DEPARTMENT OF THE INTERIOR
HUBERT WORK, Secretary

UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, Director

WATER-SUPPLY PAPER 495

GEOLOGY AND GROUND-WATER RESOURCES

OF

SACRAMENTO VALLEY, CALIFORNIA

BY

KIRK BRYAN

Prepared in cooperation with the Department of Engineering of the State of California

WASHINGTON
GOVERNMENT PRINTING OFFICE
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INTRODUCTION.

AGRICULTURAL AND INDUSTRIAL DEVELOPMENT OF THE GREAT VALLEY OF CALIFORNIA.

The Great Valley of California, whose alluvial plains form the largest continuous area of agricultural land in the State, comprises two divisions—Sacramento Valley at the north and San Joaquin Valley at the south. (See Pl. I.) This immense area is comparable with the valleys of the Ganges and the Nile in fertility, climate, and character of drainage system, but it is unlike those sites of ancient civilization in its relatively sparse population.

The possibilities of the Great Valley were early appreciated by the Spanish colonists of California, but the vastness of the province, its distance from Mexico, and the intractability of the northern Indians prevented them from making settlements north of Sonoma. American immigrants, beginning with Gordon, Knight, Wolfskill, and Sutter, recognized the value of Sacramento Valley for raising cattle and established ranches on lands granted by the Mexican Government. The valley was the stronghold of the Americans during the conquest in 1845, and after the discovery of gold in 1848 many of the settlers became rich by mining. The commercial production of wheat in this area was begun by Gen. John Sutter in 1843,[1] and until very recently the growing of wheat and barley by dry-farming methods has been the principal agricultural industry.

The Indians depended on the bounty of the land in fruit and game, living in gluttonous idleness in the good seasons and suffering uncomplainingly in the bad. The dry farmer prospered in careless husbandry in the good year, but stood by helpless when drought shriveled his grain in the ear or floods covered his land. The present, however, is a new era. Levees are being built to control the river floods for

[1] Bancroft, H. H., History of California, vol. 5, p. 228, and note, p. 187, 1886.

the protection of land and as an aid to navigation; irrigation systems are being constructed to use both surface and ground waters; small farm units, intensive cultivation, and high-priced crops are transforming the agricultural life of the valley. Cities born of trade and nurtured as educational and social centers are being built and with the expected low cost of power should become industrial centers.

In all this picturesque and in some respects startling change water presents a constant problem. Water in the great rivers means navigation and irrigation, requiring restraint in flood and augmentation by storage for the increase of the low-water flow. Water in its descent from the mountains furnishes electricity for light and power. In a less conspicuous way water for domestic or public supply makes possible the very existence of man. In Sacramento Valley the interrelationships of the various problems of water are most complicated. The ground-water problems are only a part of a general problem, the solution of which will determine the most economical and effective use of the resources of the valley to the advantage of its inhabitants. Although only the ground waters are discussed in this report, comprehensive plans for development should give due consideration to the present and future use of surface water for irrigation and to the related problems of reclamation and drainage.

IRRIGATION AND AGRICULTURE IN SACRAMENTO VALLEY.

The use of water for irrigation in Sacramento Valley has developed slowly and has encountered a curious apathy, in contrast to the enthusiasm for reclamation by drainage. Because of a mild climate, a concentrated winter rainfall, and a shallow water table, many field crops and deep-rooted plants thrive without irrigation. Irrigation is not a necessity; it only makes possible larger yields, the cultivation of crops with a higher return to the acre, and the cultivation of certain lands otherwise chiefly valuable for grazing. Such advantages have had little weight with owners of large holdings to whom the original cost of the land was small. However, the crowding in of home seekers from the East, the diminishing profits of grain farming, and the increase in land values have combined to bring about the subdivision and sale of many large parcels of land. To the purchasers of such tracts the advantages of irrigation appeal more strongly.

The price of land in this region is based on its anticipated value under irrigation and not on its value for dry farming. When subdivided, it is sold for two to three times its value for grain raising, and in many tracts the purchaser must provide the means of irrigation. The colonizing of subdivided lands has become a business and is in the main conducted by reputable firms. A large block of land is purchased and surveyed into small tracts with provision for roads and perhaps for a town site. Irrigation works may be provided or a demonstration well and pumping plant installed with the intention that the settlers shall install private plants, using wells for obtaining water. Purchasers are attracted by agents and advertising. Charges of fraud have been made, and doubtless some of these are justified, but wide publicity and cooperation among real-estate men are eliminating false and exaggerated statements. Intending settlers should exercise caution, view the property offered, compare it with similar offers, and be sure that they are getting good land well situated for a fair price. The value of farm land rests primarily on the quality of the soil and the value of the crops that it will produce, but the price of similar land varies with proximity to market, towns, and schools, with danger of floods and assessments for reclamation, with the kind of irrigation feasible, and with many other local factors. The formation of an intelligent judgment will be assisted by a study of reports of the United States Bureau of Soils, covering large parts of the valley, which are given in the following list:

Lapham, M. H., Root, A. S., and Mackie, W. W., Soil survey of the Sacramento area, Calif.: U. S. Dept. Agr. Bur. Soils Field Operations, 1904, pp. 1049–1087, 1 map.

Lapham, M. H., Sweet, A. T., Strahorn, A. T., and Holmes, L. C., Soil survey of the Colusa area, Calif.: Idem, 1907, pp. 927–972, 2 maps.

Mann, C. W., Warner, J. F., Westover, H. L., and Ferguson, J. E., Soil survey of the Woodland area, Calif.: Idem, 1909, pp. 1635–1689, 2 maps.

Strahorn, A. T., Mackie, W. W., Holmes, L. C., Westover, H. L., and Van Duyne, Cornelius, Soil survey of the Marysville area, Calif.: Idem, 1909, pp. 1689–1740, 1 map.

Holmes, L. C., and Eckmann, E. C., Soil survey of the Red Bluff area, Calif.: Idem, 1910, pp. 1601–1656, 1 map.

Holmes, L. C., Nelson, J. W., and party, Reconnaissance soil survey of the Sacramento Valley, Calif.: Idem, 1913, advance sheets, pp. 1–148, 1 map.

Attention should also be given to Circular 121 of the University of California Experiment Station on "Some things the prospective settler should know," by F. F. Hunt and others.

The following reports of the United States Department of Agriculture treat of various phases of irrigation and the growing of crops:

Adams, Frank, Irrigation resources of California and their utilization: Office Exper. Sta. Bull. 254, 1913.

Fortier, Samuel, Irrigation in the Sacramento Valley, Calif.: Office Exper. Sta. Bull. 207, 1909.

Fortier, Samuel, and Beckett, S. H., Evaporation from irrigated soils: Office Exper. Sta. Bull. 248, 1912.

Beckett, S. H., Progress report of cooperative irrigation experiments at California University farm, Davis, Calif., 1909–1912: U. S. Dept. Agr. Bull. 10, October 30, 1913.

Fortier, Samuel, Irrigation of alfalfa: Farmers' Bull. 373, 1909.

In the report of the Conservation Commission of California on the irrigation resources of the State, Adams[2] gives the figures on future

[2] Adams, Frank, Irrigation resources of California: California Conservation Comm. Rept. 1912, pp. 90–327.

irrigation, which have been combined with the figures of the 1920 census in the following table:

Summary of agricultural, irrigated, and irrigable lands of California.

	Agricultural land.		Irrigated land, 1919.		Estimated area that will ultimately be irrigated.		
	Acres.	Per cent of the total for California.	Acres.	Per cent of agricultural land.	Acres.	Per cent of agricultural land.	Ratio to area irrigated in 1920.
Southern California	6,070,325	27	1,035,611	17.0	1,949,600	32	2
Central California	9,665,000	44	2,356,043	24.3	4,300,000	44	2
Northern California (including Sacramento Valley)	6,201,000	28	827,384	13.3	3,510,000	56.6	4
All California	21,936,325	100	4,219,040	19.2	9,759,600	44	2
Sacramento Valley—Tehama, Butte, Glenn, Yuba, Colusa, Sutter, Yolo, Sacramento and Solano counties	3,305,000	15	472,994	14.3	2,500,000	75	5

NOTE.—Irrigation figures are taken from the irrigation census of 1920, and estimates of future irrigation are based on the most reliable data available.

It will be seen from the table that Sacramento Valley contains 15 per cent of the agricultural land of the State. Only 14.3 per cent of the area was irrigated in 1919, but it is estimated that at least 75 per cent, or five times the area irrigated in that year, will ultimately be brought under water. The area irrigated has increased nearly four times since 1909 and most of this development has taken place since this report was written. The still large possibilities have led to a rapid increase in the number of irrigation projects and an influx of men and capital from other parts of California to derive profit from the development of the land, their expectation being that the permanent future population will come from the Eastern States or from Europe.

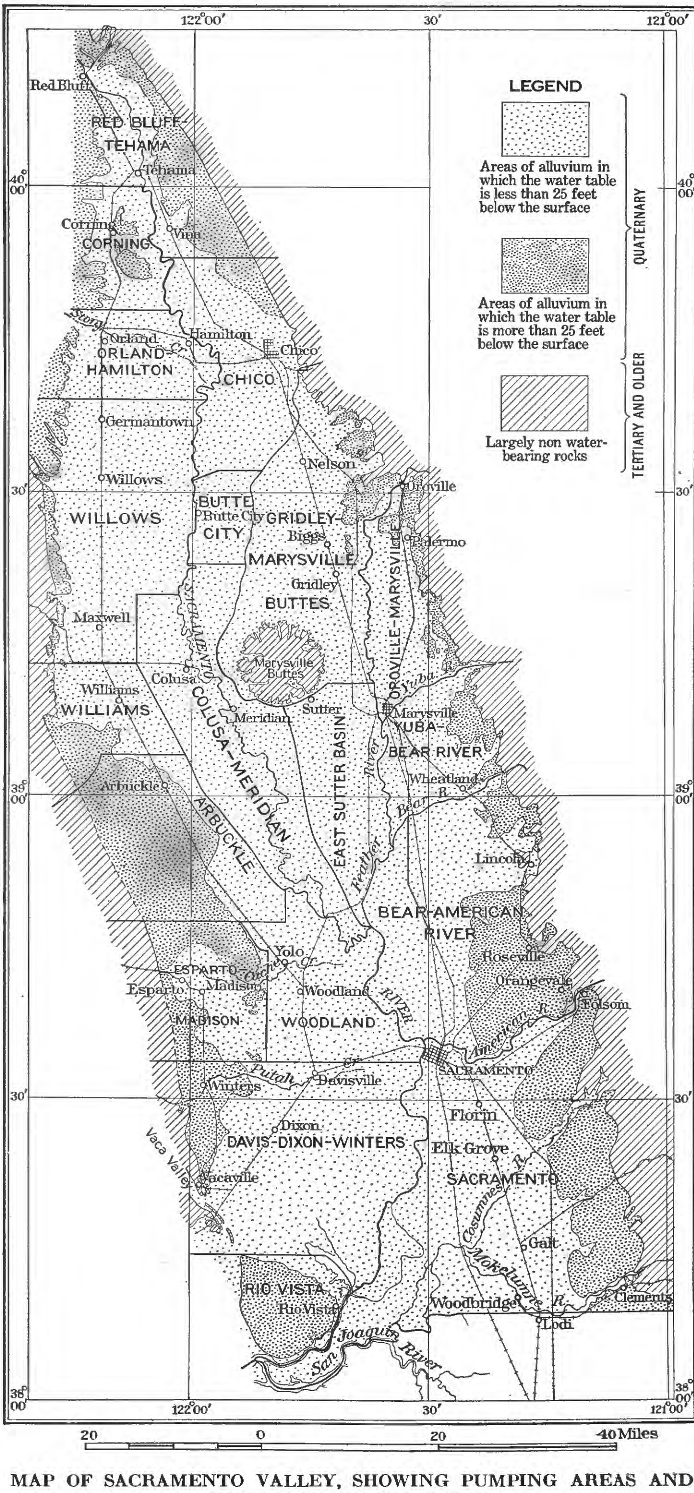
Sacramento River and its tributaries have a mean annual discharge more than sufficient to irrigate all the valley lands and maintain navigation.[3] However, gravity systems of irrigation from the rivers and streams involve heavy expenditures for diversion, storage, and the construction of laterals; legal difficulties arise; and adjustment to other water problems—especially those of navigation and flood control—is necessary. Such troubles are perhaps more apparent than real and will disappear when the common interests of the individual landowners and of the several communities are better recognized. In the meantime many enterprising men, unwilling or unable to wait for larger projects, have installed small private plants, pumping water from streams and wells. Whole communities now depend on wells for their irrigation water.

In the following table are presented the data collected in the present investigation in regard to pumping plants and the acreage of land

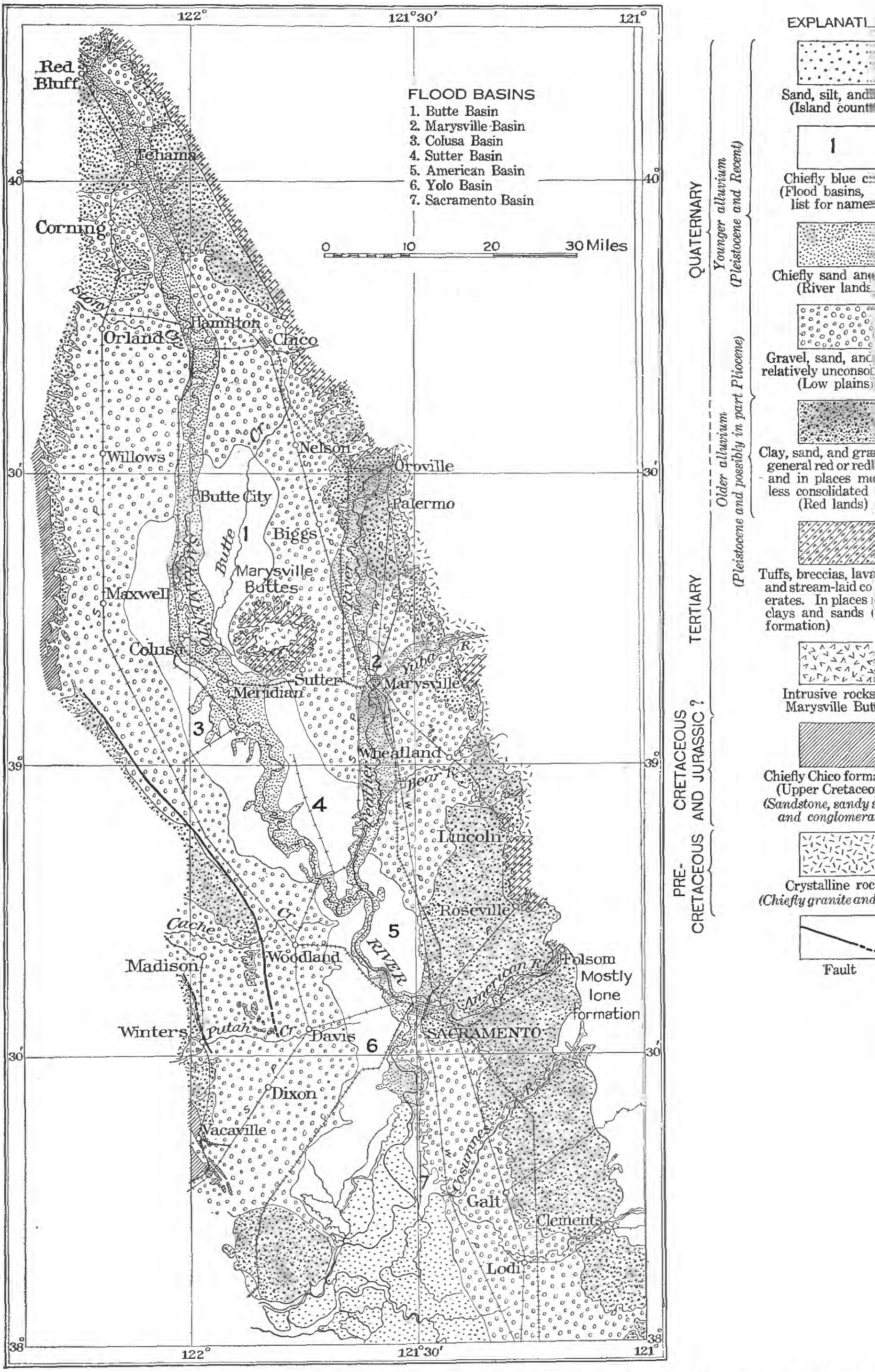
[3] Adams, Frank, op. cit., pp. 167 et seq.

RELIEF MAP OF NORTHERN CALIFORNIA

Showing boundary of Sacramento Valley and location of precipitation and stream-flow stations



MAP OF SACRAMENTO VALLEY, SHOWING PUMPING AREAS AND DEPTHS TO WATER TABLE.



MAP OF SACRAMENTO VALLEY, SHOWING GEOLOGY, PHYSIOGRAPHY, AND LOCATIO[N] OF FLOOD BASINS.

irrigated with water pumped from wells in 1913 (Sacramento County figures are for 1914). In this table the valley is divided into 19 areas in which pumping is more or less concentrated in groups. These areas, the boundaries of which are arbitrary, are shown on the map of the valley (Pl. II).

Statistics of ground-water irrigation in Sacramento Valley for 1913.

Area. (See Pl. II.)	Number of plants.	Number of owners.	Area irrigated.	Nominal electric power.	Nominal gasoline, oil, and steam power.	All power.	Average power per plant.	Average area irrigated for each plant	Average area irrigated for each horsepower.
			Acres.	*Horsepower.*	*Horsepower.*	*Horsepower.*	*Horsepower.*	*Acres.*	*Acres.*
Red Bluff-Tehama	25	8	1,387	297	30	327	13.0	55.4	4.2
Chico	16	15	1,345	375	34	409	25.5	84.0	3.3
Butte City	7	5	470	45	30	75	10.6	68.2	6.2
Gridley and Marysville Buttes	5	5	115	105	15	120	24.0	23.0	.9
Oroville-Marysville	23	23	370	150	39	189	8.2	16.1	1.9
East Sutter Basin	167	126	4,144	1,106	195	1,301	7.7	24.8	3.2
Yuba-Bear River	22	19	607	175	52	227	10.3	27.6	2.6
Bear-American River [a]	81	77	1,450	129	530	659	8.1	17.9	2.2
Corning	84	66	1,780	483	73	556	6.6	20.2	3.2
Hamilton-Orland	14	11	1,405	160	45	205	14.6	100.3	6.8
Willows	67	46	2,431	575	122	697	10.4	36.2	3.5
Williams	15	13	280	100	63	163	10.8	18.6	1.7
Colusa-Meridian	14	14	529	165	139	304	21.7	37.7	1.7
Arbuckle	7	7	70	....	28	28	4.0	10.0	2.5
Woodland	37	26	7,988	1,812	140	1,952	52.7	215.8	4.1
Esparto-Madison	10	10	148	25	60	85	8.5	14.8	1.7
Davis-Winters-Dixon	128	111	5,696	1,302	529	1,831	14.8	44.5	3.1
Rio Vista	3	3	19	20	4	24	8.0	6.3	.8
Sacramento [b]	939	837	10,625	3,661	2,329	5,990	6.3	11.3	1.7
	1,664	1,422	40,859	10,685	4,457	15,142	9.1	24.5	2.7

[a] Collected in part by J. W. Muller in 1914. [b] Collected by J. W. Muller in 1914.

In the study of this table it should be remembered that since 1913 there has been a very great increase in the number of plants pumping water from wells and in the area irrigated. The cultivation of rice, which had just reached a commercial basis in 1913, proved a profitable industry. The flat and heavy soils of the flood basins are not only suitable for the growth of rice but are easily prepared for irrigation and have a high water table. Thousands of acres heretofore of little agricultural value in Glenn, Butte, Colusa, and Sutter counties have been devoted to this crop. A large part of the water necessary for this irrigation is derived from wells. The rapid development of these regions can be seen in the following table comparing the results of the United States censuses of 1910 and 1920:

Irrigation of all kinds in four counties in which the agricultural land is largely in the Sacramento Valley, 1909 and 1919.

County.	Area irrigated (acres).		Ratio of irrigation in 1919 to irrigation in 1909.
	1909	1919	
Glenn	5,661	105,004	18 times.
Butte	28,754	93,559	3 times.
Colusa	4,276	44,097	10 times.
Sutter	1,173	42,305	36 times.
The State	2,664,104	4,219,040	1½ times.

PURPOSE AND METHODS OF GROUND-WATER SURVEY.

Recognition of the great value of the ground water of Sacramento Valley for domestic and public supplies and irrigation led the United States Geological Survey, in financial cooperation with the California State Department of Engineering, to undertake a survey of the ground waters of the valley. The writer began field work in September, 1912, and continued it until February, 1913. In June, 1913, he returned to the field and continued the work until January, 1914. During this season Chester R. Thomas acted as field assistant from July 1 to October 1. The writer also spent the month of September, 1914, in the field. Beginning in November, 1914, J. W. Muller, of the Geological Survey, spent two months in collecting statistics of pumping in Sacramento County. A preliminary statement of the results obtained by the Survey has already been published.[4]

A team of horses and a wagon were used in the work, and camp was made along the road each night. The whole valley was covered, the work consisting of three parts—(1) a general study of the physiography and geology with relation to the occurrence of ground water; (2) the collection of well data; and (3) the collection of statistics of pumping and irrigation with ground water. In the collection of well data measurements of the depth to water were made for the purpose of constructing the hydrographic contour map shown as Plate IV. For this purpose, so far as possible, measurements were made at wells not more than 1 mile apart. Each pumping plant was visited, and the area actually irrigated was determined. Some difficulty was found in deciding what should be considered a pumping plant for irrigation. Many plants with 2-inch centrifugal pumps and 5-horsepower engines that are used to obtain water for stock and domestic supply were not considered as irrigation plants; but plants of the same size near Corning, which are used for irrigating commercial orchards, were listed as irrigation plants, though they also furnish water for domestic use. In the Sacramento area the combined suburban home and small farm is so common that practically all plants are listed. Irrigation was credited to a plant only where there was evidence that the plant was so used at the time the plant was visited or where information to that effect was deemed reliable. The material thus collected is presented in the table on page 5 and in the tables of pumping plant data given under the several irrigation districts.

Samples of water were collected from 68 wells in the valley, located as shown on Plate IV. The results of examination of these samples are discussed in the section on quality of water (pp. 94–97).

The entire investigation was made under the direction of O. E. Meinzer, geologist in charge of ground-water investigations, who

[4] Bryan, Kirk, Ground water for irrigation in the Sacramento Valley, Calif.: U. S. Geol. Survey Water-Supply Paper 375, pp. 1–49, 1915.

completed certain details of the report after the author had gone to France with the American Expeditionary Forces.

ACKNOWLEDGMENTS.

The kindness and hospitality of the people of the valley were of constant assistance in the progress of the investigation. Many of the persons who supplied information regarding wells and pumping plants are mentioned in the report as the owners or managers of plants. This information was furnished freely by all concerned and was found in general to be accurate and intelligent. Special thanks are due to Mr. S. H. Beckett, of the State Agricultural Experiment Station at Davis; Mr. E. G. Linscott, of the Linscott Drilling Co.; Mr. C. E. Arnold, formerly engineer of the Sacramento Valley Sugar Co.; Mr. E. C. Mills, engineer for the Mills Orchard Co.; Mr. O. E. Oliver, general manager of the Natomas Consolidated; Mr. H. Stillman, engineer of tests for the Southern Pacific Co.; Mr. E. R. Feicht, engineer for the Sacramento Valley Sugar Co.; Mr. John P. Ryan and Thomas L. Knock & Sons, of Willows. For many personal kindnesses from the late Mr. George R. Davis and from Mr. James R. Gaskill, jr., of the local office of the Geological Survey at Sacramento, the writer wishes to express his thanks.

PHYSIOGRAPHY.

GENERAL FEATURES.

Sacramento River rises in a small lake on Mount Eddy, one of the peaks of the Trinity Mountains, about 50 miles south of the northern boundary of California. It flows eastward about 12 miles and then southward 370 miles to the head of Suisun Bay, 50 miles from San Francisco, where it unites with San Joaquin River. The source of the river is about 6,600 feet above sea level, and the upper part of the river lies in a narrow valley between rugged mountains. Fifty miles below its source the Sacramento is joined by Pit River, which at the junction carries more water than the main stream. (See p. 53.)

The fall of the Sacramento is 5,913 feet in 50 miles above the mouth of Pit River and 447 feet in the 67 miles between Pit River and Red Bluff. In the remaining 250 miles of its course the fall is only 240 feet, or less than 1 foot to the mile.

From the mouth of Pit River southward the mountains recede on each side and the river is bordered by flat flood plains and low hills as far as Red Bluff. This is the beginning of the Great Valley of California, which extends as a great plain between the bordering mountains southward to the Tehachapi Pass.

Sacramento Valley, the northern division of the Great Valley of California, is a wide plain extending from Red Bluff 150 miles to Suisun Bay. It is about 40 miles across in the widest part, and its altitudes range from slightly below sea level to a little more than 300 feet above sea level.

The term "Sacramento Valley," like many other geographic names, has been used with varied meanings. In a popular sense it is often applied to the whole drainage basin of Sacramento River, including all the country from the crests of the Coast Ranges to the crest of the Sierra Nevada, bounded on the north by the crests of the Klamath and Cascade ranges. In a more restricted sense it is used to cover only the lower lands, not the mountains, between the Coast Ranges and the Sierra Nevada as far north as Redding, in Shasta County. If the valley is considered as a structural depression [5] this use of the term is justified, but topographically the very considerable range of hills north of Red Bluff so distinctly separates the main valley from the lowland to the north that it seems best to confine the term to the country south of Red Bluff. The smaller areas of valley land north of Red Bluff may best be called by local names, such as Happy Valley, Anderson Valley, and Redding Valley. As thus defined Sacramento Valley is bounded on the east by the Sierra Nevada and the Cascade Range and on the west by the Coast Ranges and Klamath Mountains. (See Pls. I, III, and IV.)

The Sierra Nevada rises gradually from altitudes of 100 to 200 feet above sea level at the edge of the valley to a general altitude of about 8,900 feet on the crest of the range, at an average distance of about 60 miles. North of Feather River the range is surmounted by volcanic peaks 10,000 feet or more in height, but the rivers rise at lower altitudes east of the crest and break through the mountains on their way to Sacramento River. The belt of mountainous country west of the valley and tributary to it is about 35 miles wide. As far north as Stony Creek the mountains on this side belong to the Coast Ranges, and few peaks exceed 6,000 feet in elevation. North of Stony Creek the North and South Yolla Bolly Mountains, parts of the Klamath Mountains, attain altitudes between 7,000 and 8,600 feet. On the south Sacramento Valley merges with San Joaquin Valley in the network of sloughs and swamps that constitutes the island country. The southern boundary is fixed arbitrarily along the course of Mokelumne River.

In the midst of the great plain of Sacramento Valley stand the Marysville Buttes—a circular rugged mass of hills about 12 miles in diameter. North Butte and South Butte, the principal peaks, are 1,863 and 2,132 feet in altitude, respectively. The buttes are the

[5] Diller, J. S., Tertiary revolution in the topography of the Pacific coast: U. S. Geol. Survey Fourteenth Ann. Rept., pt. 2, p. 405, 1894.

remnants of an ancient volcano and project like an island above the surrounding sea of sedimentary deposits.

Sacramento Valley is largely a constructional or aggraded plain, built up with sediment brought by the streams from the surrounding mountains. For a long time the valley has been sinking and the bordering mountains have been rising. With the uplift of the mountains erosion increased and the streams carried much sediment; with the depression of the valley stream grades were decreased and the sediments were dropped. The present configuration of the plain is due largely to the forms produced by deposition of sediment. However, parts of the valley have been raised above the general level by faulting and folding, and this uplift has afforded opportunity for the streams to erode these parts and to produce hilly or rolling country that contrasts more or less strongly with the parts of the valley that are being molded entirely by aggradation.

The aggraded surface is very flat and monotonous and to the casual traveler appears as an almost limitless plain, dotted here and there with oaks and bands of woods. The horizon is obscured by an always present haze. Differences in altitude are so slight that many of them can hardly be detected without a surveyor's instrument, yet each elevation and depression has a distinctive form and meaning, which is significant in the physiographic history of the valley and in the life of the people.

The valley comprises five natural subdivisions—the red lands, the low plains, the river lands, the flood basins, and the island country.

The red lands form belts of hilly or gently undulating country that extend along both sides of Sacramento Valley, and in most places they have a general slope toward the axis of the valley. These belts were once almost as smooth and regular as the lower parts of the valley at the present time. They were constructed by the streams that flowed from the mountains into the valley and there deposited most of their burden of gravel, sand, and silt, building up these marginal belts until they formed smooth plains that sloped gently from the borders of the mountains toward the middle of the valley. These plains were then raised by warping or faulting of the earth's crust and were subsequently eroded by the same streams that built them, thus acquiring most of their present irregularities. They are hilliest and most sharply contrasted to the rest of the valley where the uplift has been most pronounced and the erosion has consequently been most active, as in the Hungry Hollow and Montezuma hills; they are gently undulating and most indefinite in outline where the uplift has consisted of only slight regional warping, as in the vicinity of Sacramento. Plate V, *B*, shows a typical orchard on the red lands, and Plate VI, *A*, the boundary between the red lands and the mountains.

The low plains lie in general between the red lands and the river lands, but in some places, where the red lands are absent, they extend to the mountains. They are somewhat lower than the red lands and are nearly level except for very gentle slopes toward the axis of the valley. These plains were built by the streams that enter the valley from the mountain borders and that have dissected the intervening red lands. They owe their remarkable smoothness to the fact that they are still in process of construction, as is fully demonstrated by frequent floods that spread over them and leave behind thin deposits of silt.

The river lands are relatively narrow belts that rise 5 to 20 feet above the adjacent lands and extend along both sides of the two master streams—Sacramento and Feather rivers. They consist of natural levees sloping very gently toward the flood basins or adjacent low plains. They have been built in times of flood with sediment deposited by the overflow of the rivers. Like the low plains, they are the result of processes that are still in operation. Although the height of these belts above the adjacent country is not great, it is sufficient to make them habitable and arable and thus to separate them rather sharply from the swampy and frequently submerged wastes through which they extend for many miles.

The flood basins are broad but shallow troughs between the low plains and the river lands. They are the lowest and flattest parts of the valley. In times of flood they are filled by the side streams that pour across the low plains in broad sheets and by the rivers which discharge into them either through definite channels or directly over the natural levees, or river lands. These basins, like the low plains and the river lands, are the result of processes of deposition that are still active, but the deposition is essentially that resulting from standing water rather than running water, and hence their surfaces are almost horizontal planes. Each basin, however, has gentle slopes toward the center and toward the downstream end. The basins differ also from the low plains and the river lands in having heavier soils, less well adapted to ordinary agriculture, but now successfully used for the cultivation of rice.

The island country of Sacramento Valley lies along the lower part of Sacramento River near its mouth and is continuous with a similar area along the lower part of San Joaquin River. It consists of numerous tracts of land each of which is surrounded by branching channels of the river. The natural levees of these channels slope away from the channels toward the centers of the islands. Thus each island has a saucer-shaped surface and under natural conditions is swampy near the center.

MOUNTAIN REGIONS TRIBUTARY TO SACRAMENTO VALLEY.

CONTIGUOUS NORTHERN REGION.

The mountainous region north of Sacramento Valley may be divided into two parts—the Klamath Mountains on the west and the Cascade Mountains on the east. Both of these ranges extend far enough south to inclose the upper part of the valley.

The Klamath Mountains embrace all the peaks and ridges lying between the fortieth and forty-third parallels of latitude and west of Sacramento River. The most conspicuous members are the Salmon, Trinity, and Scott mountains of California and the Siskiyou and Rogue River mountains of Oregon. A prong of these mountains extends southward between the Coast Range and Sacramento Valley to the headwaters of Stony Creek. The western part of this prong is called the South Fork Mountains, the eastern part the Yolla Bolly Mountains. The Yolla Bolly Mountains form a dissected platform, between 6,000 and 7,000 feet above sea level, with summits rising to higher altitudes.[a]

East of Sacramento River the Cascade Mountains consist of a broad range surmounted by volcanic cones. Of these the most prominent are Mount Shasta (altitude 14,380 feet) and Lassen Peak (altitude 10,437 feet). The western slopes are covered by thick flows of lava and tuff, now trenched by deep, steep-walled canyons. The flows extend south from Pit River in a ridge about 50 miles long and 25 miles wide to the North Fork of Feather River, which is considered the southern boundary of the Cascade Range.

SIERRA NEVADA.

The south half of the eastern border of Sacramento Valley is formed by the western slope of the Sierra Nevada, a bold continuous range about 75 miles wide.

These mountains consist of a great earth block that has been faulted and upraised on the east side, and therefore the eastern slope is abrupt and the western slope gentle. The western slope bevels across all the rock formations and represents an old land surface that was reduced by stream erosion to moderate relief and subsequently upraised and tilted toward the west. In this uplifted slope great canyons have been cut by all the major streams. It is easy to travel northeast or southwest on this slope, for the interstream areas are relatively smooth and unbroken, but travel northwest and southeast across the canyons is very difficult. The principal rivers, named in order from north to south, are the Feather, Yuba, Bear, American, Cosumnes, and Mokelumne.

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[a] Diller, J. S., Topographic development of the Klamath Mountains: U. S. Geol. Survey Bull. 196, p. 22, 1902.

The climate of the range and particularly of the western slope is in great contrast to that of the semiarid valley on the west and also of the arid region, known as the Great Basin, on the east. The annual precipitation is more than 30 inches at altitudes above 1,400 feet and as much as 70 inches at 7,000 feet. On the east side of the mountains the precipitation amounts to 30 inches only at altitudes above 6,000 feet. Between 6,000 and 9,000 feet on the western slope the soil is poor and thin because of the scouring of former glaciers. Below 6,000 feet vegetation is distributed in three well-defined zones—the well-watered, heavily forested zone between 3,000 and 6,000 feet, known as the timber belt; the drier transition belt of thin forest below 3,000 feet; and the nearly treeless rolling grassy hills below 1,500 feet.[7]

COAST RANGES.

The Coast Ranges from Stony Creek southward consist of a series of nearly parallel and somewhat rugged ridges with intervening valleys. The ridges trend west of north, so that they run out toward the sea north of Cape Mendocino and west of the southern part of the Klamath Mountains. Some of the intervening valleys are broad and rolling. The largest is occupied by Clear Lake, whose elevation is 1,325 feet above sea level and whose area at mean low water is 65 square miles.[8] The surrounding mountains rise with rugged, precipitous slopes to about 6,000 feet above sea level. The northern slopes are covered with fir, white oak, and yellow pine; elsewhere the vegetation consists of greasewood and chaparral.[9]

Cache Creek, the outlet of Clear Lake, and Putah Creek are the principal streams south of Stony Creek that discharge into Sacramento Valley from the west.

Putah Creek rises in the rugged mountains known as the St. Helena Range, whose peaks are about 5,000 feet above sea level. The lower slopes of this range support a sparse forest of oak and manzanita and a luxuriant growth of grass.

FEATURES OF THE BORDER ZONE.

FOOTHILLS OF THE CASCADE RANGE.

About 9 miles above Red Bluff Sacramento River passes through Iron Canyon, which it has cut through two projecting spurs of the Cascade Mountains. From these spurs, which are about a mile long and half a mile wide, to Chico the mountain front is remarkably smooth and regular and forms a façade that rises in a distance of less

[7] Bowman, Isaiah, Forest physiography, p. 173, 1911.

[8] Chandler, A. E., Water storage on Cache Creek, Calif.: U. S. Geol. Survey Water-Supply Paper 45, p. 32, 1901.

[9] Idem, p. 1.

A. TYPICAL HOME ON A WELL-ESTABLISHED DRY-FARM RANCH IN SACRAMENTO VALLEY.

B. ORCHARD OF ORANGE AND OLIVE TREES ON THE RED LANDS OF SACRAMENTO VALLEY.

A. BOUNDARY BETWEEN RED LANDS AND MOUNTAINS NORTH OF YUBA RIVER.

B. A DRY-FARM RANCH IN THE MONTEZUMA HILLS, SHOWING UNDULATING TOPOGRAPHY.

VIEW LOOKING NORTH ACROSS TOOMES CREEK, SHOWING THE CHICO MONOCLINE.

A. TYPICAL SLIGHTLY DISSECTED RED LANDS WITH FOOTHILLS OF THE SIERRA NEVADA IN BACKGROUND.

B. RED LANDS, SHOWING "HOG-WALLOW" MOUNDS NEAR ROSEVILLE.

than a mile from the level of the valley, about 500 feet above the sea, to an elevation of about 1,000 feet. From the top of this façade the volcanic plateau rises toward the Lassen Peak region at a rate between 100 and 200 feet to the mile. Through this smooth, regular front, which is due to monoclinal folding in middle Pleistocene time, streams from the volcanic plateau have cut V-shaped notches, the outlets of wild and desolate gorges that traverse the plateaus (Pl. VII).

Near Chico the slope formed by the monocline is less steep and prominent. South of Chico it swings to the east, and in the reentrant thus formed east of Durham it is dissected and broken into a series of promontories and detached mesas capped with lava.

From Dry Creek to Oroville the valley is bordered by a lava-capped mesa called Table Mountain, which rises about 900 feet above the adjacent red lands and low plains. Just north of Oroville there are two flat-topped lava-capped outliers—South Table Mountain and an unnamed hill north of it—which are separated from the mountains by gaps and which decrease in altitude to the west where their lava surfaces pass beneath the sedimentary deposits of the red lands. They present a steep front on all sides except the west and form particularly striking landmarks.

From Chico southward the lava plateau has a good soil and, in strong contrast to the sterile lava plateau farther north, is well forested above 1,500 feet.

FOOTHILLS OF THE SIERRA NEVADA.

The foothills of the Sierra Nevada rise from the border of the valley in a series of rounded knobs and ridges that reach progressively higher altitudes toward the east. (See Pl. VIII, *A*.) Rocky gorges and winding valleys are common. The harder rocks stand out as ridges which have a distinct northwesterly trend. The softer rocks form lower hills, more rounded summits, and gentler slopes, and the districts in which they crop out, as near Lincoln, are well suited for agriculture. The entire lower slope of the Sierra below 3,000 feet is suitable for orchard growing. It is often called the "thermal belt," because good air circulation gives it immunity from frost.

In general the foothills proper present a marked contrast to the red lands, for they support a sparse growth of chaparral, oak, and pine. Where the soils are favorable, however, oaks also grow on the higher parts of the red lands and so obscure the boundary.

From Oroville to Yuba River the red lands abut directly on a prominent ridge of diorite that shuts off from the main valley the agricultural districts of Wyandotte and Browns Valley, which are underlain by amphibolite schist. The appearance of this boundary is shown in Plate VI, *A*.

From Yuba River to American River the border of the valley is formed by flat-topped hills that present a steep face toward the mountains and a smooth, barren slope toward the valley. They are capped by resistant andesitic breccia which overlies soft Tertiary and Cretaceous sand and clay. The breccia caps are remnants of once more extensive beds which lay on the crystalline rocks of the mountains. At Lincoln the underlying rock is granodiorite and the topography is softer and more rounded. Here certain of the lava-capped hills are detached from the mountains and descend westward until the lava is partly buried by the sediments of the red lands. South of Lincoln the flat-topped andesitic hills are more conspicuous and really form the mountain front. From American River southward to the Mokelumne no lava occurs at the foot of the mountains, but the Tertiary sand and clay are very thick. There is every gradation from red lands formed of older alluvium to flat-topped hills of Tertiary clay and tuff with only a thin veneer of alluvium, and finally patches of the Tertiary beds in the form of flat-topped hills resting on rounded masses of crystalline rock.

FOOTHILLS OF THE COAST RANGES.

The larger ranges and valleys of the Coast Ranges owe their relief in large part to faulting.[10] In detail the topography is due to the relative resistance of the rocks to weathering. The sandstones and conglomerates form ridges, and the shales form valleys. As the rocks have been tilted to high angles, the ridges generally trend in the same direction, and most of the valleys are narrow.

The lowest hills are unforested and grass covered; the higher ones are covered by only a scanty growth of low trees. The linear ridges with their steep slopes make a sharp contrast with the adjacent red lands and low plains.

From Stony Creek to Williams the trend of the ridges is slightly west of north. Toward the west each succeeding ridge rises higher above the blanket of alluvium on the lowest ridges and the intervening valleys become in general narrower and higher. The lower ridges have somewhat smooth crests except where streams have cut charp V-shaped notches. These crests indicate an old plain of erosion on which the alluvium was laid down. This plain has been deformed and plunges under the valley fill on the east and rises into the mountains on the west, where it is lost in a tangle of serrate ridges.

South of Williams the ridges trend southeastward. They follow the western margin of the plateau of alluvium thrown up by the Hungry Hollow fault (see p. 79) and the fringe of alluvium of similar origin south of Esparto.

[10] Lawson, A. C., U. S. Geol. Survey Geol. Atlas, San Francisco folio (No. 193), p. 15, 1914.

Near Vacaville the ridges project into the valley toward the Montezuma Hills. They gradually decrease in altitude from 800 feet to 100 feet and are surrounded and isolated by the alluvium of the low plains. West of this line of hills between Suisun Bay and the indented and abrupt border of the mountains lies a low plain which is often called Suisun Valley. It is not properly a part of Sacramento Valley.

MARYSVILLE BUTTES.[11]

The Marysville Buttes are a cluster of hills about 10 miles in diameter, culminating in South Butte, 2,132 feet above sea level. North Butte has an elevation of 1,863 feet. The central area, about 4 miles in diameter, is composed of andesite, a lava that was pushed up from the interior of the earth in a molten but stiff condition. Around the andesite is an irregular belt of sandstone and shales of Tertiary age, bent upward by the force of intrusion of the andesite so that they dip away from the center at angles of 18° to 90°. An outer belt, about 2 miles wide, of tuffaceous breccias, consisting of angular fragments of lava of various sizes with some pebbles of other rocks, surrounds the sandstone and shales. The material of these breccia beds probably once flowed from the crater of the volcano as a thick stony mud. The streams flowing down from the buttes have broad valleys which are filled with alluvium in their lower courses. The hills have an outer slope of 250 feet to the mile and a steeper in-facing scarp or bluff. A projection of the outer slope to the center would restore the outline of the old volcano, making it about 5,000 feet high, or over twice the present height.

RED LANDS.

CHARACTER AND DEFINITION.

On both sides of the valley, lying above its flat interior parts and below the rugged foothills of the adjacent mountains, are broad belts, gently undulating and in places even hilly, which are here designated the red lands. They are variously known as "high plains," "valley plains," or simply "plains." Where much broken they are called hills, as Montezuma Hills and Hungry Hollow Hills. The name red lands is used because these belts have a somewhat red soil except between Red Bluff and Chico, and even here, where all the soils are brown because of their derivation from the Tuscan tuff, the soil of the red lands is more reddish than that of the low plains.

ORIGIN.

The red lands are composed of alluvium laid down by the streams after the adjacent mountains were uplifted. This alluvium, which

[11] Diller, J. S., and others, Guidebook of the western United States, Part D, The Shasta Route and Coast Line: U. S. Geol. Survey Bull. 614, p. 75, 1915.

is called the older alluvium, has also been uplifted and is now being dissected by the streams. The red lands are therefore deformed and eroded alluvial slopes, whose character depends on their original form, the nature of the deformation, and later erosion.

After the mountains were uplifted débris from them was deposited in the valleys, first at a rapidly increasing and then at a gradually decreasing rate. Fluctuation in the volumes of the streams produced differences in the rate, but on the whole the streams carried so much water that they swept the bulk of the material far out toward the center of the valley and dropped only small amounts immediately adjacent to the mountains. This appears to have been the method of distribution of the older alluvium, for in most places it is thin—less than 50 feet thick along the border of the valley and probably nowhere more than 400 feet except, perhaps, in the vicinity of Oroville.

The movements that uplifted the older alluvium were diverse in kind but appear to have been nearly simultaneous. Where similar material was lifted the same distance above base-level, the degree of dissection is about the same, indicating equal lengths of time for erosion, as is shown, for example, by the mature stage of erosion attained in the Montezuma Hills (see Pl. VI, *B*) and in the southern part of the Hungry Hollow Hills (Pl. IX, *B*) and the comparable degree of dissection of the red lands south of Red Bluff and between American and Mokelumne rivers. This subject is further discussed under the heading "Terraces" (p. 21).

The movements that elevated the red lands and exposed them to erosion were of three well-defined types. The uplift on the east side of the valley from Red Bluff to Chico took place along a monoclinal flexure, which affected not only the older alluvium but also the underlying Tuscan tuff. This movement resulted in the uplift of the alluvium in a narrow belt from the Iron Canyon to the Rio de los Berrendos and in a broader belt from that stream southward to Chico. On the opposite side of the valley the alluvium was uplifted on the western limb of a broad synclinal warp of slight curvature, which affected this portion of the valley. The amount of uplift was about 50 feet near the river but increased to 200 to 300 feet or more near the Klamath Mountains, 25 miles west. As a result, the older alluvium was uplifted in a belt about 12 miles wide. From Orland southward to Williams a similar uplift took place but with a greater curvature, so that the outcrop of the older alluvium forms only a fringe along the foothills that decreases in width southward as the older alluvium plunges beneath the younger alluvium with increasing dip. On the east side of the valley from Chico to Mokelumne River the uplift consisted of warping similar to that between Red Bluff and Williams. The amount and curvature of the warping were not the same in different localities, and in consequence there is considerable variation both in elevation and in slope toward the center of the valley throughout this area. From Williams southward to Vacaville there was uplift along two nearly parallel normal faults, with the upthrow on the mountain side. Of these the Hungry Hollow fault is by far the longer and more pronounced.

NORTHERN SECTION.

In the northern part of the valley, from Red Bluff to Hamilton, the red lands extend almost to the middle of the valley and Sacramento River runs in a wide, shallow trench between the discontinuous bluffs that border these lands (Pl. III).

On the east side the red lands are narrow and not sharply separated from the low plains in the vicinity of Red Bluff, but farther south they increase in width and definiteness until at Vina they are about 4 miles wide and are separated from the low plains by a bluff about 50 feet high. In this region they are cut by narrow terraced valleys which contain streams of considerable volume heading in the adjacent volcanic plateau. South of Vina the red lands become lower and narrower and disappear before reaching Chico.

West of the river the inner or eastern border of the red lands forms an almost continuous bluff from Red Bluff south to Tehama. From Tehama to the Glenn County line, near Stony Creek, the border is more broken and comes down toward the river in a series of more or less detached knolls and ridges. Below the rolling summits which give the plainlike character to the region are narrow flat-bottomed valleys of the tributary streams, from 1 to 4 miles apart. The dissection of the plain by the streams has not been a simple process, but there have been successive stages in the downcutting, as is shown by a series of terraces along the streams and by broad flats here and there that are only slightly below the general level of the plain. The soil on such flats is slightly different from that of the general surface of the red lands, which is distinguished on the soil maps under the name Tehama series.[12]

SOUTHERN SECTION.

EAST SIDE.

From Chico southward to Yuba River the red lands occupy a considerable area on each side of the deep and terraced gorge of Feather River. From Chico southward and from Yuba River northward the red lands increase from scattered patches of higher land surrounded by lowland to broader and broader tracts of highland

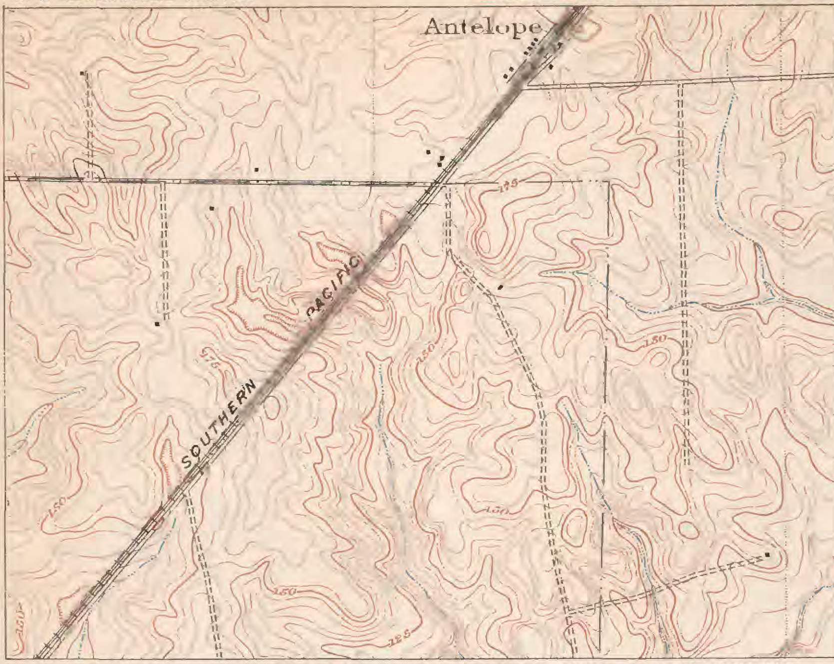
[12] Holmes, L. C., and Eckman, E. C., Soil survey of the Red Bluff area, Calif.: U. S. Dept. Agr. Bur. Soils Field Operations, 1910, map, 1912.

with flanking spurs and more or less detached knolls until on each side of Feather River they form broad bench lands from 300 to 425 feet above sea level. These bench lands slope toward the middle of the valley, and near Biggs they merge into the low plains by a smooth gradation, as if the higher plains dipped under and were submerged by a rising flood of material which now composes the low plains. South of Feather River, however, Honcut Creek and Wyman Ravine are bounded by steep bluffs and rugged hills. Here the edges of the red lands are ragged spurs and sharp slopes which are in marked contrast to the low plains that form the valleys of these streams. In the region lying south of Yuba River, east of Feather River and the American Basin, and west of the foothills, the red lands are only slightly elevated above the present level of the streams. These lands rise gradually eastward to an altitude of 100 to 300 feet, but their transition into the low plains is so gradual that their western boundary is poorly defined and must be drawn somewhat arbitrarily. A typical tract of dissected red lands is shown in Plate IX, *A*, and the general appearance of such areas in Plates V, *B*, and VIII, *A*. South of American River as far as Mokelumne River the same gradual transition in the low plains is evident, but the eastern parts of the red lands are higher and merge into flat-topped foothills of Tertiary sands and clays. Only the tops of the hills are covered with alluvium, and their form is largely the result of the erosion of the harder and older rocks. The valleys of American River, Cosumnes River, Laguna Creek, Dry Creek, and Mokelumne River divide the red lands into broad, flat-topped masses that are but slightly modified by erosion and have been dissected by minor streams only along the margins.

WEST SIDE.

Although the red lands on the west side of Sacramento Valley are less extensive than those on the east side they are much more sharply defined. This difference is due (1) to the character of the movement which uplifted the red lands and which tended to make a sharper break between them and the low plains; and (2) to the decided difference in color between the older and younger alluvium of the west side. The younger alluvium, composing the low plains, is brown or yellow, whereas the older alluvium, composing the red lands, has a decided red tinge. This contrasting color is absent in many places on the east side, where the two bodies of alluvium are of nearly the same color.

From Stony Creek south to Williams the red lands occupy very small areas flanking the foothills of the mountains. Near Willows they are 2 to 3 miles wide and rise from 100 to 200 feet above the adjacent streams. They have a greatly dissected surface that slopes abruptly from the foothills to the low plains. From Willows south

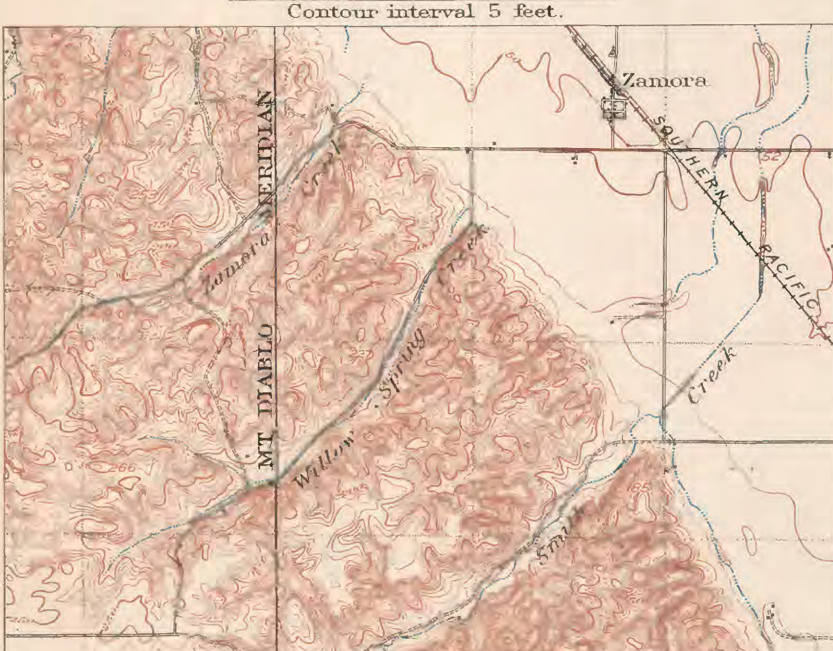


***A.* MAP OF TYPICAL RED LANDS OF THE EAST SIDE OF SACRAMENTO VALLEY, CALIF.**

Showing dissection of older alluvium.

0 ½ 1 Mile

Contour interval 5 feet.



***B.* MAP OF VICINITY OF ZAMORA, CALIF.**

Showing escarpment of Hungry Hollow Hills, position of streams cutting the escarpment, dissection of the plateau, and channel-ridged plain at foot of hills.

0 ½ 1 2 Miles

Contour interval 10 feet.

ENGRAVED AND PRINTED BY THE U. S. GEOLOGICAL SURVEY

A. VIEW OF PASKENTA, SHOWING TWO TERRACES ON THOMAS CREEK.

B. TERRACES ON THOMAS CREEK EAST OF PASKENTA.

toward Williams the red lands decrease in width and altitude and finally are represented simply by patches of gravelly soil at the base of the foothills.

The most extensive area of red lands on the west side begins at Williams and extends southeastward to Cache Creek. The southern part is called the Hungry Hollow Hills, and this name is sometimes used for the whole area as far north as Williams. It consists of a plateau from 100 to 450 feet above sea level composed of flat-lying soft alluvial materials and volcanic ash. It is bounded on the northeast by a remarkably straight and uniform escarpment produced by faulting. The streams cross the plateau from southwest to northeast flowing at right angles to this escarpment. (See Pl. IX, *B*.) In the southern part they have thoroughly dissected the plateau so that it now consists of a series of hills and valleys with remarkably steep slopes, yet each hill rises to the common level of the plateau surface. Farther north considerable tracts of the original flat-topped plateau remain. Here the altitude is great enough to assure a considerable rainfall, and a sparse forest of oak and manzanita covers the hills. The southern section, or Hungry Hollow Hills, has always been treeless and is at present wholly devoted to the growing of grain. South of Cache Creek the plateau dies out in a series of isolated rounded knolls, which rise above the low plain and may be distinguished at considerable distances by their reddish color.

South of Cache Creek, but with an offset toward the west, another tract of red lands, apparently bounded by a fault scarp, fringes the foothills, increasing in width toward the south until at Winters it is from half a mile to 2 miles wide. Southward from Winters the red lands decrease in width, and about 4 miles north of Vacaville they come to an end.

At the south end of the valley, on the north side of the narrow throat through which San Joaquin and Sacramento rivers find their way into Suisun Bay, are the Montezuma Hills. This group of hills is circular in outline, is approximately 12 miles in diameter, and on its west side abuts against somewhat detached outliers of the Coast Range. It forms a greatly dissected part of the red lands, sloping from altitudes of 250 or 300 feet above sea level on the southwest to only 25 feet on the northeast, where the hills merge with the surface of the low plains and with that of Yolo Basin. On the south and southwest the hills are bounded by sharp bluffs which overlook Sacramento River or small plains from half a mile to a mile wide, bordering the salt marshes and Suisun Bay. Although the tops of the hills rise to a common level that slopes toward the northeast, the hills are rounded, and practically no flat surfaces of the former plain remain. (See Pl. VI, *B*.) Streams working in from all directions but principally from the south and west have carved the original plateau into a maze of hills and valleys having extremely steep slopes. This dissection has been rapid and comparatively recent, for the streams have not yet developed flood plains or meanders and are still engaged in cutting down rather than in widening their valleys. Thus this plateau has about reached a stage of maturity in its erosion, yet a maturity which represents a comparatively short interval of time, because of the softness of the material in which the streams are working. The slopes of the hills, although very steep, retain a soil and are under cultivation.

EROSION IN THE RED LANDS.

The smooth slopes and rounded summits characteristic of the Hungry Hollow Hills (Pl. IX, *B*), the Montezuma Hills, and other areas of red lands (Pl. IX, *A*) are a reflection of the strictly seasonal rainfall of the valley, combined with the relatively high winter temperatures. (See pp. 45–51.) In August and September the soil is dry, hard, and commonly cracked to considerable depths. With the first rains, which usually come in October, grass springs up, either from seed or perennial rootstocks. With the usual mild winter temperatures growth of grass and other vegetation continues through the winter and culminates in the spring.

The effect of this vegetative cover on erosive processes is striking, for the surface of the ground is protected during the five winter months of rainfall, and erosion takes place under conditions similar to those of a humid climate. During the summer, when the grass dries up and the surface of the ground is least protected, so little rain falls that no erosion takes place. In effect, the seasonal rainfall of the Sacramento Valley gives the topographic results of twice the amount. The mean annual rainfall of the Hungry Hollow and Montezuma hills is between 20 and 25 inches; they have, however, the rounded forms, smooth slopes and soil of an area with 40 to 50 inches of rain. If they received 20 inches more uniformly or even irregularly distributed throughout the year, the soft sands, incoherent gravels, and clays would doubtless be carved into more irregular hills and probably into badlands. A similar analysis of topographic form might be profitably made in the lower parts of the Sierra Nevada and Coast Range.

The soils, however, because of freedom from plant growth and of thorough oxidation in the dry summer season, are similar to other arid soils in containing undecomposed feldspars and other minerals and in high nitrate content. It seems probable also that erosion, being operative for half the year only, is only half as rapid as in a humid climate.

TERRACES.

CHARACTER AND INTERPRETATION.

The streams tributary to Sacramento Valley have terraced valleys in the edges of the foothills and in the red lands. These terraces vary in height and width in the different valleys, but in any one valley they are constant in their relative height above the stream and fall into two groups—a higher group and a lower group intermediate between the upland surface of the red lands and the flood plains. The terraces occur as detached benches along the valley sides, the upper ones from 20 to 50 feet below the general upland of the red lands and the lower ones from 10 to 20 feet below these and from 5 to 20 feet above the modern flood plains (Pl. X, *A*, *B*). In some places, as in the Hungry Hollow Hills, each terrace is capped by gravel and sand from 2 to 10 feet thick.

Only the streams that rise in the mountains and cross the valley border have terraces. No terraces occur along the streams that have cut the swales in the red lands near Corning, nor along the streams of the Montezuma Hills. The Marysville Buttes have steep-sided radial valleys without terraces, which are flat-bottomed, especially near their lower ends. These valleys contain from 10 to 40 feet of alluvium, whose surface is continuous with the low plains. The buttes appear to be drowned in a rising tide of alluvium which constantly raises the local base-level of the streams and thus causes them to aggrade their valleys.

The terraces represent not less than three stages of cutting of the older alluvium. The series of events appears to have been as follows: (1) Erosion of valleys in the older alluvium; (2) deposition of sand and gravel on the floors of these valleys; (3) erosion of new valleys, leaving the remnants of the previous valley floors as the high terraces; (4) deposition of sand and gravel on the new flood plains; (5) erosion to the approximate level of the present stream channels, leaving as before the remnants of the previous valley floors as low terraces. The number of these stages appears to be the same for the whole valley. The terraces are also comparable in magnitude. They must therefore be the result of a general agency operative over the whole valley and the area draining into it.

The origin of the terraces is probably to be explained by one of the following two hypotheses: (1) That the terraces are due to stream erosion and lateral planation accompanied by incidental deposition during a series of earth movements which deformed the borders of the valley—this may be called the diastrophic hypothesis; (2) that the terraces are due to fluctuations in the ratio of sediment to volume of water, caused by changes in climate during the period of dissection of the older alluvium that followed uplift—this may be called the climatic hypothesis.

DIASTROPHIC HYPOTHESIS.

Earth movements resulting in the uplift of the bordering mountains and depression of the valley preceded deposition of the alluvium. Similar movements have continued more or less intermittently to the present day (p. 78).

The red lands were uplifted above stream grade by such movements, which were diverse in character and amount. (See p. 78.) If these uplifts occurred in a series of stages separated by pauses, with each uplift a valley would be formed in the older alluvium and some deposition of channel gravel would take place, and by renewed uplift this valley would again be cut. This series of events would form the present terraces. In any one group they could not readily be distinguished from those formed under the climatic hypothesis.

The terraces, irrespective of the locality, are the same in number and comparable in relative height. This implies an uplift of a total amount varying from 100 to 400 feet, in three stages, yet each with the same relative amount throughout the valley, the first greater than the second and the second greater than the third. For a large region such as Sacramento Valley such correspondence implies an exceeding delicacy of adjustment of the earth's crust. Study of the mechanism of the movement shows that uplift took place by faulting, monoclinal folding, and warping of several degrees of magnitude. Yet the hypothesis holds that there were three stages in uplift at many localities and that with each of these stages there were several types of uplift. The Montezuma Hills, however, in the extreme southern part of the valley, form an area of uplifted alluvium, which shows no terraces, so that the results of this uplift are strikingly different from those of other movements. Under the climatic hypothesis this exceptional condition is easily explained (p. 24).

It might be assumed that the full uplift of the older alluvium took place in a single movement of somewhat diverse character, and that the terraces are due to a change in base-level produced by changes in the outlet of the river at Carquinez Straits. Such an assumption would imply that when the tributary streams were at the level of the upper terrace Sacramento River was at a higher altitude in the middle of the valley or that the sea occupied the valley. As there are no projecting remnants of river deposits in the center of the valley nor marine fossils at shallow depths, this modification of the hypothesis appears untenable.

CLIMATIC HYPOTHESIS.

The terraces were cut at a time of fluctuating climate in the Pleistocene epoch and thus may be due primarily to a climatic cause.

If uplift of the older alluvium took place in a single movement and at a time when the volume of the streams was large in proportion to the amount of sediment, erosion of the alluvial belt between the mountains and the middle of the valley would take place easily and valleys would be formed. A change in the regimen of the streams by which the amount of water was reduced in proportion to the amount of sediment would tend to choke the channels with débris and cause deposition rather than erosion in this belt. This is illustrated by the effect upon the channels of Bear and Yuba rivers of the sediment poured into these streams by the operations of the gold mines. A return to the first condition, however, would result in the cutting of a new valley, portions of the old valley floors being left as the first or highest terrace. Completion of the cycle would form the second terrace.

If the middle of Sacramento Valley were fairly deep at the beginning of the process or sank gradually at equal pace with the filling, then there would be no evidence of fluctuation in the rate of deposition in the central region. The topography of the Marysville Buttes is quite consistent with this assumption.

Changes in climate and their effects on erosion and sedimentation extend over large areas. If the terraces of Sacramento Valley are due to climatic causes, similar terraces should occur in San Joaquin Valley. Terraces occur generally along the streams of San Joaquin Valley, but no detailed study of them has been made. In certain places there are more terraces than can be found on the streams in Sacramento Valley. On Zapato Creek, near Coalinga, Arnold and Anderson [13] noted seven terraces, and one of their photographs [14] shows at least five terraces. Some of the terraces are probably due to local deformation, but variation in the number of terraces could be caused in a number of ways under the climatic hypothesis.

1. If uplift in the several parts of the region was not synchronous but took place at different times throughout a period of fluctuating climate, streams in the areas first uplifted would show more terraces than those in areas affected later. The same number of terraces on all streams, as in Sacramento Valley, implies coincident uplift. There is, however, nothing improbable in the assumption that uplifts occurred earlier in San Joaquin Valley than they did in Sacramento Valley.

2. With coincident uplift certain terraces may be suppressed because the climatic changes occurred within so short a period after the uplift that the stream action was so controlled by the increased grade as to make climatic fluctuations ineffective.

3. A terrace may have been formed and subsequently destroyed by lateral erosion of the stream or by weathering.

[13] Arnold, Ralph, and Anderson, Robert, Preliminary report on the Coalinga oil district, Fresno and King counties, Calif.: U. S. Geol. Survey Bull. 357, p. 61, 1908.

[14] Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Coalinga district, Calif.: U. S. Geol. Survey Bull. 398, pl. 4, 1910.

4. It is doubtless true also that certain streams whose headwaters lie in the zone of maximum effect of climatic change would be more sensitive to such change than others. These streams would have terraces which recorded the minor pulsations of climate, and such terraces might be faint or lacking on other streams.

It would appear, however, that there are many more terraces along Zapato Creek than on adjacent and similar creeks. If such differences are common throughout the region, they would imply that at least some of the terraces are due to pauses in an uplift which varied locally in its rate and in its amount. Thus the occurrence of seven terraces on Zapato Creek lends strength to a hypothesis of diastrophic origin of all the terraces of the Great Valley. So far as Sacramento Valley is concerned the hypothesis of climatic origin of the terraces has by far the strongest backing, for it postulates a single earth movement, somewhat diverse in its mechanism, resulting in the uplift of the mountains and the downbowing of the valley, in contrast to a series of such movements comparable in amount in spite of variation in mechanism from place to place.

The questions then arise as to what changes of climate will produce the necessary changes in regimen of the streams and what changes in climate are possible. In regard to the first question, the known fluctuations of climate in Pleistocene time were from cold to warm; are, then, simple changes from cold to warm sufficient to give the required change in regimen of the stream?

In mountainous regions of large precipitation, such as the Sierra Nevada, increased cold would cause all the precipitation at higher levels to fall as snow. The blanket of snow would prevent increased frost action and would add to the volume and violence of the spring floods.[15] Thus with no increase in sediment there would be more effective stream action, resulting in erosion on the alluvial slopes and in the sweeping of sediment farther out into the valley. If increased cold were accompanied by increased precipitation, the effect would be accentuated not only by increase in the total run-off but also by the decrease in load resulting from a better vegetative cover on the lower slopes and foothills of the mountains, for such a cover would prevent erosion.

A change to warmer conditions would cause moisture to fall as rain, instead of snow, leading to increased frost action in the upper parts of the mountains and perhaps also to increased chemical action in the middle slopes. In addition, the run-off would be more constant throughout the rainy season and the floods of the streams would be of less volume because more prolonged. Consequently besides a probable increase in the volume of waste there would be a decrease in the

[15] Barrell, Joseph, Relation between climate and terrestrial deposits: Jour. Geology, vol. 16, pp. 174-175 1908.

effective stream volume. If this change toward warmer climate were accompanied by decreased precipitation the run-off would be further diminished, while the loss of vegetation accompanying the decrease of rainfall on the lower slopes and foothills of the mountains would bring about increased erosion and an increase in the sediment supplied to streams.

That there were changes in precipitation as well as in temperature seems to be indicated by the conditions of erosion in the Coast Ranges. In the higher parts of the Sierra Nevada active and vigorous erosion due to frost action is undoubtedly going on, but it seems probable that in the middle slopes of the mountains, where the annual rainfall is from 30 to 40 inches and the climate mild, erosion is not of great importance in furnishing material to the streams. This conclusion is based upon the fact that in the V-shaped canyons of the Yuba in the vicinity of North San Juan disintegrated granite and residual soil are found upon the steep slopes close to the river, which shows that even on the steep slopes erosion is not so vigorous as to prevent the formation of residual soils. In the Coast Ranges, however, the bulk of the mountain mass is below the level of abundant rainfall, and erosion takes place under more arid conditions. Under such conditions a change from warm to cold climate would tend to increase frost action and consequently increase the sediment supplied to the streams.[16]

For the Coast Ranges, therefore, unless increased cold is accompanied by some increase in moisture and consequent protection of the lower parts of the ranges by a forest cover, this climatic change might produce results opposite to those on the other side of the valley. As the results appear to have been similar on both sides of the valley, it is necessary to postulate changes both in temperature and in precipitation.

As to whether the cold periods of Pleistocene time were accompanied by increase in precipitation and the warm periods by decrease in precipitation no very precise conclusion has been reached. The work of Huntington[17] in central Asia has shown that glacial moraines of the mountains are associated with terraces along the rivers and with strand lines around the salt lakes in the centers of the desert basins. He concludes that these features are due to a common climatic cause, that moist epochs follow dry epochs, and that increase in moisture may be due either to heavier precipitation or to diminished evaporation because of lower temperature.

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[16] Barrell, Joseph, op. cit., p. 174.

[17] Huntington, Ellsworth, Some characteristics of the glacial period in nonglaciated regions: Geol. Soc. America Bull., vol. 18, pp. 351-388, 1907.

LOW PLAINS.

The low plains consist of very gentle alluvial slopes on the opposite sides of the valley. (See Pl. V, *A*.) They are bounded on their outer sides by the red lands or by the foothills of the mountains, and on their inner sides by the level lands known as the basins or by the river lands. They owe their form to processes of deposition which are still in action. The operation of these processes is generally recognized, even by the farmers, who take advantage of the overflow of the streams to fertilize their land and to fill low spots with sediment carried by the flood waters.

RELATION OF TOPOGRAPHIC FORM TO THE REGIMEN OF STREAMS.

Rivers tend to produce certain topographic forms by the deposition of sediment along their courses. These forms may be either evanescent or permanent. If the stream tends to pick up material which it has temporarily laid down, the topography near the channel will vary each year. If material once deposited is not again picked up, either because of decreased volume of water or because of some other change in the character of the stream, the resulting topographic forms are permanent. It is found also that these topographic forms differ according to whether the stream is perennial, intermittent, or ephemeral in its flow. The streams of the west side of the valley are largely intermittent or ephemeral; most of those of the east side are perennial. Consequently characteristics of intermittency are developed largely on the west side, the only notable exception being in the alluvial fan near Chico.

SIMPLE ALLUVIAL FANS.

Where an ephemeral or intermittent stream, carrying large quantities of relatively coarse sediment, flows from a higher area into a lower one it may build up in the lower area a sloping plain more or less semicircular in outline, having its highest point, or apex, near the debouchure of the stream. Thus the plain has the form of part of a low, flat cone. Old stream channels radiate from the apex of the cone and thus on a map it resembles a fan. Such a plain is called an alluvial cone or fan. The stream builds up its channel in periods of flood, when as it overflows its banks the velocity of the current is checked and consequently the sediment is deposited. When a channel has been built above the adjacent parts of the fan, the stream tends to break out, to take a lower course, and to build that up in turn. Consequently, the stream shifts from side to side along the radii of a circle which has its center at the point of debouchure from the higher land. As the water subsides erosion takes place and one or more channels are cut into the surface of the fan. There are two notable examples of such fans in Sacramento Valley—the Stony Creek fan and the Chico fan.

STONY CREEK FAN.

The fan of Stony Creek has its apex west of Orland, at the point where the stream enters the valley. (See Pl. IV.) The stream has swung back and forth in a quarter circle between the bluffs of the red lands on the north and the foothills of the Coast Ranges on the west. The lower slopes of the fan extend almost to Sacramento River and south as far as Willows. The fan covers an area of about 10 miles east and west and about 15 miles north and south. Stony Creek has at present a gravel-bottomed channel from an eighth to a quarter of a mile wide extending along the northern part of the fan through Orland to Sacramento River at Munroeville. It is the most southerly of the west-side streams to reach the river. During the greater part of the year there is but little water in the channel. During floods, however, the stream is wide and transports large quantities of relatively coarse material, as much as 2 inches in diameter. South of the present channel, spread out over the fan in irregular radii, are ridges of gravel that represent old channels occupied by the creek in former times.

CHICO FAN.

The Chico fan lies west and southwest of the town of Chico and is built up from the deposits of Little Chico and Chico creeks and to a minor extent from the deposits of Butte Creek. It is a rudely semicircular area about 8 miles in diameter, bounded on the north by the remnants of the dissected red lands and fading out toward the south into the upper parts of Butte Basin (Pl. III). The streams occupy channels 10 to 40 feet wide and 5 to 20 feet deep. Small amounts of water flow in these channels until late in the summer. The spring floods ordinarily overflow the banks and form broad sheets of moving water which spread over the country in all directions. The gravel in the channels is exceedingly coarse and much waterworn. The predominant pebbles are about 6 inches in diameter. The fan, however, is composed largely of fine sand or sandy loam, and the slope is more gentle and more uniform than that of the Stony Creek fan. The characteristics of this topography can be distinguished on Plate IV by careful inspection or may be seen in detail on the large scale topographic maps of the area. This difference between the two fans appears to be due to the differences in the regimen of the streams. Little Chico, Chico, and Butte creeks flow out of high, well-watered, and wooded mountains composed of relatively hard rocks. Consequently their floods are less pronounced and have longer duration. The streams overflow their channels, which are deep and relatively narrow, for only a short time, and during the remainder of the spring they are confined to the channels. Thus they deposit in their channels chiefly coarse, well-rounded gravels that can not be borne along by the relatively swift restricted streams, and during their overflow they deposit fine material only. Stony Creek, on the other hand, flows from a drier and relatively unforested range, composed of relatively soft rocks. Consequently it is characterized by more violent floods. It carries larger volumes of sediment and during the periods of highest water completely overflows and deserts its old channels, laying down mixtures of coarse and fine material. Thus, although in general the same kind of topographic form is produced on each side of the valley, a difference in the regimen of the streams, due to differences in climatic conditions and topography of the drainage basins, produces differences in detail relating not only to the width of stream channels and to the minor rugosities of the surface but also to the size and degree of sorting of the material laid down.

COALESCING FANS.

When two or more streams flow out from a highland closely adjacent to one another they may build a sloping plain which is relatively high near the highland and lower farther out and which is composed of a series of fans in whose growth there has been mutual interference. This process produces a piedmont slope or series of coalescing fans. The low plains at the foot of the Hungry Hollow Hills in the vicinity of Arbuckle consist of such a series of coalescing fans (Pl. IV). Here the streams that supply the sediment are short. They rise within the Hungry Hollow Hills and derive their sediment from the dissection of the soft alluvium of which these hills are composed. Deposition takes place only during the floods, as the streams are ephemeral not perennial. Consequently the material is poorly assorted, coarse being mixed with fine, and there are numerous irregularities of the surface due to the presence of many abandoned channels.

CHANNEL RIDGES.

On the west side of Sacramento Valley, from Willows southward to the Montezuma Hills (Pl. IV), there are many intermittent streams that issue from the foothills or red lands, loaded mainly with fine silt. These streams have built topographic features that differ markedly from those properly called fans. The channel of each stream is paralleled by raised banks that are essentially natural levees and that are built of sediment dropped by the water as it overflows in time of flood. These raised banks attain a height of 3 to 20 feet above the bottom of the channel, according to the size of the stream. The gentle outward slopes vary in width, becoming narrower downstream, and according to the size of the stream may attain a width ranging from 500 yards to 3 miles.

It is the habit of these streams, however, not merely to build up their banks but also by deposition gradually to raise their beds, the tendency being to flatten the gradients. Bed and banks together thus slowly gain in elevation until in the course of time they form a double-crested ridge that stands 10 to 25 feet above the lowland on each side. Owing to the gentleness of their outer slopes such ridges are not conspicuous topographic features; some of them, indeed, are so inconspicuous that the eye scarcely perceives them, and leveling by means of accurate instruments is necessary to indicate their presence. In time of flood, however, when the lowland on either side is inundated, their double crests often remain emergent above the water for long distances and resemble sinuous causeways or dikes. A casual inspection of the map (Pl. XI) shows that most of the farmhouses in this region are located at or near the crests of channel ridges.

Occasionally during floods the stream breaks one of its raised banks. A part or all of the water rushing through the gap and down the slope of the natural levee forms a new divergent channel, which in time is built up like the old one. The abandoned channel below the point of diversion then remains with its raised banks as a low, perhaps partly disconnected double-crested ridge. Diversions of this kind may occur at several points along the course of the stream, and thus there arises a system of irregularly forking ridges.

The ridges described are not inherently different from those produced on a larger scale by certain aggrading rivers such as the Mississippi and the Sacramento. They have, however, not been recognized as likely to occur as features of intermittent or small streams. Only slight attention has been given to them by physiographers, but features of this type in Sulphur Spring Valley, Ariz., have been described.[18] It is tentatively proposed to call them "channel ridges."

In local usage the inhabitants of Sacramento Valley generally apply the term "slough" to small streams, particularly to sluggish or swampy streams. The dry channels on abandoned channel ridges have the same form as active streams and are frequently called "dry sloughs." This term, however, seems scarcely appropriate and will not be used here.

A traveler going north or south through the western part of Sacramento Valley crosses a large number of these channel ridges. Some still contain the beds of intermittent streams; others are abandoned and permanently dry. They are especially numerous and well developed along the west side of Yolo Basin. Indeed, the low plains of this region are so largely made up of branching and interlacing channel ridges that they form a distinct type of alluvial slope which may be called a channel-ridged plain.

[18] Meinzer, O. E., and Kelton, F. C., Geology and water resources of Sulphur Spring Valley, Ariz.: U. S. Geol. Survey Water-Supply Paper 320, p. 31, 1913.

The contours representing the ridges on the map (Pl. IV) describe long loops pointing downstream and sending forth lateral loops here and there. On some ridges the channel is deep enough to be shown by a narrow reentrant loop; on others, more especially on the older abandoned ridges, the channel is too shallow to be thus indicated and the double-crested character of the ridges is not brought out. It will be seen that the gradient of the ridge crests is very low, usually 5 to 10 feet to the mile. Between the channel ridges intermittent streamlets carry off the local rain water in the hollows and assist in draining the flood waters. These streamlets thus have a minimum of sediment and some of them erode their beds and form slight gullies.

One of the largest channel ridges in Sacramento Valley and one that may be considered typical is known as Knights Landing Ridge (Pl. XI). It marks a former channel of Cache Creek called Cache Creek Slough. The ridge is about 6 miles long and fully 25 feet high. It has been built out to the very middle of Sacramento Valley, and at the time when it was built up Cache Creek must have been a tributary of Sacramento River.

VALLEY FLOOD PLAINS.

Toward the sides of Sacramento Valley the low plains merge into and are represented by the flood plains of the tributary streams. These flood plains are of two types—those of large, relatively permanent streams, which carry large quantities of water in proportion to the amount of sediment, and those of relatively minor streams, which are intermittent or ephemeral. The intermittent streams usually form alluvial plains of the several types already described, but certain of them are so inclosed between bounding valley walls that there is no opportunity for the formation of alluvial fans or channel ridges.

In the first class are the flood plains of Mokelumne, Cosumnes, and American rivers. These plains are from half a mile to 2 miles wide and lie from a few feet to 20 feet above the rivers, and through them the rivers run with sinuous but not meandering courses. The river channels are floored with gravel, but the flood plains are underlain by a few feet to 20 feet of sand, silt, and clay. During low stages the rivers occupy only their channels, where they roll along the pebbles and boulders of the channel gravels, rounding them by attrition. During floods muddy water spreads over the whole area of the flood plain and deposits the fine material, with which less well rounded gravels are somewhat rarely associated. Characteristic features of these flood plains are flood channels, abandoned river channels, and lakes formed by channels cut below the ground-water level.

The regimen of Bear and Yuba rivers has been so changed by the activities of man that the flood plains no longer present their original appearance. In 1850 Yuba River was a clear stream, flowing on a gravel bottom about 20 feet below the level of the pier at D Street in Marysville, a mile above its junction with Feather River. At the present time Marysville is inclosed in a levee to protect it from floods, and Yuba River occupies a great raised channel way from a quarter of a mile to 2 miles wide, subdivided into several braided gravelly channels (Pl. IV). During floods the river water is about 20 feet above the level of D Street in Marysville. This condition is a result of mining activities in the mountains. Large quantities of recent and ancient gravels, disturbed in washing for gold, have given to the river an excessive load of débris. This mass of material has been constantly pushed downstream by recurrent floods and is now 84 feet deep at the Narrows, in the foothills, and 7 feet deep in the neighborhood of Marysville.[19] The finer material has been largely carried away, but the coarser gravel and sand is prevented from being spread over the adjacent low plains only by artificial levees. Thus the flood plain of Yuba River, which formerly lay between inclosing banks of alluvium and merged gradually with the low plains and river bottoms near Feather River, is now raised to the level of parts of the red lands and stands as a ridge above the adjacent low plains. Consequently the country between this ridge and the ridge composed of the natural levee of Feather River has been converted into a new basin in which lies the town of Marysville.

Many small streams have flood plains along their courses through the rocks of the valley border or through the red lands. These flood plains vary in width and in the character of the material underlying them. In general they are continuous with the low plains and form connecting links, strings, and bands of more fertile and tractable soil, which extend into the red lands. (See Pl. III.)

RIVER LANDS.

PRINCIPLES OF RIVER DEPOSITION.

When the ratio of water to the amount of sediment furnished to a river is large, the river handles this sediment in suspension or by rolling it along the bottom. The river may thus maintain its gradient or may erode its bed by picking up additional material. If, however, the amount of sediment is greater, the river may be unable to carry all of it and may deposit a part. The factors that govern the transportation of sediment are five in number—(1) the slope of the channel, (2) the discharge, or volume of water, (3) the fineness of the material, (4) the form of the channel, and (5) the velocity of the water.[20]

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[19] McGlashan, H. D., and Henshaw, F. F., Water resources of California, pt. 1, Stream measurements in Sacramento River basin: U. S. Geol. Survey Water-Supply Paper 298, p. 23, 1912.

[20] Gilbert, G. K., The transportation of débris by running water: U. S. Geol. Survey Prof. Paper 86, p. 10, 1914.

These factors are interdependent, and a change in any one of them brings about a change in all the others. When, however, the discharge is constant, or is subject to recurrent oscillations of the same value, as with a single river between tributaries, then the velocity of the water is dependent largely upon the slope of the channel and the character of the material carried. The form of the channel becomes, then, largely dependent upon the factors of slope and consequent velocity, as is evident from the characteristics of Sacramento River at many points along its course. The entrance of a large tributary, by the addition of water and sediment, affects both discharge and volume of sediment and may notably change the habit of the river. The radical change in the Sacramento below the mouth of Feather River seems to be due to this cause. (See p. 36.)

As the discharge of a river varies from day to day and from season to season, it is obvious that the other four factors of river transportation are constantly changing. But as changes in the volume of water are competent to change the slope of the channel by only a small amount, and even then only by acting through considerable time, variations in discharge affect chiefly the character and amount of the material carried and the form of the channel. The topographic forms associated with Sacramento River are therefore the result of a summation of its effective discharges, which at Red Bluff range from a minimum flow of approximately 3,980 cubic feet per second to a flood discharge of approximately 254,000 cubic feet per second. Our knowledge as to the direct results of such discharges is not yet quantitative in character. It is, however, obvious from a consideration of the great rivers of the world that streams of large volume, subject to considerable seasonal variation in discharge, tend, on sufficiently flat grades, to produce topographic forms consisting of channels with natural levees and associated flood basins.

The grade of Sacramento River between Red Bluff and Stony Creek is about 2.5 feet to the mile.[21] Feather River between Oroville and Burts Ferry (near Gridley) has a grade of 4.2 feet to the mile but a smaller volume of water than the Sacramento. For these portions of their courses the two rivers develop somewhat similar topographic forms and have flood plains of a quite ordinary type.

Sacramento River from Stony Creek to Colusa has a grade of 1.3 feet to the mile, whereas Feather River from Burts Ferry to the mouth of Yuba River has a fall of 1.7 feet to the mile. Through these stretches the forms developed by the two rivers are fairly comparable, though the meanders of Feather River are smaller, probably owing to its smaller volume. Both rivers have natural levees, but the transition into the adjacent flood basins is rather vague.

[21] This and the following figures are taken from tables on pages 15, 42, 43, and 54 of Report of Commission on Rivers and Harbors to the governor of California (C. F. Reed, C. E. Grunsky, J. J. Crawford, commissioners), Sacramento, 1890.

The Sacramento from Colusa to the mouth of Feather River has a grade of 0.34 foot to the mile. Feather River from the mouth of the Yuba to its junction with Sacramento River has a grade of 1.1 feet to the mile. In these stretches the resemblance between the two rivers is not marked. This is partly due to differences in grade, but more particularly to a silting of the channel of Feather River by mining débris from Yuba and Bear rivers and levee construction along the banks of Feather River. Both rivers, however, have well-defined levees and a fairly sharp separation between the natural levees and the adjacent flood basins.

LEVEE FORMATION.

Under ordinary conditions overflow from the river channel takes place with every great flood. The water spreads as a smooth sheet over the banks. Here its velocity is checked and the sediment carried by the water is dropped, forming natural levees which constitute the river lands. Only the finest material is carried into the low lands beyond. The natural levees are consequently composed of sand and silt and have a fertile loamy soil, in contrast to the fine clay soils of the low lands that constitute the basins.

Under conditions which are defined in part below, overflow from the river channel is localized and a considerable volume of water is discharged into the overflow basins in a stream. The current of such streams breaks down the natural levee and forms a crevasse. Where an artificial levee caps the natural levee crevasses are a serious menace to life and property. Attempts to prevent crevasses and to close them when formed afford some of the most exciting and picturesque episodes of life along such rivers as the Sacramento and the lower Mississippi.

The factors which induce the formation of crevasses are imperfectly understood. A low or weak spot in the natural levee seems to be essential. The burrows of small animals, the paths of larger animals going to water, and the burning of protective vegetation seem to be minor causes that may fix the site of a break. However, the main factor appears to be the relation between deposition and the periodicity of the flood wave that induces crevasses at certain points along the main channel.

Many crevasses remain open and discharge water into flood basins whenever the river is in flood. Levee building takes place along these currents of water just as it does along the main river. In consequence sinuous double-crested ridges are built out into the flood basins. These ridges are very similar to the channel ridges of the low plains, though many of them are longer and lower. Onemile Creek, near Princeton, and Cheney Slough, which starts near Hamilton Bend, are examples of such ridges. Gilsizer Slough, which once carried flood water from Feather River at Yuba City southwestward in Sutter Basin, is a very perfect type of such a ridge (Pl. IV).

The river channel also constantly shifts in position. The movement may be slow and relatively regular, as when the banks are undermined on the outside of meanders and built up on the inside, or rapid, as when the narrow neck of a meander is cut through. These changes in the position of the channel diversify the crest of the natural levee with numerous hollows, the most notable of which are of course oxbow lakes. These features are illustrated in the detailed maps on the scale of 2 inches equals 1 mile, which are now available for nearly all the area of the Sacramento Valley. An index map for these sheets is given on Plate IV.

SACRAMENTO RIVER.

RED BLUFF TO HAMILTON.

From Iron Canyon, above Red Bluff, to Hamilton Sacramento River has built a flood plain which lies between fairly well defined bluffs and is from 1 to 3 miles wide (Pl. IV). The channel of the river is sinuous, and its bed lies 10 to 20 feet below the general level of the flood plain. It is from 300 feet to about 2,500 feet wide and includes a number of islands of considerable size, especially at the bends. These islands are of two types—(1) sand bars in wide parts of the channel rising about 10 feet above the surface of the water, such as those near Missouri Bend and Hoodlum Chute; and (2) islands that lie on one side of the main channel and are separated from the mainland by side channels or sloughs that carry only small volumes of water. The islands of the second type and their associated sloughs resemble somewhat the braided or anastomosing channels of North Platte River, in Nebraska. Mooney, Gazelle, and Foster islands are examples.

The surface of the flood plain is broken by long, shallow depressions, in general less than 10 feet deep, which are rather complicated and sinuous in pattern but have a general parallelism with the trend of the flood plain. Such channels are in part the remnants of old river channels but owe the details of their form to the washing of currents during high stages of the water, when the whole flood plain is submerged. Features of this type appear to be associated with a relatively steep, narrow flood plain and with coarse material such as this part of Sacramento River transports.

The tributary streams, notably Mill Creek and Elder Creek, have built on the flood plain small alluvial fans 10 to 30 feet high. The smaller fans appear not to influence the course of Sacramento River, but the fan of Mill Creek has forced the river toward the west in the vicinity of Tehama. These fans have a soil only slightly different from the typical loam of the river bottom, but their elevation and consequent freedom from floods tend to make them good town and house sites.

HAMILTON TO COLUSA.

From Hamilton to Colusa Sacramento River takes a general southward course marked by many meanders and irregular bends (Pl. IV). Its channel is one-eighth to five-eighths of a mile in width and has banks 10 to 20 feet high. Its natural levees form a strip of so-called river land 3 to 5 miles wide and 20 to 30 feet above Colusa Basin, which lies on the west, and Butte Basin, which lies on the east. The largest bend of the river is between Hamilton and Munroeville, where the material of the Stony Creek fan appears to have pushed the river eastward against the base of the Chico fan, but even along this bend the river has a typical meandering course (Pl. IV).

On the east side of the river near the upper end of Butte Basin there are a series of channels that parallel the river and range from 1 to 10 feet in depth and 5 to 20 feet in width (Pl. IV). The principal one, called Angel Slough, extends from a point near Chico Landing southward to a junction with Butte Creek near the Glenn County line. Many smaller channels not shown on Plate IV drain into Angel Slough. These channels are unlike the crevasse channels previously described. They appear to be due to overflows from the river in the vicinity of Hamilton and Chico Landing, which, starting as broad sheets of water, tend gradually to collect in separate channels and thus to pursue their way into Butte Basin. The balance between erosion and deposition in these channels is so even that no natural levees are formed.

Adjacent to the river are a number of oxbow lakes, which represent meanders that have recently been cut off and abandoned by the river (Pl. IV). In addition to the oxbow lakes there are smaller depressions of similar origin which are not sufficiently deep to penetrate the water table and consequently do not contain water except immediately after floods.

COLUSA TO VERNON.

From Colusa to the mouth of Feather River, at Vernon, Sacramento River pursues a general southeasterly course, approximately parallel to the escarpment of the Hungry Hollow Hills (Pl. IV). This course appears to be more or less definitely fixed at two points—at Colusa by the presence of the Marysville Buttes on the east, and in the vicinity of Vernon by the alluvial fan of Cache Creek, which tends to force the river over toward the east side of the valley. The course of the river is highly sinuous, and yet there are fewer large meanders in this stretch than north of Colusa. Oxbow lakes are not so common, though several of rather small size occur in the vicinity of Grimes and larger ones farther south, near Grand Island. The channel of the river is only one-sixteenth to one-eighth of a mile wide and is inclosed between rather regular natural levees which rise 20 to 30 feet above mean water level and slope rather abruptly toward the basins on each side.

This part of the river is marked by well-defined ridges of distributary channels extending into the adjacent basins. The most prominent of these is Sycamore Slough, which separates the upper part of Colusa Basin from the lower part. One of the most nearly perfect is the ridge called Cole Grove Point, north of Kirkville, which extends 2½ miles into Sutter Basin and has a width of approximately a quarter of a mile. (See Pl. IV.) South of Kirkville is a similar ridge except that it is recurved and not straight.

VERNON TO CLARKSBURG.

From Vernon to Clarksburg, at the head of Elkhorn Slough, the course of Sacramento River consists of a series of smooth, large bends in no way suggestive of ordinary meanders (Pl. IV). These bends are from 4 to 5 miles in length and depart from the main course of the river by about 2 miles. The channel is smooth and straight for short distances. In general it is without islands or bars and has a width of an eighth to a quarter of a mile. The natural levees, topped in most places by artificial levees, are about 10 feet above the mean water surface and are relatively narrow, sloping sharply to the basins which lie on each side. This abrupt change in the form of the river at Vernon seems to be due to the influx of the waters of Feather River and perhaps also to the effect of the tide, which before the days of hydraulic mining was felt as far north as Marysville. At present the limit of the tide is at Sacramento. Throughout this part of its course the river receives no tributary except American River at Sacramento, which approaches almost at right angles in a plain formed by the natural levees of both rivers. Before artificial works were put in this junction was a place of constantly recurring breaks in the river channel.

The only large distributary channel that leaves the river in this stretch is Babel Slough, which has formed a ridge half a mile wide and 5 to 10 feet above the adjacent parts of the river lands. This ridge extends into Yolo Basin, where it is called Willow Point (Pl. IV).

Forms resulting from breaks in the natural levees are imperfectly shown on Plate IV. These features, however, have a fan shape and resemble deltas in pattern. They are unlike the ordinary distributary channels such as Cole Grove Point, which resembles the channel ridges of the low plains of Cache and Putah creeks. It seems probable that these forms are the result of crevasses which have been open for only short periods. A succession of discharges through a crevasse is probably necessary to form a ridge.

At Clarksburg Elkhorn Slough leads off from the river toward the west. Although this channel has been artificially closed, it may be considered the beginning of the island country, or delta region.

FEATHER RIVER.

Feather River leaves the foothills of the Sierra Nevada at Oroville and flows for about 5 miles southwestward in a flat-bottomed, terraced valley (Pl. IV). On both sides of the valley are the rolling plains of the red lands. At Haselbusch the river turns sharply and, except for local bends, runs almost due south to a junction with Sacramento River at Vernon.

OROVILLE TO HASELBUSCH.

For the first part of its course Feather River has a flood plain of typical loamy soils underlain by coarse gravel deposited in the channel of the river. This flood plain has been so greatly changed by the work of the gold dredges as to have lost its original character. The dredge operations tend to pile up great mounds of gravel and completely change the local topography.

