DEPARTMENT OF THE INTERIOR
FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, Director

WATER-SUPPLY PAPER 446

GEOLOGY AND GROUND WATERS OF THE WESTERN PART OF SAN DIEGO COUNTY CALIFORNIA

BY
ARTHUR J. ELLIS AND CHARLES H. LEE

Prepared in cooperation with
THE DEPARTMENT OF ENGINEERING OF THE STATE OF CALIFORNIA AND THE CITY OF SAN DIEGO

WASHINGTON
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GEOLOGY AND GROUND WATERS OF THE WESTERN PART OF SAN DIEGO COUNTY, CALIFORNIA.

By Arthur J. Ellis and Charles H. Lee.

INTRODUCTION.

HISTORY OF GROUND-WATER UTILIZATION.

By C. H. Lee.

According to the irrigation census taken in 1910 under cooperative agreement between the Bureau of the Census and the Department of Engineering of the State of California, 9,297 irrigation pumping plants were in operation in California during that year and 277,000 acres were irrigated by pumping from wells. In 1914 the number of pumping plants in the State had increased to 24,589,[1] and if the area irrigated from such plants had increased in the same proportion, it was in that year approximately 700,000 acres. The total area irrigated from surface and ground waters in California in 1914 was about 3,200,000 acres.[2] The data therefore indicate that ground water served nearly one-fourth of the irrigated lands of the State at that time, and it furnishes a far greater part of the water used for domestic, manufacturing, and municipal supplies.

In San Diego County (Pl. I) extensive utilization of the ground waters was begun only a few years ago, and much additional development is still possible. The potential demand probably exceeds that in any other settled part of the State. Irrigation is necessary for the successful cultivation of most of the agricultural crops to which the climate and soil of the region are adapted. Furthermore, the climatic and scenic features of much of the county make it very attractive as a place of either temporary or permanent residence. As the delightful climate of the San Diego coast becomes more widely known, the region will undoubtedly become one of the most popular playgrounds of the United States, drawing upon the heated regions of the Southwest during the summer and the Eastern and Northern States during the winter. There will also be an ever-increasing permanent population. The demand for water for household and garden uses is already large and is destined far to exceed the demand for water for irrigation in commercial agriculture.

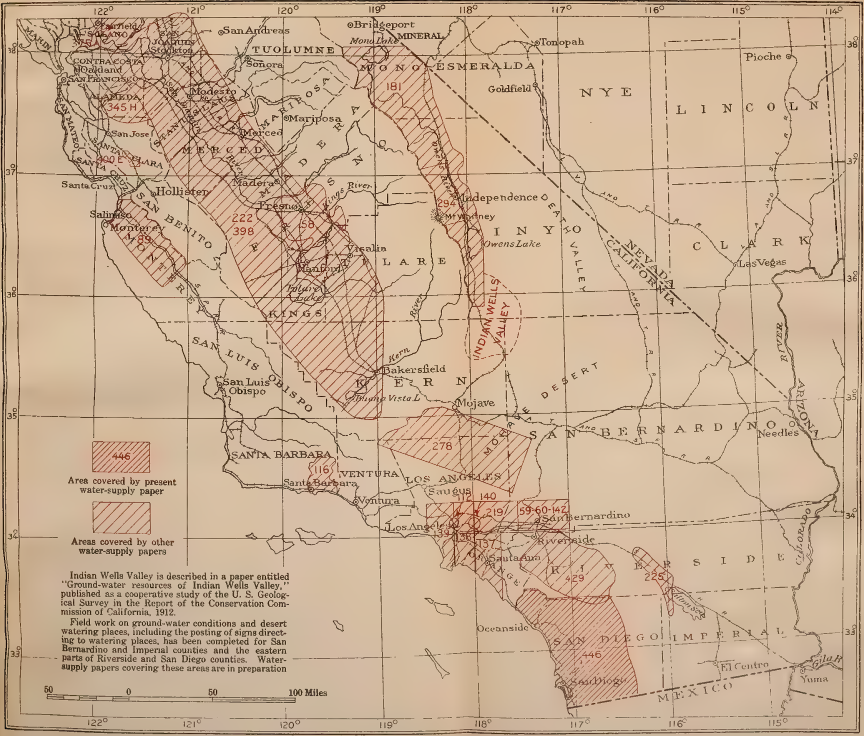
[1] Adams, Frank, Progress report of irrigation investigations * * * in California, 1912–14: In California Dept. of Engineering Fourth Bien. Rept., Dec. 1, 1912, to Nov. 30, 1914, pp. 158–210, 1914. See pp. 177–178.

[2] 3,196,000 acres in 1912: Idem, p. 207.

The surface waters, though at times overwhelming in volume, are unfortunately not dependable and require expensive storage and transmission works for their utilization. There are no perennial streams except at high levels and at a considerable distance from the coast where they are too small to be of much practical value. Precipitation of sufficient magnitude to produce run-off is confined to three or four months of the year, and in years of average precipitation the larger streams do not maintain a permanent flow for more than five or six months. To obtain from the surface streams the unfailing water supplies required for irrigation and especially for domestic uses, it is necessary to provide large storage reservoirs. Conditions are made even more unfavorable by the wide variations in precipitation from one year to another and by the occasional periods of severe drought. This condition necessitates holding in reserve sufficient water (in storage) to supply the full requirements for a three or four year period. The expense of providing the necessary storage works is great, and after the water has been stored the losses by evaporation from the exposed water surface may amount to a large proportion of the volume originally stored. The problem of keeping water up to a standard of potability for domestic use after being held in storage for two or three years is also very difficult.

On the other hand, supplies of ground water, if available at all, are relatively reliable, especially if they are drawn upon only to supplement surface supplies. They are also protected from evaporation and can be more easily protected from pollution.

Ground water was first largely used in San Diego County in 1898—the first year of serious drought subsequent to the early eighties, when the extensive settlement of the county was begun. This drought continued with varying severity until 1905, rainfall and stream flow being far below normal throughout the whole period. Large consumers of water at that time were the communities of ChulaVista and National City, supplied from Sweetwater Reservoir, which was built and operated by the San Diego Land & Town Co., the orchard and farm lands supplied by the San Diego Flume Co. from storage and gravity flow of San Diego River, and the city of San Diego, supplied by San Diego flume and other sources. In the effort to serve these consumers when the surface waters failed wells were sunk and pumping plants installed at the nearest sites that gave promise of yielding adequate quantities of water. The San Diego Land & Town Co. sank batteries of wells at a number of points in the valley of Sweetwater River; the San Diego Flume Co. installed two plants in the upper San Diego River valley above Lakeside; the city of San Diego drew from several batteries of wells in Mission Valley; and many orchardists endeavored to augment from small plants on their own lands the inadequate supplies furnished by the



SKETCH MAP OF PART OF CALIFORNIA

Showing areas treated in the present report and in other water-supply papers of the U. S. Geological Survey relating to ground water

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companies. With the return of normal conditions of stream flow in 1905, the use of the larger pumping plants was discontinued and most of the equipment was removed, and the use of many of the private plants that had been but moderately successful was also discontinued.

Activity in the settlement and development of the county was not renewed until about 1909, and in the interval rapid strides had been made in the manufacture of cheap, efficient pumping equipment. The river valleys, with their ample stores of ground water and low pumping lifts, offered attractive agricultural opportunities for small land owners. In the period beginning with 1909 much of the Tia Juana, Otay, Sweetwater, and San Diego river valleys was put under cultivation by irrigation from individual pumping plants. A few of the many efforts that were made to obtain irrigation water outside the river valleys were moderately successful, but only in the major valleys have supplies adequate for the irrigation of large areas been developed. Nevertheless there remains much additional land in small tracts outside the major valleys that can be irrigated from ground waters obtained locally.

The importance of ground water as a reserve in periods of drought makes accurate knowledge of the quantity available essential to permanent settlement. For instance, the over use of ground water to irrigate an orchard in the early periods of a protracted drought might make it impossible later in the period to obtain enough water to keep the fruit trees alive or even to supply the domestic needs of the owners. The investigations here reported were made not only for the purpose of suggesting where and how ground waters can be obtained, but also to indicate the limits to which supplies of ground water should be utilized.

