HILGARDIA

A Journal of Agricultural Science Published by the California Agricultural Experiment Station

VOLUME 14 | OCTOBER, 1941 | NUMBER 3

CONTENTS

HYDROLOGIC STUDIES OF THE PUTAH CREEK AREA IN THE SACRAMENTO VALLEY, CALIFORNIA

MARTIN R. HUBERTY and C. N. JOHNSTON

CHEMICAL COMPOSITION OF WATER IN THE PUTAH CREEK BASIN

C. S. BISSON and MARTIN R. HUBERTY

UNIVERSITY OF CALIFORNIA · BERKELEY, CALIFORNIA

H I L G A R D I A

A Journal of Agricultural Science Published by the California Agricultural Experiment Station

VOL. 14 | OCTOBER, 1941 | No. 3

HYDROLOGIC STUDIES OF THE PUTAH CREEK AREA IN THE SACRAMENTO VALLEY, CALIFORNIA[1,2]

MARTIN R. HUBERTY[3] AND C. N. JOHNSTON[4]

INTRODUCTION

THE DEEP ALLUVIAL FILL of Putah Creek forms a storage basin from which much irrigation water is pumped. Continued and expanding demand upon the underground water supply has caused a gradual recession in the water plane. This condition leads many farmers to question the permanency of their water supply.

The College of Agriculture at Davis is located within the basin of Putah Creek. In years of low rainfall, the underground basin is its sole source of water supply. Hence, since the early days of the institution, the Division of Irrigation has observed underground water conditions on the University Farm.

The deficient rainfall of the winter of 1930–31 emphasized the need for a comprehensive study of the water supply in the Putah Creek area. Although Bryan (*2*)[5] studied the basin in 1912, conditions have changed materially since that date. An informal project, outlining a study to supplement existing information on the water supply and the pumping conditions of the area, was formulated by the divisions of Agricultural Engineering, Chemistry, and Irrigation. In the summer and fall of 1931 and the spring of 1932, information was secured on the characteristics of the underground basin, on the quality of water with special regard to

[1] Received for publication October 11, 1940.

[2] Assistance was given by the Federal Works Progress Administration, under projects 3657 and 7164, in drafting maps and charts used in this publication.

[3] Associate Irrigation Engineer in the Experiment Station.

[4] Assistant Irrigation Engineer in the Experiment Station.

[5] Italic numbers in parentheses refer to "Literature Cited" at the end of this paper.

boron content, and on the pumping plants. The findings were presented in a typewritten report to the Director of the College of Agriculture at Davis in 1932.

Some phases of the 1931–32 investigation have been continued by the Division of Irrigation. This publication summarizes the combined results of about twenty-five years' observations.

PHYSIOGRAPHY OF THE AREA

Putah Creek rises on the eastern slope of the Coast Range south of the Cache Creek basin and north of the Napa Valley. Drainage water from Mt. St. Helena passes southeastward through Putah Creek Canyon to

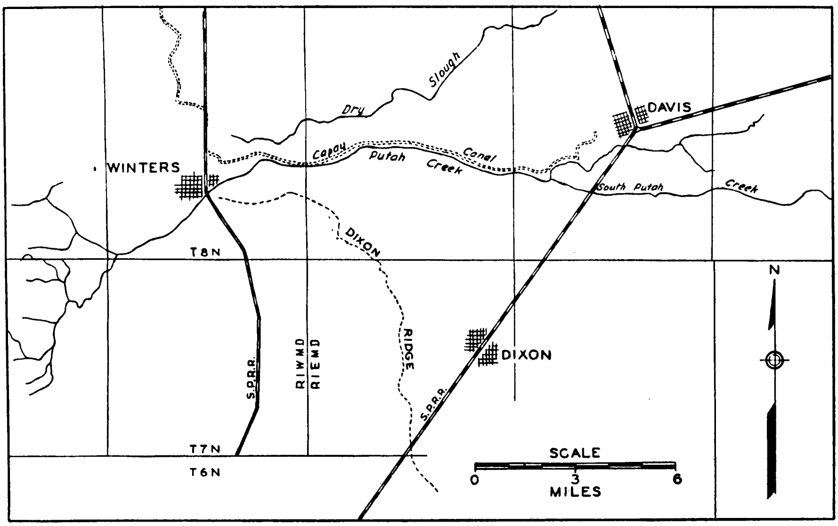

Fig. 1.—Lower basin of Putah Creek.

the Putah Creek lower basin. This discussion concerns the lower basin rather than the area from which the flow is derived. The upper basin is a rugged terrain ranging from an altitude of 5,000 feet at the head waters to about 125 feet at the upper end of the lower basin. The mean annual precipitation varies from a maximum of 100 inches, recorded at Helena Mine on the northern slope of Mt. St. Helena, to a normal of 28 inches in the lower foothills. The average annual precipitation along the central portion of the upper basin is about 40 inches. The chief tributaries of the upper basin of Putah Creek are Soda Creek from the north and Pope Creek from the west. Because the terrain is rugged, rain water moves rapidly to the stream beds, producing discharges of considerable volume through the lower basin.

Two suitable reservoir sites are available in the main bed of the upper basin—one about 6 miles west of Winters, the other near Guenoc. A reservoir at either site would be beneficial in equalizing runoff from the basin.

Figures 1 and 2 show the plan view of the upper and lower basins of the creek. The division between the two areas lies several miles west of the town of Winters, approximately as figures 1 and 2 are divided.

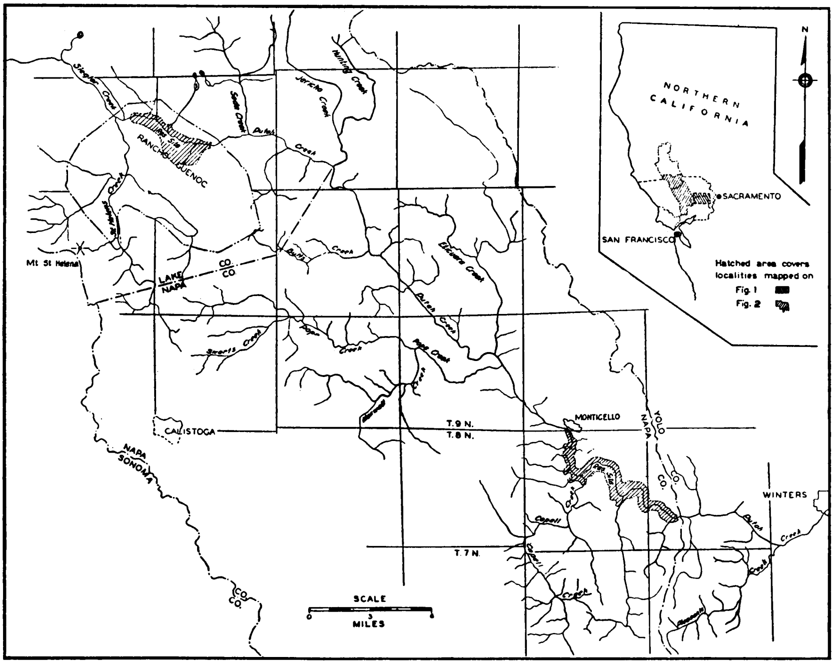

Fig. 2.—Upper basin of Putah Creek.

Figure 3 presents the geological aspects of the two areas. One may see that the area includes a variety of soils and rock formations. The lower basin is composed of products of decomposition of the upper. Since water has borne most of the disintegrated matter away from the upper basin, the stream bed there contains little loose material. Almost no seepage loss occurs, accordingly, in the stream flow while it traverses the upper basin.

The present bed of Putah Creek forms the boundary between Yolo and Solano counties as it crosses the major part of the valley floor eastward from the upper basin. The lower basin itself is a fanlike area spreading outward from near Winters to the northeast and southeast for about 20 miles. It retains the typical form of alluvial fan deposits, in which the surface slopes away from the apex of the fill and also away from the immediate bank of the stream whose waters have formed it. Scars on the surface indicate the wanderings of Putah Creek over the area in comparatively recent times. One such surface trace, the Dixon ridge, may be followed from Winters directly to Dixon.