HASELBUSCH TO MARYSVILLE.

The sharp bend of the Feather near Haselbusch marks the beginning of the Feather River ridge, consisting of the natural levees of the river (Pl. IV). In great floods and under natural conditions the river is likely to break its banks at this point. It then may flow through the narrow gap between the red lands on the north and the isolated hills east of Biggs in an overflow channel now occupied by the Gridley Canal. At such times the water from this point and from points north of Honcut Creek spreads westward across Butte Basin. It is even stated that exceptional floods have jumped the channel of the Sacramento and poured into the upper part of Colusa Basin.

From Haselbusch to Gridley the flood plain of Feather River is about 4 miles wide, and through it the river pursues a somewhat irregular course, the low-water level being about 20 feet below the level of the flood plain. The flood plain is marked by a number of irregular anastomosing channels 5 to 10 feet deep and 100 to 200 feet wide, which preserve a general parallelism with the main trend of the stream. These channels appear to have been formed during high stages, when the river occupied the whole flood plain. This part of the Feather River flood plain resembles the Sacramento River flood plain between Red Bluff and Hamilton.

From Gridley to Marysville Feather River has a meandering course in which the meanders are from 1 to 4 miles apart and have radii of one-half to 1 mile. Numerous abandoned channels and oxbow lakes are characteristic of the river lands in this part of the course. At ordinary stages the river lies about 20 feet below its banks, and the banks slope away from the channel at the rate of about 5 feet to the mile toward Butte Basin on the one side and at a lesser rate and for a shorter distance toward the low plains on the other. North of Honcut Creek there is no flood basin, but the natural levee slopes toward an unnamed slough which doubtless represents an old channel of the river. The slope from the natural levee south of Honcut Creek toward the shallow depression between Yuba and Feather rivers is very gentle. This depression originally drained into the Feather at Marysville by a number of sloughs, of which Nigger Jack Slough is the principal one. The raised channel of Yuba River and artificial levees have confined the low tract on the east side of Feather River north of Marysville and prevent its direct drainage into Feather River, thus forming the new Marysville Basin. South of Gridley the river bank slopes away from the river very gently toward a flat depression which lies between Marysville Buttes and the river and which drains into the upper part of Sutter Basin.

South of Marysville the channel of Feather River is without notable meanders, though it has very considerable and somewhat irregular bends. It lies upon a relatively high ridge that slopes on both sides toward the adjacent lowlands. In the vicinity of Vernon the banks are rather low and are frequently breached in times of flood, so that the waters of the Feather pour indifferently into the Sutter Basin on the one side and into the American Basin on the other. North of this point the river is inclosed by artificial levees on both sides, which follow the somewhat irregular higher parts of the natural levees. A number of lakes, some of them long and narrow, others more or less circular and pan-shaped, exist within the levees. (See Pl. IV.) The river lands between the levees are thus quite different in character from those along other rivers. This difference has been accentuated by the tremendous quantities of sand and gravel brought down by Yuba and Bear rivers and dumped into the Feather. As there is a constant tendency for the channel of the Feather to be built higher and higher by the deposit of sand, the efforts to reclaim the adjacent land are increasingly troublesome. Moreover, the levees that have been built along the river prevent the direct access of the waters of some of the smaller tributaries, and thus Plumas and Messick lakes have been formed by the water of Reeds Creek.

The ridge of Gilsizer Slough extends from Yuba City southwestward toward Sutter Basin for a distance of 10 miles. (See Pl. IV.) This ridge stands from 5 to 10 feet above the adjacent country and has a medial depression about 10 to 15 feet deep and an eighth to a quarter of a mile wide. It represents an old distributary channel of Feather River through which its water poured into Sutter Basin. It is somewhat higher and better-drained land than the low plain bordering

Sutter Basin, over which it extends. Along this section of Feather River reclamation has been in operation a long time and has been very successful.

FLOOD BASINS.

GENERAL FEATURES.

On both sides of Sacramento River, between the natural levees and the low plains, are broad, shallow flood basins, locally known also as "tules" because of the heavy growth of tules, or rushes, which they formerly supported. There are five principal basins—Butte, Colusa, Sutter, American, and Yolo basins and two smaller ones, Marysville and Sacramento basins.

These basins are dry for the larger part of the year and sometimes for whole seasons. During floods, however, they are filled with water and constitute veritable inland seas. It has been estimated that before any reclamation had been accomplished 60 per cent of the valley was subject to overflow, including in addition to the basins the river lands and a considerable portion of the low plains.

The flood basins resemble the jheels of the Ganges plain of India, which are described by Ferguson[22] as follows:

> In India these back waters are called jheels and are large sheets of clear water existing during the cold weather at about the same level as the river. During the rains they rise nearly pari passu with the rivers, partly owing to the quantity of rain water that drains into them, partly to leakage through sandy strata, partly to small creeks or openings from the rivers, and partly also from almost all of them being open at their lower ends so as to feel the reflex of the inundation.

The flood basins can be defined either as the tracts actually covered by water during the highest known floods or as the flat areas between the sloping low plains on one side and the river lands on the other, occupied by heavy soils and commonly having either no vegetation or a strictly swamp vegetation. Under either definition the boundaries of the basins are indefinite and usually are transitional in character. In this report the term basin is used in the second sense because it is physiographically more precise and because reclamation works are continually limiting the areas covered by floods.

BUTTE BASIN.

Butte Basin lies between Sacramento River and Feather River and is bounded on the north by the Chico fan and on the south by the Marysville Buttes (Pl. III). It is a broad, flat area of dark clayey and adobe soils (Pl. XII, *B*). During general floods the basin holds a slowly moving sea of water that covers from 30 to nearly 150 square miles.

[22] Ferguson, James, The recent changes in the delta of the Ganges: Geol. Soc. London Quart. Jour., vol. 19, p. 325, 1863.

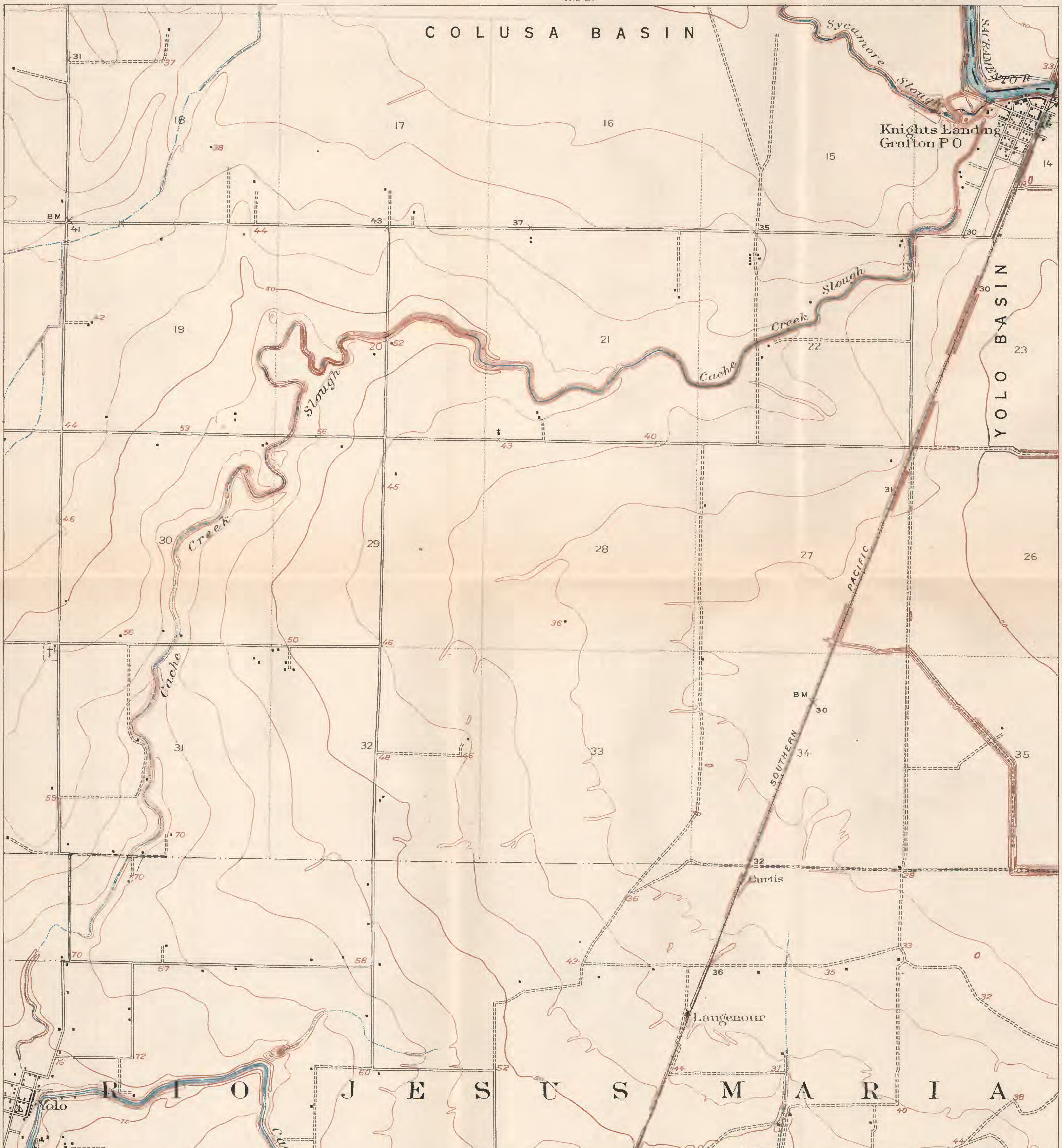
This body of water has a sloping surface dependent on the locality of greatest accession of water and a volume between 5 and 20 billion cubic feet.[23] Butte Slough, southwest of the Marysville Buttes (Pl. IV), is connected with Butte Basin, with Sacramento River, and with Sutter Basin. The water from Butte Basin drains through this slough into Sutter Basin, but at high stages of the river a water dam is formed by water pouring out of the river into Sutter Basin. Water is then backed up in Butte Basin to about the 60-foot contour, or if the basin is empty it is filled to this height. Only under exceptional circumstances does the basin drain into the river. Butte Basin is filled normally by overflow from the river south of Chico Landing through Angel and other sloughs already mentioned and by water from Chico and Butte creeks. Its exceedingly flat surface is crossed by a well-defined feature of human origin—the so-called Cherokee Canal, which is an extension of Dry Creek in a southwesterly direction across the basin and was constructed to take care of the fine débris from the famous Cherokee gold diggings. The hydraulic process of mining furnished large quantities of débris to Dry Creek, and in consequence the floods of the stream became troublesome to adjacent farmers not only because of the water but because of the sediment deposited. The canal consists of two banks or levees about one-sixteenth of a mile apart and is now in many places completely filled with sand and fine gravel.

COLUSA BASIN.

Colusa Basin lies on the west side of Sacramento River and extends from the southern part of the Stony Creek fan southward to Knights Landing (Pl. III). The basin is divided into two parts by a ridge constructed by a distributary of the river called Sycamore Slough.

The upper part of Colusa Basin, north of this slough, is approximately 35 miles long and from 1 to 6 miles wide. Along the river it is rather sharply bounded by the slope of the natural levee, but on the west side it has many indentations due to the irregularities of the low plains. The small streams that have built up the low plains in this region have formed channel ridges of light loamy soil which extend out across the clay and adobe soils of the basin. Along this boundary line ground water escapes to the surface and evaporates, producing alkaline conditions in the soil. On account of the alkali the western part of Colusa Basin is marked by large areas of salt grass and low land covered with mounds. This part is known as the "goose lands" and in addition to being subject to occasional overflow is almost worthless for ordinary cultivation unless effective

[23] Report of the Commission on Rivers and Harbors to the governor of California (C. F. Reed, C. E. Grunsky, J. J. Crawford, commissioners), p. 62, Sacramento, 1890.



MAP SHOWING THE CHANNEL RIDGE OF CACHE CREEK SLOUGH (KNIGHTS LANDING RIDGE) AND THE DIVISION BETWEEN COLUSA AND YOLO BASINS, CALIF.

Scale $\frac{1}{31680}$

1 ½ 0 1 Mile

Contour interval 5 feet.

Datum is mean sea level.

ENGRAVED AND PRINTED BY THE U. S. GEOLOGICAL SURVEY

A. LOW PLAINS, LOOKING EASTWARD ACROSS VALLEY NEAR HAMILTON.

B. BUTTE BASIN, SHOWING THE FLAT CHARACTER OF THE FLOOD BASINS.

A. BRECCIA ON BACKBONE ROAD EAST OF RED BLUFF.

B. OLDER ALLUVIUM ON TOOMES CREEK, SHOWING INDURATED CONDITION.

drainage works are constructed. Like other areas of heavy soil in the basins it is now largely used for growing rice.

The lower part of Colusa Basin has an upper portion called Mormon Basin, between Sycamore Slough and a similar ridge known as Dry Slough. The waters of the two distributary channels have built up levees of fertile soil which are in marked contrast to the other parts of the basin. As they are slightly higher than the surrounding country, they are not often overflowed, and consequently they are the sites of prosperous farms. The widest portion of Colusa Basin is south of Dry Slough. Here alkali is confined rather closely to the western border, between the flood basin and the low plains, but the central area is so subject to overflow that until the completion of the reclamation works now being built it will have little value for agriculture. Colusa Basin is separated from the upper end of Yolo Basin by a ridge from one-fourth to 1 mile wide and about 20 feet high, called the Knights Landing Ridge. This ridge has a medial groove known as Cache Creek Slough. The slough is evidently an ancient distributary of Cache Creek, and the ridge is a typical channel ridge. (See p. 30 and Pl. XI.) It marks a former junction of Cache Creek with Sacramento River, though the present channel of Cache Creek debouches into the upper end of Yolo Basin below the ridge.

The upper part of Colusa Basin is filled by overflow from the river at numerous points where the levees are weak and by back water from overflow below Colusa. The lower part of Colusa Basin is filled by overflow from the river, largely below Kirkville, and by the very considerable volume of water from the minor tributary streams. At times of very high water it overflows the Knights Landing Ridge, and the permanent reclamation of this basin can therefore be accomplished only by a canal cut through the ridge.

SUTTER BASIN.

Sutter Basin is a heart-shaped area lying between Sacramento and Feather rivers south of the Marysville Buttes (Pl. III). Its western border is 1 to 3 miles from Sacramento River. Its eastern border between Vernon and Chandler is within a mile of Feather River. North of Chandler the border of the basin swings northwestward to a rather broad transitional zone and thence to the base of the Marysville Buttes, west of the town of Sutter.

Sutter Basin is filled at every high stage of Sacramento River by back water which enters its lower end through Sacramento Slough and other outlet channels. In addition water enters from Butte Basin or from Sacramento River through Butte Slough and over the banks from Feather River. Strong levees prevent overflow from the

Feather except south of Chandler. According to the report already cited,[24]

> The elevation of high water at the mouth of Feather River in ordinary floods is about 34 feet. When Sutter Basin is full of water to this height, its surface has an area of 138 square miles and its contents range from 25 billion cubic feet of water to 39 billion, according to prevailing conditions of inflow.

In wet years much of the western part of the basin is marshy, but in dry years the entire basin becomes a great expanse of smooth, almost level barren land. Large areas are now devoted to the cultivation of rice.

AMERICAN BASIN.

The American Basin lies north of American River and south of Bear River, between the river lands of Feather and Sacramento rivers and the low plains (Pl. III). On the east side of Feather River from Yuba River southward there is a slight depression, and during great floods this depression drains into Bear River and the upper end of American Basin. In general American Basin is supplied with water by the overflow of the Bear, which since the silting of its channel has had a rather indefinite connection with Feather River, by overflow from Feather River, and by the flood waters of the minor streams. In addition high water of American River occurring during a high stage of Sacramento River overflows into the lower end of American Basin. With the completion of levees now being built Bear River will drain wholly into Feather River. Originally the basin drained into Sacramento River by a number of deep channels or sloughs. Silting of the river channel by material from Feather River has raised the low-water stage at Sacramento 7 to 8 feet, and in consequence some water remains in the lower part of American Basin throughout the year in a marshy depression known as Bush Lake.[25]

With the river at 32 feet at Sacramento in December, 1889, the water surface of the basin had an average elevation of 33 feet. The area flooded was 110 square miles, and the content of water 25 billion cubic feet. The quantity of water necessary to cause a rise or fall of 1 foot in this reservoir is equivalent to the flow of Sacramento River for 10 hours at flood stage past Sacramento.[26]

YOLO BASIN.

Yolo Basin lies between Sacramento River and the low plains on the west side from the Knights Landing Ridge southward to the Montezuma Hills (Pl. III). Its lower end is below sea level and consists of a large tidal lagoon that connects with Sacramento River. At the upper end it is separated from Colusa Basin by the Knights Landing

[24] Report of the Commission on Rivers and Harbors to the Governor of California (F. C. Reed, C. E. Grunsky, J. J. Crawford, commissioners), p. 63, Sacramento, 1890.

[25] Idem, pp. 65–66.

[26] Idem, p. 66.

Ridge. Below this ridge the waters of Cache Creek and Putah Creek find their way into the basin. During high water Yolo Basin is filled by the flood waters of these streams and particularly by the back water, which moves northward from its open lower end, advancing to a level equivalent to that of the river at the lower end of Grand Island. At times of flood its capacity is about 50 billion cubic feet.[27] In spite of the so-called Tule Canal, which traverses Yolo Basin from the sinks of Cache Creek to Washington Lake and thence south to Duck Slough, the basin contains some water even in the dry season as far north as the Southern Pacific causeway west of Sacramento and has a swamp vegetation of tule (*Scirpus lacustris*) northward as far as the Cache Creek Sink.

The western border is somewhat indefinite and is marked by two prominent projections of the low plains. Channel ridges associated with the present channel of Cache Creek extend the low plains out to the Cache Creek Sink, and similar ridges of the main channel of Putah Creek and of the artificial channel known as South Putah Creek also extend into the basin. In addition to these two main projections there are numerous minor projections into the basin due to channel ridges of old channels of Putah and Cache creeks or of minor streams. (See Pl. IV.) In the indentations of this crenulated border the ground water is near the surface and alkaline spots occur.

MARYSVILLE BASIN.

Marysville Basin is the small triangular area between the river lands of Feather River and the ridge of Yuba River (Pl. III). At its lowest point is the town of Marysville, completely surrounded by levees and thus protected from flood water. This basin is almost wholly the indirect result of the activity of man, but it appears that in past time somewhat similar basins have existed at the junction of these two rivers, because of the claylike character of the soil and the blue clay and dark sand which occur in most of the wells of Marysville. (See p. 157.)

SACRAMENTO BASIN.

Sacramento Basin is an irregular narrow basin south of the city of Sacramento, lying between the river lands of Sacramento River and the low plains of the east side, which are here somewhat dissected and form a series of low mounds or ridges, producing a very irregular eastern border. Beach Lake and Stone Lake are the lowest portions of this basin and receive the waters of a series of drainage canals and ditches. By building levees the flood waters of American and Sacramento rivers have been cut off, and this basin has practically been abolished as an overflow reservoir.

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27 Idem, p. 67.

ISLAND COUNTRY.

At Clarksburg Sacramento River begins to give off a number of minor channels, known as sloughs, which flow independently for a short distance and then unite with other sloughs or with the main river. In this fashion channel after channel leaves the river and returns to it, so that the river may be said to flow into a plexus of channels, each communicating with others and with the main channel and similarly connecting and communicating with the channels of San Joaquin River. San Joaquin and Sacramento rivers enter Suisun Bay by separate channels, confined in a gap about 4 miles wide between the Montezuma Hills and the north end of the Diablo Range. On account of the communicating channels above the river mouths parts of the discharge of Sacramento River may reach the bay through San Joaquin River, or vice versa, according to the relative stages of the two streams.

The channels of Sacramento River are bounded by natural levees that slope away from the banks, and as the channels communicate with one another the levees surround tracts of lower land, which are commonly known as islands. (See Pl. IV.) The central parts of the islands are flat and but a few feet above or below sea level. Under natural conditions these islands were covered with water throughout a large part of the year and were always flooded at high stages of the river. The tide raised and lowered the level of water over large areas, and this process helped to scour out and keep open the minor channels. Thus the immediate banks of the rivers and sloughs are made of silt and loam deposited during overflow, and the central parts of the islands are covered by peat formed by decaying vegetation which grew in the shallow bodies of water that covered them a large part of the time.

The islands therefore differ in physiographic character and in soil from the other parts of the valley. Reclamation has been most successful in this region, because the many channels of the river allow only a relatively low rise during floods, and the building of levees by dredging the river channels and piling the dredged material upon the banks is a relatively inexpensive process. Consequently each island is surrounded by an artificial levee built upon the natural levee. To dispose of rainwater and seepage from the river, a drainage canal has been cut through the central flat of each island leading toward its lowest part, and pumping stations are maintained for lifting the water over the river bank. In the long dry season irrigation has been found profitable, particularly on the higher sandy land immediately inside the levee. Here pumps are installed for taking water out of the river for irrigation, and the surplus water runs through the drainage ditches to the lower end of the island, where it is pumped back into the river. Owing to these conditions the water is completely within the control of the farmers, who can thus provide excellent cultural conditions for the naturally fertile soil.

CLIMATE.[28]

TEMPERATURE.

The mean annual temperature of Sacramento Valley is 60° at Sacramento and 63° at Red Bluff. On the mountains east and west of the valley temperatures are lower; at Summit, for example, 7,000 feet above sea level, the mean annual temperature is 42°. At Sacramento the highest temperature on record is 108° and the lowest 19°, a range of 89°. At Summit the highest temperature on record is 98° and the lowest 12° below zero, a range of 110°.

Although the prevailing winds of California are westerly, the highly accented topography of the State locally modifies or changes the direction of the wind. Sacramento Valley, being sheltered by the high Coast Ranges, is little affected by the sea breeze, which apparently gets but a short distance inland, except opposite the Golden Gate, where it reaches as far as the Montezuma Hills. Not infrequently the valley is visited by "northers"—hot, dry winds from the north, which seriously injure ripe fruit and wheat. They occur most frequently in May, June, and July. Thunder storms and tornadoes are almost unknown in the valley.

PRECIPITATION.

With all the great diversity of climate in California, ranging from torrid heat to arctic cold, from aridity to heavy rainfall and equally heavy snowfall, one climatic characteristic is common to all parts of the State—there is a wet and a dry season, corresponding to the cold and warm seasons of the States of the Atlantic coast. Of the annual precipitation in the Sacramento drainage basin 83 per cent falls from November to April, inclusive.

The cause of this unequal distribution of precipitation lies in the presence of the Pacific Ocean and the direction of the prevailing winds. Water receives heat and parts with heat more slowly than the land. Hence in the same latitude the sea is warmer than the land in winter and cooler in summer. Moreover, with its currents, tides, and waves, the sea maintains a more uniform temperature in different latitudes than the land. The prevailing westerly winds come from the Pacific laden with moisture. When such air currents reach a land that is cooler than they are, as happens in the winter, they are chilled below the point of saturation and drop a part of their moisture as rain or snow. If, on the other hand, they meet a

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[28] The description of the climate is in large part adapted from McGlashan, H. D., and Henshaw, F. F., Water resources of California, Part I: U. S. Geol. Survey Water-Supply Paper 298, 1912.

land warmer than they are, as commonly happens in summer, they pass over it with little loss of moisture.

The mean relative humidity[29] of the atmosphere in Sacramento Valley ranges from 69 per cent at Sacramento to 57 per cent at Red Bluff. On the mountains it is higher. At Sacramento the relative humidity in the wet season is 76 per cent and in the dry season 62 per cent.

The mean annual precipitation[29] ranges from 15 inches in the southern part of the valley to 25 inches in the northern part; in the foothills and mountain area it ranges generally from 20 to 60 inches and in an occasional year exceeds 100 inches. Snow begins to accumulate on the mountains in November and reaches a maximum depth of packed snow in March, when it begins to melt. Melting continues until the middle of June or first of July. The storage of precipitation in the form of snow has had a great effect on the flow of streams, those streams that head in the crest of the high mountains having a much larger flow during June, July, and August than those that head at a lower latitude.

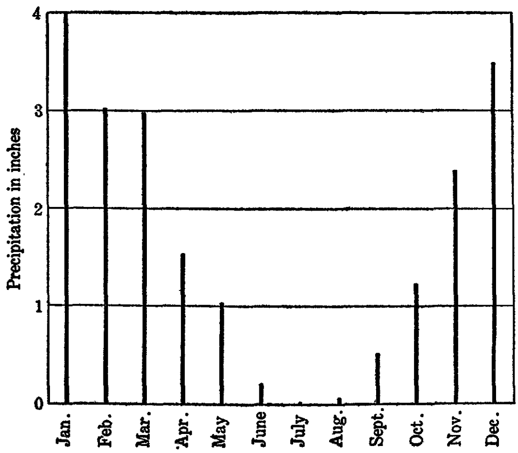

FIGURE 1.—Diagram showing average monthly precipitation in Sacramento Valley.

The mean monthly precipitation in Sacramento Valley, determined from records at 18 places prior to 1910, is shown in figure 1. January is the wettest month, having an average precipitation of about 4 inches. December has a little less than 3.5 inches. February and March have each about 3 inches. June, July, and August are almost rainless. The total for the six months April to September is about 3.4 inches and for the six months October to March about 16.9 inches.

The annual precipitation at Sacramento for the 68 years from July, 1849, to June, 1917, is shown in figure 2. Each 12-month period extends from July 1 of one year to June 30 of the following year. The mean for the 68 periods of 12 months each is 19.07 inches. It may be noted that there is a variation in the precipitation of these 12-month periods from 4.71 inches to 36.35 inches. The maximum precipitation is 1.9 times the mean for the 68 years and the mean is 4 times the minimum. The precipitation is above the mean for 29

[29] Based on data prior to 1910.

years and below the mean for 39 years. During the 55-year period 1849–1903 the greatest precipitation at Sacramento in January was 15.04 inches, in April 14.2 inches, and in December 13.4 inches. The greatest in August—the month of least precipitation—was 0.20 inch. The smallest precipitation in January during this period was 0.15 inch, in February 0.04 inch, in March 0.04 inch, and in each of the other nine months of the year 0 or a trace. Fourteen times during these 55 years the hourly rate has been greater than 0.20 inch; three times the hourly rate has been greater than 0.40; and once it was 1 inch an hour for two hours. The total precipitation in 24 hours has been 2 inches on nineteen occasions and 4 inches on four occasions. Once it was 7.24 inches in 22 hours. The increase of precipitation from Folsom, near the eastern edge of the Sacramento Valley, to

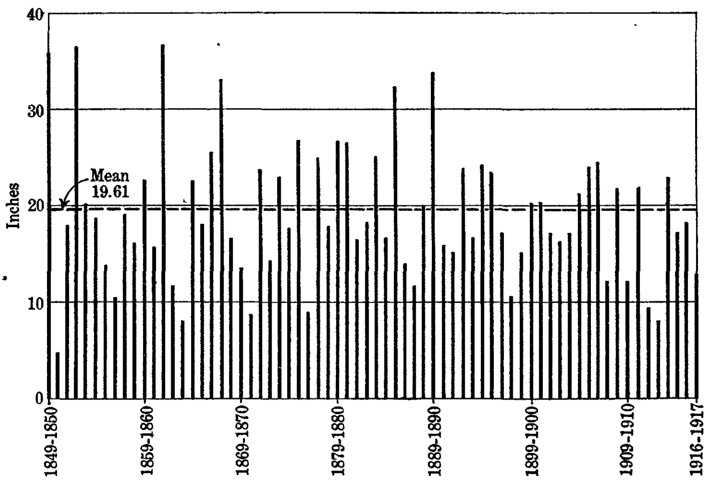

FIGURE 2.—Diagram showing annual precipitation at Sacramento, 1849–50 to 1916–17.

Colfax, is more than 1 inch for every 100 feet rise in altitude, but the increase is different for different storms.

The character of the climate is accurately reflected in the life and industries of the people. With the beginning of the rains in the fall the grass springs up and cattle and sheep are brought down from the mountains, where they have passed the summer. The overflowed tule lands in the center of the valley are grazed only in the long dry summer, and when the rains begin the cattle are moved to the higher plains. The grain farmer sows his wheat and barley in the fall and harvests them in the spring; this is called winter sowing. Or he may plow his land after the rains in the spring and let the plowed land lie fallow through the summer, to be planted before the rains in the fall; this is known as summer fallowing. Because the ground is too dry and hard to plow after the grain ripens, land that bears a crop can not be summer fallowed the same year, so that summer-fallow land has a crop only every other year. The concentration of the rainfall, with a shallow water table, enables all deep-rooted plants to survive the summer, and the mild temperatures are favorable for delicate plants. On these conditions rests the orchard industry of the valley. All the deciduous fruits bear heavy crops and are rarely damaged by frost. The more delicate fruits and nuts—apricots, almonds, walnuts, olives, lemons, and oranges—grow well and are a commercial success in favored localities. The extensive grape industry is also dependent on the climate; the less hardy varieties of the vine may be grown, and the long dry season is favorable to the concentration of sugar in the grapes and to the drying of the grapes to make raisins.

The long growing season, from February to October, makes possible the cultivation of rice, to which the clayey soils of the flat basin areas are especially adapted.

The following tables give the annual precipitation and average monthly precipitation during the periods covered by records of the United States Weather Bureau at 15 stations in Sacramento Valley. The daily and monthly records for these and other stations in the valley and for numerous stations in the areas tributary to the valley are given in the reports of the Weather Bureau.

Annual precipitation at 15 stations in Sacramento Valley.

[From records of U. S. Weather Bureau. The numbers in black-face type with the names of stations refer to corresponding numbers on Pl. I.]

Year (July 1 to June 30).	**1.** Chico.	**2.** Corning.	**3.** Davis.	**4.** Dunnigan.	**5.** Durham.	**6.** Marysville.	**7.** Orland.	**8.** Oroville.	**9.** Palermo.	**10.** Red Bluff.	**11.** Sacramento.	**12.** Tehama.	**13.** Vacaville.	**14.** Willows.	**15.** Woodland.
1849–50											36.00				
1850–51											4.71				
1851–52											17.98				
1852–53											36.35				
1853–54											20.06				
1854–55											18.62				
1855–56											13.76				
1856–57											10.46				
1857–58											14.99				
1858–59											16.04				
1859–60											22.06				
1860–61											16.18				
1861–62											36.30				
1862–63											11.59				
1863–64											7.79				
1864–65											22.59				
1865–66											17.91				
1866–67											25.32				
1867–68											32.79				
1868–69											16.64				
1869–70											13.57				
1870–71											8.47				
1871–72	31.32					21.57					28.65	6.00			
1872–73	14.64		11.95			13.10					14.19	11.05			
1873–74	25.30		18.30			27.74					22.92	14.60			23.00
1874–75	18.76		11.18			13.68					17.70	5.95			14.18
1875–76	24.70		18.72			17.86					26.30	21.19			22.14
1876–77	16.32		5.12			12.16					9.19	10.57			10.67
1877–78	34.72		20.00	22.12		23.74					24.96	29.94			26.67
1878–79	19.47		12.93	12.41		15.76				21.17	17.85	9.35			15.93
1879–80	17.55		17.03	13.93		18.93				30.36	26.47	15.65		13.96	21.67
1880–81	17.62		18.85	19.65		17.43				28.90	26.57	10.40	45.00	18.85	17.87
1881–82	16.93		11.63	11.61		14.38				21.12	16.51	12.82	20.44	8.28	12.05
1882–83	17.20		15.78	16.23		15.25				18.58	18.11	14.53	27.61	8.45	16.95
1883–84	21.44		18.80	19.67		15.26	17.83			24.01	24.78	18.20	36.74	18.84	23.74
1884–85	12.97		9.79	11.69		8.15	8.78			14.69	16.58	11.32	21.78	7.80	10.82
1885–86	26.99		24.50	29.50		22.27	21.96	31.21		35.16	32.27	23.14	37.08	19.45	23.20
1886–87	15.76	14.35	12.23	13.86		12.86	10.18	17.44		15.72	13.97	10.51	17.12	8.67	13.07
1887–88	12.97	15.38	12.00	14.35		14.28	13.52	17.76		17.27	11.56	16.18	18.02	9.92	12.79
1888–89	20.22	17.21	20.13	21.33		23.28	14.62	27.56		23.41	19.95	24.76	25.16	10.30	21.42
1889–90	37.39	34.64	37.41	37.45		38.91	27.75	49.64		41.87	33.80	38.16	50.05	29.94	30.69
1890–91	18.81	20.79	21.38	18.51		15.72	15.12	21.37		22.44	15.81	19.07	20.50	18.91	13.80

Annual precipitation at 15 stations in Sacramento Valley—Continued.

Year (July 1 to June 30).	1. Chico.	2. Corning.	3. Davis.	4. Dunnigan.	5. Durham.	6. Marysville.	7. Orland.	8. Oroville.	9. Palermo.	10. Red Bluff.	11. Sacramento.	12. Tehama.	13. Vacaville.	14. Willows.	15. Woodland.
1891–92	25.43	13.40	12.42	14.85	....	18.99	14.03	26.90	24.02	21.57	15.18	23.34	21.80	18.82	13.92
1892–93	34.42	24.16	24.31	30.58	....	22.93	24.00	28.46	27.02	32.32	23.95	51.98	28.90	27.30	21.03
1893–94	21.54	15.79	15.16	14.29	....	10.27	12.78	21.86	16.32	22.21	16.35	15.02	24.11	11.45	12.80
1894–95	37.23	33.90	22.58	28.39	....	26.83	24.66	34.48	32.10	29.71	24.11	27.83	38.91	26.04	25.88
1895–96	27.33	25.25	22.71	28.96	26.01	19.61	21.95	34.22	23.22	23.56	23.23	26.62	32.08	22.18	24.65
1896–97	26.44	25.15	18.82	21.60	25.01	17.77	22.95	29.60	25.68	25.44	17.32	21.39	29.19	18.82	17.91
1897–98	15.86	9.11	8.96	11.68	16.31	12.74	7.89	17.97	10.94	15.18	10.51	10.03	12.77	6.58	6.43
1898–99	18.85	16.34	13.19	16.82	17.38	16.53	15.39	23.47	17.70	21.68	15.04	16.92	23.22	13.05	15.15
1899–1900	23.72	25.73	13.29	19.06	28.12	28.07	18.07	34.71	27.86	23.88	20.24	20.61	19.59	15.23	15.53
1900–1901	22.12	23.76	17.79	21.08	25.39	24.02	21.13	30.17	25.90	24.64	20.21	24.23	24.34	17.49	19.63
1901–2	23.59	26.65	15.72	23.28	28.53	20.54	25.31	29.73	26.75	31.74	17.27	22.69	27.28	21.67	17.12
1902–3	24.27	18.65	16.18	17.92	22.78	21.26	17.33	24.25	25.17	24.22	16.62	20.85	21.79	17.10	14.34
1903–4	27.74	24.35	18.47	22.74	32.46	22.50	21.59	32.69	28.92	31.50	16.87	24.51	31.74	20.28	18.30
1904–5	33.00	32.30	22.75	29.12	32.11	26.50	29.18	33.44	32.77	33.82	21.98	30.57	29.28	24.55	28.29
1905–6	30.99	29.30	24.46	27.34	30.59	27.76	23.31	33.47	29.51	34.59	23.93	28.75	30.75	19.85	25.33
1906–7	28.61	19.05	23.93	26.46	29.52	32.25	14.91	37.03	31.67	27.97	24.04	21.99	28.21	17.88	24.53
1907–8	18.46	16.75	13.16	14.14	17.98	16.91	14.19	19.43	18.12	20.08	12.20	17.74	13.72	13.44	10.79
1908–9	30.61	25.03	22.07	23.00	29.31	20.72	22.17	34.11	28.47	31.13	21.78	26.63	32.92	22.09	23.00
1909–10	21.05	15.32	11.77	16.27	21.71	16.64	14.49	22.53	19.09	16.43	12.18	16.13	25.08	14.03	....
1910–11	24.86	20.94	21.23	23.97	23.75	26.42	20.83	29.06	25.64	24.70	21.98	25.80	28.70	19.43	....
1911–12	14.26	13.99	9.46	8.40	15.30	11.76	11.45	19.50	13.15	16.80	9.55	13.76	13.18	11.26	....
1912–13	21.55	16.29	8.41	11.07	24.31	10.48	13.51	21.05	13.70	18.35	8.03	16.66	26.71	9.81	....
1913–14	38.19	26.63	28.70	30.16	35.44	28.52	28.77	38.90	24.59	34.48	22.95	30.82	27.59	29.28	....
1914–15	32.73	32.97	20.05	26.16	32.48	27.57	27.78	36.82	....	34.79	17.21	32.20	35.79	27.19	....
1915–16	28.91	....	20.88	....	26.70	21.69	17.30	31.33	....	21.35	18.29	....	22.56	18.11	....
1916–17	23.88	....	14.11	....	20.79	16.14	12.27	23.81	....	19.25	12.95	....	....	11.43	....
Average	23.84	21.83	17.29	20.25	25.54	19.72	18.44	28.56	23.84	25.02	19.07	20.24	26.93	16.89	18.48

Average monthly and annual precipitation at 15 stations in Sacramento Valley.

[From records of U. S. Weather Bureau.]

Station.	No. on Plate I.	Length of record (years).	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual.
Chico	1	46	5.20	3.73	3.20	1.62	1.01	0.43	0.03	0.02	0.56	1.20	2.59	4.18	23.77
Corning	2	29	4.55	3.77	3.31	1.36	.95	.16	......	.02	.42	1.32	2.42	3.58	21.86
Davis	3	45	4.13	2.75	2.57	1.17	.72	.17	.02	.01	.26	.75	1.63	3.23	17.40
Dunnigan	4	38	4.58	2.99	2.96	1.34	.97	.20	Tr.	.01	.41	.99	2.08	3.61	20.14
Durham	5	22	6.17	3.52	3.57	1.58	1.12	.38	.01	.03	.84	1.27	2.77	3.81	25.59
Marysville	6	46	4.19	3.07	2.84	1.40	.89	.25	Tr.	.01	.35	1.09	2.17	3.57	19.80
Orland	7	34	3.91	2.89	2.67	1.16	.87	.34	.01	.01	.48	.96	2.11	3.02	18.43
Oroville	8	32	6.22	4.22	4.03	1.80	1.50	.37	.02	.02	.69	1.43	3.30	4.76	28.36
Palermo	9	23	5.04	3.88	3.72	1.54	1.30	.35	.03	.03	.70	1.27	2.77	3.28	23.90
Red Bluff	10	39	4.67	3.70	3.27	2.16	1.33	.49	.03	.02	.67	1.36	3.10	5.31	26.11
Sacramento	11	68	3.82	3.15	2.94	2.28	.96	.17	Tr.	Tr.	.36	.90	1.65	4.14	20.37
Tehama	12	44	3.55	2.75	2.86	1.27	.90	.33	.06	.04	.36	1.99	2.39	3.47	20.27
Vacaville	13	36	5.99	4.14	4.20	1.97	1.33	.16	Tr.	.03	.43	1.35	2.86	5.18	27.64
Willows	14	38	3.85	2.52	2.32	1.12	.75	.21	Tr.	.02	.36	.82	1.31	3.09	16.99
Woodland	15	36	3.83	2.81	2.54	1.33	.83	.25	Tr.	.02	.30	1.04	2.24	3.10	18.29

Mean annual temperature (°F.) at stations in Sacramento Valley.

Year.	Sacramento.[a]	Red Bluff.[b]	Summit.	Year.	Sacramento.[a]	Red Bluff.[b]	Summit.
1853	62.6			1886	58.8	63.2	41.5
1854	59.5			1887	59.9	64.4	41.9
1855	59.5			1888	61.2	64.0	43.0
1856	60.1			1889	60.9	63.2	43.4
1857	60.7			1890	59.4	61.5	
1858	59.5			1891	60.6	62.4	45.1
1859	58.7			1892	60.2	62.2	44.9
1860	59.0			1893	58.8	60.6	
1861	60.1			1894	60.3	62.0	42.0
1862	60.2			1895	60.2	62.2	
1863	60.4			1896	60.7	62.5	
1864	62.8			1897	59.8	62.0	
1865	61.0			1898	59.5	62.5	
1866	62.1			1899	59.6	62.4	
1867	59.9			1900	59.9	62.5	
1868	60.1			1901	60.1	63.1	
1869	60.4			1902	59.2	61.4	
1870	59.6			1903	59.4	61.5	
1871	59.6			1904	60.1	62.8	45.9
1872	60.4	63.8		1905	59.7	62.9	46.8
1873	60.7	64.0		1906	60.4	62.9	48.8
1874	59.8	62.5		1907	59.6	61.2	39.3
1875	62.5	68.7	43.2	1908	59.7	62.2	42.2
1876	61.7	65.0	42.5	1909	59.7	62.1	43.9
1877	62.3	66.0	42.9	1910	59.9	62.9	45.6
1878	61.3	64.0	42.2	1911	58.4	61.1	40.1
1879	60.3	63.3	42.7	1912	59.3	60.8	38.2
1880	57.2	61.8	39.2	1913	60.4	62.5	41.0
1881	59.2	62.1	41.1	1914	59.8	62.4	42.2
1882	58.5	61.6		1915	60.4	62.2	
1883	58.8	61.5	40.8	1916	59.5	61.3	39.7
1884	58.8	60.8	38.5	1917	60.7	63.2	
1885	61.2	64.4	42.2	1918			

[a] Record to July, 1877, by State Board of Health; subsequent record by U. S. Weather Bureau.
[b] Record to July, 1877, by Central Pacific Railroad Co.; subsequent record by U. S. Weather Bureau.

NOTE.—Highest temperature on record at Sacramento 110°, at Summit 90°; lowest temperature on record at Sacramento 19°, at Summit —8°. (Extremes to include August, 1918.)

SURFACE WATERS.[30]

SACRAMENTO RIVER.

The mountain torrent that forms the head of Sacramento River issues from a small lake lying 6,600 feet above sea level on Mount Eddy, one of the peaks of the Trinity Mountains, a part of the Klamath Mountains. About 8 miles east of this lake, or 12 miles by the course of the stream, it receives Wagon Valley Creek, which is fed by springs emerging from the lava beds at the southwest base of Mount Shasta. These springs are frequently referred to as the source of the Sacramento. At a point 370 miles south of its junction with Wagon Valley Creek Sacramento River unites with the San Joaquin and enters Suisun Bay, 50 miles from San Francisco.

The river is joined by numerous tributaries from the east and west. Those coming from the Sierra Nevada flow almost southwest; those from the Coast Ranges flow in a general easterly direction. The broad western slope of the Sierra furnishes by far the greater part of the drainage and all the large tributaries. Most of the streams from the Coast Ranges do not reach the Sacramento directly but become lost "in the intricate plexus of sloughs which meander through the tule lands bordering the main river. On the east, also, only the larger tributaries reach the Sacramento by a definite channel, and often that becomes an exceedingly tortuous one."[31]

Of the total fall of the river—6,600 feet from source to sea level—5,913 feet occurs in the 56 miles above the mouth of Pit River and 447 feet more in the 67 miles between Pit River and Red Bluff, leaving only 240 feet of fall for the remaining 250 miles of course. The distribution of the fall is indicated by the following table:

Distances and altitudes along Sacramento River from source to mouth.

	Total distance.	Altitude above sea level.	Distance between points.	Fall between points.	Fall per mile.
	Miles.	*Feet.*	*Miles.*	*Feet.*	*Feet.*
Source	0	6,600			
Mouth of Wagon Valley Creek	12	3,400	12	3,200	266
Delta	40	1,000	28	2,400	86
Mouth of Pit River	56	687	16	313	20
Bridge above Redding	76	500	20	187	9
Red Bluff	123	240	47	260	5.5
Tehama	140	190	17	50	3
Mouth of Stony Creek	177	140	37	50	1.3
Junction with San Joaquin River	370	0	193	140	.8

Above the mouth of Pit River the Sacramento is a comparatively small stream, flowing swiftly in a well-defined channel; below the Pit

[30] The following description of streams tributary to Sacramento Valley is adapted from McGlashan, H. D., and Henshaw, F. F., Water resources of California, Part I: U. S. Geol. Survey Water-Supply Paper 298, 1912.

[31] Ransome, F. L., The Great Valley of California: California Univ. Dept. Geology Bull., vol. 1, p. 379, 1896.

it is larger; and at Red Bluff, where it enters Sacramento Valley, it becomes a sluggish stream, of small slope and small capacity. It is navigable to Red Bluff, 250 miles above its mouth.

PIT RIVER.

Pit River is formed near Alturas, in Modoc County, by the union of its North and South forks. The South Fork rises on the western slope of the Warner Mountains, about halfway between Warren and Eagle peaks, at an altitude 8,000 feet above sea level, and flows southwestward 10 miles, westward about 10 miles, and northward 16 miles through a swampy meadow to its junction with the North Fork. The North Fork flows southward from a point about half a mile south of Goose Lake but normally receives no overflow from that lake. As overflow has been recorded, however,[32] and as it is possible that water from the lake may reach the river by underground channels in the porous lavas of this region, the area tributary to the lake is considered a part of the Pit River basin. The principal direct tributaries of the North Fork of the Pit—Swedrengen, Joseph, and Parker creeks—rise on the western slopes of the Warner Mountains, 6,000 feet above sea level, and flow westward, descending 1,200 feet in courses that measure less than 12 miles.

From Alturas the Pit takes a general southwesterly course to its junction with the Sacramento, about 12 miles north of Redding. The total fall between the head of the South Fork and the mouth of the main stream is about 7,300 feet, of which 3,550 feet occurs on the South Fork in the first 18 miles of its course.

Physically the Pit basin is tributary to the larger Sacramento basin but is not really its upper extension under a different name. It comprises about 7,000 square miles, equal to about 23 per cent of the total area of the Sacramento River basin. The greater part of the basin of the Pit exceeds 4,000 feet in altitude and consists chiefly of barren lava beds in the north and numerous small, flat, marshy meadow valleys in the south. The area contains also many volcanic buttes and peaks, of which Mount Shasta (14,380 feet above sea level) and Lassen Peak (10,437 feet above sea level) are the highest, but these peaks are on the Pit basin divide and are shared in common with the upper Sacramento and Feather River basins, respectively.

About 50 per cent of the Pit basin, chiefly in the northern and eastern parts, is devoid of forests. There are two well-forested areas in the basin—one south of Pit River and north of Lassen Peak and the other north of Pit River and south of Mount Shasta, extending westward from Fall River to the upper Sacramento River and includ-

[32] Waring, G. A., Geology and water resources of a portion of south-central Oregon: U. S. Geol. Survey Water-Supply Paper 220, p. 38, 1908. See also Water-Supply Paper 295, p. 40, 1912.

ing the McCloud River basin. All the public land in the forested areas is included in national forests.

The principal tributaries of Pit River are McCloud River, Squaw Creek, and Fall River from the north and Burney, Hat, Beaver, Ash, and West Valley creeks from the south. McCloud and Fall rivers are the largest, each having a minimum flow of 1,200 to 1,500 second-feet. Hat and Burney creeks have a minimum flow of less than 100 second-feet. Goose Lake, though topographically tributary to the Pit Basin, has discharged water to it only once since 1869; it is said to have overflowed in 1881 for more than two hours during a severe storm from the north.

McCloud River drains an area of 649 square miles lying just east of the upper Sacramento basin. The river rises in large springs southeast of Mount Shasta, but its main water supply comes directly from the southern and eastern slopes of Mount Shasta through Squaw, Mud, Cold, and Ash creeks. The river flows southward, is about 60 miles long, and falls more than 4,000 feet. It discharges into Pit River about 4 miles east of the confluence of the Pit with the Sacramento.

The precipitation in the Pit River basin is very unevenly distributed. In the upper eastern part of the basin it is only about 10 inches annually and occurs largely as snow, which at moderate altitudes soon melts. In the western and northwestern parts, however, the mean annual precipitation reaches 75 inches at the highest points and occurs principally as rain except on the upper slopes of Mount Shasta, Lassen Peak, and other high peaks. In the McCloud basin the precipitation is seldom less than 40 inches and occasionally reaches 100 inches annually. Practically all the precipitation is confined to the rainy season—from November to April of each year.

The valleys of the Pit basin are used chiefly for meadow lands and the growing of stock feed. Some of them are flooded artificially for the raising of wild hay. The uplands are used only for domestic pasturage and for general stock raising, which is carried on extensively.

Numerous reservoir sites on the upper reaches of the Pit and its tributaries have been surveyed by the United States Reclamation Service. A reservoir at the Big Valley site, near Bieber, would store more water than the river furnishes at this point. Warm Spring reservoir, at Canby, would also have a large storage capacity.

The basin also affords exceptional opportunities for power development, especially below Fall River Mills, which is about halfway between the source and the mouth of the Pit. It is estimated that Fall River could develop more than 30,000 horsepower and McCloud River more than 200,000 horsepower continuously. Pit River and its tributaries could develop a total of about 1,000,000 horsepower continuously. About 50 per cent of this amount is commercially feasible of development, and only about 2 per cent has been developed.

Many perennial springs issue from crevices in the lava beds, and some of them discharge several hundred second-feet. Fall River is fed by large springs about 10 miles above its mouth, which discharge approximately 1,500 second-feet. Hat and Burney creeks are fed largely by springs, and McCloud River draws heavily from numerous large springs on the southern slope of Mount Shasta. Most of the smaller tributaries are also spring fed.

COTTONWOOD CREEK.

Cottonwood Creek has three principal forks. North Fork rises in Bully Choop Mountain, which reaches an altitude of 7,073 feet above sea level. It is about 20 miles long, drains an area of 112 square miles, has a total fall of about 4,200 feet, and unites with Middle Fork a short distance below Gas Point. Middle Fork is about 30 miles long, has a fall of 5,900 feet, and drains an area of 261 square miles. South Fork rises in the Yolla Bolly Mountains, which reach an altitude of about 6,000 feet above sea level, and unites with the main creek a few miles west of the town of Cottonwood. It is about 45 miles long, drains an area of 395 square miles, and has a fall of 4,600 feet. The main creek flows eastward and empties into the Sacramento about 5 miles east of the town of Cottonwood and opposite the mouth of Battle Creek. The total drainage area is 929 square miles.

The crest of the Coast Ranges, which forms the western boundary of the basin for a distance of about 50 miles, rises 6,000 to 8,000 feet above sea level. From the crest toward the east the basin slopes at a high angle to the foothills around the north end of Sacramento Valley and is regularly furrowed by numerous drainage ways. About two-thirds of the area is more than 1,000 feet above sea level.

The basin is well timbered, but at the lower altitude the growth is more or less scrubby. The upper parts of the basins of Middle and South forks are included in the Trinity National Forest.

The mean annual precipitation ranges from 25 inches in the lower part of the basin, where it occurs as rainfall, to more than 50 inches along the crest of the Coast Ranges, where much of it occurs as snow.

Some irrigation on a small scale is carried on in this basin, especially in the northern part, along the North Fork, and there is opportunity for further development. Storage and power development are undoubtedly possible in this basin, but to what extent is not known.

STONY CREEK.

Stony Creek drains an area on the eastern slope of the Coast Range, north of the Cache Creek basin and south of the basin of Thomas Creek, which lies between it and the Cottonwood Creek basin on the north.

The total drainage area comprises about 828 square miles, of which about 600 square miles is embraced in an irregular parallelogram, 10 to 15 miles wide, that touches the crest of the range for a distance of 50 or 60 miles. The creek rises in the south end of this area and flows northward along its eastern border about 35 miles, then northeastward about 15 miles, and finally southeastward to its junction with the Sacramento near St. John. The creek is about 90 miles long, and its fall is 4,000 to 5,000 feet.

The principal tributaries of Stony Creek are Little Stony Creek from the south end of the area, Briscoe Creek from its middle, Grindstone Creek from its north end, and North Fork, which enters the main creek about 10 miles northwest of Orland.

The drainage basin of Stony Creek is somewhat peculiar, topographically and geologically. The main stream lies wholly in sedimentary rocks; the tributaries from the west come from the granitic crest of the range and have heavy gradients. At several points in the basin the streams intersect conglomerate ridges which, because of their resistance to erosion, have produced favorable sites for dams and reservoirs. The basin ranges in altitude from a few hundred feet in the valley to 6,000 feet or more at the summit of the range.

The basin is covered with a good growth of grass and dense brush at the lower altitudes and heavy, commercially valuable timber on the mountain summits. About three-fourths of the upper part of the basin is included in the California National Forest.

The mean annual precipitation ranges from 18 inches in the valley to 40 inches or more on the mountain summits, where more or less of it occurs as snowfall. The heaviest freshets occur during the winter.

For years this creek has been used as a source of water for irrigation on a small scale in the northeastern part of Glenn County. The United States Reclamation Service now has under construction the Orland reclamation unit, which takes water from Stony Creek and from the East Park dam on Little Stony Creek to irrigate 20,000 acres around Orland.[33]

The most important reservoir sites on the main stream and its tributaries were surveyed several years ago by the United States Geological Survey.[34] Without storage only a comparatively small amount of power could be developed continuously in the Stony Creek basin, but with a comprehensive storage system many thousand horsepower could be developed.

CACHE CREEK.

The Cache Creek drainage basin lies on the eastern slope of the Coast Range in Lake, Colusa, and Yolo counties, immediately south and west of the south end of the Stony basin and north of the Putah Creek

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[33] Davis, A. P., U. S. Recl. Service Eighteenth Ann. Rept., pp. 97-105, 1919; Nineteenth Ann. Rept., pp. 100-108, 1920.

[34] See U. S. Geol. Survey Water-Supply Paper 86, 1903.

basin. The upper part of the area, comprising about 824 square miles, lies in the central part of Lake County, south of the divide separating the Eel River and Cache Creek basins. It is roughly rectangular in shape and contains Clear Lake in its center. From Lake County the basin extends southeastward to Sacramento Valley as a strip about 50 miles long and 10 miles wide. The total area of the basin is 1,290 square miles.

Cache Creek is the only known outlet of Clear Lake. The lake is very irregular in shape and has an area of 65 square miles and an altitude of 1,325 feet at mean level. Its length is 20 miles and its greatest width 7 miles. The upper part, or main lake, has a maximum depth of 35 feet, but the lower neck has a few small areas as much as 50 feet deep. The drainage area tributary to the lake is about 417 square miles, chiefly toward the south and west. The principal streams flowing into the lake are Scotts, Middle, and Clover creeks from the west, and Doba, Kelsey, and Cole [35] creeks from the south. They are torrential during the rainy season but are practically dry in the summer.

From the lake Cache Creek flows southeastward to Yolo Basin and ultimately into Sacramento River through Yolo Basin. Its total length is about 80 miles.

The largest tributary of Cache Creek is the North Fork, which drains 250 square miles in the eastern part of Lake County. The only other important tributary is Bear Creek, which drains the western part of Colusa County. These creeks are very small in the summer but rarely become dry. All the tributaries are torrential during the rainy season.

The upper part of the Cache Creek drainage basin in Lake County is mountainous and very rugged. Some of the peaks reach an altitude of 6,000 feet above sea level, and their slopes, as well as those of the lowest ranges, are very steep. About 5 miles below the outlet the creek enters Cache Creek canyon, in which it flows for 25 miles on an average grade of 35 feet to the mile. In some places the canyon walls are vertical cliffs 300 feet high. Below the canyon the creek enters Capay Valley, from 1 to 3 miles wide and 20 miles long, through which it winds for a distance of nearly 30 miles before entering Sacramento Valley.

On the northern slope of the ranges around Clear Lake are fine belts of fir, oak, and pine. Elsewhere on the high ranges the vegetation consists of a dense growth of greasewood and chaparral. A strip along the northern edge of the basin is included in the California National Forest.

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[35] Cole Creek is not named on Punnett's map of Lake County or on the sketch map accompanying U. S. Geol. Survey Water-Supply Paper 45.

The mean annual precipitation ranges from 17 inches in Sacramento Valley to 40 inches or more on the mountainous summits in Lake County, where much of it occurs as snowfall in the winter season.

Cache Creek furnishes exceptional opportunities for irrigation development in Yolo County. At the present time many ditches take water from the creek for irrigating land in the vicinity of Woodland and Yolo, and in 1912 about 14,570 acres was irrigated.[36]

Good storage sites are also available in this basin. Clear Lake is a natural storage reservoir which is very powerful in regulating Cache Creek.[37] The opportunities for water-power development on Cache Creek are excellent.

The upper part of this basin contains springs, a number of which, especially in the North Fork basin, attract hundreds of visitors during the summer. Bartlett Springs are probably the best known.

FEATHER RIVER.

Feather River heads on the crest of the Sierra Nevada and takes a general southwesterly course to its junction with the Sacramento, about 30 miles south of Marysville and 15 miles northwest of Sacramento. It is about 175 miles long, and its drainage area comprises approximately 6,590 square miles, lying on the western slope of the Sierra Nevada, south of the Pit River basin and north of the basin of American River.

The basin is roughly triangular in shape and is naturally subdivided into three comparatively large basins—North Fork basin, at the north and west, with a total drainage of about 2,220 square miles; Middle Fork basin, in the center and at the east, with a total drainage area of about 1,340 square miles; and Yuba River basin at the south, with a total drainage area of more than 1,300 square miles.

The drainage basin of the North Fork, here regarded as the continuation of the main stream, includes the eastern part of Butte County, the greater part of Plumas County, and the southwest corner of Lassen County. It does not exceed 75 miles in length, and its width in Plumas County is about 65 miles.

The Middle Fork basin is long but comparatively narrow except at its east end, where it broadens out and includes Sierra Valley, a large meadow valley at an altitude of 5,000 feet above sea level. Beckwith Pass, which opens into this valley from the east, is the lowest pass in the Sierra Nevada, being about 5,200 feet above sea level. Sierra Valley and the surrounding country are very dry in the summer. The greatest elevation in the Middle Fork basin is

[36] Adams, Frank, Irrigation resources of California and their utilization: U. S. Dept. Agr. Office Exper. Sta. Bull. 254, p. 21, 1913.

[37] For a detailed account of storage on Cache Creek see U. S. Geol. Survey Water-Supply Paper 45, 1901; also Wilson, J. M., Irrigation investigations on Cache Creek: U. S. Dept. Agr. Office Exper. Sta. Bull. 100, pp. 155-191, 1901.

about 8,500 feet. The Middle Fork unites with the North Fork in Butte County, about 6 miles northeast of Oroville.

The third subdivision, the Yuba River basin, is described below under the heading "Yuba River."

Above Prattville there are two small basins of almost equal size, the eastern one drained by Hamilton Branch and the western by North Fork. The eastern basin ranges in altitude from 4,300 to 7,500 feet, has an area of 230 square miles, and includes the East Arm of Big Meadows and the large level area called Mountain Meadows. The western basin has an area of 245 square miles, ranges in altitude from 4,300 to 10,000 feet, and includes the West Arm of Big Meadows and the higher country about Lassen Peak. Hamilton Branch unites with North Fork about 3 miles east of Prattville, at the lower end of Big Meadows.

The greater part of the Feather River basin is rough and mountainous and the slopes are deeply trenched by numerous stream channels. The rocks in the southern and eastern parts of the basin are principally granites; at the lower altitudes some porous and deeply eroded slates and lavas are also found. The northern part of the basin contains many cones, craters, deposits of volcanic ash, and lakes, which indicate recent volcanic activity. The soil of the basin is porous, absorbs moisture readily, and serves to equalize the stream flow. The numerous meadows and valleys that exist in different parts of the area also help to maintain a steady flow in the streams during the dry season.

The basin is well forested. At the lower altitudes the growth consists for the most part of brush and scrubby timber. The mountain sides, except around the summits of the highest peaks, such as Lassen Peak, are covered with merchantable timber. About two-thirds of the entire basin, or 4,300 square miles, is inclosed in national forests, which include all the upper part of the basin except Sierra Valley on Middle Fork, the meadows around Prattville on North Fork, and a few other very small valleys.

The mean annual precipitation in the Feather River basin is about 30 inches in the foothill belt and increases toward the mountain summits. It ranges from 40 to 60 inches in the North Fork and Middle Fork basins, at the north and east, and from 40 to 75 inches in the Yuba River basin, at the south. In the winter much of it occurs as snowfall, and the snow does not disappear from the summits until summer.

Very little irrigation is practiced in the Feather River basin, though some water is diverted for use in the small valleys and in Sacramento Valley below the foothills. Considerable water is used for mining and power.

The basin affords many excellent storage sites, especially on the North and Middle forks. Surveys of a large number of reservoir sites in this area have been made by the United States Reclamation Service, and many others have been made by private companies.

The minimum flow of the streams in the Feather River basin is sufficient to develop more than 500,000 horsepower, and this amount could be almost doubled with storage. On North Fork alone about 300,000 horsepower could be developed at low water, and with storage 500,000 horsepower would be available. On Middle Fork only about 66,000 horsepower could be developed at low water, and on Yuba River only about 130,000. At the present time the Great Western Power Co. is engaged in developing sites in the North Fork basin.

The basin has many large springs, especially in the lava districts, which supply a more or less steady flow throughout the year. In the North Fork basin especially occur large perennial springs, discharging 50 to 100 second-feet. One of the largest, Dotta Spring, about 3 miles east of Prattville, has a maximum discharge of 100 second-feet and a minimum of 70 second-feet. Many perennial springs are also found in the Yuba River basin. The basin of the Feather also contains many small glacial lakes, chiefly in Yuba River and North Fork basins.

YUBA RIVER.

Yuba River rises near the crest on the western slope of the high Sierra and flows southwestward to its junction with Feather River at Marysville. The total length of the stream is about 90 miles. Its basin lies south of the basin of the Middle Fork of Feather River, west of Truckee River basin, and north of the American and Bear River basins, is chiefly in Yuba, Sierra, and Nevada counties, and is one of the principal subdivisions of the Feather River basin. It has an area of more than 1,300 square miles and is triangular in shape, with the base of the triangle along the crest of the Sierra Nevada. Its extreme length from the mouth of Yuba River to the crest of the Sierra is about 70 miles, and its greatest width is about 35 miles. The river is formed by three principal forks. The Middle Fork, which is considered the continuation of the main stream, rises in Sierra and Nevada counties on the west and south slopes of Weber Peak and takes a general southwesterly course. It receives the North Fork in Yuba County, in the northeastern part of T. 17 N., R. 7 E., and the South Fork in Nevada County, in the southwestern part of T. 17 N., R. 7 E.

The topography of the Yuba River basin is rugged and mountainous. From the edge of Sacramento Valley the surface rises gently through the foothills and then more abruptly through rounded and broken mountains to the crest of the Sierra, which along the Yuba-Truckee divide has a mean altitude of about 8,000 feet and a few peaks exceeding 9,000 feet. The streams have cut deep canyons, which head well up in the mountains. Slates and kindred rocks, much eroded, are found in the lower western part of the basin; in the higher eastern part the rocks are granites and lavas. A stratum of serpentine traverses the basin parallel to the crest of the range but at a considerable distance from it.

The soil is deep in most places and supports a hardy growth of brush and timber, especially along the sides of the canyons. The North Fork basin has at present the best forest cover, and that of South Fork the poorest, but this difference is the result of lumbering operations. All the upper part of the Yuba River basin, more than 800 square miles, is now included in the Tahoe National Forest.

The mean annual precipitation ranges from 18 inches at Marysville to about 70 inches near the mountain crest. In the upper and central parts of the basin the precipitation ranges from 50 to 70 inches and occurs principally as snow, which remains on the ground all winter and well into the summer. The North and South Fork basins probably receive the greatest precipitation.

Little irrigation is practiced in the Yuba River basin, but the main stream could undoubtedly be used for irrigating a part of Sacramento Valley.

Storage sites in the Yuba River basin are not numerous, though considerable storage is feasible, particularly along the upper part of South Fork. Numerous small lakes near the headwaters of the South Fork are utilized as storage reservoirs. The stored water was originally used in hydraulic mining. At present this water is used for irrigation along the foothill fruit belt in the vicinity of Auburn and also for power development. The minimum flow of the streams is sufficient to develop about 125,000 horsepower without storage.

The principal power development on Yuba River is that of the Pacific Gas & Electric Co. at its Colgate plant, about 12 miles above Smartsville. The water is diverted from North Fork below Bullards Bar.

Perennial springs are found in many parts of the Yuba River basin, particularly along the North Fork. In the South Fork basin at the higher altitudes there are many small glacial lakes, rounded, denuded summits, and glacial valleys.

The channel of Yuba River for many miles above its mouth has been filled with enormous quantities of tailings from hydraulic mining. (See pp. 30–31.) An attempt has been made to restrain this débris from moving downstream by building barrier dams, but it has not been successful.

INDIAN CREEK.

Indian Creek rises in the Sierra Nevada and flows westward to its junction with North Fork of Feather River. The stream is about 50 miles long, and its drainage area, comprising 733 square miles,[38] is much greater than that of North Fork above the junction of the two streams. The basin is in the northeastern part of Plumas County, north of Middle Fork of Feather River and east of the upper part of North Fork. For about 45 miles it lies along the Sierra divide, which separates it from the Honey Lake drainage basin at the east. The principal tributaries are Squaw, Red, Clover, Little Grizzly, and Spanish creeks from the south and Light and Wolf creeks from the north.

Practically all of the Indian Creek basin has an altitude exceeding 5,000 feet, and much of it is underlain by a lava formation and attains 6,000 to 7,000 feet. The entire basin is included in the Tahoe National Forest, except a few meadows, of which Indian and American valleys are the largest.

The mean annual precipitation is between 40 and 45 inches, and a large part of it occurs as snowfall. During the winter the streams freeze over occasionally.

The basin affords several good storage reservoir sites. Opportunities for power development are also good. With the available fall the flow of the streams is sufficient to generate at least 20,000 horsepower continuously, and by utilizing storage 60,000 horsepower could be developed.

BEAR RIVER.

Bear River drains a narrow strip on the western slope of the Sierra Nevada below an altitude of 5,500 feet. The basin, which is about 60 miles long and not more than 10 miles wide, lies south of the Yuba River basin and north of the American River basin. Its total area is less than 300 square miles.

The river rises in the extreme northeastern part of the basin near Emigrant Gap, and flows southwestward to its junction with Feather River, about 15 miles south of Marysville. It is the boundary line between Nevada and Placer counties and closely parallels the Bear-American divide, which is 1 to 2 miles south of it. Its principal tributaries are Steep Hollow Creek, Greenhorn River, and Wolf Creek, all from the north.

The Bear River basin has very little forest, except on a small area in the upper part. The mean annual precipitation ranges from 21 inches in the valley to 52 inches at the source of the river, where much of it occurs as snow that soon disappears.

Some irrigation is practiced in this basin. Storage is not feasible, and the minimum flow of the streams is not sufficient to develop much power.

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[38] U. S. Recl. Service Fourth Ann. Rept., p. 93, 1906.

AMERICAN RIVER.

American River drains the area lying on the western slope of the Sierra Nevada south of the Bear and Yuba river basins, west of Lake Tahoe and the Truckee River basin, and north of the Cosumnes and Mokelumne river basins. The area is triangular, about 80 miles long and 50 miles in maximum width along the crest of the Sierra, and covers about 2,000 square miles.

American River is formed by the union of its three principal forks and flows southwestward about 110 miles to its junction with Sacramento River just above the city of Sacramento. North and Middle forks are about 60 miles long, have a fall of nearly 8,000 feet, and drain areas measuring, respectively, 349 and 640 square miles. South Fork, about 60 miles long, falls nearly 9,000 feet and drains an area of 861 square miles. North and Middle forks unite near Auburn, about 20 miles above the mouth of South Fork, which is only a few miles above Folsom. Each of the forks has many other forks, branches, and tributaries.

Almost half of the American River drainage basin exceeds 5,000 feet in altitude, and probably one-third of it ranges from 6,000 to 9,000 feet. The rocks of the upper part are chiefly granites, which have yielded to glacial and erosional action to such an extent as to form many regular ridges and drainage channels.

The lower elevations of the basin are barren or sparsely timbered, but the higher elevations support a good growth of timber. All the upper part of the basin, amounting to considerably more than half of the total, is included in the Tahoe and Eldorado national forests.

The mean annual precipitation ranges from 21 inches in Sacramento Valley to probably 60 inches near the summit of the Sierra, where it occurs as snow, which does not disappear till summer. In the foothill region it ranges from 25 to 30 inches, and in the central region from 45 to 55 inches. It is probably somewhat greater in the northern than in the southern part of the basin. At the higher altitudes there is much snow and ice during the winter.

Some water is diverted from the American River for irrigation, particularly in Sacramento Valley, but further development is possible.

Storage on a large scale is not possible in this basin, though considerable storage for power and mining is feasible, particularly on the Middle and South forks.

American River was until recently the source also of the water supply of the city of Sacramento.

The minimum flow of the streams in this basin, with the existing fall, is sufficient to develop about 100,000 horsepower without storage, of which about 40 per cent is on the South Fork and nearly 30 per cent on the Middle Fork.

The upper part of the American River basin shows evidence of glaciation, which has left many small lakes, some of which have been dammed and used for storage in connection with mining.

PUTAH CREEK.

The Putah Creek basin lies on the eastern slope of the Coast Range south of the Cache Creek basin and north of Napa Valley. It includes the southern part of Lake County, the northern half of Napa County, and small parts of Yolo and Solano counties. The basin is rather long from northwest to southeast and comparatively narrow, being about 20 miles wide at the north and less than 10 miles at the east. It has a total area of about 810 square miles.

Putah Creek rises in the northwest corner of the basin in the St. Helena Range and flows southeastward into the Yolo Basin near Davis and thence into Sacramento River through Cache Slough. The total length of the creek is about 80 miles. It has numerous tributaries, which have a heavy flood discharge in the winter but are practically dry during the summer. The chief tributaries are Soda Creek from the north and Pope Creek from the west.

The topography of the Putah Creek basin is very rugged. Much of the upper basin is rough and precipitous. The underlying rock is impervious slate and serpentine, with only a thin soil covering. There is very little tilled land in the basin except below the foothills. Altitudes range from about 100 feet in the valley to about 5,000 feet on the mountain summits.

The lower parts of the basin are comparatively barren of timber, though they support a considerable growth of grass and brush which extends down as far as the foothills. At moderate elevations timber grows scatteringly, and the mountain summits are covered by a fairly heavy timber growth.

The mean annual precipitation varies widely in the different parts of the basin. Along the foothills it averages about 28 inches, in the central part about 40 inches, and along the crest of the divide, where some of it occurs as snowfall in the winter, about 65 inches. Helen Mine, on the northern slope of Mount St. Helena, receives almost 100 inches annually.

Below the foothills is a large area of rich irrigable land, which could be supplied with water from Putah Creek. Some of this land is already irrigated and has been proved to be susceptible of the highest state of cultivation.

At least two good reservoir sites exist on the main stream, one near Winters and the other near Guenoc.

Only a small amount of power could be developed continuously in the Putah Creek basin without storage, because of the torrential nature of the streams. By utilizing the storage sites, however, many thousands of horsepower could be developed.

STREAM-FLOW DATA.

The following table gives the annual flow of Sacramento River and of seven of its principal tributaries near the points where they discharge into the valley; also the annual flow of the Sacramento where it leaves the valley. The location of the gaging stations is shown on Plate I. As the ground water of Sacramento Valley is derived from the precipitation upon the valley and the discharge of streams that flow into the valley, the tables on pages 49–50 and the following tables together give data on the quantity of water available for absorption.

The daily and monthly records of flow for these and other streams in the Sacramento drainage basin are given in the following reports of the United States Geological Survey:

Water-Supply Paper 298, Water resources of California, Part I, Stream measurements in Sacramento River basin, prepared under the direction of J. C. Hoyt by H. D. McGlashan and F. F. Henshaw, 1912.

Water-Supply Paper 331, Surface water supply of the United States, 1912, Part XI, Pacific coast basins in California, by H. D. McGlashan and G. C. Stevens, 1914.

Water-Supply Paper 361, idem for 1913; N. C. Grover, chief hydraulic engineer; H. D. McGlashan and F. F. Henshaw, district engineers, 1916.

Water-Supply Paper 391, idem for 1914; N. C. Grover, chief hydraulic engineer; H. D. McGlashan and F. F. Henshaw, district engineers, 1917.

Water-Supply Paper 411, idem for 1915; N. C. Grover, chief hydraulic engineer; H. D. McGlashan and F. F. Henshaw, district engineers, 1918.

Water-Supply Paper 441, idem for 1916; N. C. Grover, chief hydraulic engineer; H. D. McGlashan and F. F. Henshaw, district engineers, 1918.

Stream flow in Sacramento River basin.

A. Sacramento River near Red Bluff.

[At lower end of Iron Canyon, 4 miles above Red Bluff; drainage area, 10,400 square miles.]

Year (Oct. 1 to Sept. 30).	Discharge in second-feet.				Run-off.	
	Maximum.	Minimum.	Mean.	Per square mile.	Depth in inches on drainage area.	Total in acre-feet.
1902 (Feb.–Sept.)						9,290,000
1902–3	131,000	3,980	13,500	1.30	17.58	9,760,000
1903–4	188,000	4,420	22,000	2.12	28.68	15,900,000
1904–5	108,000	4,760	14,700	1.41	19.07	10,600,000
1905–6	137,000	4,760	15,400	1.48	20.02	11,100,000
1906–7	196,000	5,470	19,100	1.84	24.69	13,700,000
1907–8	83,300	4,650	10,700	1.03	13.92	7,720,000
1908–9	254,000	4,760	20,100	1.93	25.91	13,400,000
1909–10	90,800	4,760	12,400	1.19	16.07	8,910,000
1910–11	130,000	5,000	13,700	1.32	17.86	9,910,000
1911–12	55,000	4,420	8,770	.843	11.48	6,370,000
1912–13	58,000	4,390	9,440	.908	12.30	6,840,000
1913–14	160,000	4,390	18,700			13,500,000
1914–15	249,000	4,880	17,100	1.84	24.89	12,400,000
1915–16	91,300	4,790	14,400	1.55	21.13	10,500,000
1916–17	176,000	4,200	9,550	1.03	13.93	6,910,000
1917–18	52,100	3,510	7,080			5,130,000
1918–19	118,000	3,660	10,400			7,500,000
1919–20	28,500	3,240	5,380			3,890,000
1920–21	104,000	3,490	15,400			11,100,000

Stream flow in Sacramento River basin—Continued.

B. Stony Creek near Fruto.

[At Julian's ranch, about 7 miles northwest of Fruto, in the SW. ¼ NE. ½ sec. 14, T. 21 N., R. 6 W.; drainage area, 601 square miles.]

Year (Oct. 1 to Sept. 30).	Discharge in second-feet.				Run-off.	
	Maximum.	Minimum.	Mean.	Per square mile.	Depth in inches on drainage area.	Total in acre-feet.
1901 (Feb.-Sept.)						226,000
1901-2	21,300	0	930	1.55	20.41	654,000
1902-3	6,580	5	798	1.33	17.95	576,000
1903-4	22,200	9	1,050	1.74	23.48	753,000
1904-5	7,280	10	704	1.17	15.86	508,000
1905-6	22,200	13	743	1.24	16.69	535,000
1906-7	26,500	15	1,070	1.78	23.91	765,000
1907-8	7,800	3	469	.780	10.54	338,000
1908-9	29,300	8	1,260	2.10	28.02	894,000
1909-10	9,010	.5	487	.810	10.955	351,000
1910-11	15,400	2	736	1.22	16.69	535,000
1911-12	1,480	15	175			127,000

C. Feather River at Oroville.

[At Oroville highway bridge; drainage area, 3,640 square miles.]

1902 (Jan.-Sept.)						3,930,000
1902-3	93,000	1,170	6,140	1.69	22.87	4,440,000
1903-4	95,000	1,540	12,900	3.55	48.06	9,330,000
1904-5	68,400	1,200	6,210	1.71	23.11	4,490,000
1905-6			9,280	2.55	34.56	6,710,000
1906-7	187,000	1,650	13,000	3.56	48.07	9,340,000
1907-8	16,300	1,250	4,810	1.32	17.95	3,490,000
1908-9	36,500	1,250	10,200	2.81	26.71	7,380,000
1909-10	29,200	1,010	6,220	1.71	23.17	4,500,000
1910-11	75,400	940	9,670	2.66	35.95	6,980,000
1911-12	16,400	820	2,880			2,090,000
1912-13	16,400	845	3,690	1.01	13.78	2,670,000
1913-14	121,000	980	10,700			7,740,000
1914-15	91,000	1,710	8,130	2.23	30.29	5,880,000
1915-16	57,200	1,560	9,360	2.57	35.03	6,790,000
1916-17	99,000	1,970	6,700	1.84	25.00	4,860,000
1917-18	35,000	1,180	3,520	.967	13.44	2,550,000
1918-19	54,600	1,540	4,750	1.31	17.72	3,440,000
1919-20	21,000	905	2,830	.777	10.57	2,050,000
1920-21	64,200	950	7,900	2.17	29.48	5,730,000

D. Yuba River at Smartsville.

[One mile north of Smartsville, at The Narrows, in sec. 22, T. 16 N., R. 6 E.; drainage area, 1,220 square miles.]

1903-4	59,800	445	5,690	4.67	62.96	4,100,000
1904-5	17,900	415	3,330	2.73	36.93	2,400,000
1905-6	48,000	415	5,020	4.11	55.81	3,630,000
1906-7	100,000	380	6,220	5.10	68.58	4,560,000
1907-8	8,410	320	2,200	1.80	24.47	1,590,000
1908-9	111,000	320	5,380	4.41	59.70	3,880,000
1909-10	37,000	295	3,690	3.03	41.02	2,670,000
1910-11	39,000	320	4,870	4.00	53.90	3,510,000
1911-12	7,640	263	1,560			1,130,000
1912-13	10,000	220	1,930			1,400,000
1913-14	45,700	216	3,960			2,870,000
1914-15	46,500	285	3,450	2.83	38.40	2,500,000
1915-16	25,100	279	4,260			3,090,000
1916-17	38,800	226	3,190			2,310,000
1917-18	13,100	165	1,580			1,140,000
1918-19	29,400	155	2,410			1,740,000
1919-20	19,500	106	1,490			1,080,000
1920-21	24,800	158	3,970			2,870,000

Stream flow in Sacramento River basin—Continued.

E. Bear River at Van Trent.

[About 500 feet below the highway bridge at McCourtney crossing, 1 mile below Van Trent post office, and 8 miles above Wheatland, in the SE. ¼ sec. 2, T. 14 N., R. 6 E.; drainage area, 263 square miles.]

Year (Oct. 1 to Sept. 30).	Discharge in second-feet.				Run-off.	
	Maximum.	Minimum.	Mean.	Per square mile.	Depth in inches on drainage area.	Total in acre-feet.
1904–5 (Oct. 8–Sept. 30)						315,000
1905–6	17,900	10	776	2.95	40.02	561,000
1906–7	25,800	20	1,010	3.84	51.72	726,000
1907–8	2,350	25	260	.988	13.42	188,000
1908–9	25,300	20	731	2.78	37.41	525,000
1909–10	9,960	16	354	1.35	18.25	256,000
1910–11	22,200	23	710	2.70	36.60	512,000
1911–12	1,020	8	121			87,600
1912–13	3,650	8	147			106,000
1913–14	17,000	13	750			543,000
1914–15	12,700	34	653			472,000
1915–16	19,400	46	902			655,000
1916–17	10,800	12	470			340,000
1917–18	4,930	2	177			128,000
1918–19	19,800	4	418			303,000
1919–20	6,800	4	134			97,100
1920–21	15,700	3	645			467,000

F. American River at Fairoaks.

[At Fairoaks highway bridge, about 1,500 feet north of the railroad station; drainage area, 1,910 miles.]

Year (Oct. 1 to Sept. 30).	Maximum.	Minimum.	Mean.	Per square mile.	Depth in inches on drainage area.	Total in acre-feet.
1904–5 (Nov. 4 to Sept. 30)						1,960,000
1905–6	44,500	130	6,580	3.45	46.76	4,762,000
1906–7	105,000	250	7,930	4.15	56.02	5,710,000
1907–8	8,460	100	2,000	1.05	14.26	1,450,000
1908–9	98,000	100	6,330	3.32	44.65	4,540,000
1909–10	47,000	180	4,900	2.56	34.78	3,540,000
1910–11	69,100	225	7,600	3.98	53.80	5,480,000
1911–12	11,300		1,740			1,260,000
1912–13	11,600		1,980			1,430,000
1913–14	57,700	85	5,460			3,950,000
1914–15	41,800	124	4,230			3,060,000
1915–16	33,200	170	5,300			3,850,000
1916–17	37,600	83	3,910			2,830,000
1917–18		65	1,960			1,420,000
1918–19	45,000	104	2,980			2,150,000
1919–20	18,800	100	1,920			1,390,000
1920–21	32,800	123	4,450			3,220,000

G. Cache Creek at Yolo.

[At old wagon bridge on the road from Woodland to Yolo, about 1,000 feet above railroad bridge; drainage area, 1,230 square miles.]

Year (Oct. 1 to Sept. 30).	Maximum.	Minimum.	Mean.	Per square mile.	Depth in inches on drainage area.	Total in acre-feet.
1903 (Jan.–Sept.)						397,000
1903–4	11,200	0	1,230	1.00	13.56	890,000
1904–5	11,300	0	875	.711	9.57	629,000
1905–6	18,900	0	1,030	.834	11.29	740,000
1906–7	19,200	0	1,380	1.12	14.95	983,000
1907–8	6,080	0	446	.363	4.87	309,000
1908–9	20,100	0	1,810	1.47	19.46	1,280,000
1909–10	4,120	0	349	.284	3.83	250,000
1910–11	18,400	0	786	.639	7.574	496,000
1911–12	875	0	50.9			36,900
1912–13	3,790	0	99.9			72,300
1913–14	19,100	0	1,620			1,170,000
1914–15	19,300	0	1,380			999,000
1915–16	19,000	0	943			686,000
1916–17	17,700	0	200			145,000
1917–18	995	0	42.1			30,400
1918–19	7,500	0	147			107,000
1919–20	812	0	3.94			2,860
1920–21	12,300	0	5.38			389,000

Stream flow in Sacramento River basin—Continued.

H. Putah Creek at Winters.

[About 600 feet below railroad bridge; drainage area, 805 square miles.]

Year (Oct. 1 to Sept. 30).	Discharge in second-feet.				Run-off.	
	Maximum.	Minimum.	Mean.	Per square mile.	Depth in inches on drainage area.	Total in acre-feet.
1905–6	25,400	10	804	0.999	13.57	583,000
1906–7	30,000	10	954	1.18	16.07	691,000
1907–8	8,600	3	278	.346	4.64	199,000
1908–9	28,800	3	1,240	1.54	20.55	881,000
1909–10	12,000	1	327	.391	5.30	228,000
1910–11 (Oct. to May 16)						483,000
1911–12						
1912–13	8,080	0	184			134,000
1913–14	40,000	0	1,240			895,000
1914–15	39,400	6	980			710,000
1915–16	42,400	6.2	977			709,000
1916–17	33,400	1	393			284,000
1917–18	3,190	0	123			88,800
1918–19	27,200	0	436			315,000
1919–20	2,830	0	58.7			42,600
1920–21	23,300	0	705			510,000

I. Sacramento River at Collinsville.

[At mouth of Sacramento River; drainage area, 26,020 square miles.]

Year.	Discharge in second-feet.		Run-off.	
	Mean.	Per square mile.	Depth in inches on discharge area.	Total in acre-feet.
1878–79 (Nov.-Sept.)				25,900,000
1879–80	44,500	1.70	23.10	32,300,000
1880–81	44,600	1.70	22.90	32,000,000
1881–82	35,000	1.34	18.12	25,300,000
1882–83	24,600	.939	12.76	17,800,000
1883–84	41,200	1.57	21.41	29,900,000
1884–85	25,100	.958	12.97	18,100,000

GEOLOGY.

GENERAL FEATURES.

Sacramento Valley occupies a basin whose sides and bottom are probably formed of the same granitic, schistose, and slaty rocks, of pre-Cretaceous age, that compose the greater part of the Sierra Nevada and the core of the Coast Ranges. In this basin lie sandstones and shales of Cretaceous age, which are thin on the east side but thicker on the west.[39] These formations carry little water and may be considered as an impervious floor on which the Tertiary and Quaternary water-bearing formations have been deposited. (See Pl. III.)

[39] Diller, J. S., Tertiary revolution in the topography of the Pacific coast: U. S. Geol. Survey Fourteenth Ann. Rept., pt. 2, p. 415, 1894. Lindgren, Waldemar, U. S. Geol. Survey Geol. Atlas, Sacramento folio (No. 5), 1894.

CRYSTALLINE ROCKS.

The Sierra Nevada, the Klamath Mountains, and the cores of the Coast Ranges are composed in large part of crystalline rocks. These rocks are of both sedimentary and igneous origin and record a long series of geologic events.

Before Carboniferous time the larger part of northern California was probably a land surface undergoing erosion. In the Klamath Mountains there are, however, thin deposits of the Devonian Kennett formation (Middle Devonian), which represent an invasion of the sea,[40] and in the Taylorsville region a Silurian invasion is represented in the Montgomery limestone, of Niagara age.[41]

In Carboniferous time the region was occupied by a sea in which were deposited limestones and calcareous shales. Interbedded and associated with these rocks are lava flows and tuffs, which indicate extensive volcanic activity at this time. In the Sierra Nevada the thickness of these beds (Calaveras and Robinson formations) is between 4,900 and 16,400 feet.[42] In the vicinity of Redding the thickness of the Carboniferous formations (Bragdon, Baird, McCloud, and Nosoni) is nearly 10,000 feet.[43]

After the deposition of the Carboniferous sediments came a period of volcanic activity and disturbance of the earth's crust, followed by erosion. The extent of this disturbance is not known, but it may have been widespread.

In Triassic time the sea again invaded the region at present occupied by the Klamath Mountains and deposited thick beds of shale, limestone, and tuff. The combined thickness of the Pit formation, Hosselkus limestone, and Brock shale in the vicinity of Redding is 2,600 feet.[44]

Active volcanism prevailed throughout Triassic time and continued with increased violence into Jurassic time. The sea again invaded the region, and sandstones, shales, and volcanic tuffs were laid down. These sediments now constitute the auriferous Mariposa slate of the Sierra Nevada.[45] The Modin and Potem formations of the Redding region also belong to this period and have a thickness of several thousand feet.[46] At approximately the same time or later were deposited in the Coast Range the beds of the Franciscan group. This group comprises (1) a voluminous accumulation of sedimentary formations, some of them clearly marine, others doubtfully so; (2) some inter-

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[40] Diller, J. S., U. S. Geol. Survey Geol. Atlas, Redding folio (No. 138), 1906.

[41] Diller, J. S., U. S. Geol. Survey Bull. 353, pp. 16–17, 1908.

[42] U. S. Geol. Survey Geol. Atlas, folios 3, 5, 11, 18, 37, 39, and 43; U. S. Geol. Survey Bull. 353.

[43] Diller, J. S., U. S. Geol. Survey Geol. Atlas, Redding folio (No. 138), 1906.

[44] Diller, J. S., idem, pp. 4, 5.

[45] Turner, H. W., The rocks of the Sierra Nevada: U. S. Geol. Survey Fourteenth Ann. Rept., pt. 2, pp. 449–456, 1894.

[46] Diller, J. S., op. cit. (Redding folio), p. 5.

calated lavas of contemporary age; and (3) certain crystalline schists produced by the metamorphism of both the sedimentary and igneous rocks.[47] The sedimentary rocks consist of sandstones, limestones, and radiolarian cherts, in all about 6,300 feet thick.

The later part of Jurassic time was a period of disturbance and mountain making, accompanied by great igneous intrusions of a batholithic character. In the Sierra Nevada all the pre-Jurassic rocks were metamorphosed and converted into slates, schists, and marbles. In the Klamath Mountains less metamorphism took place but the rocks were folded and faulted. In the Coast Ranges similar batholithic intrusions took place, apparently prior to the deposition of the Franciscan group. Basic rocks were, however, intruded into the Franciscan, so that it also is metamorphosed in many places.[48] This period of uplift, mountain making, and metamorphism was followed by profound erosion, which in certain areas has continued to the present time.

CRETACEOUS FORMATIONS.

With the beginning of Cretaceous time, or perhaps late in Jurassic time, a depression was formed along the line of the Great Valley. From the elevated Coast Ranges and Sierra Nevada sediments were washed down into a sea that occupied the depression. Thus were deposited the Knoxville, Horsetown, and Chico formations, which in general, are thicker on the west side of the valley and in the Coast Ranges than along the western border of the Sierra Nevada.

The Knoxville consists of sandy shales and thin bands of sandstone with a few conglomerates and thin limestones. Its thickness on Elder Creek, west of Sacramento Valley, is 20,000 feet, and the overlying Horsetown, of similar composition, is about 6,000 feet thick. The Chico, of Upper Cretaceous age, contains more conglomerate and sandstone and is about 4,000 feet thick on the west side of the valley. On the east side of the valley, along the base of the Sierra Nevada, the Chico is exposed at intervals, resting unconformably on the crystalline rocks. It consists of greenish and yellowish sandstone, in places fossiliferous, from a few feet to 69 feet in thickness.[49]

In figure 3 the relation of the Cretaceous deposits to the valley is brought out. On the west they are very thick and dip steeply into the valley; on the east they are thin and dip gently under the valley. As only the upper part (Chico) extends completely under the valley and as it is much thinner on the east than on the west, shifting of the basin axis is indicated.

Cretaceous time was followed by a period of disturbance—the Laramide revolution. At this time the region now occupied by the Coast

[47] Lawson, A. C., U. S. Geol. Survey Geol. Atlas, San Francisco folio (No. 193), p. 4, 1914.
[48] Lawson, A. C., idem, p. 7.
[49] Diller, J. S., U. S. Geol. Survey Geol. Atlas, Redding folio (No. 138), 1906. Lindgren, Waldemar, U. S. Geol. Survey Geol. Atlas, Sacramento folio (No. 5), 1894.

Ranges was folded and uplifted, and uplift of a lesser amount without folding took place in the Klamath Mountains and Sierra Nevada. Erosion accompanied the uplift, and about the borders of the valley the Tertiary formations rest on the eroded surface of the Chico.

TERTIARY FORMATIONS.

IONE FORMATION.

Overlying the Chico is a series of sands, clays, and tuffs known as the Ione formation. It was originally described as Miocene, but Dickerson[50] has shown that in Sacramento Valley it is of Eocene age and represents the upper part of the Tejon formation. According to Dickerson the sea advanced eastward from the coast of California over the site of the present Coast Ranges through Eocene time. Late in the Eocene epoch the shore line was along the base of the Sierra Nevada, and a gulf extended between the Klamath Mountains and Sierra Nevada beyond Redding. Into this sea streams entered from the low-lying Sierra Nevada and the peneplaned Klamath Mountains, and their sediments are now preserved as the gold-bearing gravels of the Tertiary streams of the Sierra, as the clays, sands, and coal beds of the Ione formation along the foot of the mountains, and as sands and shales where uplifted in the Marysville Buttes in the center of the valley.[51]

TERTIARY VOLCANIC ROCKS.

At the end of Eocene time volcanoes burst forth in the Sierra Nevada and the Cascade Range. Lavas, flow breccias, and mud flows poured down the mountain slopes. The stream channels were thus covered, and in

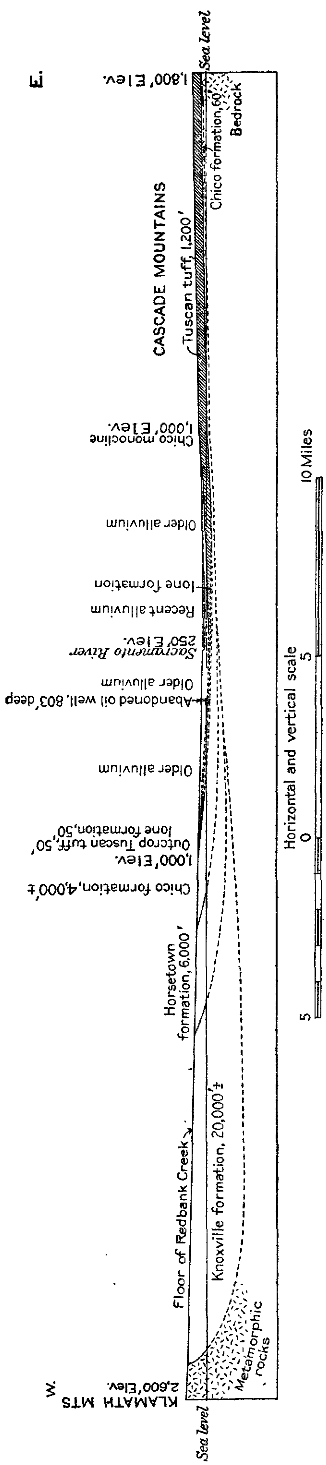

FIGURE 3.—Geologic section of Sacramento Valley along floor of Redbank Creek.

[50] Dickerson, R. E., Stratigraphy and fauna of the Tejon Eocene of California: California Univ. Dept. Geology Bull., vol. 9, No. 17, p. 417, 1916.

[51] Idem, pp. 467–474.

many places the lavas extended down to the valley. Doubtless also the whole valley was covered from time to time by showers of volcanic ash.

ANDESITE BRECCIAS AND BASALT.

The lava flows which cap the gold-bearing gravels in the ancient stream channels of the Sierra Nevada and which diverted the rivers into their present channels covered the Ione formation on the edges of the valley and now extend as a bed of lava grading into tuff beneath the more recent sediments in the valley, as is shown by the deeper wells of the east side. In some wells good water is obtained in sands and gravels that apparently occur at this horizon.