PREVIOUS GEOLOGIC WORK.

By A. J. Ellis.

The earliest geologic survey of this region was that conducted by C. C. Parry and Arthur Schott, in connection with the United States and Mexican Boundary Survey.[1] From July, 1849, to March, 1851, Dr. Parry was in the vicinity of San Diego, and resided during the fall and winter of 1850–51 at San Luis Rey. His excursions extended northward along the coast to Monterey and eastward to Gila River, and embraced the region then known as southern California. Parry's collections of rock specimens and fossils were classified and described by James Hall[2] and T. A. Conrad.[3]

[1] Parry, C. C., and Schott, Arthur, Geological reports: United States and Mexican Boundary Survey, vol. I, part 2, pp. 1–98, 1857.

[2] Hall, James, Paleontology and geology of the boundary: United States and Mexican Boundary Survey vol. 1, part 2, pp. 103–140, 1857.

[3] Conrad, T. A., Description of Cretaceous and Tertiary fossils: Idem, pp. 141–147.

The first geological survey of California was conducted during the years 1851 to 1856 by Dr. John B. Trask, but San Diego County was not included in the areas investigated.

In December, 1853, William P. Blake, as geologist of the expedition under Lieut. R. S. Williamson, Corps of Topographical Engineers, to ascertain the most practicable and economical route for a railroad from Mississippi River to the Pacific Ocean, traveled from San Felipe to San Diego and thence north to San Pedro, and made a report on the geology of the region based on observations along his route.[1] J. S. Newberry, geologist of the expedition under Lieut. J. C. Ives for the exploration of the Colorado River, crossed from San Diego to Yuma in December, 1857, and obtained notes on the geology.[2]

Under the second State geological survey of California in 1872, W. A. Goodyear made a reconnaissance of San Diego County,[3] and in 1892 H. W. Fairbanks made an accurate reconnaissance survey of this and adjacent counties.[4]

All reports of the California State Mining Bureau subsequent to the fifth contain notes on the mineral resources of San Diego County, including observations on the general geology. In 1914 that bureau published a pamphlet by Dr. F. J. H. Merrill giving a general outline of the geology of San Diego and Imperial counties.[5] Some studies of the paleontology and stratigraphy of the coast have been made to which specific reference will be made in the following pages.

PURPOSE AND SCOPE OF THIS INVESTIGATION.

The area described in this paper comprises approximately that part of San Diego County which is drained directly into the Pacific Ocean. With unimportant exceptions, it does not include that part of the county whose streams discharge into an interior basin or into the Gulf of California. (See Pls. I and II.) The eastern limits of the area covered are, however, not sharply defined. Plates II, III, and XV (in pocket), which show topography, locations of wells, geology, and precipitation, cover the area lying west of longitude 116° 30′ and south of latitude 30° 30′. This area is about 60 miles long and 50 miles wide and embraces about 3,000 square miles.

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1 Blake, Wm. P., Geological report, explorations and surveys for a railroad route from the Mississippi River to the Pacific Ocean: 33d Cong., 2d sess., S. Doc. 78, pp. 122–130, 176, 1856. *Also* Observations on the physical geography and geology of the coast of California from Bodega Bay to San Diego: United States Coast Survey Rept., 1855, pp. 376–398, 1856.

2 Newberry, J. S., Geological report: In report upon the Colorado River of the West, explored in 1857 and 1858 by Lieut. J. C. Ives under the direction of the Office of Explorations and Surveys: 36th Cong., 1st sess., H. Doc. 90, pp. 13–18, 1861.

3 Goodyear, W. A., San Diego County: California State Min. Bur. Eighth Ann. Rept., pp. 516–528, 1888.

4 Fairbanks, H. W., Geology of San Diego County; also of portions of Orange and San Bernardino counties: California State Min Bur. Eleventh Rept., pp. 76–120, 1893.

5 Merrill, F. J. H., Geology and mineral resources of San Diego and Imperial counties: California State Min. Bur., 1914.

The investigation on which this report is based was made under the direction of O. E. Meinzer, geologist in charge of the ground-water investigations of the United States Geological Survey, in financial cooperation with the State of California and the city of San Diego. The purpose was to obtain accurate and comprehensive information with regard to the ground waters of the western part of San Diego County available for use by landowners, water companies, and communities in the solution of their water-supply problems.

The field work was begun in September, 1914. The geologic survey was made from September to December of that year. The observations on ground water were continued without interruption until August, 1915, but data were not systematically gathered after December, 1915, and any changes brought about by the floods of January and February, 1916, have not been considered in this report. The important conclusions of the report are, however, not affected by these floods.

In addition to the study of the geology and physiography of the area the field work included measurements referred to sea level of the water levels in wells; observations of flow of Tia Juana River near Nestor; measurements at irregular intervals of other streams; tests of typical wells and pumping plants; collection of information concerning other wells and pumping plants and of the materials penetrated by wells; tests of porosity of water-bearing deposits; collection of records of precipitation and evaporation and of general information pertaining to the development and use of ground water throughout the county; and the collection of water samples.

Most of the analyses of water were made by S. C. Dinsmore, under contract with the United States Geological Survey; others were made in the water-resources laboratory of the Survey. The analyses were classified and interpreted by Alfred A. Chambers, who also rendered much assistance in the preparation of the chapter relating to the quality of the waters.

Measurements of the flow of the streams in the region and of the water levels in certain wells have been made for a period of years by the United States Geological Survey in cooperation with various agencies. Most of this work has been done by F. C. Ebert, under the direction of H. D. McGlashan, district engineer. The complete records of stream flow are published in a separate volume (Water-Supply Paper 447), but use has been made of the records in the ground-water investigations reported in this paper.

ACKNOWLEDGMENTS.

K. B. Sleppy, assistant engineer, and D. L. Lee assisted in gathering and compiling the records pertaining to wells, stream flow, and precipitation, and in collecting the samples of water for analysis. The pumping tests were made by W. R. Layne, assistant engineer. Assistance in the study of these tests and in the preparation of the discussion thereon was rendered by Raymond Matthew, assistant engineer.

The writers wish to acknowledge the public spirit and interest shown by the officers of the city of San Diego, the Cuyamaca Water Co., Volcan Land & Water Co., Sweetwater Water Co., San Diego Consolidated Gas & Electric Co., and other organizations in furnishing data and in otherwise expediting the work. Acknowledgments are especially due to Mr. W. S. Post, chief engineer for the first two companies mentioned, Mr. R. T. Hill, geologist, Mr. H. A. Whitney, hydraulic engineer, department of water of the city of San Diego, Mr. John F. Covert, engineer for the Sweetwater Water Co., Mr. A. E. Holloway, of the San Diego Consolidated Gas & Electric Co., Mr. Rudolph Wueste, of the same department, and Mr. C. S. Alverson, hydraulic engineer, Mrs. M. J. Herman, Dr. W. E. Wisecup, Capt. J. F. Scott, and Mr. Wilkes James, for their cooperation and for the valuable information which they furnished. The writers are also very much indebted to Mr. A. E. Hatherly, of San Diego, for the complete logs which he furnished for wells that he has drilled in Tia Juana, Otay, Mission, and other valleys and on the mesa in the vicinity of Nestor. The cooperation of the owners of wells and pumping plants in permitting measurements to be made was of great assistance in the work and is hereby acknowledged, together with their many other courtesies. Credit for specific information is given in the appropriate places in the text.

PHYSIOGRAPHY.

By A. J. Ellis.

INTRODUCTORY STATEMENT.

The part of San Diego County described in this report consists of a mountainous highland area and a narrow belt along the shore characterized by broad, flat-topped sea terraces, called in this report the San Diego coastal belt. The highland area is a part of a great upland region that extends far south into Lower California. This upland is limited on the east by a steep descent to the Gulf of California and the Salton basin, but its plateau-like surface slopes gradually westward toward the ocean. It appears like a huge block of the earth's crust that has been broken and uplifted along its eastern side. In form and position it resembles the Sierra Nevada, but the amount of uplift and tilting has been much less.