There is evidence that Putah Creek did not always find its outlet to the east from the mountains. Judging, however, from the hundreds of

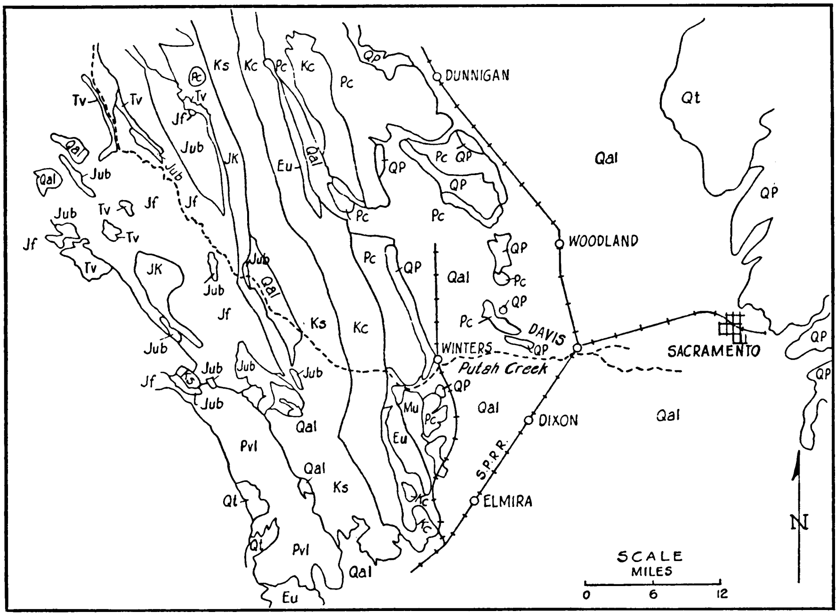

Fig. 3.—Geologic map of Putah Creek drainage basin and adjacent areas: *QP*, Quaternary and Upper Pliocene sediments; *Qal*, alluvium; *Pc*, undivided Pliocene nonmarine sediments; *Kc*, Upper Cretaceous marine sediments; *Mu*, Upper Miocene marine sediments; *Eu*, Upper Eocene marine sediments; *Pvl*, Lower Pliocene volcanics and interbedded sediments; *Qt*, terrace deposits; *Jub*, Jurassic ultra-basic intrusives; *JK*, Knoxville formation; *Jf*, Franciscan group; *Tv*, Undivided Tertiary volcanics; and *Ks*, Lower Cretaceous marine sediments. (Data from O. P. Jenkins, Chief Geologist, California State Division of Mines.)

feet depth of water-deposited materials throughout the lower basin, the present outlet has been used for a long time. The well-driller encounters several layers of gravel throughout the lower basin. Judging from their composition, all these are related to the formations still in place in the mountains to the west. The gravels and other strata slope with the dip to the east—as might be expected, since they were laid down by water moving from the west. The large particles represented by the water-bearing, coarser gravels were deposited during periods of heavy stream flow with high water velocities, while materials grading down to clays were deposited in quieter water. The presence of considerable depths of both types of deposit and of intermediate classifications suggests a wide range in conditions of runoff and deposition.

Because Putah Creek has laid down all these upper strata, its bed cuts across many of the older porous layers, thereby permitting its waters to replenish the underground supply.

Around Davis and eastward, a blue-clay stratum underlies the soil surface at a depth of about 350 feet. This blue coloring is generally assumed by geologists to result from deposition in relatively deep water where oxidation processes were restricted. Such deposits are found where the sea has covered an area such as the Sacramento Valley.

RESULTS OF THE INVESTIGATION

Methods and Scope of Work.—In this study of the problems of water distribution and supply in the lower basin of Putah Creek, consideration was given to: (1) ground-water levels; (2) water-bearing strata; (3) properties of underground waters; (4) climatic conditions of and runoff from the Putah Creek basin; (5) zones of ground-water recharge; and (6) interpretation of data.

Water levels may be presented as measured depths to water from the ground surface or as elevations of such water surfaces. In this paper all elevations are referred to mean sea level datum which is zero elevation. Several types of sounding devices are available for measuring the depth to water, which is best obtained when the well is not being pumped.

Although most of the data on thickness and position of water-bearing strata were obtained from well-drillers' records, some were secured by College of Agriculture investigators who observed the drilling.

The properties of the waters noted were temperature and chemical composition. The water samples for chemical analysis were collected and water-temperature readings were made while the well was being pumped. Chemical analyses are presented in detail in the companion paper (*1*), but in the present paper boron concentrations are referred to as a possible means of determining sources of underground water supply.

Long-time records of weather and of storm runoff in the Putah Creek area are available. Such information is valuable for estimating the probable available water supply of the area and for explaining fluctuations in underground water levels.

Because graphic presentation provides the best method for showing comparisons in the periodicity of ground-water levels and for relating location with such factors as temperatures and chemical composition of waters, it has been preferred to the tabular method.

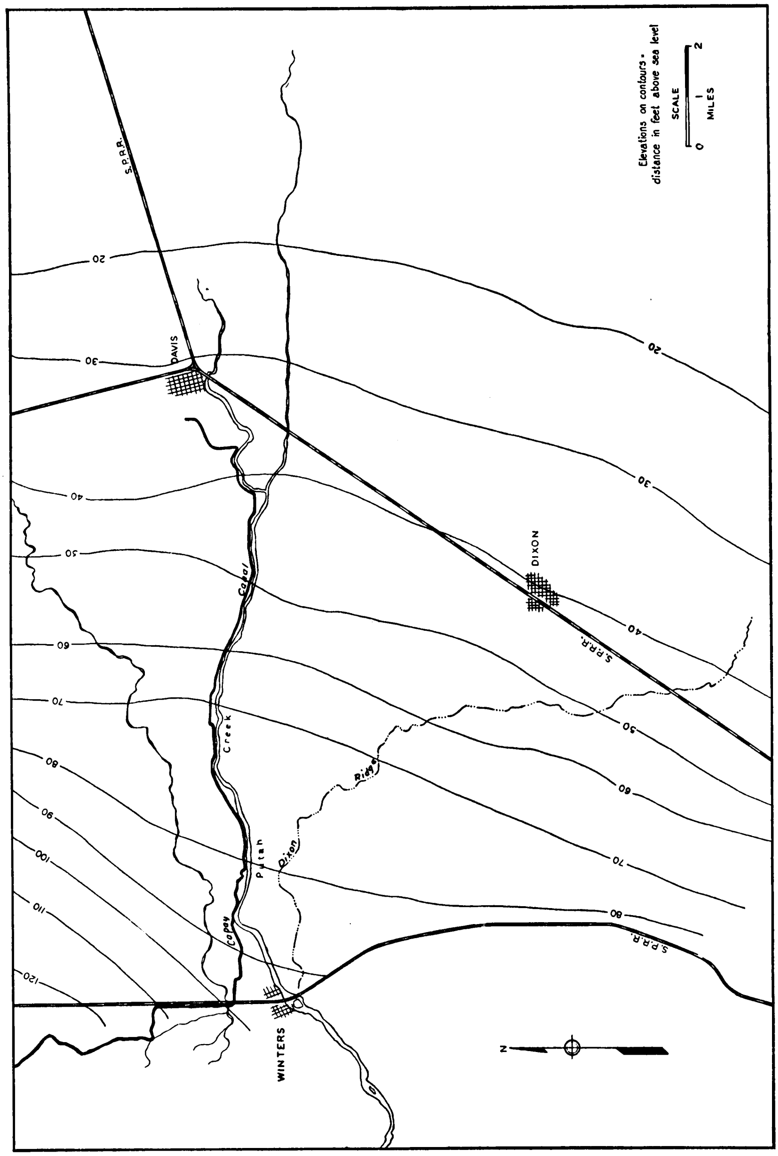

Fig. 4.—Underground water elevations on Putah Creek cone area as found by Bryan (*2*) in 1912.

Ground-Water Levels and Ground-Water Movement.—Water levels in the lower basin of Putah Creek were first studied in detail by Kirk Bryan (*2*) in 1912 during a comprehensive study of the underground water of Sacramento Valley. Figure 4 presents Bryan's findings for this area. As this figure shows, the slope of the water levels at that time was gradually up from the Sacramento River and the ground-water contours were parallel to that stream and at right angles to Putah Creek. Bryan reported 125 pumping plants in the Davis–Dixon–Winters area. Horizontal centrifugal pumps installed in shallow pits predominated. This type of equipment could be used economically because the depth to water was then about 20 feet. With continued pumping, water levels subsided materially, till a change from horizontal centrifugal to deep-well turbine pumps was required.

As early as 1922, the Irrigation Division undertook a study of water levels in shallow wells on the University Farm to determine whether the water table approached the ground surface closely enough to influence the results of irrigation experiments on orchard trees, as well as to be informed regarding the water table over the entire University Farm. According to observations of the first few years, the water levels lay beyond the rooting depth of most plants. Consequently, as these shallow wells caved they were not always recleaned. Subsequent notes on such wells did not report depth to water, but merely stated that it was below a certain depth.

Figure 5 shows the location of shallow and deep wells on the University Farm. Wells 1, 3, 4, 5, 6, and 9 are deep-irrigation wells.

Besides the shallow-well tests, water levels in University Farm irrigation well 1 have been recorded since 1912, supplemented, since 1931, with weekly records of levels in University Farm irrigation well 3. Since these records for both shallow and deep wells were taken at weekly to monthly intervals during some periods, they afford a means of comparing the behavior of deep and shallow wells.