Basalt of similar origin and history caps the Ione formation in South Table Mountain, near Oroville, and in a group of hills farther north. The basalt is not known as a water bearer in the valley, but rain water which enters its jointed and porous outcrops seeps out at its contact with the Ione to form several perennial springs in the mountain and the basalt-capped hills near by.

TUSCAN TUFF.

From Durham northward to Red Bluff and beyond the Sierra foothills are formed by beds of andesite lava, breccias, and volcanic ash aggregating 1,000 to 1,500 feet in thickness. The flow breccia characteristic of much of this formation is shown in Plate XIII, *A* (p. 41). These beds, which are known as the Tuscan tuff, consist of materials that were extruded from volcanoes in the vicinity of Lassen Peak.[52]

The formation is considered by Diller to be of Pliocene age, but small eruptions of similar material have continued through Quaternary time to the present day. That a long time was needed for the accumulation of these deposits is shown by the presence of interbedded gravels whose smooth, waterworn pebbles of andesite and basalt were laid down by large graded streams that flowed over the volcanic plain and eroded its surface between successive volcanic eruptions. The main mass of the volcanic material to which the name Tuscan is given was uplifted by a monoclinal fold (Chico monocline) extending along the border of Sacramento Valley from Chico northwestward to Iron Canyon (fig. 3). This movement, which involves also the older alluvium, lifted the Tuscan tuff from 500 to 900 feet above the valley. In the plain thus formed a number of deep and desolate gorges have been cut by perennial streams, of which Antelope, Mill, Deer, Chico, and Butte creeks are the largest.

From the foothills of the Sierra the Tuscan tuff extends beneath the alluvium of the valley with diminished thickness and increasing fineness of grain. It is exposed about 12 miles west of Sacramento River along Thomas, Elder, and Redbank creeks as a pinkish tuff about 50 feet thick overlying the Ione formation.

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[52] Diller, J. S., Tertiary revolution in the topography of the Pacific coast: U. S. Geol. Survey Fourteenth Ann. Rept., pt 2, p. 412, 1894.

The dip of the Tuscan tuff in the monocline is 10°–15° W. at the edge of the valley (Pl. VII) but flattens to horizontal in the center. Thus the depth to the formation within 2 or 3 miles from the outcrop east of Chico increases to 500 feet, but farther out in the valley it seems to lie at no greater depth. These relations are brought out in figure 4.

The depth of the formation beneath the valley has been estimated by interpretation of well logs. (See also pp. 267–269.) The wells of the Chico Water Co. and the Morehead wells (see fig. 4) are certainly in the lavas at the depths indicated, but the Parrott well has a log which is not quite so easily interpreted. The "lava ash" reported at 377 feet and again at 399 feet may be only a fine silt and not a tuff bed of the Tuscan formation.

The inclined position of the Tuscan tuff is favorable for artesian water, but the absence of an impervious cover prevents the accumulation of the necessary head. Certain beds within the formation

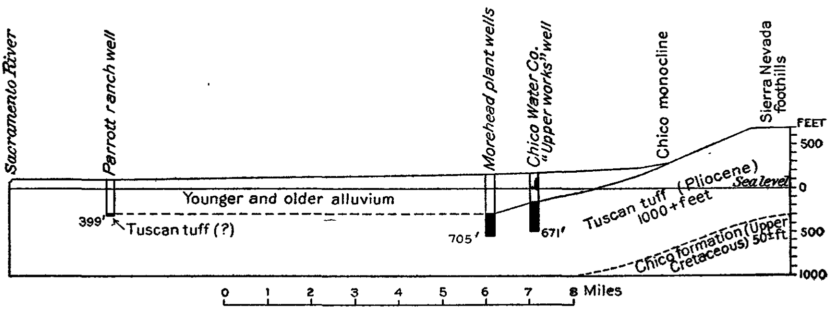

FIGURE 4.—Section through Chico, showing probable position of Tuscan tuff.

seem to be dry, and in many of the wells water stands slightly below the level of water in near-by shallow wells. In the wells of Stanford University east of Durham, however, the water stands 3.5 feet above the water table in the alluvium.

Drilling in the Tuscan tuff is difficult because the rock is hard and deep wells are necessary. The expense of drilling will be justified only where large supplies are needed or for stock and domestic water on the stony plains east of Vina, where shallow wells go dry in summer.

TUFF BEDS OF THE WEST SIDE.

Evidence of volcanic activity in the Coast Ranges is abundant. Ash beds and tuffs below the older alluvium and fine tuffs in the older alluvium of the west side indicate that, in part at least, this volcanism in the Coast Ranges was coincident with the Pliocene and Pleistocene eruptions of the Sierra Nevada.

TUFF BEDS OF THE MARYSVILLE BUTTES.

A thick mass of volcanic material, which once made up the lower slopes of a large volcano, forms an outer ring of hills around the Marysville Buttes. The volcanic material consists of tuff with embedded angular fragments of andesite and, more rarely, rhyolite of all sizes.[53] In places there is also more or less sand, gravel, and clay. These beds were poured out from vents in the center of the buttes as great flows of hot volcanic mud. They retain their original dip and form bare and sterile hills with gentle slopes toward the low land and steep in-facing scarps toward the center of the buttes. Doubtless these beds, with decreasing fineness of grain, extend out from the buttes in all directions beneath the younger alluvium. The tuffs have not been recognized in wells, however, except at Sutter, where a well showed 55 feet of alluvium above the tuffs,[54] though the pumice found in John Borgman's well (p. 276) may be representative of these tuffs.

OLDER ALLUVIUM.

GENERAL FEATURES.

The great volcanic eruptions of the Pliocene epoch were followed by uplift and erosion along the borders of Sacramento Valley but probably by continued deposition in the center. Deposition over the whole valley area then began and continued into Pleistocene time. The deposits thus laid down are known only where they have been exposed by later uplift on the borders of the valley, and when encountered in wells they can rarely be distinguished from the overlying younger alluvium. At the edge of the valley they rest on the andesite lava, the Tuscan tuff, and the Ione formation, in some places in apparent conformity but in many places with evidences of extensive stream cutting before their deposition. In some localities the Tertiary beds have been removed and the alluvium lies directly on the granites and schists.

The older alluvium is of Pleistocene and possibly late Pliocene age and is differentiated from the younger alluvium by the fact that it is now uplifted and dissected. In some places, particularly in the northeastern part of the valley, it has become considerably cemented and indurated (Pl. XIII, *B*). It is composed of clay, sand, and gravel and varies much in appearance and composition. It is characteristically red and is always redder than the neighboring younger alluvium, but the hue changes from place to place, and samples from different areas have no superficial resemblance. This is due to the fact that the alluvium was deposited by streams varying in volume

[53] Lindgren, Waldemar, and Turner, H. W., U. S. Geol. Survey Geol. Atlas, Marysville folio (No. 17), 1895.

[54] Idem, p. 2.

and permanence and draining areas of different types of rock. Only the deposits of tributary streams are exposed; the contemporary deposits of Sacramento River are now deeply buried.

Four large divisions of the older alluvium can be made and mapped—the southeastern, the northeastern, the southwestern, and the northwestern. (See Pl. III.)

SOUTHEASTERN DIVISION.

The southeastern division of the older alluvium extends from Oroville southward to Lodi and comprises the deposits of Feather, Yuba, Bear, American, Cosumnes, and Mokelumne rivers. In Pleistocene time these strong streams trenched great canyons in the Sierra Nevada and discharged the eroded materials into the valley. The Sierra throughout this region is composed largely of granite, and the alluvium is everywhere arkosic—that is, it contains undecomposed particles of feldspar and mica with quartz, the constituent materials of this rock. The clay is red or brownish red, is tough and tenacious, and contains particles of iron-stained feldspar and muscovite mica. The sands are quartzose and carry a little feldspar and much mica, both muscovite and biotite. The gravels are usually well-rounded pebbles of the harder rocks. Quartz and quartzite pebbles predominate, but pebbles of granite, diabase, andesite, and schist also occur. In size they range from cobblestones near the mountains to pebbles an inch or less in diameter near the center of the valley. The gravels are in most places cemented with calcium carbonate, and "hardpan" is common throughout the formation. Hardpan composed of clay or sand cemented with lime and hydrous silicates of iron is commonly found near the surface. It is covered with a few inches to several feet of red soil, which has a superficial coat of pebbles due apparently to concentration by rain wash. Such soil and hardpan are characteristic of the red lands. Irrigation and special treatment of the soil are necessary for full agricultural development of the rolling plains and hills of this formation.

NORTHEASTERN DIVISION.

The older alluvium of the northeastern division extends in irregular patches from Oroville to Chico and is more conspicuous from Chico along the east-side plains to Red Bluff. It is of the same age and was formed by the same processes as the older alluvium farther south, but as the comparatively short streams which furnished the sediments had their courses over the great blanket of Tertiary lavas that here mantles the Sierra the deposits are composed almost wholly of volcanic materials. The older alluvium of this part of the valley is thin, being nowhere over 60 feet thick where uplifted along the Chico monocline, and is composed chiefly of rather large, waterworn gravels, cemented by lime, with smaller amounts of brown clay and sand. The color of the formation as a whole is a deep brown, of slightly redder hue than the brown of recent deposits. Only small patches occur between Oroville and Chico, but north of Chico the older alluvium is the predominant surface formation on the east side of the valley. The surface is a treeless plain, covered with large and small stones, the finer material having been washed away by the rain. A thick grass springs up between the stones after the fall rains, and at such times the plains are used for grazing.

NORTHWESTERN DIVISION.

The northwestern division of the older alluvium extends from Stony Creek to Red Bluff. It forms a prominent bluff that overlooks the river and, with the prevailing red color, gives the name to Red Bluff and to several other local features. The clays, sands, and gravels of the formation were deposited by the Sacramento and its western tributaries. The gravels are in places 2 to 3 inches in diameter and are composed of igneous and metamorphic rocks from the Klamath Mountains. The formation is thin where it rests on the Tuscan tuff about 12 miles west of the river and is over 400 feet thick near the river. The upper part laps over the east-side alluvium in the vicinity of Iron Canyon, and this part of the formation is therefore younger. The Sacramento was evidently gradually crowded over to the east during early Pleistocene time by the mass of material brought down by western tributaries.

SOUTHWESTERN DIVISION.

In the southwestern division the older alluvium is composed of gray, brown, and yellow clay and fine sand, with local tuffaceous clays and ash beds. A reddish gravelly clay from a few inches to 25 feet thick occurs at the top of the formation and serves to distinguish it from the surrounding yellow and brown clays and loams of the younger alluvium. The formation rests on the eroded edges of Cretaceous and perhaps Tertiary rocks of the Coast Range, which have been beveled by erosion to a rather smooth plain. This plain extends from the alluvium up toward the mountains in successively higher ridges for a mile or more and is probably similar in origin and age to the plain that bevels the Cretaceous rocks in the northern part of the valley.[55] The formation was uplifted in Pleistocene time by movement of two kinds. From Stony Creek to Williams the older alluvium was tilted as the mountains went up and the valley down, so that it now projects out of the modern alluvium in a thin and irregular

[55] Diller, J. S., op. cit., p. 405.

fringe, nowhere over a mile wide. From Williams to Cache Creek the older alluvium forms a plateau from 200 to 500 feet above sea level, uplifted by movement due to faulting along a northwest-southeast line marked by the present front of the plateau. Another fault, en échelon with this one, starts at Esparto and, skirting the mountains, brings up the alluvium along the foothills to a point opposite Allendale, where the fault disappears. Farther south, around Elmira, the older alluvium comes close to the surface of the plains, which are only veneered with modern wash. It reappears in the Montezuma Hills, a well-dissected plateau of alluvium about 200 feet high on the west with a gentle slope to the northeast. These hills form the terminus of the plains and confine the waters of the Sacramento and San Joaquin in a narrow throat against the Diablo Range, with Suisun Bay on the west and the island country on the east.

YOUNGER ALLUVIUM.

The deposition of the older alluvium was followed by uplift in both the Sierra Nevada and the Coast Ranges, which is regarded as part of the Pleistocene uplift of these ranges. The edges of the valley were bent up and the center gently bowed down.

With this uplift Sacramento River and its tributaries began the deposition of the younger alluvium, the material being eroded from the older alluvium or brought down from the mountains.

The younger alluvium covers the central area of the valley and lies in narrow strips along the tributaries of the Sacramento. It varies in character, like the older alluvium, but also includes the deposits of the main river in addition to those of the side streams. The formation is probably nowhere in the valley more than 300 or 400 feet thick. Every high water adds to it, and this fact is so well understood that some farmers deliberately turn flood water on their land for the benefit derived from the "sediment."

The younger alluvium is the most productive water bearer of the valley formations. It is uncemented over most of the area and consists largely of sands and gravels. Many house wells draw water from the clays, but except under unusual conditions large supplies are derived only from the sand or gravel. Successful development consists in the search for sufficient sand and gravel and in the use of adequate well methods.

These beds were deposited by the present streams, and the coarsest and cleanest gravels were formed by the larger streams. But as these streams, in building up the valley deposits, have shifted their courses many times, their gravels are found over a wide area. The gravels are not continuous beds but irregular lenses and strings of material separated by sand and clay. Consequently the logs of adjacent wells may be very unlike. Where a stream is confined in a valley of older alluvium it is comparatively easy to sink a line of wells across the valley and determine the place where the maximum amount of gravel has been deposited. Where a stream debouches from the mountains directly upon the plain its deposits occupy a triangular area with the apex near the mountains. The gravels, representing old stream courses, extend in irregular wavy lines from the apex to the base. The largest amount of gravel is then at the mouth of the canyon, and the smallest near the mountains in the interstream areas.

Along the larger rivers wells draw from either sand or gravel, and the gravels encountered are of the same size as those in the river bed at that place. Thus the Sacramento has gravels 3 to 6 inches in diameter near Red Bluff, 2 to 3 inches at Hamilton, 1 to 2 inches at Butte City, and about 1 inch at Colusa. From Colusa southward gravels are rare, but the sands are in many places coarse and gravelly, and even as far south as Rio Vista pebbles half an inch in diameter are found in the sands. Feather River carries gravels 6 to 8 inches in diameter at Oroville, but at Marysville most of its load is sand.

STRUCTURE.

Throughout the greater part of geologic time Sacramento Valley has been a subsiding area. In general the subsidence since the beginning of the Tertiary period has consisted in a gentle down bowing of the valley along its medial line. The amount of subsidence has ranged from practically nothing at the head of the structural depression north of Redding to a maximum at the south end of the valley. In consequence the Tertiary and later formations thicken toward the south. The most recent movements, those which deformed the older alluvium, differed in amount and in mechanism in different parts of the valley. In the northern part, above Hamilton, the movement was the most intense and resulted in raising the valley floor above the grade of Sacramento River, so that the river runs in a trench cut through red lands (Pl. IV). On the east side the movement produced a monoclinal flexure which extends northeastward from Chico to Iron Canyon. This flexure involves the Tuscan tuff and the older alluvium. The dip of the beds in the monocline increases from about 10° near Chico to 15° at Antelope Creek. The displacement amounts to approximately 500 feet, so that the altitude of the plains is about 500 feet and that of the edge of the volcanic plateaus a mile east is 1,000 feet. (See Pls. III and IV.)

The head of the valley is formed by the Red Bluff arch, a broad, low dome[56] which bows up the alluvium in the vicinity of Iron Canyon. This doming is accomplished by two rather sharp folds which cross

[56] Diller, J. S., Guidebook of the western United States, Part D, The Shasta Route and Coast Line: U. S. Geol. Survey Bull. 614, p. 71, 1915.

the Chico monocline at right angles. Sacramento River at Iron Canyon cuts through the northern fold but swings west and avoids the southern. (See Pl. III.) At this place the northwestern type of older alluvium overlies the northeastern type and both are deformed by the folding. The great bulk of the sediment carried by the west-side streams forced Sacramento River to the east side, and the deposits of the east-side streams were buried. When uplift took place the river cut through both beds of alluvium and into the underlying Tuscan tuff.

On the west side of the valley uplift took place by a broad flexure, so that the alluvium was elevated about 50 feet at the river and now stands at altitudes of about 1,000 feet 12 miles west of the river. The mapping of the areas west and east of Sacramento Valley shown on Plate III is adapted from reports by Diller.[57] The thickness of the older alluvium in this part of the valley is estimated at 400 feet, from the logs of wells drilled as oil prospects in the Orchard Park tract, south of Red Bluff. (See pp. 253–255.) The thickness of the younger alluvium is estimated at not over 100 feet. The structure of this portion of the valley is shown in figure 3.

South of Hamilton the center of the valley sank as the sides were raised. On the east side from Chico south to Dry Creek the elevation was so small that almost none of the older alluvium appears above the level of the younger alluvium, but from this point southward the uplift increased to a maximum of about 425 feet at Oroville. From Oroville to Bear River the amount of uplift decreased. Throughout this section the older alluvium was rather sharply tilted, and the fragments and patches that remain have a rather steep slope into the valley. From Bear River to the Mokelumne the uplift was more gentle.

From Stony Creek to Williams the older alluvium was tilted as the mountains went up and the valley down, so that it now projects out of the modern alluvium in a thin and irregular fringe, nowhere over a mile wide. From Williams to Cache Creek the older alluvium forms a plateau from 200 to 500 feet above sea level, uplifted by movement due to faulting along a northwest-southeast line marked by the present front of the plateau. The minimum movement was at least 400 feet on the north and about 200 feet at Cache Creek. The same fault turns to the south at Cache Creek and extends, as shown by a line of low red hills, to Putah Creek. The plateau, which in the southern part is known as the Hungry Hollow Hills, is thoroughly dissected by short streams at right angles to the fault. Another fault, en échelon with this one, starts at Esparto and, skirting the mountains, brings

[57] Diller, J. S., Tertiary revolution in the topography of the Pacific coast: U. S. Geol. Survey Fourteenth Ann. Rept., pt. 2, pls. 44 and 45, 1894; Geology of the Lassen Peak district: U. S. Geol. Survey Eighth Ann. Rept., pt. 1, pl. 47, 1889.

up the alluvium along the foothills to a point opposite Allendale, where the fault disappears. Farther south, around Elmira, the older alluvium comes close to the surface of the plains, which are only veneered with modern wash. It reappears in the Montezuma Hills, a well-dissected plateau of alluvium about 200 feet high on the west with a gentle slope to the northeast.

WATER-BEARING FORMATIONS.

The younger alluvium (see Pl. III) is the most productive water bearer in Sacramento Valley. It is uncemented in most of the area and consists largely of sands and gravels that yield water freely and in large quantities. Most of the large irrigation pumping plants derive their water from this formation. Successful development consists in the search for sufficient sand and gravel and in the use of adequate methods of constructing wells.

The gravels are not continuous beds but irregular lenses and stringers of material separated by sand and clay. Consequently the logs of adjacent wells may be very unlike. Where a stream is confined in a valley of older alluvium it is comparatively easy to sink a line of wells across the valley and determine the place where the maximum amount of gravel has been deposited. Where a stream debouches from the mountains directly upon the plain its deposits occupy a triangular area with the apex near the mountains. The gravels, representing old stream courses, extend in irregular wavy lines from the apex to the base. The largest amount of gravel is then at the mouth of the canyon and the smallest near the mountains, also but distant from the mouth of the stream.

General information on the water levels in the younger alluvium and on the source, discharge, quantity and quality of the water is given on pages 82–99, and detailed data regarding the water in this formation in all parts of the valley are given in the description of pumping areas on pages 129–252.

The older alluvium (see Pl. III), described on pages 74–77, is on the whole more compacted and cemented than the younger alluvium, but in some parts it is also a valuable source of water.

The northwestern division of the older alluvium is not tightly cemented, though wells can not be sunk in it without using a drill. In a few places the gravels are dirty and cemented, but as a rule they are clean and are good water bearers. Excellent wells have been obtained in the first 300 feet in the vicinity of Red Bluff, and wells drilled recently near Corning are promising.

In the northeastern division dug wells have been the common type and have not been very successful. Drilled wells are more likely to develop water, but large supplies can not be expected from this division of the older alluvium.

In the southeastern division water is usually obtained from fine sand, as the gravels of the formation are commonly so well cemented as to furnish but little water. Because the clays stand without casing the sand is usually pumped out and water is drawn from the cavities thus formed. Wells so constructed have a large seepage area, and many of them, particularly in the lower part of the plains, are very successful. Wells in this formation should be drilled, as the material is too hard for successful auger work except in certain favored places.

Detailed data in regard to the occurrence and yield of water in the older alluvium are given in connection with the deep-well records on pages 253–280 and in the descriptions of the subdivisions of the valley on pages 129–252. Information regarding the quality of the water is given on pages 98–99.

On the east side of the valley near Chico the Tuscan tuff supplies seven wells, the weakest of which has a yield of 600 gallons a minute. In the center of the valley shallow wells from overlying formations are likely to furnish sufficient water, but on the higher plains from Durham northward to Red Bluff, where the alluvium is thin and cemented, wells should be sunk to the Tuscan tuff if large supplies are needed. The dip of the formation is 10°–15° W. at the edge of the valley but flattens to horizontal in the center. Thus the depth to the formation within 2 or 3 miles from the outcrop east of Chico increases to 500 feet, but farther out in the valley it seems to lie at no greater depth. These relations are brought out in figure 4 (p. 73). Little is known of the water-bearing properties of the Tuscan tuff on the west side of the valley. A description of this formation is given on pages 72–73, and detailed data regarding the wells that have been sunk into it on pages 267–269. An analysis of the water obtained from it is given on page 155.

The andesite breccias, described on page 72, are not important sources of water, but in some wells good water is obtained in sands and gravels that apparently occur at this horizon. (See pp. 273–276.)

The basalt mentioned on page 72 is not known as a water bearer in the valley, but rain water that enters its jointed and porous outcrops seeps out at its contact with the Ione to form several perennial springs in South Table Mountain and the basalt-capped hills near by.

The Ione formation has not been recognized in wells in the valley, but deep wells near Lincoln obtain salty water from fine sand below a thick blue clay or shale, which is either the Ione or the underlying Cretaceous. (See pp. 169 and 173.)

The pre-Tertiary rocks carry little available water and may be considered as forming the impervious basin that holds the water-bearing deposits.

WATER TABLE.

FORM AND POSITION.

Throughout the valley the alluvium at a depth of a few feet is saturated with water. This water, which is known as ground water, fills the interstices of the ground to an indefinite distance downward. In general, the earth's crust becomes more compact with increasing depth, and in every region there is a depth at which the pores of the rocks are so small that they yield little or no water. The top of this zone of saturation is called the water table. It is the level at which water stands in shallow wells.

Sacramento Valley is remarkable for the large area in which the water table stands close to the surface. During the summers of 1912 and 1913—two dry years—the depth to water in more than 80 per cent of the valley was less than 25 feet. Water was more than 25 feet deep over the plains area on both sides of the river north of Hamilton; in a fringe of interstream areas of older alluvium, or red lands, on both sides of the valley; on the steep fan west of Arbuckle; and in the apricot district around Winters. These areas are outlined on the maps (Pls. II and IV). In the rest of the valley water stood at depths of less than 25 feet.

The form and position of the water table is shown in Plate IV by contours, or lines drawn through points where the water table has equal altitudes above sea level. The contours are based on about 2,500 observations of the depth to water in wells. The depth to water from the top of the casing was measured with a steel tape to the nearest tenth of a foot. The height of the casing above ground was added to the altitude of the ground surface as determined from the large-scale topographic maps of the valley. From this total the depth to water was subtracted to give the elevation of the water surface. It is believed that the errors incident to measurement and estimation from the maps generally amount to less than 1 foot.

Contours for the west side of the valley were made in the fall and winter of 1912, and for the rest of the valley, except the extreme southern portion, in the summer and winter of 1913. The map was completed in 1914. As the seasons of 1912 and 1913 were very dry the contours represent conditions of nearly maximum depth to water.

The water table slopes from the sides of the valley toward the center and from the north to the south. The grade is slightly less than that of the land surface, so that water is shallower in the basin areas than toward the hills. In the northern part of the valley the ground water slopes toward Sacramento River and except during flood times escapes to and feeds the river. From Hamilton southward the water table slopes to the basins from the plains and also from the river down the slope of the natural levees to the basins. The grade in the basins from north to south is very slight, so that the ground water is practically stagnant in these areas. Thus the fluctuations of the river affect only the wells near the river bank.

No attempt was made to plot the contour of 10 feet above sea level or the sea-level contour. Thus the depth to water over large parts of American, Sutter, and Yolo basins and of the adjacent river lands and the island country is not represented. In these areas the depth ranges from a maximum of 20 feet along the river bank to only a few inches in parts of the basins. Along the river banks there is a large fluctuation between times of high and low water in the river or its distributaries. In the basins the maximum depth is 6 feet in the very dryest years. In the island country the depth to water is often artificially controlled.

In four places the contours present anomalous features due to the activities of man.

Along Yuba River the 50, 60, 70, and 80 foot contours have peculiar westward bulges. The change in direction begins near the river levee and indicates that the water table is higher within the levees than outside. This is due to saturation of the mass of sand and gravel brought down by the river since the beginning of mining and now forming a ridge across the region (p. 30). The similar westward bulges of the 60, 70, and 80 foot contours north of the Marysville-Brownsville road are due to irrigation.

On the west side of Feather River, near Gridley and Biggs, the 60, 70, 80, and 90 foot contours have peculiar bulges to the south which inclose the district irrigated by the Butte County canal. Within this area the water table has been raised from depths ranging from 10 to 20 feet to a level within 5 feet of the surface. Northwest of Biggs water stands at 3 feet below the surface during the irrigation of rice, and the recent increase in the area of rice culture has probably greatly modified the form of these contours.

Southwest of Yuba City a lowering of water level has been caused by pumping. On this account the 30-foot contour has a large northeasterly bend. (See p. 89.)

FLUCTUATIONS.

The annual fluctuations of the water table are large. The rise begins in September and is gradual until the coming of the rains, when the rate of increase is more rapid until some time in March. Beginning about in March the water falls until, in the latter part of June, it reaches the summer level, which is nearly constant except when affected by pumping. The characteristic fluctuations in the basin lands are shown in figure 5, which gives the average of the depths to water observed weekly in 24 wells in Colusa Basin. The curve is very similar to the curves given by Lee[58] for the moist lands in Owens Valley. The summer low stage is more protracted, however, and the rise and fall before and after the winter rains are much sharper. The rise of ground water in the fall before the winter rains

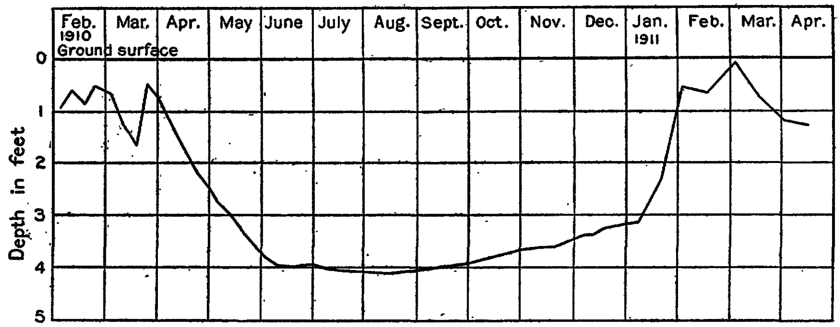

FIGURE 5.—Diagram showing average fluctuations of the water table in 24 wells in Colusa Basin.

begin is due chiefly to decrease in loss by evaporation with cooler weather, while replenishment by percolation from higher levels continues. In the plains areas, where the depth to water is 15 to 25 feet in summer, the winter rise brings the water within 5 to 15 feet of the surface.

Additional data on the fluctuation of the water table are given under "Quantity of ground water" (pp. 86–91).

INTAKE AND DISCHARGE OF GROUND WATERS.

INTAKE.

The ground water of Sacramento Valley is derived from the precipitation on the valley and from the streams that discharge into the valley. As is shown in the tables on pages 49–51 and 65–68, the quantity of water available for absorption in an average rainy season is very large. As the younger alluvium is porous and as it lies exposed over most of the valley, its facilities for intake are excellent. Consequently in a normal rainy season the underground reservoir is filled virtually to its capacity, and in the wettest winters there is a very large excess that runs to the ocean or fills the flood basins. Thus, even though the supply may be seriously depleted during one or more years with deficient precipitation, the effects of such depletion will be obliterated almost completely by recharge during a wet winter. Thus, also, the depletion caused by heavy pumping will increase the available capacity of the underground reservoir and will in large part be overcome by absorption of water that would otherwise run to waste.

[58] Lee, C. H., An intensive study of the water resources of a part of Owens Valley, Calif.: U. S. Geol. Survey Water-Supply Paper 294, pp. 80–81, 1912.

Rapid absorption occurs through the gravelly streamways, but the recharge in the interstream areas is largely effected from the local rain before there is time for the water from the streams to percolate to these areas. The ground water is therefore derived in part from rain that falls on the valley.

DISCHARGE.

The fact that water in wells rises in winter and falls in summer means that a large amount of water is taken into the ground in winter and is lost again in summer. Loss occurs by movement down the slope of the water table to seeps and sloughs in the basin lands where the water evaporates; by evaporation from moist lands where the ground water stands less than about 8 feet from the surface; and by transpiration where the ground water is within reach of the roots of plants. When the water evaporates the dissolved salts are left in the ground and may form "alkali" land.

Pumping results in the recovery of water that would otherwise be discharged through one of the three processes mentioned above, and it also lowers the water table farther than it would otherwise be lowered and thus provides room for an increase in the recharge during the ensuing rainy season.

ALKALI RESULTING FROM DISCHARGE.

Although there are in the valley large areas that have a shallow water table, which is favorable to evaporation and the accumulation of alkali, only comparatively small areas are unfitted for agriculture from this cause. This condition seems to be due to the following reasons:

1. The ground waters are of good quality. The east-side waters contain from 100 to 250 parts per million of dissolved substances, mostly calcium and the bicarbonate radicle, and the west-side waters contain from 200 to 600 parts per million of dissolved substances, largely calcium and the bicarbonate and sulphate radicles. (See pp. 98–99.)

2. The water table is very flat over the basins, and movements of the ground water are sluggish. Water is supplied more freely at the bases of the slopes, and for this reason the principal concentration of alkali occurs at the edges of the basins. This is particularly the case on the west side, where alkaline patches and areas of salt grass border the basins along their western edges. The distribution of alkaline land on the west side of the valley is set forth in the soil reports on the Colusa and Woodland areas.[59]

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[59] Lapham, M. H., and others, Soil survey of the Colusa area, Calif.: U. S. Dept. Agr. Bur. Soils Field Operations, 1907, pp. 927–972, 1909. Mann, C. W., and others, Soil survey of the Woodland area, Calif.: Idem, 1909, pp. 1635–1687, 1912.

3. The heavy winter rains leach out much of the salts concentrated at the surface. Similarly flood waters wash out the salts in overflowed lands, and on the edges of the plains the same waters deposit mud or sediment, which often covers up the alkali.

QUANTITY OF GROUND WATER.

The total quantity of ground water in the valley is very great. The sands and gravels contain from 20 to 40 per cent of water. The pore spaces of the sand and gravel are much larger than those of the clay, and the rate of flow through these materials is consequently much greater and they give up a larger proportion of their water. Hence they become for practical purposes the water bearers. The sands and gravels are distributed through the alluvium, which thickens from less than 50 feet at the edge of the valley to 500 feet or more in the center.

The rapidity of the winter rise and its sensitiveness to rainfall afford the best indication of the quantity of water available for pumping, for the available ground water in any district is the average amount which, falling as rain, percolates into the soil or, being collected in the mountain valleys, is carried to the plains by torrential streams and there sinks into the ground, less the amount which escapes through seepage and evaporation before or during the pumping season. It is very difficult to estimate this amount. In the neighborhood of Dixon, where pumping for irrigation had been practiced for 12 years and on a large scale for 5 years, water was lower in the wells in the summer of 1912 than it had been since pumping began. The water stood about 5 feet below the normal August level, according to the observations of many irrigators, and it was necessary to deepen pumping pits and lower pumps. This sinking of the water table was not due entirely to pumping but in part to the excess of natural loss over gain because of the small rainfall of the previous two winters. In the summer of 1912 a lowering of the water level in wells probably averaging 2 or 3 feet below the seasonal normal had been commonly noticed by well owners throughout the valley, and it may be inferred that only the additional lowering of 2 or 3 feet near Dixon in the same season was due to the withdrawal made by the hundred plants in the immediate vicinity of the town.

The well of T. T. Eibe, near Dixon (p. 234), is 97 feet deep and is cased to the bottom with galvanized-iron casing 10 inches in diameter. It is at one side of an 8 by 8 foot cement pit 8 feet deep and is equipped with a 5-inch horizontal centrifugal pump connected by belt in an inclined beltway to a 12-horsepower gasoline engine. When this plant was visited in December, 1912, the water stood 7 feet below the cement floor. Mr. Eibe stated that it had never before been lower than 2 feet below the floor and that in the winter of 1907 it stood 2 feet from the top of the pit—that is, 6 feet above the floor. Even in June, 1912, there was 4 feet of water in the pit, and in order to do any pumping it was necessary to replace the belt with a chain drive. In this place, then, there was in the dry year of 1912 a variation in level of 11 feet in seven months. In wet years the amount of fluctuation is probably not so great, because summer lowering from natural causes is about the same each year, but with increasing withdrawals of water by pumping there will be an increase in the volume of unsaturated ground and consequently also in the absorption and storage of water during wet winters. This increase in depth to water during the pumping season even after a wet winter like that of 1913 is shown by the fact that in this well the water stood 11.8 feet below the floor of the pit in August, 1914.

The winters of 1911 and 1912 were dry, less than half the normal rainfall being recorded at most of the valley stations. In consequence the winter rise of ground water was smaller than usual, and in the summer of 1913 the water table was exceptionally low. With the heavy rains of the succeeding winter, however, recovery was general, though there were exceptions in regions of heavy pumping.

These conditions are brought out in figure 6, which is a record of water levels in the well of the Irrigation Investigations Office, United States Department of Agriculture, at the California University farm at Davis. The upper curve in the figure shows the depth to the water level when the well is not in use, and the lower curve shows the depth when the pump is operated. The observations were made on the first of each month by S. H. Beckett, irrigation engineer, who generously furnished the record. The monthly rainfall at Davis, obtained from the United States Weather Bureau, is plotted for comparison.

Figure 6 shows that the fluctuations of the water table at Davis followed the rainfall closely and that with heavy rains the recharge was prompt and large. In the winter of 1912–13, when the rainfall was deficient, the water level was below the seasonal normal. The following spring and summer the lowering was moderate—only about 2.3 feet when no pumping was being done—probably because the water level was so low that natural losses were reduced to a minimum. A gradual rise began in August, although there was no rain until October 31. This was no doubt due largely to the general flattening out of the water table, which produced a rise in pumping districts, where lowering was especially great. Promptly after the heavy rains of the winter of 1913–14 the water level rose rapidly, until on February 1 it stood more than 8 feet about the lowest level of the previous summer. Although a part of this rise must be attributed to the general flattening out of the water table, most of it was undoubtedly due to recharge in the rainy season. Thus, if 6 feet of the rise is attributed to recharge and a porosity of 25 per cent

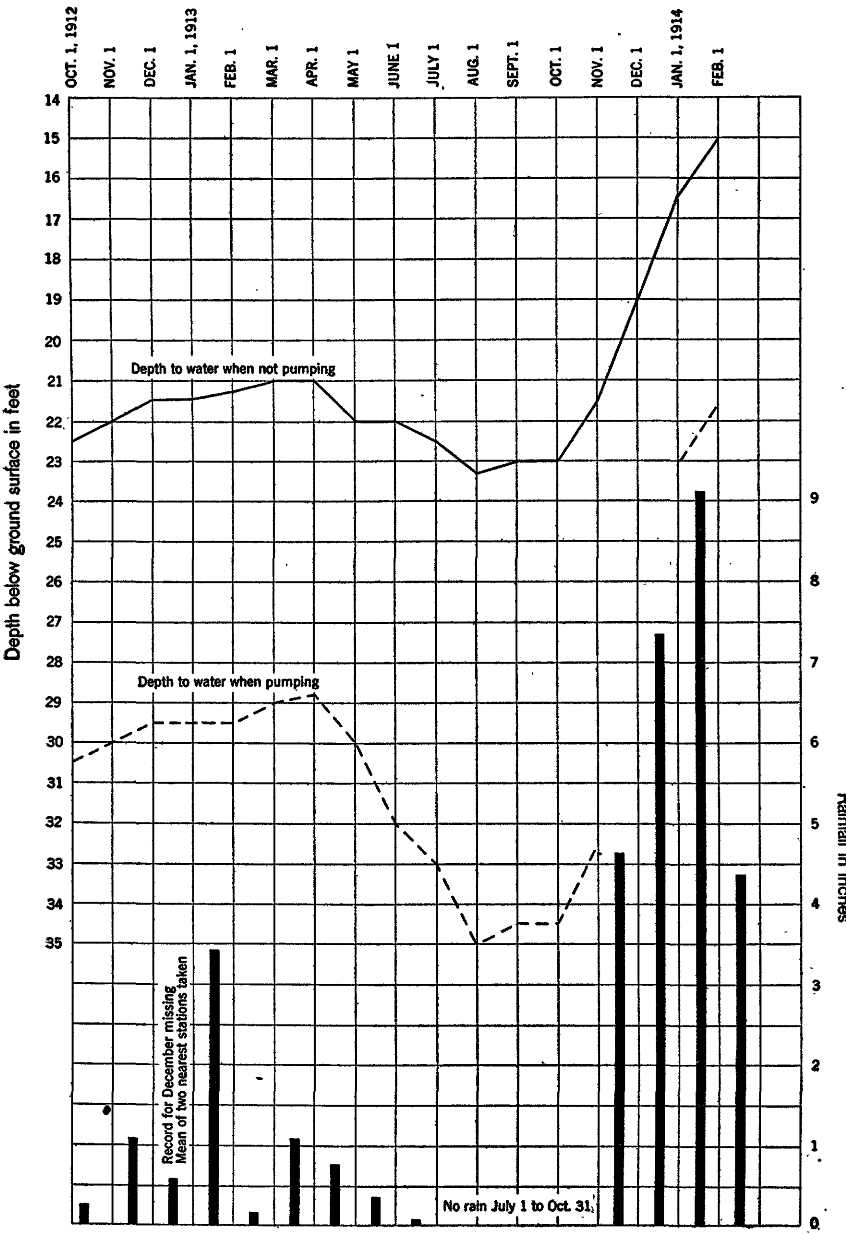

FIGURE 6.—Diagram showing rainfall and fluctuations of the water table at Davis, October 1, 1912, to February 1, 1914. Data furnished by S. H. Beckett.

is assumed, the supply of water added prior to February 1 amounted to a sheet of water 1½ feet deep.

Figure 7 shows the position of the water table near Yuba City in September, 1913. The general slope from Feather River west and south to Sutter Basin, indicated by contours, is normal to the locality, though the water table was from 2 to 3 feet lower than usual in 1913 because of the dry season. The principal pumping was done along Gilsizer Slough, and here the water table was lowered a maximum of about 5 feet in addition to the general lowering, as is shown by the backward swing of the contour lines. The approximate position of the water table if there had been no pumping is indicated by broken lines.

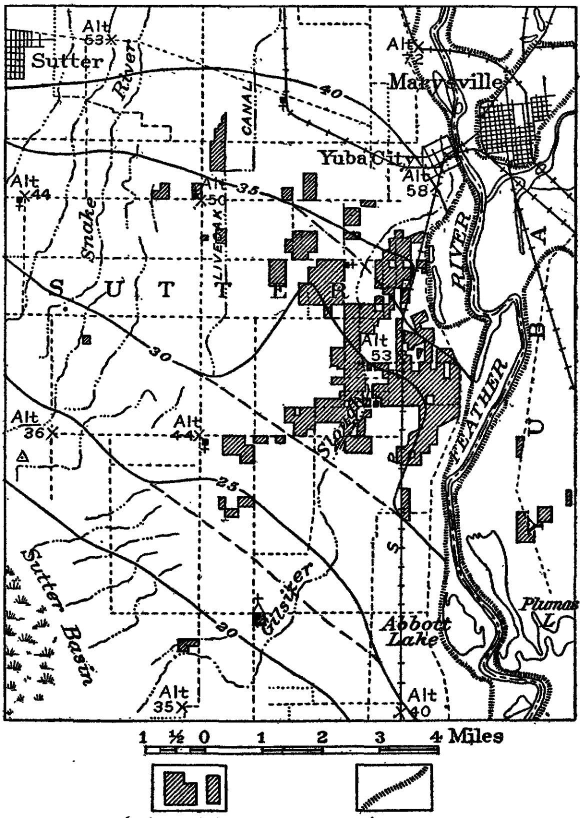

FIGURE 7.—Map showing position of water table in relation to pumping for irrigation near Yuba City, September, 1913. Unbroken lines show contours of water table (feet above sea level); broken lines indicate probable position of contours of water table if there had been no pumping.

Similar lowering of the normal ground-water level was found along Knights Landing Ridge northeast of Yolo. In July, 1900,[60] the depth to water in J. R. Fisher's wells was 24 feet. These wells were pumped with a 6-inch centrifugal pump from 1898 to 1900, when the pumping plant was removed. On September 29, 1912, the water stood 23.8 feet below the top of the pump pit. Mr. Fisher stated that early in the spring of 1913 the water was only 21 feet below the surface and that in normal winters the water rises within 10 to 15 feet of the surface. In the spring of 1913 a 3-inch centrifugal pump was installed and 10 acres of alfalfa was irrigated. Moreover, the St. Louis pumping plant of the Sacramento Valley Sugar Co., a quarter of a mile north of these wells, was operated for about 70

[60] Chandler, A. E., Water storage on Cache Creek, Calif.: U. S. Geol. Survey Water-Supply Paper 45, p. 25, 1901.

days during the season of 1913 at a capacity of 7,000 gallons a minute. On June 27, 1913, the depth to water in the Fisher wells was 39 feet. On a temporary shutdown of the St. Louis plant in 1913 Mr. Fisher observed the water rise 22 inches in his wells.

When the pumping plant of A. W. Dick & Sons, 2 miles north of the Fisher plant, was installed January 1, 1913, the pump, set in a pit 15 feet deep, primed at a vacuum of 2.5 inches of mercury, which is equivalent to a depth of water of 2.8 feet below the pump; in July it primed at a vacuum of 12 inches of mercury, indicating a lowering of the water level to 13.5 feet below the pump, or a net lowering of 10.7 feet. In the house well of B. Weiss, 1½ miles west of the Dick plant and 1¼ miles from the nearest pumping plant, the water level was 12.9 feet below the top of the casing on October 1, 1912, and 15.5 feet on July 1, 1913, a lowering of 3.6 feet. Lowering was not evident near the river, as is shown by the fact that in C. A. Piper's well, near Knights Landing, the water level was 17.7 feet below the top of the casing on September 7, 1912, and 17.6 feet on July 1, 1913.

On heavy pumping the water in a well lowers, and this lowering is called the drawdown. (See fig. 8, p. 114.) The water is also lowered in the ground for some distance around the well. Wells near by are often affected and, if shallow, may be rendered useless. This depression of the water table, or "cone of influence," is large when the supply of water is scanty or pumping is heavy but is small when the water is plentiful and pumping is not excessive. If the ground water were simply a pool in the pore spaces of the ground this cone of influence would gradually extend until the whole body of water would be permanently lowered. However, the ground water is constantly in motion, receiving increments from the rains and moving toward the center of the valley, where it is lost by seepage and evaporation. Its level rises and falls according to the amount that is passing by. Hence, when the water table at any point is depressed by pumping, movement takes place toward that point from all directions.

The available data show that pumping produces only a local depression of the water table and that the winter rise in normal years is rapid and effective. General lowering of the ground water may be expected in the summer, and it will be large during periods of deficient rainfall. Heavy pumping may be expected to create still further depression, which, if the whole valley were irrigated by pumping, would increase the general lowering. However, pumping increases the volume of unsaturated soil capable of receiving and retaining water and thereby increases the amount of water that is stored underground in the succeeding rainy season.[61] Wells in or

[61] Smith, G. E. P., Arizona Univ. Agr. Exper. Sta. Bull. 64, p. 189, 1910.

near land that will in the future be irrigated from ditches will have a decreased lift after irrigation is begun, because of the rise of ground water that accompanies the ordinary wasteful methods of applying water. (See Pl. IV and p. 83.) Along the edges of the flood basins, within reclamation districts and in other localities where the ground water stands very near the surface, lowering of the water table by pumping will be beneficial.

The economic limit for pumping will be reached when the ground-water level is so greatly depressed at the end of two or three dry seasons that the cost of the increased lift absorbs the profit from the crop. In view of the high lifts common in southern California, where water is being pumped for irrigating alfalfa with a lift of 100 feet and for irrigating citrus fruits with a lift of 200 to 400 feet,[62] and in view of the small amount of depletion that has resulted from heavy pumping in Sacramento Valley in the past, it is believed that a very considerable increase in the number of plants can safely be made in the existing pumping districts of the valley.

ARTESIAN CONDITIONS.

Only a small number of flowing wells have been obtained in Sacramento Valley, and of these only a few have strong flows. There is no large area of artesian flow, as in San Joaquin Valley.

Water in wells may be brought to the surface by either hydrostatic pressure or gas pressure. Ordinary artesian wells are due to hydrostatic pressure, but under special conditions flowing wells may be due to gas pressure. For the operation of either force certain geologic conditions are necessary.

FLOWING WELLS DUE TO HYDROSTATIC PRESSURE.

For flow from hydrostatic pressure it is necessary that water be confined in a pervious bed below a relatively impervious bed, and that the intake of the pervious bed be at a sufficient altitude to give the water enough pressure to overcome resistance within the pervious bed and to rise to the surface when this bed is pierced by a well.

Alternating pervious and relatively impervious beds occur in the Cretaceous and later formations, but their outcrops along the border of the valley are at low altitudes (see Pl. III) and there is generally not sufficient pressure to cause artesian flows in the lower parts of the valley.

Other conditions are also unfavorable. Along the east side of the valley sandstone of the Chico formation is almost everywhere buried under clays of the Ione formation. Even if it were otherwise a good water bearer it is not in position to receive a supply. On the west

[62] Tait, C. E., The use of underground water for irrigation at Pomona, Calif.: U. S. Dept. Agr. Office Exper. Sta. Bull. 236, p. 96, 1911.

side of the valley where the Chico and other Cretaceous rocks in places are at high altitudes and dip under the valley (fig. 3, p. 71), the sandstones and conglomerates seem to be too dense to act as water bearers.

The Ione formation consists in large part of clay or fine-grained tuff and sandstone and is therefore not a water bearer.

The volcanic rocks on the east side seem more favorable, but south of Oroville the andesite breccia crops out at a low altitude and is very dense and impervious at the outcrop. The Tuscan tuff, however, forms the surface rock on the flanks of the Cascade Mountains, where the rainfall is heavy and there are many large streams. It has many porous beds, and these become charged with water. Its inclined altitude (figs. 3 and 4) is suitable for producing a pressure head, but an impervious capping is absent. Thus good wells are obtained but no artesian flows.

The older alluvium in only one locality appears to have the requisite character to produce flowing wells. From Williams northward to Stony Creek (Pl. III) the older alluvium pitches sharply under the valley. The outcrop is a broad hilly area of red lands where rain may easily be absorbed. The formation includes many coarse sands and gravels interbedded with clays. These sands and gravels form excellent aquifers. Artesian flows were obtained from two wells in this area. The Shaw well, at Germantown, yields a flow of about 200 gallons a minute, and the French well yields a flow of about 100 gallons a minute. These wells are about 800 feet deep. The area in which artesian flows can be obtained extends about 6 miles north of Germantown and probably covers 5 to 10 square miles.

Along the west side of Yolo Basin, from Davis northward to Woodland, and in Colusa Basin, from College City northward to Willows, small artesian flows are obtained from many of the deeper wells. The most southerly of these is the Chandler well, which has a flow of about 3 gallons a minute; the most northerly is the well on the Spaulding (formerly Rideout) ranch, near Norman station, south of Willows (see log on p. 259), which also has a flow of a few gallons a minute.

The largest group of flowing wells in the valley is south of Colusa, along Dry and Sycamore sloughs. The material encountered consists of thick beds of clay with streaks of fine sand in which the artesian water is found. The wells range in depth from 100 feet to nearly 1,000 feet. The pressure is rarely great enough to raise the water more than 2 or 3 feet above the surface of the ground. In some wells the water rises only a few inches above the normal water table, and some of the wells flow only in winter. These variations in depth and pressure indicate that the beds underlying the valley are not uniform in structure but that the flows are due to recurring favorable structural conditions which have their origin in the manner in which valley filling took place.

Flood basins or similar depressions appear to have existed in approximately their present position during most of the period of valley filling. In these depressions clays and similar impervious deposits were for the most part laid down, but occasionally streams extended into the basins and deposited beds of sand. These sands are connected with the sands and gravels of the low plains and are supplied by them with water. Where the level of ground water in the plains is enough higher than the surface of the adjacent basin to overcome the friction of flow through the sands, wells in the basin will overflow. Fluctuations of ground-water level in the plains therefore cause fluctuations in the flow of certain of the wells. As the difference in altitude of the basins and the low plains is slight, only small pressures are obtained.

FLOWING WELLS DUE TO GAS PRESSURE.

On the east side of the valley from Sacramento northward to Bear River there are a number of wells in which water and gas occur together. (See pp. 269–276.) The gas is inflammable and consists largely of methane (CH_4), or "marsh gas." In these wells flow takes place because of the presence of gas, after the same fashion as in an air-lift pump. The gas entering the well at the bottom expands as it flows upward, forming bubbles of various sizes in the water. The column of water and gas within the well is lighter than the water outside the well and hence rises above the level of the ground water.

At Sacramento and also at Stockton this natural gas has for many years formed a large part of the city supply. In these wells the water is salty and is not fit for drinking.

North of Sacramento a number of wells yield flowing water of good quality and gas. Among these are George Howsley's well, near Pleasant Grove, 660 feet deep (see log, p. 275), and the Natomas well (No. 14, Pl. IV), near Sankey, 875 feet deep (see log, p. 276).

Gas was first obtained at Sacramento at a depth of about 900 feet, but at present the gas zone lies between 1,500 and 2,500 feet. It seems probable that the gas originates in the fine, somewhat carbonaceous blue and gray sediments at these depths and migrates upward in small quantities. In the lower zone the water is salty, but the migration of the gas brings it into beds containing good water.

In the Whitney flowing well, near the edge of the valley south of Lincoln, salty water with gas occurs at 1,155 feet. The log on page 273 shows that this well penetrates to the lower part of the Ione formation or more probably to the Chico formation, and this formation appears to be the gas bearer.

In much of the area between American and Bear rivers wells sunk to depths of 800 feet or more will probably obtain some gas. The flows of water will not be large, and in most wells it will therefore be necessary to pump if fairly large yields are required. In pumping operations the gas is a disadvantage. It causes centrifugal pumps to lose their prime and otherwise interferes with the proper functioning of pumps. However, by allowing a well to discharge into a large sump the gas may be dissipated and the water pumped without special difficulty. This method has been used in the Natomas pumping plants, near Sankey.

QUALITY OF WATER.

By W. D. Collins.

SOURCES OF DATA.

In connection with the study of occurrence and utilization of ground water the quality of water from different sources was determined by analysis or assay of samples collected by Mr. Bryan. Analyses of 45 samples were made under contract by S. C. Dinsmore, Reno, Nev. Assays of 23 samples were made under contract by G. H. P. Lichthardt, Sacramento, Calif. Plate IV shows the location of wells from which samples were taken.

METHODS OF ANALYSIS.

The analyses were made according to methods in common use, which are described in works on water analysis [63] or on general quantitative analysis.[64] Assays were made in the laboratory, standard titration methods being used for chloride, carbonate, and bicarbonate radicles and the customary soap method for hardness. Sulphate was determined as barium sulphate by use of the turbidimeter as described by D. D. Jackson.[65] The constituents found are reported as radicles in parts per million.

INTERPRETATION OF ANALYSES.

The value of a water for irrigation, for boiler use, and for many other purposes is determined largely by the amounts of sodium, calcium, and magnesium in solution but is affected also by the iron and silica and by the relative proportions of the carbonate, bicarbonate, sulphate, chloride, and nitrate radicles. The amounts of these constituents do not show whether or not a water is safe to drink. Therefore statements in this report in regard to the quality of water for domestic use refer only to the effects of the mineral constit-

[63] American Pub. Health Assoc. Standard methods for the examination of water and sewage, 3d ed., 1917. Mason, W. P., Examination of water, 5th ed., John Wiley & Sons, Inc., 1917.

[64] Scott, W. W., Standard methods of chemical analysis, 2d ed., D. Van Nostrand Co., 1917.

[65] U. S. Geol. Water-Supply Paper 151, pp. 70-71, 1905.

uents and do not take into consideration the possibility of pollution with harmful organic wastes or disease-producing bacteria.

Sodium salts are the chief cause of trouble in irrigation. If the acid radicle is largely carbonate or bicarbonate "black alkali" may be formed from a water containing much sodium. If the acid radicles are sulphate and chloride the less harmful "white alkali" results from evaporation of the water.

Calcium and magnesium usually have the most effect on the value of water for industrial use. Their compounds make the largest part of the scale formed in steam boilers, and their property of forming insoluble compounds with soap causes trouble in laundries and in other industries where soap is used.

Iron in large amounts gives a disagreeable taste to water. If present in excess it precipitates when exposed to the air, making the water turbid and leaving a red or brown stain on enameled vessels and on porcelain plumbing fixtures. It is harmful in many cleansing, bleaching, and dyeing processes.

The tables of analyses show the amounts of various constituents found in the waters, and also certain values computed from the analytical results, with classifications based on the analyses and computations. These computations and classifications follow the system which has been in use in publications of the United States Geological Survey for a number of years. They are discussed at length by Stabler[66] and by Dole[67] in earlier reports.

COMPUTATIONS.

ANALYSES.

Sodium and potassium were determined in only a few analyses. Sodium reported as "calculated" is the amount which with the determined calcium and magnesium is chemically equivalent to the acid radicles.

Total hardness, H, is the calcium carbonate equivalent to the total calcium and magnesium and is calculated by the formula $H = 2.5\ Ca + 4.1\ Mg$.[68]

The scale-forming ingredients are assumed to be silica and such compounds of calcium and magnesium that the total quantity is given by the formula $SiO_2 + 2.95\ Ca + 1.66\ Mg$.

The quantity of ingredients which may cause foaming in boilers is calculated as 2.7 times the combined quantities of sodium and potassium.

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[66] Stabler, Herman, Some stream waters of the western United States, with chapters on sediment carried by the Rio Grande and the industrial application of water analyses: U. S. Geol. Survey Water-Supply Paper 274, pp. 165–181, 1911.

[67] Mendenhall, W. C., Dole, R. B., and Stabler, Herman, Ground water in San Joaquin Valley, Calif.: U. S. Geol. Survey Water-Supply Paper 398, pp. 50–82, 1916.

[68] Chemical symbols used in this discussion represent parts per million of the radicles.

The alkali coefficient is that proposed by Stabler.[69] He assumes that the relative toxicities of sodium as sulphate, chloride, and carbonate are 1, 5, and 10, respectively, and that the maximum tolerance of sensitive cultures is 1,500 pounds of sodium as sulphate in 4 feet of soil over an area of 1 acre. The alkali coefficient, k, is the number of inches of water which would yield, upon evaporation, sufficient salts to render a 4-foot depth of soil injurious to the most sensitive crops.

If the quantity of sodium is not more than sufficient to balance the chloride, $k=\frac{2,040}{Cl}$. If it is more than equivalent to all the chloride and not more than equivalent to all the sulphate in addition, $k=\frac{6,620}{Na+2.6\ Cl}$. If it is more than equivalent to all the chloride and sulphate, $k=\frac{662}{Na-0.32\ Cl-0.43\ SO_4}$.

ASSAYS.

The determinations of chloride, carbonate, and bicarbonate are as reliable in the assays as in the analyses. The sulphate method does not give as accurate results in the assays, and the determination of hardness is subject to even more uncertainty, especially in very hard waters. Therefore the quantities computed from assays are less definite than those computed from analyses. It has been shown, however, in connection with a similar study [70] that the classification of a water is nearly always the same in every respect, whether based on the results of an analysis or an assay.

Total dissolved solids (T. S.) is calculated by the formula [71]

$$T.S.=SiO_2+1.73\ CO_3+0.86\ HCO_3+1.48\ SO_4+1.62\ Cl.$$

The value used for silica in these computations is 41 parts per million, which is the average of the results obtained in the 45 analyses.

Sodium (Na) is computed by the formula [72]

$$Na=0.83\ CO_3+0.41\ HCO_3+0.71\ Cl+0.52\ SO_4-0.5\ H.$$

On account of possible uncertainty in the sulphate and hardness values this is the least accurate of the computed results, but the error is in no case sufficient to cause serious doubt of the reliability of the classification.

Foaming ingredients and the alkali coefficient are computed as in the analyses. In the reports of some assays definite values are not given for sodium, foaming ingredients, and irrigation coefficient. The first two are reported as "low" and the last as "high." These

[69] U S. Geol. Survey Water-Supply Paper 274, p. 179, 1911.
[70] U. S. Geol. Survey Water-Supply Paper 398, pp. 46-50, 1916.
[71] Idem, p. 81.
[72] Idem, p. 57.

terms are used to indicate that the sodium value shown by the assay is such that it has no effect to lower the classification of the water for use in steam boilers or for irrigation.

CLASSIFICATION.

MINERAL CONTENT.

Waters are classified as to mineral content according to the following table:

Rating of waters by total solids.

Total solids (parts per million).		Classification.
More than—	Not more than—	
....	150	Low.
150	500	Moderate.
500	2,000	High.
2,000	....	Very high.

DOMESTIC USE.

Standards of quality for domestic use must vary with localities and individuals, and any classification will be open to question. The following limiting values in parts per million have been taken for classification as "good" in this report: Hardness, less than 200; chloride radicle (Cl), less than 250; sulphate radicle (SO_4), less than 300; iron (Fe), less than 1.5; carbonate radicle (CO_3), equivalent to sum of carbonate and bicarbonate radicles (HCO_3), less than 200; total solids, less than 500.

Waters with analyses exceeding these limits in any respect have been classed as "fair," "poor," "bad," and "unfit," according to the number and magnitude of the excesses.

BOILER USE (SCALE AND FOAMING).

Classification for boiler use with reference to scale and foaming has been based on the table given below.

Ratings of waters for boiler use according to scale-forming constituents and according to foaming constituents.

Scale-forming constituents.			Foaming constituents.		
Parts per million.		Classification.[a]	Parts per million.		Classification.[b]
More than—	Not more than—		More than—	Not more than—	
....	90	Good.	....	150	Good.
90	200	Fair.	150	250	Fair.
200	430	Poor.	250	400	Bad.
430	....	Bad.	400	....	Very bad.

[a] Am. Ry. Eng. and Maintenance of Way Assoc. Proc., vol. 5, p. 595, 1904.
[b] Idem, vol. 9, p. 134, 1908.

IRRIGATION.

Classification for irrigation is based on the alkali coefficient (k) proposed by Stabler and conforms to the limits given by him in the following table:

Classification of irrigation waters.[a]

Alkali coefficient.	Class.	Remarks.
More than 18	Good	Have been used successfully for many years without special care to prevent alkali accumulation.
18 to 6	Fair	Special care to prevent gradual alkali accumulation has generally been found necessary except on loose soils with free drainage.
5.9 to 1.2	Poor	Care in selection of soils has been found to be imperative, and artificial drainage has frequently been found necessary.
Less than 1.2	Bad	Practically valueless for irrigation.

[a] U. S. Geol. Survey Water-Supply Paper 274, p. 179, 1911.

RESULTS.

The analyses given in tables in connection with discussions of separate areas show that the quality of ground water in Sacramento Valley is much more uniform than in many other areas of similar extent. The water is fairly hard, containing mainly calcium, magnesium, and bicarbonate radicles. The quantity of sodium salts is so small in nearly all the waters analyzed that no difficulty should be experienced in the use of these waters for irrigation.

The effect of the mineral ingredients on the value of the waters for domestic use is confined almost wholly to the increased soap consumption necessary with those that contain the larger quantities of calcium and magnesium. These harder waters may cause trouble from scale when used in steam boilers, but they can be improved by any of the commercial methods of softening.

Three exceptionally bad waters were analyzed. One, No. A47, is from a well 64 feet deep near Arbuckle, at the western edge of the valley. It contains between four and five times the quantities of calcium and magnesium found in most of the waters in the valley and more than ten times the average chloride. Two deep wells in the eastern part of the valley, analyses Nos. A25 and A26, also yield very bad waters. These are brines containing large amounts of calcium and sulphate in addition to the sodium chloride, which is the main constituent. The three exceptional waters are omitted from the averages which have been obtained to show the general composition of waters in different parts of the valley.

Examination of 42 analyses shows no general relation of quality to depth or to geologic formation. Neither is there any great variation in proportions of the constituents in different waters. The valley may, however, be divided roughly into three parts according to the mineral content and hardness of the waters. The area west of the river north of Germantown and east of the river north of Marysville Buttes will be referred to as the northern part of the valley. The remaining areas on the two sides of the river will be called the eastern and western parts of the valley. Eight analyses are available for the northern part and seventeen for each of the other parts. The following table gives averages of analyses for the three parts of the valley.

Average analyses of ground waters in Sacramento Valley.

[Parts per million.]

	Northern part.	Eastern part.	Western part.	General average.
Number of analyses	8	17	17	42
Silica (SiO_2)	45	47	33	43
Iron (Fe)	.10	.11	.25	.17
Calcium (Ca)	25	34	46	37
Magnesium (Mg)	13	15	32	22
Sodium and potassium (Na+K)	11	22	47	30
Bicarbonate radicle (HCO_3)[a]	126	162	324	221
Sulphate radicle (SO_4)	18	12	34	22
Chloride radicle (Cl)	9.2	30	31	27
Nitrate radicle (NO_3)	3.8	4.7	8.9	6.2
Total dissolved solids	180	250	394	295

[a] In computing averages carbonate (CO_3) reported in a few analyses was computed to equivalent bicarbonate (HCO_3) and added to the amount of bicarbonate found.

These results show a progressive increase in practically all constituents from the northern part through the eastern part to the western part of the valley. The quality of the waters for all purposes falls off as the quantity of dissolved solids increases.

WELL PROBLEMS.

GENERAL CONSIDERATIONS.

The development of a pumping project has three main phases—prospecting to locate the best available water-bearing beds, sinking wells, and installing pumping machinery. Although it is possible from geologic evidence to determine for any part of the valley the general distribution and character of the water-bearing beds, the precise location of these beds and their value as sources of water can be determined only by sinking wells. Test wells should therefore be put down to determine the best place to locate permanent wells, although the advantage of having the plant at the highest point of the tract to be irrigated may cause the acceptance of poorer gravels at this point. The cost of this preliminary work is small in comparison to the cost of developing a supply in a poor location that is arbitrarily chosen, or in comparison to the losses that result from an inadequate supply.

DUG WELLS.

The early settlers depended altogether on dug wells which penetrated to or slightly below the water level. Most of these wells have now been abandoned, owing to the difficulty of maintaining them in a sanitary condition. However, in the red lands, particularly on the east side of the valley, such wells are still in common use. As the materials here are very compact and the gravels are in many places cemented, little curbing is necessary, and this reduces the cost. In parts of the valley where the alluvium is soft curbing is necessary, and in spite of the ease with which unskilled workmen can put down a dug well in such material, the cost and trouble of maintaining a curbing make a bored well much cheaper. During dry seasons the water table frequently falls below the sand or gravel which supplies these wells, causing them to fail. Bored wells sunk deep below the water table do not go dry, though their yield may be decreased.

In the development of supplies for irrigation dug wells are suitable for obtaining the largest possible amount of water from a single water-bearing bed close to the surface. In the valleys in the older alluvium and along the foothills there are places where the principal supply of water is in such a bed. In such places dug wells are valuable and sometimes the only suitable method of obtaining ground water.

The two most serious difficulties connected with the sinking of dug wells are casing the sides of the hole and disposing of the water after the water level is reached, so that digging may proceed.

In most localities where such wells are valuable, as in the older alluvium in the neighborhood of Chico, on the high plains of the east side, and in the older alluvium on the west side, the ground is sufficiently tight to stand without support until a considerable hole has been dug. In these localities a timber or concrete lining can be built in sections as digging progresses. The clays encountered on the east side are so tough that they have stood in the walls of certain dug wells for 30 years without curbing. Pick marks made in digging are still visible in the walls of some of these old wells.

Where the material is soft a square or annular shoe of timber protected with sheet iron should be constructed and a masonry or concrete wall built upon it. As the earth is dug out at the center the curb settles by its own weight, and successive additions may be made to it. Care should be exercised to keep the curb plumb, in order to prevent jamming.[72a]

Dug wells have been used successfully in the Watt-Gridley colony. Very coarse boulders and cemented gravels prevent the use of augers except at a price prohibited by the means of the settlers. The pro-

[72a] Smith, G. E. P., A concrete caisson well: Cement Age, vol. 7, 304, 1908.

cedure is as follows: A hole 4 by 6 feet is dug to water level, which is at a depth of 16 to 20 feet. The hole is then timbered with a square set of 4 by 4 inch pine or redwood and vertical lagging of 1½ or 2 inch plank. A pump and motor are installed, the end of the suction pipe being equipped with a strong rubber hose and a foot valve. A windlass is erected over the well, and the earth is removed in a bucket as it is dug out by hand. The material stands without caving, and it is easy to timber up after digging. The greatest difficulties are with the water. Large pulleys are put on the motor so as to increase the speed of the pump and enable it to handle more than its normal capacity. As digging progresses the pump and motor are moved down the pit on a series of stages erected on the square sets. When it is no longer possible to keep out the water the well is considered finished and able to supply the same pump if operated at normal speed.

The difficulties in moving the pump are much greater where a gasoline engine is used for power. Where caving ground occurs the cost may run very high. However, where the material is hard and electric power is available, it is possible by proceeding in an orderly and systematic manner to make very satisfactory wells by this method. In the Watt-Gridley colony the cost of such a well, sunk 15 to 20 feet below water level, was from $125 to $175 in 1913. When the owner contributes his own labor the cash outlay is smaller. However, for large supplies and where means are available, other methods will be found more satisfactory.

DRILLED WELLS.

Of the three methods of drilling wells—percussion, hydraulic, and abrasion methods—only the first is commonly used in Sacramento Valley.

The hydraulic method has been successfully used on a few wells, notably the artesian wells of the Spaulding ranch. (See p. 259.) The method has two variations—the hydraulic rotary, in which the casing with a cutting shoe attached to the bottom is revolved while a stream of water is forced down inside of the casing and out between the casing and the wall of the well, and the jetting method, in which the drill bit is moved by hollow rods carrying water under pressure, which loosens and carries the drillings upward inside the casing.[73]

Over the great central part of the valley and in the areas of recent alluvium on the west side as far north as Willows the materials are soft and hydraulic methods can be used. Their great advantage is rapidity and cheapness, but success depends on the skill of the driller in meeting thick sands and coarse gravels. Great difficulties are

[73] Bowman, Isaiah, Well-drilling methods: U. S. Geol. Survey Water-Supply Paper 257, pp. 70–78, 1911. This paper contains an adequate discussion of the methods of sinking wells and should be in the hands of every well driller and every person intending to make any large well development.

likely to be encountered. In deep wells sands 50 to 100 feet thick will probably be found, and coarse gravels are widely distributed. The cost of meeting the obstacles is likely to absorb the benefits derived from this method where only clay is encountered.

As the process depends on plastering up the sand and gravels with mud to make the walls stand, the water is cut off. In finishing the well this mud must be removed. This is done by alternately forcing water down the well under pressure and then pumping it out.

The hydraulic rotary system of sinking deep wells has made its great success in the Gulf States and in parts of California where unconsolidated deposits similar to those of the west side and central parts of Sacramento Valley occur. In this success skillful well drillers have been an essential element. Until more such men can be found it is probable that the hydraulic systems will not make much headway in Sacramento Valley in competition with the methods now in general use there.

Percussion drilling is carried on by successively raising and dropping a heavy rod equipped with a cutting edge, the broken rock or drillings being removed from the hole with a bailer or sand pump. "The percussion principle is utilized in the standard, portable, pole-tool, self-cleaning, and California methods, whose outfits are recognized as distinct but differ in their arrangement for handling the tools rather than in the operation of drilling."[74]

The standard method involves the use of a wooden or steel derrick erected over the well. A portable or stationary steam engine is generally used and is erected at one side. The tools vary with the character of the work. The method developed for oil-well drilling is not ordinarily used for water wells. A light standard rig has been used on the Shaw ranch, and a modified form of the standard rig is used at Sacramento in drilling the gas wells. In general the standard method is too expensive for use in water wells except where large holes more than 1,500 feet deep are desired and relatively hard formations are encountered.

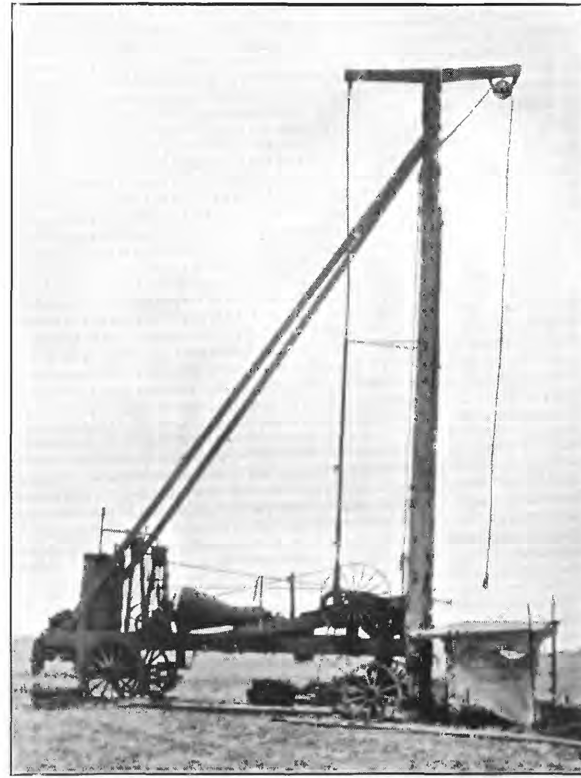
The portable drilling rig may be moved either with horses or traction engine or under its own power. It consists of a heavy framework mounted on wheels. A mast or derrick, which can be folded back over the machine, stands at the front end and is supported by the truck and guyed to stakes or deadmen. A steam or gasoline engine is mounted on the rear of the truck and furnishes power to handle the tools (Pl. XIV, *A*).

The construction of the truck and the devices to give a reciprocating motion to the tools differ in the machines of different manufacturers. Full descriptions with good illustrations can be found in the manufacturers' catalogs. "Each rig includes some device which

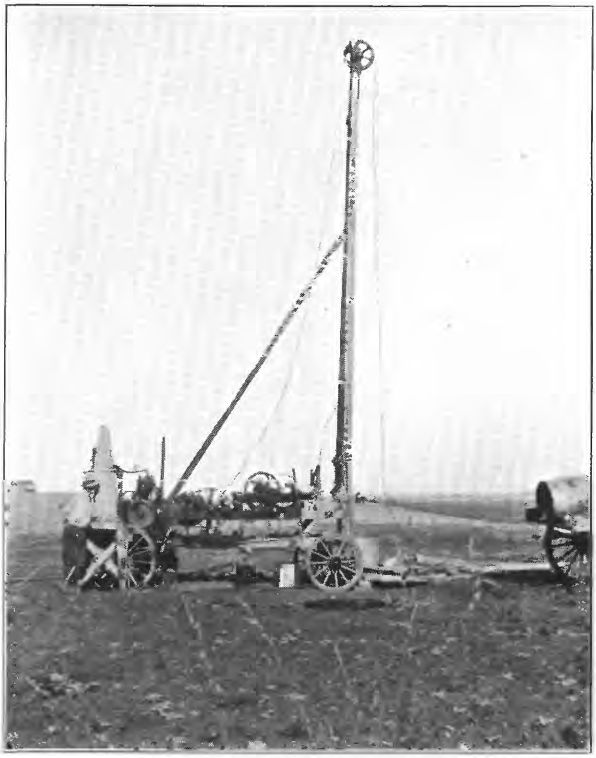
[74] Bowman, Isaiah, op. cit., p. 32.

A. PORTABLE CABLE PERCUSSION DRILLING RIG.

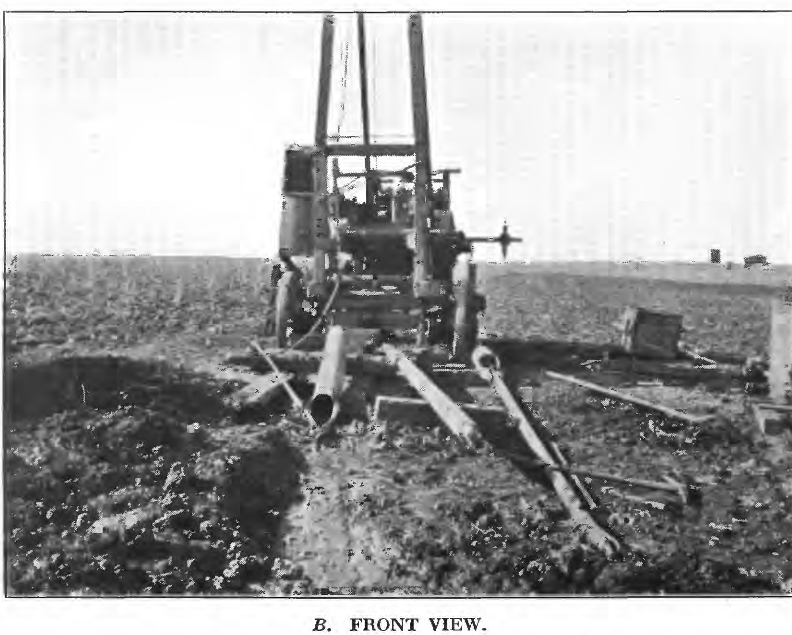
Rig used on the 950-foot Trowbridge & Hill well, near Sheridan.



B. PORTABLE CALIFORNIA OR MUD-SCOW DRILLING RIG.



A. SIDE VIEW.

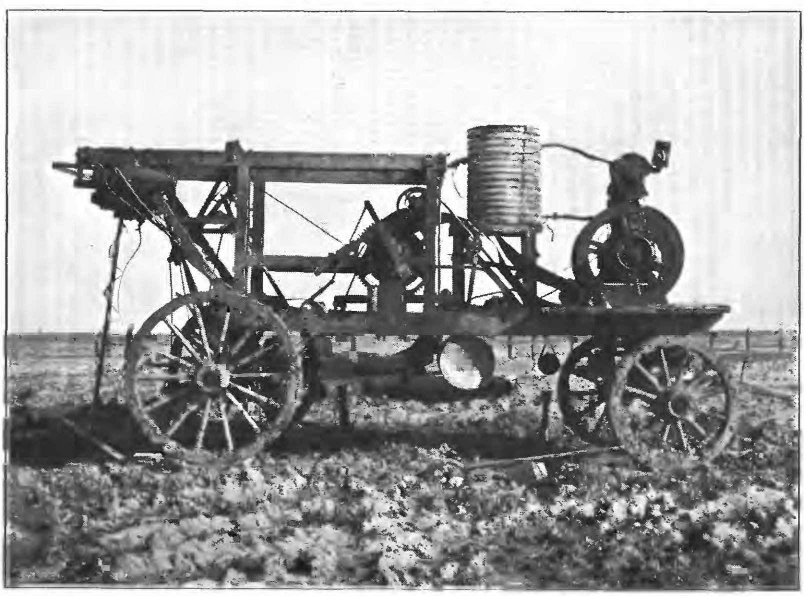


B. FRONT VIEW.

Shows sand pump, drill, and clay digger used in percussion drilling.

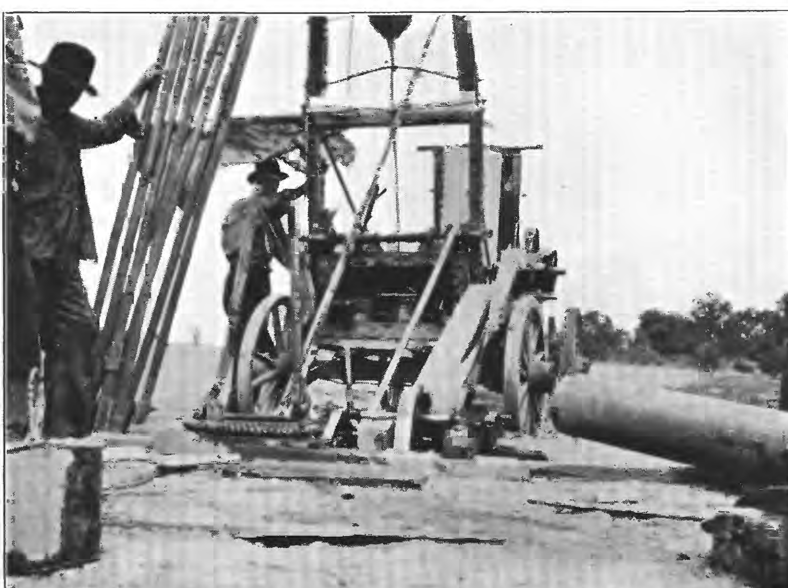
SMALL COMBINATION HYDRAULIC AND PERCUSSION DRILLING RIG.

A. SMALL BORING RIG OR WELL AUGER.



B. BORING RIG OR WELL AUGER WITHOUT A MAST.

A. DISTANT VIEW.



B. NEAR VIEW.

BORING RIG OR WELL AUGER.

makes it in certain respects superior to others, but no portable well-drilling machine is perfect. Unfortunately, the invention of a new device usually results in building a new machine, and the embodiment of all good devices in one nearly perfect machine is impossible on account of patents."[75] In a general way those machines which are adapted for handling stiff, heavy clay and drilling in a wet hole will be most successful in Sacramento Valley.

Plate XIV, *A*, is a photograph of a portable cable percussion rig drilling the Trowbridge & Hill well. At the time the picture was taken the hole was down 450 feet, and drilling was stopped at 950 feet. The hind wheels have been taken off and the axles blocked up; the front end of the truck is supported by jacks. A string of tools, consisting of a rope socket, jars, stem, and bit, hang from the derrick and are pulled to one side for the operation of the sand line—a light steel rope attached to the sand pump, which may be seen at the left. The sand pump has just been dumped over the wooden blocks, and the drillings have run out into a pool and thence down the ditch in the foreground. The machine is arranged for spudding, the steel cable passing from the derrick sheave to a forward pulley on the walking beam and thence back over the hind pulley and down to the drum. In hard materials motion is given to the tools by operating the walking beam, which is of the double "grasshopper" type—that is, hinged at the back and driven up and down by two pins and pitmans attached to the cogged wheels at the front of the machine. The driller has modified the machine by allowing the hind spudding pulley a little forward play controlled by heavy springs. This gives the spudding stroke a little more spring. Power for drilling and moving the machine is furnished by a steam engine and oil-burning boiler at the rear of the truck.

Plate XIV, *B*, is a photograph of a portable California or "mud-scow" outfit, just put in place for drilling. The walking beam is on top of the derrick, which rests on the front of the truck and is supported by jacks. A steam engine and oil-burning boiler is placed at the rear. The smokestack has been taken off and placed in front of the engine during transportation. The walking beam is actuated by a wooden rod and pitman from the shaft in the front end of the truck. Steel cable is used and is strung from the drum in the front through a pulley in the derrick to a pulley in the walking beam. No sand line is used, as drilling is done with a heavy sand bucket, or bailer, equipped with a steel cutting shoe at the bottom. The canvas shelter was erected to protect workmen installing the hydraulic jacks that are used in raising and lowering the casing. With this rig is used the double stovepipe casing discussed on page 109.

[75] Bowman, Isaiah, op. cit., p. 57.

A small combination rig is shown in front and side views in Plate XV. Power is furnished by a gasoline engine. When the rig is operated for percussion drilling the clay digger, drill, and sand pump, shown in the foreground in Plate XV, *B*, are used. A spudding device takes the place of a walking beam. The machine by this method has a capacity of about 300 feet. The sprocket on the side of the machine may be used for driving a rotating table set on the ground. As a pump is mounted on the truck the rig can be used to sink a well by hydraulic methods, or the revolving table may be used to turn auger rods, as in the slightly heavier machine shown in Plate XVII. These small combination outfits have been very successful in meeting the conditions of the east side of the valley for domestic wells. For irrigation wells in these areas, except in the younger alluvium, heavier percussion outfits are probably more suitable.

BORED WELLS.

GENERAL FEATURES.

In the soft, unconsolidated materials that underlie so large a part of the valley bored wells have been very commonly used. Practically all domestic wells are of this type. Many of the ranchers have had experience in making them, and the ease with which a well 20 to 40 feet deep and 3 to 8 inches in diameter can be put down with an ordinary post-hole auger fitted with extension rods has had a material effect on the early development of stock raising and farming. These broad fertile plains, destitute of permanent streams and with few springs, could never have been settled in so short a time but for the ease with which the ground waters could be reached.

The bored well, because of its cheapness, soon superseded the dug well, except in regions where cemented gravels commonly occur or where the water table lies at a depth of 50 to 200 feet. At first the hole was left unsupported or was protected only by thrusting in four narrow planks. These old methods are still used in the temporary wells sunk to provide water for stock, but most of the wells are now cased, commonly with galvanized sheet iron.

Bored wells are ordinarily 4 to 26 inches in diameter. From 4 to 8 inches are common sizes for domestic wells and 10 to 12 inches for irrigation wells, but larger diameters are becoming popular, especially where a turbine centrifugal pump can be installed. Wells have been put down 350 feet with augers, and most well borers claim that they can go to this depth. In practice only the best men are successful in boring wells more than 150 feet deep, and most of the bored wells are less than 100 feet deep. In many places shallow wells furnish all the water that is necessary. For larger supplies a battery or gang of shallow wells is usually cheaper than one deep well. The largest pumping plant in the valley has 12 wells in a row, placed 30 feet apart, none of which is more than 107 feet deep. Yet this plant, when operated day and night for a month, furnished 7,000 gallons a minute, or an average of 583 gallons for each well.

HAND AUGER RIGS.

The hand auger outfits used in Sacramento Valley are similar to those described by Bowman,[76] except that hollow steel instead of wooden rods are used. The augers vary in shape and design with nearly every outfit and are usually made by the local blacksmith. They are from 4 to 8 feet long and 4 to 12 inches in diameter. Long barrels tend to keep the hole straight, but they must not be too long or their weight and awkwardness overcome this advantage. A worm screw with sharpened point or a chisel-bit drill is occasionally needed to penetrate hard layers or to break partly cemented gravel. The bailer is either a simple bailer—that is, a tube of steel with a flap valve at the bottom—or a sand pump, which has an iron rod that slips through a ring in the bale of the pump and has at its end an iron disk with a swab of burlap. This piston, actuated by moving the rods up and down, sucks the sand into the bailer, where it is retained by the valve at the bottom.

Until recent years all the boring was done by hand, and the greater part of it is still done that way. A tripod and windlass[77] are used to raise and lower the tools. Three men make up the crew. After setting up the tripod, the men start the hole with the auger attached directly to a horizontal iron drive bar about 6 feet long. One man holds the auger plumb; the others, one on each side, move around, pushing and bearing down so as to force the auger into the ground. When the auger is about two-thirds full it is lifted by means of the windlass and emptied. As the boring is deepened an extension rod is attached to the upper end of the auger. This rod has a series of holes, 6 inches apart along its entire length for inserting the drive bar, and as the boring is still further deepened, new rods without holes are inserted between this one and the auger. When the material is very dry water is poured in at the top to make the auger work easily.

The bailer or sand pump is used when sand or fine gravel is encountered. If the sand or gravel is uncemented and forms a bed more than 2 feet thick it is usually necessary to case the well and keep the casing ahead of the hole until the bed is passed.

The casings used all come in short lengths, 2 to 3 feet. As each length is added the whole tube is pushed down either by driving with a maul or by applying pressure with a lever. Some of these levers are 14 to 15 feet long and capable of exerting pressures of 1,500 pounds.

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[76] Bowman, Isaiah, Well-drilling methods: U. S. Geol. Survey Water-Supply Paper 257, p. 90, fig. 18, 1911
[77] Idem, p. 89, fig. 18.

Most of the difficulties arise through trouble in inserting the casing. If the hole is not straight or is not quite large enough the casing as it goes down must cut its way, and it is likely to buckle under the strain. To avoid this mishap a reamer is often used to enlarge the hole, and some well men customarily bore with a 10-inch auger for a 12-inch casing and depend on reaming the hole out. Various forms of reamers are used. Heavier casings with a starter and a drive shoe [78] would help these troubles and would prevent buckling at the bottom when a boulder is struck.

Progress on these wells is often very rapid. The outfit can be set up and the hole can be bored 70 to 90 feet through clay and small sand streaks in a single day, but if the sand is thick or there is coarse gravel progress is slower. As these materials are the water bearers and as in most places a well is good in proportion to their amount, the delay is not without compensations. Below 70 to 90 feet the rate of sinking varies with the material encountered and the ability of the borer.

If the casing is not already perforated it must be perforated after it is put down in order to make openings to admit the water. The perforator is usually of local manufacture and varies with each outfit but is in general similar to that used in the California or stovepipe method.[79] It consists of a heavy metal frame attached to the auger rods, with a heavy steel knife that swings vertically on a pivot and projects at right angles to the frame and toward the casing. This knife can be moved by a second line of small piping or by a rope. As hydraulic jacks are not used, the perforating is done by the weight of the tools. The knife is allowed to swing down and clear the casing until the proper place is reached, when it is pulled up by the line of small pipe and jammed into the casing by letting the full weight of the frame and auger rods fall on it. As they pass on down the well the knife swings up and is pulled out. This process produces a slot of a size and shape regulated by the form and dimensions of the knife. In coarse material or in careless work, after the knife is stuck the whole apparatus is raised with the windlass and long slits are made in the casing. The stroke must be rapid and clean or the knife will simply dent or "egg" the casing instead of piercing it. Good workmen, with care, can put from four to eight slots at one level in a 12-inch casing and place a round of slots every 6 inches vertically. Experience and judgment are necessary to choose the right kind of knife and to determine the size and number of perforations that will admit the water and keep out the sand or gravel in any particular bed.

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[78] Bowman, Isaiah, op. cit., p. 68.

[79] Idem, p. 69, fig. 12.

Prices for boring vary from place to place, but in general in 1914 well borers in Sacramento Valley charged from $1 to $2 a foot for 10 and 12 inch wells not more than 150 feet deep, the well owner paying for the casing. For greater depths or where unusual difficulties were expected, $10 a day was the usual charge.

GASOLINE AUGER RIGS.

Recently a number of boring outfits with gasoline engines have come into the field. The machine consists of a truck with a small derrick that folds back over the truck when moving. A gasoline engine is mounted on the back of the truck and furnishes power for hoisting the tools and for boring. A steel cable passes through the sheave at the top of the derrick to a drum that is set on the front of the truck. By means of a friction clutch the drum is connected to a small line shaft run by a belt from the engine. In many outfits the engine is used only for raising and lowering the tools and the boring is done by hand.

The power is applied to the tools by various devices, some of which are patented. In some outfits a revolving iron platform with a cogged edge is set on the ground, the tools and casing passing through a hole in the center. This platform is similar to that used in hydraulic methods (Pl. XVII, *B*). A chain or belt from the line shaft on the truck drives a small shaft set on the ground alongside the platform. This shaft ends in a cogwheel, and the whole contrivance can be shifted with a lever bar so that the cogwheel engages the cogged edge of the platform and revolves it. Near the periphery of the platform are two sockets into which are set vertical iron rods that engage the drive bar. After the auger is in the hole the drive bar is put in place, the vertical rods are set, the shaft is shifted so that the cogs engage, and the revolving platform turns the auger. If the auger does not bite in, the men put their weight on the drive bar and even stand on it, holding the auger rod and throwing their weight first to one side and then to the other. Plate XVI, *A*, shows a small boring rig or well auger in use near Marysville. Plate XVII gives two views of another typical boring rig operated by a gasoline engine.

The boring rig shown in Plate XVI, *B*, has had considerable success near Willows. A gasoline engine is mounted at the front of a truck. There is no mast, but a heavy framework overhangs the rear of the truck. In this frame is supported a device for rotating the auger and a sheaf for the cable. The sheaf may be shifted to one side when the auger is to be turned. The cable is attached to a swivel at the top of the auger and remains in the hole while boring is in progress. The extension rods are short, about half the length of those shown in Plate

XVII, *A*, and are attached to each other and to the auger by a square pin and socket. The overhead rotating device is advantageous because it requires no preparation before beginning operations. The rig has been very successful in wells 100 feet in depth, particularly because of the speed it attains in handling clay.

Auger rods are generally made from lap-welded steel piping about 1½ inches in diameter. In the hand outfits they are usually 27 feet long and have screw couplings. In many power rigs the rods are shorter so as not to interfere with the top of the derrick in hoisting, and they are joined by a square nub and socket. There are two methods of hoisting the string of tools. In one the cable is fastened to a swivel above the auger and remains in the hole while boring is being done. As the tools are raised by means of the cable and a coupling appears above the top of the casing, a slotted plate is slipped over the casing or the rod is gripped with slide tongs and the weight of the tools is held by the coupling of the lower rod resting on the slotted plate or tongs while the upper rod is being removed. If hoisting is to be done by this method, the nub and socket are fastened together only by a buckskin thong. In other rigs the cable is fastened to the rods directly by a chain hitch, and as a new rod appears in hoisting it is grasped and held with slide tongs while the upper rod is removed. The cable is then attached to the lower rod, and the operation is repeated. As each coupling must bear the weight of the tools below, screw couplings are used or the square nub and socket are fastened together by an iron pin.

By using power rigs the work can be done much more rapidly and with less of the heavy work formerly required. The crew sometimes consists of only two men, though there is generally work for three. Charges have not yet been reduced, but as better work is now required, especially in irrigation wells, the rates are not unreasonable. The celerity with which the wells can be sunk under good conditions is remarkable. One land company, operating its own rig, has, with a crew of two men, sunk and cased an average of two 15-inch wells 100 feet deep in three days.

Boring wells by means of augers is a very ancient and primitive way of making wells. The inherent limitations as to depth and the impossibility of handling hard materials by this method have led to its being abandoned in most parts of the United States. In Sacramento Valley, however, because of the prevalence of soft material and shallow water, this method is very cheap and suitable. Success depends in a large measure on the skill, experience, and conscience of the well borer. As the cost of tools is small and few patented articles are required, responsible well men have no protection against competition. Landowners frequently begrudge money paid out for wells and look for the cheapest man to do their work. It is hard for them to believe that there is any material difference between the knowledge required to sink a well to yield 500 gallons a minute and that required to make a hole 20 feet deep with a post-hole auger to supply a pitcher pump. As a consequence in many communities all the capable men have quit the business. As most of the failures to obtain ground-water supplies for irrigation have been due to faults in the wells and not to lack of water in the ground, the importance to a community of retaining well-trained, ingenious, and honorable men in the well business is evident, and such well borers should be paid a reasonable price for their experience and skill.

CASINGS.

The object in casing a well is to prevent the caving of the walls and to provide a straining surface to hold back loose material and admit water. In certain districts, notably in the vicinity of Florin, wells last a remarkably long time without casing, the stiff clays and hardpans and cemented sands of the alluvium standing without support even when a well is heavily pumped. For permanent wells, particularly on the west side, casing is usually necessary.

Oil-well or screw casing is commonly used for deep wells made with drilling rigs. Screw casings have the advantage of strength to resist strains of all kinds and can usually be successfully removed. If made of wrought iron these casings are relatively resistant to rust. Double slip-joint or stovepipe casing is made of sheet iron riveted in tubes of two sizes. One size fits inside the other. In inserting the casing into a well the larger 2-foot length projects 1 foot beyond the smaller, and the joints are thus broken. The lengths are fastened together by denting with a sharp pick. This casing is used for both shallow and deep wells. Boring outfits ordinarily force the casing down with a lever; the drilling rigs are equipped with hydraulic jacks.

The advantages of stovepipe casing have been summed up by Slichter [80] as follows, but many of the advantages which he mentions apply also to single sheet-iron casings, and some are of no value in Sacramento Valley.

1. The absence of screw joints liable to break and give out.
2. The flush outer surface of the casing without couplings to catch on boulders or hang in clay.
3. The elastic character of the casing, permitting it to adjust itself in direction and otherwise to dangerous stresses, to obstacles, etc.
4. The absence of screen or perforation in any part of the casing when first put down, permitting the easy use of sand pump and the penetration of quicksand, etc., without loss of well.
5. The cheapness of large-size casings because made of riveted sheet metal.
6. The advantage of short sections, permitting use of hydraulic jacks in forcing casing into the ground.

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[80] Slichter, C. S., Field measurements of the rate of movement of underground waters: U. S. Geol. Survey Water-Supply Paper 140, p. 101, 1905.

7. The ability to perforate the casing at any level at pleasure is a decided advantage over other construction. Deep wells with much screen may thus be heavily drawn upon with little loss of suction head.

