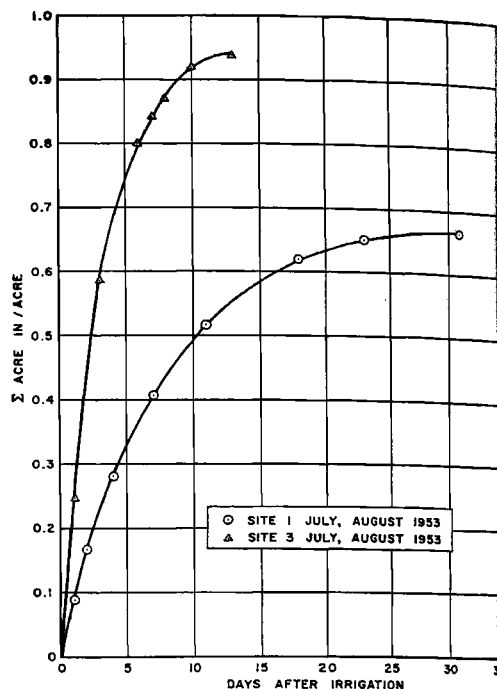


FIG. 5—Cumulative tile discharge

made at each site. Originally measurements following rainfall were expected to provide some reliable information. Natural precipitation tends to be more uniform than irrigation, and the quantity of water applied is easily calculable from rain gage figures. Unfortunately, the only rainfall of sufficient intensity or duration to raise the water table appreciably also raised the drainage ditch level above the lower end of the tile drain. Investigation of drainage characteristics of tile lines were therefore confined to the summer irrigation season. Three tile lines were selected and the outlets equipped with tipping buckets. Plots of the effluent rate versus time are shown in Figure 4 for Sites 1 and 3. The initial rates are not maximum for these tile systems since effluent data with the soil saturated to the surface were impossible to obtain.

Cumulative discharge—Figure 5 shows the cumulative discharge at Site 1 and Site 3 in 1953. The 1952 records of Site 3 are meaningless because the tile line was found to be partially plugged with eucalyptus roots. On the other hand, in 1953 with a normal irrigation cycle, there was no flow before irrigation and measurements were made until flow again ceased. The irrigation was light, the water table rose to a maximum of 0.15 ft above the top of the tile and yet 27 pct of the water applied

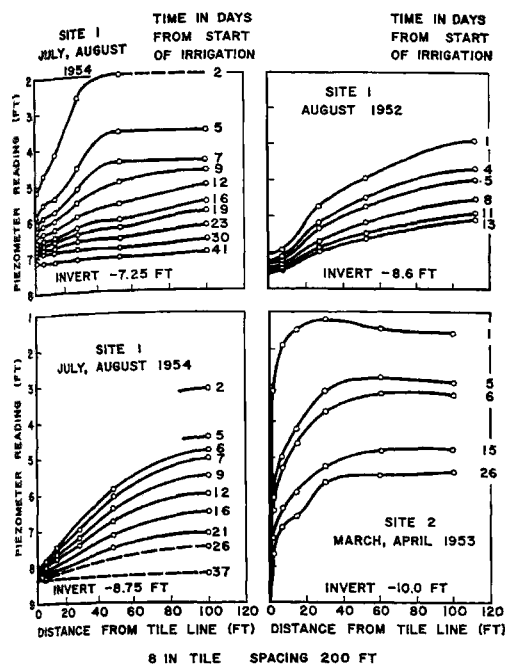


FIG. 6 - Water-table recession

was ultimately discharged to the ditch as waste.

Total cumulative discharge figures for three irrigations were 0.66, 0.94, and 0.96 acre inch per acre. Including drainage directly into ditches 1.0 acre inch per acre would appear to be a representative figure for the quantity of excess leaching water applied per irrigation. The annual pumping draft is 18 inches which means that, assuming four irrigations per year, $\frac{1}{4}$ or 22 pct of applied water is ultimately discharged as waste. The U. S. Salinity Laboratory method of computing leaching requirement, using the ratio of the EC of water applied to that of the drain effluent, yields 1.4/6.0 or 23 pct. It appears that on the basis of the above calculation the amount of leaching water used is not excessive. Approximately half of the total effluent is discharged in the first $\frac{1}{4}$ of the flow period. However, a detailed study of salt balance in this area might lead to a reduction in the presently excessive pumping draft on the deeper artesian aquifers.

Water-table recession—Piezometer readings on the recession of the water table following irrigation were made at all locations. Piezometers of three different lengths were originally installed at each point but gave identical readings in the shallow zone down to the tile line. Thereafter a row of single piezometers on one side of the tile was used with an electrical sounder to establish water levels.