Figure 6 indicates the elevation of waters in a selected group of typical shallow wells, together with those from deep wells 1 and 3. There are three items of interest: first, the different plane occupied by the water in deep well 1 as contrasted with all the shallow wells; second, that irrigation well 3 conforms in water elevation to the shallow wells and not to irrigation well 1; third, the tendency of water in shallow wells, and also in well 3, to rise and fall with the same frequency as in well 1 but slightly behind it in phase. The explanation for these three singularities appears to be as follows:

1. The downward-moving surface waters supplied by rains and irrigation cause the elevations of the water in shallow wells to be higher than

in the deep wells. That is, the deep-well water elevation results from water pressure within the water-bearing strata pierced by the well. This pressure is also present throughout the immediate area, which includes some shallow wells. Under static conditions where no outside influence

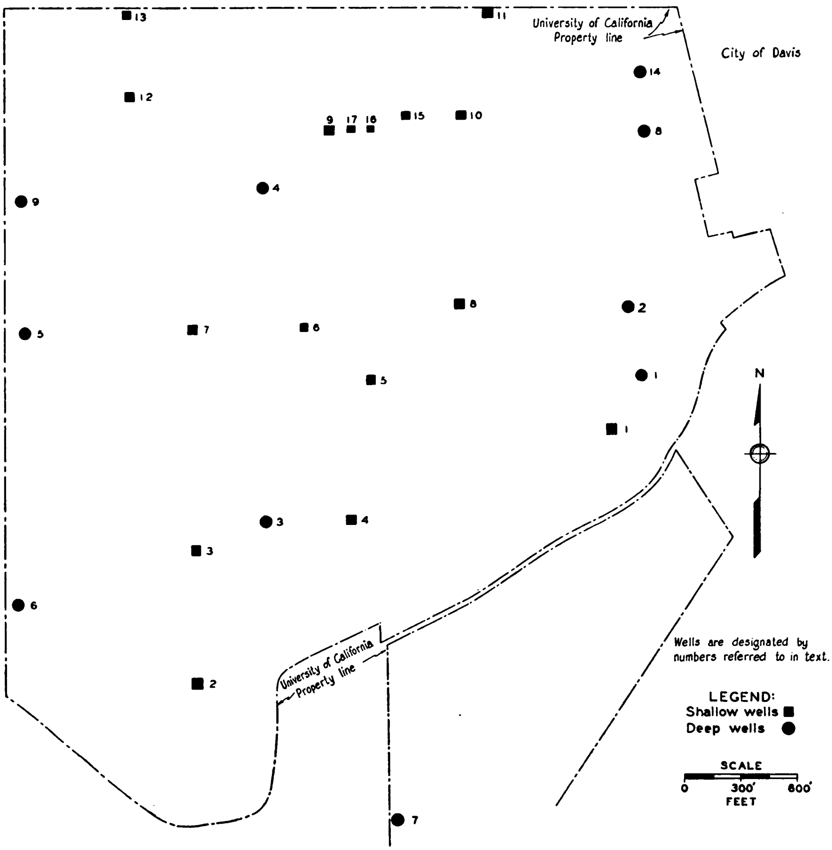

Fig. 5.—Shallow and deep wells on University grounds at Davis. The wells are designated by numbers referred to in the text.

(such as downward-moving surface water or pumping of deep wells) was present, the shallow wells would show the same water elevations as a nearby deep well. The difference in elevation of water surfaces between deep and shallow wells represents the friction head lost in moving existing flow from the water table of the shallow well to the aquifer supplying water to the deep well. In areas such as artesian basins, where water is moving upward, deep wells indicate higher water levels than nearby shallow wells (*3, 4*). Shallow wells show less marked fluctuations in the

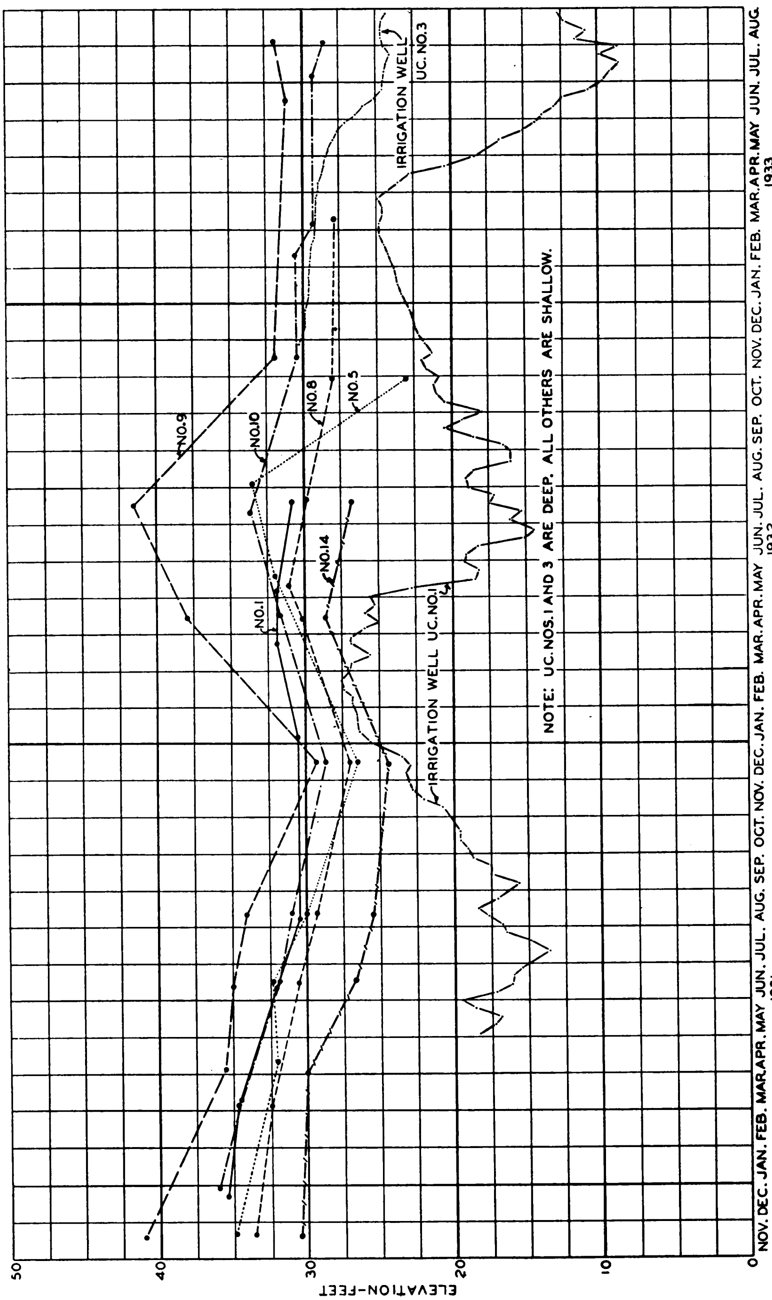

Fig. 6.—Seasonal water elevations from wells on University grounds for the years 1931 through 1933. Elevations are from sea level.

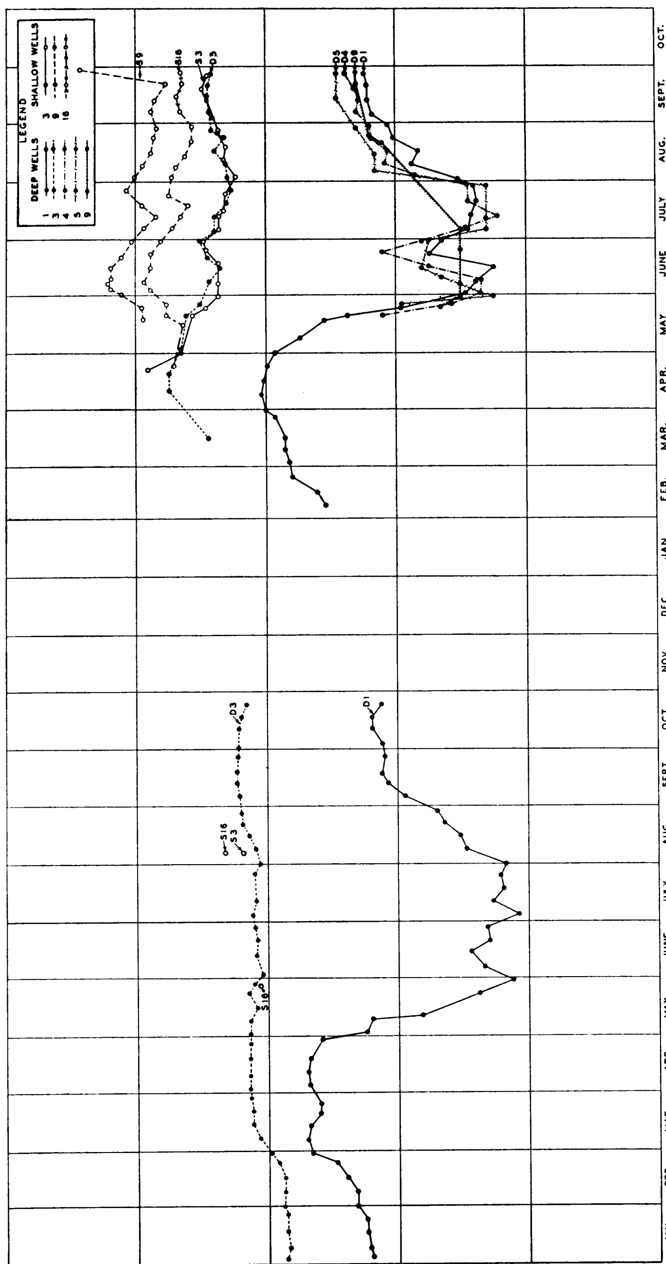

Fig. 7.—Seasonal water elevations from wells on University grounds during the years 1936 and 1937. Data are missing from November 1936 to February 1937.

water level than deep ones because the relatively impermeable strata restrict flow, thereby retarding the transmission of pressure differences from the deep strata.