8. The character of the perforations made by the cutting knife is the best possible for the delivery of water and avoidance of clogging. The large side of the perforation is inward, so that the casing is not likely to clog with silt and débris.

9. The large size of casing possible in this system permits a well to be driven down in boulder wash where a common well could not possibly be driven.

10. The uniform pressure exerted by the hydraulic jacks is a great advantage in safety and in convenience and speed over any system that relies upon the driving of the casing by a weight or ram.

11. The cost of construction is kept at a minimum by the limited amount of labor required to man the rig as well as by the good rate of progress possible in what would be considered in many places impossible material to drive in and by the cheap form of casing.

The common type of casing for bored wells is made of galvanized sheet iron (soft steel), No. 20 to No. 14 gage, though any type of casing coming in short sections may be used. Sheet-iron casing is usually riveted into 2 or 3 foot lengths by the local tinsmith or the well borer. The upper part of each joint is spread a little and the lower part contracted so that the joints can be riveted together with a lap of 1 to 2 inches. To give greater strength a band or collar 3 to 6 inches wide is sometimes used at each joint. It is then called "collared casing." Where it is desirable to exclude the upper water, the joints are soldered as the casing is put down. It is thus made watertight. Perforations are made with a cold chisel or a machine punch before the flat sheets of metal are shaped and riveted into cylinders. For house wells 4 to 8 inches in diameter such casings have been very satisfactory. In many places where they are inserted in gravel at depths of 25 to 100 feet, they require no perforation to furnish water for a windmill or a small centrifugal pump. Some wells so equipped have been in continuous use for 30 to 40 years, but in general such wells should not be used over 15 to 20 years without recasing. The older wells are usually found to be full of tree roots, which may form such a mat as to clog the pipe. The presence of such vegetable matter, with its consequent decay, is undesirable in drinking water, as it is liable to give the water a bad odor or taste and to induce disease.

Single casings have not been so satisfactory in wells of larger diameters. In the weights ordinarily used sheet iron is not strong enough to stand the pressures that arise when obstacles are encountered, especially if the casing has been weakened by perforation. The use of such casings in large wells intended for irrigation is responsible for many failures to obtain good irrigation supplies. Double slip-joint or heavy single iron, No. 12 to No. 8 gage, should be used. The disadvantages of single sheet-metal casings are as follows:

1. Single No. 20 to No. 14 sheet iron or soft steel is too weak to stand the stresses and pressures likely to be developed in inserting a casing, particularly when no drive shoe or starter is used.

2. The casing may buckle at any point, perhaps entailing the loss of the well, whereas a stovepipe casing will usually buckle at the top, where it consists only of a single thickness, thereby causing the loss of only the top joint.

3. The caving that often accompanies heavy pumping is likely to crush single casing and thus ruin the well.

4. If the casing is to be perforated before insertion, a test well is necessary in order to locate the perforations properly.

The advantages of single sheet-metal casing may be summed up as follows:

1. It is cheaper than double casing and for wells of small diameter is sufficiently strong.

2. Perforations can be smaller, because they are made in the flat rather than after the casing is inserted in the well.

3. If sufficiently heavy metal is used a larger area of perforations can be put in without too great loss of strength.

SCREENS.

TYPES OF SCREENS.

Success or failure in well making is dependent largely on the method of handling the water-bearing beds. The variations in the depth, thickness, and coarseness of the beds are so great and the possible combinations of these factors are so many that each well becomes a separate problem, which must be solved on the ground.

A description of the ordinary methods of screening in use in Sacramento Valley, illustrated by examples, together with a description of two screens not commonly used, is given in the following paragraphs. It is thought that this discussion will serve as a guide in meeting the conditions likely to be encountered in any particular well.

The common method of making a screen is to perforate the casing. It may be done before the casing is put down, but that practice is justified only when the depth and character of the water-bearing beds are known. In screw casings slots are cut with a chisel—two or three slots 2 feet long at each end of a 10 to 20 foot joint. Sheet-iron casings are frequently perforated in the flat with a hatchet or cold chisel and when riveted into pipe the burrs are turned outside. Slots are also cut out by machine punches, and by this process a larger number of holes can be cut. Casings are greatly weakened by being perforated and are therefore liable to be crushed when inserted.

Perforation of the casing after it is in place is a common practice. The size and position of the water-bearing beds are noted, and after the casing is inserted slots of a suitable size are cut by perforating machines. These machines are of various local patterns, but a common form consists of a heavy frame that nearly fills the casing and is hung from the derrick by a rope or pipe line. A knife is pivoted in the frame and controlled by a second rope or pipe line. The machine is lowered to the desired place, and the slot is cut by pulling on the knife directly or by pulling the knife into position and sticking it through the casing by letting the full weight of the frame fall upon it. Skillful men working on wells that are not too deep can put from six to eight slots in a round, and one round every 6 inches in "red steel"[81] slip-joint casing. The shape of the slot is governed by the shape of the knife, but very small slots are difficult to make, for a thin and consequently weak knife must be used. Slots three-eighths of an inch wide and 3 to 4 inches long are common and are suitable for the gravels ordinarily encountered.

Specially constructed well screens may be inserted in the water-bearing beds. These are of various types, but where it is necessary to obtain large water supplies from sand the wire-wrapped screen best meets conditions for the deeper wells. This screen is made by boring numerous holes in a length of pipe and then wrapping it with wire. The wire is spaced at a uniform distance, which is dependent on the size of the sand grains. Originally round wires were used, but these have been abandoned for a triangular wire which forms a slot narrow on the outside and larger within. Thus any material which passes the slot goes clear in and does not clog the screen. The spacing of the wires may be varied from one-thousandth to one-eighth of an inch. The size of the sand grains must, however, be determined by a test well, and screens of suitable sizes and lengths must be placed in the casing as it is put down. When only the sand at the bottom of a well is to be drawn on, a screen made to handle that sand may be inserted below the casing, as in oil wells. Wire-wrapped screens are manufactured under several patents and vary in detail.

In the ordinary methods of screening wells the best results are attained where the water-bearing bed is a mixture of coarse and fine material. The screen should allow the finer material to pass but hold back the coarser material to form a natural screen about the well. Such a gravel screen can be obtained artificially by introducing gravel or crushed rock or tile into the hole.[82] A number of elaborate schemes have been devised for making an artificial gravel screen,[83] but ordinary conditions may be met by relatively simple devices. A sheet-iron casing 16 to 26 inches in diameter may be sunk by

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[81] "Red steel" is a trade term for a certain steel made especially for well casings, containing a small percentage of copper. It is of reddish color.

[82] Hall, C. W., Meinzer, O. E., and Fuller, M. L., Geology and underground waters of southern Minnesota: U. S. Geol. Survey Water-Supply Paper 256, p. 87, 1911. Meinzer, O. E., and Hare, R. F., Geology and water resources of Tularosa Basin, N. Mex.: U. S. Geol. Survey Water-Supply Paper 343, pp. 120-122, 1915.

[83] Maury, D. H., Open wells and turbine pumps: Eng. News, vol. 52, No. 7, pp. 138-140, Aug. 18, 1904.

ordinary well methods, and a thoroughly perforated casing set inside of it. The perforations in this inner casing should be large and as numerous as possible without making the casing too weak. Selected gravel or crushed rock should then be poured between the casings, and the outer casing should be gradually lifted while the well is pumped. If the gravel settles, more gravel should be added at the top until a stable condition is reached, when the outside casing can be removed entirely. Wells of this type are successful in dealing with sand near Enid, Okla.[84] Their cheapness and effectiveness recommend them for use in places where the clays are so soft that they will cave if the sand under them is pumped out and not replaced by some other material and where no beds of gravel can be found.

EFFECTIVENESS IN SAND.

Where hardpan or clay beds will support a roof the best method of obtaining water from sands is to pump them out and draw water from the resulting open cavity, but in soft material or where the beds of sand are very thick, screens must be provided. The results of the methods in common use are not very satisfactory. The difficulties are brought out in the account of L. F. Torry's well, south of College City, which was visited October 15, 1912. (See also p. 215.) The well is 12 inches in diameter and more than 100 feet deep. It has a single galvanized-iron casing perforated in alternate 2-foot joints with 50 to 60 fine slits cut in the flat with a cold chisel. The following is a partial log of the well:

Partial log of L. F. Torry's well, near College City.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and clay	34	34
Sand and some gravel	2±	36±
Not recorded, probably clay	20	56
Fine sand	4	60
Clay	2	62
Fine sand	6	68
Coarse sand	2	70
Clay	10	80
Soft clay	12	92
Clay	4	96
Hardpan	2	98
Sand	1–2	
Unknown below		

The equipment consists of a 3-inch horizontal centrifugal Goulds pump, set 10 feet below the surface in a 6 by 6 foot planked pit 11 feet deep and belted to an 8-horsepower Union gas engine. The depth to water when the well was not being pumped, on October 15, 1912, was 18.3 feet. After the pump had been run 10 minutes the depth to water inside the casing was 35.7 feet, a drawdown of 17.4

[84] Schwennesen, A. T., Ground water for irrigation in the vicinity of Enid, Okla.: U. S. Geol. Survey Water-Supply Paper 345, p. 18, 1914.

feet. In boring the well the upper part of the hole was made more than 12 inches in diameter, and thus there was a circular opening between the ground and the casing. The water level in this opening was 22.5 feet from the surface, and water was spraying through the perforations of the casing between this level and the level of the water inside the casing. These conditions are shown diagrammatically in figure 8. Under these conditions the yield of the well could be increased by lowering the pump to 18 feet, the level of ground water, and thus increasing the head under which the waters enter the well. This would involve a larger lift for the pump and consequent greater cost of operation. By increasing the capacity of the strainer and

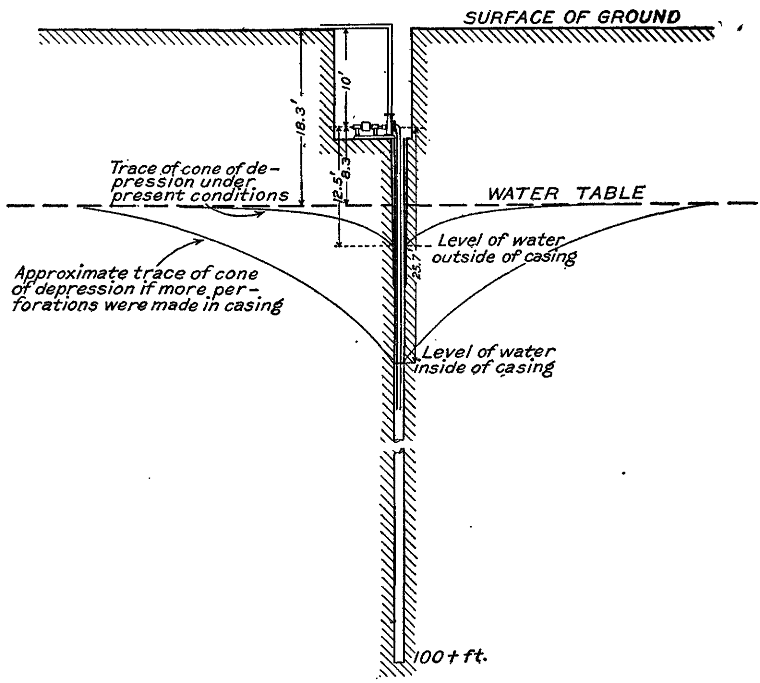

FIGURE 8.—Diagram of L. F. Torry's well, near College City.

admitting the water now being held out, more water could be obtained with practically the same lift. With the present type of casing the number or size of the holes can not be increased materially without weakening the casing or admitting so much sand as to cause the well to cave. A common plan is to sink a new well of the same type and connect it with the plant by a suction main. The problem may also be solved by using a more efficient strainer of the wire-wrapped type or a lining of gravel around the well, as described on pages 112–113. The first cost of wells constructed by these methods will be higher, but wells so constructed will have a longer life than wells with the ordinary single sheet-iron casing.

EFFECTIVENESS IN GRAVEL.

Screens made by perforations of the single or double sheet-iron casings are more effective in gravels or in sands carrying a sufficient number of pebbles to form a gravel screen around the well. The following descriptions of the Morris and St. Louis plants will bring out the characteristics of these screens in dealing with the thick gravel beds near Cache Creek:

The plant of Lindsay S. Morris, 3 miles north of Yolo, is an example of good construction with single-thickness casings. (See also p. 221.) The plant consists of a 10-inch horizontal centrifugal Krogh pump belted to a 50-horsepower General Electric motor. The two wells are 12 inches in diameter, 50 feet apart, and 103 and 98 feet deep. Gravel similar to that which occurs in the present bed of Cache Creek is found between depths of 58 and 114 feet, and water is drawn from this gravel only, the sand in the upper 58 feet being cased off. The casing is single galvanized sheet iron perforated in the flat by a machine punch with 333 holes $\frac{5}{16}$ by 1 inch to each 2-foot joint. Each well has 50 feet of perforated casing in the gravel. The bottoms of the wells are closed with cast cement plugs, each having eight holes $1\frac{1}{4}$ inches in diameter. The plugs were lowered into place by a bail and are designed to prevent the sucking in of gravels when pumping and yet admit sufficient water for the resulting current to prevent the accumulation of sand in the bottom of the well. The yield of the wells is estimated at 3,000 gallons a minute, or 1,500 gallons each. In the season of 1913 the drawdown recorded by a vacuum gage was 27 inches of mercury, equivalent to 30.5 feet. Six-inch test wells were sunk 18 inches from each of the main wells, and on June 28, 1913, the depth to water in these wells was 24.5 feet, measured from the center of the pump, with the vacuum gage at 27 inches as before. In other words, the water outside of the casings stood 6 feet higher than was indicated by the gage for the inside. If a head of 2 feet is allowed for friction in the suction pipe, the difference in level between the inside and outside of the well was 4 feet. Further perforation of the casing to admit this water was impossible. Mr. Morris accordingly sank a 16-inch well with a similar casing between the other wells and 8 feet distant from a line connecting them. Water stood in this well, when only the other two were being pumped, 22.5 feet from the center of the pump, or 6 feet higher than the level of the other wells. This well is expected to reduce the lift and therefore the cost of pumping and to slightly increase the amount of water.

The St. Louis plant of the Sacramento Valley Sugar Co., half a mile north of Yolo, will serve as an example of good well construction with stovepipe or double sheet-iron casing. (See also p. 222 and Pl. XVIII, *A*.) The plant consists of 12 wells set 30 feet apart in a north-south line. A 15-inch horizontal centrifugal Byron Jackson pump in a 10 by 12 foot cement pit 17 feet deep, belted to a 150-horsepower Westinghouse motor, is located at the center of the line of wells. The suction main lies in a series of tunnels connecting the pump pit with pits 4 feet square at each well. The suction pipes are 7⅝ inches in inside diameter and are connected to the suction main by a four-way union, which allows sand pumping of the wells without removal of the suction pipe. The diameter of the suction main increases from 7⅝ inches at the ends to 14 inches at the two sides of the pump. The plant discharges in two directions, east and west, to the banks of Cache Creek Slough, by riveted sheet-iron pipes. The east pipe is 18 inches in diameter and the west pipe 12 inches. The total lift is 42 feet, 15 feet discharge and 27 feet suction. The plant has a capacity estimated by C. E. Arnold, engineer for the company, at 7,000 gallons a minute.

The wells range from 98 to 108 feet in depth and tap two water-bearing gravels. The upper gravel is from 2 to 15 feet thick; below it is 9 to 29 feet of clay, and at the bottom 55 to 60 feet of gravel. The casing is No. 14 gage "red steel" slip-joint or stovepipe casing and extends within 1 foot of the bottom of the lower gravel, the wells being open at the bottom. The perforations were made after the casing was inserted and are triangular in shape, half an inch wide at the top and tapering out in a length of 3 inches. The attempt was made to put eight holes in a round and one round every 6 inches for the depth of the gravel. The logs of the wells and the tally of the holes actually cut are given in the following table:

Logs and record of perforations of wells of St. Louis plant of Sacramento Valley Sugar Co.

[Bored by Garrison Bros., January and February, 1912. Thickness and depth in feet.]

	1	2	3	4	5	6	7	8	9	10	11	12
Soil	14	12	12	13	12	12	12	12	12	12	13	13
Dry gravel or sand	4	6	6	5	6	3	6	6	6	6	3	3
Water gravel	12	14	15	11	12	10	10	6	6	6	8	2
Quicksand	......	......	......	......	......	3	......	......	......	......	......	......
Yellow clay	12	10	9	13	12	17	20	25	24	24	22	29
Water gravel	57	56	56	56	59	51	51	54	56	60	61	60
Total depth	99	98	98	98	101	96	99	103	104	108	107	107
Thickness of water-bearing gravels	69	70	71	67	71	61	61	60	62	66	69	62
Number of perforations:												
Total	896	990	941	816	[a]636	768	760	832	800	860	864	862
Per foot of gravel	12.9	14.1	13.2	13.6	11.7	12.5	12.4	13.8	12.9	13.0	12.5	13.9

[a] About 200 more were put in but not tallied.

The perforating in these wells was done by competent workmen under good supervision, and the result may be taken as an example of the best strainer possible with casing of this type. The yield from each well is 583 gallons a minute. This compares unfavorably, however, with that of the wells of the Morris plant, each of which yields about 1,500 gallons a minute from gravels similar in size but in beds not quite so thick.

The wells of these plants, although they conform to the best practice characteristic of the valley, illustrate the faults common to many wells. Where a number of thin gravel beds occur the perforated stovepipe casing will be effective, because its perforations will admit all the water which the beds can transmit. In thick beds of gravel, however, perforations can not be made in sufficient number to admit the water. This condition is illustrated by the difference in the yield per well of the Morris and St. Louis plants. Even the Morris wells do not have a great enough area exposed to the gravel. Sufficient perforations could be made in very heavy sheet-metal collared casing of No. 10 to No. 8 gage without reducing its strength and permanence below that of stovepipe casing. The use of heavy sheet metal would eliminate the risk run in the insertion of light perforated casing.

In shallow wells of large yield the velocity of the water is so great that in order to prevent the rise of gravel in the well the bottom must be closed. In many wells the bottom is closed by insertion of the casing in the underlying clay. Sand enters the perforations, and part of it settles to the bottom of the well. The wells must then be cleaned by sand pumping. An accumulation of 1 to 2 feet of sand a year is not uncommon in such wells, and cleaning is only delayed by boring a cavity in the clay.

When such wells are closed at the bottom by a perforated plug, as in the Morris plant, the movement of water through the holes in the plug keeps the sand moving. It is then drawn out through the pump and except for damage to the pump causes no further trouble.

PUMPING PROBLEMS.

GENERAL CONSIDERATIONS.

The selection of proper pumping machinery for irrigation is a combined agricultural and engineering problem. Primarily that machinery which will lift the desired water most economically is the best, but machinery varies in the care and attention it requires and in its adaptability to overload and underload, and the most efficient form is different with different capacities and lifts.[85] The conditions of agricultural practice are thus brought into the problem, and this is particularly the case in an area like Sacramento Valley, where most of the plants are installed for single ranches by their owners.

[85] Etcheverry, B. A., The selection and cost of a small pumping plant: California Univ. Agr. Exper. Sta. Circ. 117, 1914.

AMOUNTS OF WATER.

The amount of water required for the irrigation of a tract of a given size varies with the climate, soil, and crops. The amount of water used for each unit of land irrigated is called the duty of water and is usually expressed in feet or inches of depth of water applied, or in acre-feet or acre-inches to the acre. Wide variations in the duty of water are common,[86] but a safe figure for alfalfa on the "sediment" land is 30 acre-inches or 2.5 acre-feet to the acre.[87] Tighter soils and orchard lands usually require less water. A duty of 2.5 acre-feet is equivalent to a continuous flow of 0.00839 cubic foot a second, or 3.76 gallons a minute, for 5 months of 30 days each. For continuous operation of a pumping plant it is necessary to have a reservoir of sufficient size to hold the water pumped at night. The expense of a reservoir and the trouble of continuous operation are at present justified only when the yield of wells is small or there is a large reduction in the cost of power if taken continuously. The ordinary rancher does not expect to run his plant more than 20 days a month for 12 hours a day during the 5-month season, which would require a flow of 11.3 gallons a minute to furnish 2.5 acre-feet. Most small plants are probably in operation during an even smaller proportion of the time. At times of extreme heat the crop, particularly alfalfa, is likely to demand a quantity of water above normal, and it is therefore advantageous to have a margin of safety. The capacity should be large enough to provide water in such times of stress by pumping every day or possibly at night.

A small head is not economical in irrigating porous soils, because water seeps away rapidly in such soils, and a head of water large enough to get over the ground must be used. Near Dixon, where the soil is a characteristic west-side loam, 3-inch centrifugal pumps are the smallest used and 5 or 6 inch pumps are considered the smallest practicable for irrigating alfalfa. In the Winters district, however, in the basin irrigation of orchards planted on similar land, about 400 gallons a minute, the yield of a 4 or 5 inch pump, is as large an amount as can be handled, though plants of this capacity may irrigate 100 acres. Near Corning, where the soil is tight and runs together when wet, small heads of water give the best results, and many 10-acre tracts of orchard and alfalfa are being irrigated with 2-inch pumps. Conditions somewhat similar to those at Corning prevail over the east-side plains.

In view of all these considerations a discharge of at least 12 gallons a minute to the acre should if possible be provided for alfalfa on

[86] Fortier, Samuel, Irrigation in the Sacramento Valley, Calif.: U. S. Dept. Agr. Office Exper. Sta. Bull. 207, 1909.

[87] Beckett, S. H., Progress report of cooperative irrigation experiments at California University Farm, Davis, Calif., 1909-1912: U. S. Dept. Agr. Bull. 10, p. 7, Oct. 30, 1913.

ordinary loam soils in tracts of 40 to 200 acres, with larger capacities for smaller tracts and slightly smaller capacities for larger tracts.

In many places the problem is reversed, and it is necessary to provide suitable equipment for wells of a known capacity and lift. After wells are sunk and tested this is the problem to be solved, although in most localities in Sacramento Valley it is possible to develop, through a series of wells, any desired capacity. The limiting factor is generally the cost, and in those localities where only small supplies are obtained by ordinary methods and with reasonable expenditure, such crops should be grown as require a minimum of water and that in small heads.

FORMS OF PUMPS.

The centrifugal pump, because of its adaptability and ease of operation, has long been a favorite with irrigators. Modern practice in designing has increased the efficiency of these pumps, and except for extremely high lifts they are without question superior to displacement pumps for irrigation. The air lift is a device suitable for pumping from deep wells where power is furnished as a by-product of a larger plant and where constant expert attendance is available. The mechanical efficiency of the air lift is not high, and the method is not suitable for isolated plants that are run discontinuously. Because the air lift is very effective in cleaning the sand from a well and developing it to maximum capacity, it is useful in cleaning and testing new wells and has been so used by several large development companies.

A centrifugal pump consists of a set of vanes mounted on a shaft and inclosed in a pump case. When the shaft is rotated the water, which is admitted at the base of the vanes along the shaft, is given a radial motion, and, as it is confined by the pump case, this motion is converted into pressure and lateral motion or discharge. Loss of the power applied to the shaft occurs through friction of water against the vanes and pump case, in eddies and swirls, and through the internal friction of the water. The different designs attempt to overcome these losses with a minimum cost.

A pump in which the water after leaving the vanes is directed by curved plates or diffusion vanes, set in the pump case, is known as a turbine. These pumps ordinarily develop the best efficiency and are capable of operating against high heads. They are used principally for hard, continuous service or as fire-pressure pumps.

The ordinary centrifugal pump is built without diffusion vanes and has a volute case which increases in size spirally toward the discharge and looks very much like a snail shell. Within the case revolve the vanes connected in a casting called the impeller. In a pump of the "open runner" type the vanes are in direct contact with the case and water slippage is prevented only by matching of the vanes and case. A pump of the "closed runner" type has plates cast or bolted to the vanes, and these plates are the only part of the impeller in contact with the pump case. Water is admitted through ports at the hub and does not come into contact with the case except at the top of the impeller. When there is much sand and grit in the water, as is common in wells, all exposed surfaces are liable to wear, which may considerably decrease the efficiency of the pump. Certain models are provided with renewable rings, which may be adjusted against the impeller and thus provide for wear.

A pump set on a horizontal shaft is called a horizontal centrifugal pump. Because of the difference in pressure between the suction and discharge of the pump the impeller tends to move toward the suction side. This is called end thrust and is taken care of by a friction bearing, by a water-balance device, or by admitting water on both sides of the impeller, as in double-suction pumps. The horizontal is the standard form of centrifugal pump and should be used wherever practicable. In pumping from wells or in other positions requiring a deep pit, a vertical centrifugal pump is sometimes used. This pump, with its vertical drive shaft, has the advantage that a short belt or direct drive can be used on the surface and power transmitted by the shaft. The pump will operate under water, and this is convenient where large fluctuations of the water table are likely to occur. The weight of the shaft and the end thrust must be supported by bearings, and friction losses from this cause decrease the efficiency of these installations. Top suction and a water-balance device afford some relief from end thrust. These pumps should not be used except to avoid long belts in places where the depth to water is more than 40 feet. Even for depths greater than 40 feet the direct-connected centrifugal pump or deep-well turbine should be given consideration.

Where electric power is available centrifugal pumps are often connected directly to the motor. The horizontal pump is usually built on an extended cast-iron base, and the shaft is connected by a flexible leather-link coupling to the shaft of a motor set on the same base. A considerable saving in power is effected by discarding a belt, but as motors have a fixed speed depending on their make, their horsepower, and the kind of current used, each unit, whether a vertical or a horizontal pump, must be separately designed to fit the conditions under which it is to work. The manufacturers on being furnished with complete information will design a direct-connected unit and guarantee a given discharge and efficiency.

In a form of centrifugal pump that has recently come into use the shafting is inclosed in the discharge pipe and the impellers in a series of small bowls, so that the whole apparatus will fit inside a well casing. As the impellers are small a number of bowls or stages are usually provided—one to each 20 or 30 feet of lift. Diffusion vanes guide the water from one impeller chamber to the next, so that this pump is of the turbine type. It is usually called the turbine centrifugal or deep-well centrifugal. The pump is supported at the ground and hangs free in the well. Power is applied at the surface by a quarter-turn belt to a pulley on the shaft or directly by a vertical electric motor. These pumps are built in sizes from 9⅝ to 24 inches in diameter. With larger sizes a special circular steel pit to hold the pump is sunk by ordinary well methods around the well. The pit should be securely fastened to the top of the well casing. As the number of impellers can be easily increased, high heads can be handled, and the pump is proving very popular where water is deep. These pumps are also effective in obtaining maximum yields from poor wells. This is accomplished by setting the pump far below water level and pumping the water down more than is possible with the horizontal centrifugal pumps. This excessive lowering of the water level, however, causes a high lift and a heavy cost for power. Turbine centrifugal pumps take up but little room, are usually set so as not to require priming, are oiled from the surface, and require only a cheap pit, which is covered and not dangerous to men and animals. However, a permanent derrick should be maintained over the pump, because for repairs or inspection the whole apparatus must be removed from the well.

SIZES AND CAPACITIES OF PUMPS.

Centrifugal pumps are rated according to the size of the discharge openings in inches and are spoken of as 4-inch, 6-inch, etc., or No. 4, No. 6, etc. These sizes or numbers give but a general idea of the capacity of the pumps, for the capacity varies with the head, with the speed at which the pump runs, and with the design of the impeller. The variation in capacity with speed and head makes it difficult to compare different manufacturers' designs. Normal capacity is usually figured for a 40-foot lift, and of course the maximum efficiency is obtained under the conditions for which the pump is designed. The lift may be varied either way 20 to 50 per cent, with a resulting loss in efficiency dependent in amount on the form of the impeller. The small sizes run at higher speeds than the large sizes, and the same pumps must be run at a higher speed for greater heads. The large pump manufacturers maintain engineering departments whose services are available to customers, and consultation with them would avoid many of the common mistakes in installation.

The following table is taken from the catalogue of a well-known manufacturer and gives the capacities and characteristics of horizontal centrifugal pumps:

Size, capacity, and horsepower of single-stage belt-driven centrifugal pumps.

No. of pump (size of discharge and suction openings in inches).	Normal capacity at 40 feet total head.		Theoretical horsepower for each foot of lift at normal capacity.	Recommended horsepower for each foot of lift at normal capacity.
	Gallons a minute.	Second-feet.		
¾	10	0.02	....	....
1	20	.04	0.006	0.02
1½	50	.1	.013	.04
2	100	.2	.025	.06
2½	150	.3	.038	.085
3	225	.5	.057	.114
3½	300	.6	.08	.16
4	400	.9	.10	.20
5	700	1.5	.17	.34
6	900	2.0	.23	.39
7	1,200	2.6	.31	.50
8	1,600	3.5	.41	.67
10	3,000	6.6	.76	1.17
12	4,500	10.0	1.13	1.75

EFFICIENCY OF PUMPS.

Manufacturers' tests of efficiency and capacity, as reported in the trade catalogs, frequently give results that can not be attained in actual practice. As a rule this is due not to any attempt by the manufacturers to deceive but to the fact that the pumps are tested at the factory under favorable conditions that are not attained in most installations. The most important of these favorable conditions is a small suction lift. Throughout Sacramento Valley suction lifts greater than those recommended by manufacturers are common, and it is a regular practice to increase the speed of the pump until the maximum suction lift, about 28 feet, results. This custom is justified during a dry season when crops demand water and the yield of the well is decreasing, but it should be practiced only in emergencies. It is more profitable in the long run to increase the supply of water by sinking more wells. It is ordinarily considered that with a centrifugal pump more than a 20-foot suction lift should not be attempted. However, high suction lifts are difficult to avoid where there are large fluctuations in the water table if horizontal centrifugal pumps, which must be kept above water, are used. Thus, if the pump is installed just above the water level in March of a wet year it will be far above the water level in August of a dry year, and high suction lifts will be unavoidable unless suitable arrangements are made to lower the pump.

Adjustments to retain the efficiency and capacity of the plant with the changing lifts due to fluctuations of the water table can be made only after the extent of these fluctuations for the locality is known. If the pump is belted to the engine or motor its capacity can be adjusted to the lift by varying the pump speed. Two sets of pulleys, one for use in the spring, when the lift is low, and the other for use late in the summer, when the lift is high, should be provided. Direct-connected outfits have a constant speed, and the only means of adjusting them is to provide two impellers, one for the low lift and the other for the high lift. The saving in power that will result from such adjustments, which should be made only after consultation with the pump manufacturers, will amply repay the cost.

INSTALLATION OF PUMPING PLANTS.

After the completion of wells rough pits temporarily planked up are sufficient for testing, but when the size and type of pump are decided on a permanent pit of concrete should be built. The bottom of this pit should be at water level during the summer season, so that the pump may be set as close as possible to the water. The other dimensions of the pit depend on the size of the pump and whether it is belted or direct-connected. The pit should be carefully designed so as to afford working room around the pump and yet have no waste space. Dimension plates are published by all pump manufacturers, and from these the room required by the pump can be obtained. The pit may be either rectangular or circular; the circular form is slightly stronger but harder to construct. A 6-inch concrete wall without reinforcement is sufficiently strong for ordinary pits 10 to 20 feet deep. Reinforcement with woven wire or steel rods should be used in the shoulders of an inclined beltway, or the pressure of the soil will cause a failure of the wall at this point.

Bolts or timbers should be let into the side walls to facilitate the building of a stage on which to set the pump for pumping early in the spring when the pit is flooded. Another method is to make the concrete water-tight and seal the well around the suction pipe. This involves considerable expense and trouble and is not always successful. In installing direct-connected outfits means should always be provided for lifting the motor out of the pit during the winter.

When the pump is left in the pit during the winter adequate precautions should be taken to protect it from the water. The shaft and bearings should be packed in paraffin, and the pump core and impeller should be covered with a coat of waterproof paint.

When two or more wells are connected to a pump, a small pit should be constructed around each well. Except where sand occurs at water level, the cheapest method of connecting the several pits is by tunneling. The tunnel should be supported by timber or concrete.

Large pipes should be used throughout, and in order to avoid excessive losses from friction large-angle elbows should be used. Loss of head due to friction on entrance to the suction pipe and exit from the discharge pipe may be avoided by enlarging these openings. (See fig. 9.) The enlargement should not be abrupt but gradual. The following rule is given by Gregory:[88] The diameter of the end should be 1¾ times that of the pipe, and the enlargement should begin at a distance from the end 2½ times the diameter. The discharge pipe should lead to the bottom of a cement trough of large size. The trough should lead to the ditch without any drop or waste head. Probably 50 per cent of the existing plants pump water from 1 foot to 6 feet higher than is necessary.

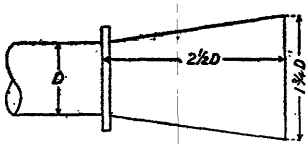

FIGURE 9.—Diagram showing dimensions of enlargement of discharge and suction pipes.

A suitable house should be built over the plant to protect it from the weather. This should be done the first season, for a few grains of sand or a little rust may do irreparable damage.

DISTRIBUTING SYSTEMS.

Only a few of the plants in the valley have an adequate system of distribution. Crude earthen ditches are sufficient in tight soils, but in the loams of the west side and the river bottoms the loss by seepage in such ditches is great, and most of the water that is lost percolates downward and is of no value to the crop. The relatively tight soil of the Richfield tract, north of Corning, showed a loss of 17 per cent to the mile with a stream of 1,100 gallons a minute. In loam soils the loss often amounts to as much as 20 per cent in half a mile.

The use of cement pipe will prevent these losses and also bring about a saving of land and a reduction in the cost of irrigation. A comprehensive account of the manufacture and cost of cement pipe in southern California is given by Tait,[89] and in Arizona by Smith,[90] who gives costs in 1918 for machine-made pipe.

John Borgman, a rancher near Nicolaus, gave the following description of the methods he used in making 2,000 feet of 12-inch pipe: This pipe was laid continuously in a trench by the use of a form consisting of a 4-foot length of 12-inch galvanized pipe fitted with a handle in one end. The trench was carefully shaped, rounded on the bottom, and 15 inches wide. A layer of concrete 1½ inches thick was put in the bottom of the trench, and the form was laid on top and

[88] Gregory, W. B., The selection and installation of machinery for small pumping plants: U. S. Dept. Agr. Office Exper. Sta. Circ. 101, p. 19, 1910.

[89] Tait, C. E., The use of underground water for irrigation at Pomona, Calif.: U. S. Dept. Agr. Office Exper. Sta. Bull. 236, pp. 56-60, 80-83, 1912.

[90] Smith, G. E. P., Machine-made pipe for irrigation systems and other purposes: Arizona Univ. Agr Exper. Sta. Bul. 86, 1918.

covered with strips of burlap. Wires 14 inches long were bent over the form and thrust into the concrete on both sides. Concrete was then laid over the form for a depth of 2 inches. As soon as the next 4-foot bed of concrete was ready the form was slipped out and forward. The burlap strips allowed the form to slip out, and the wire reinforcement was sufficient to hold up the arch. Mr. Borgman and his son, after they became skillful, laid from 80 to 90 feet of pipe a day. The occasional leaks were not serious, but it was found that a mixture of 1 part cement, 2 parts sand, and 2 parts gravel was necessary to prevent seepage through the walls. Although pipe cast in molds is preferable for strength and adaptability and has the advantage that it can be easily inspected for defects, it is thought that the method devised by Mr. Borgman, with such simple adaptations as will occur to the irrigator, will enable men of small capital to equip their ranches with an effective pipe system.

IRRIGATION WITH WELL WATER.

Progress in irrigation has been rapid in Sacramento Valley within the last few years, the principal development being in private irrigation plants using ground water. Most of the plants are situated in groups around the towns, partly because of economic reasons and partly because irrigation is infectious and the installation of one plant makes converts among the neighbors.

Pumping plants used for lifting water from wells for irrigation are shown in Plate XVIII, *A* and *B*, and Plate XIX, *A*. It will be noted that an electric plant even as large as the one shown in Plate XVIII, *A*, may be a very inconspicuous affair. Plate XVIII, *B*, shows the four units of the Cooke plant, in Cache Creek Slough. The discharge pipes, only one of which appears in the view, discharge in a common box in the ditch on the top of the channel ridge. Plate XIX, *B*, shows small tracts irrigated by Chinamen with water which they carry out of a shallow but large dug well by means of buckets suspended by a bar across their shoulders. The irrigated tracts are used for raising vegetables for the market. Although this method of obtaining an irrigation supply is very primitive and is of little importance for the valley as a whole, it is nevertheless a practical industry for these Chinese gardeners.

Statistics of irrigation were collected in the summer and fall of 1912 for the region west of Sacramento River between Willows and Rio Vista, and in the summer and fall of 1913 for the rest of the valley except Sacramento County. By correspondence and a short trip in 1913 the west-side material was brought up to date, so that the figures in the accompanying table represent conditions in 1913. The statistics for the east side were collected in 1913. Two short trips into

Sacramento County were made by the writer in 1913 and 1914. In the winter of 1914 J. W. Muller, of the United States Geological Survey, spent two months collecting statistics of pumping. The figures for the Sacramento area and the southern part of the Bear-American River area are the result of his work and cover the season of 1914.

An attempt was made to visit each pumping plant and to determine the area actually irrigated. Some difficulty was found in determining what should be considered a pumping plant for irrigation. Many plants with 2-inch pumps and 5-horsepower engines are used to obtain water for stock and domestic purposes and for watering lawns and house gardens and were not considered irrigation plants, but plants of the same size near Corning that are used for irrigating commercial orchards were listed as irrigation plants, though they are also used for domestic purposes. In the Sacramento area the combined suburban home and small farm is so common that practically all plants in this area are listed. Irrigation was credited to a plant only where there was local evidence of irrigation at the time the plant was visited or where information that the plant was so used was deemed reliable. Proposed irrigation was rigidly excluded from the statistics.

The installed plants and acreage irrigated in 1913 (Sacramento County, 1914) are presented in the table on page 5. In this table the valley is divided into 19 areas in which pumping is more or less concentrated in groups. These areas, the boundaries of which are arbitrary, are shown on the map of the valley (Pl. II).

The areas actually irrigated by well water are shown in green on Plate IV.

Of the total horsepower used 70 per cent is electric; the rest is developed by internal-combustion engines and by a few steam engines in old plants. High-tension electric-power lines of several different companies cross the valley to the Bay cities from water-power plants in the Sierra Nevada. Local power lines at lower voltage run out through the country from numerous transformer stations on the main lines. Those areas in which the power produced by gasoline, oil, and steam engines equals or exceeds the electric power have scattered plants, many of which are far from power lines. The large use of gasoline power in the Davis-Winters-Dixon area is due partly to the fact that a number of plants were installed before electric power was available and partly to a belief that gasoline plants are cheaper.

The average horsepower to a plant is 9.1, and the average area irrigated 24.5 acres, or 2.7 acres for each horsepower used. Wide variations in the size of the plants and the acreage per horsepower exist in the several districts. They are not due primarily to differences in lift, for the lifts do not vary much from one district to the other, but to differences in soil and crops and in the size of farm units.

A. ST. LOUIS PUMPING PLANT OF SACRAMENTO VALLEY SUGAR CO., NEAR YOLO.

B. COOK PUMPING PLANT OF ALAMEDA SUGAR CO., NEAR YOLO.

A. MORRIS NO. 6 PUMPING PLANT OF ALAMEDA SUGAR CO., NEAR WOODLAND.

B. CHINESE GARDENS AT SACRAMENTO.

Irrigated with water from a shallow dug well, carried out of pit on shoulders of men.

The Butte City and Hamilton-Orland areas have a large acreage per horsepower because of the economical irrigation of young orchards by large companies. The East Sutter Basin area is also predominantly an orchard district, but the plants supply small tracts because the land is in small blocks and each owner irrigates only his own land. Relatively large heads of water are, however, required in this area to cover the ground, and therefore small plants are not practicable. Economy could be effected by cooperation between neighbors. The use of one plant by several ranchers would reduce the interest and depreciation charges, which form so large a part of the cost of pumped water.

The average irrigation in all areas is brought down by the inclusion of plants recently installed, which irrigated only small tracts in the first year. When a new plant is installed an effort should be made to complete the grading and checking of the land so that the plants can be brought into full use without undue loss of time.

The machinery installed in the pumping plants of the valley is capable of a certain amount of work, which can be estimated for assumed conditions and compared to the actual results in acreage irrigated. While no large series of tests have been made, it may be assumed that the plants have an over-all efficiency of 40 per cent—that is, that 40 per cent of the nominal horsepower of the motors and engines is actually effective in lifting water. This figure is assumed on the ground that the large number of direct-connected electric units of high efficiency will balance the plants of low efficiency. The average lift may be taken at 40 feet, which is perhaps a high rather than a low figure.

The average of 9 horsepower to the plant, as given in the table (p. 5), with a plant efficiency of 40 per cent and a lift of 40 feet, will deliver 358 gallons a minute. On page 118 it is stated that the time a plant ordinarily runs is 12 hours a day and 20 days a month for 5 months. With this pumping time 11.3 gallons a minute is necessary to furnish 2.5 acre-feet an acre for the season, which is nearly the right figure for alfalfa, though much too high for orchards. This pumping time is based on five irrigations of 6 inches each, which is common on alfalfa. However, the irrigations are not always evenly divided, the third and fourth irrigations often being much heavier than the others. A discharge of 11.3 gallons a minute to the acre will allow 7½ inches to be applied in 28 days' pumping, 12 hours a day. Heavier irrigations are seldom necessary but can be provided by night pumping. The time required for one irrigation can also be reduced by operating the plant for a longer time each day. The necessity which may arise at certain times for large applications of water and for getting a field irrigated quickly in order to keep the crop growing justifies large installations. The intelligent irrigator will, however, attempt to reduce the peak load on his irrigation plant by adjustments of his system of agriculture in order to use as small a plant as is possible.

At 11.3 gallons a minute to the acre a discharge of 358 gallons a minute (from a 9-horsepower plant) for 12 hours a day will irrigate 31.6 acres with 2.5 feet of water for the season. By increasing the pumping time to 16 hours a day for the 100-day season, the same discharge will irrigate 42.3 acres with the same amount of water. With this increased pumping time and a reduction in the amount of water applied from 2.5 feet to 2 feet the same plant will supply 52.8 acres.

While 24.5 acres, the average acreage to the plant derived from the statistics (p. 5), is a rough figure and includes many different kinds of plants pumping on different kinds of crops, it is so near the 31.6 acres obtained by assuming the conditions stated above in full that it indicates either that the valley plants are fairly efficient and well used or that the assumptions do not represent average conditions as to lift and duty of water. It will be seen from the following analysis that the assumptions are good for an average plant irrigating field crops. Many plants have low lifts or irrigate orchards and do not comply with the assumptions. In irrigating porous soils a discharge as small as 358 gallons a minute is easily lost by seepage and will not irrigate as much land as the figures call for. The large increase in acreage with increased running time is exceedingly significant. Analysis shows that the average area irrigated by each plant can be raised when, through a keener realization of the saving effected, each owner obtains for his plant the best mechanical efficiency and fullest economical use.

It is believed that the assumption for lift of 40 feet is about the average for the valley, but that, although 2.5 feet is the proper amount of water to use on alfalfa and is used in good practice in Dixon and other places, much less water is usually applied in good practice to orchards. The average use of water is therefore less than 2.5 feet. If the assumption of 2.5 feet for duty of water is too high, then it is evident that the acreage irrigated is too small and should be increased.

An increase of pumping time by 4 hours a day will increase the average acreage for each plant to 42.3 acres, and at many plants this increase, with the consequent reduction in cost to the acre for irrigation, can easily be made. The assumption of a 40 per cent over-all efficiency of the plants may be too high, but this is a minimum standard to which irrigators should try to bring the mechanical efficiency of their plants. It is usually exceeded in direct-connected electric units. Improvements in efficiency of many plants can be made by slight, inexpensive changes, such as enlargement of discharge pipes, elimination of unnecessary elbows, reduction of discharge height to that just necessary to put water in the ditch, and other devices which are illustrated by the numerous plants of high efficiency to be found in any pumping district. It is obvious that the irrigators have an opportunity to make much greater use of their present aggregate investment in wells and pumping machinery.

DETAILED DESCRIPTIONS OF SUBDIVISIONS OF SACRAMENTO VALLEY.

RED BLUFF-TEHAMA AREA.

GENERAL CONDITIONS.

The extreme northern portion of Sacramento Valley differs from the remainder of the valley in having steeper slopes, rougher topography, and more sharply defined differences between the several alluvial formations, on which the quality of soil and the amount of ground water depend. The area extending southward from Iron Canyon to Thomas Creek on the west side and to Pine Creek on the east is discussed as the Red Bluff-Tehama area. The southern part of this area is not very different from contiguous portions of the Chico and Corning areas. The Corning area, however, is a business and social unit which it is convenient to treat separately, and only the northern edge of the Chico area is similar to the Red Bluff-Tehama area. (See Pls. II, III, and IV.)

The substantial town of Red Bluff, with a population of 3,104 (1920), is the county seat of Tehama County and the principal commercial center of this part of the valley and the adjacent mountains. It is the head of navigation on Sacramento River, but during summer low water boats do not attempt to go above Chico Landing. The Southern Pacific Railroad serves the area. The Marysville line, on the east side of the river, and the Portland line, on the west, meet at Tehama (population 196) and then continue as a single line through Red Bluff to Portland, Oreg.

The principal industries are agriculture and stock raising. These were begun by the early settlers, William G. Chard, A. G. Toomes, and R. H. Thomas, who established cattle ranches in 1843. The first grain was planted in 1852. Wheat was for a long time the dominant crop, and practically all the valley land has been cultivated in the past. At present only the river bottoms and more fertile side valleys are farmed.[91] The plains are given over almost wholly to winter pasture for sheep and cattle, which are taken to the high mountains on either side of the valley for the summer grass. In this area, according to Adams,[92] 9,600 acres was irrigated in 1912 on the east

[91] Holmes, L. C., and Eckman, E. C., Soil survey of the Red Bluff area: U. S. Dept. Agr. Bur. Soils Field Operations, 1910, pp. 1601–1656, 1912.

[92] Adams, Frank, California Conservation Comm. Rept., 1912, p. 155.

side of the valley. The water comes from Antelope, Mill, and Deer creeks. On the west side 1,000 acres near Tehama was irrigated by pumping, with some small and scattering areas.[93]

The plants pumping from wells in this area can be considered in three groups—four plants east of Red Bluff, the Tehama plants, and the plant in Orchard Park, near Rawson station. (See Pl. IV.) The following table summarizes the ground-water development for irrigation.

Pumping plants in the Red Bluff-Tehama area.

	Number of plants.	Number of owners.	Area irrigated, 1913 (acres).	Electric horse-power.	Gasoline and steam horse-power.	Total horse-power.	Area irrigated per horse-power (acres).
Red Bluff group	4	4	67	27	20	47	*a* 2
Tehama group	21	4	1,320	280	....	280	4.7
Orchard Park	1	1	....	40	....	40	(*b*)
	26	9	1,387	347	20	367	....

a Bressler's plant is not included. *b* Installed 1914.

The United States Reclamation Service in cooperation with citizens of Tehama County is investigating the feasibility of Iron Canyon as a dam site for storage and diversion of Sacramento River. Such a dam would provide irrigation for a large part of the area. A comprehensive gravity system is probably the best means of irrigating the whole area. Experience at Orland, however, shows that well development will be stimulated by the use of gravity water. Plants will be installed to irrigate while waiting for the ditch water. Water will also be in demand for places inaccessible from the ditches.

GEOLOGY AND PHYSIOGRAPHY.

Just north of Red Bluff the area is closed in by wooded gravel hills. These hills and Iron Canyon separate the main Sacramento Valley from its northern subdivisions—the Anderson and Redding valleys. The area is divided into three strips parallel to the river—the east-side plains, the west-side plains, and the river bottom lands.

The east-side plains are most extensive near Vina, where they are about 5 miles wide. They decrease to about a mile in width east of Red Bluff. These plains are floored with older alluvium of Pleistocene age, which is slightly elevated above the present level of erosion. The elevation was accompanied by folding in a monocline that extends from Chico in a northwesterly direction to Red Bluff, where it terminates in two cross folds at Iron Canyon. Both the older alluvium and the Tuscan tuff, a series of andesite breccias, tuffs, and volcanic gravels more than 1,000 feet thick, are involved in the monocline

[93] Adams, Frank, op. cit., p. 146.

(fig. 3, p. 71). The dip of the beds in the fold increases from less than 10° near Chico to 15° at Red Bluff, forming an increasingly bolder bluff along the east border of the valley. From long, narrow canyons in the volcanic plateau east of this bluff emerge several strong streams, which have cut narrow, shallow valleys across the plains. It is in the fertile tracts in these valleys and on the border of the plains and neighboring river bottoms that the waters of Deer, Mill, and Antelope creeks are used for irrigation.

The west-side plains consist of reddish alluvium of Pleistocene age, which caps a great area of Cretaceous rocks. These rocks project from under the alluvium and its underlying Tertiary formations about 12 miles west of Sacramento River and rise in low hills and interstream plains to the Klamath Mountains. The west-side streams cross these plains in terraced valleys. Only the eastern part of the plains, which is covered with alluvium, is shown on the Sacramento Valley map, and the investigation was not carried farther west.

The central strip of river bottom land is bounded on each side by rather steep bluffs 20 to 50 feet high, which are broken only where some tributary stream enters the valley. Here is deposited a fan of material that lies above and modifies the soils of the river bottoms. The current of the river is swift, even in floods, and the river channel is not bounded by natural levees or ridges, as it is farther south. Water drains off rapidly after high water, and on the fans of side streams or the neighboring bluffs there are many house sites which are not flooded. Winter flooding for a day or two does not irretrievably damage grain or alfalfa, and the residents have stoically put up with this annual inconvenience. The present loss is probably sufficient to warrant flood protection, however, and further development is dependent on it.

The synclinal character of the valley is brought out in the cross section, shown in figure 3, and the discussion of geologic history on page 70. Briefly, the Tuscan tuff, 1,000 to 1,500 feet thick, with the underlying Chico formation, about 50 feet thick, is bent sharply in the Chico monocline. The Tuscan tuff continues under the valley and appears 12 miles west of the river as a pinkish tuff about 50 feet thick. Below it is the Ione, a thin formation of sands and clays, and the two rest on the eroded edges of the Chico formation, which is here a series of sandstones and shales 4,000 feet thick. Below the Chico and standing at increasingly higher angles are the similar Horsetown and Knoxville formations of marine sandstones and shales, 26,000 feet thick.

Above all these formations lies the older alluvium, deposited by Sacramento River and its tributaries. The western tributaries, drawing their material from the Klamath and Coast ranges, deposited the alluvium of the northwestern division, and the eastern streams laid down that of the northeastern division. The older alluvium is uplifted and dissected. The tributary streams are now depositing similar material in the terraced side valleys, while the river has filled the inner valley. A more elaborate subdivision into 26 soil types is made by Holmes and Eckman.[94]

GROUND WATER.

The water-bearing formations are the older alluvium, the younger alluvium, and the Tuscan tuff. Wells are dug for domestic purposes in the residual soils of the Cretaceous formations. East of longitude 122° 15′, the western boundary of the area shown on the Sacramento Valley map, no water wells are known to reach the Cretaceous or even the overlying Ione.

WATER TABLE.

The older alluvium on the west side of the valley and the younger alluvium are saturated with water. The upper surface of this saturated zone is represented by contour lines in Plate IV.

The water table slopes with the land, though less steeply, from the sides of the valley to the river and from north to south. In the river bottoms the water levels are controlled by the river, but except on the immediate banks and during very high water the movement is toward the river. The ground water feeds the river at least as far south as Hamilton. No attempt is made to draw contours through the east-side plains, where owing to the character of the alluvium well levels are highly variable. The contour lines for the west-side plains are not as accurate as those for most other parts of the valley, owing to the small number of wells and to a slight artesian head in certain wells. (See p. 134.) Throughout the lower plains and river bottoms the contours are accurate for the late fall of 1913. They represent conditions after two excessively dry seasons. The depths to water indicated are probably close to the maximum.

WELLS IN TERTIARY AND CRETACEOUS ROCKS.

Where the Cretaceous rocks compose the plains in the area west of the territory shown on the Sacramento Valley map (Pl. III) and extending thence to the mountains, the surface is mantled with deep residual soils, in which water collects after the rains. Shallow dug wells supply sufficient water for stock and domestic use.

The Tuscan tuff is exposed in a series of low bluffs facing west and dips toward the east below the alluvium. No wells are known to penetrate this formation, but it is porous and adequately exposed for receiving water. Wells drilled into this formation in the region 8 to 10 miles west of Sacramento River should obtain water.

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[94] Holmes, L. C., and Eckman, E. C., op. cit., pp. 1601-1656.

On the east side of Sacramento River the Tuscan tuff underlies the plains at depths of 100 to 250 feet. A well drilled in 1915 on the Read ranch, near Vina, is 329 feet deep and appears to enter the Tuscan tuff at about 150 feet. (See log, p. 266.) A good supply of water was obtained between 290 and 327 feet. The depth to water is 64 feet.

The success of this well confirms the inference that the Tuscan tuff is as valuable a water bearer in this area as in the neighborhood of Chico. Adequate drilling machinery must be used, as both the older alluvium and Tuscan tuff are hard and cemented.

WELLS IN NORTHEASTERN DIVISION OF OLDER ALLUVIUM.

The plains of the east side are composed of coarse waterworn gravels, brown sand, and tuffaceous clays, derived from the erosion of the Tuscan formation. Near the mountains the materials are coarse, boulders 12 to 18 inches in major diameter being common. Andesite is the principal rock, though basalt and rhyolite are common, and pebbles of calcareous sandstone from the exposures of the Chico 12 miles to the east have been found. The alluvium is cemented with lime and forms a compact and resistant mass (Pl. XIII, *B*). The cementation seems to have taken place as the material was laid down, partly by direct deposition from the stream waters and partly by the decomposition of the boulders. Deposition of lime by the present streams is evident from the crust of calcium carbonate which coats the modern gravels, especially in low parts of the channel where pools of water evaporate after a flood.

The steep grade of the streams enables them to transport large boulders during floods, and the relatively large and constant summer flow tends to round and polish the channel gravel. A large amount of already waterworn material is furnished by the Tuscan formation from intercalated gravel beds. As the streams emerge from the hills most of the finer material is carried to the river and only the coarser remains.

Weathering of the older alluvium produces a thin brown soil beneath a capping of loose pebbles and boulders. The plains are of little value for farming and are used principally for grazing.

Water for stock and domestic use is obtained from the streams and dug wells. In the fall and winter many of the minor streams are dry, and dug wells are not very successful. For instance, the well at Lone Pine Camp, dug 85 feet deep, was dry in October, 1913. Drilled wells that penetrate deeper into the formations are likely to be more successful. The well of Mr. Rausch at the mouth of Rio de los Berrendos canyon, in sec. 13, T. 26 N., R. 2 W., is dug to a depth of 40 feet and drilled 96 feet deeper and has a 6-inch screw casing. It has a deep-well hand pump, and the water is said to stand 40 feet below the surface. (For an assay of this water see A5, p. 139.) The well at the demonstration farm of the Los Molinos Citrus Farms Co. is drilled 156 feet deep and cased with 6-inch screw casing for 120 feet. Water is said to stand 69 feet below the surface. The well supports a small cylinder pump, belted to a 3-horsepower gas engine. A number of wells have been drilled at the edge of the plains in the Los Molinos colony to obtain water for domestic purposes. The quality of the water is good, and the quantity is sufficient for domestic use. (See A3, p. 139.) The wells range in depth from 50 to 150 feet and the depth to water varies in adjacent wells. On this account the contours of the water table in the eastern part of the colony, based on these wells, are drawn in broken lines. (See Pl. IV.) The cost of drilling was in 1913 $2.50 a foot for a 6-inch well. Screw casing is used, and one or two lengths are inserted to keep the upper part of the well from caving. To prevent the seepage of irrigation water and surface filth into the wells the casing should be very firmly seated in the clay or hardpan some distance below the ground-water level.

WELLS IN NORTHWESTERN DIVISION OF OLDER ALLUVIUM.

The treeless plains of the west side of the valley are composed of clays, sands, and gravels, of a prevailing bright-red color. This material has been called the Red Bluff formation.[95] The red color of the bluffs overlooking Sacramento River gave the name to the original Mexican grant, La Barranca Colorada, also to the town of Red Bluff and other local features.

The Klamath Mountains west of this portion of the valley are relatively high, and the rugged mass has a central core made up largely of crystalline and metamorphic rocks. At the eastern edge the sloping plains formed on the eroded edges of the Cretaceous rocks begin abruptly. To the east the plains are formed by younger rock (fig. 3, p. 71).

The northwestern division of older alluvium forms the plains for about 12 miles west from the river. The alluvium was deposited by the predecessors of the present streams. These flowed on similar gradients and carried similar material, so that the alluvium partakes of the character of the material now handled by the adjacent streams.

Pebbles of quartz, quartzite, schist, and gneiss are abundant in the gravels. They are derived from the metamorphic core of the mountains and perhaps in part from the destruction of Cretaceous conglomerates. The gravels are in general considerably waterworn. The massive materials, such as quartz and quartzite, yield rounded pebbles, but the schists break along the cleavage and at joint planes,

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[95] Diller, J. S., Tertiary revolution in the topography of the Pacific coast: U. S. Geol. Survey Fourteenth Ann. Rept., pt. 2, p. 411, 1894.

producing elongated and flat pebbles. The gravels contain a large percentage of sand and, unless cemented with lime, are usually good water bearers. In many places clay instead of sand is found in the gravel, which is then called "dirty gravel" and is generally a poor water bearer.

The bulk of the northwestern division of older alluvium consists of clay or sandy clay. This material was deposited by floods of the several streams in the same manner as similar material is now being deposited on the Stony Creek fan. Each newly deposited layer was exposed to the air in the succeeding dry season. The combined action of heat, dryness, and the presence of oxygen from the air converted the iron in the clay to the anhydrous and ferric condition. The red color was thus produced. Beds of yellow clay here and there show that the process of dehydration was not everywhere completed. An additional effect of this process of exposure during deposition is the formation of hardpan.

Within 2 feet or 18 inches of the surface over most of the plains area is found a compact, hard layer from a few inches to 2 feet deep. It is in places of a slightly deeper red than the friable loam which lies above. Many of the gravel beds also are cemented and hard. There are thus two kinds of hard layers in the alluvium—the hardpan near the surface and the cemented gravels largely found below the surface.

The hardpan seems to be due to a concentration of the finer parts of the soil and to cementation by iron silicates. This result was accomplished in part by the washing of the soil by rain, the coarser particles being left on the surface. In consequence the soils are gravelly. Wind may also have removed some of the finer soil particles, but no direct observation of the effectiveness of winds is available. Most of the dust in present wind storms seems to rise from the roads or other places where the soil has been disturbed by man.

The hardpan appears to have been formed during and just after the formation of the alluvium. It caps the plains but does not extend down the slopes where present streams are dissecting the alluvium. At that time the water table was probably higher than now, and if so the deposition of salts in the soil is more readily explained, evaporation concentrating the salts from water drawn up by capillarity and rain water in turn dissolving the salts and carrying them downward. The maximum concentration of salts would then occur where these two forces struck a balance. The hardpan forms a serious obstacle to the downward percolation of rain water. Consequently the run-off after a rain in the areas where it occurs is very rapid.

The cemented gravel seems to be due to a slightly different process. Imany places cementation of the channel gravels can now be seen taking place. As the streams dry up a white coat of calcium carbonate is frequently formed on the outside of the pebbles. This coat is thin and not sufficient to cement the gravel. Additions are probably made by the evaporation of water from the shallow water tables found in many stream channels. With this preliminary coating of calcium carbonate, due to conditions of deposition, the gravels were buried. Further cementation probably took place by the deposition of calcium carbonate from circulating ground water.

Throughout the plains the water table has a steady slope to the river, somewhat less steep than the grade of the streams. Thus the depth to water increases westward. Various irregularities exist, however. Because of many impervious beds in the alluvium perched water tables and even slight artesian heads are known (fig. 10).

A perched water table occurs where an impervious bed prevents the water in an overlying pervious bed from percolating downward to the main water table. Wells in such a place have the advantage of

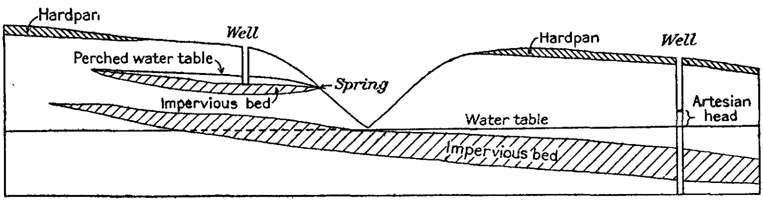

FIGURE 10.—Diagrammatic section to illustrate a perched water table and artesian conditions in the northwestern division of older alluvium.

shallow water, but as they draw water from only a small area they are of small capacity and often go dry.

Artesian conditions occur where an impervious bed overlies a porous one. As all the layers slope toward the river the impervious bed prevents the underlying water from rising to the water table. When an artificial opening is made in the impervious bed, as in a well, such water may rise above the water table, giving an artesian although not always a flowing well.

Wells are few in number and are largely situated in the valleys and swales. In the valleys they draw water largely from the recent gravels. Most of them are dug wells and furnish small but adequate supplies for domestic use and for stock.

The recent developments of the Exposition Fruit Lands Co. near Rawson have demonstrated that large supplies of water may be obtained by deep drilling. These wells are from 250 to 350 feet deep. Water stands 35 to 40 feet from the surface in all the wells except No. 3, where it stands at the surface. This well is in a slight depression surrounded by boggy ground due to a spring nearby. For chemical composition and classification of the waters of two of these wells see A2 and A4 (p. 139).

The following logs illustrate the character of the water-bearing beds:

Driller's log of Orchard Park well No. 1, lot 73.

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Surface (soil)	15	15	Clay	54	130
Dry gravel	10	25	Gravel	76	206
Clay	22	47	Clay	14	220
Water gravel	29	76			

NOTE.—Drilled, 12 inches in diameter, by Kopfer & Storm, 1913.

Driller's log of Orchard Park well No. 2, lot 106.

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Surface material	28	28	Gravel, good	24	141
Clay, yellow	18	46	Clay, yellow	26	167
Gravel, good	31	77	Gravel, fair	24	191
Clay, yellow	40	117	Clay	101½	292½

NOTE.—Drilled, 12 inches in diameter, by Kopfer & Storm in 1913.

A study of the logs of deep wells near by indicates a depth for the alluvium of not more than 400 feet. (See p. 254.) The first 200 feet is shown to be water-bearing. Similar conditions may be expected throughout the rest of the area of the older alluvium. Occasional failures are probably due to the large amount of cemented and "dirty" gravel. Adequate drilling machines and proper well methods are necessary. (See pp. 101–104.)

WELLS IN YOUNGER ALLUVIUM.

The younger alluvium is confined to the central strip of river bottom land and to the immediate flood plains of the tributary streams. In the central strip the alluvium is the recent deposit of Sacramento River. These river bottoms have soils of loam and sandy loam, underlain by coarse channel gravels that are similar to those of the present river bed, being waterworn and clean. The pebbles of the gravel in the river bed at Red Bluff are 6 to 8 inches in diameter; at Hamilton they are 2 to 3 inches in diameter. The water table lies from 15 to 20 feet below the surface.

In consequence of the low lift and the free water-bearing gravel, wells are cheap, and the supply of water good. To this condition the rather extensive development near Tehama is due. Alfalfa and hops are the principal crops. Fruits would also be profitable, but orchard development is impeded by lack of protection from floods. The quality of the water is shown by the house well of F. F. Anderson, A6, Plate IV and page 139.

The younger alluvium of the flood plains of the tributary valleys is of little value as a source of water. In general it is of shallow depth and occurs in narrow belts. In the west-side valleys domestic supplies can be obtained from shallow wells, and perhaps small areas of the rich bottom land may be irrigated. In the east-side valleys shallow wells are of little value, even for house supplies. On Deer Creek and in the lower part of Mill Creek valley irrigation by surface water has saturated the younger alluvium. It is relatively loose porous material from 5 to 50 feet thick and lies on the highly cemented older alluvium. The downward percolation of irrigation water is prevented by the older alluvium, and a fully saturated upper layer results. On Deer Creek the lower spots are swampy, and shallow wells have water within 5 feet of the surface. Less wasteful irrigation and better drainage will relieve the water-logged condition of the soil. A more wholesome domestic supply can be obtained by wells drilled into the deeper parts of the older alluvium or the underlying Tuscan tuff.

Along the eastern edge of the river bottoms the deposits of Sacramento River are modified by those of the tributary streams. The east-side streams carry during floods large quantities of silt, which is dumped out on the river flood plain. Fans are built up of brown and reddish-brown soils, coarser in texture and darker in color than the river soils. These lands are largely under the Los Molinos ditch, and wells are needed only for domestic purposes. Drilled wells 6 inches in diameter and 40 to 60 feet deep are successful. The water stands from 18 to 25 feet below the surface, and varies irregularly in depth, differing in adjacent wells as much as 3 or 4 feet. This variation is due to the irregular porosity of the lower beds. The ordinary price for drilling was in 1913 $2.50 a foot. Usually only one 20-foot length of screw casing is used, the rest of the well being uncased. Care should be taken to seat the lower part of the casing firmly in the clay below the water table. In this way surface filth and polluted seepage from irrigated fields may be kept out of the wells.

QUALITY OF WATER.

The analyses and assays in the accompanying table show a general uniformity in quality of water, regardless of depth of well or location. Only one of the six waters has over 200 parts per million of solids. All are calcium and magnesium bicarbonate waters without significant amounts of other constituents. The calcium and magnesium in the Anderson well (A6) cause it to be classed as poor for boilers and only fair for domestic use. The same constituents cause all the others to be classed as fair for boiler use on account of probable scale formation. All can be made satisfactory for boiler use by any of the reliable softening processes. All are good for irrigation, and except for excessive soap consumption required by the Anderson water, all are classed as good for domestic use.

Chemical composition and classification of ground waters in Red Bluff-Tehama area.

[Samples collected October and November, 1913. Analyses by S. C. Dinsmore; assays by G. H. P. Lichthardt. Parts per million except as otherwise designated. Numbers at heads of columns refer to locations so marked on Pl. IV.]

	Analyses.			Assays.		
	A1	A2	A3	A4	A5	A6
Silica (SiO_2)	47	48	68	....	....	....
Iron (Fe)	.05	.05	.10	....	....	....
Calcium (Ca)	30	26	23	....	....	....
Magnesium (Mg)	10	11	13	....	....	....
Sodium and potassium (Na+K)[a]	15	6.1	9.9	5	(b)	11
Carbonate radicle (CO_3)	.0	.0	.0	0	0	0
Bicarbonate radicle (HCO_3)	148	109	112	136	139	200
Sulphate radicle (SO_4)	17	17	22	6	0	80
Chloride radicle (Cl)	5.0	7.0	11	4	4	18
Nitrate radicle (NO_3)	4.2	8.0	2.8	....	....	....
Total dissolved solids	187	166	193	a 170	a 170	a 360
Total hardness as $CaCO_3$	a 116	a 110	a 111	114	115	250
Scale-forming constituents[a]	150	140	160	160	160	290
Foaming constituents[a]	40	16	27	10	(b)	30
Alkali coefficient (inches)[c]	110	270	170	430	(d)	110
Classification:						
Domestic use	Good.	Good.	Good.	Good.	Good.	Fair.
Boiler use	Fair.	Fair.	Fair.	Fair.	Fair.	Poor.
Irrigation use	Good.	Good.	Good.	Good.	Good.	Good.
Mineral content	Moderate.	Moderate.	Moderate.	Moderate.	Moderate.	Moderate.

a Calculated.
b Low. (See p. 96.)
c Depth in inches of water which on evaporation would yield sufficient alkali to render a 4-foot depth of soil injurious to the most sensitive crops.
d High. (See p. 96.)

A1. Public supply of Red Bluff (taken from Antelope Creek and two wells, 300 and 376 feet deep, 10 inches in diameter. (See log of 376-foot well, p. 253.)
A2. No. 2 drilled well of Exposition Fruit Lands Co., 292½ feet deep, 12 inches in diameter, Orchard Park, near Red Bluff.
A3. Public supply of Los Molinos (well about 50 feet deep, 6 inches in diameter).
A4. No. 5 well of Exposition Fruit Lands Co., Orchard Park, near Red Bluff.
A5. Drilled well, 136 feet deep (first 40 feet dug), owned by Mr. Rausch, SW. ¼ sec. 13, T. 26 N., R. 2 W.
A6. Well of F. F. Anderson, 50 feet deep; 2 miles north of Tehama.

PUMPING PLANTS.

Pumping plants in the Red Bluff-Tehama area.

Red Bluff group.

Owner.	Location.			Diameter of well.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horsepower.	Area irrigated.
	Section.	Township N.	Range W.						
				Inches.	*Feet.*	*Feet.*	*Inches.*		*Acres.*
Henry Bressler	SE. ¼, 14	27	3	(a)	40	25±	3	20	None.
N. M. Cunningham	NW. ¼, 21	27	3	(b)	35	....	2	2	7
Mrs. F. G. Weeks	N. ½, 16	27	3	10	245½	c 33.7	4	10	40
J. H. Guernsey	SW. ¼, 15	27	3	d 12	244	....	6	15	20
Orchard Park Exposition Fruit Lands Co., No. 5.	Near Rawson station			e 12	220	43	8	40	....

a Dug well 5 by 5 feet.
b Dug well 9 feet diameter, curbed with brick 1 to 15 feet; 3 feet diameter, 15 to 35 feet.
c Measured in November, 1913.
d 1 to 50 feet; 10-inch casing 58 to 244 feet.
e Cased to bottom.

Pumping plants in the Red Bluff-Tehama area—Continued.

Tehama group.

Owner.	Location.	Diameter of well.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horsepower.	Area irrigated.
		Inches.	*Feet.*	*Feet.*	*Inches.*		*Acres.*
E. Clements Horst Co., 4 similar plants, 2 movable engines.	Las Flores rancho	10	180±	....	6	40	480
Shasta View Hop Co.:							
9 similar plants and 5 movable motors.	....do	12	110 to	....	6	100	290
1 plant	....do	12	210	....	4	10	
G. M. Shattuck	....do	*e*8	153	*c* 21.4	5	10	60
Alfalfa Products Co.:							
Aitken plant	Saucos rancho	12	200	....	6	20	50
Shultz plant	....do	12	200	....	6	20	75
Crane plant	....do	12	160	....	6	20	40
Finell plant	....do	12	200	....	6	20	100
Mooney plant	....do	12	....	....	....	....	125
Dunn plant	....do	12	224	....	6	20	100

c Measured in November, 1913. *e* Cased to bottom.

CHICO AREA.

GENERAL CONDITIONS.

Chico is a substantial and prosperous city, which, with its suburbs, Chico Vecino and Chapmantown, has about 10,000 inhabitants. It is the commercial center of what may be called the Chico area. It is reached by the Southern Pacific and Northern Electric railroads and is the terminal of the Butte County Railroad, which brings lumber from Sterling City, in the Sierra Nevada, to the big factory of the Diamond Match Co., the city's principal industrial enterprise. The Chico area is a natural unit with rather indefinite boundaries that have been fixed arbitrarily by Frank Adams [96] as follows:

> This [area] covers 138,000 acres of valley plains in Butte County, south of the Tehama County line, east of Sacramento River, north of Butte-Glenn County line, and west of Butte Creek and the lava foothills north of Chico. [See Pls. II and IV.]

In 1913 there were in this area 15 plants pumping from wells for the irrigation of 1,315 acres and using 389 horsepower. Adams [97] reports 800 acres irrigated in 1912, largely by pumping from streams. Many of the plants pumping from wells irrigated land for the first time in 1913. It is probable that the total irrigated acreage in that year was about 2,000 acres. In addition two plants pumping for other purposes are listed.

GEOLOGY AND PHYSIOGRAPHY.

East and north of the city of Chico rise the bare slopes of the foothills of the Cascades, composed of the bedded Tuscan tuff, which

[96] Adams, Frank, California Conservation Comm. Rept., 1912, p. 156.
[97] Idem, p. 156.

dips gently under the valley. These rocks are an alternating series of lavas, massive flow breccias, fine tuffs, and stream deposits of sand and gravel. The lavas originated high on the slopes of the mountains in the volcanoes of the Lassen Peak region,[98] and as they were deposited in successive layers they buried, during a long period of volcanic eruption, ashes and gravels distributed over the plain by the wind and water. This mass of bedded rocks is over 1,000 feet thick where exposed in the canyons of Chico and Butte creeks. Its character and history are more fully described in the section on geology (p. 72). The fold or monocline that bends these rocks under the valley is not so sharp near Chico, and the slope under the valley is even less steep. These relations are brought out in the geologic section through Chico (fig. 4, p. 73) and in the discussion on page 267.

Abutting against the lavas, the older alluvium forms a gradually narrowing plain from Pine Creek to Chico. The height of the surface above the present level of erosion is less than it is farther north, near Vina, and the older alluvium is covered by a thicker blanket of recent material. On this account the soil is more fertile, and shallow wells obtain more water. In places the younger alluvium is so thick that it gives form and character to the plains, and the boundary must be drawn in an arbitrary way.

South of Sandy Gulch the older alluvium disappears beneath the recent deposits of Little Chico, Chico, and Butte creeks, which blend in a semicircular sloping plain that has been named the Chico fan. (See p. 27 and Pl. IV.) The city lies about 200 feet above sea level at the head of the fan, which, resting against the plains of older alluvium on the north, swings in a curving line to the vicinity of Clear Creek, about 4 miles east of Durham. The creeks flow in narrow channels 10 to 20 feet deep, cut by the low water of late spring and summer. In freshets they often break their banks and cover the whole country, leaving a layer of sediment behind to add to the deposits of former years and make the soil more fertile. The slope is about 15 feet to the mile and is sufficient to provide effective drainage for surface and ground waters. The slight elevation above the valley tends to good air drainage and relative freedom from frost. The fan merges gradually with the river flood plain about 5 miles west of Chico near the Sacramento Avenue School, and with the heavier lands of Butte Basin south of Dayton and Durham.

Throughout the fan the older alluvium is masked by the younger, and in well sections it is impossible to distinguish between them, though it seems probable that the younger alluvium is not very thick. The top soil is a brown sandy loam, and below occur beds of water-worn gravels, largely derived from the erosion of the Tuscan tuff and

[98] Diller, J. S., Geology of the Lassen Peak district: U. S. Geol. Survey Eighth Ann. Rept., pp. 422 et seq., 1889.

its associated lavas. Pebbles of limestone and sandstone from the Chico formation and of granite and schist from the subjacent series occur here and there. The gravels are waterworn, and pebbles 8 or 10 inches in diameter are present in the gravels east of Chico. The gravel beds are firmly cemented with a matrix of lime, clay, and sand. Sand beds, where found, are usually cemented also.

The water-bearing formations are the older and younger alluvium and the Tuscan tuff. The older alluvium appears at the surface in a small area just south of Pine Creek and is of relatively small importance as a source of water.

GROUND WATER.

WATER TABLE.

The beds forming the Chico fan contain a large amount of water, and the water table rises with the sloping plain, though less rapidly. In 1913 water stood about 15 feet from the surface at the edges of the fan and 18 to 24 feet from the surface just west of Chico. These relations are brought out by the contours on Plate IV. Through the town of Chico and east of it the level of water in wells is rather variable, owing to the relative imperviousness of the alluvium and to its thinning toward the foothills. Slight drains on the ground water tend to lower the level rapidly, and local irrigation or proximity to a stream may result in filling a gravel bed with water above the true zone of saturation and thus give to a shallow well a very high water level. East of Chico the alluvium is in many places only 10 or 15 feet thick. Below lie the hard upper layers of the Tuscan tuff, and at the contact enough water seeps in along the rock to supply ordinary house wells. It is impossible to draw contours through this area, but such water as is found in the alluvium stands within 25 feet of the surface.

WELLS IN TUSCAN TUFF.

When the Tuscan tuff crops out on the surface the country presents a bare and forbidding appearance, as in the vast lava plateaus that extend north and east of Chico. Yet springs and seeps are relatively common in such areas, and the streams, which lie in deep, narrow canyons, have a relatively constant summer flow. Such conditions show that there are places where the rock is open and porous and capable of receiving and holding rain water. The distribution of the scant vegetation is controlled by the presence of soil and moisture, and the scrub oaks are larger and more numerous and the grass is thicker in those parts of the plateau where jointed and porous rocks occur. Fringes of vegetation at various heights above the streams extend up and down the canyons for miles and lend a symmetry and grace to these otherwise wild and uninviting gorges.

The trees and bushes cling to the outcrops of certain beds, usually where some jointed lava or coarse breccia overlies a bed of fine-grained impervious tuff. Such seeps of water are probably a large element in the permanent summer flow of Deer, Mill, and other creeks.

Natural indications of the presence of water are supplemented by the comparative ease with which small supplies of water have been obtained in dug wells along the Humboldt road (see analysis A10, p. 148) and in the vicinity of Paradise. But the great value of the Tuscan tuff as a water bearer was not appreciated until the Chico Water Co. in 1909 sank three wells into it. The well at the upper works is 671 feet deep and struck "black sand with red particles like brick" at 330 feet. At the Chapmantown plant the deep well is 603 feet deep and struck the "black sand" at 300 feet. The well at the lower works is 607 feet deep and struck the "black sand" at 366 feet. It is evident from these wells that the "black sand," which seems without doubt to be the lava of the Tuscan formation ground up by the drill, is shallower east of Chico. Within 2 miles of the Chapmantown plant the lava rises from the plain in the Sierra foothills. West of Chico the black sand is about 500 feet deep in the wells of the Morehead plant. A structure section based on these wells is given in figure 4 (p. 73), and logs are presented on page 267. (See also Pl. III.) The yield of wells in the Tuscan tuff is large; no one of the seven known to penetrate it yields less than 600 gallons a minute. (See table, p. 267.)

In the wells of the Morehead plant the water level is about 12 feet lower than in adjacent wells in the alluvium. In the water company's wells the water is 3 to 4 feet below the ground-water level. The wells on the Durham ranch of Stanford University (p. 268) have a head of 3¾ feet above the surface water. Such conditions are probably due to the presence of dry or impervious beds which respectively drain off or confine the water.

The Tuscan tuff is from 1,000 to 1,200 feet thick in the foothills east of Chico and probably extends for a considerable distance, though with diminished thickness, under the valley. It is then an important source of underground water for the whole Chico area and may be tapped when shallow wells give too little water. Wells must be sunk by percussion drilling and properly cased to prevent sloughing. Large and heavy rigs should be used, and drilling should commence with as large a hole as practicable so as to provide for reduction in size with increasing depth.

The Tuscan tuff is a hard and brittle formation, and shooting with dynamite on completion of a drill hole will be found effective in creating a percolation chamber and in opening crevices. This should not be done until further drilling is impracticable, and then the casing should be drawn back out of the way and the explosives should be handled by competent and experienced men. Explosion inside the casing will frequently so warp and bend it as to prevent further drilling in the hole or even the necessary cleaning.

Development of water from this formation is expensive because it lies deep in many places and because drilling in the hard rock is difficult. One well about 700 feet deep is reported to have cost an average of $2.38 a foot for drilling and perforating. In addition, the casing and the necessary fuel oil for the steam drill were paid for by the owner.

WELLS IN OLDER ALLUVIUM.

On the plains or red lands of older alluvium water is needed principally for domestic use and stock. Dug wells are the usual type, but even the large percolation area afforded by such wells fails to develop much water from the highly cemented gravels. Water levels are variable and depend on the draft from the wells and on the accident of striking porous or jointed places in the gravels. No drilled wells were found in the red lands of the area, but the successful use of drilled wells in the region to the north indicates their value here whenever economic conditions warrant the further development.

WELLS IN YOUNGER ALLUVIUM.

In the upper parts of the Chico fan wells are bored with difficulty and percussion drilling is usually necessary. Supplies of water for domestic purposes have been obtained in wells from 30 to 150 feet deep and 6 to 10 inches in diameter, and the quality of the water is shown by analysis A8 (p. 148). Dug wells are common and have the usual unsanitary disadvantages. In the past they have been the only source of large supplies. A large area for percolation from the gravel is afforded, but the limit to development comes when the cost of digging the well and galleries exceeds the value of the water. The experience of the Chico Water Co., more particularly described on pages 146–147, is a case in point. At the upper works there is an elaborate system of four dug wells about 31 feet deep with extensive galleries, which in the dry season of 1913 was capable of furnishing less than 1,500 gallons a minute. Of the 15 irrigation plants in the Chico area 5 depend wholly or in part on dug wells. The plants of Mrs. Straughn, Mr. Beavans, and G. E. Barnham, having dug wells only, are of small size. The Barnham plant pumps from the creek in the spring, but in October, 1913, pumping only from the well did not obtain as much water as the full capacity of the pump. The Morehead plant of the Sacramento Valley Sugar Co. has a 16 by 16 by 47 foot timbered well, used also as a pump pit, which has an estimated yield of 500 gallons a minute. The plant of Cooley Bros. has a dug well and 100 feet of gallery connecting with two bored wells. The owners claim that the gallery furnishes most of the water. The construction of such galleries is a dangerous and expensive piece of work. Wherever the alluvium is 100 feet thick or more, drilled wells—if necessary several to each plant—are to be recommended. Such a plant is that of L. D. Choisser, where two 12-inch uncased wells, 27½ feet apart, are supplying a 4-inch horizontal centrifugal pump. The wells are 100 and 141½ feet deep. The log of the deeper well is given below.

Driller's log of L. D. Choisser's well near Chico.

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Surface soil	13	13	Red hardpan	3	78
Gravel, cement	15	28	Sandstone	3	81
Hardpan	3	31	Gravel	8	89
Cement sand	9	40	Log defective	9	98
Fine gravel and sand	1	41	Porous hardpan	10	108
Hardpan	17	58	Gravel, getting coarser; 8 to 10 inches in diameter at bottom; stood, did not cave; no sand pumped out	33½	141½
Sandy formation	2	60			
Hardpan	5	65			
Sandstone	10	75			

NOTE.—Drilled by Hemstreet; 12 inches in diameter, uncased.

In the river bottom lands large quantities of water can be obtained from wells 50 to 200 feet deep. The materials are soft and unconsolidated, and the gravels are clean and coarse. Pebbles 3 to 4 inches in diameter are common in the river bed at Hamilton and are also found in wells. Wells of large diameter can be bored with inexpensive rigs, and sheet-iron casing can be inserted without the use of hydraulic jacks. Such conditions extend into the border zone of the Chico fan.

The Wilson plant of the Sacramento Valley Sugar Co., near Nord, is an excellent example of what can be done. Of the eight wells at this plant one was boggled in sinking and furnishes very little water. The other seven, ranging in depth from 62 to 122 feet, furnish about 700 gallons a minute each. They are 12 inches in diameter, with "red steel" slip-joint casing, perforated with slots after the well was put down. The following is the log of well No. 8:

Driller's log of well No. 8, Wilson plant, near Nord.

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	26	26	Extremely hard clay	7	98
Sand, some clay	10	36	Sand clay	3	101
Gravel	27	63	Sand	6	107
Yellow clay	18	81	Concrete gravel	½	107½
Very hard clay	7	88	Gravel; lots of water	14½	122
Sand clay	3	91			

RECOMMENDATIONS.

In the plains north of Chico water is desired chiefly for stock and domestic use. It can be obtained by drilling either in the older alluvium or in the underlying Tuscan tuff. Drilled wells will be found more satisfactory than the present dug wells.

Over the Chico fan, as the orchards grow older, there will be an increasing demand for water to supplement rainfall, especially in the dry years. Experience at Winters and Yuba City has demonstrated the value of irrigation in bringing about increased yields and improvement in the quality of deciduous fruits and almonds. The same results would probably be accomplished in this area, as the prune orchard of Mr. Choisser would seem to demonstrate. Dairies and truck gardens to supply the growing city will also require water. Irrigation from Butte and Chico creeks, draining an area of 230 square miles, could be increased by storage, but the situation is complicated by preexisting water rights. A high-line ditch from Sacramento River is feasible but could be undertaken only as part of a large project involving the cooperation of many persons who are not yet convinced of the value of irrigation. For these reasons irrigation by surface water is likely to be delayed, and those who desire irrigation will resort to underground sources.

Supplies for orchards and truck gardens, between 200 and 500 gallons a minute, can be obtained in the area west of Chico from wells drilled in the alluvium, though several wells to each plant may be necessary. East of Chico, in case of failure in the alluvium, wells drilled into the Tuscan tuff will be successful, though they will involve additional cost.

In the lower parts of the Chico fan and in the river bottoms larger supplies can be obtained with less expense, but careful consideration should be given to pumping from the river. For land situated immediately on the river bank and having riparian rights this is the natural and probably the cheapest means of obtaining water, but freshets are likely to damage the plant. For lands at a distance from the river ditches must be built, and these involve a large annual expense for upkeep and a loss of water in the porous soil. These conditions should be duly considered, and in this as in any other irrigation development the advice of competent local engineers is usually worth the money it costs.

PUBLIC SUPPLIES.

The Chico Water Supply Co. serves about 1,600 consumers in the city of Chico and its suburb Chapmantown. The other towns in the area have no public supply. Three plants make up the Chico system—the upper works, the lower works, and the Chapmantown plant. Information as to the system has been furnished by Mr. Simpson, the manager.

The upper works are in the center of the city, at Fifth and Olive streets. Because of a gradual development and numerous experiments the plant is rather complicated. The "main sump," constructed in 1886, is 31 feet deep and 20 feet in diameter and has a brick curb. A gallery at the bottom of the well extends 25 feet to the south. A similar gallery 60 feet long extends to the northwest to a second well 14 feet in diameter. A third well is 10 feet in diameter and is connected to the second by a gallery. In 1904 a new well was put down 1,250 feet from the "main sump." It is 30 feet in diameter and 31 feet deep and has a gallery to the north for 42 feet 6 inches and one to the south for 48 feet. A 14-inch siphon pipe 1,250 feet long connects this system with the "main sump." It has an estimated capacity of 1,000 gallons a minute. A 12-inch well 671 feet deep was drilled in 1909. The log is given on page 267. A 6-inch pump and 20-horsepower motor pumps about 650 gallons a minute from this well into the "main sump." A double-acting Laidlaw, Dunn & Gordon steam pump with a capacity of 2½ million gallons a day is installed at the "main sump" and in a dry season fully uses the water supplied by this elaborate system of wells.

The lower works are at Second and Cherry streets, west of the main business section. Here water is pumped directly into the mains. A dug well 33½ feet deep and 5 to 6 feet in diameter has a gallery extending due north for 25 to 30 feet. A companion dug well of the same depth and 10 feet in diameter feeds the first by means of a siphon. These wells were constructed in 1874–75. A triplex pump with a capacity of 630 gallons a minute and a 50-horsepower motor constitute the equipment. In 1913 these wells showed the effect of the dry season and could not be operated the full 24 hours a day. In 1909 a 12-inch well was drilled 60 feet deep into the same formation as that at the upper works (Tuscan tuff). It has yielded on test 665 gallons a minute. It is equipped with a triplex pump having a capacity of 450 gallons a minute.

The Chapmantown plant has a drilled well 12 inches in diameter and 603 feet deep. The Tuscan tuff was struck at 300 feet. The equipment consists of a two-stage 5-inch horizontal centrifugal Dow pump direct connected to a 75-horsepower motor. The estimated present capacity of this plant is 650 gallons a minute. It pumps directly into the mains.

The lower works and Chapmantown plant are used most heavily in the summer. The daily winter consumption, as shown by a test from 6 p. m. March 22, 1913, to 6 p. m. March 23, was 1,165,200 gallons, or about 145 gallons per capita. The summer consumption is more than twice as much. Tests made in July, 1912, showed a consumption of 2,912,000 gallons in 24 hours, or 364 gallons per capita. After obtaining the maximum capacity of shallow wells, the company in 1909 sank the three deep wells mentioned and demonstrated for the first time the existence of large supplies in the underlying Tuscan tuff. For an analysis of water from shallow wells at the upper works, see A7, below. An incomplete examination of a sample from the deep well indicates that the water is practically the same as from the shallow wells.

QUALITY OF WATER.

The one analysis and three assays in the table below show fairly uniform composition for waters in this area. The dissolved mineral matter consists chiefly of calcium, magnesium, and bicarbonate. The waters are classed as good for irrigation and for domestic use and fair or poor for boiler use. All can be improved for boiler use by suitable treatment.

Chemical composition and classification of ground water in Chico area.

[Analysis by S. C. Dinsmore; assays by G. H. P. Lichthardt. Parts per million except as otherwise designated. Numbers at heads of columns refer to locations so marked on Pl. IV.]

	Analysis.	Assays.		
	A7[a]	A8	A9	A10
Silica (SiO_2)	37			
Iron (Fe)	.10			
Calcium (Ca)	20			
Magnesium (Mg)	14			
Sodium and potassium (Na+K)[b]	10	([c])	([c])	([c])
Carbonate radicle (CO_3)	.0	0	0	0
Bicarbonate radicle (HCO_3)	100	200	225	92
Sulphate radicle (SO_4)	29	5	4	0
Chloride radicle (Cl)	13	6	10	4
Nitrate radicle (NO_3)	.00			
Total dissolved solids [b]	172	230	260	130
Total hardness as $CaCO_3$	[b] 107	176	200	87
Scale-forming constituents [b]	120	220	240	130
Foaming constituents [b]	27	([c])	([c])	([c])
Alkali coefficient (inches) [d]	150	([e])	([e])	([e])
Classification:				
Domestic use	Good.	Good.	Good.	Good.
Boiler use	Fair.	Poor.	Poor.	Fair.
Irrigation use	Good.	Good.	Good.	Good.
Mineral content	Low.	Moderate.	Moderate.	Low.
Date of collection	Sept. 28, 1913.	Oct. 17, 1913.	Oct. 17, 1913.	Oct. 13, 1913.

[a] A sample from the well 671 feet deep at the upper works at Chico was found to have 161 parts per million of dissolved solids, with calcium 19, bicarbonate 107, and chloride 10. These values are nearly the same as those for the shallow well.
[b] Calculated.
[c] Low. (See p. 96.)
[d] Depth in inches of water which on evaporation would yield sufficient alkali to render a 4-foot depth of soil injurious to the most sensitive crops.
[e] High. (See p. 96.)

A7. Dug well 31 feet deep at upper works of Chico Water Co., Chico.
A8. Well of William Bennett, 30 feet deep, 4 inches in diameter, 2 miles east of Nord (NE. ¼ sec. 12, T. 22 N., R. 1 W.).
A9. Composite of three wells about 150 feet deep, 10 inches in diameter, at pumping plant of Chico Nursery Co., 1 mile northwest of Chico.
A10. Dug well about 10 feet deep on Humboldt Road (SW. ¼ sec. 21, T. 22 N., R. 2 E.).

PUMPING PLANTS.

Pumping plants in the Chico area.

Owner.	Location. Section.	Township N.	Range E.	Diameter of well.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horsepower.	Area irrigated.
					Feet.	*Feet.*	*Inches.*		*Acres.*
Sacramento Valley Sugar Co., Wilson plant	Bosquejo rancho			[a]12 inches	43-122	....	12	100	650
Edmund Gale	Arroyo Chico rancho			[b]12 inches	....	....	6	20	30
W. B. Smith	do			10 inches	30	....	2½	5	15
F. M. Calloway	do			10 inches	....	[c]9.0	2	3	5
Geo. E. Canfield	do			12 inches	80 180 180	....	7	15	10½
Wm. Hollingsworth	do			10 inches	186	....	4	5	4
Butte County Hop Co., 3 portable pumping plants.	do			Several inches.	Not over 150 feet.	....	4	10	50
Sacramento Valley Sugar Co., Morehead plant: [d]									
Dug well	do			16 by 16 feet.	47	[c] [e]30	12	150	360
No. 1 well	do			9⅝ inches	705	....			
No. 2 well	do			11⅝ inches	624	....			
No. 3 well	do			....	180	....			
Mrs. Straughn	do			6 by 6 feet	40	....	3	6	20
Chico Nursery Co	do			3 wells	150±	....	4	15	30
G. E. Barnham				3½ by 3½ feet.	12	....	5	7½	5
L. D. Choisser	36	22	1	[f]12 inches	100 and 141½	....	4	20	35
Plant Introduction Gardens	....	....	....	Dug.	20	....	6	20	40
Mr. Beavens	N. ½, 22	21	3	8 by 12 feet.	....	[c]14.9	2	3	10
Cooley Bros	SE. ¼, 31	21	2	([g])	([h])	[i]35.3	6	20	50
Mrs. Annie E. K. Bidwell	Chico Vecino			Dug.	27	....	3	30	([j])
Diamond Match Co	Chapmantown			[k]8 inches	150	....	Air lift.	....	([l])
				Dug well.	....	....			

[a] 8 wells same diameter in east-west row; Nos. 1 to 6, 30 feet apart; No. 70, 50 feet from No. 6; No. 8, 50 feet from No. 7. Estimated yield 4,000 gallons per minute.
[b] 3 wells.
[c] Measured in October, 1913.
[d] In same structure there is a plant pumping from creek; combined discharge 7,500 gallons per minute, of which wells furnish 2,500 gallons per minute.
[e] Stream of water entering pit 5 feet above water level.
[f] 2 wells, no casing.
[g] Dug well 9 by 9 feet, 45 feet deep; galleries at 38 feet lead 50 feet north and south to bored wells, 10 inches in diameter, 132 and 115 feet deep.
[h] Pumping; normal reported, 14 feet.
[i] Measured in September, 1913.
[j] Domestic.
[k] Several of these drilled wells; some practically abandoned.
[l] Manufacturing.