SAN DIEGO COASTAL BELT.

GENERAL FEATURES.

The coastal belt consists, for the most part, of several relatively flat, high, upland benches or terraces that are dissected by stream channels and that extend from the highlands westward to the ocean, where, except in the region of San Diego Bay, they terminate in a line of sea cliffs. The terraces are generally referred to collectively as "the mesa," but some of the interstream areas have received individual names, such as Otay Mesa, which lies between Tia Juana and Otay rivers, and Linda Vista Mesa, which extends from San Diego River to Los Penasquitos River.

The major stream valleys are wide and flat bottomed and are bounded by very steep slopes that in many places are several hundred feet high. The minor stream valleys are the valleys of young streams that, with few exceptions, rise on the mesa. They are short, narrow gashes in the terraces and are tributary to the main streams or open directly into the sea. The major valleys are occupied by older rivers that head far back in the highland area.

North of Mission Bay and rising high above the mesa Soledad Mountain forms a broad peninsula that extends a few miles into the ocean; south of Mission Bay, Point Loma forms a second peninsula that partly incloses San Diego Bay.

From La Jolla (see map, Pl. II, in pocket) the coast line extends northward, bearing gradually more and more to the west without any considerable irregularities; but south of La Jolla it winds about bays and peninsulas so that the distance from La Jolla to the international boundary measured along the shore is more than 75 miles, whereas the distance between these points in a direct line is less than 25 miles. The total length of the shore line in San Diego County, including the bays, is about 125 miles, although the distance in a direct line from the southwest corner of the county to San Mateo Point at the northwest corner is only 68 miles.

The controlling influence in the development of the physiographic features of the coastal belt has been oscillation—that is, the rising and sinking of the land with respect to the sea level. Such vertical movements of the land seem to have been almost continuous since the oldest sedimentary formations in the coastal belt were laid down. As a result of these movements deep valleys have been cut repeatedly by the streams and subsequently partly filled, and different levels have been successively exposed to the waves, so that numerous terraces have been formed. As described in more detail on page 22, these movements have been irregular, being rapid at some periods and slow at others. At times they have affected only certain parts of this region; at other times the whole coastal belt in San Diego

County seems to have moved uniformly. Within very recent geologic time the land has stood considerably higher than at present, and there are indications (see p. 23) that along most of the coast sinking is now in progress. The net result of these oscillations, however, has been a general elevation of the region.

COAST LINE.

From San Onofre to the mouth of Soledad Valley the coast line is bordered by cliffs which in places rise sheer from the margin of the water and in other places are separated from the water by a narrow band of beach sand. These cliffs have been formed by the waves cutting into and undermining a terrace that stands 75 to 100 feet above sea level. (See Pl. V, *A*.) From the mouth of Soledad Valley to La Jolla the lower terrace is absent and the cliffs, which here mark the edge of Linda Vista Mesa, reach heights of more than 400 feet.

Nine streams reach the sea between San Mateo Point and La Jolla. The lower parts of all their valleys have broad, flat, marshy bottoms and contain lagoons that on drying up in summer leave broad tracts heavily coated with salt. These lagoons lie where beach ridges have been built across the mouths of the valleys by waves and shore currents, so that most of them are entirely cut off from the ocean, and their drainage, except in times of flood, reaches the sea by percolation through the sand. Only the Santa Margarita, the San Dieguito, and the Soledad are able to keep narrow channels open through the beach deposits.

The beach ridges, cliffs, and terraces are the results of wave erosion and deposition by shore currents, together with changes in the elevation of the land with respect to sea level. The mode of their development may be illustrated by a brief discussion of the physiographic history of the area about Oceanside. Before the materials that form the 75 to 100 foot terrace bordering the coast near Oceanside were deposited the land stood possibly as much as 200 feet higher than it does at present. At that time the shore was no doubt somewhat farther west. While the land was rising and while it stood at this highest elevation the streams cut their valleys down to what was then sea level—that is, about 200 feet below the present valley floors. The land then sank to a level about 100 feet below that at which it now stands, so that the sea advanced over the lowlands and flooded the valleys. During this time of submergence the waves cut into the ends of the ridges between the estuaries and formed a line of sea cliffs with a wave-cut terrace at the base. Part of the material derived from this cutting was washed out into deeper water by the undertow and part was swept along shore and formed bars across the mouths of the estuaries in the same way that bars have been formed along the present shore. At the same time the streams were washing

A. DIABASE DIKE IN EOCENE SEDIMENTS AT LA JOLLA.

B. SEA CLIFFS OF CRETACEOUS ROCKS (CHICO FORMATION) AT LA JOLLA.

Shows caves produced by wave erosion.

A. WEST EDGE OF LINDA VISTA MESA NEAR ENCINITAS.

Shows sea cliff. Looking north.

B. BEACH PEBBLES DEPOSITED BY STRANDED SEAWEED, ENCINITAS.

sand and gravel down their valleys and filling the lagoons behind the bars. In this manner a nearly continuous terrace was formed along the shore beneath the water's edge. When the land was again elevated the newly formed terrace emerged, the streams began to remove the filling from their valleys, and the bars were cut through. As the terrace rose new streams were established on it and produced topographic features that are distinctly contrasted to those adjacent on the east. This relation is called by Salisbury a "topographic unconformity." [1] The land had probably reached an elevation somewhat higher than it is at present and the streams had probably cut their beds slightly lower than they now are when sinking began again. This sinking, possibly now in progress, is shown by the partly drowned and consequently marshy valleys of all streams that reach the ocean in this part of the county.

About 3 miles north of La Jolla a dike of igneous rock (basalt) about 2 feet wide extends from the base of the cliffs southwestward into the ocean (see Pl. III, in pocket, and Pl. IV, *A*). The total length of the dike exposed at low water is, according to Fairbanks, about 1,800 feet. Its northern end is now covered by talus, so that its relation to the mesa formations is concealed, but in 1892 Fairbanks reported that it did not extend into the cliffs, "the only signs being a fault in line with the dike." [2]

At many places along the shore, but particularly between Delmar and Encinitas, accumulations of large flattened, smooth-surfaced pebbles or small boulders lie a few feet above high-water mark and extend along the beach in narrow ridges, in some places 2½ feet in height. The average pebble is about 5 inches long, 3 inches wide, and 2 inches thick. Plate V, *B*, shows one of these ridges near Encinitas. The concentration of pebbles in this form is due to the action of storm waves whose inrush carries sand and pebbles to a position beyond the reach of the waves under normal conditions. These waves retreat much more feebly than they advance, and consequently while the sand and small pebbles are dragged back to the surf, the large pebbles are left stranded. It has been observed that kelp, which is brought ashore by the waves, sometimes carries pebbles of this kind inclosed in its rootlike bases. These pebbles have served as supports or anchors for the kelp and have been lifted from the sea bottom when the plant attained a sufficient buoyancy, or have been dragged along when the plants were torn from their moorings by storm waves.[3] Fragments of seaweeds, some of which are root-

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[1] Salisbury, R. D., Three new physiographic terms: Jour. Geology, vol. 12, 1904. Salisbury, R. D., and Atwood, W. W., The interpretation of topographic maps: U. S. Geol. Survey Prof. Paper 60, p. 73, pl. 151, 1909.

[2] Fairbanks, H. W., Geology of San Diego County, etc.: California State Min. Bur. Eleventh Ann. Rept., p. 97, 1892.

[3] Shaler, N. S., Sea and Land, p. 55, 1894.

like masses still inclosing pebbles, are shown in Plate V, *B*. Attention is being directed to these deposits as a possible source of grinding pebbles.

From La Jolla southward to the international boundary the coast line is characterized by peninsulas, bays, steep wave-washed cliffs, sandy beaches, and muddy and marshy tidal flats. The peninsula on which La Jolla stands is the most noteworthy irregularity of the coast. It extends about 2 miles into the sea and is about 4 miles wide. Soledad Mountain, which forms this peninsula, is 822 feet high and is separated from the bench on the east by Rose Canyon, which has cut down 300 to 400 feet below the level of the mesa. A record of the oscillations of the coast line is preserved on Soledad Mountain in sea terraces which appear at short vertical intervals from the base to the top of the mountain. For a distance of several miles along the shore near La Jolla the present sea cliffs are washed by the waves at high tide, and in some places they have been deeply carved by wave action. Just east of La Jolla, at the edge of the village, the waves have cut large caves which, though flooded at high tide, may be entered at low tide (see Pl. IV, *B*) and which are objects of much interest to sight-seers.