2. Irrigation well 3 conforms more closely to the shallow wells than to irrigation well 1, being an abandoned irrigation well whose lower strata have been sealed by use of a cement plug. As a result, well 3, although open to a depth of 125 feet below the soil surface receives its water from the shallow sources and not from the deep stratum it originally tapped. Figure 7, presented to identify further the characteristics of well 3, shows that the elevations of 1, 4, 5, and 9, all deep irrigation wells, behave similarly, while well 3 behaves like shallow wells on the University Farm. The fact that irrigation well 3 is typical of the shallow wells is fortunate in that one may gain a general idea of the trend of all of the shallow wells on the farm by studying its water-level records, which are for weekly intervals since 1931. This period is deficient in water-level records for shallow wells of the University Farm.

3. The lack of phase agreement between deep and shallow wells is caused by the resistance of the conducting medium to the flow of water. The fine-textured subsurface materials damp the magnitude of the deep-well–water-level cycle, and thus retard the phase of the water elevations in the shallow well.

Figure 8 shows the ground-water contour elevations in the lower basin derived from the data collected before the winter rains of 1931–32. Comparison of this graph with figure 4 shows a decided shift in ground-water elevations, the result of increased and long-continued pumping. Data for both shallow and deep wells obtained in the 1931 survey are plotted in figure 8. As the contours show, the subsurface water levels had been lowered most markedly about the town of Dixon, where a depression had been created. This survey came a month or so too late to get the maximum depression in the deep-well water levels that occurs in this area usually during September. Figure 8 shows a contraction of the contours along the Dixon ridge a few miles northwest of Dixon. This contraction evidences a decided change in underground-flow characteristics. Another interesting item in this figure is that water levels north of Winters are higher than those shown by Bryan. This condition may be explained by the importation of water from Cache Creek for irrigation into this area after Bryan's survey.

Figure 9 presents the contour elevations existing in the spring of 1932. By comparing these contours with those for December, 1931, one may discern a pronounced recovery of water levels in the Dixon area.

From the spring of 1932 through the spring of 1940, ground-water levels have been obtained in the fall about November 15 and in the spring

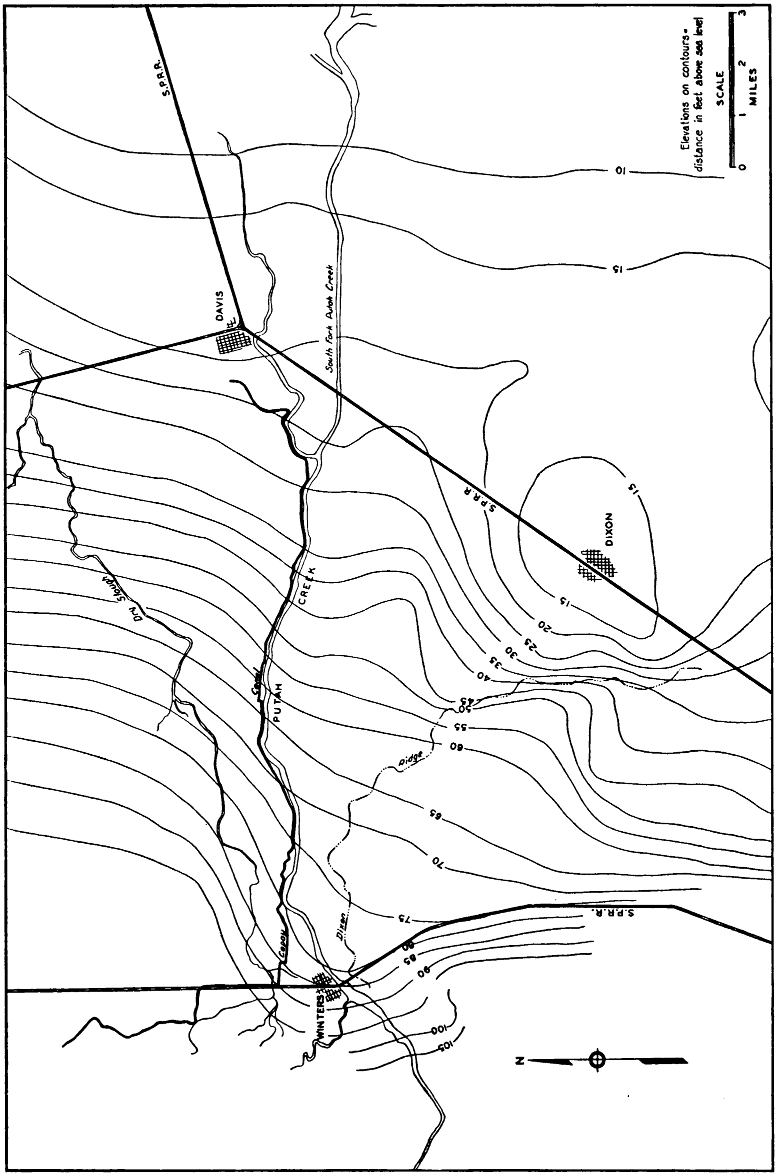

Fig. 8.—Underground water elevations on Putah Creek cone in December 1931.

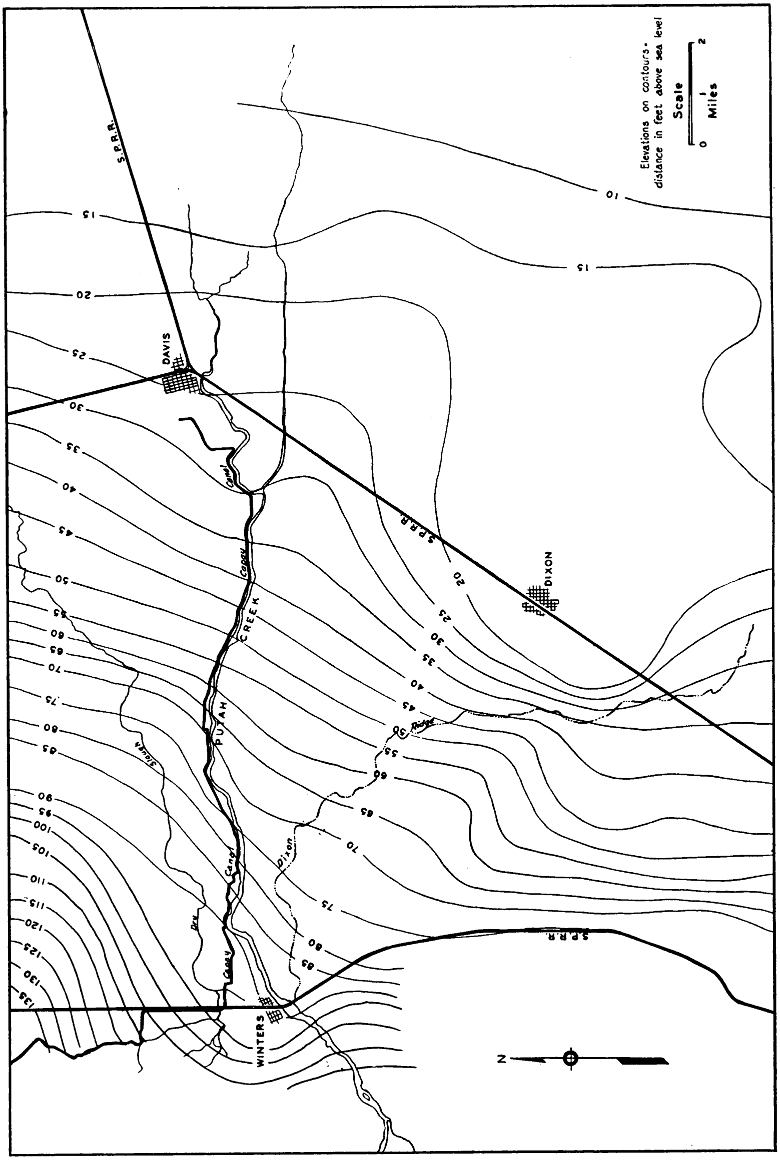

Fig. 9.—Underground water elevations on Putah Creek cone in the spring of 1932.

about April 15. Since the inaccessibility of certain wells made it impracticable to visit them regularly, a number have been dropped from the list. Unfortunately, the deep-well records are in the minority: few of these installations are so arranged as to permit access for measuring the water depth. This is a common fault of such installations and one most undesirable to the operator who wishes to keep informed of his pumping conditions.