BUTTE CITY AREA.

GENERAL CONDITIONS.

The Butte City area comprises that part of Glenn County east of Sacramento River (Pl. II). It is a low-lying, relatively sparsely populated area. The principal settlement is Butte City (population 279 in 1910), on Sacramento River. No railroad passes through the area, and rapid development of fruit farming can not be expected. In 1913 there were in this area seven pumping plants, which supplied water from wells for the irrigation of 470 acres.

GEOLOGY AND PHYSIOGRAPHY.

This area lies just north of Butte Basin and is everywhere underlain by younger alluvium. It is characterized by a series of sloughs which run approximately parallel to Sacramento River and drain flood waters derived from Chico Creek and other sources southward to Butte Basin. The northern limit of this basin is very indefinite, and in times of heavy floods most of this region is submerged with a sheet of water that moves slowly southward. The best land for general agriculture is within a few miles of the river, where the surface is slightly higher and the soil somewhat less heavy than elsewhere. The heavier lands of Butte Basin, however, are adapted for growing rice. The western part of the area, as mapped by the United States Bureau of Soils, has silt loam, and the eastern part has clay or clay loam.

GROUND WATER.

Ground water is everywhere near the surface, as shown by the contours on Plate IV. In the pumping plants described on the following pages the depth to water is between 10 and 15 feet.

Wells ordinarily encounter coarse gravel within 100 feet of the surface which resembles the gravel now found in the bed of Sacramento River. The gravel undoubtedly represents the channel of the river when in past time it shifted its position, just as it has recently done in the production of oxbow lakes (p. 35). These lateral shifts seem to have extended for at least 4 miles east of Butte City. In the strip of this width the gravels are numerous, uncemented, and free water bearers. In this part of the area wells for irrigation can be obtained with certainty and with little expense. On the borders of Butte Basin sufficient water for domestic use will be obtained by shallow wells, but in some localities gravels may form only a small part of the younger alluvium and deep wells may be necessary to obtain large supplies of water.

Three assays of well waters given in the following table show the quality to be similar to that in the areas to the north, but a slightly greater amount of dissolved mineral matter is present. The waters are classed as good for irrigation and can all be so treated as to be suitable for boiler use. They contain too much calcium and magnesium to be satisfactory without softening.

Chemical composition and classification of ground waters in Butte City area.

[Assays by G. H. P. Lichthardt. Parts per million except as otherwise designated. Numbers at heads of columns refer to locations so marked on Pl. IV.]

	Assays.		
	A11	A12	A13
Sodium and potassium (Na+K) [a]	(b)	(b)	13
Carbonate radicle (CO_3)	0	0	0
Bicarbonate radicle (HCO_3)	205	231	236
Sulphate radicle (SO_4)	5	9	3
Chloride radicle (Cl)	12	12	8
Total dissolved solids [a]	240	260	260
Total hardness as $CaCO_3$	208	264	182
Scale-forming constituents [a]	240	260	220
Foaming constituents [a]	(b)	(b)	30
Alkali coefficient (inches) [c]	(d)	(d)	70
Classification:			
Domestic use	Good.	Fair.	Good.
Boiler use	Poor.	Poor.	Poor.
Irrigation use	Good.	Good.	Good.
Mineral content	Moderate.	Moderate.	Moderate.
Date of collection	Sept. 8, 1913	Sept. 8, 1913	Dec. 6, 1913

[a] Calculated.
[b] Low. (See p. 96.)
[c] Depth in inches of water which on evaporation would yield sufficient alkali to render a 4-foot depth of soil injurious to the most sensitive crops.
[d] High. (See p. 96.)

A11. Composite of two wells about 70 feet deep, 12 inches in diameter, at pumping plant in orchard of Carson Colony No. 3 (NE. ¼ sec. 4, T. 18 N., R. 1 W.).
A12. Composite of two wells 63 feet deep, 12 inches in diameter, at pumping plant of K. Schuiling, north of Marvin Chapel (NE. ¼ sec. 15, T. 18 N., R. 1 W.).
A13. Bored well about 30 feet deep, 6 inches in diameter, owned by Frank Steel, near Princeton (SE. ¼ sec. 20, T. 18 N., R. 1 W.).

PUMPING PLANTS.

Pumping plants in the Butte City area.

Owner.	Location.			Diameter of well.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horsepower.	Area irrigated.
	Section.	Township N.	Range W.						
				Inches.	*Feet.*	*Feet.*	*Inches.*		*Acres.*
Carson colony	4, 10, 11	18	1						400
A. B. Faner	SE. ¼, 28	19	1	8	34		4	7½	20
K. Schuiling	SW. ¼, 10	18	1	[a] 12		[b] 11.4	4	7½	10
Do	NE. ¼, 15	18	1	[c] 12	63	[b] [d] 2.3	4	7½	10
G. A. Warfield	NE. ¼, 29	18	1	[e] 18	116		[f] 18	30	35

[a] 2 wells, 15 feet apart.
[b] Measured October, 1913.
[c] 2 wells, cased to bottom. For assay of water see A12, above.
[d] Below center of pump.
[e] Cased to 86 feet.
[f] Turbine centrifugal pump.

NOTE.—There are several plants in the Carson colony of which the details are not known.

GRIDLEY-MARYSVILLE BUTTES AREA.

GENERAL CONDITIONS.

The Gridley-Marysville Buttes area lies between Feather River and Butte Creek and extends from the Marysville Buttes northward to the Chico fan and the foothills of the Sierra Nevada (Pl. II.) It is traversed by the Portland line of the Southern Pacific Railroad, and there is also an electric line from Marysville to Chico. The principal town is Gridley, which in 1920 had a population of 1,636. Irrigation under the Butte County Canal in the vicinity of Biggs and Gridley in 1912 covered 14,000 acres, mostly in alfalfa and rice. The acreage in rice has been increased tremendously since 1914. Northwest of Oroville, on the red lands near Thermalito, about 840 acres of orchard was irrigated in 1912.[99] Only a small amount of irrigation development by pumping from wells has thus far been made, but the conditions are believed to be favorable for further development along this line. In 1913 there were in this area five pumping plants, which supplied water for irrigating 115 acres.

GEOLOGY AND PHYSIOGRAPHY.

The mountains along the margin of the valley north of Oroville consist largely of the Ione formation, overlain by the Tuscan tuff and the basalt of Table Mountain. Bordering these formations is a very irregular fringe of red lands, underlain by older alluvium, from which the low plains underlain by younger alluvium extend westward and southward until they gradually merge into flat flood basins. The younger alluvium has in large part been deposited by Butte Creek and Feather River, and consequently coarse, clean gravels are found in wells that penetrate it.

GROUND WATER.

WATER TABLE.

The water table (see Pl. IV) slopes from the foothills to Nelson at the rate of 7 feet to the mile. Only in the red lands is the depth to water more than 25 feet. From Nelson southwestward into Butte Basin the slope of the water table becomes gradually more gentle, but the slope of the land decreases at a greater rate, and over large parts of the basin ground water stands less than 10 feet from the surface. Along the right bank of Feather River from Biggs southward the 60, 70, 80, and 90 foot contours show peculiar southern bulges, which have been produced by the rise in the water table induced by irrigation in the vicinity of Biggs and Gridley, under the Butte canal. Near the river, under the levee, the original depth to water in dry

[99] Adams, Frank, op. cit., p. 159.

seasons was about 20 feet. In 1913 the water stood from 7 to 10 feet and in low spots less than 5 feet from the surface. West of Gridley and Biggs, where the original depth to water had been 10 feet, it had been raised to 3 feet in the rice fields. Wells half a mile from the irrigated district, however, were not affected by this rise in the water table.

Near Marysville Buttes the water table slopes from the buttes in all directions, but in the alluvium-filled valleys which indent the buttes water stands not more than 20 feet from the surface.

WELLS IN PRE-PLEISTOCENE ROCKS.

Wells for domestic purposes can be obtained in the crystalline rocks and in the lavas and Tuscan tuff in most localities where these rocks crop out in the foothills. In Table Mountain and the hills north of it springs break out at the contact of the lavas with the underlying more impervious Ione formation, and these springs are the common source of domestic and stock water.

The Ione formation in this area consists of clays and interbedded sands, and no wells are known to obtain large amounts of water from it. In the valley north of South Table Mountain a thin layer of younger alluvium overlies the Ione, and wells obtain water from the alluvium.

WELLS IN OLDER ALLUVIUM.

Water sufficient for domestic use and stock is obtained from the older alluvium. Along Dry Creek, west of the Chico and Oroville road, S. W. Cheyney sank two wells in 1913. One of them, in the NW. ¼ sec. 18, T. 20 N., R. 4 E., is in the flat of Dry Creek about a quarter of a mile north of the bluff that bounds the older alluvium. Its log is as follows:

Log of S. W. Cheyney's well in the NW. ¼ sec. 18, T. 20 N., R. 4 E.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil	6	6
Cement gravel	2	8
Sandy clay with pebbles of volcanic rocks	12	20
Sandy clay with streaks of gravel, stands without casing	135	155

The well is 12 inches in diameter and is surrounded by a plank pit in which water stood in September, 1913, at 17.5 feet. The upper 6 feet of soil was saturated at the base, and water was seeping into the pit. The upper 6 feet seems to be the younger alluvium, which rests upon the more cemented older alluvium, derived largely from the erosion of the foothills of Tuscan tuff near by. This well has been tested successfully with a 6-inch centrifugal pump. A similar well half a mile northeast, in the SW. ¼ sec. 7, T. 20 N., R. 4 E., is 105 feet deep and penetrates the same material. This well has been tested successfully with a 4-inch centrifugal pump.

WELLS IN YOUNGER ALLUVIUM.

The value of the younger alluvium as a water-bearing formation varies with the amount, size, and cleanness of its gravel beds.

North of Biggs and east of the line between Tps. 3 and 4 E. the younger alluvium is thin and was deposited by small streams, so that large supplies can not be expected from it. Drilling in the older alluvium or Tertiary lavas may, however, be successful.

West of the line mentioned above, but north of Biggs, much of the younger alluvium was deposited by Butte Creek. The channel materials of this stream are clean gravels and sands and will make excellent water bearers. The large areas southwest of Nelson suitable for the growing of rice can probably be irrigated in part from wells where surface water from the Butte County canal is not available.

Along Feather River near Biggs and Gridley coarse clean gravels deposited by the river are found in wells. The Harkey, Johnson, and Stanton plants, south of Gridley, give an idea of the large supplies obtainable from shallow wells. Pumping in this area will also tend to reduce the rise of water incident to irrigation with surface waters. Farther west, in Butte Basin, sands rather than gravels are likely to be found in wells, and the cost of well construction will therefore be higher. This increase will, however, be compensated in part by low lift.

The Manaugh plant, 1 mile west of Pennington, gives some data on the characteristics of the alluvium that forms a narrow band sloping in all directions from Marysville Buttes. The gravels are not well sorted, and large supplies can not perhaps be expected, but small plants, for the irrigation of orchards, may easily be developed. Stohlman's plant, 2 miles northwest of Sutter, shows that the alluvium is at least 74 feet deep in this little valley and probably equally deep in other flat-bottomed valleys of the buttes. This alluvium is water-bearing and will supply a quantity of water dependent on the size of the local drainage basin.

QUALITY OF WATER.

Only one analysis of water in this area was obtained. The water is derived from the Tuscan tuff. (See log, p. 268.) The results given below show a moderate mineral content, consisting mainly of calcium, magnesium, and bicarbonate. This water is classed as good for irrigation and for domestic use, although it is a little hard and will therefore require the use of more soap than would be needed for a softer water. It is classed as only fair for use in steam boilers, on account of the scale-forming constituents. It is probable that other waters in the area are harder rather than softer, but experience throughout the valley indicates that the general classification is likely to be the same for all.

Chemical composition and classification of water from west well (560 feet deep) at Durham ranch of Stanford University (A14, Pl. IV).

[Collected Sept. 23, 1913; analyzed by S. C. Dinsmore. Parts per million except as otherwise designated.]

	A14		A14
Silica (SiO_2)	60	Total hardness as $CaCO_3$ [a]	122
Iron (Fe)	.15	Scale-forming constituents [a]	160
Calcium (Ca)	24	Foaming constituents [a]	15
Magnesium (Mg)	15	Alkali coefficient (inches) [b]	420
Sodium and potassium (Na+K) [a]	5.4		
Carbonate radicle (CO_3)	.0	Classification:	
Bicarbonate radicle (HCO_3)	145	Domestic use	Good.
Sulphate radicle (SO_4)	8.6	Boiler use	Fair.
Chloride radicle (Cl)	4.0	Irrigation use	Good.
Nitrate radicle (NO_3)	.00	Mineral content	Moderate.
Total dissolved solids	178		

[a] Calculated.
[b] Depth in inches of water which on evaporation would yield sufficient alkali to render a 4-foot depth of soil injurious to the most sensitive crops.

PUMPING PLANTS.

Pumping plants in the Gridley-Marysville Buttes area.

Owner.	Location. Section.	Township N.	Range E.	Diameter of well.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horsepower.	Area irrigated.
				Inches.	*Feet.*	*Feet.*	*Inches.*		*Acres.*
W. S. Harkey	N. ½, 19	17	3	[a]12			8	35	40
R. F. Johnson	N. ½, 30	17	3	[b]12		5.8	10	35	30
E. W. Stanton, jr	Boga rancho			[c]12 12 12	310 65 65		8	35	
A. Manaugh	SW. ¼, 25	17	1 W.	8	78		1½	3½	5
F. W. Stohlman	NW. ¼, 5	15	2	8	74		4	12	40

[a] Three wells.
[b] Two wells.
[c] *No. 1 is 50 feet east of No. 2, which is 30 feet east of No. 3; cement pit between Nos. 2 and 3.*

OROVILLE-MARYSVILLE AREA.

GENERAL CONDITIONS.

The Oroville-Marysville area is a triangular area between Feather River and the Sierra Nevada, north of Yuba River (Pl. II).

Marysville (population 5,461 in 1920), at the junction of Feather and Yuba rivers, is the principal town and commercial center not only of this area but of all the adjacent areas. Two lines of the Southern Pacific Co. from the south and two lines from the north enter the town. One of these lines crosses the area to Oroville, as does the main line of the Western Pacific Railroad. The Northern

Electric Railroad also runs trains to Oroville by a route lying west of Feather River.

Oroville (population 3,340 in 1920) lies at the foot of the mountains on Feather River. It has always been a trading point with mining regions to the east. The development of dredging for gold has added to the prosperity of the town. The culture of citrus fruit and olives, begun under the Thermalito and Palermo systems, assures a more permanent prosperity.

Near Palermo, south of Oroville, the system of the Palermo Land & Water Co. irrigated in 1912 with water from Feather River 1,880 acres, mostly in oranges, olives, and peaches. A small body of land was irrigated in 1912 from Honcut Creek. The Stall and Hallwood ditches from Yuba River cover 3,640 acres north of that river and east of Marysville.[1] In 1913 the area contained 23 pumping plants that were lifting water for irrigation, and the total area irrigated with well water was 370 acres. Most of the pumping plants are rather small.

GEOLOGY AND PHYSIOGRAPHY.

Feather River crosses the last granite outcrop at Oroville. Thence it flows southwestward through hills of dredge tailings to Haselbusch. On either side rise terraced bluffs to the level of the red lands. They form a wide bench with a greater elevation (350 to 425 feet) than elsewhere on the east side of the valley. They border the river for several miles east of Oroville, where the older alluvium masks and conceals the roughnesses of the granite on which it lies.

From Oroville to Haselbusch the river flood plain was formerly flat—the normal flood plain of a graded river; it is now covered by great piles of gravels from the gold dredges.

From Haselbusch southward, the river lies between natural levees capped by artificial levees. The land slopes from the river eastward to a long, narrow depression between the natural levee and the low plains built out from the foot of the red lands. The recent building up of the channel of Yuba has converted the south end of this depression into Marysville Basin (p. 31).

GROUND WATER.

WATER TABLE.

The water table, as shown in Plate IV, slopes from the northeast to the southwest but at a somewhat lower angle than the land. Considerable areas of the red lands have water more than 25 feet from the surface. Shallow ground water near Palermo is due to irrigation with surface water. Along the natural levee of Feather River ground water stands about 20 feet from the surface during dry seasons.

[1] Adams, Frank, op. cit., p. 159.

In the depression that borders the river on the east water is less than 10 feet from the surface, and small areas immediately north of Marysville are swampy. North of Yuba River irrigation with surface water has saturated the soil, and water stands from 7 to 10 feet from the surface.

WATER IN CRYSTALLINE ROCKS.

The area is bordered on the east by the foothills of the Sierra Nevada, which are here composed of crystalline rocks. Dug wells encounter sufficient crevices in the jointed rocks to supply water for domestic use and stock, particularly in Browns Valley, 11 miles east of Marysville, where weathering of amphibolite schist has produced a layer of soil and loose rock about 25 feet thick. In this layer wells obtain water.

WELLS IN OLDER ALLUVIUM.

The benches of older alluvium or red lands, because of good air, drainage, and suitable soil, are valuable orchard land.

Wells in this formation have not had large yields. Most of them are dug wells which penetrate only a few feet below the water table. After the water stored in the wells has been pumped out they have only a small flow. The more efficient methods of digging in the Watt colony have produced some successful dug wells, such as those of Arboney, Wagoner, and Cooksey. (See also p. 100 and analysis A15, p. 159.) Drilled wells, however, should be more successful, though the cemented gravels of the older alluvium can not be expected to yield as freely as the loose gravels of the younger alluvium. In a number of localities wells can be sunk on the low plains and the water pumped to the red lands with no more expense than would be involved in deep drilling in the red lands.

WELLS IN YOUNGER ALLUVIUM.

Wells in the younger alluvium near Feather River will strike coarse gravels deposited by the river. Large yields from inexpensive wells are possible, as in the Porter plant (p. 160). Along Honcut Creek the gravels yield water freely, as shown by the plants of J. F. White and of Kee, Williams & Briggs (p. 160).

In the Marysville Basin much blue clay and fine sand may be found in wells, and many wells have small amounts of hydrogen sulphide gas. The Marysville Basin is due to recent and artificial changes, but wells encounter fine-grained clays and sands which may easily have been deposited under conditions that now exist in the basins. The following logs give a general idea of these beds:

Log of Marysville Water Co.'s well No. 3.

[Bored June, 1915; log furnished by A. C. Bingham.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	5	5	Blue shale	2	98
Shale	6	11	Soft blue sediment	12	110
Blue sediment	10	21	Blue shale	60	170
Gray sand	3	24	Coarse blue sand (water)	14	184
Blue pipe clay	7	31	Blue shale	6	190
Sand and sediment	34	65	Coarse blue sand (water)	17	207
Sand and coarse gravel (water)	25	90	Blue shale	48	255
Blue sand	6	96			

Log of Marysville Water Co.'s well No. 8.

[Drilled September, 1913; log furnished by A. C. Bingham.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	5	5	Coarse blue sand	16	196
Hardpan	11	16	Sand and small gravel	2	198
Gray sand	8	24	Blue clay, sticky	22	220
Blue clay	7	31	Sand, cemented	5	225
Sandy sediment	36	67	Blue clay, sticky	30	255
Coarse gravel and sand	16	83	Blue clay, soft	7	262
Blue sand	1	84	Blue sand, hard and coarse	1½	263½
Blue clay, soft	16	100	Blue clay, soft	36½	300
Blue clay, sticky	55	155	Blue sand (water)	15	315
Blue sand, hard	10	165	Blue clay, sticky	5	320
Blue sand, soft	10	175	Blue clay, some sand	20	340
Blue clay, hard	5	180			

The so-called Buckeye Mill well, in Marysville, was bored to a depth of 218 feet. Between 80 and 140 feet clay containing impressions of shells was found.[2] On account of the shells and the fine-grained texture of the beds Lindgren and Turner think that the dark and "blue" beds are older than the younger alluvium and belong to the marine Tertiary. Whatever their age, which can be established only by the finding of fossils, they yield water freely, though adequate screens must be installed to exclude sand. The quality of this water is shown by analysis A16, which represents a composite of samples from the several wells that supply the system.

QUALITY OF WATER.

The two analyses and one assay in the accompanying table indicate that waters in this area resemble those found elsewhere throughout the valley. They have low or moderate mineral content, with calcium, magnesium, and bicarbonate making up practically all the dissolved mineral matter. The Marysville city supply contains

[2] Lindgren, Waldemar, and Turner, H. W., U. S. Geol. Survey Geol. Atlas, Marysville folio (No. 17) p. 1, 1895.

hydrogen sulphide when drawn from the well, but this is removed by aeration before distribution. All the waters are classed as good for irrigation and for domestic use, although soap consumption with A15 and A17 is slightly increased by the hardness and with A16 is appreciably greater. For boiler use softening would pay, especially with A16.

Chemical composition and classification of ground waters in Oroville-Marysville area.

[Analyses by S. C. Dinsmore; assay by G. H. P. Lichthardt. Parts per million except as otherwise designated. Numbers at heads of columns refer to locations so marked on Pl. IV.]

	Analyses.		Assay.
	A15	A16	A17
Silica (SiO_2)	53	55	
Iron (Fe)	.35	Trace.	
Calcium (Ca)	15	43	
Magnesium (Mg)	15	17	
Sodium and potassium (Na+K) [a]	13	[b]20	([c])
Carbonate radicle (CO_3)	.0	.0	0
Bicarbonate radicle (HCO_3)	121	167	115
Sulphate radicle (SO_4)	13	16	Trace.
Chloride radicle (Cl)	7.0	41	8
Nitrate radicle (NO_3)	7.0	.00	
Total dissolved solids	173	277	[a] 150
Total hardness as $CaCO_3$	[a] 99	[a]177	116
Scale-forming constituents [a]	120	210	150
Foaming constituents [a]	35	54	([c])
Alkali coefficient (inches) [d]	130	50	([e])
Classification:			
Domestic use	Good.	Good.	Good.
Boiler use	Fair.	Poor.	Fair.
Irrigation use	Good.	Good.	Good.
Mineral content	Moderate.	Moderate.	Low.
Date of collection	Sept. 15, 1913.	Dec. 30, 1913.	Aug. 8, 1913.

[a] Calculated.
[b] Determined. Na=15; K=5.2 parts per million.
[c] Low. (See p. 96.)
[d] Depth in inches of water which on evaporation would yield sufficient alkali to render a 4-foot depth of soil injurious to the most sensitive crops.
[e] High. (See p. 96.)

A15. Dug well (35 feet deep; diameter 6 by 7 feet) at pumping plant of G. W. Cooksey, near Gridley (SW. ¼ sec. 35, T. 18 N., R. 3 E.)
A16. Composite from several wells of Marysville Water Co. at Marysville.
A17. Dug well at road house 10 miles east of Marysville (SE. ¼ sec. 19, T. 16 N., R. 5 E.).

PUMPING PLANTS.

Pumping plants in the Oroville-Marysville area.

Owner.	Location.			Diameter of well.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horsepower.	Area irrigated.
	Section.	Township N.	Range E.						
				Feet.	*Feet.*	*Feet.*	*Inches.*		*Acres.*
O. W. Halstead	NW. ¼, 7	18	4	4 by 6	68	[a] 52	3½	15	6
F. S. Thomas	SW. ¼, 7	18	4	7 by 10	35	[b] 10.7	1½	2½	8
Greene & Eilerman	NW. ¼, 18	18	4	[c] [d] 8	150	70	([e])	2½	10
Smith & Heilig	SE. ¼, 25	18	3	6 by 8	32	....	3	5	....
	NE. ¼, 30	18	4	6 by 12	....	....	2	5	....
J. C. Martin	SW. ¼, 28	18	4	[d] 10	145	....	([f])	8	25
Watt & Co	SW. ¼, 25	18	3	4 by 6	43	....	2½	5	....
Mr. Passmore	SE. ¼, 26	18	3	4 by 6	20	[b] 16.4	....	....	....
Peter E. Arboney	N. ½, 35	18	3	4 by 6	35+	....	3	7½	....
George T. Wagoner	NE. ¼, 35	18	3	6 by 6	40	....	3	8	16
L. F. Pratt	SW. ¼, 35	18	3	4 by 6	37½	....	2½	5	10
Watt & Co	SW. ¼, 35	18	3	Bored.	205	....	....	....	....
G. M. Cooksey	SW. ¼, 35	18	3	[g] 6 by 7	35	....	4	10	15
C. E. Porter	NW. ¼, 2	17	3	[d] 12	....	....	4	7½	15
Mr. McDuncan	S. ½, 1	17	3	4	30	[b] 15.7	3	3	....
S. N. D. Smullin	NW. ¼, 17	17	4	Dug.	27	....	3	5	5
Oroville Olive Co	NW. ¼, 17	17	4	[h] 6	38	....	4	10	23
J. F. Gatgens	SE. ¼, 14	17	3	[d] [i] 12	45	....	5	10	8
J. F. White	Honcut rancho			[d] 12	70	....	5	10	44
Kee, Williams & Briggs	do			[d] [j] 12	145 to 188	....	7	25	70
Dr. Copley	do			[d] 12	70	[b] 17.2	4	8	20
L. E. Spafford	NW. ¼, 8	16	4	[d] 6	....	[b] [k] 9.7	2	4	5
W. A. Beard	Honcut rancho			[d] 12	....	....	6	20	20
W. A. Hayne	do			[d] 12	46	....	3	5	5
	do			[d] 10	....	[b] 11.3	3	5	10

[a] Reported normal; 54.5 September 19, 1913, after pumping; well pumped dry in 30 minutes; requires 2½ hours to recover.
[b] Measured in September, 1913.
[c] Two wells; depth of north well given.
[d] Inches.
[e] 3-inch cylinder, 2-foot stroke.
[f] 4½-inch cylinder, 2-foot stroke.
[g] For analysis see A15, p. 159.
[h] Curbed with brick; pumps dry in 40 minutes.
[i] Cased to 35 feet.
[j] Two wells 60 feet apart, 145 feet deep; third well between other two, 188 feet deep.
[k] From top of casing.

EAST SUTTER BASIN AREA.

GENERAL CONDITIONS.

The East Sutter Basin area lies south of the Marysville Buttes and extends from Feather River westward into Sutter Basin (Pl. II). The principal town is Yuba City, county seat of Sutter County, which in 1920 had a population of 1,708. It is on the Oroville branch of the Southern Pacific Railroad, which traverses the eastern part of the area, and is on Feather River opposite Marysville. The principal agricultural and irrigation developments are in the eastern part of the area, mostly in Reclamation District No. 1, which is protected from overflow of Feather River by a levee on the west bank. There is a large irrigation pumping district in the vicinity of Yuba City. Most of the water is used for the irrigation of cling peaches, which thrive in this locality. The superior varieties of the peach and the technique of growing the fruit are the result of the intelligence and enterprise of the local inhabitants, who are largely the descendants of the original settlers in this vicinity. In 1913 there were in this area 167 pumping plants, which supplied water for the irrigation of 4,144 acres, largely orchard land in small tracts.

GEOLOGY AND PHYSIOGRAPHY.

All of the East Sutter Basin area is underlain by younger alluvium. A belt along the east side consists of river land which has been built up at times of overflow to a level somewhat above the rest of the area. From the river land the surface slopes very gently westward to Sutter Basin, which is one of the large flood basins of the valley. The natural levee is marked by a very large distributary channel, Gilsizer Slough, which extends through the area from Yuba City southwestward to Sutter Basin. The best lands lie along Gilsizer Slough, where the principal development of orchards and of pumping has taken place.

GROUND WATER.

WATER TABLE.

The water table slopes from north to south in the area between Yuba City and Sutter, but farther south it slopes from Feather River southwestward. (See Pl. IV.) The changes brought about by pumping are described on page 89 and shown in figure 7. The depth to water along the levee of Feather River is usually about 20 feet in the dry season and less than 10 feet in Sutter Basin. Owing to evaporation of ground water from the soil there are patches of alkali along the eastern margin of Sutter Basin.

Gilsizer Slough has a medial depression, the old channel, which is 20 feet below the surrounding country near Yuba City and decreases to about 5 feet near the basin. The depression was originally a swampy flat from a hundred yards to a quarter of a mile wide. Ground water lay close to the surface or even formed a sluggish stream. Evaporation concentrated alkali in the soil, and there was in most places a growth of salt grass. With the increasing height of the flood plain of Feather River, due to the combined effects of débris from Yuba River and the building of levees, the slough became a nuisance. After prolonged litigation a ditch about 4 feet wide and 2 feet deep was dug the length of the slough at a cost of about $50,000, of which $40,000 is said to have been spent in litigation. The ditch lowered the water table, and most of the depression is now cultivated either to fruit or asparagus. For the asparagus crop the alkaline land is an advantage.

WELLS.

In this area water in quantities adequate for irrigation is usually found in sand interbedded with dark clays within 200 feet of the surface. The clays are tough and do not cave easily, so that most of the wells have practically no casing. In ordinary practice the sand underlying the clays is pumped out, and from the resultant cavity good yields of water are obtained. Much of the water contains small quantities of hydrogen sulphide, and many local people prefer the "sulphur" water for drinking. Too much gas, however, is a nuisance, as it breaks the priming of centrifugal pumps, as in the plant of J. H. Palmer (see table, p. 166), where two previous wells had to be abandoned. The best device for overcoming this difficulty is to sink the pump pit below the water table and pump from it, allowing the water to flow over the top of the casing into the pit. During this overflow the gas is dissipated into the air.

In the western part of the area, along the flood basin, and in the southern part, near Marcuse and Chandler, the ground water is of poorer quality than farther northeast, but most of the water found in these parts is usable for irrigation.

QUALITY OF WATER.

The two analyses and two assays in the accompanying table show a wide range in composition of the waters. Analyses A18 and A19 represent calcium and magnesium bicarbonate waters slightly harder than the average water of the valley and may be taken as typical of waters used for irrigation in the numerous pumping plants of the area. They are classed as good for irrigation and for domestic use and as only fair for boilers. Softening would improve them for boiler use and would result in saving of soap in laundry work.

Assays A20 and A21 show much poorer waters than are found generally in the valley. The dissolved solids, hardness, and chloride are from 10 to 100 times the amounts found in the greater number of samples examined. The waters are classed as bad or unfit for domestic use or for boiler use. The computed values indicate that they should not be used for irrigation, although water from the Edwards plant (A21) has been successfully used on alfalfa. This classification, however, is based on computations from values which are difficult to determine by assay methods, and therefore the results are not as definite as those based on analyses.

Chemical composition and classification of ground waters in East Sutter Basin area.

[Analyses by S. C. Dinsmore; assays by G. H. P. Lichthardt. Parts per million except as otherwise designated. Numbers at heads of columns refer to locations so marked on Pl. IV.]

	Analyses.		Assays.	
	A18	A19	A20	A21
Silica (SiO_2)	50	34	....	....
Iron (Fe)	.06	Trace.	....	....
Calcium (Ca)	36	42	....	....
Magnesium (Mg)	28	14	....	....
Sodium and potassium (Na+K) [a]	[b] 29	8.1	940	240
Carbonate radicle (CO_3)	0	0	0	0
Bicarbonate radicle (HCO_3)	274	204	302	256
Sulphate radicle (SO_4)	18	Trace.	Trace.	0
Chloride radicle (Cl)	22	9.0	2,170	860
Nitrate radicle (NO_3)	13	.00	....	....
Total dissolved solids	321	217	[a] 3,800	[a] 1,600
Total hardness as $CaCO_3$	[a] 205	[a] 162	1,450	950
Scale-forming constituents [a]	200	180	1,500	990
Foaming constituents [a]	78	22	2,500	650
Alkali coefficient (inches) [c]	47	130	.9	2.4
Classification:				
Domestic use	Good.	Good.	Unfit.	Bad.
Boiler use	Fair.	Fair.	Unfit.	Unfit.
Irrigation use	Good.	Good.	Bad.	Poor.
Mineral content	Moderate.	Moderate.	Very high.	High.
Date of collection (1913)	Dec. 30.	July 2	Aug. 18	July 21

[a] Calculated.
[b] Determined. Na=24; K=4.8 parts per million.
[c] Depth in inches of water which on evaporation would yield sufficient alkali to render a 4-foot depth of soil injurious to the most sensitive crops.

A18. Municipal supply (composite of two wells, 85 and 165 feet deep, 12 inches in diameter), Yuba City.
A19. Well at camp near New Chandler.
A20. Shallow well, 6 inches in diameter, at camp of Hudson estate (SW. ¼ sec. 7, T. 13 N., R. 2 E.).
A21. Well (42 feet deep, 12 inches in diameter), at pumping plant of E. R. Edwards, 3 miles southwest of Nicolaus (SE. ¼ sec. 10, T. 12 N., R. 3 E.).

PUMPING PLANTS.

Pumping plants in the East Sutter Basin.

Owner.	Location.			Diameter of well.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horsepower.	Area irrigated.
	Section.	Township N.	Range E.						
				Inches.	*Feet.*	*Feet.*	*Inches.*		*Acres.*
W.F. Sperry	Yuba City			10	....	....	3	5	20
Giblin Bros. No. 1	Outskirts of Yuba City			12	75	....	3	5	20
Giblin Bros. No. 2	...do			12	40	....	3	7½	
J. G. Sternes	SE. ¼, 12	15	2	8	40(?)	[a] [b] 17.4	3	7½	10
J. G. Choffin	SE. ¼, 12	15	2	10	65	[a] [c] 14.9	3	6	12
Yuba Dairy Co. No. 1	NW. ¼, 19	15	3	[d] 12	178	....	6	20	80
Yuba Dairy Co. No. 2	SW. ¼, 18	15	3	12	148	....	6	20	40
W.L. Henson	SE. ¼, 17	15	3	[e] [f] 10	8	....	3	6	17
J. J. Weber No. 1	SE. ¼, 20	15	3	[e] 10	46	....	5	15	80
J. J. Weber No. 2	SE. ¼, 20	15	3	[e] 10	45	....	5	20	
Mr. Paten	SE. ¼, 20	15	3	[e] 12	....	[g] 16.8	4	6	10
J. L. Welter	SE. ¼, 24	15	3	8	20±	....	3	6	15
John Storm	SW. ¼, 24	15	2	[h] 12	56	....	4	8	30
G. W. Knight	SW. ¼, 24	15	2	[h] 12	40	[c] [g] 14.6	3	6	12
W. A. Clements	SW. ¼, 21	15	2	[f] 10	40 and 50	....	3	5	20
E. W. Bixson:									
Plant No. 1	SW. ¼, 30	15	3	10	[e] 86	....	3	6	27
Plant No. 2	S. ½, 29	15	3	10	[i] 75	....	4	8	

[a] Measured in September, 1913.
[b] From floor of pump house.
[c] From bottom of timbers over pit.
[d] Cased to 40 feet.
[e] No casing.
[f] Two wells, machinery shifted from well to well.
[g] Measured in August, 1913.
[h] Cased for 6 feet below pit.
[i] Cased to 45 feet.

Pumping plants in the East Sutter Basin—Continued.

Owner.	Location.			Diameter of well.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horsepower.	Area irrigated.
	Section.	Township N.	Range E.						
				Inches.	*Feet.*	*Feet.*	*Inches.*		*Acres.*
Rosenberg Bros.:									
Plant No. 1	SE. ¼, 29	15	3	*e* 12	72	....	4	10	
Plant No. 2	SE. ¼, 29	15	3	*j* 8	60	....	3	5	130
Plant No. 3	SE. ¼, 29	15	3	*e* 10	38	....	3	6	
Plant No. 4	SE. ¼, 29	15	3	*e* 10	42	....			
P. McCune	SW. ¼, 28	15	3	8	....	*c g* 18.4	2	5	10
Mrs. H. D. Littlejohn	NE. ¼, 28	15	3	*e* 8	42	*c g* 17.0	3	5	10
Jud. White	NE. ¼, 28	15	3	....	*e* 36	....	4	6	48
Judge Morrissey	Platt tract *k*			10	....	*g* 17	4	10	14
J. B. Montane	do			*l* 10	103	....	3	7½	20
F. S. Walton	do			8	125	....	2½	5	12
Phil. McNamara	do			10	157	....	4	10	30
Dave Thomas	do			10	45	....	4	6	10
Mr. Nelson	do			8	45	....	2½	5	5
F. S. Walton	do			10	80	....	3	5	12
L. A. Walton	SW. ¼, 27	15	3	12	72	....	4	7½	30
Do	SW. ¼, 27	15	3	8	95	....	2½	5	20
J. A. Ashley:									
Plant No. 1	SE. ¼, 27	15	3	*m* 12	55	....	3	5	50
Plant No. 2	SE. ¼, 27	15	3	12	50	....	3	5	
Edwin Winship	New Helvetia rancho			10	110	....	3	7½	20
A. F. Bradford	do			12	84	....	3	5	10
O. C. Powell	do			*n* 6	97	....	3	7½	20
A. C. Powell	do			*o* 6	115	....	3	7½	12
Mr. Shumach	do			10	....	....	3	5	5
J. F. Peters	do			8	....	....	3	5	24
C. P. Peters	do			10	35	*c g* 20.2	3	7½	17
John Kaas	do			10	36	(*p*)	3	7½	25
John L. Duncan	NE. ¼, 34	15	3	....	....	....	3	7½	20
E. B. Barrett	N. ½, 34	15	3	....	....	....	3	7½	20
S. Cook	NW. ¼, 34	15	3	*q* 8	40	....	3	7½	14
J. A. Riley	NW. ¼, 34	15	3	8	40	....	3	6	5
L. A. Walton	NW. ¼, 34	15	3	*r* 12	....	....	5	15	80
Frank Davis	SW. ¼, 34	15	3	8	87	....	2	5	6
J. W. Mayfield	SW. ¼, 34	15	3	8	*s* 37	....	2½	(*t*)	5
E. B. Jackson	SW. ¼, 34	15	3	....	....	....	3	5	7
F. Brandstatt:									
Plant No. 1	SW. ¼, 34	15	3	*u* 8	128	....	4	10	40
Plant No. 2	SW. ¼, 34	15	3	*e* 10	37	....	4	6	
Mrs. M. S. Smith	SE. ¼, 34	15	3	12	160	....	3	10	*v* 80
G. W. McCampbell	NW. ¼, 33	15	3	12	*w* 216	....	5	20	160
G. H. Taylor	SW. ¼, 33	15	3	12 12	40 54	....	5	15	100
Guy Walton	SW. ¼, 33	15	3	8	....	....	3	7½	....
C. K. Wood	NE. ¼, 32	15	3	*e* 10	75	....	3	7½	20
Chris. Christianson	NE. ¼, 32	15	3	10	46	....	3	7½	10
J. S. Cope	SE. ¼, 32	15	3	12	55	....	4	7½	50
L. E. Dahling	NW. ¼, 32	15	3	*e* 12	75	....	8	35	80
I. J. Trueman, jr	NW. ¼, 2	14	2	10	100+	*g* 12.5	6	12	40
Leonard Pryor	SW. ¼, 4	14	3	10	75	....	4	7½	40
C. E. Littlejohn	SW. ¼, 4	14	3	8	75	....	3	5	12
Mrs. M. S. Smith:									
"Fig orchard" plant	NE. ¼, 4	14	3	....	....	....	4	10	*x* 120
"Asparagus" plant	NE. ¼, 4	14	3	12	160	....	5	10	
R. W. Kells	SE. ¼, 4	14	3	8	75	....	3	5	40
Andrew Weiger:									
Plant No. 1	SE. ¼, 4	14	3	8	85	....	3	5	27½
Plant No. 2	SE. ¼, 4	14	3	*e* 8	30	....	3	5	

c From bottom of timbers over pit.
e No casing.
g Measured in August, 1913.
j Cased to 22 feet.
k Locations of plants and irrigated areas not accurately shown on Plate IV.
l Cased to 52 feet.
m Cased to 29 feet.
n Cased to 42 feet.
o Cased to 50 feet.
p Owner's statement 11 feet in 1911, 14 feet in 1912, 17 feet in 1913.
q Cased to 20 feet.
r Two wells.
s Cased to 24 feet.
t J. A. Riley's engine used.
u Cased to 60 feet.
v With Mrs. Smith's "Asparagus" and "Fig orchard" plants irrigates 200 acres.
w Cased to bottom.
x See Mrs. Smith's other plant.

Pumping plants in the East Sutter Basin—Continued.

Owner.	Location.			Diameter of well.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horsepower.	Area irrigated.
	Section.	Township N.	Range E.						
				Inches.	*Feet.*	*Feet.*	*Inches.*		*Acres.*
R. T. Hoon	SE. ¼, 4	14	3	8	54	....	3½	3	6
Sam Smith estate	SE. ¼, 4	14	3	8	150	....	3	5	10
Mrs. A. E. Buckingham	SE. ¼, 4	14	3	8	70	....	3	5	20
E. B. Jackson	NW. ¼, 4	14	3	....	....	....	2½	5	6
Madie P. Van Fleet	NE. ¼, 3	14	3	8	175	....	4	10	40
Richard Walton	SE. ¼, 3	14	3	8	110	....	3½	7½	20
R. M. Klingensmith	SE. ¼, 3	14	3	8	63	*g* 19±	4	7½	10
Buckingham Bros	SW. ¼, 3	14	3	8	43	....	3	5	12
Marion Gray	SW. ¼, 3	14	3	8	64	....	2½	5	25
Morrison Bros.:									
"House" plant	New Helvetia rancho			8	50	....	3	5	5
Plant No. 2	do			10	*b g* 80	20.5	4	10	15
Plant No. 3	do			8 10	70 80	....	5	15	65
J. B. Montane	do			*e* 8	175	....	2½	5	10
Burks Bros	do			8	37	....	3	7½	7
Madie P. Van Fleet	do			8	100	....	4	7½	27½
R. T. Hoon	do			8	42	....	3	6	14
Charles Beaver	do			10	60	....	3½	7½	10
Mr. Newkom	do			12	58	....	3	5	7
Berry Bros	do			10	65	....	4	10	25
J. R. Foster	do			12	....	*g y* 9.6	4	7½	25
Howard Reed	do			....	55	....	4	10	26
Mr. Newkom	do			12	70	....	3	5	5
Berry Bros	do			10	59	....	4	10	50
H. P. Lind	do			8	180	....	3	5	11
Conrad Crist	do			10	174	....	3	7½	10
James Clark	do			*e* 8	76	....	3	7½	15
C. H. Holmes	do			(*e*)	38	....	3	7½	10
F. Brandstatt	do			....	....	....	5	15	25
L. D. Braun	do			10	42	....	4	10	20
C. M. Peterson	do			10	40	....	3	7½	10
L. M. Lehner	do			12	....	....	4	10	10
C. P. Carlson	do			8	32	....	3	7½	20
E. L. Davis	do			*e* 8	32	....	3	5	17
Philip Andrews:									
Plant No. 1	do			12	51	....	3	5	[illegible]
Plant No. 2	do			10	61	....	4	15	60
Mr. Newkom	do			*u* 12	80	....	5	15	45
Isaac Drake	do			10	35	....	4	7½	20
F. J. Koch	do			8	45	....	4	7½	20
Frank Luyster	do			....	....	....	4	10	20
George Magruder	do			12	*z* 72	....	4	10	19
Henry Heidothing	do			12	....	....	4	10	50
J. J. Heidothing:									
Plant No. 1	do			8	30	*g y* 17.1	4	7½	27
Plant No. 2	do			8	70	....	3	7½	
C. C. Redman	NW. ¼, 10	14	3	*e* 12	36	....	4	10	40
H. C. Stohlman	NW. ¼, 10	14	3	*aa* 10	100	....	4	10	40
E. F. Yates	NW. ¼, 10	14	3	*bb* 8	32	....	3	6	20
T. W. Nichols	NW. ¼, 10	14	3	8	64	....	3	5	30
Charles Best	NE. ¼, 9	14	3	8	....	....	8	5	37
C. M. Spitzer	NE. ¼, 9	14	3	*cc* 8	155	....	3	7½	33
P. B. Montane	NE. ¼, 9	14	3	*dd* 8	100	....	4	10	20
Howard Reed	NE. ¼, 9	14	3	12	150	....	3	7½	45
E. B. Jackson	SW. ¼, 10	14	3	*ee* 8	136	....	3	7½	*k* 20
P. B. Montane	SW. ¼, 10	14	3	8	56	....	4	8	*k* 20
H. C. Stohlman	SE. ¼, 9	14	3	8	60	....	3	5	18
M. S. Peters	SE. ¼, 9	14	3	(*e*)	26	....	3	6	10
F. J. Koch	SE. ¼, 9	14	3	8	....	....	3	6	10
R. Keck	SE. ¼, 9	14	3	*d* 12	120	....	4	8	65
S. E. Best	NE. ¼, 16	14	3	12	63	....	4	10	60
Mr. Johnson	NW. ¼, 16	14	3	12	....	....	4	7½	20

b From floor of pump house
d Cased to 40 feet.
e No casing.
g Measured in August, 1913.
u Cased to 60 feet.
y From top of casing.
z Deeper wells at this place had so much gas that the water could not be pumped with centrifugal pump.
aa Cased to 66 feet.
bb Cased to 27½ feet.
cc Cased to 76 feet.
dd Cased to 70 feet.
ee Cased to 90 feet.

Pumping plants in the East Sutter Basin—Continued.

Owner.	Location.			Diameter of well.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horse-power.	Area irrigated.
	Section.	Township N.	Range E.						
				Inches.	*Feet.*	*Feet.*	*Inches.*		*Acres.*
C. M. Spitzer	NW. ¼, 9	14	3	*ff* 8	58	*g* 10.6	....	....	20
J. A. Littlejohn	NW. ¼, 9	14	3	8	64	....	3	5	15
H. A. Littlejohn	NW. ¼, 9	14	3	8	60	....	3	7½	30
M. S. Peters	SW. ¼,	14	3	8	*gg* 65	....	3	5	12
A. Bower	SW. ¼, 9	14	3	8	....	....	4	5	20
G. J. White	SW. ¼, 9	14	3	*i* 8	108	*g y* 10.0	3	6	10
Carl Kimmerer	SW. ¼, 9	14	3	8	....	....	3	5	20
Z. Buckingham	SW. ¼, 9	14	3	8	35	....	3	7½	18
H. A. Carpenter	SE. ¼, 8	14	3	8	88	....	3	7½	20
August Dacosse:									
Plant No. 1	SE. ¼, 8	14	3	8	65	....	4	15	15
Plant No. 2	SE. ¼, 8	14	3	10	113	....	4	15	40
W. A. Coats	SE. ¼, 8	14	3	8	40	....	3	4	10
C. S. Inglerock	SE. ¼, 8	14	3	*hh* 10	105	....	3	7½	30
J. A. Harris:									
Plant No. 1	NW. ¼, 17	14	3	10	72	....	3	7½	10
Plant No. 2	NW. ¼, 17	14	3	*e* 13	80	....	4	10	15
J. L. Kinch	NE. ¼, 18	14	3	*e* 10	40	....	3	7½	15
W. F. Kinch	NE. ¼, 18	14	3	8	38	....	2	5	4
D. C. Kinch	NE. ¼, 18	14	3	10	96	....	4	10	38
W. F. Kinch	NE. ¼, 18	14	3	10	107	....	4	10	38
Judge Mahon	NE. ¼, 18	14	3	*ee* 10	115	....	5	15	33
D. N. Richardson:									
Plant No. 1	N. ½, 19	14	3	*ff* 10	43	....	4	8	4
Plant No. 2	N. ½, 19	14	3	10	76	....	4	(*ii*)	45
W. K. Coats	NW. ¼, 32	14	3	10	68	....	3	7	7
R. Porter	E. ½, 36	14	2	10	80	....	7	12	27
F. Houss	New Helvetia rancho			*e* 12	29	*g* 20±	5	10	105
F. E. Drake	do			12	45	....	3	5	14
Andrew Smith	do			12	120	....	4	15	30
Gould Bros.	do			10	45	....	4	10	30
E. J. Ottenwalter	do			*e* 10	45	....	3	5	10
E. Guy Newman	do			*e* 10	45	....	2½	5	10
Strother Buckingham	do			8	....	....	3	5	20
Joseph Peter	NE. ¼, 15	14	3	12	45	....	4	10	15
J. H. Palmer	New Helvetia rancho			12	45	....	5	15	30
	do			....	....	*c g* 15.4	4	6	10
William Potts	N. ½, 22	14	3	*d* 8	48	....	2	6	5
	N. ½, 22	14	3	....	....	....	3	6	15
M. J. Newkom	S. ½, 27	14	3	....	100	....	4	10	20
Solomonson & Johnson:									
Plant No. 1	N. ½, 14	13	3	12	31.5	*g y* 5.3	4	8	40
Plant No. 2	N. ½, 14	13	3	12	88	....	(*f*)	(*f*)	
F. E. Willard	SW. ¼, 15	13	3	10	80	....	3	6	20
F. L. Ford	New Helvetia rancho			*e* 12	35	*c jj* 12.2	4	10	30
E. R. Edwards	do			*e* 12	42	*c jj* 11.3	5	10	24

c From bottom of timbers over pit.
d Cased to 40 feet.
e No casing.
f Two wells, machinery shifted from well to well.
g Measured in August, 1913.
i Cased to 52 feet.
ff Cased to 36 feet.
gg Cased to 54 feet.
hh 6-inch diameter 37 to 105 feet.
ii Uses engine of plant of same owner in SE. ¼ sec. 8.
jj Measured in July, 1913.

YUBA-BEAR RIVER AREA.

GENERAL CONDITIONS.

That part of the east-side plains lying east of Feather River and between Yuba and Bear rivers forms the Yuba-Bear River area (Pl. II). Wheatland (population 435), on Bear River, is the only town of importance.

The Southern Pacific Railroad crosses the area from Wheatland to Marysville. The relatively new Western Pacific and Northern Electric railroads are developing the hitherto more backward region near Feather River.

The area has suffered severely from the accumulation of mining débris. The Yuba, which formerly was a deep, clear stream, now runs in braided channels from 10 to 40 feet above its old bed. High levees confine the débris to a strip from 2 to 3 miles wide, but the formerly fertile bottom lands are buried. The entrance into Feather River is so narrow that the Yuba in flood commonly breaks its banks and overflows the low land east of the Feather.

Similarly the Bear runs in a sand-filled channel between levees. Near Wheatland, however, the flood plain is fertile and farmed to hops and alfalfa.

As the levees on the west side of the Feather are stronger than those on the east, floods are frequent along the river.

These conditions have prevented development on the most easily cultivated lands. The low plains and red lands have been farmed for grain and hay, but more intensive development is dependent on irrigation. A start has been made in the use of ground water Twenty-two irrigation plants are listed, which irrigated 607 acres in 1913, with the use of 227 horsepower.

GEOLOGY AND PHYSIOGRAPHY.

The eastern border of the area is formed by the foothills of the Sierra Nevada, against which rests a bench of rolling country underlain by older alluvium and known as the red lands. This bench is divided into two portions by the valley of Dry Creek. Westward the smooth low plains slope toward Feather River. A few rounded hills capped by older alluvium break the monotony of the low plains, and there is a slight break in them as the flood plain of Feather River is approached. This break is present also north and south of Yuba and Bear rivers but must have been much more noticeable before the silting of the river channels.

The older alluvium in some places rests on the crystalline rocks, in others on the andesite breccia. In a number of places the Ione formation crops out, surrounded by older alluvium. The older alluvium was deposited by streams similar to those of the present day on an irregular surface, the material being supplied by erosion of all the older rocks. The number and distribution of the outcrops of the Ione indicate that in general in the red lands the older alluvium is less than 50 feet thick.

In the valley of Dry Creek a thin mantle of younger alluvium covers the eroded surface of the Ione. The thickness of this mantle increases from 5 or 10 feet near the hills westward to the round hills north of Wheatland, where it is less than 100 feet.

In the low plains the younger alluvium comprises two varieties. The material in the flood plains of the river is loose and porous, being composed of clay, sand, and gravel, covered with loamy soils. It has a thickness of less than 100 feet. (See p. 158.) Separated by a small break in topography and frayed at the edges by local erosion, the low plains between the rivers are composed of younger alluvium deposited by the minor streams. The material is redder, coarser, and more cemented than the alluvium of the river bottoms. The soils are tight and in many places are underlain by a hardpan similar to that of the older alluvium. In these plains it is impossible to distinguish between the older and younger alluvium in wells. Consequently the thickness of the younger alluvium is not known.

GROUND WATER.

WATER TABLE.

Ground-water conditions are somewhat more diverse in this area than in other parts of the valley. The Ione formation lies close to the surface over the eastern portion of the area, and its thick clay beds prevent downward percolation and cause local perched water tables.

Plate IV shows contours of the water table, or upper surface of the zone of saturation, for the area underlain by younger alluvium. The water table slopes toward Feather River, like the surface but not quite so steeply. The depth to water therefore increases toward the hills. Depths of more than 25 feet are confined, however, to areas of older alluvium. In the younger alluvium of Dry Creek shallow water occurs close to the foothills. This water is held near the surface by the underlying Ione. Water in deep wells would not necessarily rise to the same level.

Between the levees of Yuba River the porous débris is saturated with water which lies close to the surface. This fact causes the peculiar westward bulge of the contour of the water table on crossing the Yuba flood plain.

WELLS IN PRE-TERTIARY ROCKS.

In the crystalline rocks of the foothills shallow dug wells obtain sufficient water for domestic use. The best wells are dug where the soil is thick or the rocks are much jointed.

The Chico sandstone is not exposed in this area, but it probably underlies the Ione in places. Water obtained at the horizon of the Chico farther south is highly mineralized. (See p. 272.)

WELLS IN TERTIARY ROCKS.

The Tertiary rocks exposed in this area include the andesite breccia and the Ione formation. These rocks overlie the Chico and the crystalline rocks of the foothills and dip gently westward beneath the valley.

The andesite breccia was formed by ash showers and mud flows from volcanoes in the Sierra Nevada. It is not continuous over the area, and the only outcrop is between Yuba River and Dry Creek. Wells near the outcrop will probably find it dry. Water is found at what is thought to be the same horizon in the area to the south. (See p. 273.)

The Ione formation consists of white and gray clays with interbedded sands. Black carbonaceous deposits occur near Lincoln, and coal has been mined at Ione. Wells in the upper part of the formation obtain water in small amounts. In the lower part of the formation and in the underlying Chico highly mineralized water is usually found.

As the Ione lies close to the surface in the red lands and in the intervening lowland of Dry Creek, it is likely to be struck in wells. The wells at the Wheatland waterworks are about 150 feet deep and obtain good water. (See analysis A24, p. 170.) A well drilled 300 feet deep, which undoubtedly penetrated the Ione, is reported to have furnished salty water and was abandoned.

In the low plains of this area deep wells will probably penetrate to the horizon of the andesite breccia. Large supplies of water should be encountered in this formation between 600 and 800 feet.

WELLS IN OLDER ALLUVIUM.

The older alluvium consists of clays, sands, and gravels of a prevailing reddish tint. In the red lands, where it forms the surface formation, it is of irregular thicknes, but the maximum is probably not over 50 feet. Throughout the red lands it will furnish only small supplies, though enough for domestic purposes in favorable localities. In the low plains it is indistinguishable from the overlying younger alluvium.

WELLS IN YOUNGER ALLUVIUM.

With the exception of the J. W. Mills plant (see table on p. 171), all the pumping plants in this area derive their water from the younger alluvium.

In the bottoms of the three rivers coarse gravels similar to those of the present streams are found in wells. The materials are soft and porous, providing a free flow of water to the wells. Casings are necessary to prevent caving.

In the interstream areas the younger alluvium was laid down largely by minor streams which dissected the older alluvium. The gravels are likely to be cemented. Water is found in the sand, and as the clays are tough and stand well, the sand may be pumped out and water drawn from the cavities thus formed.

The water is of good quality, but irrigation leads to a concentration of black alkali along the ditches. This was observed at nearly every plant in the area, but the vegetation did not seem to be affected. Treatment with gypsum would mitigate the evil and improve the tilth of the soil.

PUBLIC SUPPLIES.

Wheatland, the only considerable town in this area, has a public water supply. The waterworks are owned by the town, having been acquired by purchase from a private company in 1905. The supply is obtained from several wells in the eastern part of the town, where the surface is underlain by the younger alluvium. These wells are about 150 feet deep and probably penetrate the older alluvium. A well 300 feet deep obtained salty water and is not used. The well ordinarily used is 157 feet deep and 12 inches in diameter, and the water stands about 16 feet from the surface. The plant comprises a 3-inch Byron Jackson horizontal centrifugal pump direct connected to a 7½-horsepower Westinghouse motor. For fire service there is a 12-inch Doble 4-stage turbine centrifugal pump direct connected to a 250-horsepower vertical Westinghouse motor. In case of failure of electric power, recourse may be had to an 8 by 12 by 12 inch Blake steam pump for which a 4 by 10 foot wood-burning steam boiler is maintained. The reservoirs consist of two 30,000-gallon galvanized tanks set 37 feet above ground on a wooden tower, also a 60,000-gallon wooden tank on a steel tower 90 feet high, which gives a pressure of 38 pounds to the square inch. In addition to the regular distributing system there is a special set of fire mains. The number of consumers in 1913 was about 125.

QUALITY OF WATER.

Analyses of three samples show moderate mineral content in all and close agreement in composition. The waters have slightly less than the average amount of most constituents. They are classed as good for irrigation and for domestic use. The formation of scale in steam boilers can be prevented by proper treatment of the water, but for small installations the moderate amount of scale would not justify much expenditure for its prevention.

Chemical composition and classification of ground waters in Yuba-Bear River area.

[Analyses by S. C. Dinsmore. Parts per million except as otherwise designated. Numbers at heads of columns refer to locations so marked on Pl. IV.]

	A22	A23	A24
Silica (SiO_2)	50	62	27
Iron (Fe)	Trace.	.40	Trace.
Calcium (Ca)	30	28	32
Magnesium (Mg)	6.3	10	16
Sodium and potassium (Na+K)	[a]7.4	[a]9.3	[b]16
Carbonate radicle (CO_3)	.0	.0	.0
Bicarbonate radicle (HCO_3)	115	103	124
Sulphate radicle (SO_4)	Trace.	8.2	30
Chloride radicle (Cl)	16	25	27
Nitrate radicle (NO_3)	Trace.	4.4	1.4
Total dissolved solids	153	206	208
Total hardness as $CaCO_3$ [a]	101	111	146
Scale-forming constituents [a]	150	160	150
Foaming constituents [a]	20	25	43
Alkali coefficient (inches) [c]	130	82	76
Classification:			
Domestic use	Good.	Good.	Good.
Boiler use	Fair.	Fair.	Fair.
Irrigation use	Good.	Good.	Good.
Mineral content	Moderate.	Moderate.	Moderate.
Date of collection (1913)	Aug. 9	Aug. 9	

[a] Calculated.
[b] Na=9.7; K=6.3 parts per million.
[c] Depth in inches of water which on evaporation would yield sufficient alkali to render a 4-foot depth of soil injurious to the most sensitive crops.

A22. Drilled well (225 feet deep, 8 inches in diameter) at pumping plant No. 1 of J. M. Henderson near Harvard Station, Arboga.
A23. Bored well (67 feet deep, 8 inches in diameter) at pumping plant of Meek & Perry (NE. ¼ sec. 10, T. 14 N., R. 4 E.), near Ostrom.
A24. City supply (from shallow wells about 150 feet deep), Wheatland.

PUMPING PLANTS.

Pumping plants in the Yuba-Bear River area.

Owner.	Location.			Diameter of well.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horsepower.	Area irrigated.
	Section.	Township N.	Range E.						
				Inches.	*Feet.*	*Feet.*	*Inches.*		*Acres.*
Jason Jones	SW. ¼, 18	15	5	12	149	[a] [b] 24.3	2	6	4
J. W. Mills	22	15	4	12	108	[a] [b] 21.0	4	25	30
Erhman Olive Co	NE. ¼, 3	14	4	[c] 6 by 8	([d])	....	3½	17	25
Meek & Perry	NE. ¼, 10	14	4	[e] 10	67	....	4	20	100
J. E. Casey:									
Plant No. 1	SW. ¼, 10	14	4	8	....	[a] [f] 15.5	4	7½	20
Plant No. 2	SW. ¼, 10	14	4	8 8	67 40	[a] [g] 6.7	5	15	40
John Morrison	N. ½, 15	14	4	10	46	[a] [b] 15.1	3	10	5
David Bahrs	SW. ¼, 5	14	4	[c] 5	[h] 20	[a] [b] 16.5	3	4	6
J. W. Youngren	SW. ¼, 8	14	4	8	210	....	5	10	20
J. M. Henderson:									
Plant No. 1	New Helvetia rancho			8	225	....	5	15	7
Plant No. 2 [i]	do			....	....	....	....	....	....
Mr. Strom	NW. ¼, 19	14	4	12	135	[a] [b] 11.5	3	5	8
A. Erickson	NE. ¼, 24	14	4	8	197	....	4	7½	40
I. Erickson	New Helvetia rancho			8	175	....	4	10	10
E. Hallner	do			8	137	....	5	7½	40
O. V. Hansen	NW. ¼, 19	14	4	12	162	[a] [b] 12.5	3	5	....
E. Mejia	SW. ¼, 34	14	4	6	....	....	2½	5	100(?)
J. W. Dickinson	SE. ¼, 33	14	4	6	21	....	3	5	20
....	SW. ¼, 28	15	5	[j] 12	....	[b] [k] 40.4	1½	8	3
G. X. Fleming et al.:									
Plant No. 1	S. ½, 24	14	4	12	140	....	5	15	80
Plant No. 2	NE. ¼, 25	14	4	8	210	....	3	7½	
A. G. Oakley	Johnson rancho			8	....	....	4	7½	7½
H. W. Luchensmeyer	do			[l] 10	192	[k] 5.5	4	7½	30

[a] Measured in August, 1913.
[b] From top of pit.
[c] Feet.
[d] Dug well is 18 feet deep. Uncased bored well in center furnished most of the water.
[e] Cased for 10 feet below pit. For analysis see A23, p. 170.
[f] 12.0 feet in March, 1912; owner's measurement.
[g] From top of casing.
[h] Uncased bored well in center to depth of 75 feet.
[i] Approximately same as plant No. 1.
[j] In bottom of circular pit 4 feet diameter, 40 feet deep.
[k] Measured in July, 1913.
[l] Cased with screw casing; no perforations to 70 feet.

BEAR-AMERICAN RIVER AREA.

GENERAL CONDITIONS.

The Bear-American River area is bounded on the north by Bear River, on the south by American River, on the west by Feather and Sacramento rivers, and on the east by the foothills of the Sierra Nevada (Pl. II). It is traversed by the main lines of the Southern Pacific and Western Pacific railroads, by a branch line of the Southern Pacific leading northward from Roseville through Lincoln, and by the Northern Electric. The principal towns are Roseville (population 4,477) and Lincoln (population 1,325). The area lies just north of the city of Sacramento, to which it is tributary. About 4,000 acres, mostly in oranges, olives, and deciduous fruits, was irrigated in 1912 near Fair Oaks and Orangevale by surface water.[4] In 1914 there were

[4] Adams, Frank, op. cit., p. 162.

in this area 76 pumping plants used for irrigation, and the total area irrigated with ground water was 1,025 acres. Most of the development is in the southern part, where there are numerous small irrigated tracts. Considerable additional irrigation is possible by pumping from wells.

GEOLOGY AND PHYSIOGRAPHY.

The part of the Sierra Nevada adjacent to this area consists chiefly of granite and other crystalline rocks. Along the border of the valley the crystalline rock is in places overlain by the Ione formation, which in turn is overlain by andesite breccia. Large outcrops of these rocks occur between Roseville and Lincoln, in an isolated tract north and west of Lincoln, and in a tract several miles north-northeast of Lincoln. (See Pl. III.)

In this area separation of the younger and older alluvium must be rather arbitrary. The red lands, underlain by older alluvium, increase in width toward the south until south of Roseville and Riego they extend from the foothills to the flood basin.

Feather River discharges into the Sacramento some distance below the mouth of Bear River. Both the Feather and the Sacramento have developed prominent natural levees, which stand above the level of the flood basins on either side and form a strip of agricultural land that is known as river lands. In the southwestern part of the area, occupying the angle between Sacramento River and American River, is the American Basin, which receives some of the flood water of these two streams. (See p. 42.)

The red lands are gently undulating and merge imperceptibly with the low plains. The older alluvium, which underlies the red lands, consists largely of undecomposed particles derived from the granite of the Sierra Nevada. The gravels are in most places cemented with calcium carbonate, forming hardpan, which is common throughout this part of the area. It is covered with a red or brownish-red soil, and in the red lands there are large areas of "hog wallow" land (Pl. VIII, *B*, p. 13).

GROUND WATER.

WATER TABLE.

The slope of the water table is westward from the higher land toward Feather River and American Basin (Pl. IV). From Feather and Sacramento rivers, however, the water table slopes toward American Basin in the narrow strip of river land. Over most of American Basin, where the depth to water varies from practically nothing to 10 feet, the water table is very flat and the ground water must be virtually stagnant.

East of Lincoln, where the younger alluvium rests directly on the crystalline rocks, water is found at the contact and there is no continuous body of ground water. In the red lands the depth to water depends on the presence of pervious and impervious beds and is irregular. There are, however, large areas where the depth to water is greater than 25 feet. Near Fairoaks and Orangevale it is in places as much as 60 feet.

WELLS IN THE CRYSTALLINE ROCKS.

The residual soils and jointed upper parts of the crystalline rocks contain water which may be obtained by dug wells in sufficient quantities for stock and domestic purposes.

WELLS IN IONE AND CHICO FORMATIONS.

The Ione formation, consisting of white or light-gray clays, sands, and tuffs, overlies the Chico formation, which consists of gray or brown marine sandstones. Both formations crop out on the border of the valley and dip gently westward beneath the andesite breccia. The most notable well in these formations, the Whitney well (p. 273), obtained flowing but salty water (for analysis see A25, p. 176). E. A. Boyden, 2 miles west of Lincoln, put down a well 600 feet deep from which he obtained flowing water with some gas. The water was hard and in small amount (see A26, p. 176). Only 100 feet from the well is his pumping plant, which obtains a fair supply from two pits 20 feet deep and a well 350 feet deep (see A27, p. 176).

WELLS IN ANDESITE BRECCIA.

The andesite breccia near Lincoln and for several miles to the south is a coarse volcanic conglomerate from 150 to 225 feet thick. In its outcrops it is usually dry, but underground it should be a good water bearer. The relatively large supplies obtained by drilling to the horizon supposed to be that of this formation from Riego northward to Bear River are discussed on pages 269–276.

WELLS IN OLDER ALLUVIUM.

The older alluvium occupies large areas between Bear and American rivers. Success in growing oranges and olives at Fairoaks and Orangevale (see Pl. V, *B*, p. 12) with surface water has led to an increasing number of attempts to obtain water in the older alluvium. In Orangevale the older alluvium is thin and only a few house wells obtain water in it. Some of the wells seem to penetrate the andesite breccia, where they obtain water, as shown in the following logs:

Log of well of Thomas Tarnbull, Orangevale.

[Drilled by Folsom Deep Well Drilling Co.; water struck at 126 feet rose within 46 feet of the surface.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	21	21	Lava ash, soft and plastic	5	91
Hardpan or heavy clay	35	56	Gravel, no water	5	96
Sand	7	63	Lava ash	9	105
Gravel, small amount of water	18	81	Conglomerate, lava pebbles	42	147
"Sandstone"	5	86			

Log of well of Vey Cramer, Orangevale.

[Drilled by Folsom Deep Well Drilling Co.; water struck at 193 feet rose within 25 feet of the surface; yield in test, 409 gallons a minute.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil and clay	30	30	Clay	12	96
"Sandstone"	8	38	Lava cobbles	72	168
Sand and clay mixed	30	68	Loose gravel	25	193
Coarse gravel, water	16	84			

Near Roseville, in the NW. ¼ sec. 15, T. 11 N., R. 5 E., A. E. Zonneville put down a well in 1913. (See Pl. XV.) The well is 12 inches in diameter and 194 feet deep. Water-bearing sand was found at 48 feet, and fine gravel at 190 feet. The water stands at 16 feet from the surface, and the well will support a 4-inch centrifugal pump.

At a point even closer to the edge of the valley, in the NE. ¼ sec. 33, T. 11 N., R. 6 E., W. J. Kaseberg has two wells 8 inches in diameter, 120 and 210 feet deep, that supply sufficient water for windmills. The fact that these wells were both bored is a good indication that they are wholly in the older alluvium and do not penetrate the andesite breccia.

On the lower parts of the red lands successful wells are common. (See data on Morehead plant and the numerous plants on the Del Paso grant, pp. 176–177.)

WELLS IN YOUNGER ALLUVIUM.

Coarse gravel or sand is commonly found within 150 feet of the surface in all the area of the low plain north of Riego. Numerous pumping plants have been installed. The clays are tough and stand well, so that casings are almost unnecessary and wells can be cheaply constructed. In American Basin the materials near the surface are fine grained, and shallow wells are likely to have a low yield. The deep wells of the Natomas Co. show that the whole area is underlain, at a depth of about 800 feet, by good water-bearing beds which yield water of good quality, though it may be flowing and gaseous.

QUALITY OF WATER.

The seven analyses in the table below show a general agreement in quality of the waters examined. Some have more dissolved mineral matter than others, but the differences do not affect classification of the waters for irrigation or for domestic use. They are all classed as good. All contain enough scale-forming constituents to make it necessary to classify them as only fair for boiler use, but the scale-forming material can be removed by any of the standard methods of treatment.

The two analyses of deep-well waters from the eastern part of the area given on page 176 indicate that these waters are unfit for almost any use. They contain excessive amounts of calcium and sodium and of sulphate and chloride. The assay, A27, represents a group of wells, one 350 feet and two 20 feet deep, about 100 feet from A26. The water is like that from nearly all the wells of moderate depth in the valley and in no way resembles the water from the two wells 600 and 1,155 feet deep.

Chemical composition and classification of ground water in Bear-American River area.

[Analyses by S. C. Dinsmore. Parts per million except as otherwise designated. Numbers at heads of columns refer to locations so marked on Pl. IV.]

	A28	A29	A30	A31	A32	A33	A34
Silica (SiO_2)	26	43	51	50	69	74	67
Iron (Fe)	Trace.	.30	Trace.	Trace.	.30	.10	Trace.
Calcium (Ca)	34	38	40	27	36	23	30
Magnesium (Mg)	23	8.3	13	16	21	2.1	13
Sodium and potassium (Na+K)[a]	21	19	5.3	5.5	37	45	19
Carbonate radicle (CO_3)	0	0	0	0	0	0	0
Bicarbonate radicle (HCO_3)	236	173	165	129	121	148	178
Sulphate radicle (SO_4)	6.1	Trace.	2.5	8.6	27	10	2.0
Chloride radicle (Cl)	18	20	15	18	85	23	13
Nitrate radicle (NO_3)	.00	.00	7.0	6.0	11	.00	3.0
Total dissolved solids	255	229	226	200	359	243	236
Total hardness as $CaCO_3$[a]	179	129	153	133	176	66	128
Scale-forming constituents[a]	160	170	190	160	210	140	180
Foaming constituents[a]	57	51	14	15	100	120	51
Alkali coefficient (inches)[b]	52	52	140	110	24	20	47
Classification:							
Domestic use	Good.	Good.	Good.	Good.	Good.	Good.	Good.
Boiler use	Fair.	Fair.	Fair.	Fair.	Fair.	Fair.	Fair.
Irrigation use	Good.	Good.	Good.	Good.	Good.	Good.	Good.
Mineral content	Moderate.	Moderate.	Moderate.	Moderate.	Moderate.	Moderate.	Moderate,
Date of collection	July 15, 1913.	July 15, 1913.	July 19, 1913.	July 21, 1913.	Sept. 7, 1912.		

[a] Calculated.
[b] Depth in inches of water which on evaporation would yield sufficient alkali to render a 4-foot depth of soil injurious to the most sensitive crops.

A28. Well about 20 feet deep, 4 inches in diameter, owned by Mr. Schnall, 1½ miles east of Nicolaus (SE. ¼ sec. 5, T. 12 N., R. 4 E.).
A29. Well 125 feet deep, 8 inches in diameter, at pumping plant of John Borgman, Nicolaus (NW. ¼ sec. 24, T. 12 N., R. 3 E.).
A30. Well 265 feet deep, 8 inches in diameter, at pumping plant of F. W. Algeo, Pleasant Grove (NW. ¼ sec. 33, T. 12 N., R. 4 E.).
A31. Well (owner and depth unknown), in NW. ¼ sec. 11, T. 12 N., R. 5 E.
A32. Dug well, 30 feet deep, of Gladding-McBean Co., Lincoln.
A33. Artesian well (depth 858 feet) of the Natomas Consolidated of California, Riego (SE. ¼ sec. 35, T. 11 N., R. 4 E.).
A34. Well 120 feet deep, 8 inches in diameter, of W. J. Kaseberg, 1 mile northwest of Roseville (NW. ¼ sec. 34, T. 11 N., R. 6 E.).

Chemical composition and classification of water from wells near Lincoln, Bear-American River area.

[Analyses by S. C. Dinsmore; assay by G. H. P. Lichthardt. Parts per million except as otherwise designated. Numbers at heads of columns refer to locations so marked on Pl. IV.]

	Analyses.		Assay.
	A25	A26	A27
Silica (SiO_2)	24	8.0	
Iron (Fe)	3.5	Trace.	
Calcium (Ca)	385	267	
Magnesium (Mg)	9.8	46	
Sodium and potassium (Na+K)[a]	[b] 1,855	2,499	
Carbonate radicle (CO_3)	11	14	0
Bicarbonate radicle (HCO_3)	36	112	156
Sulphate radicle (SO_4)	693	728	Trace.
Chloride radicle (Cl)	3,180	3,834	10
Nitrate radicle (NO_3)	.00	.00	
Total dissolved solids	6,653	7,613	[a] 190
Total hardness as $CaCO_3$[a]	1,000	856	
Scale-forming constituents [a]	1,290	870	
Foaming constituents [a]	5,000	6,800	
Alkali coefficient (inches)[c]	.6	.5	
Classification:			
Domestic use	Unfit.	Unfit.	Fair.
Boiler use	Unfit.	Unfit.	
Irrigation use	Bad.	Bad.	
Mineral content	Very high.	Very high.	Moderate.
Date of collection	Sept. 11, 1912.	July 22, 1913.	July 22, 1913

[a] Calculated.
[b] Determined. Na=1,825; K= 30 parts per million.
[c] Depth in inches of water which on evaporation would yield sufficient alkali to render a 4-foot depth of soil injurious to the most sensitive crops.

A25. Artesian well (1,155 feet deep) of J. Parker Whitney, NW. ¼ sec. 4, T. 11 N., R. 6 E.
A26. Well (600 feet deep) of E. A. Boyden, NE. ¼ sec. 21, T. 12 N., R. 6 E.
A27. Composite of three wells (two 20 feet deep and one 350 feet deep, 8 inches in diameter) at pumping plant of E. A. Boyden, NE. ¼ sec. 21, T. 12 N., R 6 E.

PUMPING PLANTS.

Pumping plants in the Bear-American River area.

Owner.	Location.			Diameter of well.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horsepower.	Area irrigated.
	Section.	Township N.	Range E.						
				Inches.	*Feet.*	*Feet.*	*Inches.*		*Acres.*
G. W. Bray	SE. ¼, 28	13	4	8	60	15.0	4	8	3½
Dooley Bros	SE. ¼, 33	13	4	8	60	15	4	10	10
John Borgman	NW. ¼, 24	12	3	[a] 8	125		6		40
A. T. Morehead	SE. ¼, 2	12	4	[b] 12	210		4	8	15
William Yuhre	SE. ¼, 32	12	4	12	140		6	12	15
F. W. Algeo	NE. ¼, 33	12	4	8	265		5	15	14
J. R. Catlett	S. ½, 33	12	4	5	26	10.0	2	5 (?)	5
	NW. ¼, 34	12	4			12.0	5	10	10
F. B. Drennon	SW. ¼, 36	12	4	12	190		4	9	5
E. A. Boyden:									
Plant No. 1	SE. ¼, 17	12	6	8	600+	Flows.	([c])		
Plant No. 2	SE. ¼, 17	12	6	[d] 8	350	11.0	4	12	20
David McCarthey	19	12	6	5 by 5 feet.	46	11.6	3		Very small.
G. H. Trevathan	SW. ¼, 1	11	4	10	55	13.5	3	6	5
George Howsley	NW. ¼, 3	11	4	[e] [f] 12	207		5	15	18
E. J. Baker	SW. ¼, 3	11	4	[b] 12	216	10.6	3	6	7
Thomas Howsley	SW. ¼, 3	11	4	12	159	12.3	4	6	5
	NW. ¼, 12	11	4	([f])			2	3	4½

[a] For analysis of water, see A29, p. 175.
[b] 6 inches in diameter from 40 to 210 feet.
[c] Would not supply 4-inch centrifugal pump. For analysis, see A26, above.
[d] Dug well 8 by 10 feet, 20 feet deep, into which drilled well discharges, and this pit discharges through tunnel to second dug well of same size in which pump is set. For analysis, see A27, above.
[e] Replaced by new well, 1913. (See log, p. 275.)
[f] No casing.

Pumping plants in the Bear-American River area—Continued.

Owner.	Location.			Diameter of well.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horsepower.	Area irrigated.
	Section.	Township N.	Range E.						
Arcade quadrangle.				*Inches.*	*Feet.*	*Feet.*	*Inches.*		*Acres.*
David Compton				[g] 8	94	10	2	4	3
L. S. Deuront	7	10	5	(f)	80	15	2½	5	10
E. S. Robinson	7	10	5	(f)	50	10.2	2	4	10
William Writt				[h] 8	88	16	3	6	10
W. M. Carter				(f)	87	12	2½	4	12
C. Waite				(f)	38	11	3	9	12
P. Scheidel	11 miles north of Sacramento.			(f)	30	12	2	4	2
B. Vervoy				[h] 10	75	16.4	3	4	None.
V. F. Stranch				5	30	9	2	4	2½
L. Johnson				[i] 8	80	16	3	6	10
C. T. Horgan				[i] 6	148	5	4	8	7
E. Davidson				[j] 8	97	14.2	3	6	8
David Smith				[h] 12	110	10	4	12	20
Do				[i] 8	43½	10	2	13	2
George Jefferson				[h] 6	64	10	3	4	5
T. E. Abbey				[k] 6	53	10	2½	4	3
A. M. Whipple				(f)	80	16	2½	4	5
A. J. Dentry				[h] 6	55	14	2½	2	5
H. Sadler				[k] 6	57	14.8	2	8	12
John Hoefling				[l] 12	115	15	3½	15	......
J. A. Reader				[k] 8	90	12	6	8	45
J. M. Green				[h] 8	80	10	5	8	......
J. A. Reader				(f)	45	10	3	8	25
Acme Realty Co				10	47	8	3	6	4
—— Bright				6	43	18	2	1½	2
H. Kittinger	6 miles north of Sacramento.			8	42	20	2½	6	4
C. L. Rood				[i] 6	26	10.2	1½	1½	2
J. Z. Strauch	6 miles north of Sacramento.			[h] 6	86	17.2	2	2	2
H. E. Manning				[l] 8	78	13	2	4	10
Fred Tonny				[h] 6	67	18.8	2	2½	5
Lathrop J. Wortz				[i] 8	81	16	3	4	5
F. J. Newyin	Del Paso Heights			(f)	58	14	2	5	5
F. R. Woods				[h] 8	86	15	2	4	5
H. Smith				[i] 6	94	17.9	3	5	5
A. Tonny				[k] 8	98	18.2	3	8	5
George Meister				[j] 12	152	17.3	2½	8	5
George Littlefield				[h] 8	100	14.3	4	9	7
H. A. Woodward				[h] 8	45	13	2	2	1
H. Skinney				[i] 8	88	10.4	2	3	5
M. Kensey				[k] 10	98	10.2	3	4	8
Tom Oats				[h] 8	102	9.7	3	6	10
John Wesley				[i] 8	80	9.2	1½	2	2
H. Lusk				[h] 8	87	10	2	4	6
Charles Tutts				[k] 8	94	10.7	2	3	5
M. Brook				(f)	157	12	3	5	10
George Gorman				[g] 10	170	13.2	3	7½	10
Antelope quadrangle.									
Antelope Town				......	......	100–125	......	......	None.
Walter Ransom	4 miles northeast of Sacramento.			[i] 8	42	8	4	8	12
J. M. Oxley	do			[h] 12	107	42	4	20	60
E. D. Longstretch				[h] 10	126	48	4½	15	40
E. Eckrem				[h] 8	117	40	2½	5	5
L. H. Sanborn	3 miles north of Sacramento.			[k] 8	76.5	44	3½	15	Not in use.
F. M. Washburn				[m] 8	110	40	2	5	2
M. Cross				[h] 12	75	35	3	10	15
I. M. Dawson				[h] 8	80	37	2½	7½	10
E. M. Bradley				[k] 12	63	33	2½	10	26
Brighton quadrangle.									
Sacramento City				[n] 4	125	8	3	15	......
E. C. Horst Co				[j] 12	94	20.2	6	25	75
Do				[h] 12	115	20	6	25	75
Do				[l] 12	157	20	6	25	75
Do				[h] 12	90	20	6	25	75
Mills quadrangle.									
P. F. Engberg	5 miles east of Sacramento.			[h] 8	108	52	2½	6	10
E. Day				[h] 8	1,011	48	3	8	25

[f] No casing.
[g] Cased to 70 feet.
[h] Cased to 40 feet.
[i] Cased to 20 feet.
[j] Cased to 60 feet.
[k] Cased to 30 feet.
[l] Cased to 50 feet.
[m] Cased to 80 feet.
[n] Cased to 100 feet.

CORNING AREA.

GENERAL CONDITIONS.

The country west of Sacramento River between Thomas Creek and the Tehama-Glenn county line is discussed as the Corning area. This area is very similar to the western part of the Tehama-Red Bluff area, but its ground-water development is more advanced. The town of Corning is the trade and social center for a large plains country to the west and the adjacent subdivided lands or colonies. It is a growing and prosperous place to which the census of 1920 gave 1,449 inhabitants.

Old Richfield lies west of Corning, and more of the colony is west of the area shown on the Sacramento Valley map. Small tracts aggregating 1,700 acres are irrigated by a ditch from Thomas Creek.[5]

The Maywood colony, which lies around Corning, in 1913 contained 72 pumping plants, owned by 60 different persons or companies, irrigating 5 acres or more each, or 1,013 acres in all. The new Richfield colony comprises 5,000 acres 3 miles north of Corning and in 1913 had 9 plants irrigating 767 acres. The total acreage irrigated from wells in the Corning area is 1,786, with a total nominal installed horsepower of 556. The average area irrigated per horsepower is 3.2 acres.

The Maywood colony was begun with the assumption that dry-farming methods would be successful in growing deciduous fruits and olives. The margin of profit on even the best lands is small, and it is now pretty generally recognized that irrigation is necessary to obtain a paying yield from year to year. With the recent rise in the value of olives resulting from the discovery of methods for pickling and canning the ripe fruit, the courage and persistence of the colonists is likely to be rewarded. The colony contains many mature olive orchards which need only pruning, some of them grafting also, and irrigation to produce good crops. The location of a pickling plant in Corning by the H. J. Heinz Co. and a rather heavy investment by that company in olive land assure a market for the fruit, and the company's improved methods are stimulating the whole orchard industry.

GEOLOGY AND PHYSIOGRAPHY.

The Corning area lies almost wholly in the red lands, which here, as farther north, are separated from the river bottoms by a low bluff except where streams come into the river from the west. Sacramento River hugs the western bluffs, and the bottoms on the west side are narrower and more subject to flooding than those on the east side.

[5] Adams, Frank, California Conservation Comm. Rept., 1912, p. 146.

The red lands are more dissected than those in the Red Bluff-Tehama area. Thomas Creek has cut a broad flat-bottomed valley. Rice Creek and other minor streams have cut wide valleys which coalesce to form broad swales with a darker and more fertile soil than the hill areas of older alluvium.[6]

The successful dry-farmed orchards are on these lower lands. On this account and because of lower lifts and cheaper wells, the swales have been the site of the principal development of ground water.

West of the area mapped tilted Cretaceous rocks extend to the foot of the Klamath Mountains. On the beveled edges of these rocks rest the older alluvium and underlying Tertiary sediments.

The ground-water conditions in this region are adequately treated in the discussion of the Red Bluff-Tehama area (p. 134).

GROUND WATER.

WATER TABLE.

Both the older and younger alluvium are saturated with water, though parts of the older alluvium are so cemented as to seem almost dry. The water table follows the form of the land and is higher in the hill areas than in the swales. It slopes toward the river, and in the river bottoms it slopes also downstream.

The depth to water is more than 25 feet in the western hill area except in stream channels, where shallow water is found for long distances. Along Thomas Creek and in the swales around Corning and Kirkwood water varies from 6 to 20 feet. In the hills east of Corning and Kirkwood the water is again deep, from 25 to 60 feet below the surface. These relations are brought out in Plate IV, where the contours show the position of the water above sea level and lines inclose areas of over 25 feet to water.

Pumping in the lower areas reduced the water level 3 to 6 feet in the dry seasons of 1912 and 1913. Rapid recovery may be expected in wet winters in these beds from the direct rainfall and from the minor streams, which often flow all winter. Seasonal fluctuations in the hill area have not been closely observed, but there is reason to believe that the fluctuations are similar to those of the low lands. C. F. Foster's well, in the hills east of Corning, is known to show a winter rise of about 12 feet, beginning in September before the rains and having a maximum about February. The more thoroughly cemented older alluvium that forms the hill areas has a smaller percentage of pore space to hold water and numerous impervious layers. In consequence when the water table in this material is once lowered by pumping recovery will probably be less rapid. However, it absorbs rain rapidly, and after a heavy rain the soil above the

[6] Holmes, L. C., and Eckman, E. C., Soil survey of the Red Bluff area, Calif.: U. S. Dept. Agr. Bur Soils Field Operations, 1910, p. 1615, 1912.

surface hardpan is oversaturated. For several days water comes to the surface at the outcrops of the hardpan and feeds the temporary streams, which run bank full of clear water. How much water reaches the water table by soaking through the hardpan it is impossible to say, but the cultivation of these lands should tend to increase the amount. There are in this area a number of local perched water tables, due to the saturation of a pervious bed above the main water table.

WELLS IN OLDER ALLUVIUM.

The hilly areas of older alluvium have been avoided by orchardists because of the less tillable soil and the greater depth to water. The plants of C. F. Foster and W. N. Woodson are the only ones strictly within the area of the older alluvium. The primary lift in both is about 60 feet, and in view of the marked development in southern California with greater lifts, it seems probable that other plants will follow these pioneer projects.

Many wells on the edge of the hills and the deeper wells generally indicate that water can be found in the first 400 feet. Further drilling will encounter first dry beds and then water-bearing beds that have not yet been tested for capacity (p. 255).

WELLS IN YOUNGER ALLUVIUM.

The younger alluvium includes the soft sands, clays, and gravels of the river bottoms and the deposits of tributary streams in the valleys and swales of the plains area.

The plant of Beresford Bros. is the only one in the area located in the river bottom lands. It lies in a slough or depression which is an abandoned channel of the river. The well is curbed with plank and is dug 5 feet wide, 36 feet long, and 6 feet deep. It supplies a 4-inch horizontal centrifugal pump. No attempt has been made to develop large supplies in the river bottoms, but with the methods outlined on pages 111–115 for deposits of this character wells of large yield can be obtained.

The wells in the valleys of the plains area are in two groups—those of the Maywood colony and those of the Richfield Land Co.

In the Maywood colony land is held in small plots, 10 acres being a common size. The first wells were put down to obtain water for house use, and these were later developed into irrigation plants. Compared to the more cemented beds in the hills, the younger alluvium is soft. Augers are commonly used for boring wells, though difficulties with cemented gravels and thin layers of hardpan are not unusual. Water is drawn largely from the gravels, which are derived from the erosion of the older alluvium. The gravel beds are rarely clean, the interstices being filled with clay. On this account few of the wells have a large yield.

The deeper wells pass into the harder material of the older alluvium, which from the log of the McClelland well (p. 256), is judged to be about 400 feet thick. The depth of the younger alluvium is difficult to estimate. In the flat around Corning soft material extends to a depth of about 100 feet. On the assumption that all the softer material is younger alluvium this would be a maximum thickness. In the Richfield tract it is probably not over 40 feet thick. The thickness and volume of the younger alluvium are important, because the material is relatively permeable by water, whereas the older alluvium is not. This relation is brought out in the apparent damming of the ground water in the narrow valley southeast of Corning and along Rice Creek near Kirkwood. In both these places water is from 5 to 7 feet below the surface during most of the year. On this account the pumping lift at the plants of Messrs. Pugh, Carr, Brubaker, and Measer is less than at plants west of Corning.

The water of the shallow younger alluvium does not communicate rapidly with water in the older alluvium. This is brought out in wells of the Richfield Land Co., where it is possible to pump out the dug wells without affecting the level of water in the drilled wells, which draw from lower beds only.

Small heads of water are of value in this locality for three reasons. First, orchards can be irrigated with a small head, because the time of application is not so short as in field crops; second, the soil is rather dense and "runs together" when wet, making small, frequent applications effective; third, the ground water is close to the surface and there is not much soil to wet. These reasons, with small land divisions, have led to the installation of smaller plants than is customary in the Sacramento Valley for commercial irrigation.

The Richfield Land Co. has put down a number of wells and installed plants for the eventual irrigation of 5,000 acres. The plan is one common in southern California. The land is being sold in small blocks, to be irrigated from a coordinated system owned by a mutual water company, one share of stock being sold with each acre of land. Information regarding the company's operations was freely furnished by Mr. J. B. Knight, chief engineer, at the time the colony was visited.

Eight pumping plants have been installed, drawing water from both dug and drilled wells. The plants are in the lowlands along Thomas Creek, and the upper beds penetrated by the wells belong to the younger alluvium. It is impossible to draw a sharp dividing line between the younger material and the older alluvium below, but there is a notable increase in hardness with increasing depth. The dug wells, which do not exceed 20 feet in depth, have a slightly higher water level than some of the deeper wells, especially in the winter. This would indicate that the younger and more permeable upper beds absorb the local rainfall and are influenced by the flow of Thomas Creek, whereas the lower material belonging to the older alluvium derives its water from points farther west.

A large number of wells have been bored and drilled, the deepest being No. 10, which is 524 feet deep. The log of this well is given on page 256, where it is discussed in comparison with the near-by McClelland well. Dry beds were found at the lower depths, and on the completion of the well the water stood at 35 feet from the surface.

RECOMMENDATIONS.

The Corning district is fortunate in having begun the use of ground water in an economical manner, which should lead to many further economies. The common practice of providing an elevated tank and using the irrigation plant to supply domestic water is to be commended; but care should be taken to prevent contamination of the water. A concrete pump pit and a heavy well casing for several feet below ground-water level should be sufficient protection. Many of the gravel lenses that occur throughout the area are inclosed in impervious clay and are thus practically pipe lines through the ground. If a cesspool is drained into such a gravel bed, it may easily contaminate a heavily pumped well some distance away. On this account septic tanks should be substituted for cesspools.

For shallow wells in the younger alluvium auger rigs can do satisfactory work. The casings heretofore used have been too light to resist buckling in passing cemented gravel. A larger number of perforations than is now the practice would also increase the efficiency of wells. As the water-bearing gravels are on the whole coarse, the perforations can in many places be made larger than is now customary without damage. (See p. 115.)

PUBLIC SUPPLIES.

Within this area only Corning and Richfield have public supplies. The Richfield plant belongs to the company that is developing the colony and is described in the notes on pumping plants.

Corning has a municipally owned plant, built in the summer and fall of 1911, at the same time that a sewer system and septic tank were installed.

The plant consists of a neat building and a 16 by 28 foot cement pit 9 feet deep. The wells are three in number; two, 20 and 40 feet from the pump house, are 190 and 320 feet deep, respectively. The third well, 200 feet west of the others, is 210 feet deep and now yields only 250 gallons a minute. All the wells are 10 inches in diameter and are cased with double slip-joint casing. The pumping equipment consists of a service unit that includes a 6-inch 2-stage Alberger turbine pump direct-connected to a 5-horsepower General Electric motor and having a rated capacity of 600 gallons a minute. In the same pit is a fire unit consisting of an 8-inch 3-stage Alberger turbine pump direct-connected to a 100-horsepower motor and having a capacity of 800 gallons a minute against a pressure of 125 pounds to the square inch. The reservoir is a steel kettle-bottomed tank holding 100,000 gallons. Its height is 118 feet to the top of the tank, giving a pressure of 50 pounds to the square inch when the tank is full.

In November, 1913, there were 328 connections and 340 consumers. The charge was $1.50 a month for a house and grounds up to half an acre. When water is used for irrigation alone the charge is $2.50 per half acre per month.

A water sample was obtained from the plant in November, 1913. The analysis (A35) is shown in the table below.

Information was furnished by the town clerk and superintendent of the plant.

QUALITY OF WATER.

The analysis and assay given below show that the waters contain less mineral matter than the average throughout the valley. The composition of the dissolved mineral matter makes them suitable for irrigation and domestic use, and although A36 is classed as only fair for boiler use, it is barely over the line from being classed as good.

Chemical composition and classification of ground water in Corning area.