Soledad Mountain may owe its origin to a fault that extends southeasterly along its eastern flank approximately in line with Rose Canyon.

Point Loma forms a second peninsula probably produced in the same way as Soledad Mountain, but its greatest elevation, which is at the southern end of the point, is only 400 feet. This peninsula is 7 miles long, north and south, and varies in width from a quarter of a mile on the south to 3 miles on the north. The neck of land that connects Point Loma with the mainland consists of delta deposits laid down by San Diego River. Point Loma was an island during Quaternary time and it is said that it continued an island to a time within the memory of Indians living when San Diego was settled.

Mission Bay occupies a syncline of which Soledad Mountain forms the northern and Point Loma the southern limb. The silting up of this bay has reached a fairly advanced stage. The entrance is nearly closed by Point Medanos, which is a sand bar extending southward from the north shore to within a quarter of a mile of the south shore, and owing to its continuation under water the depth of water in the present channel at mean low tide is only 4 feet. Over fully 75 per cent of the area of the bay soundings have shown a depth at low water of less than 2 feet, and depths greater than 20 feet were measured at only two places. A mud flat that covers about 2 square miles and lies only slightly above high water forms the southern shore of the bay.

From Point Loma south to the Mexican boundary the coastal belt is occupied by San Diego Bay and the lowlands, including a considerable area of tidal marsh between the mouth of Otay River and the south slope of Tia Juana Valley. The topographic features of this area and depths of water in the bay and off its entrance are shown on Plate VI. San Diego River formerly emptied into San Diego Bay, but the silt which it carried into the bay threatened to destroy the harbor so that in 1853 the stream was diverted into Mission Bay.[1] The rate of silting up of the bay was thus materially reduced but the amount of sediment carried in by other streams necessitates dredging to keep the bay open for shipping.

The long neck of land that connects Coronado Island with the mainland and incloses the bay on the east is a sand bar built by waves and shore currents that have also formed a narrow land connection between Coronado Island and North Island and would undoubtedly close the channel between North Island and Point Loma but for the jetty east of the channel, which was constructed to prevent the closing of the bay.

Fairbanks[2] states that "San Diego Bay has probably been formed through the drowning of a river valley in connection with the action of ocean waves and currents." It is possible that when the land stood at a higher level Tia Juana River may have flowed through that valley, Otay and Sweetwater rivers being then tributary to it. The Tia Juana seems to be much more competent to occupy such a valley than the Otay, although no evidence has been found as yet that a river crossed the terraces between Tia Juana River and San Diego Bay. It is likely that a stream as large as the Tia Juana would leave recognizable traces of an ancient channel.

TERRACES.

GENERAL RELATIONS.

The terraces, locally known as mesas, range in height from 20 to 1,200 feet above sea level, but they are most extensively developed between elevations of 300 and 500 feet. North of Otay River the principal terraces slope gently toward the ocean from an elevation of about 500 feet near the eastern margin to about 300 feet near the western margin. South of Otay River the terrace, or top of the mesa, slopes in the opposite direction. The western edge of Otay Mesa (see Pl. VI) is nearly 550 feet high; 4 miles farther east the elevation is but little more than 500 feet. The actual slope is, however, much less than it appears to be when the terrace is viewed from a lower level a few miles north of its northern edge.

[1] U. S. Army Chief of Engineers, Ann. Rept. for 1868, p. 886.

[2] Fairbanks, H. W., The physiography of California, p. 43; reprinted from Am. Bureau Geog. Bull., vol. 2, pp. 232-252, 329-350, 1901.

The terraces were originally formed below sea level. Each in turn was leveled by the combined wave erosion and marine deposition, as described on page 22, and then lifted above the sea and subjected to stream erosion. The highest terrace is the oldest. Most of the present irregularities of the surface are due to stream action. The elevation of the land progressed irregularly, being relatively rapid at some times and much slower at others. During times of slow or interrupted rise the sea cut cliffs at successively lower levels on the edges of the terraces, such as those now being formed along the shore at La Jolla, and during times of rapid elevation parts of the sea bottom were lifted above the waves to form successive terraces. These cliffs and terraces are now conspicuous features of the landscape.

In the region about San Diego Bay, as shown by Plate VI (in pocket), there are five terraces, which, north of Tia Juana River, are, respectively, about 20, 50, 100, 250, and 500 feet above sea level. These elevations are, however, only general, for each of the terraces was originally somewhat uneven, and, moreover, they have been considerably modified by erosion, so that their true relations can be seen only by observation from selected localities. Viewed from a distance, as from a point northeast of Chulavista on the south bluff of Sweetwater Valley, the minor irregularities of the terraces disappear, and they are seen as a succession of nearly flat benches or steps rising from the low shore of San Diego Bay to the border of the highlands on the east.

The darker colors on Plate VI indicate the remnants of the terraces; the lighter shades indicate their probable extent previous to erosion. As indicated on this map the marine terraces extend into the major valleys and show that these valleys were estuaries when the terraces were formed.

The terraces south of Tia Juana River exhibit somewhat different topographic relations. Only a small part of these terraces is in the United States, but even in this part the cliffs are steeper and higher, and the terraces are separated by larger vertical intervals than the corresponding cliffs and terraces north of the river. For example, the terrace on which Oneonta is situated, which is the highest terrace between Tia Juana and Otay rivers on which Quaternary fossils are found, is about 50 feet above sea level; but the broad, perfectly developed terrace which extends for many miles south of the Tia Juana and on which Quaternary fossils are abundant, is about 100 feet above sea level along its eastern margin and is nowhere less than 75 feet above the sea. The terrace north of Tia Juana River which, at an elevation of about 200 feet, corresponds to a terrace south of the Tia Juana at an elevation of about 400 feet, and Otay Mesa, shown on Plate VI at about 500 feet above sea level, is represented south of the Tia Juana by a table-land that is about 700 feet above sea level and that extends from a point near the international boundary southward to Table Mountain. Each of these terraces is of marine origin, and therefore must have been of uniform elevation throughout its extent when it was formed. If the correlations of the disconnected parts of the several terraces as indicated are correct, their present relations probably mean that the land south of Tia Juana River has risen higher and more rapidly than that to the north.

In addition to the principal terraces shown on Plate VI, comparatively inconspicuous benches at other elevations mark short pauses in the retreat of the shore line. One of these is on the south side of Otay Mesa at 425 feet above sea level, and another, at 300 feet above sea level, may be seen at several places between the international boundary and Sweetwater River. No doubt careful field studies would reveal still others.

In the geologic reports of the United States and Mexican Boundary Survey, Parry[1] mentions three terraces in this region, the lowest being that which is shown on Plate VI (in pocket) as the Nestor plain, the second being the top of Otay Mesa, and the third Table Mountain, a flat-topped mountain about 17 miles south of the international boundary, visible from San Diego as a conspicuous feature on the sky line. Surveys made in 1909 show the altitude of Table Mountain to be 2,275 feet above sea level.[2] It is not necessary, however, to go south of the boundary to find remnants of a much higher terrace than Otay Mesa. The high ridges that radiate from the granite range west of Foster and extend westward to Miramar and from El Cajon Valley to Poway Valley and that form those steep grades in the county highway known as the "Poway grade" are remnants of a very old and much eroded marine delta terrace. The tops of these ridges are about 900 feet above sea level near the west ends and rise gradually to about 1,200 feet above sea level at the east, where they join the higher slopes of crystalline rocks. These branching ridges taken together are referred to in this report as Poway Mesa. Linda Vista Mesa extends from the western edge of Poway Mesa to Soledad Mountain and the ocean and was originally continuous southward to Otay Mesa. Comparison of the amounts of erosion that have been accomplished on the surfaces of Linda Vista Mesa and Poway Mesa gives some indication of the relative ages of the two original terraces. The map forming Plate VII shows parts of Linda Vista Mesa and Poway Mesa. As shown on this map, Linda Vista Mesa is in general flat and stands 400 to 500 feet above sea level between the ocean and Miramar. Its western part is dis-

[1] Parry, C. C., and Schott, Arthur, Geological reports: United States and Mexican Boundary Survey, vol. 1, pt. 2, chap. 5, p. 86, 1857.