Judging from season-to-season records of ground-water elevations, the depressed condition in the Dixon area has not become worse. Local spots about Davis have recently shown a depressed ground-water elevation. This situation can probably be explained by the large increase in pumping that has resulted from the recent development of previously unirrigated lands for the growing of sugar beets and tomatoes.

From this statement regarding the lowering of ground-water levels in the Dixon area, one might conclude that the territory was not experiencing a true overdraught to date. Seasonal shortages in water supply may, however, create unusual lowering of water tables. The return of normal precipitation brings the water levels back not to those found by Bryan in 1912, but to some intermediate plane. This plane is lower than that found by Bryan: flow in the underground strata encounters resistance; and unless there is an increase in the differential levels between the water source and the area where the water is used, there will be insufficient gradient to permit the necessary movement. The present water levels represent, then, the balance between supply and demand. The difference in water-table elevations between 1912 and 1931 represents the difference in head necessary to supply the 1931 pumping need as compared with the 1912 demand. This lowering of the water table does not indicate an overdraught, but rather is the ground water gradient necessary to meet increased pumping demands.

The discussion of deep and shallow well-water levels for the University Farm calls for an application of the same line of reasoning to the larger area—namely, the Putah Creek lower basin. If readings on the shallow wells of the University Farm differ from those on the deep wells, it might be assumed that readings from a miscellaneous collection of wells located throughout the basin might not present a true picture either. Figure 10 shows water-surface contours for both shallow and deep wells in the area for the fall of 1936, the dash lines representing elevations for deep wells, and the solid for shallow wells. Comparison of figure 11 with figure 10 reveals that the shallow wells, which are represented in greatest numbers, have governed the location of contours in figure 10. As previously noted, these data were obtained at the same time each year and may therefore be compared.

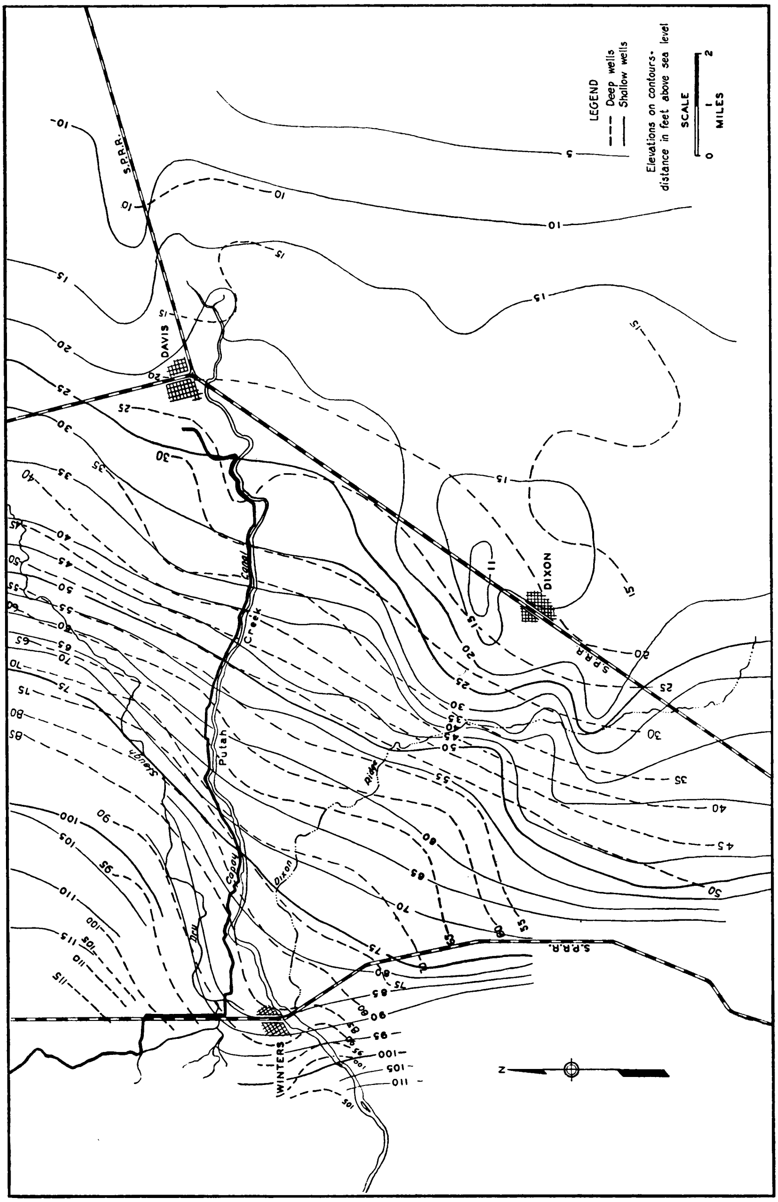

Fig. 10.—Underground water elevations on Putah Creek cone in the fall of 1936.

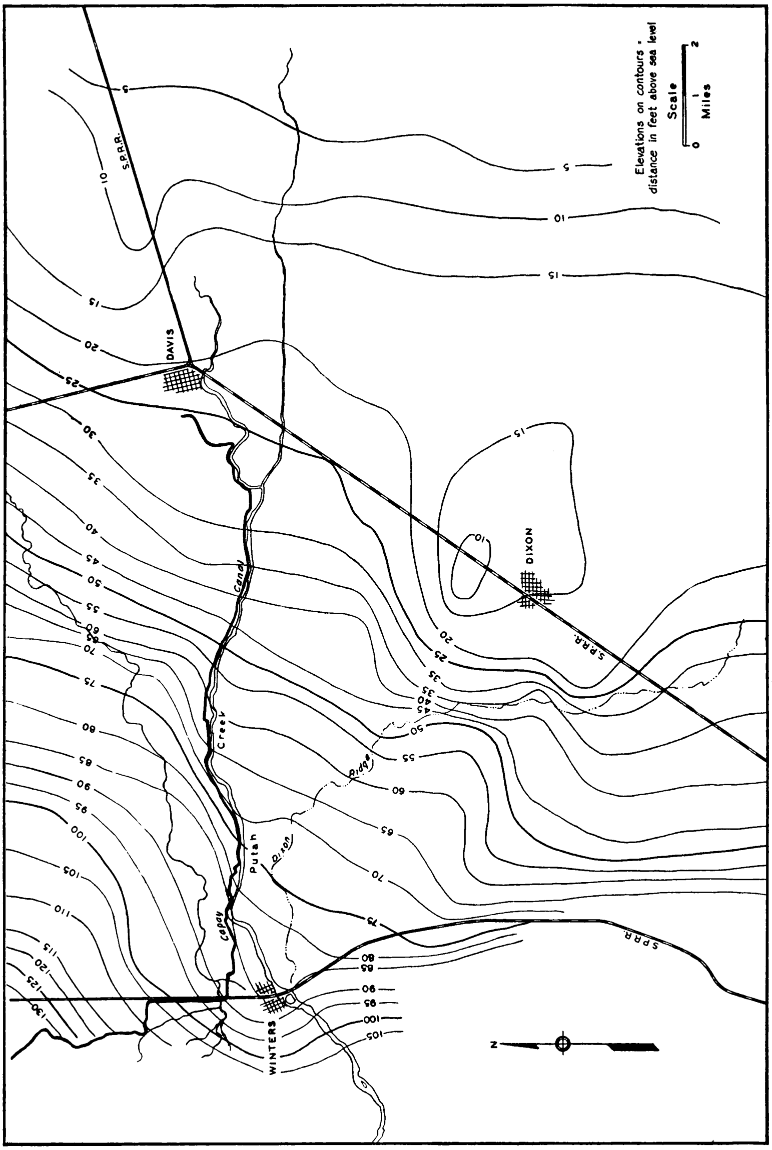

Fig. 11.—Underground water elevations on Putah Creek cone in the fall of 1936, using all deep and shallow well readings.