[Analysis by S. C. Dinsmore; assay by G. H. P. Lichthardt. Parts per million except as otherwise designated. Numbers at heads of columns refer to locations so marked on Pl. IV.]

	Analysis (A35).	Assay (A36).
Silica (SiO_2)	26	
Iron (Fe)	Trace.	....
Calcium (Ca)	16	....
Magnesium (Mg)	11	....
Sodium (Na)	9.6	(a)
Potassium (K)	3.3	....
Carbonate radicle (CO_3)	.0	0
Bicarbonate radicle (HCO_3)	87	165
Sulphate radicle (SO_4)	14	6
Chloride radicle (Cl)	8.0	4
Nitrate radicle (NO_3)	.00	....
Total dissolved solids	145	[b] 200
Total hardness as $CaCO_3$	[b] 85	150
Scale-forming constituents [b]	92	190
Foaming constituents [b]	35	(a)
Alkali coefficient (inches) [c]	150	(d)
Classification:		
Domestic use	Good.	Good.
Boiler use	Good.	Fair.
Irrigation use	Good.	Good.
Mineral content	Low.	Moderate.
Date of collection (1913)	Nov. 17	Nov. 22

[a] Low. (See p. 96.)
[b] Calculated.
[c] Depth in inches of water which on evaporation would yield sufficient alkali to render a 4-foot depth of soil injurious to the most sensitive crops.
[d] High. (See p. 96.)

A35. Composite of three wells (190 to 320 feet deep) at Corning municipal plant.
A36. Composite of four wells (one dug 44 feet deep and three about 250 feet deep) at No. 2 pumping plant of the Richfield Land Co., 3 miles north of Corning.

PUMPING PLANTS.

Pumping plants in the Corning area.

Owner.	Location.			Diameter of well.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horsepower.	Area irrigated.
	Section.	Township N.	Range W.						
Richfield Land Co.:				*Inches.*	*Feet.*	*Feet.*	*Inches.*		*Acres.*
Plant No. 1	Saucos rancho			Dug.	20		8	25	
				12	275				
Plant No. 2	do			Dug.	44		6	20	
	do			12	225		6	20	
				12			6	10	
				24			6	15	
Plant No. 4	do						5	15	767
Plant No. 5	do						6	20	
Plant No. 6	do						5	15	
Plant No. 7	do						6	50	
Plant No. 9	do			Dug.	[a] 26		4	5	
Plant No. 12	do			Dug.	[b] 20		5	15	
"Municipal" plant	do			([c])			3	10	Domestic.
W. H. Samson	NE. $\frac{1}{4}$, 3	24	3	Dug.	[d] 19		6	10	80
E. R. Christie	SW $\frac{1}{4}$, 3	24	3	8	124	[e] 23	2	3	10
H. J. Heinz Co.	NE. $\frac{1}{4}$, 10	24	3	8	[f] 200		3	6	25
L. Crichton	NE. $\frac{1}{4}$, 10	24	3	8	96	([g])	2	3	10
Do	SW. $\frac{1}{4}$, 10	24	3	8	54		Not used in 1913.		
R. D. Forrest	SW. $\frac{1}{4}$, 10	24	3	8	75		2	3	10
L. Crichton	SW. $\frac{1}{4}$, 10	24	3	8	133	([h])	2	3	10
				8	140				
E. D. Wright	NW. $\frac{1}{4}$, 9	24	3	8	108		2	5	10
Mr. Grossman	NW. $\frac{1}{4}$, 9	24	3	8	100±		2	5	10
L. Crichton	NW. $\frac{1}{4}$, 16	24	3	8	63		$2\frac{1}{2}$	5	15
Ed. Worthington	NW. $\frac{1}{4}$, 16	24	3	8	285	[i] [j] 16.5	3	3	10
H. J. Heinz Co.	NW. $\frac{1}{4}$, 16	24	3	[k] 8	245		3	6	10
W. N. Woodson:									
Plant No. 1	SE. $\frac{1}{4}$, 15	24	3	10	252		5	10	72
Plant No. 2	SE. $\frac{1}{4}$, 15	24	3	10	250		4	$7\frac{1}{2}$	
Plant No. 3	SE. $\frac{1}{4}$, 15	24	3	8	80		2	3	10
H. W. Stewart	NW. $\frac{1}{4}$, 22	24	3	8	84		2	3	5
B. G. Rawson	NE. $\frac{1}{4}$, 21	24	3	8	80		2	3	10
V. L. Schrock	NW. $\frac{1}{4}$, 22	24	3	Dug.	[l] 20		$2\frac{1}{2}$	5	10
James Peterson	SW. $\frac{1}{4}$, 22	24	3	8	115		2	3	10
J. W. Gage	NW. $\frac{1}{4}$, 27	24	3	8	98		2	4	10
Mr. Townsend	NW. $\frac{1}{4}$, 27	24	3				2	3	7
Mrs. Eva Colvin	NW. $\frac{1}{4}$, 27	24	3	8	115		2	3	10
Mrs. F. J. Roche	NW. $\frac{1}{4}$, 27	24	3	5	103		2	3	6
Packard Bros	NE. $\frac{1}{4}$, 27	24	3	8	90		2	3	5
R. E. Hopkins	NE. $\frac{1}{4}$, 27	24	3	8	68		2	3	10
L. J. Rinehart	NW. $\frac{1}{4}$, 34	24	3	10	85		2	3	20
L. B. Courtright	SW. $\frac{1}{4}$, 33	24	3				3	5	10
H. M. Gee	SW. $\frac{1}{4}$, 33	24	3	8	95		3	6	15
Gee Bros	N. $\frac{1}{2}$, 4	23	3	8	80		3	([m])	10
R. M. Clingle	N. $\frac{1}{2}$, 4	23	3	8	84	[i] [n] 7.0	3	5	32
S. H. Laraby	4	23	3	8	95		2	3	12
Do	4	23	3	6	100+	[i] [o] 16.0			10
C. F. Foster	SE. $\frac{1}{4}$, 14	24	3	10	155	([p])	3	10	40
W. M. Woodson:									
Plant No. 4	NE. $\frac{1}{4}$, 23	24	3	8	154	60+	([q])	$7\frac{1}{2}$	10
Plant No. 5	SW. $\frac{1}{4}$, 24	24	3	10	99		$3\frac{1}{2}$	10	35
W. H. MacArthur	SW. $\frac{1}{4}$, 24	24	3	6	224		2	3	10
Andrew McDonald	SE. $\frac{1}{4}$, 24	24	3	6	217		1	3	7

[a] Bored 40 feet deeper.
[b] One drilled well.
[c] Machinery set in same pit as plant No. 2. Draws water from well 225 feet deep; for assay of this water see A36, p. 183.
[d] Bored 29 feet more.
[e] Owner's statement, 22 feet in 1913, 11 feet in 1905.
[f] Cased to 190 feet.
[g] Owner's statement, water level 11 feet spring, 1911; 22 feet spring, 1912, 17 feet spring, 1913.
[h] Owner's statement, water level 14 feet 1910 and 1911; 24 feet 1913; second well put in this year.
[i] Measured November, 1912.
[j] From bottom of pit.
[k] No casing.
[l] Bored 10 feet more.
[m] Uses engine of H. M. Gee.
[n] From top of casing.
[o] From surface.
[p] Owner's statement, summer depth to water 35 feet, winter rise 20 feet.
[q] 4-inch Leitweiler cylinder pump.

Pumping plants in the Corning area—Continued.

Owner.	Location.			Diameter of well.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horse-power.	Area irrigated.
	Section.	Township N.	Range W.						
				Inches.	*Feet.*	*Feet.*	*Inches.*		*Acres.*
Guy C. Jones	SW. ¼, 24	24	3	8			2	3	10
B. H. Brubaker:									
"House" plant	SW. ¼, 24	24	3	2 wells.			2	3	20
"Packing house" plant	SW. ¼, 24	24	3				2	3	
E. M. Harness	SE. ¼, 23	24	3	8	48		2	3	10
A. Simons	SE. ¼, 23	24	3	8	64		2	3	10
F. H. Brundage	SE. ¼, 23	24	3	8	80		2	3	10
J. J. Pugh	SE. ¼, 23	24	3	8	105		3	5	20
L. M. Kittredge	SE. ¼, 23	24	3	8	96	[i]13.0	2	3	10
F. H. Chandler	SE. ¼, 23	24	3	8	86		2	3	5
E. J. Carr	SE. ¼, 23	24	3	8	83		2	3	10
John Cockcroft	SW. ¼, 23	24	3	(r)			3	3	20
H. E. Horting	SW. ¼, 23	24	3	8	100±	[i, n]9.0	2	2	10
Dr. M. T. Moore	SW. ¼, 23	24	3	10	117	[i, j]8.5	2	2	10
D. O. Hughes	SW ¼, 23	24	3	8	76	[i, o]14.5	2	5	10
J. F. Larson	SW. ¼, 23	24	3	8			2	3	5
H. E. Allison	SW. ¼, 23	24	3	8	95		3	5	20
George W. Prentiss	NW. ¼, 26	24	3				2	3	5
J. Stinebaugh	NW. ¼, 26	24	3	8 8	90		2 (s)	3 3	12
M. Parker	SW. ¼, 26	24	3	8	54		2	4	10
H. J. Heinz Co.	SW. ¼, 26	24	3	8	102		3	5	48
Do.	SW. ¼, 26	24	3	10	140	[t]10.0	3½	6	
J. J. Measer	NW. ¼, 25	24	3	6	18(?)		2	3	10
Frank Peterson	NW. ¼, 25	24	3	8			2	3	10
D. L. Hughes	NW. ¼, 25	25	3	(u)			3	3	20
George S. Hofman	NW. ¼, 35	24	3	6 3	60 175		2	3	5
Mr. Gale	NW. ¼, 35	24	3				2	3	10
B. E. Glick	NW. ¼, 35	24	3	8	93		2	3	10
W. T. Wilson	NE. ¼, 35	24	3	6	48		2	3	[v]30
J. A. Trobee	SW. ¼, 35	24	3	6	90	[i, o]11.4	2	3	5
H. R. Eustis	SW. ¼, 35	24	3	8	90		2	2	8
E. M. Critchfield	SW. ¼, 35	24	3	8	80	[i, n]7.8	3	5	12
G. H. Blabon	SE. ¼, 35	24	3	8	60	[t]12.0	2	3	6
Thomas Maley	NW. ¼, 2	23	3	8	56		3	5	10
F. H. Cutter	NW. ¼, 2	23	3	8	90		2	3	8
L. J. Irwin	NW. ¼, 2	23	3	8	85		3	4½	11
C. E. Rice	SE. ¼, 2	23	3	8	87		4	6	15
Beresford Bros.	S. ½, 3	23	2	(w)			4	6	30
Mrs. L. B. Christian	SW. ¼, 36	23	3	8	317	[i, o]35.0	6	15	20

[i] Measured November, 1912.
[j] From bottom of pit.
[n] From top of casing.
[o] From surface.
[r] Dug well 4 by 5 feet, 20 feet deep, with bored well in bottom to 125 feet.
[s] Plunger pump.
[t] Summer of 1913.
[u] Pumps from large hole in creek bed, equivalent during most of season to a dug well.
[v] Insufficient water for the acreage.
[w] Dug well 36 by 5 feet, 6 feet, deep, in slough.

ORLAND-HAMILTON AREA.

GENERAL CONDITIONS.

The Orland-Hamilton area is bounded on the north by the Tehama-Glenn county line and on the south by an arbitrary line drawn north of Germantown. The foothills of the Coast Range form the western boundary. The eastern boundary is Sacramento River. These boundaries were chosen to include the area covered by the alluvial fan of Stony Creek and the country naturally tributary to the towns of Orland and Hamilton.

Orland (population 1,582), like other west-side towns, is on the Southern Pacific Railroad. It is the site of the Orland project of the United States Reclamation Service. Reservoirs have been built to impound and divert the waters of Stony Creek for the irrigation of about 20,000 acres of land surrounding the town. The town is most substantially built, the new construction being largely of reinforced concrete—a significant difference from the type used in most rapidly growing towns and a testimony to the confidence which a Government irrigation project inspires.

Hamilton is connected with Orland by a branch line of the Southern Pacific Railroad and with Chico by the Northern Electric Railway. The town depends for its existence on the Sacramento Valley Sugar Co., which has a beet-sugar factory here and also farms a large acreage on both sides of the river.

Fifteen pumping plants in this area are listed on page 189. In 1913, a total of 1,405 acres was irrigated. This acreage will be much increased when the newly installed McCurdy plants and others which were projected at the time of the investigation are in full use. The total horsepower installed was 205, of which 160 was electric and 45 gasoline.

GEOLOGY AND PHYSIOGRAPHY.

The area may be considered in two parts—the alluvial fan of Stony Creek and the river bottom lands.

Stony Creek debouches from the mountains at the northwest corner of the area. It has a doubly terraced valley in the Cretaceous rocks and a very small fringe of older alluvium. From the foothills it flows southeastward to Sacramento River at Monroeville. The gravelly channel or series of channels is from an eighth to half a mile wide. The channel is bordered by a low flood plain of silty soil. To the north along the Tehama-Glenn county line are low bluffs of older alluvium. These bluffs prevent the stream from turning to the north.

The alluvial fan of Stony Creek is a plain with its high point about 4 miles west of Orland. (See p. 27 and Pl. IV.) It slopes to the east and south. The grade is about 20 feet to the mile in the northwest and decreases to 10 feet at the upper border of Colusa Basin. Extending out radially from the northwest are a series of channels which serve to carry away the rain water. They appear to be old channels of Stony Creek, which in past time has occupied all parts of the fan. As the stream filled up the land adjacent to its course it broke over into near-by depressions and commenced depositing there.

The soils of the fan are gravelly and red and similar in many ways to the northwestern division of the older alluvium. However, they are not cemented, and there is no hardpan. Gravel is abundant and is distributed in long radial belts both on the surface and below ground. Gravel pits opened in several places show that these gravels are similar to those in the present bed of Stony Creek. The characteristic pebbles consist of cavernous quartz and are from 1 to 2 inches in diameter.

East of the Stony Creek fan is a narrow strip of river bottom in which the soils are derived largely from river overflow and only slightly modified by material from Stony Creek. Oxbow lakes and cut-off meanders indicate that the river channel has been recently shifted to the east. This is probably due to the low embankment which Stony Creek is building from St. John to the river at Monroeville.

GROUND WATER.

WATER TABLE.

Except in the narrow fringe of older alluvium along the foothills, water is within 25 feet of the surface over the whole area. The water table is, however, subject to large fluctuations. Even under natural conditions the porous soil soaks up water rapidly. The steep gradient of the water table favors loss of this water by movement to the lower levels. During irrigation on the Orland project the water rises, though it seeps away rather rapidly at the close of the irrigation season. The contours on Plate IV are based on conditions in November, 1913, and probably show the lowest normal depth to water.

WELLS IN OLDER ALLUVIUM.

No wells are known in the narrow strip of older alluvium, which belongs to the northwestern division. The conditions in this strip are similar to those of the Willows area (p. 189). The older alluvium underlies the Stony Creek fan, but artesian conditions do not seem to be present, as shown by the deep well of the Black Butte Land Co. (p. 257).

WELLS IN YOUNGER ALLUVIUM.

All the pumping plants of the area are in the younger alluvium either of the Stony Creek fan or the river bottom.

Wells in the Stony Creek fan commonly strike large amounts of clean, coarse gravel. Ordinary well methods and screens should be adequate, but plants should be adapted to large fluctuations in water level. (See p. 122.)

In the river bottom lands wells may be obtained with ordinary methods. The gravels are coarse; pebbles from 2 to 3 inches in diameter are common. Eight plants were in operation in the river lands in 1913. Well No. 1, Hamilton unit of the Mills Orchard Co. lies near the bank of Stony Creek in the flat lands at the base of the fan. The following log gives an idea of conditions in the transition area between the fan and river bottom:

Log of well No. 1 of the Hamilton unit, Mills Orchard Co.

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	10	10	Clay and gravel	23	87
Clay	2	12	Sand and gravel	21	108
(?)	3	15	Clay	32	140
Gravel	15	30	Gravel	15	155
Clay	15	45	Clay	5	160
Gravel	19	64			

NOTE.—Drilled by Clark & Davidson in the southeast corner of lot 1117, company's plat of Hamilton unit. Log from graph by E. C. Mills, engineer.

PUBLIC SUPPLIES.

Both Orland and Hamilton have public water supplies, the water for which is drawn from wells. The town supply of Orland is owned and operated by the town. It was built in 1911 at a total cost of about $32,000. In a neat building is the concrete pump pit 30 feet wide and 14 feet deep. The wells are 10 feet away on either side, in circular cement pits 5 feet in diameter and 14 feet deep. They are thus 50 feet apart. The east well (No. 1) is 170 feet deep. All the water-bearing gravel is above 100 feet. When tested alone with a 4-inch centrifugal pump it yielded 450 gallons a minute with a 14-foot drawdown. Well No. 2 is 99 feet deep and is said to give an equally good yield.

The equipment consists of a service pump with a capacity of 500 gallons a minute and a fire pump with a capacity of 750 gallons a minute, both direct connected to motors. The reservoir consists of a steel kettle-bottomed tank holding 80,000 gallons, giving maximum and minimum pressures of 57 and 45 pounds to the square inch. The number of consumers in 1913 was 125. An analysis (A37) of the water will be found on page 189. Information was furnished by Mr. E. L. Wright, superintendent.

QUALITY OF WATER.

The only available analysis of water in this area is that of the municipal supply at Orland, which is probably typical of the well waters throughout the area. Its composition is nearly that of the average for the whole valley.

The analysis indicates that the water would be perfectly satisfactory for use in irrigation. The only bad effects of the mineral constituents in this water are the increased soap consumption due to the calcium and magnesium, and the formation of a moderate amount of soft scale in steam boilers. The water can be softened for laundry and boiler use.

Chemical composition and classification of composite sample of water from municipal supply at Orland, two wells, 170 and 99 feet deep (A37, Pl. IV).

[Collected Nov. 29, 1913; analyzed by S. C. Dinsmore. Parts per million except as otherwise designated.]

	A37		A37
Silica (SiO_2)	21	Total dissolved solids	229
Iron (Fe)	.03	Total hardness as $CaCO_3$ [a]	185
Calcium (Ca)	46	Scale-forming constituents [a]	180
Magnesium (Mg)	17	Foaming constituents [a]	57
Sodium (Na)	16	Alkali coefficient (inches) [b]	94
Potassium (K)	4.6		
Carbonate radicle (CO_3)	4.8	Classification:	
Bicarbonate radicle (HCO_3)	178	Domestic use	Good.
Sulphate radicle (SO_4)	23	Boiler use	Fair.
Chloride radicle (Cl)	19	Irrigation use	Good.
Nitrate radicle (NO_3)	8.4	Mineral content	Moderate.

[a] Calculated.
[b] Depth in inches of water which on evaporation would yield sufficient alkali to render a 4-foot depth of soil injurious to the most sensitive crops.

PUMPING PLANTS.

Pumping plants in the Orland-Hamilton area.

Owner.	Location. Section.	Township N.	Range W.	Diameter of well.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horsepower.	Area irrigated.
				Inches.	*Feet.*	*Feet.*	*Inches.*		*Acres.*
C. F. Purkett	Capay rancho			12	200		7	30	70
W. F. McCollum	do			(a)			4	5	30
Mills Orchard Co.:									
Plant No. 1	do			12	160		8	20	920
Plant No. 2	do						8	20	
Frank & Clark	do			12	100		5	10	70
G. W. West	do			8	75		5	10	60
G. A. Johnson	do			12	40		4	5	30
Geo. Frank	do			12	75		6	15	40
	NW. ¼, 3	21	2	24			6	15	20
Williard Boot	SE. ¼, 31	22	2	12 12 12	80 40 100		6	15	140
R. Holvick	NW. ¼, 12	21	3	12 12	80 115	[b] [c] 29.9	4	10	25
Samuel McCurdy, Loam Ridge tract:									
Plant No. 1	NE. ¼, 34	22	3	[d] 12	147		6	20	(e)
Plant No. 2	NW. ¼, 35			12	150±		5	15	
Plant No. 3				12	150±		5	15	
Frank Reagan	NW. ¼, 27	22	3	(f)					

[a] Dug well 7 by 7 feet, 16 feet deep.
[b] Measured in November, 1913.
[c] From top of pit.
[d] Also dug well 35 feet deep with bore hole in center to 60 feet.
[e] No irrigation in 1913.
[f] Dug well 8 by 8 feet, 44 feet deep, with 4 bored holes 6 inches in diameter to 72 feet.

WILLOWS AREA.

GENERAL CONDITIONS.

The Willows area extends from the foothills of the Coast Range to the center of Colusa Basin (Pl. II). It consists largely of low plains but in part of basin lands. The northern boundary is arbitrarily placed north of Germantown; the southern boundary is drawn along the Lake & Colusa Railroad, thus meeting the mountain front at the northern terminus of the Hungry Hollow fault.

Willows (population 2,190), the county seat of Glenn County, is at the junction of the San Francisco-Tehama line of the Southern Pacific Co. and the Fruito branch, which taps several small fertile valleys in the Coast Range. Germantown, 7 miles north of Willows, and Maxwell, 17 miles south, are local shipping points and trade centers. Willows is a relatively new town which arose with the increase in population that came as a result of the subdivision of the great Glenn ranch. This ranch, comprising 40,000 acres in all, covered a large part of the present Glenn County and is thought to be the largest area ever farmed in a single unit.

The Sacramento Irrigation Co., whose headquarters are at Willows, is completing a project that is intended to bring 60,000 acres under irrigation. The water is pumped from Sacramento River into a great ditch above Hamilton. Parts of the ditch were built by the old Central Irrigation Co. many years ago. It swings around the head of Colusa Basin through Willows and thence south to Williams.

Here, as in the Orland project, to the north, irrigation with surface waters has led to the sinking of wells and the installation of pumping plants to irrigate lands that lie above the canal or are for other reasons not supplied with water from the canal. In 1913 there were in this area 73 pumping plants that obtained water from wells. They were owned by 46 persons or companies, used 697 horsepower, and irrigated 2,951 acres.

GEOLOGY AND PHYSIOGRAPHY.

The area is bounded on the west by the parallel ridges of the Coast Range foothills. The ridges are even-crested, but toward the west each succeeding ridge is higher than the last. Each is upheld by a hard bed of sandstone or conglomerate of Upper Cretaceous (Chico) age. West of Maxwell the ridges trend nearly due north, but opposite Willows their direction changes to about N. 5° W. The lower ridges are covered with older alluvium, which dips gently toward the plains and here, as in other localities on the western border of the valley, rests on the eroded edges of the Chico. The mantle of older alluvium on the rock ridges is irregular and in few places more than 100 feet thick. West of Willows the belt of older alluvium is about 5 miles wide and forms a considerable red-lands area. It has been thoroughly dissected by stream erosion and consists of steep rounded hills and small intervening flat-bottomed valleys.

The low plains slope from the red lands just mentioned and, farther south, from the foothills, toward Colusa Basin. The low plains are of two contrasting types.

The northern part of the area is on the southern edge of the Stony Creek fan. The general slope is south and southeast at a grade of 8 or 10 feet to the mile. The streams are slightly below the general level and have gravelly channels. The soils have resulted from deposition by these streams and are reddish in color and in places coarse and gravelly in texture. They are the deposits of the North Fork of Willow Creek and other streams which, coming in from the north, bring materials from the Stony Creek fan. These coarser, redder soils are mapped as part of the San Joaquin series in the soil report on the Colusa area.[7]

In the southern part of the area, beginning at Lyman, the slope of the plains is more gentle and the drainage goes toward the east. The streams on emerging from the hills flow eastward and southeastward between natural levees of their own construction forming a channel-ridged plain. In floods they overflow these banks, depositing sandy loam and loam along their banks and clay in the interstream areas and in the basins. The soils are mapped as the Willows series and grade from sandy loam along the stream courses to clay in the interstream areas and along the western border of the basin lands. They have a general yellow or brownish cast. The coarser material near the streams is usually lighter in color than the clay of the interstream areas.

The eastern boundary of the Willows area is Sacramento River. The land slopes gradually from the river westward to Colusa Basin. Overflow of the river is prevented by a levee, and west of the levee runs a branch of the Sacramento Valley Irrigation Co.'s ditch from which laterals run down the slope toward the basin. The river lands have a light loamy and fertile soil. The natural vegetation, a jungle of cottonwood and willows, has been cleared except within the river levees, but valley oaks remain here and there.

Colusa Basin occupies the region between the low plains and river lands. It is a broad, flat area, with a very gentle slope to the south. The soils are dark and heavy. At the head of the basin, in the northern part, there is a considerable mixture of coarser material, but toward the south there is a gradual change to heavier clays. Along the western border tongues of loamy soil extend out into the basin, and between and around them are the "wild-goose lands," which have heretofore been intractable wastes because of their sticky clay soils and alkaline nature and the danger of overflow. Protection from floods, thorough drainage, and careful cultivation bid fair to raise them to the rank of agricultural land.

GROUND WATER.

WATER TABLE.

In the foothills.—The relatively impervious sandstones and shales of the foothills can not be said to have a water table or level of com-

[7] Lapham, M. H., Sweet, A. T., Strahorn, A. T., and Holmes, L. C., Soil survey of the Colusa area, Calif.: U. S. Dept. Agr. Bur. Soils Field Operations, 1907, pp. 927-972, 2 maps.

plete saturation. Though water is often found in the sandstones, it stands at irregular depths, its position depending on the fissuring or other means of exit rather than on the topography. The lower hills and gentler slopes are mantled with a residual clay soil, in places 8 to 10 feet in depth, which serves to retain and hold a large amount of rain water. The residual soils support a luxuriant growth of grass, and the usual sparse oak and manzanita forest characteristic of the foothills. These soils have a further effect in that they delay the passage of rain water to the streams. Floods are consequently less violent, and many minor streams continue to flow late in the spring.

Each of the small alluvium-filled valleys of the foothills has a water table whose height at the end of the rainy season is regulated by the height of the inclosing rock rim. When the stream dries up, evaporation of the ground water begins in the lower places, where water lies within 8 feet from the surface. Such places, usually of small size, are frequently covered with salt grass, and sufficient accumulation of alkaline salts has taken place to unfit the land for cultivation.

In the red lands.—The position of the water table in the older alluvium, in the small patches of this formation as far north as Willows, is not well known because of the lack of wells. From Willows north the broader belt of older alluvium forms a high plain and has a water table conforming to the irregularities of its surface. The depth to water ranges from 10 to 30 feet in valleys and from 30 to 70 feet on the hilltops. No attempt has been made to represent these conditions by contours.

In the low plains, flood basin, and river lands.—In the low plains the water table slopes with the land from the foothills toward the basin and from the north toward the south. (See Pl. IV.) From Germantown to Willows the slope is about 25 feet to the mile southeastward but becomes gradually flatter toward the basin lands. South of Willows there is a slope of 10 feet to the mile from the hills eastward to the basin, and thence a flatter slope of 5 feet to the mile to the center of the trough. Through the center line of the basin the grade is about 2.5 feet to the mile toward the south. On the east side of the basin there is a small rise of the water table to the river. The position of the top of the saturated zone shows that water moves from the foothills rather rapidly southeastward through the Stony Creek fan. Farther south, through the deposits of the minor streams, the flow is eastward toward Colusa Basin. Similarly water moves toward the basin from the river, especially during periods of high water. In Colusa Basin but little lateral movement can take place because of the low gradient. There may however, be a gentle movement to the south.

The depth to water decreases from 20 feet near the hills to less than 5 feet throughout most of the basin area. Wherever the ground water is close to the surface evaporation takes place, resulting in the accumulation at the surface of the salts contained in solution in the ground water. In consequence large areas of the lower undrained lands are alkaline.[8] These are the "wild goose lands." (See p. 40.) The depth to water is everywhere less than 10 feet, so that evaporation can take place from the soil. Many areas similar in having shallow water are, however, free from alkali.

WELLS IN THE FOOTHILLS.

Water occurs in the cracks and fissures of the sandstones and conglomerates of the Cretaceous rocks of the foothills. Little water is held in the interstices between the grains, because of the thorough cementation of the rocks.

Wells dug or drilled into these rocks will obtain water, though the intervening shales are dry. Well M-10 of the Mills Orchard Co., near Mills station, in T. 17 N., R. 4 W., is located in the plains but penetrates the alluvium at 104 feet. It then passes through 18 feet of sandstone and 603 feet of "clay" and shale, into 10 feet of gray sandstone with crevices. All these rocks belong to the truncated Cretaceous beds on which the alluvium lies. A yield of 300 gallons a minute was obtained on test from the creviced sandstone at the bottom. It seems probable that many of the Cretaceous sandstones will supply wells, but careful location of the wells is necessary to avoid the intervening shales.

For small supplies of water the thick residual soil and alluvium of the valleys is the most widely distributed and available source. Dug wells will be most satisfactory, because of the large area for percolation of water and the storage capacity afforded.

WELLS IN OLDER ALLUVIUM.

No serious attempt has yet been made to develop water in the older alluvium except for domestic purposes. Sufficient supplies for house use can be obtained in all the large areas of this formation. The materials encountered are likely to be partly cemented, and the use of drilling rather than boring rigs is advisable.

WELLS IN YOUNGER ALLUVIUM.

Wells in the northern part of the low plains near Germantown encounter coarser gravels than are found in any other part of the area. This is due to the fact that the streams from the north (p. 190) flow over the Stony Creek fan and carry coarser material than they do on emerging from the hills. During the building of the fan

[8] Lapham, M. H., and others, op. cit., p. 965 and map 32.

Stony Creek probably occupied every part of it, not only once but many times. The channel gravels of this relatively large stream are clean and coarse. Pebbles 2 to 3 inches in diameter are common. The most conspicuous and noticeable material is a white quartz which because of its numerous holes and cavities never becomes wholly rounded. The present distribution of soils derived from Stony Creek in long stringers throughout the northern part of the Willows area, especially east of the railroad, is brought out by the soil map.[9]

A peculiarly conspicuous ridge of sandy and gravelly soil extends from Orland through the "gravel pit" south of Greenwood to the gravel pits a mile northeast of Willows and continues with slight interruptions far down into the basin. J. A. Bettencourt's pumping plant No. 1 and the Tweed ranch plant are on or near this ridge. The success of these plants may be attributed to coarse gravel encountered in the wells. Similar gravel will be encountered in wells in the area over which Stony Creek wandered during the building up of the recent alluvium to a thickness of at least 200 feet. It is probable that Stony Creek only rarely deposited gravels south of Lyman, but north of this point practically all wells should strike good gravel.

South of Lyman deposition was largely accomplished by the South Fork of Willow Creek, Logan Creek, Funk Creek, and Stone Corral Creek. The bulk of the material is clay and sandy clay deposited as at the present time on the banks of and between the stream channels. Sand and gravel were deposited only in the actual channels and form long strings within the mass of clay and sand clay. Each string of gravel represents an ancient stream channel. The gravel beds will be most frequently encountered opposite the place where these streams leave the foothills. The past courses of the streams across the plains were doubtless as tortuous as they are now, and therefore probably no part of the area is without gravel, though good gravel may be absent in local spots. The experience of J. B. Turman is a case in point. Of the eight wells he put down two were definitely without gravel and only in No. 8 was satisfactory gravel found. (See table, p. 197.) On the same property within a quarter of a mile good gravel was encountered in a well 30 feet deep.

In Colusa Basin wells less than 100 feet deep obtain water from thin, discontinuous beds of sand and from cracks and holes in the clay. On the Spaulding ranch, near Norman, extensive experiments have been made for the purpose of determining the best type of well and equipment for obtaining water in the basin. In the western part of the ranch no gravel is encountered in the first 150 feet, though in the eastern and lower part gravel is known to occur. Such conditions are believed to prevail over the basin. Favored spots contain

[9] Lapham, M. H., and others, op. cit., map 31.

gravel laid down in some ancient stream channel, but the bulk of the area has nothing coarser than sand.

On the Spaulding ranch a well has been put down on each 40 acres. The wells are 15 inches in diameter and have a single thoroughly perforated sheet-iron casing. Each well is about 100 feet deep and is cased to the bottom. Experience has shown that when such a well is pumped the water table is lowered rapidly around it and that a near-by well furnishes but little water.

Deep-well turbine centrifugal pumps are used, because they facilitate pumping the well down far below the water table. By pumping the wells down to depths of 50 to 70 feet below the surface, yields of 300 to 700 gallons a minute are obtained. The most serious difficulty which has arisen is that the sand from the thin sand layers is drawn into the well, leaving unsupported cavities in the clay. Upon heavy pumping caving immediately around the casing takes place, and the supply of water is thus shut off. The casing can, however, be easily pulled, a new well bored within a few feet, and the same amount of water obtained. With the use of the Rider rig (Pl. XVI, *B*), which is most successful in material of this type, a new well costs only about $25.

On the river lands wells have so far been put down only for domestic purposes. The channel gravels of the river are, however, rather coarse, and in the building up of the alluvium the river appears to have shifted for a considerable distance on each side of its present channel. This condition explains the success of wells for irrigation in the Butte City area, east of Sacramento River. Similar conditions undoubtedly prevail on the west side of the river in the Willows area.

Throughout the low plains, Colusa Basin, and the river lands the younger alluvium is soft and uncemented. The boring method may be used in sinking wells.

FLOWING WELLS.

The causes and conditions pertaining to artesian water in this area are discussed on page 92. Flowing wells can probably be obtained at depths of about 800 feet along the western border of Colusa Basin south of Willows. As the head is small and the flows are not strong, they are not of great value. Pumping of these wells has not been attempted, but if large amounts of water were successfully obtained by pumping a more permanent and satisfactory irrigation system could be set up than is possible by the use of shallow wells where no gravel is encountered. The logs presented on pages 259–260 show that all the material is fine grained. On this account the hydraulic method of well drilling is eminently suitable for these wells.

North of Willows the French and Shaw wells have flows of sufficient volume to be useful for irrigation. In this locality irrigation from artesian wells is possible, but the original cost of the wells is likely to be high—from $3,000 to $4,000 each in 1913—because the coarse material of the alluvium makes hydraulic drilling hazardous. The interest on such an investment is so large that in many places it will be cheaper to pump from shallow wells.

PUBLIC SUPPLIES.

Willows is the only town within the area that has a public water supply. The system is owned by the Northern California Power Co. The so-called old plant has five bored wells 60 to 120 feet deep. The equipment consists of a 5-inch Dow two-stage horizontal centrifugal pump direct connected to a 50-horsepower Westinghouse motor. An auxiliary unit consists of a 5-inch Byron Jackson single-stage horizontal centrifugal pump direct connected to a 50-horsepower Westinghouse motor. The wells are said to have a capacity of 960 gallons a minute.

At the new plant, in block 10, town of Willows, a well was put down in 1912. The following is the log:

Log of well of Northern California Power Co. at Willows.

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Clay	20	20	Clay and sand	60	166
Gravel	9	29	Clay	25	191
Clay	71	100	Gravel	7	198
Gravel	4	104	Clay	1+	199+
Sand	2	106			

NOTE.—Bored well; 14 inches in diameter, No. 14 gage collared galvanized-iron casing from 1 to 29 feet, same 12 inches in diameter from 29 to 199 feet. Perforated from 54 to 198 feet by clean cuts ½ by 2 inches, 25 to 30 in a 2-foot joint.

This well is to be equipped with a two-stage 5-inch pump and 50-horsepower motor to deliver 700 gallons a minute at 155-foot head.

The reservoirs of the system are wooden tanks mounted on a tower and have a capacity of 100,000 gallons. The daily consumption in July, 1912, was 835,000 gallons. A sample of water from the "old plant" was taken in November, 1912. The analysis (A38) is given in the table on page 197.

Mr. H. A. Tedford supplied information regarding the plants.

QUALITY OF WATER.

The one analysis and three assays given in the accompanying table indicate that water found in this area may have more than the average amount of dissolved solids for water throughout the valley, although A39 resembles the waters of the areas to the north, which have less mineral matter in solution. In general the results show that the waters are suitable for irrigation. They are all harder than is desirable for laundry and steam boiler use, but this could be corrected by proper treatment. Except for the soap consumption due to hardness the mineral constituents have no unfavorable effect on the use of the water for domestic purposes.

Chemical composition and classification of ground water in Willows area.

[Analysis by S. C. Dinsmore; assays by G. H. P. Lichthardt. Parts per million except as otherwise designated. Numbers at heads of columns refer to locations so marked on Pl. IV.]

	Analysis.	Assays.		
	A38	A39	A40	A41
Silica (SiO_2)	22			
Iron (Fe)	.30			
Calcium (Ca)	36			
Magnesium (Mg)	30			
Sodium and potassium (Na+K) [a]	[b] 81	(c)	74	44
Carbonate radicle (CO_3)	0	0	0	0
Bicarbonate radicle (HCO_3)	335	175	[d] 366	341
Sulphate radicle (SO_4)	76	Trace.	94	76
Chloride radicle (Cl)	14	6	8	32
Nitrate radicle (NO_3)	12			
Total dissolved solids [a]	[e] 436	200	510	500
Total hardness as $CaCO_3$ [a]	[a] 213	168	260	316
Scale-forming constituents [a]	180	200	300	360
Foaming constituents [a]	220	(c)	200	120
Alkali coefficient (inches) [f]	15	(g)	21	50
Classification:				
Domestic use	Good.	Good.	Fair.	Poor.
Boiler use	Fair.	Poor.	Poor.	Poor.
Irrigation use	Fair.	Good.	Good.	Good.
Mineral content	Moderate.	Moderate.	Moderate.	Moderate.
Date of collection	Nov., 1912	Nov. 4, 1913	Dec. 5, 1913	Dec. 5, 1913

a Calculated.
b Determined. Na=73; K=8.0 parts per million.
c Low. (See p. 96.)
d Carbonates and bicarbonates expressed as bicarbonates.
e By summation.
f Depth in inches of water which on evaporation would yield sufficient alkali to render a 4-foot depth of soil injurious to the most sensitive crops.
g High. (See p. 96.)

A38. Municipal supply (from five wells 60 to 120 feet deep) at Willows.
A39. No. 8 well (246 feet deep, 12 inches in diameter), of Central Forest Co., near Willows (NE. ¼ sec. 17, T. 21 N., R. 3 W.).
A40. Dug well (22 feet deep, 8 by 10 feet in diameter), of Tweed Ranch & Land Co., NE. ¼ sec. 36, T. 19 N., R. 3 W.
A41. Shallow well (30 feet deep), near artesian well of Z. S. Spaulding, Norman (W. ½ sec. 10, T. 18 N., R. 3 W.).

PUMPING PLANTS.

Pumping plants in the Willows area.

Owner.	Location, Section.	Township N.	Range W.	Diameter of well.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horsepower.	Area irrigated.
				Inches.	*Feet.*	*Feet.*	*Inches.*		*Acres.*
Mr. Foerster	NE. ¼, 31	21	3	12	......	a b2.4	5	14	80
Central Forest Co.:									
Plant No. 1	NW. ¼, 17	20	3	12 12	238 308	......	6	15	20
Plant No. 2	NW. ¼, 17	20	3	12 12	119 284	......	......	......	
Plants not installed in 1917	NW. ¼, 17	20	3	12 12 12	290 312 246	......	......	......	......
	NE. ¼, 16	20	3	12	795	......	......	......	Failure.
V. A. Dunlap	SW. ¼, 21	20	3	12	67	......	5	......	70
W. R. Germain:									
Plant No. 1	E. ½, 29	20	3	c12	All less than 100 feet.	b d14.9	5	10	320
Plant No. 2	E. ½, 29	20	3	e12		d f15.3	7	20	
Plant No. 3	E. ½, 29	20	3	18		d g4.7	6	20	
Plant No. 4	E. ½, 29	20	3	c12		b d5.2	6	20	
Plant No. 5	E. ½, 29	20	3	h12		d f13.8	6	20	
W. R. Germain	NW. ¼, 31	20	3	c12	100±	......	......	......	(i)
......	S. ½, 31	20	3	18	......	d f26.5	6	......	......
J. B. Turman	S. ½, 32	20	3	12 12 12 12	145 145 140 157	d f j22.4	6	20	64

a Measured in October, 1912.
b Below top of casing.
c Two wells.
d Measured in November, 1912.
e Four wells.
f From top of pit.
g From floor of pit.
h Three wells.
i Plant not installed in 1912; reported to have irrigated 160 acres in 1913.
j Owner's statement, water level May, 1913, 17 feet and in summer of 1914, 21 feet; four wells used gave unsatisfactory yield; four others near by also failures.

Pumping plants in the Willows area—Continued.

Owner.	Location.			Diameter of well.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horsepower.	Area irrigated.
	Section.	Township N.	Range W.						
				Inches.	*Feet.*	*Feet.*	*Inches.*		*Acres.*
J. A. Davis	NE. ¼, 33	20	3	12 12	53 54	[a] [b]6.0	5	10	40
Mrs. C. V. Hamilton	SE. ¼, 33	20	3	10	....	[b] [d]3.4	3½	5	10
Mr. Sales	SE ¼, 33	20	3	12	....	[b] [d]3.4	4	7½	20
C. R. St. John	SE. ¼, 33	20	3	12	70	[b] [d]2.4	4	5	20
S. Abraham	SE. ¼, 33	20	3	12	60	[b] [d]7.9	3½	5	4
E. H. Welch	SW. ¼, 33	20	3	12	160	[b] [d]0.7	4	8	10
F. J. Klaas:									
"House" plant	N. ½, 4	19	3	8	71	....	3	7½	6
Plant No. 2	N. ½, 4	19	3	12	121	[d] [k]5.7	4		20
J. H. McDole	N. ½, 4	19	3	12	[l] 71	....	3	5	9
A. H. Bacharach	N. ½, 4	19	3	12	72	[b] [d]8.0	3	5	6
Paul Hopkins	N. ½, 4	19	3	12	54	[b] [d]5.6	3	5	10
Mr. Davis	N. ½, 4	19	3	8	121	[b] [d]6.1	3	3	5
E. S. Ball	SW. ¼, 4	19	3	12	31	....	3	5	10
George Swan	SW. ¼, 4	19	3	12	51	[b] [d]3.0	5	15	60
Larson & Hughes	NW. ¼, 8	19	3	....	....	....	7	....	80
H. F. Marshall	NW. ¼, 8	19	3	12	125	[b] [d]5.3	....	....	25
W. K. Marsh	NW. ¼, 8 and NE. ¼, 7	19	3	12	....	[d] [g]3.5	5	10	30
Sauer Bros	SW. ¼, 8	19	3	8	[m]112	....	3	6	5
J. M. Croft	SW. ¼, 8	19	3	12	64	[d] [f]14.6	2½	5	10
C. Bigelow	SW. ¼, 8	19	3	12	[n] 90	....	3	8	10
C. A. Buckingham	SW. ¼, 8	19	3	12	80	....	3	6	20
A. T. Barrow	SW. ¼, 8 SE. ¼, 7	19	3	12	....	[d] [g]1.8	....	....	40
N. W. Silsby	NW. ¼, 17	19	3	12	[o] 119	....	4	10	20
Mr. Strehlo	NE. ¼, 18	19	3	....	....	....	....	....	40
G. F. Fumassi	NW. ¼, 18	19	3	12	100	[b] [d]6.4	4	10	20
R. R. Magladerry	NW. ¼, 18	19	3	12	104	[b] [d]4.3	5	10	40
Wildeman & Wright	SW. ¼, 25	20	3	12	100(?)	[b] [d]8.7	4	7½	40
William W. Fraser	SE. ¼, 26	20	3	12	79	8.7	4	8	22
J. A. Bettencourt, plant No. 3	SE. ¼, 34	20	3	12	[p] 109	....	6	7½	40
F. E. Blakely	SW. ¼, 34	20	3	12	75	....	5	....	....
J. A. Bettencourt:									
Plant No. 1	NW. ¼, 2	19	3	12	64	[d] [g]4.2	6	10	40
Plant No. 2	E. ½, 3	19	3	12	73	....	6	10	40
M. Muñiz	N. ½, 3	19	3	12	[q] 67	[b] [d]6.7	5	15	60
E. R. Herbold	NW. ¼, 3	19	3	12	....	....	4	10	15
L. B. Corvalho	NW. ¼, 3	19	3	12	....	[b] [d]5.2	4	7½	14
Theo. Schaaf	NW. ¼, 3	19	3	12	....	....	3	5	....
W. T. Leake	NW. ¼, 3	19	3	12	52	....	3	5	25
W. H. Cook	SW. ¼, 10	19	3	12	200	....	3	8	10
Neil Cunnington	SW. ¼, 10	19	3	12	50	[d] [j]8.0	5	10	16
C. M. Sehorn	SE. ¼, 10	19	3	[c]12	125	....	4	7½	20
D. W. Ross	NE. ¼, 10	19	3	[c]12	....	....	3	10	30
Mr. Glasscock	NW. ¼, 11	19	3	([r])	....	....	12	20	130
Mrs. Freed	14	19	3	[c]12	120	....	6	10	30
Hugh Garnett	13	19	3	[s]12	125	....	7	15	[t] 320
Holmes, McNulty & Ford	NE. ¼, 23	19	3	12	....	[d] [u]8.8	6	18	70
I. Moss	NW. ¼, 19	19	2	12	....	....	5	18	20
Spaulding Ranch (near Logandale):									
Well No. 4 (14 plants of this type)	....	18	3	15	100±	....	[v]14⅜	15	[w] 480
Well No. 12	....	18	3	12	110	....	[v]12	15	

[a] Measured in October, 1912.
[b] Below top of casing.
[c] Two wells.
[d] Measured in November, 1912.
[f] From top of pit.
[g] From floor of pit.
[k] From center of pump.
[l] Well filled to 59 feet and casing was pulled up to this point.
[m] Filled to 92 feet.
[n] Cased to 50 feet. Well unsatisfactory in 1912.
[o] Cased to 56 feet; filled to 53 feet.
[p] Cased to 62 feet and casing perforated 12 feet to 24 feet.
[q] Cased to 40 feet.
[r] Large hole in bed of creek, also bored well 75 feet deep.
[s] Three wells.
[t] Irrigated with this plant and two others.
[u] From 1 foot above surface of ground.
[v] Turbine centrifugal pump.
[w] Acreage but not location of plants shown on Plate IV adjacent to point A41.

WILLIAMS AREA.

GENERAL CONDITIONS.

The Williams area is bounded on the north by the Colusa & Lake Railway and extends southward to Genevra station on the Southern Pacific (Pl. II). The eastern boundary is the center of Colusa Basin; the western boundary the foothills of the Coast Range. These arbitrary boundaries were chosen to include the pumping district immediately adjacent to Williams. The area also includes the transition between two types of mountain front.

Williams (population 625 in 1910) is a typical west-side town, a business and social center for the surrounding country. It is on the Portland line of the Southern Pacific Co. Considerable freighting is done from Williams to Cooks Spring and other points in the Coast Range.

The recent development of irrigation is beginning to boom the town. In the area and largely near the town there were in 1913 15 plants pumping from wells and irrigating 280 acres by the use of 160 horsepower. Since these figures were gathered new plants have been installed. The most notable development is the irrigation of 640 acres in sec. 36, T. 15 N., R. 3 W.

GEOLOGY AND PHYSIOGRAPHY.

The western boundary of the valley in the Williams area has a twofold character. The dividing line is where Salt Creek leaves the foothills.

From the northern boundary of the area southward to Salt Creek the plains of younger alluvium extend to the ridges of the foothills, there being no intervening area of high plains formed of older alluvium. The sandstone and conglomerates of the Cretaceous formations rise out of the younger alluvium, first as low mounds, and then each succeeding hard bed rises in a higher ridge. The intervening belts of shale are dissected into flat-bottomed valleys floored with alluvium. The tops of the sandstone ridges are remarkably even and represent an old plain which has been tilted to the east and then dissected. In the Willows area the older alluvium was deposited on this plain, but in the Williams area the alluvium has been wholly stripped off. At Salt Creek begins a plateau of older alluvium which extends southeastward along the foot of the Coast Range to Cache Creek. It forms a high plain which rises abruptly from the low plains in an escarpment about 200 feet high. The plateau is dissected by flat-bottomed, terraced valleys that cross the escarpment at right angles. The tributaries of the streams occupying these valleys have cut the plateau into a maze of hills. These rise from altitudes of

350 to 400 feet on the east to 800 or 900 feet on the west, where they abut against the high ridges of the Coast Range.

In Spring Creek valley the older alluvium is from 50 to 100 feet thick. It rests unconformably on the sandstone and shales of the upper Cretaceous. An outcrop of the Cretaceous sandstone in the stream channel gives rise to the spring after which the creek is named. South of this creek the alluvium is apparently thicker. No exposures of the underlying rocks were seen.

GROUND WATER.

WATER-BEARING FORMATIONS.

The Cretaceous rocks of the foothills are relatively poor water bearers. The older alluvium of the high plains has more possibilities, but by far the largest amount of water can be obtained in the younger alluvium of the low plains and Colusa Basin.

WATER TABLE.

Plate IV shows the position of the water table in the younger alluvium of the plains for the season of 1913. The slope of the water table is toward the northeast, with the land surface. It is, however, not quite so steep, and thus the depth to water increases toward the hills. Cortina Creek has built up a series of channel ridges from its mouth toward the town of Williams. About 5 square miles of the upper part of these ridges has a depth to water of more than 25 feet. The higher land of the ridges acts as a partial dam to the general southerly movement of the ground water in the area of the plains drained by Salt Creek. Consequently the water table is close to the surface, and there is evaporation from the ground water. Concentration of salts in the soil has taken place, and an area of several square miles immediately west of Williams is, on this account, of low agricultural value.

West of secs. 24 and 25, T. 15 N., R. 4 W., the younger alluvium is thin and rests on the relatively impervious Cretaceous rocks. Consequently the contours of the water table for this area are somewhat indefinite. In general water is less than 25 feet from the surface.

In the plateau of older alluvium shallow water is found in the valleys. On the hilltops it is generally deep. Owing to the irregularity of the surface of the water table and the lack of wells, no contours have been drawn for this area.

WELLS IN CRETACEOUS ROCKS.

The sandstones, conglomerates, and shales that constitute the bedrock of the foothills are poor water bearers. No water can be expected in the shales. A little water is found in the cracks and joints of the sandstones and conglomerates, but it is useful only for domestic purposes or stock. Some deep wells obtain salty water, as in several prospect holes drilled for oil. Dug wells in the alluvium of the valleys or in the deep soils of the lower hillside slopes usually obtain sufficient water for domestic purposes.

WELLS IN OLDER ALLUVIUM.

The older alluvium belongs to the southwestern division. It consists of gray clays, sands, and some beds of gravel, capped by about 25 feet of red gravelly clay. Few wells have been drilled in the older alluvium in this area, and the conditions are unfavorable for wells of large yield. North of Spring Creek the formation is thin and rests on impervious older rocks. To the south it is carved into numerous hills. Each of these hills is an isolated underground reservoir receiving only the water which it can absorb from the rain. As the alluvium of the southwestern division is fine grained and compact, its absorptive capacity is probably small.

WELLS IN YOUNGER ALLUVIUM.

The younger alluvium of the low plains is saturated with water. It absorbs water directly from rainfall and also from the overflow of Freshwater, Spring, and Cortina creeks. These streams on leaving the hills flow between natural levees of their own construction. Their channels consist of sand and gravel, the immediate banks or natural levees are made up of sandy loams, and in the interstream areas and in Colusa Basin are deposited the finer clays and silts. During the upbuilding of the younger alluvium the streams have occupied numerous channels. Cortina Creek abandoned the channel known as Old Cortina Creek within the memory of men now living.

The younger alluvium has a depth of at least 200 feet. It is obvious that wells of the same depth in this formation will yield water in proportion to the porosity of material encountered. As sand and gravel have larger pores than clay, the best wells will be obtained in the places that have been most often occupied by the channels of the streams. Cortina Creek has the coarsest channel gravel, and the best wells are obtained in the beds deposited by this stream. The present developments are on the ridge of Old Cortina Creek and on an old channel in secs. 35 and 36, T. 15 N., R. 3 W. A more obscure old channel runs through sec. 6, T. 14 N., R. 2 E., and sec. 31, T. 15 N., R. 2 E.

The channels of Spring and Freshwater creeks carry much finer material. The gravel-wall well (pp. 112–113) is recommended for use in the areas occupied by deposits of these streams.

In the cove of Freshwater Creek back of the first sandstone ridge in secs. 25 and 26, T. 15 N., R. 4 W., the alluvium is a thin mantle over shale and sandstone. In the spring the ground water drains over the ridge to the main valley. In the dry season the water table is below the top of the ridge, and wells then draw solely from the relatively small area of alluvium west of the ridge. Exhaustion on heavy pumping is therefore more likely than in the main valley.

In Colusa Basin only shallow wells for stock and domestic purposes have been sunk. The conditions appear to be similar to those in analogous parts of the Willows and Colusa areas.

PUBLIC SUPPLIES.

The town of Williams is supplied with water by the Williams Water & Power Co., whose plant is near the center of the town. The well is 8 inches in diameter and 70 feet deep and incased with No. 16 gage galvanized-iron casing, unperforated and with soldered joints. The log is as follows:

Log of well of Williams Water & Power Co.

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	4	4	Clay	10	43
Clay subsoil	6	10	Sand	1	44
Sand	½	10½	Clay	12	56
Stiff clay	11½	22	Sand and gravel	14	70
Coarse sand	1	23			

The equipment is a 3-inch Eclipse two-stage pump belted to a 10-horsepower Bates & Edmunds gasoline engine. Water is pumped to a small wooden tank.

Information was obtained from C. K. Sweet, manager of the company.

QUALITY OF WATER.

The two analyses given in the accompanying table are the only ones available for this area, and one of them represents a water at the arbitrary dividing line between the Williams and Arbuckle areas. The analyses indicate that the waters are suitable for irrigation. Both are more highly mineralized than the average water at the north end of the valley and are too hard to be considered satisfactory for boiler and laundry use.

Chemical composition and classification of ground water in Williams area.

[Analyses by S. C. Dinsmore. Parts per million except as otherwise designated. Numbers at heads of columns refer to locations so marked on Pl. IV.]

	A42	A43
Silica (SiO_2)	24	27
Iron (Fe)	.20	.40
Calcium (Ca)	58	60
Magnesium (Mg)	40	21
Sodium and potassium (Na+K) [a]	51	15
Carbonate radicle (CO_3)	.0	.0
Bicarbonate radicle (HCO_3)	337	206
Sulphate radicle (SO_4)	76	9.0
Chloride radicle (Cl)	33	31
Nitrate radicle (NO_3)	22	60
Total dissolved solids	466	320
Total hardness as $CaCO_3$ [a]	309	236
Scale-forming constituents [a]	260	240
Foaming constituents [a]	140	40
Alkali coefficient (inches) [b]	48	66
Classification:		
Domestic use	Fair.	Fair.
Boiler use	Poor.	Poor.
Irrigation use	Good.	Good.
Mineral content	Moderate.	Moderate.
Date of collection	Oct. 28, 1912	....

[a] Calculated.
[b] Depth in inches of water which on evaporation would yield sufficient alkali to render a 4-foot depth of soil injurious to the most sensitive crops.

A42. Well (about 100 feet deep) of T. P. Schwartz, Williams (NE. ¼ sec. 23, T. 15 N., R. 3 W.).
A43. Well (150 feet deep) of Southern Pacific Co., Genevra station.

PUMPING PLANTS.

Pumping plants in the Williams area.

Owner.	Location. Section.	Township N.	Range W.	Diameter of casing.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horsepower.	Area irrigated.
				Inches.	*Feet.*	*Feet.*	*Inches.*		*Acres.*
H. M. Goodfellow	NW. ¼, 23	15	4	[a] 12	36	[b c] 20.0	5	([d])	30
E. A. Brim	SE. ¼, 11	15	4	[a] 12	96	[b c] 11.8	6	([d])	20
G. Bruce Harlan	SE. ¼, 11	15	3	12	[e] 141	7±	5	15	12
J. L. Mendenhall	NW. ¼, 24	15	3	12	50	[b c] 3.0	8	20	20
Harlan & Manor	NW. ¼, 24	15	3	12	75	[b f] 6.5	4	10	7½
W. R. Turner	NW. ¼, 24	15	3	12	....	[b f] 5.0	5	7½	10
T. E. Stockford	NE. ¼, 23	15	3	12	....	[b c] 2.9	4	10	20
H. W. Tedford	NE. ¼, 23	15	3	12	....	....	6	10	20
T. P. Schwartz	NE. ¼, 23	15	3	....	....	....	....	....	20
L. K. Clarke	23	15	3	12	100	....	6	10	....
J. W. Forgeus	23	15	3	....	....	....	3	7½	([g])
J. E. Mitchell:									
Plant No. 1	NW. ¼, 23	15	3	12	68	[b c] 2.2	3	7½	40
Plant No. 2	NW. ¼, 23	15	3	12	60	....	3	7½	
Plant No. 3	NW. ¼, 23	15	3	12	38	[b c] 6.0	2	3	
R. E. Easton	E. ½, 26	15	3	12	....	[b c] 2.9	6	20	80

[a] Three wells.
[b] Measured in October, 1912.
[c] From top of casing.
[d] Traction engine.
[e] Filled to 50 feet.
[f] From floor of pit.
[g] Demonstration plant.

COLUSA-MERIDIAN AREA.

GENERAL CONDITIONS.

The Colusa-Meridian area includes the river lands from the south line of Larkins Children's rancho south to Knights Landing, on the west side of the river, and from the Glenn County line to the mouth of Feather River on the east side (Pl. II). The western boundary follows approximately the center line of Colusa Basin. The eastern boundary follows Butte Creek and slough to the south side of Marysville Buttes and the center line of Sutter Basin, thence to the junction of Sacramento and Feather rivers.

The population of this area is largely concentrated along Sacramento River. The river banks have the best land and the greatest freedom from flood. The agricultural products, largely grain and dairy products, are transported by river, the main artery of commerce. Colusa (population 1,846) is the largest town. It is connected with Lakeport, in the Coast Range, by a narrow-gage railroad, the Colusa & Lake. The Northern Electric Railway now has a line from Colusa through Meridian to Marysville. The Southern Pacific Co. was building, in 1913, the "beet line" from Harrington, on the Portland line, to Meridian and Colusa.

These new facilities in transportation and the sugar factory in Meridian are stimulating agriculture. Intensive development must, however, await flood protection. Adams[10] reports 68,000 acres protected from floods under the levees of the Davis, Munson, and No. 108 districts west of Sacramento River. District 70 includes 16,000 acres east of the river. Irrigation by surface water in 1912 covered 875 acres under three small projects west of the river near Colusa and an indefinite amount under the Moulton project east of the river. Irrigation by ground water in 1912 and 1913 covered 529 acres. There were 14 pumping plants with a total of 304 installed horsepower.

GEOLOGY AND PHYSIOGRAPHY.

The area is exceedingly flat, yet small differences in altitude are of great importance in connection with the quality of soil and safety from floods. Sacramento River has a fall of 50 feet in the 90 miles from Princeton to the mouth of Feather River, or an average grade of 0.55 foot to the mile.[11]

The river lies in a channel between high banks of clay. The land slopes away from the river toward broad basins on either side. On

[10] Adams, Frank, op. cit., pp. 149, 159.

[11] Reed, C. F., Grunsky, C. E., and Crawford, J. J., Report of the Commission on Rivers and Harbors to the governor of California, 1890: California Senate and Assembly, 29th sess., Jour., vol. 1, appendix, p. 46, 1891.

the west side of the river is Colusa Basin. Butte Basin lies east of the river as far south as Colusa, whence its water drains through Butte Creek and slough around the western spurs of Marysville Buttes into Sutter Basin. Sutter Basin is a broad, flat, heart-shaped lowland between Sacramento and Feather rivers.

Under natural conditions the river during flood overtopped its banks in many places. The basins were thus converted into great shallow lakes in which there was a slow movement southward. Colusa Basin drains into Sacramento River through Sycamore Slough at Grafton at low stages of the river. Sutter Basin drains into the river through Sacramento Slough near the mouth of Feather River at low stages, though a small residue of water in the lowest depression escapes only by evaporation.

In the overflow of the river sand and sandy clays were deposited where the current slackened immediately adjacent to its banks. Finer materials were carried out into the basins and there gradually deposited as clays and adobes. During ordinary floods the river broke its banks only at a few places and there built out long ridges of higher lands. Such ridges are Sycamore Slough and Dry Slough, which divide Colusa Basin into upper and lower parts and inclose between them Mormon Basin. During great floods the river was a mere thread of swiftly moving water in a great sea of water extending from the low plains of the west side to the plains east of Feather River.

With the settlement of the country levees were built along the river bank to prevent overflow. These attempts at control are only partly successful because, while they increase the capacity of the river, the increase is not sufficient to handle the normal flood flow. In consequence breaks commonly occur, and then the rise of water in the basins floods all lands not protected by back levees. The complete solution of the problem awaits the carrying out of the recommendations of the California Débris Commission.

The younger alluvium is the only formation exposed within the area. It has been laid down by the activities of the river already described. The total thickness near Meridian is probably not much over 250 feet, as indicated by the log of the Alameda Sugar Co.'s well. (See p. 262.) It is composed of sand and gravel deposited in the river channel and finer materials, mostly clay, deposited in the basins. The position of the river channel during the time involved in filling the valley 250 feet is a matter of speculation. Most of the wells are near the river, and wells in the basins are scarce. If thick beds of sand and gravel were found over large belts in the basins, ancient channels of the river would be indicated, but scattered beds of sand and gravel are not conclusive. Such gravels and particularly sands exist in the ridges extending out from the river. Cheney Slough, Sycamore Slough, and Dry Slough must have had their counterparts in the past. Streams from the west-side plains may also have carried gravels far into Colusa basin. In Butte Basin, Butte Creek carries fine gravel as far as its junction with Angel Slough. The known coarse materials already discovered in wells may be explained under the theory that the river while depositing the younger alluvium has not wandered farther than 3 miles on either side of its present channel.

GROUND WATER.

WATER TABLE.

The depth to water is less than 25 feet over the whole area. The hydrographic contour map (Pl. IV) brings out the fact that in the region just north of this area the contours bend north as they approach the river. The 60-foot contour crosses the river at Boggs Bend almost at right angles. Each lower contour swings southward along the river in a loop. North of Boggs Bend the water table then slopes toward and feeds the river. From that point south the water table slopes away from the river. The level of ground water in the immediate banks of the river is controlled by the river level. In high stages of the river the slope of the water table away from the river is steep, and seepage pools form in the depressions below the river banks. In low stages of the river ground-water movement is slow, and small fluctuations in the river level are not evident in wells half a mile away.

Evaporation of the ground water takes place when the water table is within 6 to 8 feet of the surface. As the depth to water within the basins is only from a few inches to 6 feet, evaporation is active, especially on the borders of the basins. This evaporation constitutes the principal draft on the ground water of the river areas. In the fall there is less evaporation and water rises in the basins, and this, with decreased draft, causes a rise in wells on the higher lands. This fluctuation of the water table in Colusa Basin is shown in figure 5 (p. 84).

SHALLOW WELLS.

Sacramento River carries pebbles an inch or more in diameter as far south as Colusa. Thence southward the channel material increases in fineness. At the mouth of Feather River it consists of sand with only scattered pebbles. Most of the coarse material of the younger alluvium is derived from the river, either its ancient channels or those of its distributaries. Present development indicates that wells less than 250 feet deep within 2 or 3 miles on each side of the river as far south as Grimes will generally encounter gravel. For such wells the ordinary well methods and screens will be sufficient. Farther south along the river only sand is likely to be found. As the clay beds are soft and likely to cave, the gravel-wall well is recommended. (See pp. 112–113.)

Along the east side of Colusa Basin considerable prospecting may be necessary to find coarse material. Salty water is likely to be obtained, as the wells may encounter a bed which at the time of burial was an alkaline spot similar to those that now exist.[12] Better water can often be obtained by casing off and going deeper. A new location for the well may avoid the salty spot, as they are usually small in extent.

But little development is likely in that part of Butte Basin included in this area for a long time to come. It is thought, however, that good gravels will be found in shallow wells. Along the west side of Sutter Basin gravel is probably lacking. Alkaline waters are to be feared, but so few wells are known that these conclusions are very tentative.

DEEP WELLS.

The Alameda Sugar Co.'s well at Meridian is the only deep well on the east side of the river in this area. Its log is given on page 262. It probably penetrates the older formations, but no artesian head was noted.

In Colusa Basin there are a number of wells having a slight artesian head. They are listed in the following table:

Artesian wells in Colusa Basin.

Owner.	Diameter of casing (inches)	Casing.	Depth (feet).	Flowing in October, 1912.	Depth to water in October, 1912 (feet).	Remarks.
E. H. Nutson	6	Galvanized iron	294	No	0.4	Flows 2 feet above surface until July of each year.
J. E. Sachreiter	3	Screw	360	Yes		0.75 gallons a minute at height of 2.8 feet above surface.
Mr. Baldson	2	do	260	No	(a)	Said to have risen within few inches of surface. Now tapped 4.8 feet below surface and carried to trough 10 feet lower in bottom of slough.
Fred W. Schutz	6	do	365	No	(a)	Did not flow.
Mrs. H. Davis	6	Galvanized iron	300	No	16.9	Do.
W. H. Buster	3	Screw	677	No	3.3	Flowed 3 feet above ground in winter of 1911. Fell 1.5 feet between May and October, 1912.
Harbison & Kitchen	6	do	200(?)	No		Formerly flowed at surface.

a Not known.

In Colusa Basin clays and cemented sands are commonly found at a depth of about 200 to 250 feet. Fine sands in which the water has a slight head occur from this depth downward. These sands seem to be connected with the west-side plains. The heavy clays of the basin, being almost impervious to rising water, confine the lower

[12] Lapham, M. H., and others, Soil survey of the Colusa area, Calif.: U. S. Dept. Agr. Bur. Soils Field Operations, 1907, map 33, 1099.

water. In winter the head is greater, owing to the rise of ground water in the plains and the wetting of the basin clays. The log of a typical well follows:

Log of J. E. Sachreiter's well, Colusa Basin.

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Yellow clay	300	300	Sand	10	360
Yellow clay with small veins of sand	50	350	Clay.		

NOTE.—Drilled by J. W. Ask, by jetty method. Cased with 3-inch (outside diameter) pipe to 369 feet.

Most of these wells were put down to obtain soft and sanitary water. The analyses (p. 210) show that the water is not greatly different from that in many shallow wells in the valley.

The maximum head can be obtained by the use of unperforated screw casings. The deeper layers seem to have the greatest head. In the fine materials encountered the hydraulic method of drilling is suitable, but great skill is necessary to pass the thick beds of sand often found. The wells are not likely to be of great commercial value.

PUBLIC SUPPLIES.

With the exception of the village of Grimes, in which there is a small plant pumping water from the river, Colusa is the only town in the area having a public supply.

In 1911 Colusa erected a municipal plant in the western part of the town, near the river. Prior to 1911 the town was supplied by a private system of waterworks, owned by P. J. Cooke and leased by F. E. Wright. After the building of the municipal plant the business of this system declined, and it was bought by the city in 1914. Two wells are in use at the municipal plant of which the logs are as follows:

Logs of wells of municipal plant, Colusa.

Material.	Well No. 1.		Well No. 2.	
	Thickness.	Depth.	Thickness.	Depth.
	Feet.	*Feet.*	*Feet.*	*Feet.*
Yellow clay	40	40	40	40
Not known	2	42	2	42
Gravel	2	44	2	44
Blue clay	232	276	234	278
Gravel	29	305	30	308
Blue clay			10	318
Gravel			13	331
Prospect hole in same gravel			36	367

NOTE.—Well No. 1 has 12-inch galvanized-iron casing to 276 feet; 8-inch screw casing inside, perforated in lower 32 feet. Well No. 2 has 12-inch galvanized-iron casing to 278 feet; 8-inch screw casing inside to 308 feet, perforated from 278 to 308 feet; 23 feet of perforated 5⅝-inch screw casing is inserted between 308 and 331 feet.

The two wells are at the sides of a large concrete pump pit, containing the service and five pumps. The service unit consists of a 6-inch Krogh turbine pump direct connected to a 40-horsepower General Electric motor. The unit has a capacity of 200 gallons a minute against a pressure of 56 pounds. The fire and emergency unit consists of two 6-inch Krogh turbine pumps direct connected to a 75-horsepower General Electric motor. This unit has a capacity of 700 gallons a minute against a pressure of 150 pounds. For use in case of failure of the electric current there is provided a 100-horsepower Doak 4-cylinder vertical gasoline engine, connected to the other units by line shaft belts. In 1912, there were 307 consumers. (For an analysis of this water see A44, p. 210.)

The Cooke plant is about half a mile east of the municipal plant. The logs of two of the wells are given below:

Log of well No. 1, Cooke plant, Colusa.

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Sandy loam	5	5	Gravel and rotten wood	4	48
Black loam	5	10	Blue clay and scattering gravel	1	49
Yellow clay	3	13	Blue sand and gravel	4	53
Sand	8	21	Coarse sand	4	57
Quicksand; water	9	30	Light gravel	6	63
Coarse sand	1	31	Gravel	7	70
Blue sand	1	32	Blue clay	1	71
Coarse sand	2	34	Prospected but water not good	9	80
Blue sand	10	44			

NOTE.—Bored 12 inches in diameter, September, 1898; stovepipe casing to 63 feet. Plugged at 70 feet and casing unperforated.

Log of well No. 2, Cooke plant, Colusa.

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Sandy loam	6	6	Blue clay	21	86
Black loam	8	14	Black sand, cemented	8	92
Red sand	7	21	Blue clay	3	95
Sand; water	3	24	Much sand	9	104
River-bottom mud and sand	5	29	Blue clay	6	110
Mud and sand	6	35	Hard black sand	14	124
Mud and fine sand	7	42	Cement clay	5	129
Coarse sand	19	61	Cement gravel	6	135
Light gravel	4	65			

NOTE.—Well bored 12 inches in diameter, September, 1898; stovepipe casing to 68 feet. Hole plugged at 70 feet; casing perforated from 62 to 65 feet. Auger left in bottom of well.

In a large brick and cement pit built to afford protection from high water in the river are a 6-inch Byron Jackson horizontal centrifugal two-stage pump and a 30-horsepower Westinghouse motor. This is the service pump, which pumps directly to the mains or to the banks. The auxiliary steam plant consists of a two-cylinder 8 by 12 by 12 inch Buffalo steam pump, a two-cylinder 8 by 12 by 12 inch

Worthington steam pump, and two 50-horsepower steam boilers. The reservoirs consist of several wooden tanks having a total of capacity of 100,000 gallons, on a wooden tower. The ordinary service pressure is 20 pounds to the square inch.

For use in emergency or fire there is an intake pipe from the river. It was largely the suspicion on the part of the town people that water was taken from the river rather regularly which led to the installation of the municipal plant.

The town of Grimes is supplied by a small plant belonging to G. L. Sanders. Water is pumped from Sacramento River by a 5 by 10 inch Gould Triplex pump and 5-horsepower Western Electric motor. Reserve power is furnished by a 5-horsepower Samson gas engine. The reservoir consists of a 6,000-gallon wooden tank on a wooden tower 35 feet high.

QUALITY OF WATER.

Three analyses, given in the accompanying table, show a general agreement in composition of waters analyzed in this area. They are only moderately hard, but some contain enough dissolved salts to require a little extra care in using them for irrigation. On the basis of the mineral matter in solution the waters are classified as good for domestic use. They may cause some trouble from scale or foaming in steam boilers.

Chemical composition and classification of ground water in Colusa-Meridian area.

Analyses by S. C. Dinsmore. Parts per million except as otherwise designated. Numbers at heads of columns refer to locations so marked on Pl. IV.]

	A44	A45	A46
Silica (SiO_2)	41	46	44
Iron (Fe)	.50	.15	.30
Calcium (Ca)	21	23	36
Magnesium (Mg)	7.8	5.4	19
Sodium and potassium (Na+K)[a]	[b] 69	93	36
Carbonate radicle (CO_3)	.0	.0	.0
Bicarbonate radicle (HCO_3)	245	253	214
Sulphate radicle (SO_4)	26	18	30
Chloride radicle (Cl)	12	39	28
Nitrate radicle (NO_3)	.00	Trace.	1.4
Total dissolved solids	273	356	296
Total hardness as $CaCO_3$[a]	84	80	168
Scale-forming constituents [a]	120	120	180
Foaming constituents [a]	180	250	97
Alkali coefficient (inches)[c]	13	9.1	47
Classification:			
Domestic use	Good.	Good.	Good.
Boiler use	Fair.	Fair.	Fair.
Irrigation use	Fair.	Fair.	Good.
Mineral content	Moderate.	Moderate.	Moderate.
Date of collection	Oct. 22, 1913	Oct. 23, 1913	Oct. 21, 1912

[a] Calculated.
[b] Determined. Na=54; K=15 parts per million.
[c] Depth in inches of water which on evaporation would yield sufficient alkali to render a 4-foot depth of water injurious to the most sensitive crops.

A44. Municipal supply (from two wells, 305 and 331 feet deep), Colusa.
A45. Well (677 feet deep, 3 inches in diameter), of W. H. Buster, Sycamore.
A46. Artesian well (350 feet deep, 3 inches in diameter), of J. E. Sachreiter, near Sycamore (NW. ¼ sec. 4, T. 4 N., R. 1 W.).

PUMPING PLANTS.

Pumping plants in the Colusa-Meridian area.

Owner.	Location.			Diameter of casing.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horsepower.	Area irrigated.
	Section.	Township N.	Range W.						
				Inches.	*Feet.*	*Feet.*	*Inches.*		*Acres.*
Watt Bros.	NE. ¼, 4	16	2	a 12	118	12	6	15	20
Harbison & Kitchen	SE. ¼, 9	16	2	8	120	b c 10.0	5	9	6
E. S. Halloway	Colusa rancho			10	160	b c 7.5	6	10	8
James Jamison	SW. ¼, 15	16	2	8 12	127½ 102	......	6	15	30
L. S. Ballard	Colusa rancho			d 12	50±	......	10	15	......
Warren B. Boggs	do			d 8	......	......	6	15	35
H. C. Stormer	do			a 12	70	b e 7.1	8	25	12
C. H. Gilman & Son	S. ½, 5	16	1	12 12	55 145	f 6.0	7	20	60
Mrs. L. Laux	SW. ¼, 8	16	1	16	174	f 1.0	8	35	25
P. V. Berkey	NE. ¼, 17	16	1	a 12	20	......	5	15	35
Mrs. L. A. Myers	NE. ¼, 17	16	1	16	70	......	5	15	40
D. Wiget	NW. ¼, 19	15	1 E.	12 12	35 95	......	8	25	50
Alameda Sugar Co.	18	15	1 E.	12	473	......	g 24	75	300
C. D. Crookham	NW. ¼, 30	15	1 E.	12	110	h 5.5	6	15	10

a Two wells.
b Measured in October, 1912.
c From surface of ground.
d Three wells.
e From center of pump.
f Reported depth below bottom of pit in August, 1913.
g Turbine centrifugal pump.
h Measured in December, 1913, from top of casing.

ARBUCKLE AREA.

GENERAL CONDITIONS.

The Arbuckle area is an arbitrary subdivision of the west-side plains, with the town of Arbuckle (population 800 in 1910) as its commercial center (Pl. II). The eastern boundary runs along the center of Colusa Basin. The western boundary coincides with that of the valley. On the north and south the division from the Williams, Esparto-Madison, and Woodland areas is wholly arbitrary.

Yet this area has a distinctive character, because here the lower plains of the west side are very narrow and the high plains are wide. The pumping plants listed below are experimental, and no serious attempt at irrigation has yet been made. With the increase of dairying already begun in the border lands along Colusa Basin and the development of the almond industry near Arbuckle, water for irrigation will be in demand. There are several possibilities for a supply. A high-line ditch from the north to bring in water from Sacramento River is feasible, but it involves heavy expense and an adjustment of interests of all the localities for a comprehensive division of the available water. A high-line ditch from the Capay diversion dam through Hungry Hollow to the vicinity of Oat Creek has been suggested. All the water which the company will be allowed to develop in the next few years will probably be used by lands under its present ditches. To those who wish immediate development the possibilities of ground water will appeal.

GEOLOGY AND PHYSIOGRAPHY.

The area is divided sharply into belts by the escarpment which marks the Hungry Hollow fault. The escarpment, which is remarkably straight, runs northwestward from a point near Ronda to Cortina Creek, at the southwest corner of sec. 10, T. 14 N., R. 3 W.

RED LANDS.

West and south of the escarpment is a rolling country rising toward the northwest, along Sand and Cortina creeks, from altitudes of 250 or 300 feet to 800 feet. The area belongs to the red lands division of the valley and is distinguished by its elevation and erosion from the low plains at the eastern foot of the escarpment. A typical part of the escarpment is shown in Plate IX, *B*. The southern lower portion of the high plains is treeless and is farmed; the northern portion is more rugged and supports a scant forest of oak and manzanita.

The streams run northeastward, crossing the escarpment at right angles. Their tributaries have thoroughly dissected the original plateau, of which only a few flat areas remain at the tops of the hills. The terraces along the streams are discussed on pages 21-26.

The red lands are composed of older alluvium of the southwestern division. The formation consists of gray clays with sand and scattered beds of gravel, or white and green clays and tuffs. The upper part of the series is a bed of red gravelly clay 25 to 50 feet thick. The whole is considered of the same age as the rest of the older alluvium. It has been lifted by movement along the Hungry Hollow fault. (See p. 79.)

LOW PLAINS.

East of the escarpment the streams wander over a plain sloping northeastward and eastward to Colusa Basin. Here they are depositing material derived from the dissection of the red lands and even from the foothills of the Coast Range to the west. Thus a thickness of younger alluvium has been built up to a possible depth of 400 feet. (See p. 263.)

Near Ronda and also on the north the streams have low gradients. They lie between natural levees of their own construction and have built up channel ridges. In the rest of the area the streams have deposited on a steeper slope. The individual alluvial fans coalesce in a slope which rises nearly to the top of the escarpment. The escarpment is thus almost concealed by the gravelly material built up about its foot. The steep slopes, gravelly soil, and rough surface place this area in marked contrast to the typical low plains of the west side.

East of the area of deposition by tributary streams lies Colusa Basin. Its border is broken by low tongues or channel ridges of higher land where west-side streams build out the edge of the plains with every flood.

GROUND WATER.

WATER TABLE.

Water occurs in both the older and younger alluvium. The latter is completely saturated. The water table slopes with the surface but not so steeply. At the top of the Arbuckle fan the depth to water is 80 to 100 feet. In the basin it is from 3 to 4 feet in the dry season. These conditions are represented by contours on Plate IV. In the older alluvium the water table tends to conform to the surface, though it is deep on the hilltops and shallow in the valleys. No attempt has been made to represent these conditions by contours.

WELLS IN OLDER ALLUVIUM.

The predominant clays and fine sands of the older alluvium are not good water bearers, and some beds seem to be entirely dry. In the deeper layers certain porous layers, usually gravel, contain water. The small number of wells in the red lands makes it impossible to predict how those beds will stand heavy pumping.

The following logs give a concrete idea of the conditions:

Log of S. D. Brown's well, 5 miles west of Arbuckle.

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Red loamy clay	13	13	Adobe and gravel	180	260
Adobe	57	70	Blue clay with yellow streaks	55	315
Dry gravel	10	80			

NOTE.—Imperfect log. 6-inch galvanized-iron casing. Struck water at 170, 270, 293, and 302–315 feet. Depth to water 240 feet. Small cylinder pump and 2-horsepower engine.

Log of V. Scofield's well, sec. 13, T. 12 N., R. 2 W.

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Gravelly soil	20	20	Adobe	36	182
Adobe and some blue clay	122	142	Coarse gravel	1	183
Black quicksand	16	158	Soft adobe.		

NOTE.—Bored 4½ inches in diameter; galvanized-iron casing, open in gravel. Depth to water about 70 feet. Windmill.

The red gravelly clay that caps the hills absorbs water easily. Springs are not uncommon at the contact of this material with the underlying gray clays. Some wells dug in the red clay to the underlying gray clays furnish water to supply a windmill. In the valleys shallow water in small amounts can be obtained from the loose materials of the flood plain or the lower terrace.

On the whole, the area of older alluvium or red lands is rather unfavorable for the development of large supplies of water.

WELLS IN YOUNGER ALLUVIUM.

East of the escarpment the low plains stretch eastward to the tule lands of the Colusa Basin. In general the younger alluvium is not so well sorted as in other parts of the west side. The streams which deposit it are shorter, more torrential, and of smaller volume. In addition they head in the easily eroded older alluvium of the high plains. In flood they deposit mixtures of sand, gravel, and clay along their banks. The late spring flow which washes the channel materials can handle only sand. In consequence the effective water-bearers are the buried channel sands and fine gravels.

By the use of good well screens and particularly the gravel-wall well moderate supplies for irrigation can be developed. (See pp. 112–113.) Simpler methods are sometimes effective, as in V. A. Peterson's west well.

Log of V. A. Peterson's west well, in the NE. ¼ sec. 8, T. 11 N., R. 1 E.

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	16	16	Clay and brown streaks with some sand	26	77
Clay	34	50	Sand; lower 8 to 10 inches gravel	24½	103½
Gravel and sand	1	51			

NOTE.—Bored by Nutting, 1912; 12 inches in diameter, galvanized-iron casing. Put in sack of coarse rocks; pulled casing up 20 inches from bottom and perforated lower 3 feet with 50 slots ⅜ inch wide and 6 inches long. After pumping throughout season of 1912 no sand in well.

The steep fan west of Arbuckle is the largest area of younger alluvium in the valley, and the depth to water in it is greater than 25 feet. The soil is a reddish loam. The surface has many minor roughnesses, and the higher parts are wooded. But few wells have been put down here, and none are intended to furnish a large flow. Coarse material will be found in wells, but the gravels are likely to be mixed with clay. The following log illustrates the conditions:

Log of Charles S. Friel's well, west of Arbuckle.

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	10	10	Gravel; water	14	53
Gravel	3	13	Sand and clay mixed	8	61
Clay	26	39	Gravel; water	3	64

NOTE.—Bored 6 inches in diameter; galvanized-iron casing, open at bottom and perforated for both water gravels. Depth to water 39.4 feet from top of casing, 1.5 feet from surface of ground. Hand pump. For analysis of water see A47, p. 215.

QUALITY OF WATER.

Only one analysis is available for this area, but A43, which is reported in the section on the Williams area, is on the line between the two areas. Analysis A47, given below, represents a highly mineralized water that is not well suited for any purpose, although in the absence of better water it can be used. Special care would be necessary in using it for irrigation to prevent the accumulation of alkali. Results of analyses of waters from neighboring areas indicate that other water in this area is probably much better than the sample analyzed.

Chemical composition and classification of water from bored well (64 feet deep) of Charles S. Friel, near Arbuckle (A47, Pl. IV).

[Collected Oct. 16, 1912; analyzed by S. C. Dinsmore. Parts per million except as otherwise designated.]

	A47		A47
Silica (SiO_2)	26	Total hardness as $CaCO_3$[a]	982
Iron (Fe)	.20	Scale-forming constituents[a]	810
Calcium (Ca)	201	Foaming constituents[a]	340
Magnesium (Mg)	117	Alkali coefficient (inches)[b]	3.5
Sodium and potassium (Na+K)[a]	125		
Carbonate radicle (CO_3)	.0	Classification:	
Bicarbonate radicle (HCO_3)	498	Domestic use	Unfit.
Sulphate radicle (SO_4)	14	Boiler use	Bad.
Chloride radicle (Cl)	589	Irrigation use	Poor.
Nitrate radicle (NO_3)	2.0	Mineral content	High.
Total dissolved solids	1,322		

[a] Calculated.
[b] Depth in inches of water which on evaporation would yield sufficient alkali to render a 4-foot depth of soil injurious to the most sensitive crops.

PUMPING PLANTS.

Pumping plants in the Arbuckle area.

Owner.	Location.			Diameter of casing.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horsepower.	Area irrigated.
	Section.	Township N.	Range W.						
				Inches.	Feet.	Feet.	Inches.		Acres.
G. C. Meckfessel	NE. ¼, 10	14	2	12	90	[a b] 3.5	......	......	......
E. Shirber	20	14	1	12	48	[a b] 14.6	4	8	38
L. F. Torry	8	13	1	12	98±	[a b] 18.3	3	8	3
Mr. Kane	16	13	1	12	159	[a b] 10.6	......	......	......
Friel Bros. (3 wells)	SE. ¼, 14	13	1	......	......	......	5	(c)	(d)
Mr. Watson	SW. ¼, 23	13	1	12 12	101 170	......	8	25	(e)
M. T. Emmert	SW. ¼, 35	13	1	10	125	[a f] 27.7	2	5	(g)
V. Peterson	NE. ¼, 8	11	1 E.	12 12	93½ 103½	[a h] 5.5	5	12	30

[a] Measured in October, 1912.
[b] From surface of the ground.
[c] Traction engine.
[d] Irrigation in 1912 nominal.
[e] First well uncased. It caved; second well unsatisfactory. Plant abandoned.
[f] From top of pit.
[g] Test installation gave 74.7 gallons per minute, Oct. 14, 1912.
[h] From top of casing in east well.

Logs and perforations of wells of Hennigan plant, Sacramento Valley Sugar Co.

[Bored by Bender Bros., May and June, 1912.]

	Well No. 1.		Well No. 2.		Well No. 3.	
	Thickness.	Perforations.	Thickness.	Perforations.	Thickness.	Perforations.
	Feet.		*Feet.*		*Feet.*	
Sediment	7	......	7	......	12	......
Sand	10	......	10	......	2	......
Blue clay or mud	13	......	13	......	9	......
Yellow clay	57	......	55	......	[a] 61	......
Fine gravel	22	......	22	......	24	......
Yellow clay	3	......	5	......	5	......
Blue clay	18	......	20	......	20	......
Sand	5	......	3	......	1	......
Cement gravel	......	......	8	......	......	......
Gravel	10	120	......	......	10	120
Cement fine gravel	......	......	11	......	11	......
Clay	11	......	......	......	2	......
Cement gravel	4	......	4	......	3	......
Loose gravel	51	520	8	96	27	320
Yellow clay	......	......	1	......	......	......
Loose gravel	......	......	20	240	......	......
Yellow clay	......	......	10	......	13	......
Loose gravel	......	......	11	80	9	56
Total depth	211	......	208	......	209	......
Thickness of water-bearing gravel	61	......	39	......	46	......
Number of perforations:						
Total	......	640	......	416	......	496
Per foot of gravel	......	14.9	......	10.6	......	10.7

[a] Has three streaks of sand.

NOTE.—Perforations ⅜ inch wide and 3 inches long. Casings open 1 foot from bottom of lowest gravel. Old well 12 inches diameter, log unknown. Well No. 1, 12 inches diameter, is 50 feet east of old well; well No. 3, 12 inches diameter, is 5 feet north of old well; well No. 2, 10 inches diameter, is 50 feet north of No. 3.

At the Nicholson plant of the same company the first well (No. 1) was sunk to 182 feet, but the log showed 33 feet of gravel below the water table in the first 110 feet, an amount deemed sufficient. The remaining wells were then sunk only through this gravel. The yield of this plant is 3,000 gallons a minute.

Logs and perforations of wells of Nicholson plant, Sacramento Valley Sugar Co.

[Bored by Bender Bros., January and February, 1912.]

	Well No. 1.		Well No. 2.		Well No. 3.		Well No. 4.		Well No. 5.		Well No. 6.	
	Thickness.	Perforations.	Thickness.	Perforations.	Thickness.	Perforations.	Thickness.	Perforations.	Thickness.	Perforations.	Thickness.	Perforations.
	Feet.		*Feet.*		*Feet.*		*Feet.*		*Feet.*		*Feet.*	
"Sediment"	15	......	15	......	10	......	10	......	15	......	15	......
Sand	1		1		4	......	10	......	1	......	2	......
Clay	23	......	23	......	25	......	68	......	23	......	22	......
Gravel	10	112	7	72	4	72	......	......	7	([a])	7	88
Clay	39	......	42	......	45	......	......	......	42	......	42	......
Gravel	23	([a])	21	225	21.5	312	20	225	22	([a])	23	224
Sand	3	......	......	......	......	......	......	......	......	......	......	......
Clay	56	......	......	......	......	......	......	......	......	......	......	......
Gravel	12	([a])	......	......	......	......	......	......	......	......	......	......
Cement gravel	......	......	......	......	......	......	......	......	......	......	......	......
Total depth	182	......	109	......	109.5	......	108	......	110	......	111	......
Thickness of water-bearing gravel	45	......	28	......	25.5	......	20	......	29	......	30	......
Number of perforations:												
Total	......	384	......	297	......	384	......	225	......	305	......	312
Per foot of gravel	......	8.5	......	10.6	......	15.0	......	11.2	......	10.5	......	10.4

[a] Number of perforations not known but is included in the total.

NOTE.—Casings open 1 foot from bottom of lowest gravel. Wells Nos. 1, 2, 3, and 4 are 30 feet apart north and south. No. 5 is 50 feet east of No. 1, and No. 6 is 50 feet east of No. 5.

The thickness and continuity of the gravel beds south of Woodland are well shown by the logs of the wells of the Jackson plant. Well No. 2 has yielded on test 700 gallons a minute, and the whole group 3,000 gallons a minute.

Logs and perforations of wells of Jackson plant, Sacramento Valley Sugar Co.

[Bored by Bender Bros., 1912.]

	Well No. 1.		Well No. 2.		Well No. 3.		Well No. 4.		Well No. 5.		Well No. 6.	
	Thickness.	Perforations.	Thickness.	Perforations.	Thickness.	Perforations.	Thickness.	Perforations.	Thickness.	Perforations.	Thickness.	Perforations.
	Feet.		*Feet.*		*Feet.*		*Feet.*		*Feet.*		*Feet.*	
Soil	5		6		5		5		6		5	
Sand	17		16						20			
Gravel					10		17				9	
Sand					5						8	
Black clay	13		16		18		13		12		16	
Yellow clay	3						3					
Gravel	23	256	22	248	26	272	23	240	25	256	25	288
Yellow clay	82		1								80	
Gravel			4	48								
Yellow clay			24									
Gravel			1									
Yellow clay			53									
Gravel	7	96	8	88							8	72
Yellow clay	(b)		32								(b)	
"Sandstone"			3									
Quicksand			(a)									
Total depth	150		186		64		61		63		151	
Thickness of gravel perforated	30		34		26		23		25		33	
Number of perforations:												
Total		352		384		272		240		256		360
Per foot of gravel		11.7		11.2		10.4		10.4		10.2		10.9

[a] A few inches. [b] At bottom of well.

NOTE.—Perforations ⅜ inch wide and 3 inches long. Casing open at 1 foot from bottom of lowest gravel, except in No. 2, where it is seated in the "sandstone."

In Colusa and Yolo basins the younger alluvium is finer grained. During the long period of deposition of the younger alluvium, Cache Creek has probably had numerous courses, and there are probably no parts of these basins within the Woodland area that have not been occupied by this stream. The amount of gravel and sand encountered in any one well, for a given depth, will, however, be less in the basins than on the low plains. The border of Yolo Basin east of Woodland is characterized by projections of the low plains with intervening low spots covered with salt grass and often forming temporary lakes. The soil of the channel ridges is loamy and free from alkali, but in the low spots the water table is less than 10 feet from the surface, and the consequent evaporation of ground water concentrates salts in the soil. Pumping of ground water in this area would lower the water table and relieve the alkaline conditions.

GROUND WATER.

WELLS.

In the edge of Yolo Basin flowing wells are obtained by deep drilling, and a number of shallow wells flow in the winter and spring. The Chapman well, in sec. 13, T. 9 N., R. 2 E., is the best known of these wells. It is 2 inches in diameter and said to be 305 feet deep. In September, 1912, it had a very small flow, but it is said that in former years it flowed 15 gallons a minute.

Wells for domestic purposes are easily obtained in the river lands, but no attempt to develop water for irrigation has been made.

PUBLIC SUPPLIES.

The waterworks of Woodland were purchased by the town from a private company about 1892 for $75,000. The so-called old plant has four wells ranging from 180 to 190 feet deep. The following is a partial log of the two wells in the pump pit:

Log of wells at old plant, Woodland waterworks.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil	16	16
Clay	8	24
Gravel	6	30
Blue clay	....	....
Gravel	12?	186?
Clay	4?	190

The pumping unit consists of an 8-inch horizontal centrifugal pump and a 50-horsepower Westinghouse motor. For emergencies two cylinder Dow steam pumps with a tubular boiler are also maintained. The reservoirs consist of four wooden tanks holding 150,000 gallons and a steel kettle-bottomed tank holding 120,000 gallons. This plant is in operation from 14 to 15 hours a day.

The so-called new plant lies west of the town and was erected at a cost of $5,500. There are two wells, 12 inches in diameter and 193 and 195 feet deep. For the first 70 feet a 14-inch casing was put in place and the 12-inch casing slipped inside. The annular space was grouted with concrete to prevent seepage of the upper part of the ground water into the wells. An analysis of the water from the new plant is given on page 221 (A51).

In 1912 there were about 900 consumers.

QUALITY OF WATER.

The four analyses given in the accompanying table indicate that waters in this area contain much more mineral matter than the average for the whole valley. All but one are classed as good for irrigation. The hardness and the large amounts of sodium salts make them all unsatisfactory for use in steam boilers.

Chemical composition and classification of ground water in Woodland area.