[2] U. S. Hydrographic Office, Navy Mariners' Chart No. 1149, "San Quentin to San Diego," 1909.

sected by narrow canyons that are separated by broad, flat divides, but its eastern part is a broad gently sloping plain that is practically untouched by erosion. Farther south the terrace of which this was originally a part is cut through by the deep broad valleys of San Diego, Sweetwater, and Otay rivers, and the several parts between these main streams are much dissected by smaller valleys and ravines. Yet even here considerable tracts of the original nearly flat terrace are still preserved. These topographic features are distinctly in contrast to those of the Poway Mesa, a part of which east of Miramar is shown in Plate VII. The canyons of the Poway Mesa are so close together that none of the original flat top remains, the crests of the ridges being narrow and in many places less than 10 feet wide. These divides, however, have probably not been cut far below the level of the original terrace. They are nearly uniform in height, sloping from about 1,200 feet above sea level on the east to about 900 feet on the west and they represent fairly well the slope of the terrace when erosion began. The topography of Linda Vista Mesa is "young," that of Poway Mesa is "mature," showing that the higher terrace has been exposed to erosion a much longer time than the lower one.

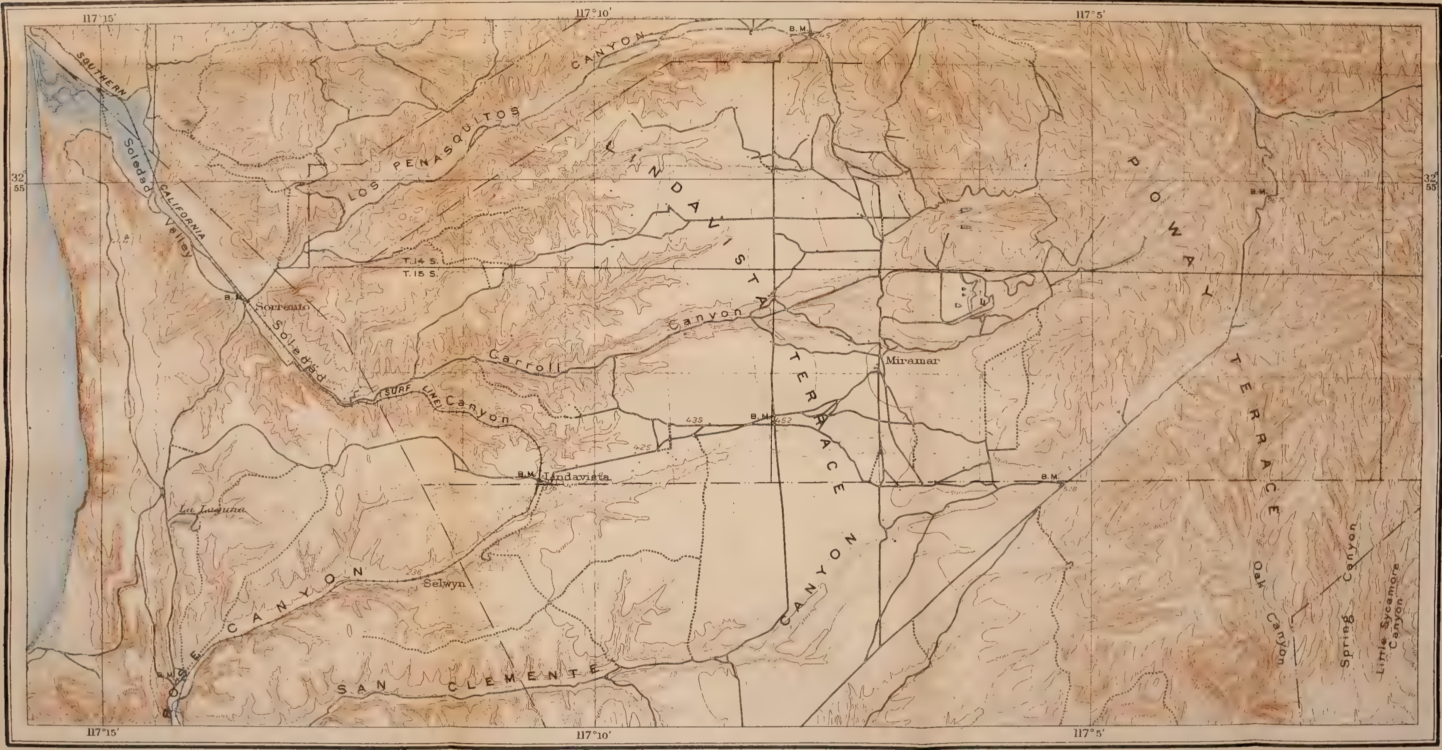
POWAY MESA.

The original extent of Poway Mesa can not be determined. Remnants of it are preserved west and southwest of El Cajon Valley and north of Poway Valley. At the time of the earth movement which brought Linda Vista Mesa above seal level Poway Mesa probably extended southward to the vicinity of La Mesa, westward over the site of Miramar, and northward nearly to Black Mountain. Previous to that time it may have extended much farther westward.

Considerable interest attaches to this high terrace on account of its possible relation to ancient stream gravel that extends eastward as far as Witch Creek, as shown on Plate III. This gravel now caps mountains which rise to elevations of 2,000 to 3,500 feet and it has generally been regarded as marking the course of some large ancient river. As suggested by Fairbanks (see p. 41), and as shown on the map (Pl. III), Poway Mesa may be the delta of such a river. But the region has been lifted 1,500 feet or more since the Poway Mesa was formed, and probably most of the features of the highland have since been developed, so that it is now impossible to visualize accurately the physiography of that time. An explanation of the origin of the so-called "placer gravels" which has been brought to the attention of many residents of San Diego is that Colorado River once may have crossed the country along the line of gravel deposits and, flowing across the terraces and through the present site of San Diego, entered San Diego Bay, and that the gravels, together with supposed stream deposits on the terrace (and underlying San Diego), were laid

ANGLE
y Terrac

3 Miles



TOPOGRAPHIC MAP OF A PART OF LA JOLLA QUADRANGLE, CALIFORNIA

Showing erosional features of Lindavista and Poway Terraces

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 Miles

Contour interval 25 feet.

Datum is mean sea level.

1919.

down by this river. But it should be remembered that when Poway Mesa was being built the present site of San Diego was possibly several hundred feet below sea level, and that the shore line must have been at least as far east as Foster, so that no fluviatile deposits in or near San Diego could reasonably be attributed to the same origin as the stream gravels east of Foster. The origin of the stream which deposited the gravels is altogether a matter of conjecture, but it certainly had no relation to present topographic conditions.

MOUNDS.

The surface of Linda Vista Mesa and, to a less extent, the terraces north and south of it are dotted with thousands of low, round hummocks that range in height from a few inches to 3 feet and in diameter from about 3 feet to 15 feet. Over wide areas they are found very close together, some being separated by less than 3 feet (Pl. VIII). Some casual observers have supposed them to have been formed by gas escaping from the freshly deposited material; others believe them to represent the work of springs of water while the plain was still near sea level. They are, however, no doubt correctly ascribed to the action of the wind as it sweeps through the sparse desert vegetation and blows away the loose soil except where it is held by plant roots. One or two shrubs are generally found growing in the center of each hummock, though many of them are bare. The barren hummocks merely indicate a former distribution of vegetation. These products of wind erosion are common features of arid plains in western North America,[1] where, owing to the absence of wind breakers and the sparse soil the eroding power of prevailing strong winds is particularly effective. A report of the United States Weather Bureau [2] describes the eroding and transporting power of the winds:

> The winds throughout the entire section are light, except when northern storms move southward, or when Sonora storms in the summer months move slowly northwestward and recurve. There are certain well-marked winds, known as Santa Ana or desert winds, which blow for periods of about three days from the north. These winds are generally dust-laden, are very dry, and are extremely trying to human and animal life. In San Diego County these are known as desert winds, as they blow rom the east; but in the other counties the direction is more from the north. Mr. Campbell describes these winds as follows, in the Monthly Weather Review for October, 1906:
>
> "They blow during periods of 3 to 6 or 9 days; but rarely last beyond 21 days. They are cool winds to us here on the mountains, while on the coast they are hot, and are skin-drying, lip-cracking, unpleasant visitants. After they reach the coast the force is mostly out of them. Sometimes their force at Campo rivals a hurricane.