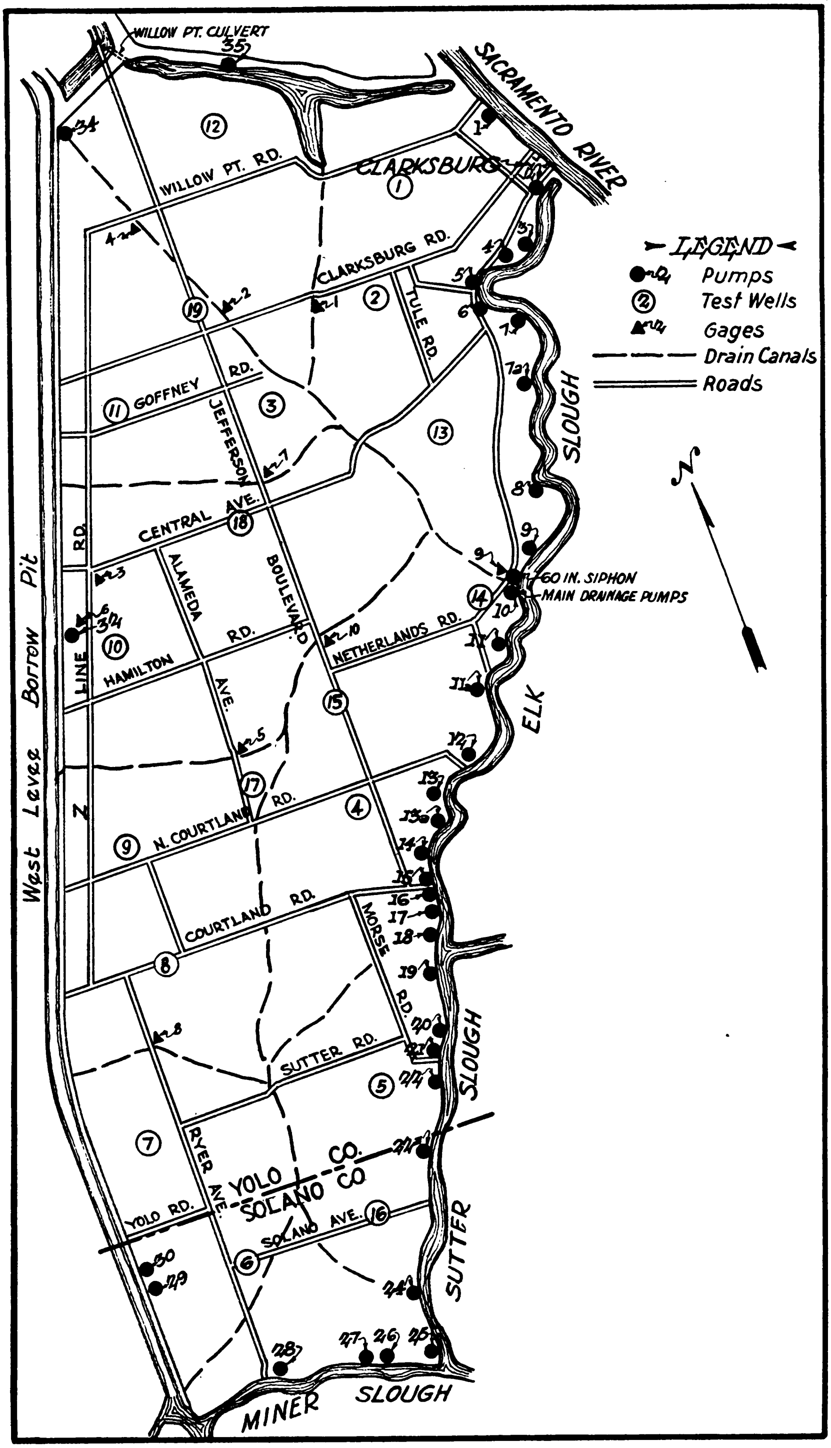

Fig. 12.—Reclamation District 999 in Sacramento Valley.

A related but slightly different set of conditions was encountered in a study instituted by the Irrigation Division during 1926 in Reclamation District 999 (fig. 12), a district which lies on the eastern edge of Putah Creek lower basin, adjoining the Sacramento River. It is a man-made island resulting from the construction of large drainage ditches and levees along its western and northern borders. The land within the island was below the Sacramento River water surface, particularly at high tide. Careful tests by the Slichter method (*5*), made along the levee banks within the island, showed no leakage through the banks.

TABLE 1

FREQUENCY DISTRIBUTION OF 133 PUMPING PLANTS, CLASSIFIED ACCORDING TO CAPACITIES AND EFFICIENCIES; PUTAH CREEK AREA, 1931*

Capacities, gallons per minute	Number of centrifugals	Number of turbines	Efficiencies, per cent	Number of centrifugals	Number of turbines
0– 99	1	1	5– 9.9	0	1
100– 199	17	3	10–14.9	0	0
200– 299	21	4	15–19.9	3	0
300– 399	13	8	20–24.9	11	1
400– 499	12	7	25–29.9	9	3
500– 599	9	7	30–34.9	15	11
600– 699	8	5	35–39.9	27	11
700– 799	3	4	40–44.9	13	12
800– 899	2	2	45–49.9	6	5
900– 999	3	2	50–54.9	3	0
1,000–1,099	0	1	55–59.9	2	0

* Mean pump discharges of centrifugals, 390 gallons per minute; of turbines, 500 gallons per minute. Mean pumping-plant efficiencies of centrifugals, 35 per cent; of turbines, 36.6 per cent. Pumping plant efficiency $= \frac{\text{horsepower output} \times 100}{\text{horsepower input}}$.

Seepage water was known to be entering the area, however, for the amount of drainage water pumped from the district exceeded the amount admitted through irrigation inlets. The construction of a series of 30-foot wells demonstrated that a very appreciable supply of water was entering the island at a depth of 20 or 30 feet below the ground surface. This water came through a sand and gravel layer extending from the river westward to the drainage canals across the island. As a result, the wells near the dikes surrounding the island flowed at high tide, and tidal effects were noted across the entire tract in diminishing degree and with retarded phase as the distance from the levee increased. In District 999 the tidal effect comes twice daily, whereas in the lower Putah Creek district, extremes of high and low water levels occur but once a year.

Pumps and Pumping Conditions.—The inventory taken during the fall of 1931 and spring of 1932 showed 301 pumping plants in Putah Creek lower basins. Of these pumps, 153 were turbines, 139 horizontal centrifugal, 8 vertical centrifugal, and 1 direct flow. Eighty per cent of the pumps enumerated were driven by electric motors.

Mechanical tests were made on 133 pumping plants by the Division of Agriculture Engineering and Irrigation. These tests provided information on well sizes and depths, pump types and sizes, depth to static and pumping, water levels, suction lifts, discharge rates, and electrical power requirements. Tables 1 to 3 present some of these data.

TABLE 2

FREQUENCY DISTRIBUTION OF 133 PUMPING PLANTS, CLASSIFIED ACCORDING TO SUCTION LIFTS, TOTAL PUMPING HEADS, AND MOTOR LOADINGS; PUTAH CREEK AREA, 1931

Horizontal-centrifugal pumps, feet of suction height	Number of plants	Feet of pumping lift*	Number of centrifugals	Number of turbines	Per cent rated motor loadings†	Number of centrifugals	Number of turbines
5- 9.9	2	25–29.9	1	1	50- 59	5	0
10–14.9	6	30–34.9	3	0	60- 69	4	0
15–19.9	18	35–39.9	7	2	70- 79	14	2
20–24.9	36	40–44.9	14	3	80- 89	13	3
25–29.9	21	45–49.9	20	11	90- 99	21	2
30–up	6	50–54.9	15	4	100–109	16	10
		55–59.9	15	13	110–119	7	10
		60–64.9	9	2	120–129	4	8
		65–69.9	4	3	130–139	0	7
		70–74.9	1	3	140–149	3	1
		75–79.9	0	0	150- up	2	1
		80–84.9	0	1			
		85–89.9	0	0			
		90–94.9	0	1			

* Pumping lift as used here is the vertical distance between the water surface at the suction end of the pump to the water surface at the maximum height of delivery. Mean suction lift of centrifugal pumps, 21.8 feet. Mean pumping lift of centrifugals, 50 feet; of turbines, 55 feet.

† Mean per cent of rated motor loading of centrifugals, 93 per cent; of turbines, 113 per cent.

Characteristics of the Water-bearing Formations.—The study of water-bearing strata for the basin has been limited to information from well-drillers' files and to personal observation of well drilling. Unfortunately some of the data are not accurate, as the drillers have no standard of classification for materials encountered in drilling wells.

Because of lack of continuity in the water-bearing formation, drillers often fail to make contact with good gravels even when drilling near a successful well. Thicknesses of water-bearing strata in the area vary widely, ranging from 2 feet to as much as 60. A rather sharp break in water-strata levels is found on a line about halfway between Winters and Davis. Here the upper water-bearing stratum passes from about sea level on the Winters side to below sea level on the Davis side. This line is marked on the surface by the Plainfield Ridge (fig. 13) a conglomerate outcrop, which extends into the lower Putah Creek basin from the northwest. At times this obstruction has doubtless acted as a dam, diverting the stream channel of Putah Creek and causing materials to be deposited on its eastern flank at elevations lower than they would have appeared had the stream been able to continue directly across the area.

The well log data determine roughly the position of the area in which gravels might be found as outcrops at the surface of the ground. Such an area, if present, would be found approximately where the soil-surface

TABLE 3

FREQUENCY DISTRIBUTION OF 133 PUMPING PLANTS, CLASSIFIED ACCORDING TO HOURS OF PUMP OPERATION; PUTAH CREEK BASIN, 1931

Hours of operation per year*	Number of centrifugals	Number of turbines
0– 199	3	3
200– 399	12	4
400– 599	12	6
600– 799	12	8
800– 999	10	5
1,000–1,199	6	6
1,200–1,399	7	2
1,400–1,599	6	5
1,600–1,799	4	3
1,800–1,999	5	2
2,000–2,199	2	0
2,200–2,399	1	0
2,400–2,599	1	0
2,600–2,799	3	0
2,800–2,999	2	0
3,000–up	3	0

* Mean hours of operation for centrifugals, 1,165; for turbines, 945.

profile coincides in elevation with that of the actual, or projected, profile of the upper surface of the water-bearing gravels. This area would be close to the head of the lower basin. According to figure 13, such an area should be found west of Winters. This supposition checks with the facts.