[Analyses by S. C. Dinsmore. Parts per million except as otherwise designated. Numbers at heads of columns refer to locations so marked on Pl. IV.]

	A48	A49	A50	A51
Silica (SiO_2)	32	27	24	33
Iron (Fe)	.30	Trace.	Trace.	Trace.
Calcium (Ca)	26	61	81	56
Magnesium (Mg)	31	41	63	31
Sodium and potassium (Na+K)[a]	117	39	55	[b] 26
Carbonate radicle (CO_3)	.0	.0	.0	7.2
Bicarbonate radicle (HCO_3)	333	375	531	287
Sulphate radicle (SO_4)	90	25	28	34
Chloride radicle (Cl)	57	47	76	39
Nitrate radicle (NO_3)	Trace.	7.0	10	1.2
Total dissolved solids	522	452	624	363
Total hardness as $CaCO_3$[a]	192	321	461	267
Scale-forming constituents [a]	160	280	370	250
Foaming constituents [a]	320	100	150	70
Alkali coefficient (inches) [c]	11	41	26	52
Classification:				
Domestic use	Fair.	Fair.	Poor.	Fair.
Boiler use	Bad.	Poor.	Poor.	Poor.
Irrigation use	Fair.	Good.	Good.	Good.
Mineral content	High.	Moderate.	High.	Moderate.
Date of collection (1912)	Sept. 7.	Oct. 7.	Oct. 7.	Oct. 7.

[a] Calculated.
[b] Determined. Na=22; K=3.6 parts per million.
[c] Depth in inches of water which on evaporation would yield sufficient alkali to render a 4-foot depth of soil injurious to the most sensitive crops.

A48. Well (103 feet deep, 4 inches in diameter) of C. A. Piper, Knights Landing (NE. ¼ sec. 22, T. 11 N., R. 2 E.).
A49. Composite from six bored wells (133 feet deep, 12 inches in diameter) at Charles T. Laugenour's pumping plant, near Yolo.
A50. Composite of three wells (54 feet deep, 12 inches in diameter) at "South Wells" pumping plant of H. E. Coil, SW. ¼ sec. 21, T. 10 N., R. 2 E.
A51. Composite of two wells (193 and 195 feet deep, 12 inches in diameter), municipal supply at Woodland (new plant west of town).

PUMPING PLANTS.

Pumping plants in the Woodland area.

Owner.	Location.			Diameter of well.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horsepower.	Area irrigated.
	Section.	Township N.	Range E.						
Alameda Sugar Co.:				*Inches.*	*Feet.*	*Feet.*	*Inches.*		*Acres.*
Morris plant No. 5	NW. ¼, 20	11	2	[a] 12	150	....	10	75	480
Morris plant No. 2	NW. ¼, 21	11	2	[b] 12	30-100	[c] 56	12	100	560
Cook plant (4 similar units)	SE. ¼, 30	11	2	12	130	....	[d] 12	25	[e] 700
McGriff plant	Rio Jesús María rancho			12	([f])	[c] 43	12	75	660
Nelson plant No. 1	do			12	([g])	....	10	50	640
Morris plant No. 6	do			[h] 28	560	....	[d] 24	150	
Peart plant	do			[i] 12	205	....	12	100	
Lindsay S. Morris	SW. ¼, 29	11	2	12 12 16	103 98 108	[j] 22.5	10	50	240
G. P. Hatcher	SW. ¼, 30	11	2	[k] 12	70	....	8	30	70
A. N. Dick & Sons	NE. ¼, 31	11	2	[l] 12	106	[m] 27.2	10	75	120

[a] Six wells set 30 feet apart in two rows, 50 feet apart.
[b] Seven wells; two 30 feet deep, one 70 feet deep, three 100 feet deep.
[c] Total head.
[d] Turbine centrifugal pump.
[e] Irrigation from combined stream. (See Pl. XVIII, *B*.)
[f] Six wells.
[g] Nine wells.
[h] This diameter for 100 feet only.
[i] Ten wells.
[j] In 16-inch well with pump running.
[k] Two wells.
[l] Three wells.
[m] Measured on June 27, 1913; according to owner's statement, depth was 17.3 feet in winter of 1912, and 15.0 feet on Jan. 1, 1913.

Pumping plants in the Woodland area—Continued.

Owner.	Location. Section.	Township N.	Range E.	Diameter of well.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horsepower.	Area irrigated.
				Inches.	*Feet.*	*Feet.*	*Inches.*		*Acres.*
J. E. Scarlett	Río Jesús María rancho			[l] 12 12	42	[n] 23.8	10	50	100
W. W. Nelson	do			[l] 12 no casing.	....	[o] [p] 13.0	10	30	160
J. P. Raiche	SE. ¼, 2	10	1	12	36	[o] [q] 19.0	3	7½	11
Jackson & Woodard	SE. ¼, 2	10	1	12 12	64 76	[r] [s] 19.5	8	25	60
J. R. Fisher	Río Jesús María rancho			[k] 12 8	60	([t])	3	10	10
Mr. Hadley	do			[k] 12	60	....	6	20	30
L. Cramer	do			[k] 12	....	....	8	35	20
Hayden Bros	do			[k] 16	104	....	7	30	120
J. W. Gallup	do			[k] 12	68	[r] [u] 3.8	6	15	30
C. K. Steinberg:									
"Old" plant	do			[v] 8	214	[w] 8.0	6	15	60
"New" plant	do			[l] 12	70	....	6	20	
C. T. Laugenour	do			[f] 12	133	....	12	50	180
W. D. Jennings	do			[x] 12	180±	[r] 9.4	12	50	160
Sacramento Valley Sugar Co.:									
St. Louis plant	do			[y] 12	98–108	[r] [u] 5.2	15	150	1,266
Hennigan plant	do			[x] 12	[z] 208–211	....	12	100	505
Nicholson plant	do			[f] 12	[z] 108–182	....	12	100	396
Coil plant	do			[l] 12	134–187	....	12	75	140
Jackson plant	NW. ¼, 9	9	2	[aa] 12	[z] 61–186	....	12	100	340
Yolo Orchard Co	Río Jesús María rancho			14 by 22 ft. 22 [k] 12	40 75 80	....	12	45	....
LeRoy Coil	do			[x] 12	76	[bb] 6.0	12	50	125
W. O. Marders	....			[k] 12	70	14.6	8	20	....
A. W. Morris & Son	Río Jesús María rancho			[cc] 12	....	....	10	50	400
H. E. Coil:									
"North wells"	SW. ¼, 21	10	2	[l] 12	49	[r] [u] 5.2	10	35	160
"South wells"	SW. ¼, 21	10	2	[l] 12	54	[r] [dd] 7.0	8	20	
R. L. Harter	NW. ¼, 28	10	2	[k] 12	55	8.5	8	20	40
H. G. Armstrong	NE. ¼, 28	10	2	[k] 12	48	....	8	20	65
B. de la Santa (lessee)	SW. ¼, 28	10	2	[k] 10	....	[ee] [u] 11.2	3	3	18
John Dinsdale	NW. ¼, 32	10	2	[k] 6	36	[r] [s] 7.8	2	3	....
H. Germeshausen	E. ½, 33	10	2	12	60	[ee] [s] 14.7	4	4	([ff])
Misses Blowers	SW. ¼, 33	10	2	18 ft.	25	[ee] [s] 13.7	6	25	80
W. T. Anderson	SW. ¼, 5	9	2	12	200	[ee] [u] 7.8	....	....	([gg])
Byron Jackson ranch	NE. ¼, 7	9	2	[e] 12	95	....	10	[hh] 25	60
N. M. Chandler	NW. ¼, 30	9	2	10	120	....	8	25	140

[f] Six wells.
[k] Two wells.
[l] Three wells.
[n] Measured June 27, 1913, with pump running; according to Chandler, 16 feet in 1900; according to owner, 10 feet in May, 1913, 20 feet normal in June, 1913. The three wells were equipped with 8-inch pump and 25 horsepower steam engine and irrigated 80 acres in 1898, 1899, and 1900; fourth well and new equipment installed 1913.
[o] Measured in June, 1913.
[p] From center of pump.
[q] From top of floor timbers.
[r] Measured in October, 1912.
[s] From top of pit.
[t] Page 89.
[u] From top of casing.
[v] 7 inches from 188 feet to 214 feet.
[w] 4 feet above local water table; water from coarse sand at bottom. This is not the Steinberg plant of Chandler, which has been abandoned.
[x] Four wells.
[y] Twelve wells. (See p. 116.)
[z] See pp. 218–219.
[aa] Six wells.
[bb] Measured in June, 1913.
[cc] Five wells.
[dd] From center of suction main.
[ee] Measured in September, 1912.
[ff] 6 acres in 1912; in 1913 had 7½-horsepower motor and irrigated larger acreage.
[gg] Test plant 1912.
[hh] Rented; plant used in 1912 only because of failure of ditch water.

ESPARTO-MADISON AREA.

GENERAL CONDITIONS.

The Esparto-Madison area includes the so-called Hungry Hollow, which lies along Cache Creek, southwest of the Hungry Hollow Hills, and it extends southward to the flood plain of Putah Creek. (See Pl. II.)

The Clear Lake branch of the Southern Pacific Railroad runs north from Winters to Madison and thence up Cache Creek to Esparto. Madison (population 300 in 1910) is a junction point, and Esparto (population 100 in 1910) is a thriving village. Cache Creek runs through the northern part of the area. Several ditches have been built since 1856 to divert water from Cache Creek for the irrigation of the adjacent land.[22] Ownership of the ditches is now consolidated in the Yolo Water, Light & Power Co. A concrete diversion dam has been built at Capay, about 3 miles west of Esparto. In 1912 about 24,000 acres was irrigated in the area between Cache and Putah creeks. The larger part of the water is used in the Woodland area and only a small part within the Esparto-Madison area.

Ten plants pumping from wells are listed on page 227, of which some were experimental and others did not irrigate as much land as their capacity warranted at the time the area was investigated. Altogether only 148 acres was irrigated in 1913 with water pumped from wells.

GEOLOGY AND PHYSIOGRAPHY.

The geologic structure is the determining factor in this area in the movement of the ground water and in the location of successful wells.

The Hungry Hollow Hills extend from the north as a prong into this area as far as Cache Creek. The broad depression which lies west of the hills and between them and the lower foothills of the Coast Range is called Hungry Hollow.

Cache Creek on emerging from the picturesque Capay Valley flows through a broad flood plain along the south margin of Hungry Hollow, eastward to Woodland and to the Yolo flood basin. At the south end of the Hungry Hollow Hills it passes through a terraced constriction between the end of these hills and a series of low red knobs, 25 to 50 feet high, which extend southward to Putah Creek. West of the red hills the plains rise gently to a low bench of alluvium which skirts the higher foothills from Esparto to Putah Creek.

The Hungry Hollow Hills form the south end of a block of older alluvium that was uplifted by a fault along its eastern border, which

[22] Chandler, A. E., Water storage on Cache Creek, Calif.: U. S. Geol. Survey Water-Supply Paper 45, 1901.

may be called the Hungry Hollow fault (p. 79). The displacement decreases gradually to the south, and with this decrease in displacement there is also a tilting, as the western part of the block has not been raised as much as the eastern. From Cache Creek southward tilting was the predominant movement. The low red hills are at the east edge of a block of older alluvium that was lifted on the east and depressed on the west. West of this block is a second fault, with uplift on the west side. It begins near Esparto, skirts the mountains along the low bench already referred to, crosses Putah Creek east of Winters, and dies out near Allentown. (See Pl. III.)

GROUND WATER.

WATER TABLE.

The younger alluvium is saturated with water. The water table or upper surface of this saturated zone is represented by contours on Plate III.

The water table slopes eastward along Cache Creek and southeastward from Hungry Hollow.[23] The 70, 80, and 90 foot contours are crowded together along the red hills. This means that the water table has a steeper slope along the line of the red hills than to the west or east. The depth to water is less than 6 feet over large areas west of the red hills and more than 20 feet immediately east of the hills. These conditions exist because the older alluvium, which is less pervious to water than the younger alluvium, projects above the plain along the Hungry Hollow fault. It forms a partial underground dam, obstructing the free movement of ground water toward the east. The water therefore comes close to the surface west of the dam but is farther below the surface east of the dam.

The area of shallow ground water east of Citrona caused by the dam along the line of the red hills is marked by the accumulation of alkali in the soil.[24] Water is here drawn to the surface by capillarity and evaporates. The action would doubtless be more pronounced but for the escape of water over and through the dam. Escape takes place at Cache Creek, in springs and seeps at the North Fork of Willow Creek, and by a general southerly movement toward Putah Creek.

WELLS IN OLDER ALLUVIUM.

The older alluvium belongs to the southwestern division. Except near the top it consists of rather regularly bedded gray clays with sand, sandy and tuffaceous clays, and some gravel. The gray clays

[23] Chandler, A. E., op. cit., p. 26.

[24] Mann, C. W., Warner, J. F., and Westover, H. L., Soil survey of the Woodland area, Calif.: U. S. Dept. Agr. Bur. Soils Field Operations, 1909, map 2.

are capped by 25 to 50 feet of red gravelly clay which gives the red color to the Hungry Hollow Hills, the red hills south of Cache Creek, and the bench of older alluvium along the foothills of the Coast Ranges. Water is absorbed rather easily by this material. Areas underlain by it have good roads, in contrast to those over the lower gray clays. Springs occur in many places at the contact of the red gravelly clay with the underlying material. Willow Spring, in sec. 36, T. 11 N., R. 1 W., is an example.

Sufficient water for stock and domestic use is obtained from dug and bored wells. Many of these wells draw from the perched water at the base of the red gravelly clay. Others are in the valleys and draw from the loose material recently washed down by streams or carried into the valleys by hillside creep.

The main body of alluvium is too fine grained to yield water freely. Wells sunk into the gray clays obtain small amounts of water from sand and thin gravel lenses. (See log of H. H. Gable's well, p. 263.)

The height above the valley of the uplands underlain by older alluvium affords good air drainage and consequent freedom from frost, which should lead to the development of these tracts as fruit land. Attempts to obtain water from wells in these tracts will in general result in failure, although here and there a good well may be obtained. Water can be pumped from the low lands, either from ditches or from wells in the younger alluvium, with no greater lift and with less risk of failure.

The Capay canal skirts the foothills from Capay to Winters. The southern part of the Hungry Hollow Hills can be supplied with water by pumping from the modern successor to the Adams ditch or from wells in the flood plain of Cache Creek. For the irrigation of the red hills south of Cache Creek water can be readily obtained from wells in the shallow-water areas to the west.

WELLS IN YOUNGER ALLUVIUM.

The younger alluvium consists of brown and yellow clays and silts with interbedded gravel and sand deposited by Cache Creek and to a minor extent by Cottonwood, Chickahominy, and other small streams. The bed of Cache Creek at Esparto is floored with clean, well-sorted gravel, consisting of pebbles generally 2 to 3 inches in diameter. Belts of similar gravels extend through the younger alluvium, which has been built very largely by the activity of Cache Creek. Indeed, distributaries from Cache Creek have probably occupied all of the area west of the red hills. Good gravels are found in sec. 6, T. 9 N., R. 1 E., and in other places. West of the railroad clean water-bearing gravel is less likely to be found in wells, because the small streams, such as Chickahominy and Cottonwood creeks, which have here formed most of the younger alluvium, deposit chiefly sand and dirty gravel or gravelly clay.

Wells along the flood plain or bottom lands of Cache Creek obtain abundant water in coarse gravel. The water stands near the surface, and the expense of pumping it from wells is moderate. The present successful irrigation pumping plants are located here. It is probable, however, that successful wells can be obtained in most other places in the younger alluvium, the only question being the relative expense of pumping from wells and the use of ditch water. The operation of pumping plants in competition with gravity water was begun too recently to justify sweeping conclusions at this time, but the installation of pumping plants in the areas of shallow water west of the red hills for the irrigation of these hills is certainly justified. Water from any source must be pumped to irrigate these hills, and the lift is practically the same, whether it is derived from wells or from ditches. Moreover, heavy pumping of ground water by lowering the water table and thereby preventing evaporation, would assist in relieving the alkaline condition of the soil.

QUALITY OF WATER.

The analyses given in the accompanying table show the waters to be somewhat more highly mineralized than the average for the entire valley. They are classed as good for irrigation, but for other uses they are not so well suited on account of the calcium and magnesium salts which are present.

Chemical composition and classification of ground water in Esparto-Madison area.

[Analyses by S. C. Dinsmore. Parts per million except as otherwise designated. Numbers at heads of columns refer to locations so marked on Pl. IV.]

	A52	A53
Silica (SiO_2)	19	23
Iron (Fe)	.20	Trace.
Calcium (Ca)	56	44
Magnesium (Mg)	19	34
Sodium and potassium (Na+K)[a]	41	23
Carbonate radicle (CO_3)	.0	.0
Bicarbonate radicle (HCO_3)	270	263
Sulphate radicle (SO_4)	36	21
Chloride radicle (Cl)	31	43
Nitrate radicle (NO_3)	5.8	2.5
Total dissolved solids	356	328
Total hardness as $CaCO_3$[a]	218	249
Scale-forming constituents[a]	220	210
Foaming constituents[a]	110	62
Alkali coefficient (inches)[b]	42	47
Classification:		
Domestic use	Fair.	Fair
Boiler use	Poor.	Fair.
Irrigation use	Good.	Good.
Mineral content	Moderate.	Moderate.
Date of collection	Sept. 23, 1912.	July 2, 1913.

[a] Calculated.
[b] Depth in inches of water which on evaporation would yield sufficient alkali to render a 4-foot depth of soil injurious to the most sensitive crops.

A52. Bored well (180 feet deep) of A. S. Crowder, at Citrona.
A53. Bored well (43 feet deep, 12 inches in diameter) at pumping plant of O. M. Peterson, Madison.

PUMPING PLANTS.

Pumping plants in the Esparto-Madison area.

Owner.	Location.			Diameter of well.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horsepower.	Area irrigated.
	Section.	Township N.	Range W.						
				Inches.	*Feet.*	*Feet.*	*Inches.*		*Acres.*
Blakeway & Lindeman	Cañada de Capay			4 by 4	17.7	[a] Dry	2½	5	⅓
Barr & Son	do			[b] 8	72	....	3	5	14
L. W. Peebles	do			12	112½	[a] [c] 5.7	4	6	23
A. Sovereign	27	10	1	12	60	[a] [c] 8.6	6	9	25
J. R. Jones	Cañada de Capay			45 ft.	....	[a] [c] 12.2	12	([d])	8
R. Howard	NW. ¼, 36	10	1	12	48	[a] [e] 13	7	15	20
Johnson & Son	Guesesosi rancho			[b] 12	60	....	7	20	12
G. J. Snyder	do			[b] 12	44	[f] 15	8	([d])	20
O. M. Peterson	do			12	43	....	6	15	20
T. F. Rooney	E. ½, 31	10	1 E.	12	52	[f] [g] 3.7	4	10	4½
R. G. Tadlock	NW. ¼, 16	9	1	12	150	[a] [g] 9.5	5	([d])	....
G. Stephani	SE. ¼, 21	9	1	16	112	....	....	....	....

[a] Measured in September, 1912.
[b] Two wells.
[c] From top of casing.
[d] Traction engine.
[e] From surface of ground.
[f] Measured in July, 1913.
[g] From center of pump.

DAVIS-DIXON-WINTERS AREA.

GENERAL CONDITIONS.

The pumping area that surrounds Davis, Dixon, and Winters extends from the vicinity of Putah Creek southward nearly to the Montezuma Hills, and from the foothills of the Coast Ranges eastward to Sacramento River. (See Pl. II.) It is crossed by the Ogden line of the Southern Pacific Railroad. A branch line extends northward from Davis, and another from Elmira through Vacaville and Winters. The principal towns, with their population in 1920, are Vacaville, 1,254; Winters, 903; Dixon, 926; Davis, 939; and Elmira, 317 (1910).

The principal stream is Putah Creek, which furnishes water for the irrigation of deciduous fruits, alfalfa, and other crops. In Vaca Valley fruit is raised without irrigation. Most of the area is still farmed without irrigation, wheat and barley being the principal crops, but in 1913 there were 128 pumping plants in operation, supplying water from wells for the irrigation of 5,696 acres, or an average of 44.5 acres for each plant. (See Pl. IV.)

GEOLOGY AND PHYSIOGRAPHY.

Most of the area consists of low plains underlain by younger alluvium, the most prominent feature being the channel-ridged plain of Putah Creek. On the east the low plains merge into Yolo Basin, one of the largest flood basins in the valley. Between Winters and Vacaville is a hilly country underlain by older alluvium that was evidently faulted up and is very distinct from the younger alluvium, both in composition and in topography. South of this hilly country of older alluvium bedrock of Cretaceous age or older forms ridges that extend into the valley and project above the low plains of younger alluvium.

GROUND WATER.

GENERAL OCCURRENCE.

The gravel beds in the younger alluvium increase in amount and coarseness from the Montezuma Hills northward, and in the vicinity of Dixon beds of rather coarse gravel are common. These gravels are mixed with sand but include pebbles from 1 to 3 inches in diameter and are similar to those in the present channel of Putah Creek. This creek has been prevented from spreading to the north by the red hills of older alluvium that extend southward from the Hungry Hollow Hills, and it has therefore deposited most of its material south of its present channel. A number of dry sloughs, or old channels, extend southeastward from Putah Creek, indicating numerous changes in the course of the creek in past time. Conditions seem to be especially favorable for obtaining water from wells in the triangle between the Dixon Ridge, Putah Creek, and Yolo Basin, and in this locality the greatest development has taken place. West of Dixon Ridge gravels are said to be less common, but the successful plants already installed indicate that this is a popular delusion. Dixon Ridge is a typical channel ridge which represents an old channel of Putah Creek, and there is no reason to suppose that its predecessors have not occupied most of the area from Allendale east to Dixon Ridge during the building of the low plains. It is likely, however, that the gravels may be thinner or more sandy in this area.

A concrete idea of the conditions likely to be encountered in wells is given by the following logs:

Log of well of Louis Warnken, plant 24, SW. ¼ sec. 1, T. 7 N., R. 1 E.

[Bored by Rowe & Wire in 1912; 12 inches in diameter, galvanized-iron casing to 62 feet; perforated between 22 and 42 feet.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	20	20	Sand	2	62
Not known	2	22	Clay	38	100
Gravel	20	42	Gravel.		
Clay	18	60			

Log of well No. 2 of J. A. Little, plant 27, NW. ¼ sec. 11, T. 7 N., R. 1 E.

[Bored by Buck & Nevin in 1912; 12 inches in diameter.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	27	27	Clay	12	71
Gravel	32	59	Gravel.		

Log of well of B. F. Newby, plant 48, NE. ¼ sec. 14, T. 7 N., R. 1 E.

[Bored by Rowe & Wire in 1909; 12 inches in diameter; cased to 72 feet; filled after pumping to 79 feet.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil and clay	20	20	Clay	46	92
Clay and some sand	10	30	Coarse black sand	4	96
Clay	15	45	Fine gravel	3	99
Sand	1	46			

The thickness and distribution of gravel east of Winters and south of Putah Creek is shown in the following log:

Log of well of Peter T. Gannon, plant 123, Rio de los Putos rancho.

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	20	20	Gravel	22	53
Soft yellow clay	5	25	Clay	12	65
Fine sand	3	28	Sand	2	67
Coarse sand	3	31	Gravel.		

In the narrow Vaca Valley the younger alluvium is fine grained and has no coarse gravels. It rests upon the older rocks and is about 60 feet thick, as shown by the wells of the Vacaville Water & Light Co. The alluvium is a free water bearer, but the supply is inadequate for the complete irrigation of the valley.

From Vacaville southeastward through Elmira to Yolo Basin the younger alluvium is thin and rests on the eroded surface of the older alluvium. The exact demarcation between the two can not be detected in well logs, but all the wells encounter cemented beds and dense clays. Wells in this area are likely to have smaller yields than wells in the vicinity of Dixon or along the banks of Putah Creek.

PUBLIC SUPPLIES.

Dixon.—The waterworks of Dixon are owned and operated by the Pacific Gas & Electric Co. The supply is obtained from two wells 200 feet deep, about 30 feet apart, which are pumped by two 2½-inch American horizontal centrifugal pumps set 6 feet below the surface and direct-connected to a 20-horsepower Fort Wayne motor. The pumps may be used in series or in parallel. Ordinary pumping to tanks is done "in parallel," but in case of fire the pumps are connected directly to the mains and used in series. There are two 35,000-gallon wooden tanks, each on a wooden tower 60 feet high. The charges for water are reported to be 35 cents per 1,000 gallons.

Winters.—The waterworks of Winters are owned by the town. At the pumping station, which is in the western part of the town, there are three wells, each 165 feet deep. Each well has a 16-inch galvanized-iron casing extending to a depth of 45 feet, where it is seated in clay, and inside of which there is a 10-inch galvanized iron casing extending to the bottom. The lowest three joints of the 10-inch casing are perforated. The space between the two casings is filled with concrete. The first well was put down in 1899, the last in 1905. The equipment consists of a 2½-inch Krogh horizontal centrifugal two-stage pump direct connected to a 15-horsepower General Electric motor. The motor can be thrown out of connection and the pump run by a 25-horsepower Westinghouse 2-cylinder vertical gas engine. The pumps lift the water to a 54,000-gallon wooden tank set 66 feet above ground.

The minimum flat rates are $1.25 a month. The canneries and the railroad have meters and are charged 25 cents per 1,000 gallons for the first 5,000 gallons, 10 cents per 1,000 for the next 200,000, and 5 cents per 1,000 for any more. (For an analysis of the water see A54, p. 233.)

Information was furnished by L. H. Gregory, city engineer, in charge of the plant.

Vacaville.—The town of Vacaville is supplied with water by the Vacaville Water & Light Co. from wells at two stations.

At the old station, northwest of the town, there is a dug well 10 by 12 feet, 38 feet deep, with a wood and brick curb, and seven wells farther east spaced 40 feet apart, each 12 inches in diameter, about 62 feet deep, with perforated galvanized-iron casing. Set in a pit 16 feet below the surface is a 2½-inch Krogh horizontal centrifugal pump, direct connected to a 7½-horsepower General Electric motor.

At the new station, southeast of the town, there is a well bored 12 inches in diameter, 55.5 feet deep, with galvanized-iron casing. The well is pumped by a 2½-inch Krogh horizontal centrifugal pump, direct connected to a 7½-horsepower motor. The pumps at both stations lift the water against a head of 78 feet to a 118,000-gallon cement reservoir on a hill.

Most of the services are metered, the charges being 25 cents per 1,000 gallons to small consumers and 15 cents per 1,000 gallons to large consumers. One dollar a month is the minimum charge, and $1.50 is the average for a small family. The daily consumption is about 100,000 gallons in winter and 200,000 gallons in summer.

The information was furnished by W. Z. McBride, manager.

Fairfield.—Fairfield, the county seat of Solano County, is supplied with water by H. G. Goosen, operating under the name of the Fairfield Waterworks. The plant is in the western outskirts of the town.

In all about 46 wells have been put down, ranging in depth from 45 to 800 feet. Fresh water is found between 50 and 150 feet and at 800 feet, but salt water is found at several depths between 150 and 800 feet. The present supply is obtained from several small units pumping from shallow wells 6 inches in diameter. There are three wooden receiving tanks set on the ground, one with a capacity of 10,500 gallons and two of 5,000 gallons. At the time the plant was visited the pumping units were as follows: Two Gardner 6 by 6 inch air compressors, belted to a 25-horsepower motor, pumped from four wells; two deep-well cylinder pumps, 3 by 9 inches, each in a well, were run by a 1-horsepower motor; two deep-well cylinder pumps, 5 by 9 inches, each in a well, were run by a 2-horsepower motor; a Gould deep-well pump, 5 by 9 inches, was run by a 2-horsepower gasoline engine; in addition there were eight windmills, each on a well, two of which were temporarily out of repair. The water from these sources was pumped from the receiving tank to five 10,000-gallon wooden tanks set on a wooden tower 60 feet high. The following units were in place: 3½ by 4 inch Gould triplex pump belted to a 2-horsepower motor; 5 by 6 inch double-acting cylinder pump belted to a 2-horsepower motor; 5 by 6 inch double-acting cylinder pump belted to a 2-horsepower motor. The lift from the water when pumping to the surface of ground was between 30 and 47 feet in 1914. In average seasons it is 28 to 30 feet. The capacity of the plant is estimated at 350,000 gallons a day.

There is a complicated system of flat rates. A dwelling with six persons pays $1.50 a month. When meters are used the charge is 45 cents per 1,000 gallons for 1,000 to 5,000 gallons; 35 cents for 5,000 to 30,000 gallons; 30 cents for 30,000 to 50,000 gallons; 25 cents for 50,000 to 100,000 gallons; 20 cents for all over 100,000 gallons. The irrigation charge is 50 cents for each 2,500 square feet.

Information was furnished by H. G. Goosen.

Binghampton.—The water supply for Binghampton is obtained from two bored wells 12 inches in diameter, depth not known. There is a cement pit 6 by 8 feet and 9 feet deep. The depth to water in September, 1914, was 1.7 feet from the top of the casing, near the bottom of the pit. The water was lifted by a 6-inch horizontal centrifugal pump belted to a 45-horsepower Brown-Cochran gas engine. This plant also supplied water for the irrigation of 20 acres of alfalfa in 1914.

Suisun.—The town of Suisun has a system of waterworks owned by the municipality. The main supply comes from three springs and a reservoir 8 miles northwest of Suisun, at the foot of Three Sisters Mountain.

The reservoir has a capacity reported at 70,000,000 gallons. A pipe line 5 miles long leads the water to a distributing reservoir, from which it is brought to town through 3 miles of 8-inch cast-iron pipe under a pressure ranging between 65 and 75 pounds to the square inch.

During 1912 and 1913 the reservoir was dry most of the time. Similar periods of deficient rainfall have led to attempts to supplement the supply. A tunnel 315 feet long was driven into the hill in the canyon near the spring. It has a capacity in normal years of about 35,000 gallons a day. A well 12 inches in diameter and 278 feet deep was sunk in 1913 and equipped with a deep-well cylinder pump. The capacity is estimated at 80,000 gallons daily. As dry seasons may be expected at intervals, it is obvious that measures should be taken to increase the supply.

Ground water may be obtained in wells over the plain extending northward to the foothills. The wells must be shallow, however, to avoid striking salt water. The alluvium is so fine grained that large yields can not be expected from single wells of the ordinary type. Large gravel-walled wells spaced over a considerable area are recommended. Such a plant, though entirely feasible, is likely to prove expensive, both in first cost and maintenance. The possibility of additional storage reservoirs near the present one should be carefully investigated.

There were 225 consumers in 1914. The flat rate for a household of three was $1.25 a month, and 15 cents additional for each additional person. Meter rates were $1.25 for the first 4,500 gallons, 50 cents per 1,000 gallons for the next 5,000 gallons, and 15 cents per 1,000 for the next 15,000 gallons. Consumers of 50,000 to 100,000 gallons a month get a special rate of 15 cents per 1,000 gallons.

Information was furnished by J. A. Wilson, superintendent.

QUALITY OF WATER.

The five analyses and three assays given in the accompanying table show a general agreement in composition of the waters analyzed. A60 resembles the waters at the north end of the valley; the others contain more dissolved solids, and all but A58 are harder than the average for the whole valley. Practically all should be entirely satisfactory for irrigation and, except for the hardness, well adapted to all other ordinary uses.

Chemical composition and classification of ground waters in Davis-Dixon-Winters area.

[Analyses by S. C. Dinsmore; assays by G. H. P. Lichthardt. Parts per million except as otherwise designated. Numbers at heads of columns refer to locations so marked on Pl. IV.]

	Analyses.					Assays.		
	A54	A55	A56	A57	A58	A59	A60	A61
Silica (SiO_2)	56	34	36	25	41			
Iron (Fe)	.30	.22	.20	.20	1.0			
Calcium (Ca)	48	47	51	53	24			
Magnesium (Mg)	21	50	65	66	6.1			
Sodium and potassium (Na+K)[a]	37	8.6	7.4	18	91	27	14	32
Carbonate radicle (CO_3)	0	0	0	0	0	0	0	0
Bicarbonate radicle (HCO_3)	299	352	452	479	260	409	122	353
Sulphate radicle (SO_4)	14	27	16	21	31	50	Trace.	85
Chloride radicle (Cl)	15	15	13	14	27	16	16	50
Nitrate radicle (NO_3)	8.0	4.8	6.0	10	.00			
Total dissolved solids	348	357	413	445	336	490	170	550
Total hardness as $CaCO_3$	[a] 206	[a] 322	[a] 394	[a] 403	[a] 85	357	95	384
Scale-forming constituents[a]	230	260	290	290	120	400	140	410
Foaming constituents[a]	100	23	20	49	250	70	40	90
Alkali coefficient (inches)[b]	25	140	160	122	9.6	100	70	40
Classification:								
Domestic use	Good.	Fair.	Poor.	Fair.	Good.	Poor.	Good.	Poor.
Boiler use	Poor.	Poor.	Poor.	Poor.	Fair.	Poor.	Fair.	Poor.
Irrigation use	Good.	Good.	Good.	Good.	Fair.	Good.	Good.	Good.
Mineral content	Moderate.	Moderate.	Moderate.	Moderate.	Moderate.	Moderate.	Moderate.	High.
Date of collection	Dec. 29, 1913.	Jan. 2, 1913.	Dec. 16, 1912.	Dec. 17, 1912.		Dec. 13, 1912.	Jan. 1, 1913.	Jan. 7, 1913.

a Calculated.
b Depth in inches of water which on evaporation would yield sufficient alkali to render a 4-foot depth of soil injurious to the most sensitive crops.

A54. Composite of three wells (165 feet deep), municipal supply at Winters.
A55. Bored well (96 feet deep, 12 inches in diameter) at pumping plant of H. R. Bowman, Winters.
A56. Bored well (120 feet deep, 12 inches in diameter) of M. D. Campbell, Dixon (SE. ¼ sec. 11, T. 7 N., R. 1 E.).
A57. Well (76 feet deep, 12 inches in diameter) at pumping plant of D. W. Wright, Dixon (SW. ¼ sec. 18, T. 7 N., R. 1 E.).
A58. Artesian well (1,030 feet deep) of W. Y. Gordon, near Davis (NW. ¼ sec. 24, T. 8 N., R. 2 E.).
A59. Well (195 feet deep, 12 inches in diameter) of Chris Olsen, Dixon (NE. ¼ sec. 21, T. 8 N., R. 3 E.).
A60. Bored well (about 61 feet deep, 12 inches in diameter) at pumping plant of S. A. Dotters, Winters (SW. ¼ sec. 19, T. 7 N., R. 1 E.).
A61. Composite of six wells (about 60 feet deep, 12 inches in diameter) supplying pumping plant No. 4 of Pacific Portland Cement Co., near Vacaville.

PUMPING PLANTS.

Pumping plants in the Davis-Dixon-Winters area.

Davis group.

Owner.	Location. Section.	Township N.	Range E.	Diameter of well.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horsepower.	Area irrigated.
				Inches.	*Feet.*	*Feet.*	*Inches.*		*Acres.*
T. S. Glide				12 12	128 87	[a] [b] 3.5	6	20	
B. C. French	SE. ¼, 12	8	1	12		[a] [c] 18.5	6	10	10
University Farm	NW. ¼, 15	8	2	12	112	(d)	4	7½	(e)
Eli Snyder	NW. ¼, 13	8	2	12	118		6	8	4
W. L. Haley	N. ½, 13	8	2	12	127	[a] [c] 17.4	6		
A. Bueri & Co.	NE. ¼, 13	8	2	12	100		4	10	35
T. Ricci	NW. ¼, 13	8	2	12	80		3	6	12
W. H. Baker	SW. ¼, 18	8	3	10 8 8	100 60 60	[a] [f] 2.0	4	6	15
Deacon ranch				14	175		[g] 13	20	15

a Measured in December, 1912.
b From floor of pit.
c From top of pit.
d Series of measurements on p. 88.
e Acreage varies.
f From top of casing.
g Turbine centrifugal pump.

Pumping plants in the Davis-Dixon-Winters area—Continued.

Dixon group.

Owner.	Location. Section.	Location. Township N.	Location. Range E.	Diameter of well.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horse-power.	Area irrigated.
				Inches.	*Feet.*	*Feet.*	*Inches.*		*Acres.*
A. T. Foster:									
Plant No. 1	Los Putos rancho			(h)		[a][c] 17.1	5	12	100
Plant No. 2	do			(i)		[a][c] 21.8	6	30	
J. H. Glide:									
South plant	do			(j)		[a][f] 5.8	7	20	160
North plant	do			[h] 12		[a][f] 6.1	8	30	
A. T. Hillhouse	do			12		[a][f] 8.5	6	15	40
O. P. Gilliam	do			[j] 12			5	15	40
Elmer McNair	Río de los Putos rancho and Los Putos rancho.			10	70		5	10	40
E. R. Teaford	Río de los Putos rancho			[h] 12	60		7	20	(k)
T. A. Sparks	Los Putos rancho			[j] 12		[a][f] 14.0	7	20	40
William Patterson	Río de los Putos rancho			[j] 12	65		6	12	40
Williams Bros	Los Putos rancho			[j] 12	45		8	25	
John Kilkenny	do			12	100	[a][f] 11.2	5	10	24
R. T. Currey	do			12	70	[a][f] 5.6	5	10	40
Collier Bros	SW. ¼, 32	8	2	10	70	[a][f] 6.6	5	15	20
Louis Warnken	SW. ¼, 1	7	1	12	100		7	20	40
H. McFadgen	SE. ¼, 2	7	1	12 12	80 180	[a][f] 10.0	8	20	80
J. A. Little:									
Plant No. 1	SW. ¼, 2	7	1	12	75		5	10	12
Plant No. 2	NW. ¼, 11	7	1	12	71	[a][f][l] 24.7			40
S. H. Fountain:									
Plant No. 1	S. ½, 3	7	1	[i] 12	30		6	15	160
Plant No. 2	S. ½, 3	7	1	[h] 12	170		8	20	160
J. Liter (W. H. Garnett)	NW. ¼, 4	7	1						80
J. Ahern	SW. ¼, 10	7	1	[h] 12	140		6	20	64
H. Kirk:									
Plant No. 1	NE. ¼, 10	7	1	10	40	[a][f] 11.3	8	20	160
Plant No. 2	NE. ¼, 10	7	1	12	70		8	35	
Mrs. N. M. Higgins	SW. ¼, 11	7	1	12	65	[a][f] 16.0	7	20	120
M. D. Campbell	SE. ¼, 11	7	1	12	120	[a][f] 14.5	7	30	40
E. D. Dudley	NW. ¼, 12	7	1	12	81	[a][f] 10.0	7	20	40
M. H. Whitacre	NW. ¼, 12	7	1	12	100	[a][f] 10.2	7		80
D. W. Wright	SW. ¼, 12	7	1	12	75	[a][f][m] 12.0	5	10	15
Mrs. George Grieve	S. ½, 12	7	1	12		[a][f] 14.6	4	7½	7
Leland S. Hyde	NW. ¼, 13	7	1	10	101		6	20	85
Elmer McNair	SW. ¼, 12	7	1	12	90		6	15	30
Thomas T. Eibe	SE. ¼, 12	7	1	10	97	[a][b] 7.0	5	12	10
J. P. Martin	NE. ¼, 12	7	1	10			6	15	65
H. R. Timm:									
Plant No. 1	NE. ¼, 13	7	1	12	99		8	35	160
Plant No. 2	NE. ¼, 13	7	1	12	100		8	25	
Mr. Bruno	NW. ¼, 13	7	1	12		[a][f] 5.2	4	6	10
Elmer E. Nudd	SW. ¼, 13	7	1	12	68		6	10	56
Fred Hutton	NW. ¼, 13	7	1	10			5	15	25
B. F. Newby	NE. ¼, 14	7	1	12	99		5	10	20
Carl Schmeiser:									
Plant No. 1	NE. ¼, 14	7	1	12	94	[a][f] 11.0	6	15	40
Plant No. 2	SW. ¼, 14	7	1	14	[n] 96		14	12	40
E. D. N. Lehe	NE. ¼, 14	7	1	12	96 (?)	[a][f] 14.3	6	15	40
J. D. Grady	NE. ¼, 14	7	1	12			6	15	40
E. R. Watson	NW. ¼, 14	7	1	[j] 12	70		8	20	180
W. A. Scott	NW. ¼, 15	7	1	10	75	[a][b] 2.0	4	10	20
J. E. Duncan	NW. ¼, 15	7	1	[j] 12	150	[a][f] 6.2	5	10	50
W. L. Bowron	SE. ¼, 18	7	1	8			5	10	40
J. B. Herold:									
South plant	NW. ¼, 18	7	1	12	104	[o][f] 5.4	4	10	30
North plant	NW. ¼, 18	7	1 W.	10	104		3	7½	
Sam Cogle	NE. ¼, 13	7	1 W.	10	100		4	10	40
Wilbur Eibe	NE. ¼, 13	7	1 W.	10	102		3	6	6

[a] Measured in December, 1912.
[c] From top of pit.
[f] From top of casing.
[h] Three wells.
[i] Four wells.
[j] Two wells.
[k] Location on Plate IV not exact.
[l] 1.5 feet above surface of ground; plant not installed on day of measurement.
[m] In August, 1914, 16.7 feet.
[n] 12 inches from 40 to 96 feet.
[o] Measured in January, 1913.

Pumping plants in the Davis-Dixon-Winters area—Continued.

Dixon group—Continued.

Owner.	Location. Section.	Township N.	Range E.	Diameter of well.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horsepower.	Area irrigated.
				Inches.	*Feet.*	*Feet.*	*Inches.*		*Acres.*
Arminini Bros	NE. ¼, 24	7	1	10	60	....	2½	5	15
R. Udell	NW. ¼, 19	7	1	10	108	(*p*)	5	15	30
J. Dodini:									
Plant No. 1	NE. ¼, 19	7	1	12	112	....	6	15	40
Plant No. 2	NE. ¼, 19	7	1	12	86	....	6	15	
S. A. Dotters	SW. ¼, 19	7	1	12	61	*o f* 4.0	5	10	90
J. L. Handbine	SW. ¼, 25	7	1 W.	10	120	*o b* 0.0	2½	5	10
H. H. Thompson	NW. ¼, 20	7	1	8	....	*o f* 8.4	4	10	20
Thomas O'Day	SW. ¼, 29	7	1	12 12	62 52	....	6	15	*q* 320
Andy Burns	NW. ¼, 32	7	1	12	....	*a c* 14.5	3	15	
Peter Yolo	SW. ¼, 31	7	1	10	70	*f* 3.9	3	7½	15
O. B. Little	NW. ¼, 33	7	1	10	96	....	....	....	(*r*)
McRae Bros	SE. ¼, 29	7	1	10	40	....	6	15	*k* 15
J. N. Garnett	NE. ¼, 21	7	1	12	196	....	6	25	55
H. R. Timm	NE. ¼, 22	7	1	12	....	....	....	....	....
Do	NE. ¼, 22	7	1	12	....	....	*g* 24	30	80
Dickie Bros	SE. ¼, 22	7	1	10	120	....	6	15	55
Stuart Grady	NW. ¼, 23	7	1	12	150	*o f* 3.1	6	15	80
E. C. Eames	NE. ¼, 26	7	1	*s* 12	71	*a f* 7.1	5	15	15
John Blume	SW. ¼, 24	7	1	*t* 8 12	80	....	7	20	50
A. Peters	NW. ¼, 24	7	1	*t* 12 8	96 96	....	5	10	30
D. D. Saltzen	NW. ¼, 7	7	2	12	46	*a b u* 10.0	5	10	25
H. R. Timm	SW. ¼, 7	7	2	*t* 12	....	....	6	15	80
H. R. Timm (lessee)	SW. ¼, 7	7	2	12	....	*a f* 7.1	6	15	40
Mr. Colwell	SW. ¼, 7	7	2	....	....	....	....	....	40
F. B. Field	NW. ¼, 18	7	2	12	120	*a f* 4.3	7	25	50
E. C. Anderson	SE. ¼, 18	7	2	12	112	*o f* 9.0	6	....	34
T. F. Fritz	NE. ¼, 18	7	2	10	200	....	*g* 24	20	80
Mrs. Edith Westmyer	NE. ¼, 18	7	2	12	55	....	6	15	80
William Tuttle	SE. ¼, 7	7	2	*t* 12	....	*a f* 7.0	8	20	80
P. S. Goodman	NW. ¼, 16	7	2	12	169	*a f v* 5.5	7	25	50
Mrs. H. Hackman	NW. ¼, 15	7	2	12	70	....	4	....	10
Ed. Fendner	NW. ¼, 21	7	2	12	146	*a f* 8.3	6	20	40
Albert Miller	SW. ¼, 21	7	2	12	86	....	*g* 12	....	20
W. F. Schaad	NE. ¼, 28	7	2	10	63	....	5	10	12
Peter W. Boyens	SE. ¼, 22	7	2	12	86	....	*g* 12	....	14
Mrs. C. M. Woodward	SW. ¼, 27	7	2	12	*w* 205	....	7	15	30
Mr. Miller	NW. ¼, 35	7	2	12	....	....	5	15	30
John M. Maxwell	NW. ¼, 12	7	2	12	135	*a f* 1.0	....	....	30
J. T. Williams	SE. ¼, 8	7	3	12	142	*a f* 14.0	....	....	....
Do	NW. ¼, 9	7	3	12	65	*a f* 5.1	....	....	12
H. F. Anderson	....	....	....	10	65	....	3	8	8
O. B. Wilbur	....	....	....	*t* 12	....	....	5	10	35
Mr. Ross	SE. ¼, 25	8	2	(*t*) 10	130 160	....	....	....	....
F. W. Hyde	....	....	....	10	*s* 180	....	5	25	20

a Measured in December, 1912.
b From floor of pit.
c From top of pit.
f From top of casing.
g Turbine centrifugal pump.
k Location on Plate IV not exact.
o Measured in January, 1913.
p Owner's statement, 1 foot from floor of pit in spring of 1912, 5 feet in December, 1912.
q Five plants similar to this one installed to irrigate this tract.
r Tested successfully with 5-inch pump.
s Cased to 54 feet.
t Caved and abandoned.
u Owner's statement, 1 foot below floor, February, 1911; 3 feet above floor, February, 1910.
v Owner's statement, 3.0 feet from top of casing, May, 1914.
w Cased to 105 feet.

Pumping plants in the Davis-Dixon-Winters area—Continued.

Winters group.

Owner.	Location. Section.	Township N.	Range E.	Diameter of well.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horsepower.	Area irrigated.
				Inches.	*Feet.*	*Feet.*	*Inches.*		*Acres.*
Wyatt Bros	NE. ¼, 13	8	1 W.	*j* 10	....	*o f* 6.2	6	20	80
M. Kahn	Río de los Putos rancho			16	160	*o c* 27.6	6	20	70
C. O. Brattin	NW. ¼, 22	8	1 W.	12	70	*o c* 28.0	3	5	20
Haven & Kettenberg	Río de los Putos rancho			14	121	*a x* 5.3	4	10	44
J. G. Young	do			8 by 10 ft.	*y* 45	*a c* 45	3	12	10
C. M. Cooper	do			8 by 10 ft.	*z* 46	....	5	20	30
Mrs. P. Udell	do			6	270	....	6	35	40
A. P. Pleasants	do			10	*aa* 101	*a c* 38.0	4	....	....
Archibald Wolfskill	do			14	65	....	*g* 14	12	20
Frank Wolfskill	do			4 by 4 ft.	*bb* 36	....	....	....	....
F. W. Wilson	do			6 by 8 ft.	*cc* 45	....	5	20	120
W. S. Baker	do			10 by 12 ft.	*dd* 45	*o c* 33.6	5	35	25
P. H. Johnson	do			13	90	....	4	10	44
H. Boyce	do			14	80	*o c* 30.0	6	20	220
H. R. Bowman	do			12	96	....	5	24	110
J. B. Bowman	do			12	102	....	5	20	60
Mr. McCormick	do			12	90	....	4	12	40
C. E. Gregory	do			....	....	....	4	10	27
Do	do			....	....	....	4	10	19
L. T. Brock	do			6 by 6 ft.	*ee* 40	*o c* 39.4	4	12	68
T. M. Johnson	do			10 ft.	42	*o c* 35	5	15	166
Peter T. Gannon	do			....	67	*o c ff* 26.5	5	18	40
A. S. Bird	do			12 12	150 70	....	6	20	100
John Forrest	do			10	56	....	4	10	30

Vacaville group.

Owner.	Section.	Township N.	Range E.	Diameter of well.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horsepower.	Area irrigated.
F. B. Chandler Co	Los Putos rancho			*h* 12	60	....	5	10	20
R. S. Clark	W. ½, 24	6	1 E.	8 12	180 70	*o c* 23.4	....	....	....
Pacific Portland Cement Co.:									
Plant No. 1	Los Putos rancho			12	60	....	(*gg*)	15	*ii* 10
Plant No. 2	do			12	60	....	(*gg*)	15	
Plant No. 3	do			12	60	....	(*gg*)	15	
Plant No. 4	do			*hh* 12	60	....	4	15	
Plant No. 5	do			*j* 12	60	....	(*gg*)	15	
Plant No. 6	do			*j* 12	60	....	(*gg*)	15	
Plant No. 7	do			12	60	....	5	15	
Plant No. 9	do			12	62	....	3	15	

a Measured in December, 1912.
c From top of pit.
f From top of casing.
g Turbine centrifugal pump.
h Three wells.
j Two wells.
o Measured in January, 1913.
x From center of pump.
y Uncased hole 7 by 9 feet, 20 feet deeper, and uncased bored hole 16 inches in diameter, 25 feet deeper; total depth 90 feet.
z Bored hole in center 12 inches in diameter, 70 feet deep.
aa Cased to 72 feet.
bb 10-inch bored well in center, 64 feet deeper.
cc 16-inch bored well in center, 30 feet deeper.
dd Two bored wells in bottom, 25 and 45 feet deeper.
ee Bored well in bottom 14 inches in diameter, 50 feet deep.
ff Owner's statement: before 1906 water stood about 28 feet, in that year rose to 22.5 feet; fell below bottom of pit in 1912.
gg 4-inch lift pump.
hh Six wells; for analysis see A61, p. 213.
ii All plants pump to 50,000-gallon tank, and thence water is pumped to company's cement plant in NW. ¼ sec. 17, T. 5 N., R. 1 W.; only surplus water used for irrigation.

RIO VISTA AREA.

The Rio Vista area includes the rolling area of the Montezuma Hills and a narrow strip bordering the hills on the east side. (See Pl. II.) The area has been largely devoted to growing grain. As shown in Plate VI, *B*, the hillsides are remarkably smooth, and in spite of the steep slopes plows, harrows, and even combined harvesters can be operated successfully.

The area is subject to cold winds and fogs, and its utility as an orchard region has yet to be proved. A few plants have been put in to pump water for the irrigation of alfalfa.

J. H. Fraser, in 1913, drilled a well 8 inches in diameter and 104 feet deep. Gravel the size of a robin's egg was found between 50 and 54 feet. This well replaced an 8-inch well 84 feet deep, which in 1912, with a 2-inch centrifugal pump and 4 horsepower engine, irrigated 4 acres of alfalfa.

Peter Hamilton drilled a well 8 inches in diameter and 165 feet deep. This well is cased to 100 feet and at about this level struck water which rose within 24 feet of the surface. A second water-bearing bed was struck at 160 feet which brought the water level to 16 feet. A slight artesian head, attributable to the eastward dip of the older alluvium (p. 77) is evident in this well. A 5-inch centrifugal pump and 10-horsepower motor were installed in 1912, but irrigation had not begun.

Fraser Bros. irrigated 16 acres from a well 8 inches in diameter, 140 feet deep, equipped with a 5-inch centrifugal pump and a 10-horsepower motor.

These wells indicated that moderate supplies of water can be obtained in the area. In the western part of the Montezuma Hills the pumping lifts are likely to be high.

SACRAMENTO AREA.

GENERAL CONDITIONS.

The Sacramento area lies chiefly in Sacramento County and includes all of the valley south of American River and east of Sacramento River. (See Pl. II.) It includes Sacramento, the largest city in the valley, and is on the whole the most highly developed area in the valley.

The city of Sacramento (population 65,908 in 1920) is a rapidly growing community. It was settled about 1841 by Gen. John Sutter and has been the State capital since 1848. From the city in all directions radiate roads, made in the early days before the public-land survey. It is a railroad center, a division point on the Ogden line of the Southern Pacific Railroad and the terminus of the Placerville and Sacramento lines. It is also on the Western Pacific Railroad. It is the terminus of the following electric railroads: Central California Traction, to Stockton; Northern Electric, to Marysville and Chico;

Northern Electric, to Woodland; Oakland & Antioch, to San Francisco.

Along the Southern Pacific Railroad south of Sacramento are Florin (population 385 in 1910), Elk Grove (population 500 in 1910), and Galt (population 985 in 1910). East of the city, in the edge of the foothills, lie Folsom (population 1,200 in 1910) and Fairoaks, a thriving colony. Woodbridge, Lockeford, and Clements are villages along Mokelumne River.

In 1912 1,700 acres was irrigated from American and Cosumnes rivers and 28,000 acres by pumping of surface water in the island country.[25] The census of 1910 reported 1,192 plants pumping from wells and irrigating 11,300 acres in Sacramento County. Most of the development is within this area. Figures collected by J. W. Muller in 1914 for this investigation gave 939 pumping plants, owned by 837 persons or companies and irrigating 10,625 acres. The total installed horsepower in 1914 was 5,990. As development was very rapid during 1912–1914, the total acreage appears low. This is thought to be due to different standards as to what constitutes a pumping plant. The census of 1910 includes many acre and half-acre plots near ranch houses which Mr. Muller disregarded as not constituting commercial irrigation

Detailed data regarding the pumping plants in this area are given in the accompanying table, and the locations of the irrigated tracts are shown in Plates IV. Parts of this area have been developed intensively by the installation of numerous small pumping plants. Near Florin there are as many as 50 or 60 plants to the square mile.

GEOLOGY AND PHYSIOGRAPHY.

The Sacramento area includes a bench of red lands lying at the foot of the Sierra Nevada, the gentle alluvial slope of the low plains, the Sacramento flood basin, a strip of river lands, and a large part of the delta of Sacramento River, called the island country.

In this area the red lands and low plains together form a broad belt whose upper part is somewhat undulating and lower part very flat. It is difficult to distinguish between the two kinds of alluvium, but in a general way the redder, higher knolls consist of older alluvium. The higher plains are formed of older alluvium capping Tertiary beds. For descriptions of the river lands, the Sacramento basin, and the island country, see pages 36 and 43–45.

GROUND WATER.

WELLS.

In the low plains, including the flood plains of American, Cosumnes, and Mokelumne rivers, good wells are obtained at small cost. In general the water comes from beds of sand between cemented gravels

[25] Adams, Frank, Irrigation resources of California: California Conservation Comm. Rept., 1912, pp. 163–165.

and clays, which do not cave readily and which therefore form good roofs, allowing extensive cleaning out of the water-bearing sands. A very large amount of development has taken place, and all the lower plains may be considered proved territory for ground water. Wells with yields large enough for orchard irrigation can probably also be obtained in the higher plains, but near the mountains the alluvium is thin and the prospects are not so good.

Information in regard to the deep wells drilled by the Sacramento Natural Gas Co. is given on pages 276–280.

QUALITY OF WATER.

The four analyses and three assays given in the accompanying table show a range in dissolved solids from 150 to 450 parts per million. In general, however, the quantity is decidedly less than in water from the west side of the valley. All but one of the waters are classed as good for irrigation. They are sufficiently hard to cause more or less trouble from scale when used in steam boilers, but this can be prevented by proper treatment. Except for the hardness, none of the mineral constituents of these waters affect unfavorably their use for domestic purposes.

Chemical composition and classification of ground water in Sacramento area.

[Analyses by S. C. Dinsmore; assays by G. H. P. Lichthardt. Parts per million except as otherwise designated. Numbers at heads of columns refer to locations so marked on Pl. IV.]

	Analyses.				Assays.		
	A62	A63	A64	A65	A66	A67	A68
Silica (SiO_2)	60	58	56	61			
Iron (Fe)	.02	.60	.10	.05			
Calcium (Ca)	20	21	58	36			
Magnesium (Mg)	12	15	26	10			
Sodium and potassium (Na+K) [a]	[b] 13	[c] 20	52	48	11	5	12
Carbonate radicle (CO_3)	0	0	0	0	0	0	0
Bicarbonate radicle (HCO_3)	102	146	222	151	107	183	212
Sulphate radicle (SO_4)	14	18	27	23	Trace.	3	3
Chloride radicle (Cl)	18	7.0	95	61	10	68	138
Nitrate radicle (NO_3)	4.0	3.0	24	2.4			
Total dissolved solids	181	214	434	296	[a] 150	[a] 310	[a] 450
Total hardness as $CaCO_3$	[a] 99	[a] 114	[a] 252	[a] 131	80	240	348
Scale-forming constituents [a]	140	140	270	190	120	280	390
Foaming constituents [a]	35	54	140	130	30	10	30
Alkali coefficient (inches) [d]	110	69	21	32	80	30	15
Classification:							
Domestic use	Good.	Good.	Fair.	Good.	Good.	Fair.	Poor.
Boiler use	Fair.	Fair.	Poor.	Fair.	Fair.	Poor.	Poor.
Irrigation use	Good.	Good.	Good.	Good.	Good.	Good.	Fair.
Mineral content	([e])	([e])	([e])	([e])	Low.	([e])	([e])
Date of collection	Dec. 24, 1913.	Jan. 22, 1913.		Dec. 22, 1913.	Dec. 18, 1913.	Dec. 20, 1913.	Dec. 23, 1913.

[a] Calculated.
[b] Determined. Na=8.8; K=3.9 parts per million.
[c] Determined. Na=13; K=6.6 parts per million.
[d] Depth in inches of water which on evaporation would yield sufficient alkali to render a 4-foot depth of soil injurious to the most sensitive crops.
[e] Moderate.

A62. Composite of seven wells supplying Oak Park Water Co., Sacramento.
A63. Well (240 feet deep, 10 inches in diameter), municipal supply at Elk Grove.
A64. Dug well (60 feet deep, 4 feet in diameter), municipal supply at Lockeford.
A65. Dug well (96 feet deep, 4 feet in diameter) at plant of W. B. Rainey, Clements.
A66. Well (about 30 feet deep, 8 inches in diameter) at Arno.
A67. Well (108 feet deep, 8 inches in diameter) at pumping plant of H. D. Warriner, near Galt (SE. ¼ sec. 14, T. 4 N., R. 6 E.).
A68. Dug well (65 feet deep, 5 feet in diameter) of John Harris, near Wallace (NE. ¼ sec. 17, T. 4 N., R. E.).

PUMPING PLANTS.

Pumping plants used for irrigation in the Sacramento area.

Owner.	Location. Section.	Location. Township N.	Location. Range E.	Diameter of well.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horsepower.	Area irrigated.
Lovdal quadrangle.				*Inches.*	*Feet.*	*Feet.*	*Inches.*		*Acres.*
Lon Burns	New Helvetia rancho			10	50	12	3	5	5
Chas. Conley	do			....	37	10.6	2	3	4
Vim. Merkeley	do			10	80	12.7	4	5	10
Joe Rope	do			8	96	12	3½	7½	6
Brighton quadrangle.									
W. Kindle	25	8	4	12	34	24	6	10	40
E. Davis	25	8	4	6	35	25	1½	2	2
F. B. Sutiff	25	8	4	10	32	24.8	4	4	4
Do	36	8	4	12	33	24.3	4	8	10
J. S. Brown	13	8	5	8	75	20	2	5	17
	13	8	5	10	76	22	3	8	40
H. S. Kirk	13	8	5	8	84	19	3	7	15
Do	13	8	5	10	88	18.4	3	10	10
Do	13	8	5	8	79	18	3	5½	4
Do	13	8	5	10	80	23	2	6	20
H. Yoshimo	13	8	5	10	92	27	2½	8	20
	14	8	5	10	80	22	3	8	20
H. Yoshimo	14	8	5	10	86	26	2½	8	20
William Niess	19	8	5	10	68	19.7	3	3	4
L. Hasan	20	8	5	10	70	22	2½	3	3
H. Bridge	20	8	5	8	67	24.3	2½	3	3
F. Hyte	20	8	5	8	60	20.2	2½	3	5
C. H. Selvey	20	8	5	10	62	19.2	3	3	5
George Ruchey	20	8	5	8	60	18.3	3	3	4
J. C. Brown	20	8	5	6	68	17.5	3	4	5
William Algar	20	8	5	8	60	17.3	3	4	5
W. Gile	20	8	5	8	64	19.2	2½	4	5
Albert Gaselly	20	8	5	10	57	18.3	3	4	4
A. D. Davis	23	8	5	12	200	22	6	22	80
	23	8	5	10	145	21	3	10	20
	23	8	5	8	163	23	3	8	30
	23	8	5	10	137	24	3	10	40
	23	8	5	10	156	22.2	3½	10	30
	23	8	5	10	169	22	3	12	40
	23	8	5	8	100	20	3	8	20
	23	8	5	10	176	23	3	10	40
	23	8	5	10	166	24	3½	12	30
	23	8	5	8	146	22	3	15	40
	23	8	5	10	152	21	3	12	30
J. M. Davis	23	8	5	10	220	20	3	8	10
H. M. Davis	....	....	....	10	88	16.2	4	4	10
H. L. Murphy	13	8	5	8	88	30	2	5	3
	24	8	5	8	180	21.3	4	10	20
W. O. Dovaris	24	8	5	12	175	23	6	20	40
	25	8	5	8	174	22	3	6	30
M. Wittenbrock	25	8	5	12	50	24	3	7½	8
Do	25	8	5	12	64	23	3	5	10
	25	8	5	10	126	18	3	8	20
	25	8	5	8	104	17	3	8	20
	25	8	5	10	98	18	3	8	20
	26	8	5	10	84	22	3	6	30
	26	8	5	10	57	23	3	6	30
W. L. Ford	26	8	5	10	102	19.3	4	10	20
C. R. Goss	26	8	5	12	62	18	3	4	6
W. O. Downs	26	8	5	10	176	19	3	7	10
P. H. Smith	26	8	5	10	180	18.4	4	15	50
Do	26	8	5	10	240	18	3	15	18
	26	8	5	8	97	19	2½	3	5
	26	8	5	8	108	20.2	2½	3	5
K. W. Remick	27	8	5	10	153	26	4	10	11
L. Lunger	27	8	5	10	80	20.4	3	2½	8
Manuel Williams	27	8	5	10	125	20.2	3	8	19
A. K. Talbot	27	8	5	10	130	22.2	3	8	10
C. B. Feil	27	8	5	....	265	16.2	4	10	45
J. Devine	28	8	5	6	60	22	2	4	2
John Shell	28	8	5	....	90	25	4	10	10
Do	28	8	5	....	165	26	5	15	12
——— Golstine	28	8	5	10	186	16.8	3	5	14
William Stoner	28	8	5	....	200	17.4	3	5	12

Pumping plants used for irrigation in the Sacramento area—Continued.

Owner.	Location.			Diameter of well.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horse-power.	Area irrigated.
	Section.	Township N.	Range E.						
Brighton quadrangle—Contd.				*Inches.*	*Feet.*	*Feet.*	*Inches.*		*Acres.*
T. J. Buell	28	8	5	10	70	24.3	2	2	3
Albert Gaselly	29	8	5	10	55	18.7	2½	5	8
Charles Gadey	29	8	5	8	48	20.5	3	7½	8
J. Sharek	29	8	5	8	56	20.2	2½	5	7
E. Stadler	29	8	5	6	63	16.4	3	3	4
M. Vott	29	8	5	8	75	17.2	2½	3	3
G. W. Stocking	29	8	5	8	77	18.8	2½	3	3
G. Galli	29	8	5	6	82	20	2½	5	7
B. Ikejii	29	8	5	6	69	19	3	6	7
	29	8	5	6	47	19	2	5	5
	30	8	5	8	56	20	2	4	3
W. Gauslin	30	8	5	12	65	23.5	4	5	8
G. H. Slowson	30	8	5	8	43	36.4	4	6(?)	6
M. Yamageta	30	8	5	5	42	14	4	5	13
Joe Homes	30	8	5	10	60	20	3½	5	10
Do.	30	8	5	10	50	22.3	3½	5	10
A. M. Wilson	30	8	5	10	40	26.2	4	4	5
	32	8	5	6	42	20	2	4	2
	32	8	5	6	57	19.3	2	4	5
—— Crawford	31	8	5	10	45	20	4	4(?)	(a)
George Imhof	31	8	5	6	60	14	2	3	5
E. Cartright	31	8	5	6	107	12	2½	5	6
Lewis Serel	31	8	5	6	106	12	2½	3½	4
	32	8	5	6	48	19	2	3	5
S. Lang	32	8	5	6	77	20	2	4	3
	32	8	5	6	54	18	2	3	5
	32	8	5	6	57	19.2	2	3	4
Elmer Nichols	32	8	5	8	66	18	2	3	3
	32	8	5	8	73	18.2	3	5	5
	32	8	5	6	62	19	3	5	8
S. Choffi	33	8	5	....	80	22.2	2½	6	10
C. B. Feil	34	8	5	....	210	16.3	3½	7½	25
A. Cordoza	34	8	5	....	90	20.3	3	8	15
K. W. Remick	34	8	5	....	200	25.2	3	10	12
	34	8	5	10	142	21	2	4	5
	34	8	5	10	139	23	2	4	5
	34	8	5	10	142	22.4	2	5	5
	34	8	5	12	147	21.8	2½	6	8
	34	8	5	10	122	21.4	2	5	5
	34	8	5	8	118	23.4	2	5	5
	34	8	5	8	147	21	2½	5	8
	34	8	5	10	154	22	2½	5	8
	35	8	5	10	124	21	2	4	5
	35	8	5	8	176	22	3	6	8
	35	8	5	8	180	22	3	5	8
	35	8	5	10	126	21	2	5	8
	35	8	5	8	112	23.2	2	5	5
	35	8	5	8	101	23	3	6	5
	35	8	5	10	106	22	2	5	7
	35	8	5	8	127	21	2	5	6
	35	8	5	8	122	22	2½	5	6
	35	8	5	10	133	21	2½	6	5
H. M. Adams	35	8	5	8	285	20	2½	5	8
	35	8	5	10	139	20	2	5	5
	35	8	5	10	187	21	2	5	8
I. Thompson	35	8	5	10	201	20	4	4	10
	35	8	5	8	89	19	2½	4	5
T. Davis	35	8	5	....	90	20	3	8	25
	35	8	5	....	89	19.6	2½	6?	5
	35	8	5	8	102	21	3	10	20
C. M. Davies	35	8	5	12	90	20	4	10	30
	35	8	5	8	90	22	3	10	20
	35	8	5	10	94	20	3	8	30
	35	8	5	10	99	19	3	8	20
	35	8	5	10	97	18.4	3	8	20
	36	8	5	10	87	21	4	10	30
	36	8	5	10	93	19.6	3	10	20
	36	8	5	10	108	20	3	10	20
Joe Danmar	36	8	5	10	150	19	2½	4	10
	36	8	5	8	100	18	2½	6	10
	36	8	5	8	97	21	2½	6	10
S. Mukai	36	8	5	....	100	15	2½	8	15

a Not yet used.

Pumping plants used for irrigation in the Sacramento area—Continued.

Owner.	Location.			Diameter of well.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horsepower.	Area irrigated.
	Section.	Township N.	Range E.						
Mills quadrangle.				*Inches.*	*Feet.*	*Feet.*	*Inches.*		*Acres.*
	24	8	5	8	92	19.7	3	15	20
	36	8	5	8	93	20	3	8	15
	36	8	5	10	87	22	3	8	15
	36	8	5	10	94	23	2½	6	10
E. T. Earl	Rio de los Americanos rancho.			12	70	46	6	40	90
George Mernke	do			12	135	22	4	15	10
S. Quale	do			.....	90	18	4	10	20
Do	do			.....	90	18	5	15	30
J. Pearson	do			10	75	22	2	2	2
Thomas Nicols	do			12	154	20	5	20	30
R. D. Stevens	35	8	6	10	154	26	5	15	20
	5	8	6	10	142	21	5	.....	60
Ely Wells	7	8	6	10	140	20	4	10	16
A. F. Counsman	7	8	6	6	60	16	2	2	60
Mary Wells	7	8	6	10	140	20	5	9	38
	7	8	6	6	130	30	5	15	40
	7	8	6	8	130	30	6	20	30
	7	8	6	5	160	30	8	40	75
	8	8	6	10	140	20	5	8	60
	8	8	6	8	130	30	6	30	50
W. Gatty	17	8	6	10	77	23	4	4	10
Do	17	8	6	8	79	24	5	15	15
	18	8	6	8	82	22	4	8	30
	18	8	6	8	84	26	3	10	30
	18	8	6	10	81	22	3	10	30
	18	8	6	8	90	24	3	8	30
H. D. Millard	19	8	6	10	45	20	5	20	20
F. Walker	19	8	6	10	201	20	3½	6	7
Joe Marty	19	8	6	8	92	22	2	10	12
G. Saskey	19	8	6	7	98	24	3?	5	13
T. Abe	19	8	6	8	114	27	4½	10	15
C. H. Imra	20	8	6	8	97	30	5	15	15
H. Arow	20	8	6	8	102	26	4	7½	20
K. Fugiwan	20	8	6	10	100	27	3	6	20
	20	8	6	10	104	26	3	8	20
W. E. Barnby	20	8	6	12	114	20	3	7½	25
Mrs. Adele Jones	20	8	6	8	100	27	4	15	10
G. F. Jones	20	8	6	8	112	27	4	15	9
George Bonby	29	8	6	12	130	28	3	5	15
R. Hintz	29	8	6	12	75	22.3	3	10	10
R. M. Bush	29	8	6	12	222	28.7	5	15	50
M. J. Finngan	29	8	6	10	242	29.2	5	8	30
H. Yoshimo	30	8	6	12	162	33	4	15	38
	30	8	6	.....	143	32	2½	4	3
W. C. Reinke	30	8	6	10	150	22	2½	8	10
P. A. Creanan	30	8	6	12	180	28	2½	5	25
	30	8	6	10	107	22	2½	6	10
	31	8	6	10	102	21.5	2½	6	10
	31	8	6	10	120	22	2½	6	10
	31	8	6	10	104	20	3	12	30
	31	8	6	.....	96	27	2½	6	20
	31	8	6	12	192	23.2	3	3?	6
Paul Gean	31	8	6	8	75	24	3	6½	20
J. D. Shroder	31	8	6	10	69	26	3	8	10
	31	8	6	10	60	23	2½	8	20
John Garbody	32	8	6	12	202	24.3	4	8	25
H. Garabaldy	32	8	6	12	240	29	4	8	35
Babel Slough quadrangle.									
	2	7	4	10	50	12	4	10	20
	35	8	4	10	40	12	2½	5	5
	11	7	4	12	30	12	6	20	100
	14	7	4	4	32	11	2	2	5
	13	7	4	6	24	10	2½	3	7
	13	7	4	6	30	8	2½	4	10
	23	7	4	6	37	7.7	3	4	10
	24	7	4	8	35	7.2	3	4	12
	24	7	4	8	37	8	3	3	10
George Morten	26	7	4	8	26	8.4	2	4	15
	26	7	4	10	29	7.6	3	5	10
	26	7	4	8	34	8.4	3	3	10
	26	7	4	10	26	9.2	3	3	24
	26	7	4	10	24	7.6	3	4	27
	26	7	4	10	31	8.2	3	3	11
	26	7	4	6	27	7.9	2½	4	18

Pumping plants used for irrigation in the Sacramento area—Continued.

Owner.	Location.			Diameter of well.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horsepower.	Area irrigated.
	Section.	Township N.	Range E.						
Florin quadrangle.				*Inches.*	*Feet.*	*Feet.*	*Inches.*		*Acres.*
W. Long	31	8	5	4	60	21	3	4	5
E. Grimes	32	7	5	12	140	16	2½	5	10
	33	8	5	10	114	20	2	4	5
J. S. Rodriguez	33	8	5	10	75	16	2	4	5
	34	8	5	8	108	20	2	4	5
	34	8	5	8	112	20	2½	4	6
H. Hansen	34	8	5	10	90	20	2	4	5
	34	8	5	8	125	20	2	4	5
M. Nishoc	34	8	5	10	137	20	2	4	5
H. Kramer	34	8	5	10	142	19	2	4	5
R. Nichols	34	8	5	10	96	10	3	12	10
	34	8	5	8	112	16	2	4	5
	34	8	5	10	82	17	2½	5	5
	34	8	5	10	140	17	2½	5	5
	34	8	5	8	70	16	2	5	5
	34	8	5	8	103	19	2½	5	6
	34	8	5	10	122	17	2	4	5
	34	8	5	8	136	17	2	4	5
	34	8	5	10	114	16	2	4	5
	34	8	5	10	90	16	2	5	5
	34	8	5	8	110	22	2	4	6
	34	8	5	8	127	22.3	2	4	4
	34	8	5	....	118	21	2	4	5
	35	8	5	8	84	21.6	2	4	5
	35	8	5	8	96	22	2	4	6
	35	8	5	8	102	20	2	4	5
	35	8	5	8	137	19	2	4	5
	35	8	5	8	173	19	2	4	5
	35	8	5	8	141	18	2	4	5
	35	8	5	8	190	19	2½	4	6
	35	8	5	8	128	18	3	6	8
H. Champion	35	8	5	10	164	21	2½	6	6
George Oss	36	8	5	....	80	22	5	20	33
	36	8	5	....	99	21	3	5	5
C. Burgess	36	8	5	10	77	21	4	6	10
Do.	36	8	5	10	78	20	3	3	10
	36	8	5	8	108	20	2½	5	5
	36	8	5	8	96	20.2	3	5	5
	36	8	5	....	101	20	2	4	5
	36	8	5	....	114	21.7	2	5	5
	36	8	5	10	94	21.2	2½	5	4
	36	8	5	8	102	21	2½	6	5
	36	8	5	8	110	20.3	2	6	5
	36	8	5	....	67	21.2	2½	6	5
	36	8	5	8	82	20	2	4	6
	1	7	5	....	147	20	2	4	7
	1	7	5	....	108	20	2	4	5
	1	7	5	8	82	20	2	6	5
	1	7	5	10	149	22	2	4	5
	1	7	5	....	136	21	2½	5	5
H. M. Dornson	1	7	5	10	155	18	3	7½	10
	1	7	5	8	140	18	2½	6	8
	1	7	5	8	114	19.9	3	5	5
	1	7	5	8	87	21	3	5	5
H. Barbo	1	7	5	8	100	14	3	5	15
F. Nutting	1	7	5	....	208	23	4	7½	12
D. W. Smith	1	7	5	10	147	18	2	4	5
	1	7	5	10	123	20	2	5	5
	1	7	5	10	138	18	2	4	5
	1	7	5	10	129	21	2	5	5
	1	7	5	10	122	19	2	5	5
	1	7	5	10	151	18	2	4	5
C. Poulass	1	7	5	10	171	18	2	4	8
	1	7	5	10	113	20	2	5	5
	1	7	5	10	167	19	2	5	5
	1	7	5	10	130	18	2	5	5
	1	7	5	10	145	17	2	4	5
	1	7	5	8	122	19	2	4	8
	1	7	5	10	160	17	2	4	5
H. Kens	1	7	5	10	122	16	2	4	5
	1	7	5	10	146	17	2	4	5
	1	7	5	10	113	18	2	4	6
	1	7	5	10	159	18	2½	4	5

Pumping plants used for irrigation in the Sacramento area—Continued.

Owner.	Location.			Diameter of well.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horsepower.	Area irrigated.
	Section.	Township N.	Range E.						
Florin quadrangle—Contd.				*Inches.*	*Feet.*	*Feet.*	*Inches.*		*Acres.*
	1	7	5	8	129	19	2	4	5
M. Fleming	1	7	5	10	129	17	2	4	5
	1	7	5	10	108	19	2	4	5
	1	7	5	8	145	17	2	5	5
	1	7	5	8	129	18	2	5	5
	1	7	5	10	114	18	2	5	5
John Polock	1	7	5	10	160	21	2	5	5
	1	7	5	10	136	17	2	4	5
	1	7	5	10	147	20	2	5	5
	1	7	5	10	157	17	2	5	5
	1	7	5	10	157	19	2	5	5
	1	7	5	10	144	18	2	4	5
	1	7	5	10	129	19	2	5	5
A. Devor	1	7	5	10	124	17	2	4	5
	1	7	5	10	180	18	2	4	5
H. Kelly	1	7	5	10	152	17	2	4	5
R. Kramer	1	7	5	8	100	20	2½	4	6
	1	7	5	10	90	21	2½	3	5
	1	7	5	10	96	18	2	4	5
	1	7	5	8	147	16	2	5	6
	1	7	5	10	160	17	2½	5	8
	1	7	5	10	137	17	2	4	8
R. H. Ritche	1	7	5	10	129	18	2	4	8
	2	7	5	10	129	19	2½	5	6
	2	7	5	10	163	16	2	5	5
	2	7	5	8	148	17	2	4	5
	2	7	5	8	210	18	2	5	5
	2	7	5	10	114	16	2	5	5
	2	7	5	8	112	17	2	4	5
	2	7	5	8	108	18	2	4	5
	2	7	5	10	143	18	2	5	5
	2	7	5	10	152	19	2	5	5
	2	7	5	8	139	18	2	4	5
	2	7	5	10	142	22	2½	4	5
	2	7	5	12	93	18.1	3	5	8
S. A. Klake	2	7	5	10	167	18	2	4	5
	2	7	5	....	123	17	3	5	8
J. M. Keene	2	7	5	10	150	18	3½	7½	10
	2	7	5	10	176	18	3	5	8
	2	7	5	10	102	17	2	4	5
	2	7	5	10	100	18	3	5	5
	2	7	5	10	90	22	2	5	5
	2	7	5	10	112	17.3	3½	7½	10
	2	7	5	10	149	17	2	4	5
	2	7	5	....	142	16	3	5	8
	2	7	5	10	92	....	3	6	8
	2	7	5	8	128	....	2	4	5
	2	7	5	10	108	16	2½	4	6
M. Tacato	2	7	5	10	143	18	2	4	5
	2	7	5	8	137	18	2	4	5
	2	7	5	10	128	18	3	6	10
	2	7	5	10	149	19	3	6	7
	2	7	5	10	168	18	2	4	5
	2	7	5	8	142	19	2	4	5
	2	7	5	10	163	18	3	6	10
E. Johnson	2	7	5	10	87	19	3	6	10
	2	7	5	10	68	19	3	6	10
M. Mariott	2	7	5	8	154	21	3	6	10
	2	7	5	10	97	19	3	6	8
H. Klinsisorgne	2	7	5	12	122	18	3	6	8
	2	7	5	8	122	19	2	4	5
	2	7	5	10	102	19	2	5	5
	2	7	5	10	100	17	3	6	10
C. Harrison	2	7	5	10	100	19	3	7	10
	2	7	5	8	113	20	3	6	10
E. Tanaka	2	7	5	8	90	20	3	6	8
	2	7	5	8	132	18	3	6	8
Y. Nishico	2	7	5	10	122	16	2	4	6
	2	7	5	12	147	18	2	4	5
	2	7	5	8	80	18	2	4	5
M. G. Evans	2	7	5	10	140	17	3	7	10
W. Kennedy	2	7	5	10	109	20	2	4	5
	2	7	5	8	117	20	2	4	5
	3	7	5	8	142	20	2	5	6

Pumping plants used for irrigation in the Sacramento area—Continued.

Owner.	Location. Section.	Township N.	Range E.	Diameter of well.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horsepower.	Area irrigated.
Florin quadrangle—Contd.				*Inches.*	*Feet.*	*Feet.*	*Inches.*		*Acres.*
	3	7	5	8	173	20	2	4	5
	3	7	5	10	167	20	2	4	5
	3	7	5	10	182	17	2	4	5
	3	7	5	10	165	17	2½	6	7
	3	7	5	12	160	21	3	7	8
Jos. Jennings	3	7	5	12	142	20	2	6	5
	3	7	5	10	84	14	2	5	5
	3	7	5	10	120	14	2	5	5
	3	7	5	8	100	18	2	5	5
	3	7	5	10	138	14	2	4	4
	3	7	5	8	130	16	2	4	5
	3	7	5	10	114	19	2½	5	6
	3	7	5	10	142	18	2	5	5
	3	7	5	10	152	16	2	4	5
	3	7	5	8	103	16	2	4	5
S. Murray	3	7	5	8	96	16	2	7	10
	3	7	5	8	108	12.1	3	6	7
	3	7	5	10	84	17	2½	4	5
	3	7	5	10	122	17	2	5	5
	3	7	5	10	122	20	2	4	5
	3	7	5	8	130	19	2½	5	6
	3	7	5	8	112	21	3	6	8
	3	7	5	10	107	19	3	5	6
	3	7	5	10	164	19	2	4	5
	3	7	5	8	182	18	2	4	5
	3	7	5	10	392	17	2½	4	5
	3	7	5	10	132	20	2	4	5
H. McComer	3	7	5	8	102	21	2(?)	5	6
J. Mason	3	7	5	8	120	12.8	3	5	10
	3	7	5	10	170	19	2	3	5
Charles Pauliss	3	7	5	8	146	22	2	4	5
H. Kennedy	3	7	5	8	120	19	2	4	5
	3	7	5	10	112	17	2	4	5
	4	7	5	10	84	20	2	5	5
	4	7	5	10	97	20	2	5	5
G. Cummings	4	7	5	10	109	22	2½	6	10
D. S. Slands	5	7	5	12	90	20	3	5	6
W. W. Grier	8	7	5	....	29	10	2	2½	1½
	8	7	5	....	37	12	2½	4	5
J. Leinbach	10	7	5	....	89	12	2½	4	5
A. E. Leinbach	10	7	5	....	68	11	2½	8	10
Do.	10	7	5	....	108	15	6	20	20
Mrs. Wilson	10	7	5	....	125	12	3	6	5
J. Leinbach	10	7	5	....	92	12.8	2½	4	5
C. L. Bates	10	7	5	10	100	22.	2	4	8
Do.	10	7	5	10	75	22	2	4	8
	10	7	5	10	84	21	3	7	8
M. Jahnes	11	7	5	8	92	19	3	6	8
M. E. Thornas	11	7	5	10	122	18	3	6	5
J. James	11	7	5	10	100	20	3	6	10
H. Hodges	11	7	5	8	126	20	2½	6	10
W. Miller	11	7	5	8	102	20	3	6	8
T. E. Thomas	11	7	5	10	122	18	3	7	10
H. Oponto	11	7	5	10	87	17	3	7	10
R. F. Sakanor	11	7	5	10	109	19	3	6	8
	11	7	5	10	68	20	3½	7	10
M. Jenkins	11	7	5	10	142	21	3	5	6
	11	7	5	8	180	14	2	4	5
	11	7	5	10	200	18	3	7½	8
	11	7	5	10	108	20	2½	4	4
	11	7	5	10	210	16	2	4	5
	11	7	5	8	146	15.6	2	4	5
	11	7	5	8	131	16.2	2	4	5
	12	7	5	10	128	17	2	5	5
	12	7	5	10	100	20	2	4	5
	12	7	5	10	128	19	2	4	5
M. Bellows	12	7	5	8	162	22	2½	5	5
	12	7	5	10	137	17	2	4	5
	12	7	5	10	149	17	2	4	5
	12	7	5	10	113	19	2	4	5
W. C. Cornelle	12	7	5	10	100	18	2	4	5
	12	7	5	10	150	18	2	5	5
	12	7	5	10	155	19	2	5	5
	12	7	5	10	126	22	2	5	5
	12	7	5	10	129	20	2	5	5

Pumping plants used for irrigation in the Sacramento area—Continued.

Owner.	Location. Section.	Location. Township N.	Location. Range E.	Diameter of well.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horsepower.	Area irrigated.
Florin quadrangle—Contd.				*Inches.*	*Feet.*	*Feet.*	*Inches.*		*Acres.*
B. Jackson	13	7	5	....	108	13	2½	4	5
P. Lawson	13	7	5	....	30	12	2½	4	4
H. Belden	14	7	5	10	90	22	3	8	10
R. E. Smith	14	7	5	10	95	25	4	8	20
	15	7	5	8	38	12	2	4	5
	15	7	5	8	47	10	2	4	8
C. L. Biggs	15	7	5	8	84	21	2½	4	8
Do.	15	7	5	....	22	8	3	6	14
	22	7	5	8	88	21	2½	5	5
	21	7	5	8	64	18.8	2	3	2
	23	7	5	8	174	19.3	3	6	10
L. F. Kennedy	23	7	5	8	28	23	3	8	20
M. Levitt	23	7	5	....	68	20	3	5	12
Do.	23	7	5	....	160	20	4	8	30
L. S. Dartts	23	7	5	8	22	22	2½	8	8
M. Levitt	23	7	5	....	62	20	3	12	12
F. Gage	23	7	5	12	80	20	3½	8	15
J. C. Phipps	23	7	5	....	180	20	5	10	40
C. Malley	24	7	5	10	76	14	4	6	6
K. McLinan	24	7	5	12	86	20	5	8	6
J. E. Dort	24	7	5	....	76	12	3	4	5
A. Dart	24	7	5	....	92	13	2½	4	5
G. Ames	24	7	5	....	194	14	2	5	4
M. Nalghon	24	7	5	10	122	16	4	8	20
King Enns	25	7	5	....	53	13	3	6	6
K. McKlellan	25	7	5	12	175	15	4	8	20
	26	7	5	....	10	20	4	6	20
H. Hewitt	26	7	5	....	88	14	6	20	60
J. A. Wilson	26	7	5	12	84	15	4	10	20
H. Hewitt	26	7	5	12	180	14	4	7½	10
Do.	26	7	5	12	50	15	5	10	50
H. Richel	26	7	5	12	184	14	4	10	20
H. Hewitt	26	7	5	12	140	14	5	10	50
F. Frule	26	7	5	12	42	18	3½	8	10
H. Hewitt	27	7	5	12	50	15	3	8	6
W. F. Hatch	27	7	5	....	80	14	4	8	20
E. O. Donofield	27	7	5	12	75	14	3	7½	10
Ed. Frye	28	7	5	....	85	12	2½	4	8
A. Webb	28	7	5	....	83	11.6	2½	4	10
Stevens Bros.	29	7	5	....	80	8	2	5	5
F. Baker	30	7	5	12	67	11	4	8	6
H. Nicols	30	7	5	....	77	9	2	5	2
H. Rasmussen	32	7	5	....	80	12	2½	4	5
	34	7	5	8	76	22	2½	5	5
H. Donovan	34	7	5	8	94	21	2½	5	6
E. W. Folks	34	7	5	8	120	21	3	6	8
	34	7	5	8	97	14	3	6	8
Charles Dickson	34	7	5	8	136	15.2	2½	5	6
	34	7	5	8	110	22	2½	5	5
	34	7	5	12	90	14	2	4	5
F. Frule	35	7	5	10	120	18	3	8	10
E. Dawson	35	7	5	10	60	18	2	3	5
M. Gagrey	35	7	5	12	88	14	2	4	5
R. Enns	36	7	5	10	140	17	3½	6	15
	36	7	5	10	102	15	2	4	5
F. Johnson	36	7	5	8	147	15.6	2½	4	5
K. Tibets	1	6	5	10	60	23	2	4	5
	1	6	5	8	103	16	3	8	8
	1	6	5	....	109	14	3	8	10
H. Franks	1	6	5	10	127	14	3	8	10
	1	6	7	10	148	15.2	3	8	8
	1	6	5	8	141	16	2½	5	6
	1	6	5	10	54	23	2	4	55
H. Mofi	1	6	5	8	83	23	2	4	6
James Lang (?)	2	6	5	8	131	15.2	2½	5	5
A Homes	3	6	5	12	112	15.6	2	4	4
H. Henryman	3	6	5	8	142	22	2	5	5
	3	6	5	10	122	19	2	4	5
	3	6	5	8	122	15.1	2	4	0
Elizabeth Johnson	3	6	5	8	250	24	7	20	75
M. Murray	7	7	5	8	91	16	2	5	2
W. F. H. Moore	10	6	5	12	130	18	3	6	1

Pumping plants used for irrigation in the Sacramento area—Continued.

Owner.	Location.			Diameter of well.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horse-power.	Area irrigated.
	Section.	Township N.	Range E.						
Florin quadrangle—Contd.				*Inches.*	*Feet.*	*Feet.*	*Inches.*		*Acres.*
H. Wood	10	7	5	8	76	20	3	5	5
Newman Bros	10	6	5	8	220	18	2	3	4
	10	6	5	2	182	19	2½	7	4
M. Lahse	10	6	5	8	260	15	2	3	3
Fred Lahse	10	6	5	....	110	25	3	7	12
Newman Bros	10	6	5	12	65	19	4	10	15
Do	10	6	5	10	65	18	4	10	15
Do	11	6	5	12	110	18	6	20	15
Do	10	6	5	12	65	19	4	15	15
Do	11	6	5	10	110	18	2½	5	5
B. Monroe	12	6	5	8	120	19	2	4	5
	12	6	5	10	90	22	2	4	5
S. E. Houke	12	6	5	10	63	23	2	4	5
	15	6	5	....	102	22	3	6	10
J. Kim (?)	15	7	5	....	56	14	6	12	8
Do	15	7	5	....	101	22	3	5	3
A. Adolph	16	7	5	12	90	12	6	20	12
A. Koff	17	7	5	12	75	12	4	10	10
H. Hawk	17	7	5	8	102	13.6	2	4	5
G. Gordon	18	7	5	8	85	14	3	8	8
M. Andrews	18	7	5	8	93	13	3	6	8
H. Devling	18	7	5	....	82	13	2	5	5
M. A. Smith	18	7	5	....	100	12	5	10	20
Elk Grove quadrangle.									
P. Kramer	36	8	5	10	120	22	2	4	6
	36	8	5	10	100	21	2	4	5
H. M. Embrose	36	8	5	8	169	21	2	4	5
H. S. Masterson	36	8	5	12	164	19.8	2½	6	6
	31	8	6	10	94	22	2	6	8
R. Bandy	31	8	6	8	142	22	2½	8	10
A. Nalarphi	31	8	6	8	109	23	2½	8	12
C. Cumingham	31	8	6	10	191	23	2	4	5
H. Bradley	31	8	6	10	87	23	2	4	5
	32	8	6	8	143	23	3	6	7
	32	8	6	8	127	23	2	4	4
F. Lewis	33	8	6	12	98	25	2½	3	1
H. Perkins	1	7	5	8	97	21	2	4	6
	1	7	5	8	149	19	2½	6	5
	1	7	5	10	112	22	2	5	5
J. Rann	1	7	5	10	130	21	2	4	5
	1	7	5	10	116	22	3	4	5
	1	7	5	10	127	22.8	2½	4	5
	1	7	5	10	146	23	2	5	5
	1	7	5	10	122	22.2	2	4	5
J. Maria	1	7	5	10	169	22.6	2	4	7
G. Clark	1	7	5	10	98	22	2½	5	8
H. Wider	1	7	5	10	108	23	2	4	5
	1	7	5	10	97	21.8	3	6	10
	12	7	5	12	123	22	3	6	8
	12	7	5	10	120	....	3	6	10
A. Devon	12	7	5	10	132	17.5	3	6	10
Joe Kelly	12	7	5	8	122	16	3	5	10
J. Spiegle	12	7	5	10	100	18	3	6	15
	12	7	5	10	142	15	3½	8	20
	13	7	5	....	109	16	2	3	....
W. Taytor	13	7	5	10	100	12	4	8	38
	24	7	5	10	146	19	3	6	10
	19	7	6	10	132	19	3	5	10
	24	7	5	10	92	19	3	6	10
	24	7	5	12	121	22	3	6	10
W. S. Robinson	25	7	5	12	142	21	5	15	....
J. W. Stevens	25	7	5	12	172	20	6	20	....
E. J. Stevens	36	7	5	12	190	21.7	4	15	20
	36	7	5	12	177	22	4	10	20
	36	7	5	12	152	23	4	10	30
	36	7	5	12	100	28	3	6	4
L. T. Everson	36	7	5	10	460	30	5	10	12
H. Thichaugi	5	7	6	....	146	24	2	4(?)	8
	5	7	6	10	127	24	2	4(?)	10
	5	7	6	8	103	24	2	4	3

Pumping plants used for irrigation in the Sacramento area—Continued.