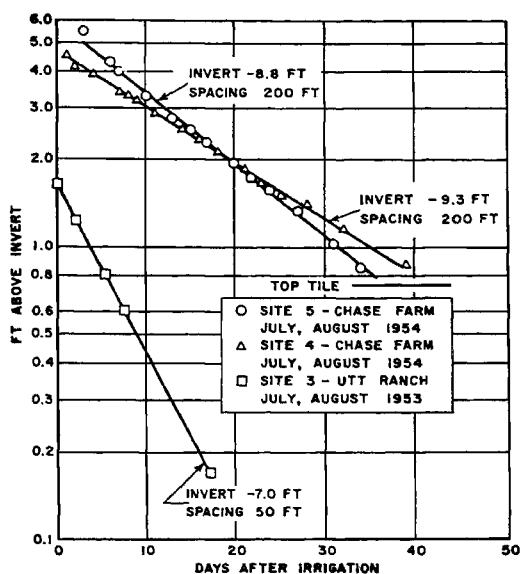


FIG. 7 - Midpoint recession, Sites 3, 4, and 5

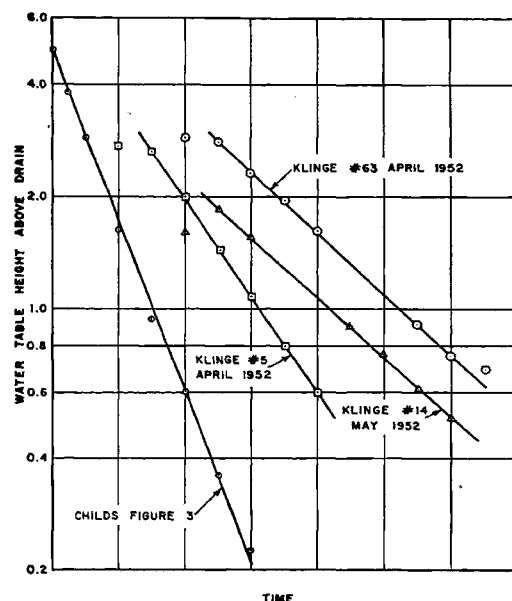


FIG. 8 - Midpoint recession, data from Childs [1947] and Klinge [1955]

Figure 6 shows examples of the type of recession curves obtained. One feature which attracts immediate attention is the very rapid drawdown over the tile line. In one set of readings indeed the water table at the midpoint stood almost eight feet above the top of the tile line, while the piezometer inserted at the tile line indicated no water above the tile at this point. A disturbance of the

TABLE 1—Time for water table to fall one foot from ground surface, extrapolated from midpoint recession curves

Site	H	c	
	ft		day
1	8	0.028	2.1
2	10	0.021	2.2
3	6	0.061	1.3

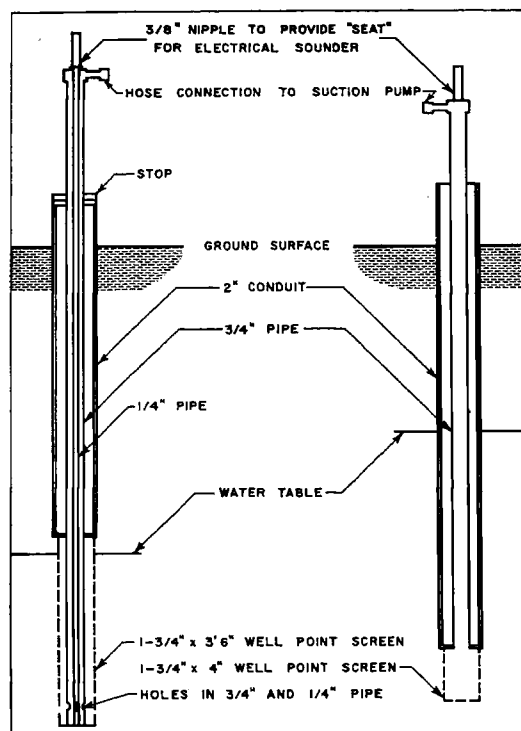


FIG. 9—Screened test hole for hydraulic conductivity measurements

original stratification in the trench dug to lay the tile line can lead to this type of recession curve. In this particular case it was difficult to confirm this by soil samples although a clay layer at a depth of five to seven feet close to the tile line was not present above the line. However, the same layer did not occur at the midpoint between lines either. It would appear that anisotropy or stratification, although not continuous, is sufficiently pronounced in this locality to make the trench effect quite apparent.

In all four recession rate plots the various stages in the recession of the water table are far from being parallel. The fall at midpoint is in all cases considerably greater than the fall near the tile itself. Clearly the succession of nearly parallel

TABLE 2—Field measurements of hydraulic conductivity

Site	No. of Measurements	K	Coefficient of variation
		ft/day	
1	3	2.01	0.2
	4	2.17	8.2
	3	3.26	3.7
2	8	0.13	1.9
	9	0.19	0.3
	10	0.14	0.2
4	11	0.93	7.8
5	8	0.61	8.0

TABLE 3—Time for midpoint recession between three feet and two feet above tile invert compared with K/f ; tile spacing constant

Site	Mean K	K/f	Time
	ft/day	ft/day	day
1	2.5	10.2	6
2	0.15	0.94	7
4	0.93	3.8	5.8
5	0.61	2.5	7

water surfaces as found by Childs [1947] is missing and will in practice never be present with drain spacings of this order (200 ft). For a 200-ft spacing the stages would no longer be parallel when the water-table height at the midpoint is less than about 25 ft above a drain [Childs, 1947, Fig. 3]. Drains are not laid at such depths and consequently the parallel surface stage is absent. The relationships between the surfaces in this non-parallel region are consequently the ones of major practical interest, and more particularly at the midpoint between drains where the water table will be highest.