The finding of extreme variations in thickness of water-bearing strata raises the question of yield and makes one wonder how the thickness of strata pierced by a given well affects the output. As previously noted, many wells were tested during the fall of 1931 and the spring of 1932. These tests gave information on discharge and drawdown (difference between static and pumping-well water levels), but the data revealed no direct relation between drawdown and stratum thickness as determined from the well logs.

If the portion of Putah Creek below Winters were a direct factor in supplying the wells, the specific yield, or discharge per unit drawdown, might be expected to be larger near the creek bed than at a distance. This supposition is not borne out by the data. In general the wells along the

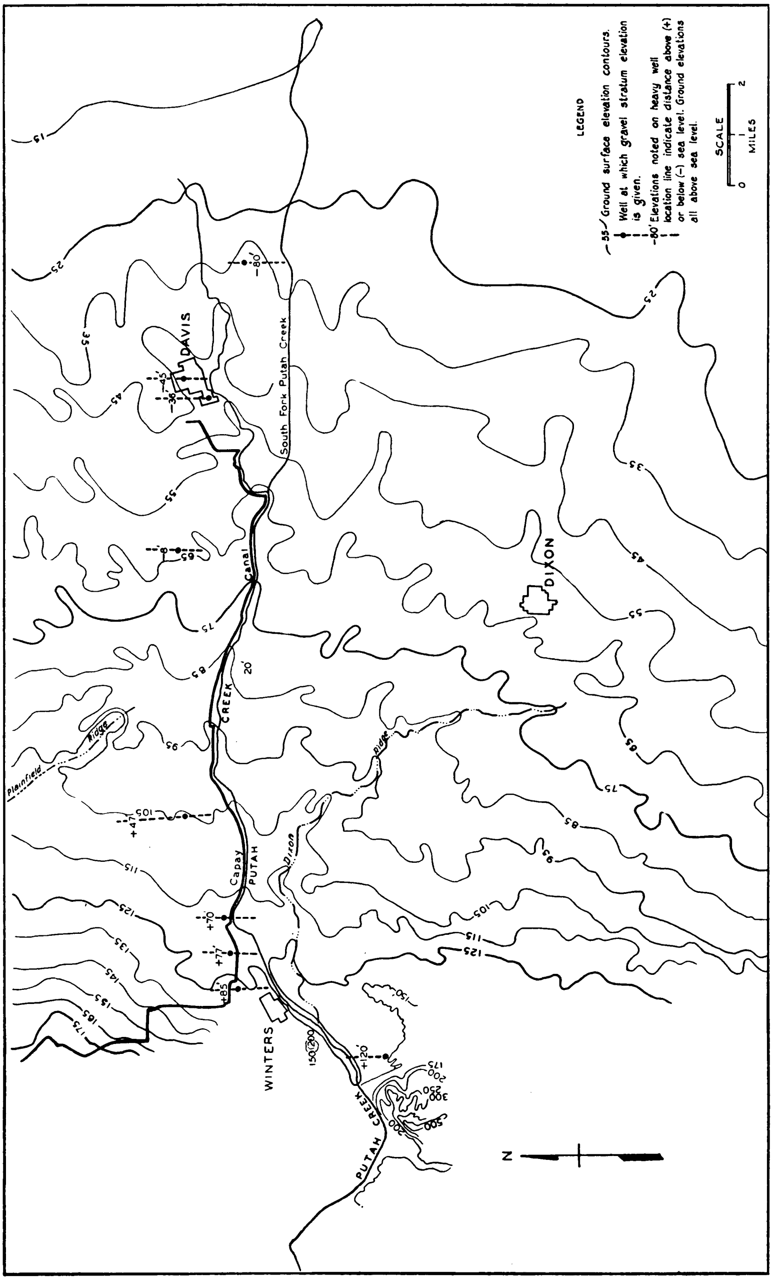

Fig. 13.—Elevations of soil surface and top of first gravel stratum on Putah Creek cone.

creek below Winters obtain their supply not from the immediate creek bed but through the water-bearing strata that tap the bed at some distance upstream.

Water Temperatures.—The temperature of the underground water is remarkably uniform, ranging from 64° to 66° F and averaging about 65°. Only one or two very deep wells give readings a few degrees higher than the average. This should be of interest to those who are interested in using air conditioning in connection with houses in this area.

TABLE 4

FLOW AND BORON CONTENT OF CACHE CREEK AND PUTAH CREEK WATERS*

Stream and sampling date	Flow, cubic feet per second	Boron content, parts per million
Cache Creek:		
December 5, 1934	150	1.02
December 30, 1934	200	6.44
February 1, 1935	510	1.45
March 4, 1935	890	1.15
May 3, 1935	350	1.98
June 2, 1935	370	2.10
July 8, 1935	224	2.34
August 1, 1935	172	2.23
September 5, 1935	131	2.46
Putah Creek:		
February 28, 1939	...	0.0
March 11, 1939	...	Trace

* Samples from Cache Creek, collected by W. D. Norton, Farm Advisor, Yolo County; analysis by United States Division of Western Irrigation, Rubidoux Laboratory, Riverside.

Boron as a Water Source Indicator.—In contrast with the uniformity of the water temperatures, there is a wide divergence in the boron content of the well waters. The data on this point are reported in tabular form in the paper by Bisson and Huberty (*1*).

As the presence of boron affords a possible means of tracing the direction of flow of underground water, supplementary data were obtained from the Cache Creek basin. The waters of Cache Creek, the next stream to the north and above Putah Creek, were known to be relatively high in boron, whereas Putah Creek was known to carry but little boron. Table 4 indicates the character of the waters from the two sources—one consistently high, the other low in boron.

If wells in the Putah Creek basin were to contain relatively high amounts of boron, one might assume that water from Cache Creek was entering the underground aquifers either artificially, via Capay Canal, or naturally. Judging from table 5, the canal and the ditches branching from it might directly influence the character of well waters. Wells above and west of the main canal showed little or no influence of the canal water, whereas the well below the canal was markedly affected. A well in permeable material immediately adjacent to a ditch (like well F) will have water similar in composition to the ditch water.

In an area about 4 miles east of Davis are several wells with water of high boron content. This is in an area where the fans of Cache and Putah Creeks merge. Those wells which are influenced by Cache Creek will have a higher boron content than those dependent upon Putah Creek.

TABLE 5

BORON CONTENT OF WELL WATERS IN RELATION TO CAPAY CANAL

Well designation and location	Date of sampling	K 10^5 at 18° C	Boron, parts per million*
A; canal	Nov. 4, 1937	59	2.97
B; well above canal, 50 feet west	Nov. 4, 1937	56	0.21
C; well above canal, ¼ mile west	Nov. 4, 1937	32	0.11
D; well above canal, 1½ miles west	Nov. 4, 1937	42	0.07
E; well below canal, ¼ mile west	Nov. 4, 1937	60	1.14
F; well at ditch bank	Jan. 7, 1936	..	1.9
	Jan. 11, 1936	..	1.75
	Jan. 28, 1936	..	1.61
	Aug. 20, 1936	..	1.65
	June 3, 1937	..	1.43
	Aug. 9, 1937	..	1.69
Ditch	May 23, 1936	..	1.74

* Analysis by Carl Hansen, Division of Pomology.

Relation of Drawdown to Discharge in Wells.—The drawdown-discharge curve for a well is obtained by plotting as coördinates the drawdown and corresponding discharge at any given time. If this point is joined by a straight line with the point of zero drawdown and zero flow, the drawdown for any intermediate discharge is located. This same line, if extended, will indicate fairly accurately the relative drawdown-to-discharge rate until the drawdown starts to uncover the upper porous water-bearing stratum tapped by the well. Since the drawdown-discharge relation holds for a single well, it might hold for a group of wells in restricted territory like that around Dixon. In other words, a given seasonal pumping load should cause a given drawdown or reduction in water levels. A rough approximation of the pumping load exists in the electric-power demand for irrigation in the area. The monthly power-consumption records for the vicinity of Dixon show 3 or 4 months during the winter when the demand is much lower than for the summer. The increase in power use corresponds to the sudden lowering of water levels in the spring; the decrease in power use, to the initial recovery of water levels in the fall.

In order to determine the amount of electrical energy devoted to irrigation pumping we may assume that the average monthly winter load is more or less constant and that we may deduct this amount from the monthly summer load. The sum of the net monthly pumping loads for the irrigation season will then constitute the seasonal power consumption.