Owner.	Location.			Diameter of well.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horsepower.	Area irrigated.
	Section.	Township N.	Range E.						
Elk Grove quadrangle—Con.				*Inches.*	*Feet.*	*Feet.*	*Inches.*		*Acres.*
T. Lewis	5	7	6	8	114	23	2	4	3
	5	7	6	8	97	23.7	2	4	3
	5	7	6	8	84	22.4	2	4	3
S. E. Negro	5	7	6	10	133	23	3½	6	15
Do	5	7	6	12	122	23	3½	6	10
	5	7	6	12	142	22	4	7½	20
H. Casey	6	7	6	12	123	22.6	3	6	15
	6	7	6	8	103	22	2½	4	6
M. Wilson	6	7	6	8	122	22	2	3	5
A. R. Hart	6	7	6	8	136	22	2	4	8
W. Turk	6	7	6	10	149	21	2	4	5
	6	7	6	10	146	22	2	4	5
	6	7	6	10	92	21	2	4	5
	6	7	6	8	122	21	2½	8	10
	6	7	6	8	77	23	2	6	6
	6	7	6	10	106	23	2½	8	10
K. Yakmento	6	7	6	8	109	23	2½	5	6
M. Yoshino	6	7	6	10	137	23	3	4	5
George Denor	6	7	6	8	146	23	2	3	5
M. Shagiki	6	7	6	10	78	23	2½	4	5
George Gaugel	6	7	6	8	148	22	3	6	10
	7	7	6	8	122	22	2	4	5
T. Polock	7	7	6	12	143	18.3	3	5	10
J. B. Jones	7	7	6	12	102	18	3	5	10
A. Abraham	7	7	6	10	92	18	3	5	10
	7	7	6	8	147	17	3	8	20
W. Williams	7	7	6	10	122	16	3	6	15
	7	7	6	8	108	15	3	6	12
H. Hastings	7	7	6	10	96	16	3	8	15
H. Ambrose	7	7	6	8	145	17	3½	8	20
	7	7	6	10	133	16.2	3½	8	20
	7	7	6	12	97	16	2½	6	10
	7	7	6	10	163	23	4	10	20
	7	7	6	10	97	23.4	3	6	20
John Petkonich	9	7	6	10	45	24	2	5	8
Do	9	7	6	12	234	24	2½	8	12
H. H. Mason	10	7	6	10	307	26	3	10	20
	14	7	6	10	280	27	3	10	20
	14	7	6	10	276	26	3	10	20
	14	7	6	10	176	25	3½	8	20
	14	7	6	10	184	24	3½	10	30
California Vineyard Co. (40 plants)	15, 16	7	6	12	65–260	20–30	3½–5	325	1,100
	16	7	6	10	184	26	2	4	6
John Holden	16	7	6	8	182	23	2	3	2
H. N. Adams	16	7	6	8	185	23	2	5	10
	16	7	6	10	137	24	3	6	15
	16	7	6	10	128	26	2	4	6
	18	7	6	10	127	14	3	6	20
C. H. Hoskin	19	7	6	10	122	18	3	6	10
	24	7	5	8	122	18.6	3	6	10
	19	7	6	10	108	19	3	6	10
M. Kodasi	19	7	6	....	100	21	3	6	10
	6	6	6	8	127	24	3	8	10
J. D. Lewis	21	7	6	12	190	25	4	12	20
J. Bender	21	7	6	8	187	22	2	5	4
J. D. Lewis	21	7	6	12	117	26	3	8	10
W. Ring	21	7	6	12	176	23	3	6	10
Do	21	7	6	12	142	24	3	6	10
G. R. Hunt	21	7	6	12	150	31	3	4	08
F. McCloud	21	7	6	12	112	24	3	5	8
	21	7	6	8	122	24	3½	8	2
John Griffis	22	7	6	4	100	22	2	3	4
	22	7	6	8	122	21	4	10	20
N. S. Clark	22	7	6	....	86	29	3	5	4
W. Bonney	14	7	6	....	80	30(?)	2	6	3
L. Pedene	23	7	6	10	92(?)	24	2½	6	5
M. Oswelt	23	7	6	10	87	24	2½	6	5
	26	7	6	8	88	27	2	4	8
H. Owen	27	7	6	8	112	22	2	4	....
H. Nunberg	27	7	6	6	94	24	2	6	10
	27	7	6	8	102	23	4	10	15

Pumping plants used for irrigation in the Sacramento area—Continued.

Owner.	Location. Section.	Location. Township N.	Location. Range E.	Diameter of well.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horsepower.	Area irrigated.
Elk Grove quadrangle—Contd.				*Inches.*	*Feet.*	*Feet.*	*Inches.*		*Acres.*
W. S. Ajax	27	7	6	12	123	25	5	12	9
	27	7	6	10	164	22.8	4	12(?)	40
J. D. Johnson	28	7	6	8	108	22	3½	4	5
W. M. Schultz	28	7	6	10	154	23	2	4	5
H. J. Lugg	28	7	6	....	98	24	3½	6	8
F. E. Schirnior	28	7	6	12	127	23	2	2	3
H. E. Barch	28	7	6	....	60	22.7	2	3	4
	28	7	6	8	147	23	3	8	20
T. Osina	28	7	6	10	108	24	3	6	8
Joe Spedilli	29	7	6	8	63	24	5	12	35
A. Swanson	29	7	6	....	135	24	3	8	15
M. Thompson	29	7	6	10	120	22	3	8	10
	30	7	6	8	108	21	2½	4	7
M. Walker	30	7	6	8	92	22	2½	4	5
H. Miller	30	7	6	12	137	24	1½	3	2
H. Thompson	31	7	6	10	148	22	4	10	20
	31	7	6	8	122	22	3	6	10
H. Trumble	31	7	6	10	77	22	3	6	10
	31	7	6	8	94	20	3	6	10
	31	7	6	10	102	21	3	6	10
	31	7	6	12	163	22	3½	8	15
W. S. Robinson	31	7	6	12	77	20	6	20	....
E. S. Miller	31	6	6	12	164	22	5	15	40
Do	31	6	6	12	152	22	5	15	40
E. F. Mix	32	7	6	....	102	22	5	12	20
Louis Nevens	32	7	6	....	137	19	4	10	20
E. Tameby	32	7	6	12	135	22	4	8	50
E. Barer	32	7	6	12	112	22	4	8	30
T. Suzimoto	32	7	6	....	150	16	4	12	17
W. L. McDonald	33	7	6	12	50	25	....	8	5
A. Huck	33	7	6	12	130	20	2½	4	5
F. Salmon	33	7	6	....	50	22	4	8	10
F. Strube	33	7	6	....	79	23	3½	6	10
H. Wans	33	7	6	....	108	23	3	6	10
C. A. Hanley	33	7	6	....	94	22.2	3	6	10
F. H. Gorton	33	7	6	....	50	27	3	6	10
	33	7	6	8	64	25	3	6	5
S. A. Etling	1	6	5	12	350	30	4	10	25
Do	1	6	5	12	120	30	4	10	25
R. Musedno	1	6	5	10	177	18	3	10	20
	12	6	5	10	190	24	4	10	20
	4	6	6	8	142	24.8	3	6	10
H. Wilks	4	6	6	8	176	24	3	6	7
	4	6	6	8	124	26	3	8	10
	5	6	6	8	147	21	2	3	3
	5	6	6	8	163	20	2	3	5
Ed. DeRosa	6	6	6	12	150	21	3	6	5
Fred Gage	6	6	6	12	124	23	3½	7	20
T. P. Lowe	6	6	6	8	220	16	4	12	15
Do	6	6	6	8	187	16	4	10	15
C. E. Darling	6	6	6	8	40	26	1	2	1
M. Powel	6	6	6	12	133	28	4	12	20
Do	6	6	6	12	177	28	4	12	20
B. C. Farnsworth	6	6	6	12	142	26	4	12	15
C. A. Tomsen	6	6	6	10	147	19	2	4	6
E. Omai	7	6	6	10	192	20	3½	10	10
Markofer & Latta	7	6	6	12	215	18	6	25	35
Do	7	6	6	12	185	18	6	25	35
	7	6	6	8	190	21	2	4	5
Mary Warner	7	6	6	8	177	20	4	8	20
C. Carr	7	6	6	8	170	27	3	6	4
V. Conns	7	6	6	....	190	20	3	6	7
C. Baker	7	6	6	10	220	25	4	6	10
R. I. Baker	7	6	6	....	210	26	5	15	14
C. Carr	7	6	6	8	70	27	2	3	2
H. Coons	8	6	6	....	88	21	3	8	24
P. R. Polhemus	8	6	6	12	148	30	3	6	15
H. M. Crow (?)	Omochumnes			8	178	22	4	8	10
	do			12	152	20	5	10	30
J. W. Mahon	do			12	140	21	5	12	20
Do	do			12	175	21	5	15	40
H. Freeman	do			10	33	10	3	8	25
Tom Maroney	do			8	47	14	3	6	10

Pumping plants used for irrigation in the Sacramento area—Continued.

Owner.	Location.			Diameter of well.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horsepower.	Area irrigated.
	Section.	Township N.	Range E.						
Elk Grove quadrangle—Contd.				*Inches.*	*Feet.*	*Feet.*	*Inches.*		*Acres.*
Tom Keatting	Sanjon de los Moquelumnes.			8	54	12	3	6	10
George Brown	....do			8	82	26	3	6	20
	....do			8	86	26	3	6	20
C. Chamberlain	Omochumnes			8	182	23	2	4	5
	....do			10	147	23	2	4	6
	Sanjon de los Moquelumnes.			8	92	27	3	5	20
H. Ticken	6	6	6	12	180	26	3	5	5
George Bodwell	1	6	5	6	143	23	2	4	2
Cosumnes quadrangle.									
	Cosumnes			10	85	32	4	....	6
Bruceville quadrangle.									
A. Allen	17	6	5	10	102	14	2	4	5
J. Miller	17	6	5	10	120	14.2	3	6	10
H. Nolton	20	6	5	10	92	13	2	4	5
H. Downs	21	6	5	12	128	14	2	4	6
F. T. Whitmore	21	6	5	....	110	14	3½	5	3
M. Angelene	21	6	5	....	133	12	2	4	5
	27	6	5	8	109	22	3	8	12
E. R. Core	27	6	5	....	110	11	2	4	6
H. H. Core	27	6	5	8	100	20	2	5	6
	27	6	5	8	112	21	2½	7	5
J. M. Jones	28	6	5	6	92	18	2	4	5
M. Dorsey	29	6	5	12	100	13	2	4	6
H. Games	29	6	5	8	108	12	2	4	5
C. Smith	29	6	5	8	93	13	2	5	5
J. Hase	29	6	5	....	120	14	2	6	4
M. Allen	29	6	5	12	126	13	2	5	8
	30	6	5	10	94	13	3	5	12
M. Teloney	31	6	5	12	170	14	2½	6	10
C. Cummings	31	6	5	10	76	12	3½	6	15
M. Hanks	31	6	5	12	122	12	2	4	5
	31	6	5	10	88	12	2½	6	8
J. Jahnas	31	6	5	12	93	12	2	4	5
	31	6	5	12	87	12	2½	5	8
J. Hatchet	32	6	5	10	102	13	3	5	8
M. Koontz	32	6	5	12	73	12	2	3	4
D. B. Perry	33	6	5	4	149	19	3	4	5
	33	6	5	6	106	20	1½	3	2
J. Baker	33	6	5	....	80	17	2	6	10
	34	6	5	6	102	23	2	5	5
	34	6	5	6	97	21	2	5	5
J. M. Kenna	3	5	5	6	104	17	3	10	7
	3	5	5	6	50	17	2	6	3
H. N. Kenna	3	5	5	6	104	17	3	10	6
George Hombalk	6	5	5	....	128	12	2	3	5
Galt quadrangle.									
T. C. McConel	18	6	6	7	175	20	3	6	4
	20	6	6	6	45	23	2	4	3
H. Stickney	20	6	6	8	45	27	4	10	4
J. F. Macano	18	6	6	8	60	24	4	10	12
N. Valensen	Sanjon de los Moquelumnes rancho.			10	140	16	4	4	3
M. Valensen	....do			10	200	22	4	5	3
	....do			10	147	22	2	5	2
Joe Foster	....do			....	112	28	3	10	25
Do.	....do			....	91	28	3	12	25
	....do			8	176	24	2½	6	5
M. Foster	....do			8	122	23	2	4	4
H. Gamble	....do			8	147	22.8	2	4	2
	....do			10	122	19	2½	4	5
Snider & Weiger	....do			12½	100	17	5	10	7

Pumping plants used for irrigation in the Sacramento area—Continued.

Owner.	Location. Section.	Location. Township N.	Location. Range E.	Diameter of well.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horsepower.	Area irrigated.
Galt quadrangle—Continued.				*Inches.*	*Feet.*	*Feet.*	*Inches.*		*Acres.*
H. A. Winger	Sanjon de los Moquelumnes rancho.			8	50	17	3	5	6
H. Sandan	do			8	72	18	2½	5	5
J. B. Jones	do			10	184	23	2	4	5
W. M. Paton	do			8	125	20	4	7½	6
H. Anderson	do			10	120	22	2½	5	5
	do			10	100	22	3	6	8
	do			8	80	19	3	5	....
Stine E. Kendrick	do			8	206	20	4	8	15
D. Cornings	do			....	142	22	2	4	3
	do			10	122	22	2	4	8
Adolph Brannolde	do			8	137	18	4	7½	....
Mr. Devol	do			8	120	18	3	4	....
H. D. Mannigan	do			8	50	12	3	5	....
Hans Modron	do			8	58	12	4	7	....
H. M. Howlett	do			8	70	17	2½	5	....
M. Scoback	do			8	80	18	2	4	11
	do			8	46	14	3	5	....
	do			8	42	14	3	5	....
	do			8	57	19.3	3	5	....
	do			8	62	22	3	5	....
J. Pollock	do			8	182	23	3	5	6
Harry Dixon	do			8	144	23	2½	6	6
A. Andrews	do			8	184	23	2½	6	8
	do			12	190	23	3	8	8
H. Lambert	do			10	129	23	2	6	5
M. Mathews	do			8	176	23	2	4	3
	do			8	127	22	2	4	5
James Simson	do			10	149	23	3	6	6
H. Billinger	do			10	122	23	3	8	8
	do			10	186	24	4	10	10
	do			12	48	22	3	5	8
H. Bowen	do			10	70	22	2½	4	5
	do			12	60	20	2½	4	5
	do			10	92	19	2½	4	5
C. A. Mance	do			12	102	21	3	6	8
	do			8	100	23	2½	4	5
M. Johnson	do			8	120	20	2½	5	8
R. E. Coker	do			8	84	21	2½	5	10
	do			8	58	21	3	5	10
	do			8	64	21	3	5	....
	do			10	90	19	3	5	8
	do			8	60	20	2	4	5
	do			8	90	22	2½	5	8
M. Hawk	do			12	82	23	2	4	5
J. A. Corton	do			12	147	22	2	5	5
	do			....	200	21	2	4	5
M. Jenkins	do			8	128	22	2	4	5
G. G. Muridge	13	5	6	8	102	18	3	5	5
C. Lamson	13	5	6	8	90	18	2½	5	5
M. Lucas	7	5	7	8	94	18	2½	5	5
A. Andrews	7	5	7	....	110	17	2½	6	8
Henry Colton	18	5	7	8	107	18.2	2½	5	5
	18	5	7	....	130	16	3½	10	25
J. W. Bird	18	5	7	....	97	16	2½	4	3
H. Hicks	Sanjon de los Moquelumnes rancho.			8	137	23	2	4	4
M. Hoskins	do			8	122	22	2	4	5
E. G. White	Cosumnes			12	150	18	3	12	4
	do			12	165	18	2	2	2
	do			8	102	14.2	3	5	30
	do			8	120	14	3	5	20
H. Patterson	28	6	7	8	147	20	2	5	4
George Wilson	Sanjon de los Moquelumnes rancho.			8	110	18	3	4	....
Golden Valley Land Co.	do			....	135	12	3	5	7
	29	6	7	8	122	19	2½	5	5
P. Pearson	4	5	7	8	92	19	2	4	4
R. Wimar	4	5	7	8	90	18.7	2	5	5
M. Considine	5	5	7	8	83	17	2	4	3
	7	5	7	8	100	17	2	5	5
H. H. Smith	7	5	7	8	120	16	2	5	5
M. Yenny	7	5	7	8	132	18	3	8	10

Pumping plants used for irrigation in the Sacramento area—Continued.

Owner.	Location.			Diameter of well.	Depth of well.	Depth to water.	Size of centrifugal pump.	Horsepower.	Area irrigated.
	Section.	Township N.	Range E.						
Galt quadrangle—Continued.				*Inches.*	*Feet.*	*Feet.*	*Inches.*		*Acres.*
M. Jones	15	5	7	8	130	18	2½	5	5
L. Shepard	16	5	7	....	105	21	3½	4	5
M. Moore	16	5	7	....	100	20	2	2½	3
C. H. Garden	17	5	7	....	92	18	2	3	5
	17	5	7	....	98	19	2	4	5
	15	5	7	8	112	19	2	5	4
C. Madon	27	5	7	8	100	19	2	5	3
Fred Bassow	28	5	7	10	185	18	3½	8	5
J. D. Adiles	28	5	7	....	118	20	3	6	5
New Hope quadrangle.									
	Near New Hope			10	73	10	3	3	15
W. J. Bates	do			4	130	12	1½	5	....
	do			12	70	6	3	4	8
H. Nicholas	do			12	142	12	2	3	5
Woodbridge quadrangle.									
H. Myers	Sanjon de los Moquelumnes rancho.			8	42	21	2	5	....
E. Moore	do			8	96	20	3	7½	20
S. Palino	do			5	35	20	2½	5	10
M. H. Healey	do			8	48	15	2½	7½	....
F. E. Eden	do			8	72	20	2½	5	10
F. H. Oldersham	do			8	60	20	2½	5	10
J. L. McGinn	do			8	106	19	2½	5	10
J. M. Robinson	do			8	56	18	3½	7½	20
E. E. Ames	do			8	96	21	2½	5	10
M. Tweger	do			8	80	18	4	10	12
Do	do			8	104	18	4	10	12
	do			8	62	19.2	2½	5	10
R. E. Coker	do			8	90	19	2½	5	10
M. E. Scott	do			8	69	19.2	2½	5	10
Valley Oaks Land Co	do			8	78	15	3	7½	10
Do	do			8	84	17	3	7½	10
Do	do			8	122	17	3	7½	10
Do	do			8	137	16	3	7½	10
F. H. Harvey	do			8	52	14	3	8	20
Do	do			8	67	14.2	3	8	20
Do	do			8	60	14	3	8	20
	33	5	6	8	82	18.2	3	7½	10
	33	5	6	8	89	18.7	3	7½	10
C. Marshall	1	4	6	6	96	24	3	6	8
	10	4	6	12	80	14	4	8	20
J. Jahnd	12	4	6	6	104	24	2	4	3
A. E. Gordon	13	4	6	8	60	14	3½	5	12
Do	13	4	6	....	62	14	4	7½	15
Walter Jahant	14	4	6	8	95	16	2	3	2
Do	14	4	6	8	50	31	6	20	35
J. C. Horing	6	4	7	8	73	21	3	6	7
Do	6	4	7	8	66	22	1½	2½	3
John Quigel	6	4	7	6	52	20	3	6	5
F. M. Eighroy	6	4	7	6	92	23	3	6	10
	7	4	5	6	104	25	3	6	10

NOTE.—Measurements of depth to water made between November 5 and December 31, 1914, by J. W. Muller.

DEEP-WELL RECORDS.

DRILLING OPERATIONS.

When ground water was used only for domestic purposes or for watering stock, sufficient supplies were obtained throughout the valley by shallow wells, and little deep drilling was done. An occasional well was put down to obtain that perennial desideratum of the American farmer, artesian water, but the record of most of these attempts has been lost. Only at Sacramento, where natural gas has long been known to occur, has there been much deep drilling. In recent years, however, a number of deep wells have been sunk to obtain large supplies for irrigation or for town use.

Descriptions and logs of many of the deeper wells are given below. Further reference to them is made in the description of the water resources of the several portions of the valley. In the notes on casing "I. D." means inside diameter, and "O. D." outside diameter.

DEEP WELLS ON THE WEST SIDE.

WELLS NEAR RED BLUFF.

The wells of the Antelope Creek & Red Bluff Water Co. are situated on a small flat near the river about 30 feet below the town of Red Bluff, Tehama County (A, Pl. IV). Well No. 2 is the deepest and shows a succession of unconsolidated clay, sand, and gravel to 260 feet. Below this depth is 110 feet of "red sand" or "sandstone" and then 6 feet of "sandstone" whose color is not given, to a total depth of 376 feet. Water is drawn only from the gravel between 228 and 260 feet. It is not likely that these wells reach the bottom of the older alluvium. (See combined analysis of public supply of Red Bluff, including this well, A1, p. 139.)

Driller's log of Antelope Creek & Red Bluff Water Co.'s well No. 2, Red Bluff.

[No. 1, Pl. III.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Clay	40	40	Clay	112	228
Sand	4	44	Gravel (perforated here only)	32	260
Gravel	2	46	Red sand or sandstone	110	370
Clay	62	108	Sandstone	6	376
Gravel	8	116			

NOTE.—Drilled in 1910; 10-inch stovepipe casing, is perforated by slots from 228 to 260 feet.

Four wells were drilled in 1910–11 as oil prospects in the Orchard Park tract south of Red Bluff (No. 3, Pl. IV). Well No. 1 is 583 feet deep, and the log is available from 211 feet down. For the first 379 feet it went through a series of red and yellow clays with beds of sand and gravel containing water and at 368 feet 1 foot of "lava." From 379 to 505 feet "red shale" and "sandstone" are reported, containing traces of oil and apparently not water bearing. At 505 feet dark clays were encountered, and some thin beds of gravel and sand below appear to be water bearing. Well No. 2 is within a few hundred feet of No. 1 and shows a water-bearing series of red and yellow clays with sand and gravel to 421 feet. There is less red material than in well No. 1 and several thin beds of brown clay. Between 213 and 214 feet "yellow clay and fossil rock, shells, etc.," were found. From 421 to 476 feet "sandstone" and "oil sand" are reported. Below 476 feet thick beds of "blue shale and clay" with "brown shales and adobe" and streaks of water-bearing sand were found down to 803 feet.

A consideration of these logs shows that there is on the west side of the Sacramento near Red Bluff a water-bearing series consisting of red and yellow clays with prominent sands and gravels and having a total thickness of about 400 feet. This series probably represents the whole thickness of the older alluvium. Below this formation blue and brown clays and shales with cemented sands occur. Water is found in these materials also, but not in their upper part. They probably represent the upper part of the Tuscan tuff or possibly the Ione formation. The fossils mentioned in the log have not been preserved. The following account of them is taken from a letter of Mr. John P. Kennedy, manager of the Exposition Fruit Land Co., under date of April 21, 1914:

The well driller (Moore) tells me that he had several pieces that had perfectly formed shells on them, ranging in size from one-half inch to 3 inches in diameter, and that he also had pieces with fishbones in them, as he termed it. One piece had almost the entire vertebra visible. There were also small round shells with openings in one end. * * * There was also a piece with a bone in it—a bone probably one-half inch thick and broken off at both ends. From all accounts it was a bone of the leg of some animal.

Driller's log of oil prospect well No. 1, Orchard Park.

[No. 3, Pl. IV.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Not recorded	211	211	Sandstone	13	444
Water, good	5	216	Red shale	14	458
Yellow clay	40	256	Dormant oil sand	15	473
Shale	6	262	Red shale	10	483
Red clay, tough	32	294	Dry sand; oil	9	492
Water, good	10	304	Flint shale	1	493
Yellow clay	3	307	Dry sand; oil	12	505
Water, good	3	310	Gray adobe	3	508
Red shale	49	359	Blue slate	13	521
Water, good	9	368	Brown shale	8	529
Lava	1	369	Dry sand; oil	26	555
Water, good	10	379	Water, good	12	567
Red shale	34	403	Sandstone	4	571
Red sand	5	408	Water, good; still in water when drilling stopped	13	584
Sandstone, hard	13	421			
Shale	10	431			

NOTE.—First 211 feet drilled by Van Ness, September, 1909; no log was kept. Water was reported at 70 to 90 feet and 115 to 165 feet. From 211 feet to the bottom drilled by Moore, July, 1910.

Driller's log of oil prospect well No. 3, Orchard Park.

[No. 3, Pl. IV.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Surface	10	10	Brown shale	4	309
Dry gravel	11	21	Yellow clay	48	357
Gravel and silt	14	35	Yellow clay and gravel	11	368
Yellow clay	24	59	Water, good	15	383
Water, fair	5	64	Soft stone, dark brown	8	391
Yellow clay	9	73	Water, poor	22	413
Red clay	33	106	Water, good	8	421
Brown clay	12	118	Sandstone	30	451
Clay and gravel	5	123	Oil sand, poor	25	476
Water, fair	22	145	Brown shale	20	496
Red clay	6	151	Blue shale	8	504
Soft yellow clay	12	163	Water, good	2	506
Sticky soft yellow clay	4	167	Sandstone	8	514
Hard yellow clay	20	187	Blue shale	170	684
Yellow sandy clay	5	192	Brown adobe	10	694
Hard red clay	7	199	Blue adobe	17	711
Dry yellow sand	4	203	Water, good	13	724
Yellow clay and gravel	10	213	Hard stone	2	726
Yellow clay and fossil rock, shells, etc	28	241	Blue adobe	1	727
			Black adobe	3	730
Yellow clay	10	251	Blue adobe	31	761
Shale	9	260	Hard blue shale	16	777
Hard yellow clay and gravel	1	261	Blue adobe	14	791
Shaly clay	40	301	Dark-brown adobe	12	803
Gray shale	4	305			

NOTE.—Drilled by Moore in 1911. Well No. 2, 339 feet deep, had same log to 308 feet.

WELLS NEAR CORNING.

The McClelland Land & Development Co. has put down the deepest well near Corning, about 2 miles northwest of the town (No. 6, Pl. IV). The first 385 feet consists of a series of water-bearing gravel, sand, and clay. From other wells, especially those of the Richfield Land Co., it is known that, though these gravels are partly cemented, they can be depended on for very good wells. The clays are red, yellow, and blue, and this part of the well is probably all in the older alluvium. From 385 to 665 feet relatively little water was found and many of the clays and sands are reported "dry." Between 665 and 675 feet 5 feet of sand was struck and the water rose to 20 feet. Below this point cemented sands and gravel were found and darker colors prevail in the clays. It seems probable that here, as at Red Bluff, the older alluvium is about 400 feet thick and below are darker clays which are parts of the Tertiary system.

The Richfield Land Co.'s well No. 10 (No. 4, Pl. III) has dark clays beginning at 204 feet. As in the McClelland well, the lower material is dry. In the same company's well No. 22 (No. 5, Pl. III) red material is reported down to 275 feet.

The conclusion seems to be that the combined thickness of the two alluviums is from 350 to 400 feet, though variations in thickness and in character are to be expected.

Driller's log of well of McClelland Land & Development Co., near Corning.

[No. 6, Pl. IV.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	25	25	Hard dry clay	30	537
Clay and gravel	20	45	Soft sandy clay	10	547
Water gravel	1	46	Clay	33	580
Yellow clay	53	99	Lime formation	50	630
Water gravel	1	100	Sandstone	5	635
Blue clay	20	120	Yellow clay	5	640
Gravelly clay	4	124	Yellow sandy clay	4	644
Water gravel	5	129	Dry clay and sand	3	647
Yellow clay	51	180	Dry hard sand	5	652
Water gravel	2	182	Clay	13	665
Tough dry clay	33	215	Fine sand; water rose within 20 feet of top	5	670
Water gravel	1	216	Clay	58	728
Tough dry clay	64	280	Hard sandstone	32	750
Water gravel	10	290	Fine sandstone	5	755
Yellow clay	10	300	Soft clay and sandstone	10	765
Water gravel	25	325	Cement gravel	5	770
Clay	20	345	Clay	15	785
Water gravel	40	385	Black rock	12	797
Brown bedrock, hard	10	395	Clay and sand	3	800
Black sandrock	13	408	Gray clay	10	810
Loose black sand	27	435	Blue clay	10	820
Gray clay	30	465	Sand	3	823
Yellow clay	25	490	Black clay	2	825
Blue sandy clay	15	505			
Hard muck	2	507			

NOTE.—Drilled by Kopfer & Storm; 12-inch screw casing; water level, 20 feet.

Log of Richfield Land Co.'s well No. 10, near Corning.

[No. 4, Pl. IV.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	14	14	Blue clay	39	380
Gravel	16	30	Sandstone	9	389
Clay	11	41	Blue shale	14	403
Gravel	2	43	Smooth black sand	9	414
Clay	18	61	Sand and gravel	18	432
Loose gravel; no water	31	92	Blue clay	3	435
Sandstone	42	134	Sandstone	3	438
Gravel	2	136	Blue clay	10	448
Sandstone	62	198	Sandstone	10	458
Sand	6	204	Sand	4	462
Blue clay	50	254	Blue clay	16	478
Blue and black clay	28	282	Blue shale	10	488
Black sandstone and blue clay	6	288	Sand	7	495
Soft blue clay	18	306	Sand and gravel	16	511
Sand and fine gravel	12	318	Gravel	12	523
Clay	4	322	Clay	1	524
Sand and hard streak of clay	19	341			

NOTE.—Drilled by Adams; 11⅝-inch I. D. casing; water level, 35 feet.

Log of Richfield Land Co.'s well No. 22, near Corning.

[No. 5, Pl. IV.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	7	7	Loose gravel	2	159
Dry gravel	13	20	White sandstone	4	163
Clean gravel	12	32	Sand clay	4	167
Dirty gravel	6	38	Sandy sediment	37	204
Clay	11	49	Sandstone	4	208
Dirty gravel	2	51	Loose black gravel	2	210
Yellow clay	20	71	Loose sand	8	218
Sand clay	3	74	Soft sandstone	13	231
Yellow clay	19	93	Sandstone	11	242
Cement gravel	28	121	Loose stone	6	248
Gray sandstone	19	140	Sand rock	6	254
Red sandstone	10	150	Sandy clay	11	265
Gray sandstone	7	157	Reddish iron clay	10	275

NOTE.—Bored with hand auger rig: 12 inches in diameter.

WELL NEAR ORLAND.

The Black Butte Land Co. in 1912 sank a well on its land 4 miles southwest of Orland to a depth of 1,155 feet. The present water level is 200 feet, and the results were considered so unsatisfactory that the well was never tested. The first 260 feet consists of a series of water-bearing clay, gravel, and sand similar to the material encountered in the McClelland well, near Corning. Below these beds is a thick series of clays or shales with cemented gravels and sands containing little water. Volcanic ash is reported at various depths. The bedding seems to be thin, but whether this is due to the actual character of the beds or to more refinement in keeping the log is difficult to determine.

Driller's log of Black Butte Land Co.'s well, Orland.

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Gravel and soil	7	7	Stiff blue clay	12	614
Cement gravel	5	12	Brown clay	11	625
Medium yellow clay	63	75	Stiff blue clay	3	628
Sandy clay	18	93	Gravel and some clay	5	633
Gravel, water bearing	2	95	Blue clay	3	636
Silt or sandy clay	20	115	Gravel and rotten clay	8	644
Stiff clay and some fine gravel	17	132	Gravel	2	646
Black sand, water bearing	5	137	Blue clay	10	656
Fine gravel	6	143	Sand	1	657
Medium clay	2	145	Clay and gravel	3	660
Black gravel	5	150	Sticky brown clay	15	675
Yellow clay	10	160	Gravel and clay	1	676
Cement gravel	8	168	Brown clay	5	681
Clay	2	170	Red clay	2	683
Gravel and some clay	8	178	Coarse sand and some clay	2	685
Stiff yellow clay	25	203	Muddy gravel	7	692
Gravel, water bearing	7	210	Cement gravel	3	695
Clay	26	236	Brown clay and sand	6	701
Cement gravel	4	240	Very sticky stiff yellow clay	33	734
Very stiff clay	15	255	Muddy gravel	8	742
Black sand	5	260	Yellow clay	5	747
Blue clay	10	270	Cement gravel	8	755
Gray sand	8	278	Loose sand	5	760
Blue clay	7	285	Tight sand	2	762
Sandy gravel	2	287	Tough yellow clay	5	767
Yellow clay	30	317	Cement gravel	2	769
Muddy gravel	5	322	Hard sticky yellow clay	46	815
Yellow clay	21	343	Soft clay or soft rock	2	817
Brown lava	12	355	Very hard yellow clay	8	825
Tough yellow clay	17	372	Soft clay	3	828
Lava ash	8	380	Cement gravel	2	830
Fine gravel in lava ash	10	390	Stiff yellow clay	20	850
Blue shale	3	393	Gray clay and some gravel	15	865
Stiff clay and some gravel	20	413	Brown clay	5	870
Blue clay	5	418	Blue clay	12	882
Gravel	21	439	Tough yellow clay	2	884
Gravel and some rotten clay	6	445	Blue clay	13	897
Sand and gravel	6	451	Lava ash	11	908
Blue clay	14	465	Blue shale	2	910
Cement gravel	5	470	Hard lava ash	5	915
Brown clay	13	483	Hard stiff clay	3	918
Stiff blue clay	13	496	Coarse black sand	2	920
Cement gravel, water bearing	10	506	Gravel and clay	2	922
Tight gravel	4	510	Stiff clay	3	925
Blue clay	33	543	Blue shale	4	929
Gravel and some clay	10	553	Gravel and clay	9	938
Blue clay	3	556	Coarse gravel	3	941
Gravel	1	557	Hard sticky blue clay	20	961
Stiff blue clay	7	564	Black sand	7	968
Sandy clay	2	566	Dirty gravel	1	969
Gravel and little clay	19	585	Sand and gravel	3	972
Sand and gravel	9	594	Blue clay	5	977
Gravel and some clay	4	598	Soft rock	3	980
Sand and gravel	4	602	Blue clay	8	988

Driller's log of Black Butte Land Co.'s well, Orland—Continued.

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Black sand	4	992	Fine gravel; some clay	10	1,080
Sand and clay	6	998	Soft rock	5	1,085
Cement gravel	2	1,000	Sand	1	1,086
Sand and clay	6	1,006	Fine cement gravel	3	1,089
Hard sticky blue clay	25	1,031	Muddy gravel	11	1,100
Very fine black sand	1	1,032	Gravel and clay	11	1,111
Blue shale	2	1,034	Soft clay	2	1,113
Hard sticky blue clay	11	1,045	Gravel and clay	9	1,122
Sandy clay	3	1,048	Cement gravel	8	1,130
Gravel	4	1,052	Stiff clay	3	1,133
Very fine black sand	6	1,058	Soft rock	3	1,136
Coarse gravel with clay enough to stand up	4	1,062	Cement gravel	2	1,138
Soft rock	4	1,066	Blue clay	3	1,141
Blue clay	4	1,070	Muddy gravel	1	1,142
			Hard sticky blue clay	13	1,155

NOTE.—Drilled by Linscott Drilling Co. in 1912; begins with 11⅝-inch I. D. casing; water level, 200 feet.

WELLS NEAR WILLOWS.

The wells of the Central Forest Co., 3 miles north of Willows (Nos. 7 and 8, Pl. IV), show the occurrence of a water-bearing series in the first 300 feet. In well No. 4 (No. 7, Pl. III), however, 323 feet of clay without gravel or sand was found from 22 to 345 feet. Below occur a series of dry beds. Water was struck, however, in 4 feet of sand and gravel at 708 feet and rose within 15 feet of the surface. This is the beginning of the water-bearing series which in the neighboring Shaw wells gives artesian water. Owing to the fact that only soil and clay were encountered in the first 345 feet of well No. 4 no water was obtained from the upper beds. In well No. 6, 1 mile west, and in six wells in the intervening area good sand and gravel were found within this depth, and these wells were developed as a source of water for irrigation. (See p. 197.)

Driller's log of Central Forest Co.'s well No. 4, near Willows.

[No. 7, Pl. IV.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	22	22	Clay	120	554
Clay	323	345	Sand and gravel	12	566
Dry gravel	7	352	Clay	142	708
Clay	78	430	Sand and gravel	4	712
Gravel and sand	4	434	Clay	83	795

NOTE.—Drilled by McMath in 1913; 9⅝-inch I. D. casing; water level 15 feet.

Driller's log of Central Forest Co.'s well No. 6, near Willows.

[No. 8, Pl. IV.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	4	4	Clay	32	150
Clay	14	18	Clay and cement chunks	20	170
Gravel	6	24	Clay	14	184
Clay and gravel	8	32	Gravel	6	190
Gravel	2	34	Clay and cement chunks	42	232
Clay	16	50	Gravel	12	244
Clay and cement chunks	20	70	Clay and cement chunks	29	273
Clay	12	82	Gravel	11	284
Clay and cement chunks	8	90	Clay and cement chunks	5	289
Clay	26	116	Gravel	1	290
Gravel	2	118	Clay and cement chunks	10	300

NOTE.—Drilled by W. A. Rice, in 1913; 12-inch stovepipe casing.

South of Willows and about 2 miles north of Norman, on the Z. S. Spaulding ranch (No. 9, Pl. IV), where ground water stands at 6 feet from the surface, a flowing well was obtained several years ago. The log was published in the report of the California State mineralogist in September, 1892, where it is referred to as the well on the Rideout ranch. The first 337 feet was reported as yellow clay. The upper 100 feet furnishes water in neighboring wells from streaks of sand and holes and joints in the clay. (See discussion of the Spaulding ranch project, p. 194.) From 337 to 442 feet hard dry sand and clay in alternating thin beds occur, and below this yellow clay and sand and clay to 841 feet. Here begin blue clays with beds of sand yielding flowing water. The well was started with a 12-inch casing, but reductions were necessary. Water comes now from a 2-inch pipe 3 feet above ground at the rate of about 5 gallons a minute. In 1913 a 3-inch well was sunk by the hydraulic method to 835 feet on the same ranch, 1½ miles southeast of the first well (No. 10, Pl. IV). On May 4, 1913, the well flowed 25 gallons a minute as measured by Malcolm A. Knock, engineer for Z. S. Spaulding. The well was uncased and the water sank to 8 feet below the surface, but it rose by November to 2½ feet. Owing to the method used in drilling, the log is probably not as reliable as that of the old well, but it shows "dry" material from 200 feet to the water at 835 feet.

Log of first flowing well at ranch house of Z. S. Spaulding, near Norman.

[No. 9, Pl. IV].

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil and yellow clay	337	337	Hard dry sand	9	442
Hard dry sand	8	345	Yellow clay	100	542
Fine sand	3	348	Alternate strata, about 2 feet thick, of clay and sand	299	841
Hard dry sand	8	356	Blue clay	20	861
Clay	30	386	Sand and gravel	15	876
Hard dry sand	2	388	Sand, with flowing water	10	886
Clay and sand	20	408	Hardpan	5	891
Hard dry sand	10	418	Blue clay	34	925
White clay	9	427	Quicksand	15	940
Sand	6	433			

NOTE.—Log from report of California State mineralogist, 1892, p. 224.

Driller's log of new flowing well, Spaulding ranch, near Norman.

[No. 10, Pl. IV.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Clay and sand	100	100	Sand	40	470
Sand	10	110	Cement sand	20	490
Clay	90	200	Hard clay sand	10	500
Hard dry sand	20	220	Clay	20	520
Sand	10	230	Cement	30	550
Clay	40	270	Sand	20	570
Cement and gravel (size of small shot)	20	290	Clay and sand	95	665
Clay	30	320	Gravel and cement	15	680
Sand	90	410	Clay	85	765
Cement and sand	20	430	Gravel	35	800
			Soft clay	35	835

NOTE.—Drilled by hydraulic method; 3 inches in diameter; no casing.

WELL AT DELEVAN.

In 1912 a well was sunk to 832 feet in the town site of Delevan (No. 11, Pl. IV) by the Sacramento Valley Irrigation Co. Predominating yellow clays appear in this well, as in the wells on the Spaulding ranch, down to 800 feet, where thick beds of blue clay come in. Flowing water was not obtained.

Driller's log of deep well at Delevan.

[No. 11, Pl. IV.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Yellow clay	170	170	Porous clay	4	618
Yellow clay and small gravel	10	180	Blue clay	8	626
Yellow clay	22	202	Yellow clay and cement lumps	14	640
Porous yellow clay	8	210	Light-blue clay	12	652
Blue clay	26	236	Brittle clay	28	680
Cemented sand	6	242	Yellow clay	30	710
Yellow clay	214	456	Sandy yellow clay and some small gravel	20	730
Sandy clay	8	464	Gravel	6	736
Yellow clay	26	490	Yellow clay	44	780
Cement	4	494	Yellow clay and cement lumps	10	790
Cemented sand	28	522	Blue shaly clay	8	798
Yellow clay	18	540	Blue sandy clay	8	806
Yellow clay and cement lumps	16	556	Gravel	4	810
Cemented sand	14	570	Blue cement	2	812
Yellow clay	10	580	Light-blue clay	18	830
Brittle clay	16	596	Light-blue sandy clay	2	832
Blue clay	8	604			
Brittle clay	10	614			

NOTE.—Drilled by W. A. Rice in 1912; 12-inch stovepipe casing; "mud-scow" rig. Log from a graph by E. C. Mills, chief assistant engineer, Sacramento Valley Irrigation Co.

WELLS NEAR MAXWELL.

The Mills Orchard Co. has put down a number of wells on its Maxwell ranch, near Mills station, on the Colusa & Lake Railroad, 5 miles west of Maxwell. A number of wells in sec. 34, T. 17 N., R. 4 W., show that the younger alluvium is about 20 feet thick in the valley of Stone Corral Creek. Well M–2, in the SE. ¼ sec. 35, T.

17 N., R. 4 W. (No. 14, Pl. IV), has 110 feet of alluvium and 36 feet of "rock and clay" and struck the sandstone of the Cretaceous at 146 feet. The first 24 feet of this well is probably in the younger alluvium, the remaining alluvium belonging to the older division. The 36 feet of "rock and clay" appears from the meager description to be a residual soil on the top of the truncated Cretaceous beds.

Well M-1 is in the SW. ¼ NE. ¼ sec. 26, T. 17 N., R. 4 W. (No. 12, Pl. IV), on the eastern slope of a patch of the older alluvium. The presence of gravel at 100 to 110 feet indicates that the older alluvium is here more than 100 feet thick.

Log of Mills Orchard Co.'s well M-2, near Maxwell.

[No. 14, Pl. IV.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	22	22	Clay	7	110
Gravel	2	24	Rock and clay	36	146
Clay	75	99	Sandstone (bedrock)	2	148
Gravel	4	103			

NOTE.—Drilled by W. A. Rice in 1912; 12-inch stovepipe casing; "mud scow" rig. Log furnished by E. C. Mills, engineer for the company.

Log of Mills Orchard Co.'s well M-1, near Maxwell.

[No. 12, Pl. IV.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	4	4	Gravel	10	110
Clay and rock	10	14	Clay	72	182
Clay	86	100	Finished in blue shale.		

NOTE.—Drilled by W. A. Rice in 1912; 12-inch stovepipe casing; "mud scow" rig. Log furnished by E. C. Mills, engineer for the company.

Log of Mills Orchard Co.'s well M-10, near Maxwell.

[No. 13, Pl. IV.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	20	20	Blue clay	458	580
Gravel	6	26	Blue shale	145	725
Yellow clay	78	104	Gray sandstone with crevices	10	735
Sandstone	18	122			

NOTE.—Drilled by W. A. Rice in 1913; 12-inch stovepipe casing; "mud scow" rig. Tested 300 gallons a minute; water from creviced sandstone at bottom. Log furnished by E. C. Mills, engineer for the company.

WELL NEAR MERIDIAN.

In 1912 the Alameda Sugar Co. sunk a well near Meridian (No. 15, Pl. IV) to obtain water for irrigating beets. (See also p. 211.) The hydraulic rotary method was used, and a depth of 473 feet was reached. Yellow clay and sand were found to 265 feet, and blue and gray sands and "shale" below this depth. If the yellow clays indicate alluvium and the gray and blue sands volcanic ash, then the alluvium is 265 feet thick above the volcanic ash from the Marysville Buttes near by.

Driller's log of Alameda Sugar Co.'s well, near Meridian.

[No. 15, Pl. IV.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Clay (largely soil)	24	28	Clay	13	233
Clay	6	34	Water sand	3	236
Shale	15	49	Clay (this clay and all clays above are yellow)	29	265
Clay	6	55	Gray water sand	5	270
Running sand	25	80	Blue water sand	10	280
Water sand	5	85	Blue sandy shale	30	310
Running sand	33	118	Water sand	19	329
Water sand	6	124	Hard fine sand	6	335
Water sand	24	148	Water sand	65	400
Clay	2	150	Blue shale	54	454
Water sand	7	157	Water sand	17	471
Shale	33	190	Granite	2	473
Clay	25	215			
Sand and shale	5	220			

NOTE.—12 inches in diameter; drilled by hydraulic rotary method; screw casing with slots covered with brass mesh. Perforation offset 26 feet owing to caving.

WELL IN HUNGRY HOLLOW HILLS.

In 1912 H. H. Gable drilled a well 730 feet deep on his ranch southwest of Dunnigan (No. 16, Pl. IV) in the flat-bottomed valley of Oat Creek near the top of the plateau of older alluvium. Water stands within 6 feet of the general surface in pools in the creek bed and in shallow wells. Below 7 feet of topsoil was 10 feet of "lava ash and hardpan," as reported by the drillers. As shown in sections exposed by the creek, this is a cemented brownish sand, with hard, limy layers or hardpan. Farther down in the older alluvium of the Hungry Hollow Hills tuffaceous clays and volcanic ash are known to occur. The rest of the log shows an alternation of yellow, brown, and blue clays and volcanic ash. Some thin streaks of fine sand and gravel furnish water that rises within 69 feet of the surface.

Driller's log of Gable well, southwest of Dunnigan.

[No. 16, Pl. IV.]

	Thickness.	Depth.
	Feet.	*Feet.*
Topsoil	7	7
Lava ash and hardpan	10	17
Soft decomposed sandstone, water bearing	9	26
Hard blue clay and gravel, containing some water	6	32
Clay with fine gravel	3	35
Medium yellow clay	6	41
Sandy clay	17	58
Hard clay, with some gravel	14	72
Sandy clay	19	91
Clay mixed with a great deal of gravel	5	96
Loose fine sand and gravel, water bearing	$3\frac{1}{2}$	$99\frac{1}{2}$
Yellow clay and gravel	$5\frac{1}{2}$	105
Blue clay	12	117
Yellow clay and gravel	68	185
Brown clay and gravel	9	194
Sticky brown clay	29	223
Lava tufa	48	271
Medium hard sandstone	7	278
Clay and gravel	1	279
Sticky yellow clay	36	315
Soft brown sandstone	6	321
Medium hard sandstone	6	327
Sticky yellow clay	45	372
Hard clay and gravel	5	377
Cement gravel	12	389
Sticky yellow clay	62	451
Lava ash	39	490
Sticky brown clay	10	500
Sandy clay	16	516
Sticky brown clay	39	555
Sticky blue clay	60	615
Yellow clay	55	670
Very fine sand; broke through in night	1	671
Sticky yellow clay	24	695
Blue clay	25	720
Decomposed blue sandstone and loose gravel, water bearing	3	723
Hard cement gravel	7	730

NOTE.—Drilled by Linscott Drilling Co. in 1912; $11\frac{5}{8}$-inch I. D. casing from 1 to 281 feet; $9\frac{5}{8}$-inch I. D. casing from 281 to 571 feet; $7\frac{5}{8}$-inch I. D. casing from 1 to $724\frac{1}{2}$ feet. "Broke through this cement gravel into small water strata under great pressure, underlying which was stratum of blue clay. Water level with all water strata shut off, except last 153 feet. Compelled to abandon well at this point. Put in charge of dynamite, 50 pounds, in hopes of opening up a water stratum, but without effect. Water has since come up in the well and now stands in the $7\frac{5}{8}$-inch casing at 69 feet." Letter from H. H. Gable, March 22, 1913.

WELLS NEAR WOODLAND.

On the ridge of Cache Creek Slough, between Yolo and Knights Landing, 7 miles north of Woodland (No. 17, Pl. IV), Lindsay S. Morris put down a test well to a depth of 611 feet to determine the presence and position of the water-bearing beds. Between 58 and 114 feet he found 56 feet of free gravel, and from this bed he developed later sufficient water for his purposes. (See description of his pumping plant on p. 115.) Down to 420 feet most of the clay is yellow and there is rather more gravel than in many regions. Between 420 and 434 feet white sand with rounded pebbles of pumice was found, and a sample that was saved by Mr. Morris was seen by the writer. Below this point was blue clay with streaks of sand to 611 feet, where yellow clay was found. The material in the upper part of the section was evidently deposited by Cache Creek, which has distributed gravels in yellow clay over a large area in the vicinity of Yolo and Woodland. These beds are free water bearers and have been extensively developed by many pumping plants. (See p. 217.) It is probable that the white sand with pumice and the blue clay below represent the top of the older alluvium exposed in the Hungry Hollow plateau. With this interpretation the throw of the fault is about 600 feet, 200 feet being shown in the present bluff. The fill of recent alluvium is about 400 feet deep. The many wells of the region show that this material is loose and saturated with water.

Driller's log of Lindsay Morris well, near Yolo.

[No. 17, Pl. IV.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil and sand (surface water at 16 feet)	38	38	Yellow clay	22	296
White clay	8	46	Hard yellow clay	2	298
Hard yellow clay	12	58	Yellow clay	44	342
Gravel	56	114	Sand and gravel	40	382
Yellow clay	9	123	Yellow clay	38	420
Hard streak of clay and sand	14	137	White sand and pumice stone	14	434
Blue clay	13	150	Blue clay, with occasional sand streaks	71	505
Yellow clay	19	169	Black sand	1	506
Sand	4	173	Blue clay	104	610
Gravel	20	193	Hard soapstone	1	611
Yellow clay	80	273	Hard yellow clay	....	....
Sand and gravel, mixed	1	274			

NOTE.—Test well drilled by Croutcher; 2-inch casing, afterward pulled.

WELLS NEAR DAVIS.

The University farm well No. 2 (No. 18, Pl. IV) is 369 feet deep. Down to 245 feet a typical series of clays, sand, and gravels was penetrated. Below this depth the clays are darker in color, and on the evidence of the log of the Gordon well (see below) and the known structure this is considered the top of the older alluvium.

Driller's log of University farm well No. 2, near Davis.

[No. 18, Pl. IV.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	14	14	Soft sandy clay	5	180
Adobe clay	4	18	Medium clay	5	185
Sandy clay	5	23	Medium clay; some gravel	20	205
Adobe clay	3	26	Clay, softer, swelling some	6	211
Stiff clay	21	47	Sticky yellow clay	34	245
Sandy clay	7	54	Blue clay; great deal of gravel	30	275
Gravel, fine and loose	8	62	Hard clay and gravel	7	282
Fine gravel	8	70	Very hard clay; resembles stone	5	287
Blue clay	10	80	Kind of sandstone	3	290
Yellow clay; some fine gravel	9	89	Hard clay and gravel	5	295
Soft clay	4	93	Medium hard clay and gravel	15	311
Gravel and clay	12	105	Loose sand and gravel	12	323
Coarse gravel	23	118	Sticky blue clay and gravel	12	335
Medium gravel	8	126	Blue shale	2	337
Tough yellow clay	6	132	Sticky blue clay with great deal of gravel	10	347
Medium clay	3	135	Very sticky blue clay	3	350
Hard, stiff clay	10	145	Blue clay and gravel	1	351
Medium clay	8	153	Soft sandstone	5	356
Stiff clay; some fine sharp gravel	18	171	Yellow clay and gravel	3	369
Very hard clay	4	175			

NOTE.—Drilled by Linscott Drilling Co., 1912; 24-inch casing to depth of 70 feet; 11⅝-inch I. D. screw casing to depth of 249 feet; 9⅝-inch I. D. screw casing to depth of 364 feet. Perforated 48 sets from 311 to 323 feet. Cement between 24-inch and 11⅝-inch casing, 51 to 70 feet.

The Gordon well, 3 miles southeast of Davis (No. 19, Pl. IV), was put down in the hope of obtaining artesian water. W. Y. Gordon, the owner of the ranch, bore the expense to about 800 feet, and the last 230 feet was paid for by subscription among the neighbors. Between 35 and 238 feet is a heavy bed of yellow clay, which is, however, not extensive, as wells but a short distance away show gravel and sand in the first 200 feet. Beginning at 304 feet dark clays and shale with little water in the intervening sands occur to 803 feet, where 10 feet of fine gravel furnished water that rose within 20 feet of the surface. Similar beds continue to the bottom at 1,030 feet. The lower water, contained in fine black sand, rose within 8 feet of the surface, or 10 feet above the water table, which lies at about 18 feet in this locality. It is thought that the well is in the older alluvium from about 300 feet down. An analysis (A58) of water from this well is given on page 233.

Driller's log of the Gordon well, near Davis.

[No. 19, Pl. IV.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Topsoil	18	18	Hard clay	5	617
Adobe	17	35	Sandy clay	11	628
Common yellow clay; hard, solid drilling	203	238	Medium hard clay	7	635
Gravel and sand	2	240	Blue clay	13	648
Clay and sand mixed	35	275	Yellow clay and gravel	5	653
Clay, sloughing	6	281	Loose gravel and sand	12	665
Large, loose gravel	23	304	Hard clay	21	686
Olive-green clay	6	310	Light-colored clay	18	704
Blue clay	15	325	Sandy clay	8	712
Shale, sloughing	16	341	Soapstone	8	720
Sandy clay	8	349	Sandy clay	7	727
Shale	11	360	Soapstone	3	730
Clay	7	367	Sandstone with signs of vegetation	7	737
Shale	4	371	Blue clay	8	745
Tough clay	13	384	Blue clay	22	767
Hard clay	3	387	Loose, coarse sand	9	776
Hard sand	8	395	Soapstone	27	803
Hard clay	10	405	Fine gravel; water level rose from 300 to 54 feet	10	813
Sand	3	408	Soapstone	7	820
Cemented sand and gravel	9	417	Hard clay	4	824
Sand	4	421	Sand and gravel in clay	3	827
Gravel in clay	4	425	Sandy clay	13	840
Sandy clay	14	439	Soapstone	26	866
Hard clay	13	452	Blue clay	2	868
Sandy clay	13	465	Bluish-brown shale	14	882
Hard blue sand	13	478	Brown sandy shale	16	898
Loose sand	2	480	Blue sand and gravel	12	910
Blue clay	3	483	Gravelly mud	10	920
Sandy clay	12	495	Sticky yellow clay	13	933
Blue clay	11	506	Fine rising sand	5	938
Sandy clay	10	516	Sticky blue clay	34	972
Blue clay	21	537	Blue-brown clay	3	975
Hard yellow clay	9	546	Hard black sandy shell	1	976
Sand and gravel; little clay	11	557	Black sand; very little water	4	980
Blue clay	8	565	Black sand	2	982
Yellow sandy clay	5	570	Blue mud	22	1,004
Yellow clay	11	581	Blue-black sand	2	1,006
Hard clay	7	588	Sand	14	1,020
Sandy clay	12	600	Blue sand	3	1,023
Hard clay	5	605	Clay and gravel	7	1,030
Sandy clay	7	612			

NOTE.—Drilled by Linscott Drilling Co., 1912; 9⅝-inch I. D. casing to 715 feet; 7⅝-inch I. D. casing to 1,022 feet; open hole from 1,022 to 1,030 feet; 9⅝-inch casing perforated from 546 to 557 feet and 653 to 666 feet; 7⅝-inch casing perforated from 767 to 776, 803 to 813, 898 to 910, and 1,004 to 1,020 feet; after casing was perforated water level rose within 8 feet of the surface.

DEEP WELLS ON THE EAST SIDE.

WELLS BETWEEN RED BLUFF AND CHICO.

There are only two deep wells on the east side between Red Bluff and Chico—that of Mrs. F. G. Weeks, opposite Red Bluff, called well No. 3 (No. 2, Pl. IV) and a well on the Read ranch near Vina (No. 20, Pl. IV), drilled in 1914.

The Weeks well is on a little knoll in the recent alluvium. After two unsuccessful attempts to get water, owing to poor well methods, a 10-inch O. D. casing was put down to 245 feet and sufficient water obtained to supply a 4-inch centrifugal pump. (See description of Weeks plant, p. 139.) The writer saw a piece of the "sandstone" obtained near the bottom of the well. It is a brown to buff volcanic sand cemented with calcium carbonate, such as is characteristic of the older alluvium of the east side as exposed near the Iron Canyon. The recent alluvium here is probably less than 100 feet thick.

The Read well was drilled to obtain pure water for use in the house. The log shows that the Tuscan tuff was struck at 140 feet, and water was obtained in the sands and gravels interbedded with the ash beds and breccias characteristic of the formation.

Driller's log of Weeks well No. 3, near Red Bluff.

[No. 2, Pl. IV.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Pit	33	33	Clay	2	198
Gravel	33	66	Sandstone	12	210
Sandstone	7	73	Clay	6	216
Shale	2	75	Sandstone	11	227
Sandstone	25	100	Clay	10	237
Cemented sand	3	103	Gravel (free)	3	240
Sandstone	93	196	Gravel	5½	245½

NOTE.—Drilled in 1913; 10-inch screw casing.

Driller's log of Read well, near Vina.

[No. 1, Pl. IV.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Black sandy loam	12	12	Sandy clay	25	195
Fine gravel	7	19	Lava ash	75	270
Coarse gravel	3	22	Lava sand and gravel	10	280
Yellow clay	8	30	Lava; hard and soft sandy streaks every 5 feet	15	295
Lava boulders	7	37	Lava ash	5	300
Coarse gravel	9	46	Loose sand and gravel	9	309
Yellow clay	18	64	Cement gravel	8	316
Cement gravel, dry	28	92	Cement sand; soft streaks every 2 feet	6	322
Soft clay; looks like topsoil	26	118	Lava sand and gravel	7	329
Sandy clay	22	140			
Cement lava sand	15	155			
Lava ash	15	170			

NOTE.—Drilled by Linscott Drilling Co. in 1915; cased with 11⅝-inch I. D. casing to 120 feet, and 7⅝-inch I. D. casing to 329 feet; perforated with double slots from 290 to 327 feet; depth to water, 64 feet.

WELLS NEAR CHICO.

The Chico Water Co., feeling a need for a larger supply for the town than could be derived from its shallow wells, in 1909 put down three deep wells. They were drilled by Van Ness, then in the employ of the company. Information concerning them was furnished by Mr. Simpson, the company's manager.

The well at the upper works, corner of Fifth and Olive streets (No. 20, Pl. IV), struck the "black sand" at 330 feet. The deep well at the lower works, Second and Cherry streets, is 607 feet deep (No. 22, Pl. IV). It starts with a 12-inch screw casing and ends with a 10-inch. "Black sand" was struck at 366 feet. The casing is perforated by slots from 80 to 607 feet. The Chapmantown plant has a similar well 603 feet deep (No. 23, Pl. IV) in which "black sand" was struck at 300 feet. The screw casing begins as 12-inch and is reduced to 10 and finally to 8 inches.

The "black sand" reported from these wells undoubtedly represents the Tuscan tuff, which rises out of the alluvium east of Chico. It is a free water bearer, for each of these wells furnishes water for a 6-inch centrifugal pump.

Since then five more deep wells have been put down near Chico, and the following table gives data regarding them:

Deep wells near Chico.

Owner.	Location.	Designation on Plate IV.	Owner's No.	Depth.	Depth to water.	Depth to lava.	Thickness of lava penetrated.	Estimated yield per minute.
				Feet.	*Feet.*	*Feet.*	*Feet.*	*Gallons.*
Chico Water Co.	Upper works	21		671		330	341	650
Do.	Lower works	22		607		366	241	665
Do.	Chapmantown	23		603		300	303–	600+
Sacramento Valley Sugar Co.	Morehead plant	24	1	705	30 +	507(?)	198	1,000
Do.	do.	24	2	624	30 +	508	116	1,000
Stanford University	Durham ranch	25	1	530	4½	37	497	855
Do.	do.	25	2	558	5	36	522	1,200 to 1,400
Parrott ranch	Llano Seco	28	1	399		377(?)	20	

Driller's log of deep well at upper works of Chico Water Co., Chico.

[No. 21, Pl. IV.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	15	15	Gravel	10	280
Loose gravel	10	25	Clay	20	300
Clay	110	135	Cement gravel	30	330
Cement gravel	25	160	Black sand, with little red particles like brick	341	671
Lava formation	20	180			
Clay	90	270			

NOTE.—Drilled by Van Ness for the water company in 1909.

Driller's log of Sacramento Valley Sugar Co.'s well No. 1, Morehead plant, Chico.

[No. 24, Pl. IV.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	5	5	Fine gravel and sand	9	428
Loose gravel	3	8	Medium clay	26	454
Medium gravel	15	23	Hard clay	6	460
Fine gravel	10	33	Hard lava ash	33	493
Red clay and fine gravel	12	45	Stiff sticky clay	14	507
Hard sticky clay	38	83	Lava ash	5	512
Clay; easy drilling	11	94	Cement gravel	4	516
Clay and sandstone	23	117	Lava ash	2	518
Sandy clay	18	135	Gravel and hard clay	7	525
Stiff clay	5	140	Soft lava clay	1	526
Sandy clay	41	181	Lava ash	19	545
Cement gravel	5	186	Sand and gravel	1	546
Hard clay and gravel; slow drilling	22	208	Hard lava ash	1	547
Soft clay; some sand	28	236	Very soft sandstone	18	565
Hard sandy clay	14	250	Sand and gravel	10	575
Soft clay	20	270	Fine sand	8	583
Tough clay	6	276	Gravel	3	586
Medium clay	19	295	Soft sandstone	22	608
Soft sandy clay	35	330	Fine gravel	8	616
Very hard clay with some gravel	17	347	Sandstone	1	617
Cement gravel, hard	10	357	Coarse sand and fine gravel	12	629
Sand and soft clay	18	375	Lava ash	24	653
Very hard clay with some gravel	11	386	Hard lava ash	11	664
Soft sandy clay	10	396	Soft lava ash	31	695
Stiff clay	17	413	Hard lava ash	10	705
Cement gravel	6	419			

NOTE.—Drilled by Linscott Drilling Co.; $9\frac{5}{8}$-inch casing to 285 feet; $7\frac{5}{8}$-inch casing to 669 feet; 32 perforations, each two slots, 6 inches long, from 520 to 545 feet and 90 perforations from 595 to 650 feet.

Driller's log of well No. 2 on Stanford ranch, Durham.

[No. 25, Pl. IV.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Topsoil	7	7	Sandstone	70	250
Soil and gravel; loose gravel at 10 feet	3	10	Medium hard sandstone	13	263
Lava sand and gravel	8	18	Sandstone	12	275
Clay and gravel; lava rock on one side of hole	18	36	Cement gravel	10	285
Hard lava rock	16	52	Sandstone; loose sand coming in	30	315
Lava ash	25	77	Sandstone	10	325
Medium hard sandstone	15	92	Lava sand	5	330
Hard sandstone	3	95	Lava sand and gravel	9	339
Loose lava sand	3	98	Lava ash and gravel	31	370
Loose lava sand; hard sandstone on one side hole	18	116	Hard sandstone	7	377
Lava ash	8	124	Cement gravel	10	387
Sandstone	16	140	Sandstone	80	467
Cement gravel; loose lava sand at 145 feet	5	145	Sandstone and gravel	23	490
Cement gravel, very hard on one side	6	151	Cement gravel	9	499
Lava ash and gravel	29	180	Loose sand and gravel	1	500
			Sandstone and gravel	15	515
			Sandstone	35	550
			Loose sand and gravel	6	556
			Lava ash and gravel	2	558

NOTE.—Drilled by Linscott Drilling Co. in 1913; starts with $11\frac{5}{8}$-inch I. D. casing; water level at 5 feet. Driller's test, between 1,200 and 1,400 gallons a minute, conservative estimate.

The well on the Parrott ranch (No. 26, Pl. IV) has never been pumped and is the only one of the eight whose yield is not approximately known. The log shows "fine lava ash" from 377 to 379 feet and "lava ash" from 391 to 399 feet. This is about 150 feet above the depth at which volcanic material is reported in the Sacramento Valley Sugar Co.'s wells, and it is doubtful whether this material is actually the Tuscan tuff continued under the valley. The section given in figure 4 (p. 73), drawn through the town of

Chico and the Sacramento Valley Sugar Co.'s Morehead wells, is based on the assumption that the Parrott well penetrates the Tuscan tuff. Further drilling may show the necessity of revising this conclusion.

Driller's log of Parrott well No. 1, Chico.

[No. 23, Pl. IV.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	16	16	Sand and gravel containing water	8	343
Sandy clay	14	30	Cemented gravel	1	344
Gravel	2	32	Sand and gravel containing water	11	355
Loose gravel containing water	13	45	Coarse gravel containing water	16	371
Gravel, some clay	5	50	Decomposed sandstone	6	377
Loose gravel containing water	13	63	Fine lava ash	2	379
Hardpan	12	75	Coarse gravel containing water	12	391
Reddish clay	250	325	Lava ash	8	399
Fine cemented gravel	10	335			

NOTE.—Drilled by Linscott Drilling Co., 1912; 9⅝-inch I. D. screw casing to 86 feet; 7⅝-inch I. D. screw casing to 399 feet; perforations, 6-inch slots, from 335 to 371 feet and 379 to 391 feet.

WELLS ALONG BEAR RIVER.

A series of wells were drilled by the Natomas Consolidated of California, in reclamation district 1001, along Bear River. Well No. 1, on the Haile ranch (No. 27, Pl. IV), shows 130 feet of sand, gravel, and clay, which represent the Quaternary alluvium. Then follows 100 feet of "lava ash," and although the driller's term is indefinite and not necessarily reliable, the tuffaceous equivalents of the andesite breccia exposed to the east should occur at this horizon. Below this he reports green, blue, and brown shales and clays to 420 feet, and then 436 feet of shale to the bottom. Similar conditions were found in well No. 2, about a mile southwest on the same ranch (No. 28, Pl. IV). Alluvium was found to 216 feet, followed by 24 feet of "lava ash," then 15 feet of clay and sand, 45 feet of lava ash, and finally 3 feet of shale at the bottom of the well. Water was found in the alluvium in both these wells, but the deeper beds were not good water bearers.

Driller's log of Natomas well No. 1, at Haile ranch, on Bear River.

[No. 27, Pl. IV.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Topsoil	2	2	Clay	5	240
Hardpan	16	18	Green shale	50	290
Clay	75	93	Shale, honeycombed with rock	37	327
Clay and gravel	7	100	Green shale	15	342
Clay	10	110	Shale	18	360
Clay and gravel	5	115	Blue shale	5	365
Clay	5	120	Sandy clay	5	370
Clay and gravel	4	124	Sandstone	1	371
Loose gravel	6	130	Brown shale	19	390
Lava ash	100	230	Brown shale, gassy	30	420
Shale	5	235	Shale	436	856

NOTE.—Drilled by Linscott Drilling Co. in 1912; log derived from a graph by Sperry; 11⅝-inch I. D. casing from 1 to 170 feet; 9⅝-inch I. D. casing to bottom. Perforated from 17 to 50 and 118 to 134 feet.

Driller's log of Natomas well No. 2, at Haile ranch, on Bear River.

[No. 28, Pl. IV.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Topsoil	6	6	Tough clay	20	165
Hardpan	5	11	Clay and gravel	1	166
Gravel	5	16	Clay	19	185
Sandy clay and gravel	24	40	Clay and gravel	7	192
Coarse sand and gravel	20	60	Clay	24	216
Fine sand and gravel	11	71	Lava ash (hard sand)	24	240
Tough yellow clay	24	95	Clay and sand	5	245
Loose sandy clay	15	110	Clay	10	255
Clay	25	135	Lava ash (sand)	45	300
Clay and gravel	10	145	Shale	3	303

NOTE.—Drilled by Linscott Drilling Co. in 1912: 9⅝-inch I. D. casing, perforated at intervals from 10 to 250 feet.

The Trowbridge & Hill well is about 1 mile southwest of Sheridan (No. 29, Pl. IV). In a general way the log confirms the results of Natomas wells Nos. 1 and 2 on the Haile ranch, which are about 3 miles distant. Below 212 feet of sandy clay, gravel, and sand, which represent the alluvium, comes 18 feet of "lava ash," and then a long series of clays and shales of dark color and streaks of sand and gravel. "Shells" are reported between 510 and 538, 540 and 611, and 796 and 798 feet. Unfortunately these fossils were not preserved. Their presence, however, indicates marine sediments, which are probably of early Tertiary or Cretaceous age.

Driller's log of Trowbridge & Hill well, near Sheridan.

[No. 29, Pl. IV.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Sandy loam	12	12	Dark-gray clay, little quartz pebbles, and shell	28	538
Sandy clay	68	80	Hard blue rock	2	540
Gravel	2	82	Gray clay with small pebbles and pieces of shell	71	611
Clay	3	85	Hard blue boulder	2	613
Small gravel and clay	8	93	Sticky gray clay	7	620
Sandy clay	17	110	Hard blue rock	5	625
Gravel and sandy clay	5	115	Soft sticky gray clay	16	641
Loose gravel and a little water	8	123	Shale	3	644
Sandy clay	27	150	Soft gray clay with gravel through it	26	670
Clay	5	155	Hard blue boulder	3	673
Sandy clay and little gravel	25	180	Soft gray clay with streaks of lava	70	743
Clay	11	191	Hard blue boulder and clay	20	763
Sandy clay and gravel	3	194	Blue sticky clay	7	770
Sand and little clay	18	212	Shell rock and clay	6	776
Lava ash	8	220	Sticky blue clay	4	780
Blue clay	75	295	Hard blue rock	1	781
Cemented sand	4	299	Sticky blue clay	7	788
Loose sand and gravel	6	305	Hard rock	2	790
Blue clay	19	324	Blue clay	4	794
Sand and gravel	5	329	Hard rock	2	796
Blue clay	16	345	Shell rock and clay	2	798
Blue clay and shale	10	355	Blue clay	17	815
Brown shale	6	361	Rock and clay	2	817
Sand	4	365	Light-blue clay and gravel	8	825
Small boulders	3	368	Hard rock	2	827
Light-gray clay	117	485	Blue clay and lava ash, sticky	103	930
Shale	2	487	Sticky blue clay, caving some	20	950
Light-gray clay	7	494			
Shale	6	500			
Cemented sand and gravel	10	510			

NOTE.—Drilled by the Linscott Drilling Co. in 1913; water level, 7½ feet; well held 6-inch pump at 27 feet during driller's test.

West of the Haile ranch, near the railroad station of Rio Oso, the Natomas Consolidated has put down four wells, Nos. 8, 9, 10, and 11 (No. 30, Pl. IV). These wells are situated in a curving line about 3 miles long. The logs of the wells show that white and yellow clay, gravel, and sand were found to a depth of about 200 feet, below which was blue clay or shale, and then varying amounts of materials reported as "lava," "lava sand," and "lava shale."

The writer did not see this material, and too much confidence can not be placed in the driller's identification, but it is thought that between 200 and 800 feet tuff beds representing the andesite breccia of the foothills are present and that the Ione and Chico occur below.

Driller's log of Natomas well No. 11, near Rio Oso.

[No. 30, Pl. IV.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Topsoil	10	10	Gravel	2	397
Hardpan	8	18	Shale	8	405
Soft clay	12	30	Lava	25	430
Fine gravel	5	35	Shale	5	435
Clay	35	70	Lava	15	450
Fine sand	4	74	Blue shale	13	463
Clay	21	95	Lava	12	475
Clay and fine gravel	25	120	Blue shale	10	485
Yellow clay	20	140	Lava	20	505
White clay	15	155	Blue shale	5	510
Yellow clay	15	170	Lava	60	570
Clay and fine gravel	36	206	Shale	10	580
Sand, gravel, and clay	4	210	Lava	105	685
White clay	19	229	Blue shale	5	690
Blue shale	42	271	Lava	20	710
Shale and lava	24	295	Blue shale	25	735
Shale	11	306	Lava ash	5	740
Lava	9	315	Lava	28	768
Shale	5	320	Loose lava	17	785
Lava	10	330	Lava	10	795
Lava sand	18	348	Loose lava	11	806
Shale	47	395			

NOTE.—Drilled by Linscott Drilling Co.; log derived from graph by Sperry; $11\frac{5}{8}$-inch I. D. casing from 1 to 38 feet; $9\frac{5}{8}$ inches from 380 to 806 feet; perforated from 380 to 800 feet.

Driller's log of Natomas well No. 10 near Rio Oso.

[No. 30, Pl. IV.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Sediment	16	16	Sandy clay	10	280
Topsoil	1	17	Blue shale	18	298
Sandy soil	10	27	Blue clay	9	307
Clay	7	34	Clay and gravel	8	315
Gravel	6	40	Lava	81	396
Clay	5	45	Lava ash and lava	52	448
Coarse sand and gravel	16	61	Lava ash and sand	22	470
Loose sand	5	66	Lava	67	537
Hard clay	44	110	Lava ash	28	565
Sandy clay	20	130	Loose lava	6	571
Clay and gravel	38	168	Lava shale and soft shale	44	615
Sandy clay	12	180	Lava ash	24	639
Blue clay	6	186	Shale	17	656
Shale	62	248	Lava	14	670
Blue clay	7	255	Lava sand	10	680
Shale	15	270	Hard quartz sand	20	700

NOTE.—Drilled by Linscott Drilling Co.; log derived from graph by Sperry; $11\frac{5}{8}$-inch I. D. casing from 1 to 130 feet; $9\frac{5}{8}$-inch I. D. casing from 130 to 396 feet; $7\frac{5}{8}$-inch I. D. casing from 396 to 700 feet; perforated from 105 to 350 feet, and 375 to 700 feet.

Driller's log of Natomas well No. 9, near Rio Oso.

[No. 30, Pl. IV.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil and clay	36	36	Loose gravel	4	430
Hardpan	3	39	Blue shale	10	440
Gravel	6	45	Clay and gravel	5	445
Clay	22	67	Shale	5	450
Cement gravel, dry	12	79	Hard sand	10	460
Fine gravel and clay	5	84	Shale	8	468
Clay	24	108	Lava sand	5	473
Stiff yellow clay	31	139	Hard shale	7	480
Sandy clay	36	175	Black shale	20	500
Clay	25	200	Lava ash	30	530
Clay and sand	5	205	Hard sand	30	560
Clay	13	218	Shale	5	565
Fine sand and gravel	5	223	Hard sand	21	586
Blue shale	19	242	Shale	24	610
Loose sand; very little water	8	250	Lava ash	12	622
Lava	5	255	Lava sand	21	643
Lava sand	6	261	Loose sand	2	645
Lava	19	280	Lava sand	5	650
Bluish-gray shale	3	283	Loose sand and decomposed lava	5	655
Blue shale	57	340	Lava	17	672
Sandy shale	10	350	Loose lava sand	22	694
Blue shale	8	358	Lava sand	1	735
Sandy clay	16	374	Lava	15	750
Blue shale	6	380	Lava sand	5	755
Clay and sand	24	404	Loose sand	10	765
Sandy clay	10	414	Sand	4	769
Quartz sand	7	421	Lava	26	795
Brown shale	5	426	Lava sand	2	797

NOTE.—Drilled by Linscott Drilling Co.; log derived from graph by Sperry; 11⅝-inch I. D. casing from 1 to 175 feet; 9⅝-inch I. D. casing from 175 to 350 feet; 7⅝-inch I. D. casing from 350 to 797 feet; perforated from 38 to 45, 78 to 85, 175 to 280, 466 to 622, 666 to 674, and 744 to 754 feet.

Driller's log of Natomas well No. 8, near Rio Oso.

[No. 30, Pl. IV.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Topsoil	4	4	Blue clay with fine sand	10	250
Hardpan	19	23	Blue clay	31	281
Sand and clay	3	26	Shale	79	360
Yellow clay	33	59	Gravel and clay	23	383
Gravel	14	73	Shale	77	460
Clay	12	85	Clay and small gravel	20	480
Loose sand	6	91	Sandy clay	10	490
Clay	25	116	Shale	15	505
Cement sand	4	120	Lava ash	25	530
Clay	55	175	Shale	10	540
Yellow clay	15	190	Lava ash	35	575
Loose sand and gravel	15	205	Shale	20	595
Blue clay	35	240	Lava	85	680

NOTE.—Drilled by Linscott Drilling Co.; log derived from graph by Sperry; 9⅝-inch I. D. casing from 1 to 285 feet; 7⅝-inch I. D. casing from 285 to 680 feet; perforations at 270 to 590 and 607 to 620 feet; cement plug at 625 feet.

WELL NEAR LINCOLN.

The deep well of the Whitney estate on the red lands south of Lincoln (No. 31, Pl. IV) is 1,155 feet deep. Flowing water with gas was obtained, but on account of the high salt content the water is used only for watering sheep. An analysis is presented on page 176 (A25). The log shows 100 feet of clay with some sand. Water occurs at the bottom of these materials. Then follows 227 feet of volcanic material belonging to the andesite breccia, which dips under the valley fill about a mile to the east. Blue clay and shale make up the rest of the section with the exception of 40 feet of "quartz sand cemented with mica and sand" at the bottom. All or part of this 718 feet is the Ione formation. The Ione[26] is only 100 feet thick where it crops out to the east, but it may thicken toward the center of the valley. That the lower part of the well is in the Chico is, however, not an unreasonable hypothesis, for this formation crops out a few miles farther south, and as it is marine it is quite likely to furnish a highly mineralized water similar to that found in this well.

Driller's log of Whitney deep well, Lincoln.

[No. 31, Pl. IV.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil, hardpan, and hard clay	15	15	Blue clay	120	457
Hard clay and sandy clay	30	45	Blue shale	78	535
Hard dry clay	45	90	Hard black clay	13	548
Sandy clay and water	10	100	Blue shale	24	572
Hard lava ash	30	130	Black clay	18	590
Fine gravel	2	132	Stiff blue clay	10	600
Hard lava ash, sloughing	25	157	Stiff black clay and gravel	4	604
Volcanic gravel	15	172	Black clay	11	615
Volcanic gravel and limestone	8	180	Blue shale	10	625
Lava tufa	104	284	Hard black clay	30	655
Lava tufa and boulders	6	290	Hard blue clay	40	695
Lava tufa	12	302	Blue shale	320	1,015
Lava sand	28	330	Quartz sand cemented with mica and lime	140	1,155
Lava mud	7	337			

NOTE.—Drilled by Linscott Drilling Co.

WELLS NEAR RIEGO.

At Riego, 10 miles southwest of the Whitney flowing well, the Natomas Consolidated in 1912 sank a well (No. 7) to a depth of 858 feet (No. 34, Pl. IV). Flowing water of good quality was obtained below 705 feet. (See analysis A33, p. 175.) Below 70 feet of soil, hardpan, and clay "lava" was found to 140 feet. Then came blue clay and shale down to 550 feet, with a bed of "lava ash" at 366 to 375 feet. This clay has streaks of sand but apparently is not much of a water bearer. Below 550 feet most of the material is reported as "lava." Well No. 6, 336 feet deep, is about half a mile away and also has "lava" in the first 200 feet. It is not known what relations exist between the lava of this well and that of the Whitney flowing well. Confusion is increased by a consideration of well No. 5 at Sankey station, 2 miles north (No. 33, Pl. IV). Here soil, sandy clay, and clay extend to 100 feet, followed by 12 feet of "lava ash," 4 feet of "light clay," 104 feet of blue clay, and then "lava ash and shale." Lava is again reported at 305 to 314 feet. Either the driller is calling

[26] Lindgren, Waldemar, U. S. Geol. Survey Geol. Atlas, Sacramento folio (No. 5), 1894.

the same things by different names or there is a great variation in the material. Although such a variation is not abnormal in alluvial materials, it would be natural to expect ash beds or at least the horizon of volcanic ashes to be rather constant. However, our present knowledge is not sufficient to give a reasonable explanation of these well logs. We know only that water may be obtained from the alluvium in the first 200 feet and that there is below the alluvium a rather dry formation of dark and blue clays and shales with local beds of "lava ash" which is likely to be dry. Below this many of the wells obtain water, though not all of them get artesian flows.

In the well of the pumping plant of John Borgman, 3 miles south of Nicolaus and 8 miles northwest of the Riego wells (No. 35, Pl. IV), rounded pebbles of pumice were pumped out of 8 feet of fine sand and gravel found in the bottom of the well. The pieces, which were saved and shown to the writer, were about half to three-quarters of an inch in diameter and well rounded. Such material might come from a long distance up river, but it is possible that this material and the "lava" of the first 100 feet in the Riego wells and the tuff at Oroville may all come from the eruptions of the Marysville Buttes in early Pleistocene time.

Driller's log of Natomas well No. 7, Riego.

[No. 34, Pl. IV.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Topsoil	2	2	Blue shale	25	501
Hardpan	33	35	Blue clay	4	505
Clay	35	70	Cement sand	40	545
Lava	70	140	Blue shale	5	550
Sandy clay	22	162	Black lava, hard	10	560
Soft sandstone	14	176	Lava sand	25	585
Blue clay	9	185	Lava ash	16	601
Gray clay	11	196	Hard shale	9	610
Blue clay	40	236	Shale	6	616
Blue clay and gravel	8	244	Lava and shale	29	645
Blue clay	27	271	Lava	18	663
Blue shale	4	275	Shale	5	668
Blue clay	29	304	Hard shale	17	685
Blue shale	5	309	Shale	20	705
Blue clay, very sticky	12	321	Lava or sandstone	13	718
Blue clay	16	337	Shale	32	750
Blue clay, sticky	6	343	Sand	5	755
Blue shale	3	346	Lava and sand	17	772
Sand	4	350	Loose sand	3	775
Blue clay	14	364	Shale	2	777
Blue shale	2	366	Loose sand	7	784
Lava ash	9	375	Lava	2	786
Blue shale	53	428	Loose sand	10	796
Blue clay	11	439	Lava	14	810
Blue gumbo with plenty of quartz	17	456	Hard shale and lava	20	830
Blue clay	3	459	Loose sand	15	845
Sandy clay	12	471	Shale	10	855
Coarse quartz sand	5	476			

NOTE.—Drilled by Linscott Drilling Co. in 1912; log derived from graph by Sperry; artesian flow; 11⅝-inch I.D. casing from 1 to 364 feet; 9⅝-inch I.D. casing from 364 to 705 feet; 7⅝-inch I.D. casing from 705 to 855 feet; perforated with slots from 700 to 725, 742 to 760, and 830 to 855 feet.

Driller's log of Natomas well No. 6, Riego.

[No. 34, Pl. IV.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Topsoil	1	1	Blue shale	45	265
Hardpan	24	25	Gravel	25	290
Clay	40	65	Shale	46	336
Lava	155	220			

NOTE.—Drilled by Linscott Drilling Co. in 1912; log derived from graph by Sperry; 11⅝-inch I.D. casing from 1 to 336 feet; perforated by slots from 260 to 290 feet.

Driller's log of Natomas well No. 5, Sankey.

[No. 33, Pl. IV.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Topsoil	2	2	Lava ash and shale	20	230
Hardpan	12	14	Sand	35	265
Sandy clay	36	50	Shale	5	270
Clay	40	90	Sandstone	20	290
Clay and gravel	10	100	Sand	5	295
Lava ash	12	112	Gravel	10	305
Light clay	4	116	Lava	9	314
Blue clay	94	210			

NOTE.—Drilled by Linscott Drilling Co. in 1912; log derived from graph by Sperry; 11⅝-inch I.D. casing from 1 to 314 feet; perforated from 12 to 28, 114 to 126, 200 to 216, 250 to 266, and 284 to 303 feet.

Driller's log of George Housley's well, near Pleasant Grove.

[No. 32, Pl. IV.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Not reported	6	6	Sandy clay	15	300
Sandy clay	2	8	Stiff clay	5	305
Stiff clay	27	35	Sandy clay	5	310
Sandy clay	5	40	Stiff clay	20	330
Stiff clay	26	66	Medium clay	35	365
Sandy clay	4	70	Very hard clay	5	370
Medium clay	11	81	Sandy clay	5	375
Stiff clay	24	105	Very hard clay, stiff	43	418
Sandy clay	5	110	Cement gravel	2	420
Stiff clay	15	125	Very hard clay with some sand	9	429
Sandy clay	23	148	Hard clay and sand	10	439
Fine gravel	1	149	Very hard clay	5	444
Stiff clay	6	155	Medium clay	11	455
Sandy clay	20	175	Very hard clay	30	485
Stiff clay	10	185	Hard clay	36	521
Medium clay	5	190	Clay and sand	9	530
Soft sandstone	10	200	Lava; little more water	30	560
Stiff clay	10	210	Lava	15	575
Sandy clay	5	215	Lava sand	10	585
Fine gravel	2	217	Lava	12	597
Stiff clay	33	250	Fine gravel and lava sand	8	605
Soft clay	10	260	Clay	10	615
Soft sandstone; sand coming in, filling hole	15	275	Lava sand and fine gravel	15	630
Cement gravel	5	280	Lava	12	642
Stiff clay	5	285	Lava, some water	16	658
			Lava	2	660

NOTE.—Drilled by Linscott Drilling Co. in 1914; flows at surface.

Driller's log of Natomas well No. 14, near Sankey.

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Hard sand and clay	53	53	Coarse quartz sand and clay; very hard drilling	13	468
Sandy clay	12	65	Blue clay	7	475
Yellow clay	10	75	Blue clay with coarse sand in it; very tough	13	488
Sandy clay	14	89	Granite sand and clay	33	521
Sandy clay and little gravel	22	111	Blue clay with some sand	9	530
Clay and gravel, dead	13	124	Blue clay	5	535
Clay	6	130	Granite and sand; some water	2	537
Fine sand	20	150	Blue clay	3	540
Sandy clay	17	167	Granite sand	10	550
Blue clay	28	195	Sand and clay	17	567
Sandy clay	15	210	Sand	8	575
Sticky blue clay	27	237	Fine gravel	14	589
Sandy clay	13	250	Lava; some water	26	615
Clay and small stones	7	257	Lava ash	52	667
Sticky clay	5	262	Lava	8	675
Sandy clay	38	300	Sticky blue clay	31	706
Sandy clay and gravel	5	305	Lava	9	715
Blue clay	30	335	Sandy clay	23	738
Sandy clay	21	356	Sticky clay	3	741
Sand	6	362	Lava	34	775
Sticky blue clay	28	390	Sticky blue clay	15	790
Blue shale	1	391	Lava	65	855
Blue clay, very sticky	21	412	Lava ash	15	870
Sandy clay	6	418	Very soft lava, sloughing badly	5	875
Blue clay	19	437			
Blue shale	8	445			
Blue clay	10	455			

NOTE.—Drilled by Linscott Drilling Co. in 1913; 11⅝-inch I. D. casing, smaller casing within; perforated from 650 to 875 feet; flows water and gas at surface.

Log of John Borgman's well, south of Nicolaus.

[No. 35, Pl. IV.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Soil	10	10	Blue clay	2	117
Sand and clay	55	65	Fine sand and gravel, with rounded pebbles of pumice	8	125
Blue clay	35	100			
Gravel more or less cemented with clay	15	115			

NOTE.—8-inch O. D. casing to 65 feet; uncased hole below.

WELLS NEAR SACRAMENTO.

The deepest well so far drilled in the valley is well No. 9 of the Sacramento Natural Gas Co. (No. 36, Pl. IV), which is more than 2,212 feet deep. This is the ninth well put down by this company to obtain natural gas. Gas is ordinarily struck between 1,500 and 2,000 feet in flowing salty water—the greater the flow of water the larger the amount of gas. The gas burns with a pale flame, and for lighting it is mixed with gas distilled from crude oil. The wells furnish about 60 per cent of the company's product. The following table gives some statistics of the wells:

Gas wells of Sacramento Natural Gas Co.

[All except No. 4 are at or near location marked 36 on Pl IV.]

Company's No.	Location.	Depth (feet).
1	Near railroad wye south of Sacramento	1,300-1,400
2	do	1,800
3	Near swimming baths	2,005
4	American River east of Sacramento	1,600-1,700
5	Near railroad wye south of Sacramento	1,600-1,700
6	do	1,560
7	do	1,680
8	Near swimming baths	2,016
9	North of swimming baths	2,212

The drilling was done with a permanent derrick and a modified standard rig. The changes in the rig have been made gradually in the last 20 years, as suggested by the experience of the company and the results obtained under similar conditions in Stockton. A steel cable is used, and the walking beam is placed high in the derrick, as in the portable California mud-scow rigs. The crank that actuates the pitman is carried on an eccentric, so as to give a quick upstroke that is useful in preventing sticking in the clays. Drilling is done with mud scows or sand buckets provided with a circular cutting edge and a sharpened cross bar. The tools are very massive, the 14-inch mud scow weighing about 1,500 pounds. The company has been very successful with this equipment, which has enabled it to carry a 10-inch casing to depths of 2,000 feet and thus obtain the maximum supply of gas possible.

The log of well No. 9 shows a monotonous succession of clay and sand. The driller, Mr. Hansen, says that below 300 feet no red or reddish material was found, but that all the material was dark gray, blue, or green. The writer saw samples from 2,035 to 2,212 feet. The "sand, gray and bluish" from 2,035 to 2,040 feet consisted largely of quartz grains less than a quarter of an inch in diameter. The quartz was well rounded but had irregular reentrant cavities like the pebbles from Stony Creek. The "small cobblestones" reported from 2,040 to 2,060 feet were about 1½ to 2 inches in diameter. The "hard sandstone" from 2,060 to 2,185 feet was a cemented sand whose grains were about one-eighth inch in maximum diameter, with a greenish cement. The gray laminated clay was represented by a piece about 4 to 6 inches long showing well-defined jointing at angles of 70° and 110°. The material was fine and rather unctuous, and the laminations were one-eighth inch or less in thickness. It must have been deposited in very quiet water.

The interpretation of the log of this well is very difficult. One conclusion seems reasonable—that the alluvium is about 300 feet thick, as indicated by the absence of red material below this depth.

Sacramento is in the zone of east-side alluvium, which (both the older and the recent) is characteristically red. W. L. Watts[27] considers that the Pleistocene and Recent filling extends down to 500 feet, or to the beginning of the harder, drier material, and comments on the thinning of the alluvium from Stockton, where it is about 1,000 feet thick, to Sacramento.

Driller's log of Sacramento Gas Co.'s well No. 9, Sacramento.

[No. 36, Pl. IV.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Sandy clay	44	44	Clay	65	1,425
Sand	50	94	Sand	7	1,432
Boulders	40	134	Hard clay	54	1,486
Sand and clay, in small streaks	198	332	Sand and clay	119	1,605
Sand	10	342	Clay	10	1,615
Clay	175	517	Sand	27	1,642
Sand and small stones	15	532	Loose sand and small stones, in small streaks, mixed	163	1,805
Clay	25	557	Hard and soft clay	21	1,826
Sand	5	562	Loose sand	6	1,832
Clay	93	655	Greenish sand with streaks of hard sand	195	2,027
Sand	7	662	Blue clay	8	2,035
Sand and clay, in small streaks	102	764	Gray and bluish sand	5	2,040
Sand	4	768	Small cobblestones	20	2,060
Clay and sand, in small streaks	157	925	Hard sandstone	125	2,185
Sand	17	942	Gray laminated clay shale, jointed at angles of 70°	27+	2,212+
Hard and soft clay	222	1,164			
Sand	21	1,185			
Clay	115	1,300			
Hard sandstone	60	1,360			

NOTE.—Drilled by Hansen in 1912-13; 14-inch casing to start, 10-inch carried to 2,212 feet; no gas encountered at that depth; log below 2,212 feet not obtained.

Record of Sacramento Natural Gas Co.'s well No. 2, Sacramento.

[From contents of bottles examined by W. L. Watts.[28]]

	Depth (feet).
Quartzose pebbles, with waterworn fragments of wood at 87 feet	66–88
Light-colored porous sandy clay	90
Fine grayish sand	98
Grayish sandy clay	99
Grayish sand, rather coarse	106
Fine micaceous cemented gray sand	108
Coarse sand with fragments of cemented fine sand	112
Light-colored clay	118
Micaceous sand with fragments of cemented sand	120
Fine micaceous sand; the particles somewhat agglutinated but friable	128
Cemented fine sand, resembling soft, friable micaceous sandstone	153
Light-brown porous sandy clay with infiltrations of white clayey matter	170
Soft agglutinated fine sand, friable	173
Fine sand with small pebbles	178
Light-colored clay	185
Fine micaceous sand	189
Light-colored sandy clay	192
Very fine sand cemented with clayey matter; indurated	194

[27] California State Mineralogist Rept., 1892, p. 79.

[28] Watts, W. L., The gas and petroleum yielding formations of the central valley of California: California State Min. Bur. Bull. 3, pp. 11-12, 1894.

	Depth (feet).
Fine sand, small pebbles, and lumps of cemented sand	212
Fine sandy light-colored clay	220
Micaceous sand and fragments of light-colored cemented sand	232
Soft cemented fine sand	238
Sand, with fragments of wood	240
Light-colored sandy clay	245
Light-colored cemented sand, with white clayey infiltrations	248
Grayish sand	261
Light-colored clay	265
Coarse sand	266
Porous cemented light-colored sand	274
Friable cemented sand	280
Fine sand	287
Whitish clay	307
Light-colored clay	310
Fine sand and fragments of cemented sand	318
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Watts states further regarding this well.

Between this depth (820 feet) and that of 872 feet the well borers state that strata of hard sandstone were passed through; that at the depth of from 840 to 845 feet a stratum of very porous sandstone yielded more water and gas; and that blue clay was penetrated between the depths of 860 and 865 feet. The sample which was marked as representing the formation at a depth of 900 feet contained a light-colored and somewhat calcareous clay.

In reviewing the record of the strata penetrated by this well and the samples from it, which have been preserved, the fact must be borne in mind that when material is first taken from the well during the process of boring it frequently looks very different from what it does when dried and kept for some time. Nearly all the light-colored clays look blue when first brought up from the well, and the micaceous sands look black, frequently becoming bluish when dry. All the loose micaceous sand is quicksand, and well borers state that it "runs badly"—that is, it runs into the boring and casing and is apt to cover the tools.

The term "agglutinated sand" is used for that whose grains adhere to one another without any visible cementing material; and the term "cemented sand" when the cementing material can be seen.

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