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[1] See Chamberlin, T. C., and Salisbury, R. D., Geology, vol. 1, p. 22, 1904. See also Barnes, G. W., The Hillocks or mound formations of San Diego, Calif.: Am. Naturalist. vol. 13, p. 565; 1879. Wallace, Alfred R., Glacial drift of California: Nature, vol. 15, p. 274, Jan. 25, 1877. Le Conte, Joseph, Hog wallows or prairie mounds: Nature, vol. 15, p. 530, Apr. 19, 1877.

[2] McAdie, Alexander, Summaries of climatological data, by sections: U. S. Weather Bureau Bull. W, vol. 1, sec. 13, p. 2, 1912.

In places they pierce window panes with little round holes as if drilled by the coarse gravel they carry like a dose of small shot. On my ranch on the Laguna Mountains, at an elevation of 6,500 feet, all the east side is in big pine and oak timber for some miles; yet on the last ridge overlooking the desert on the east, not a tree grows for miles, although north and south they grow up to within 200 yards of it all along. Even the brush changes on that last ridge from a growth of 6 to 10 feet down to all dwarf, creeping and clinging close to the ground, but of the same variety as the upright. These winds are so violent that they often tear down houses. Their duration is from October to March. We generally get our first fall rains after the blow is over; but this year the first rain, on the 15th, preceded this one. If they come in the spring after the first blooms form, both the blooms and the young fruit drop off the trees after a short time. The barometer responds more quickly to an east wind than to any other change of weather."

ANCIENT BEACH RIDGES.

An interesting topographic feature on Linda Vista Mesa is a series of low ridges that extend from Mission Valley northward for 6 to 15 miles, in many places being brought into exaggerated relief by erosion. Most of these ridges are capped by a brigh-tred sandstone which is indicated on the geologic map (Pl. III, in pocket). Portions of three of these ridges, somewhat dissected by transverse canyons but still easily identified are shown on Plate VII. The letter "A" marks the northern extremity of a ridge that extends south to Mission Valley; the letter "B" marks disconnected parts of a ridge that also extends to Mission Valley. The ridge marked "C" extends only short distances north and south of the edges of the area shown on Plate VII. It is believed that these ridges were formed by the waves along former shore lines just as similar ridges are now being formed along the shore near the international boundary, or in a manner very similar to that in which the sand spit that extends from Coronado south to the mainland (see p. 25) was recently formed. If the land were raised 100 feet San Diego Bay would be entirely dry, and the sand spit would form a ridge which would have very much the appearance of the old ridges on Linda Vista Mesa. A more striking example of the origin of these ridges may be seen in the much more recently formed sand ridge which extends along the shore between the railroad and the edge of the bluffs from Delmar nearly to Oceanside and which for long distances cuts off the view of the ocean from the train. This ridge rests on the extreme edge of the mesa, as much as 100 feet above sea level in many places, but it has been much more recently elevated above the sea (see p. 69) than the higher ridges farther east.

SAN ONOFRE HILLS.

North of San Luis Rey River the broad terraces and widely separated canyons, characteristic of the mesa farther south, give way to high, rounded steep sloped hills separated by deep, narrow, inter-

MOUNDS ON LINDA VISTA TERRACE.

locking valleys. The hills reach elevations ranging from 500 to 600 feet above sea level and have an average height of about 300 feet. Beginning about 3 miles north of Ysidora and extending northwest to Arroyo San Mateo the San Onofre Hills (including San Onofre Mountain) rise to elevations of 800 to 1,735 feet, and are flanked on the east by the dissected terrace, 300 to 500 feet high, which corresponds to Linda Vista Mesa and on the west by a low narrow sloping plain bordering the coast. The San Onofre Hills are about 3 miles wide and are intersected by several canyons which cut below the level of the terrace on the east. These hills are believed to have been formed later than the terraces and probably owe their origin to an upward movement of the land between the ocean and a fault that extends along their eastern base.

MAJOR VALLEYS.

The valleys referred to in this report as major valleys are those occupied by Santa Margarita, San Luis Rey, San Dieguito, San Diego, Sweetwater, Otay, and Tia Juana rivers. They are characterized by wide flat gently sloping floors, bordered by very steep slopes or bluffs several hundred feet high, and they contain streams that rise far back in the highland area.

Santa Margarita Valley.—Halfway between Deluz station and Home ranch Santa Margarita River leaves a rock gorge and enters a broad valley. As far downstream as the Home ranch this valley is bordered on the west by granite hills and on the east by bluffs that lead up to a terrace or mesa about 300 feet above the valley floor. Below the Home ranch it is bordered on both sides by bluffs that lead up the terrace. The valley is constricted at the Home ranch and near Ysidora, but its average width is nearly a half mile. The river is about 100 feet above sea level one mile north of the Home ranch, and its gradient is about 10 feet per mile from this point to the ocean.

San Luis Rey Valley.—About 3 miles east of the San Luis Rey Mission San Luis Rey River leaves its gorge in the highland area and enters a flat-bottomed valley incised about 300 feet below the terraces. At this point, approximately 8 miles from the ocean, the river is at an elevation of about 90 feet above sea level. Its grade below this point is about 11 feet to the mile. East of the mission the valley is about 2 miles wide but farther downstream it becomes gradually narrower, and near Oceanside it is hardly a tenth of a mile in width.

San Dieguito Valley.—San Dieguito River leaves its rock gorge about 6 miles from the ocean and enters a valley which opens abruptly to a width of half a mile. At the mouth of the gorge the river is about 40 feet above sea level and thence to its mouth its gradient is about 7 feet per mile. Through the entire length of the valley the walls rise precipitously 100 to 300 feet above the valley floor.

Mission Valley.—Mission Valley, which is the valley of San Diego River, extends from the rock gorge west of Cowles Mountain southwestward to Mission Bay, a distance of 8 miles. From the mouth of the gorge to the old San Diego Mission the valley is about a third of a mile wide, and from the Old Mission to Old Town, a distance of 6 miles, it has a fairly uniform width of about three-fifths of a mile. The valley floor is flat throughout its entire length, and from its head to the vicinity of Old Town is bordered on both sides by precipitous cliffs that rise 100 to 300 feet to the levels of the terraces. At Old Town the terraces come to an end and the valley forms part of the narrow coastal belt. The elevation of the river at the mouth of the gorge is 100 feet above sea level, and the slope from this point to the bay is about 11 feet to the mile.

Sweetwater Valley.—Sweetwater Valley extends from the vicinity of Aloha, where it leaves the highland area, to San Diego Bay, a distance of 8 miles. In this distance the descent is 100 feet, or 12½ feet per mile. This valley, like Mission Valley, has a flat bottom and steep sides leading up to the terraces 100 to 300 feet above the valley levels. It is, however, narrower than Mission Valley, being only one-fourth to one-half mile wide. It follows a meandering course, and in this respect is distinctly in contrast to the lower parts of the other major valleys, all of which are more nearly straight.

Otay Valley.—Otay Valley extends due west from the base of Otay Mountain to the south end of San Diego Bay. Its sides are high bluffs as far west as the village of Otay, but thence to the bay the stream flows across a low plain. Otay Valley differs from the other major valleys in that its grade is much steeper in the lower—miles, about 25 feet to the mile, and, in that the valley floor, instead of being flat, slopes rather steeply from the base of the bluffs on each side to the stream channel, which through most of its length is in the middle of the valley. The significance of these features is discussed on page 33.