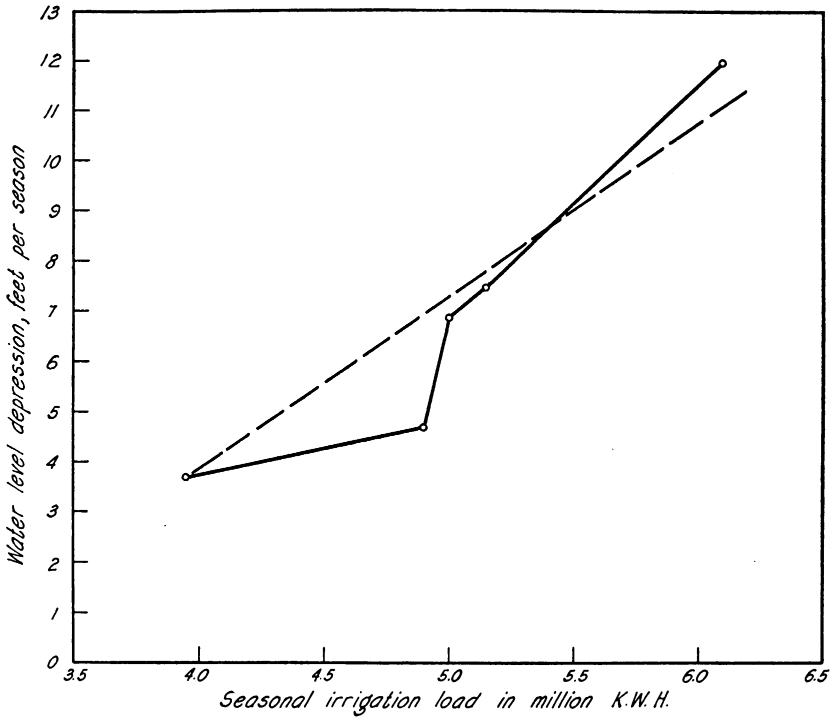

Fig. 14.—Relation between irrigation power demand and seasonal water level depression for Dixon area on Putah Creek cone. Dash line is rough average.

Figure 14, showing the result of plotting these yearly irrigation power loads against the corresponding drawdown for the area, indicates a direct relation between these factors for the Dixon area.

Recharge of Ground-Water Basin.—Stream flow in the lower basin depends upon the amount and the intensity of precipitation for there are no storage reservoirs in Putah Creek to regulate flow. This flow varies from a maximum of almost 60,000 cubic feet per second for short periods after heavy storms to nearly zero during the summer. A minimum stream flow of 4 or 5 cubic feet per second passes from the upper to the lower basin throughout the summer, but it soon disappears in the porous gravels of the lower basin. Normally no water passes the town of

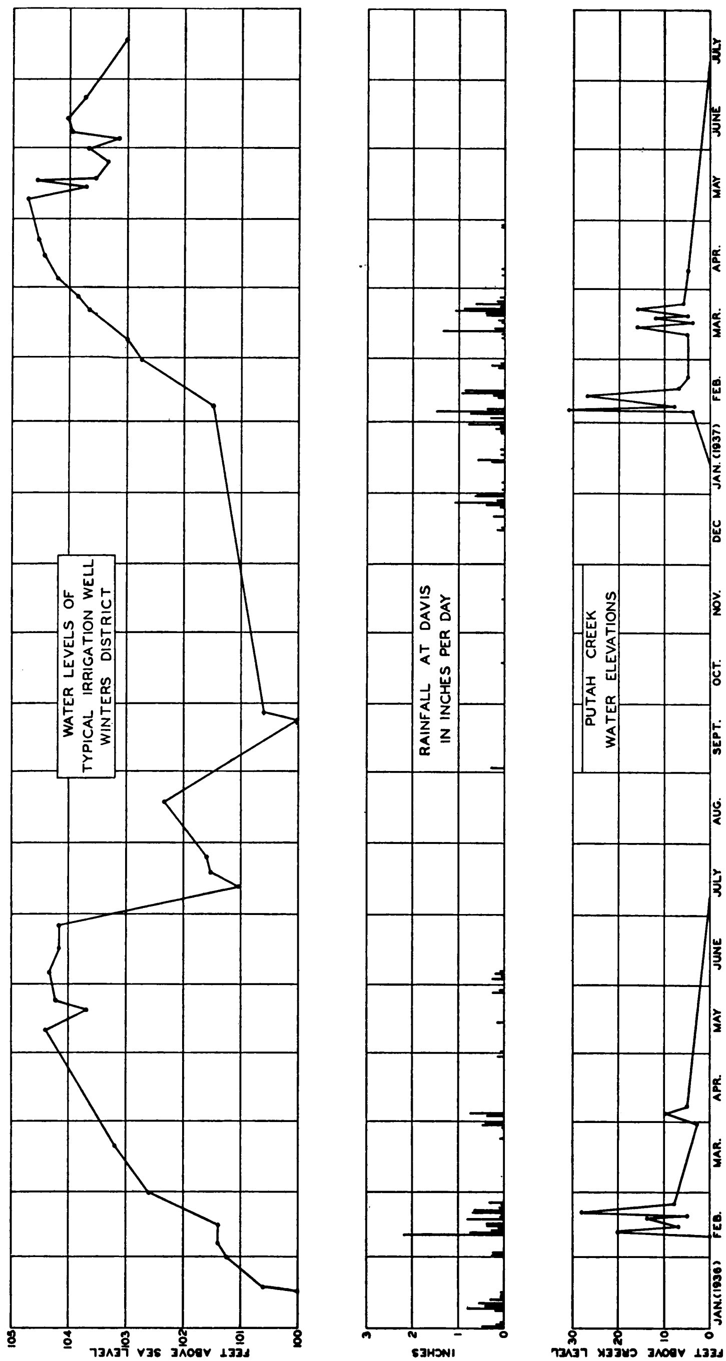

Fig. 15.—Relation between rainfall, streamflow, and well-water level for Putah Creek cone in 1936 and 1937.

Winters after July 1, percolation into the porous underground strata being at such a rate as to absorb the entire flow. That this supply does not suffice to maintain water levels even in the immediate vicinity is indicated by the lowering of levels during the pumping season.

Figure 15 portrays the rainfall and the flow in Putah Creek for 1936, showing that peaks in creek flow follow peaks in rainfall. The recovery of water levels in wells is influenced also by the presence of peak flows in the stream. As figure 15 shows, a high water crest in the creek is followed by an accelerated rise of water in the wells. This increased rate of infiltration lasts for a week or two and then subsides until a succeeding flood crest causes a further acceleration—a phenomenon indicating the close relation between stream flow and underground water supply. The lag between stream and well crests depends upon the resistance of the strata to the passage of water.

SUMMARY

Deep wells in the Putah Creek lower basin should be differentiated from shallow wells when one is studying water supplies and water tables. Although the latter wells are affected by the former, their water-level fluctuations are in general out of phase with the deeper well levels, and they normally have higher water elevations than the deep wells near by. In certain areas, such as Reclamation District 999, where shallow water strata are under pressure, the surface layers may receive some water from the pressure-bearing strata below.

Most of the ground-water supply of Putah Creek lower basin enters through the porous gravel beds near the head of the fan, in the vicinity of Winters. This finding is borne out by the accelerated recoveries of wells adjacent to the creek immediately after flood periods. This area is potentially a great spreading basin.

The boron content of the well waters varies widely. Cache Creek water imported into the district has had a marked influence upon some well waters. The data secured indicate a possible method of studying underground water movements.

The underground water temperatures are uniform throughout the basin for all but the deepest wells, which tend to be several degrees warmer than the others.

Although underground water levels in the area north of Winters have been raised since 1912 by the use of the Capay Canal water, other parts of the area have had drops in water levels of 15 to 25 feet during the period. This lowering does not represent an overdraught, but rather the changes in head resulting from increased pumping. In dry periods, the recession is greater than usual; the recharge is good during years of normal or above-normal rainfall.

ACKNOWLEDGMENTS

We wish to express our appreciation to all who have helped in the preparation of this publication, especially to Messrs. J. E. Christiansen, C. V. Givan, Albert Peterson, and Roy Wray, who collected and assembled much of the field data; to Mr. Carl Hansen, Associate in Pomology, for analyses of the boron content of water samples; to Mr. C. S. Scofield, Chief, Division of Western Irrigation, United States Department of Agriculture, for making available analyses of Cache Creek water; and to Prof. H. B. Walker, Division of Agricultural Engineering, for personal and divisional assistance.

LITERATURE CITED

1. BISSON, C. S., and MARTIN R. HUBERTY.
1941. Chemical composition of water in the Putah Creek basin. Hilgardia **14** (3):147–60.

2. BRYAN, KIRK.
1915. Ground water for irrigation in the Sacramento Valley, California. U. S. Dept. Interior, Geol. Survey, Water-Supply Paper **375**:1–49.

3. GARDNER, WILLARD, T. R. COLLIER, and DORIS FARR.
1934. Groundwater. Part I. Fundamental principles governing its physical control. Utah Agr. Exp. Sta. Bul. **252**:1–40.

4. ISRAELSEN, O. W., and W. W. MCLAUGHLIN.
1935. Drainage of land overlying an artesian groundwater reservoir. Utah Agr. Exp. Sta. Bul. **259**:1–32.

5. SLICHTER, C. S.
1905. Field measurements of the rate of movement of underground waters. U. S. Dept. Interior, Geol. Survey, Water-Supply Paper **140**:1–122.