Plots of midpoint height of water table above drain tile invert yielded a simple exponential function which was further confirmed by subsequent midpoint water-level readings in various locations as shown in Figure 7. The electric analogue results obtained by Childs [1947] and some unpublished data by Klinge [1955] are plotted in Figure 8.

If this exponential relation between water-table height and time is extrapolated, the time for the water table to fall one foot from the surface may be computed from

$$\log H - \log (H - 1) = cT \quad (1)$$

where H is the depth in feet of the tile invert

below the ground surface, T is the time in days, and c is the slope of the curve. The results are shown in Table 1. It is interesting to note that for Sites 1 and 2 the computed recession rate from the surface is close to one foot in two days as suggested by Neal [1934].

Hydraulic-conductivity measurements—Preference was given to *in-situ* methods (the auger-hole and the piezometer methods) for the determination of hydraulic conductivity. A few trial borings with a 2-inch auger indicated that open-hole methods were not feasible in the Oxnard area. A technique was, therefore, necessary to install a screened test hole in these unstable soils. Moreover the method had to be adaptable to measurements with the water table below five feet. The ground water is rarely closer to the surface except immediately following an irrigation or heavy rainfall.

The test borings indicated that continuous casing of the hole below the water table would be essential. This was achieved by jetting in a 2-inch diameter electrical conduit casing. After removing the jetting pipe one of the screen arrangements, shown in Figure 9 for the auger-hole or the piezometer method, was lowered into the conduit, which was then raised to a stop on the $\frac{3}{4}$ -inch pipe attached to the screen.

The water table was allowed to stabilize and the static level read from an electrical sounder. With the short 4-inch screen the sounder wire was run in the annular space between the $\frac{3}{4}$ -inch pipe and the 2-inch conduit. In the long screen the sounder wire was inside a $\frac{1}{4}$ -inch diameter pipe. The $\frac{1}{4}$ -inch pipe was included in the long-screen equipment since it enabled the water level to be lowered almost to the bottom of the screen. This was felt to be unnecessary with the short screen. Apart from this, installation and measurement techniques for both methods are identical. The rate at which the water level builds up is timed and the hydraulic conductivity determined from equations derived by Kirkham [1948, 1949], allowance being made for the screen and pipe volumes.

Hydraulic-conductivity measurements were made with this equipment at Sites 1 and 2 and later at Sites 4 and 5. At Site 3, the water table was not high enough above the tile line to allow a comparison with the other tile systems. Results are shown in Table 2.

Now it is reasonable to assume that, other conditions remaining the same, the rate of drop of the water table at the midpoint will vary directly as the hydraulic conductivity K , and inversely as the drainable pore space f . Comparison of the last two

columns of Table 3 clearly indicates that the field measurements fail to support this assumption.

In most aspects, all four sites are comparable. Each spacing is 200 ft. Drainable pore space f has only a limited range of values, even with 100 pct error in measurements. Any error in barrier depth is similarly limited. The major variable of unlimited range is hydraulic conductivity itself. To obtain a reliable value of hydraulic conductivity, a large number of measurements must be made, even in a relatively homogeneous soil. Spot measurements in shallow homogeneous soils, where hydraulic conductivity can be determined down to the barrier layer, may give the desired information with some assurance. The Oxnard soils, somewhat typical of the deep alluviums of southwestern United States requiring deep drainage, are far from homogeneous below the tile drains. They tend to be characterized by discontinuous stratification and marked anisotropic properties. Van Deemter [1950] has indicated that for soils with no effective barrier layer in the profile, the majority of the flow occurs in a region of depth $S/4$ where S is tile line spacing. It is quite impractical to obtain hydraulic conductivity of soil to 50 ft depth ($S/4$ for the common 200-ft spacing). Even with elaborate field equipment and power tools, as used in this work, field determinations by a few spot tests are prohibitive in cost, and clearly a great number of such tests would be required for significant results. Spot methods for hydraulic-conductivity determinations obviously have no merit here. The eventual resolution of this problem may come from the application of geophysical techniques. For the immediate future, a solution based on the recession rate midway between two widely spaced tile drains appears to hold some promise.

To attempt to correlate the recession rate with hydraulic conductivity and clay depth would involve an extensive field program. Preliminary investigations at various points indicated that neither visual inspection nor mechanical analysis were satisfactory to establish accurately the depth of an impermeable barrier. Moreover, the number of hydraulic conductivity measurements would be prohibitively large to attain even a fair degree of accuracy. Additional work using a mathematical model to investigate the relationship between the rate of recession and the parameters influencing this rate is in progress.

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