Tia Juana Valley.—Tia Juana River crosses to the north side of the international boundary at Tia Juana (Pl. II, in pocket) and extends westward 6 miles to the ocean. The valley floor at the boundary is about a mile wide and is bordered on the south by cliffs that rise 400 feet above the river. On the north side of the valley the bluffs, which extend northwestward toward Nestor and are more than 400 feet high at Tia Juana, rapidly diminish in height and leave a broad, plain through which the stream flows westward between low sloping banks less than 25 feet high. The river is about 50 feet above sea level at Tia Juana, Calif., and slopes westward at the rate of 8 feet to the mile.

Origin of major valleys.—The features of the major valleys in this region are due in part to the nature of the streams and in part to the

SANTA MARGARITA RIVER VALLEY BEFORE THE FLOOD OF JANUARY, 1916.

View in the SE. ¼ sec. 12, T. 9 S., R. 4 W.

SANTA MARGARITA RIVER VALLEY AFTER THE FLOOD OF JANUARY, 1916.

View taken at same locality as that shown in Plate IX.

LANDSLIDE IN WALL OF MISSION VALLEY.

Shows a phase of erosion in arid regions.

alternate rising and sinking of the land. The major streams originate in the mountains and their headwaters drain large areas. The precipitation is so great at certain times that large volumes of water sweep through the valleys, but during long intervals the amount of water collected in the highlands is so much smaller that it sinks into the sands of the river beds as soon as it reaches the eastern edge of the coastal belt. Broad streamways which intermittently discharge large volumes of water are characteristic of streams in arid regions, and this feature of the major valleys in San Diego County is due in part to the action of flood waters. Unusually heavy floods which swept the valleys of this area in January, 1916, furnished a wealth of evidence as to the process and efficiency of flood erosion. The accompanying photographs taken before and after the flood of January, 1916, Plates IX, X, and XI, show results of flood erosion. But the form of these valleys is in part due also to the fact that during a recent period in the geologic history of the region the land stood higher than at present, and the major streams were able to cut their valleys down to a level which is now 100 to 200 feet below the level of the sea, as is shown by the logs of wells sunk in the valleys. (See p. 111). The streams have therefore partly filled their old valleys and the widths of the present valley floors represent the distance between the valley walls possibly as much as 200 feet above their original bases. That the sides of the valleys are generally very steep, and in places nearly vertical, is due to the general aridity of the region. The flood waters are efficient in removing talus material which falls or slides down to the foot of the bluffs, but the tops of the bluffs are not worn back as rapidly as in regions where the rains are more frequent and the run-off on the surface is relatively larger. The rainfall on the terraces is small and is rapidly disposed of by the minor streams and by evaporation and percolation, so that, as in all arid regions, higher and lower levels are separated by sharp breaks and very steep slopes.

As mentioned on page 32, Otay Valley has a much steeper grade than the other major valleys and its floor, instead of being flat, slopes from the sides toward the stream channel. Moreover, records of wells show that the filling in this valley is comparatively shallow. These conditions indicate that Otay River, probably because it was younger and smaller, was unable to erode its valley to the same depth as the other major streams during the time when the land stood higher; consequently when the subsequent lowering of the land carried the bottoms of all the other major valley floors well below sea level only a part of Otay Valley was submerged and that to a comparatively shallow depth. Otay Valley therefore has characteristics of both the major and the minor valleys.

The lower parts of all the major valleys and some of the minor valleys are marshy, and some of the streams are completely cut off from the ocean by beach ridges. These features are discussed with other coast-line features (p. 22).

MINOR VALLEYS.

The largest of the minor valleys are those occupied by San Mateo, Loma Alta, Buena Vista, Agua Hedionda, San Marcos, Escondido, McGonigle, Los Penasquitos, Soledad, Rose, and Las Choyas creeks. Los Penasquitos Creek joins Soledad Creek 4 miles from the ocean, but all the other creeks mentioned discharge either directly into the ocean or into Mission or San Diego bays. Most of the minor valleys, however, are tributary to the major valleys. Except Escondido Creek and Los Penasquitos Creek, both of which rise to the highland area, the minor streams are confined to the coastal region. In general they occupy steep-floored valleys, the distance from the top of the terrace to the floors of the major valleys being usually short, and, except at the mouths of those that discharge into the ocean, they are without flood plains.

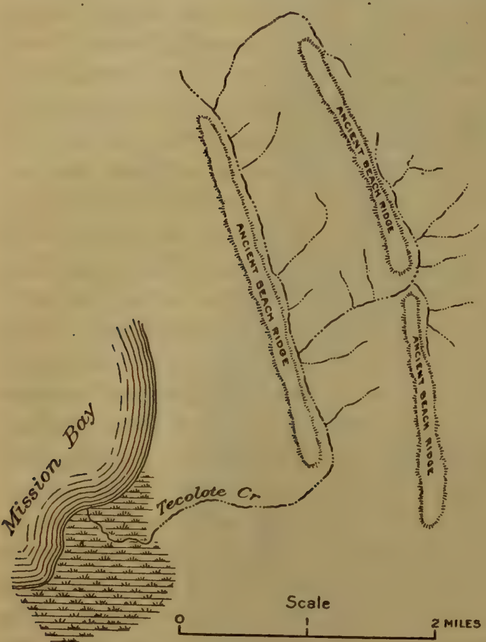

FIGURE 1.—The Tecolote drainage system, showing the angular courses of minor streams produced by ancient beach ridges on Linda Vista Mesa.

Some of the minor valleys cut in Linda Vista Mesa follow peculiar angular courses, as illustrated by the Tecolote drainage system, shown in figure 1. This condition is due to the control of the drainage by the ancient beach ridges. The surface water, which would normally flow westward in the direction of the general slope of the terrace, was deflected to the north and to the south by the ridges until it was able to cut across them at right angles. Once established, the streams deepened their valleys in these places.

THE HIGHLAND AREA.

GENERAL FEATURES.

The highland area lies east of the coastal belt and extends from the highest terraces and beyond the eastern boundary of the area covered by this report. For the purpose of obtaining a general view of the region, W. A. Goodyear in 1872 ascended Cuyamaca Mountain, which rises to an elevation of 6,515 feet above sea level, in the eastern part of the area. The following graphic description is quoted from his report.[1]

> The view from the summit of this peak is very extensive, reaching toward the south far into the Republic of Mexico and toward the north as far as the San Jacinto Peak and Mount San Bernardino, while to the west and southwest the shore for many miles, together with a very broad expanse of the ocean, are in sight; and to the northeast a considerable part of the Coahuilla Valley or the northwestern part of the Colorado Desert, and beyond it a long stretch of the southeastern continuation of the San Bernardino range of mountains running to the Colorado River along the northeast side of the Desert Valley, can also be seen. This is the best point from which to obtain a bird's-eye view of the general form and character of the mountains in the western part of San Diego County.
>
> Looking down from this standpoint over the surrounding region, the whole country from just back of San Diego easterly to the western edge of the desert is like an angry ocean of knobby peaks more or less isolated, with short ridges running in every possible direction and inclosing between and amongst them numerous small and irregular valleys. As a general rule, the higher peaks and ridges rise from 1,000 to 2,500 feet above the little valleys and canyons around their immediate bases. But in going easterly from the coast each successive little valley is higher than the one immediately preceding it, and the dominant peaks and ridges are also gradually higher and higher above the sea until we reach the irregular line of the main summit crest or water divide of the range, when the mountains break suddenly off and fall within a very few miles from 4,000 to 5,000 feet or more with an abrupt and precipitous front toward the east to the western edge of the desert.

Together with the coastal belt, the highland area has been repeatedly raised and lowered with respect to the sea level, but so far as is known these oscillations have not carried this highland area below sea level since an early geologic time. During all the time that the upper formations underlying the coastal belt were being laid down, and while the terraces were being formed and dissected, the highland area stood above the sea and was undergoing erosion. The movements of the land surface with respect to sea level produced results in the coastal belt that are readily recognized in the structure and topography. But in the highland area the effects were principally manifested in changing the gradients of the streams and, to some extent, in faulting and folding the rocks. In an area of crystalline rocks such as this neither the particular results of the several movements nor the chronologic order of their occurrence are readily detected. For this reason the physiographic history of the highland area is much more obscure than that of the coastal belt. However, a general conception of the origin and growth of the mountains and stream valleys may be obtained from a study of their individual characteristics and their interrelations.

[1] Goodyear, W. A., San Diego County: California State Min. Bur. Eighth Ann. Rept., 1887-88, p. 520.

THE MOUNTAINS.

GENERAL RELATIONS.

The mountains of the highland area belong to what has been called the Peninsular Range. As stated by Fairbanks,[1] this range extends southward, "forming the backbone of the peninsula of Lower California. Northward it becomes broader and more complex, rising in the lofty San Jacinto and San Bernardino ranges on the east, and the Santa Ana Range on the west, while the region between is filled with mountains and valleys irregularly disposed."

It will be seen from the map (Pl. II, in pocket) that in the area discussed in this report there is little regularity in the distribution of mountain peaks—that they do not lie in distinct ranges. Elevations of about 6,000 feet are common in the northeastern part, the principal peaks being Morgan Hill (elevation 5,628 feet), Palomar Mountain (6,126 feet), Hot Springs Mountain (6,250 feet), North Peak (6,028 feet), Middle Peak (5,750 feet), and Cuyamaca Peak (6,515 feet). The general elevation of the eastern half of the area is more than 3,000 feet above sea level; that of the western half ranges from 500 to 1,500 feet above sea level, though a few peaks, such as Otay Mountain (elevation 3,572 feet), San Miguel Mountain (2,573 feet), El Cajon Mountain (3,680 feet), and Woodson Mountain (2,890 feet), exceed 2,500 feet.

The southern slopes of the mountains are commonly nearly barren of vegetation, but most of the northern slopes are covered by chaparral and scattered groves of isolated trees of cedar, oak, live oak, pines, and firs. Excellent grazing is found on many of the mountain slopes and in nearly all the valleys.

Notwithstanding the complexity of the surface features, as seen from an elevated position or as shown by the topographic map, a number of features afford a certain degree of uniformity. The divide between the ocean drainage on the west and the gulf drainage on the east trends northwesterly, a direction roughly parallel to the shore line. The same general direction is followed by numerous dikes throughout the highland area, by a scarplike range of low hills at the eastern edge of Poway Mesa, by the range composed of porphyritic rocks (including Otay Mountains, San Miguel Mountain, and Cowles Mountain) and by the San Onofre Hills. Close field observation reveals among the smaller features a considerable degree of parallelism to this direction that is entirely masked by the larger topographic forms shown on the map.

ORIGIN.

In general the mountains of this area have been regarded as due principally to erosion. It is believed that previous to the elevation

[1] Fairbanks, H. W., The physiography of California, reprinted from Am. Bur. Geog. Bull., vol. 2, pp. 232-252, 329-350, 1901.

of the land it was a peneplain—that is, a region reduced by stream erosion until it had comparatively little relief—and that as the land was raised the streams were rejuvenated and cut their valleys to their present depths. Evidence of the former existence of a peneplain is found on the tops of many of the mountains throughout the area. Fairbanks [1] describes this evidence as follows:

> The features of an ancient base level are particularly noticeable upon the crests of the mountains and ridges. The summit of Smiths Mountain as well as that of the Laguna Mountains are fine examples of flat topped. Viewed from a point east of Fallbrook, the western slope of the mountains forms a nearly even sky line gently dipping toward the coast. The present canyons have been eroded in this ancient plain and in many cases they have widened to extensive valleys. The main streams are completely graded, flowing over a sand floor.

Stream erosion has probably been the principal direct agent in producing this topography, and erosion is notably affected by rising or lowering of the land surface. Such movements are also frequently accompanied by a certain amount of faulting. Some of the topographic features are due primarily to faulting. Smiths Mountain and the range of peaks forming the divide owe their origin to faulting, as explained by Fairbanks [2] and as indicated by the California Earthquake Commission. Three faults, presumably of considerable magnitude, one on each side of Smiths Mountain and Warners Valley and one along the east side of the San Onofre hills, are shown on the map published by the California Earthquake Commission (see Pl. III) and small faults, showing displacement of a few feet, are numerous throughout the area. Plate XII shows a small fault encountered in the Himalaya mine, near Mesa Grande. In an area of crystalline rocks, however, it is exceedingly difficult and often impossible to detect faults which are too large to be identified by the displacement of minor structures, such as joints and veins, and which, though of sufficient magnitude to modify the topography, are still too small to show the zones of shearing and crushing characteristic of great faults. In such an area therefore many faults of moderate size are traceable only by topographic evidence, and as that kind of evidence is rarely conclusive, knowledge of the extent to which faulting of this character has been effective is necessarily indefinite. The geologic history and the structure of the region make it reasonable to suppose that faulting has contributed toward the development of the present topography of the highland area in two ways—first, directly, by lifting certain blocks of the earth's crust higher than others and so forming mountains; and, second, indirectedly, by fracturing the rocks so that in places they were more easily worn away by the streams (see p. 49), and valleys were formed.

[1] Fairbanks, H. W., The physiography of California: Am. Bur. Geog. Bull., vol. 2, pp. 232–252, 329–350, 1901.

[2] Idem, p. 350. See also Report of California State Earthquake Commission, Andrew C. Lawson, chairman, 1910, Atlas, Map No. 1.

THE RIVER VALLEYS.

The principal streams of the highland area rise near the divide and flow to the ocean. Except where they cross the valley plains they occupy deep narrow gorges whose walls are of rock but whose floors are very commonly of sand. Well borings have shown that the rock bottoms underlying the débris in many of these valleys are more than 50 feet below the present stream beds. The presence of so much filling in all the principal valleys is regarded as an indication that the stream gradients have been lowered either by a general sinking of the land in the eastern part of the highland area or by rising of the land in the western part. It is also possible that the alternate cutting and filling of the valleys may have resulted in part, at least, from changes in stream flow due to changes in climate.

San Luis Rey Valley.—San Luis Rey River rises in Warners Valley at the foot of Palomar Mountain and flows southwestward over a sandy bed to the west corner of the valley, where it turns sharply to the northwest and enters a narrow and deep canyon which skirts the foot of Smiths Mountain. The river flows on a rocky bed from the point where the canyon becomes wider and contains a deposit of valley fill over which the stream flows. From the Rincon Reservation to Bonsall, near the western side of the highland area, the valley of the San Luis Rey contains deep deposits of valley fill, and from Rincon to the east side of Monserate ranch the stream has cut an inner canyon about 200 feet deep through valley fill. The explanation of this condition is that at an early period, while the land was rising, the San Luis Rey cut its bed to a position considerably below the present bed; that subsequently the land was depressed and this valley was filled by the river with rock débris to a level about 200 feet above the present stream, and that the land was again elevated so that the river cut down through the fill to its present position.

The total fall of the San Luis Rey from its headwaters to the edge of the coastal belt is 2,675 feet, or an average of about 60 feet per mile. The fall is everywhere only about 35 feet per mile except between the west corner of Warners Valley and the Rincon reservation. Between Warners Valley and Pala the San Luis Rey receives no tributaries from the south. All the area south of this part of the river drains southward to the Santa Maria.

San Dieguito Valley.—San Dieguito River, which is called Santa Ysabel Creek in its upper course, rises on the southwest slope of Volcan Mountain, one branch heading in the south corner of Warners Valley, and flows in a fairly direct southwesterly course to the ocean. The streams that form its headwaters occupy narrow canyons developed along a fault line, the southwest wall of the canyons being a continuation of the southwest wall of Warners Valley. The drain-

SMALL FAULT EXPOSED AT THE HIMALAYA MINE, NEAR MESA GRANDE.

EL CAJON VALLEY, LOOKING NORTHEAST FROM GROSSMONT.

age on the north side of Santa Ysabel Creek reaches it through short parallel streams that flow almost due south; that on the south side of the creek, however, does not enter the main stream directly but forms Santa Maria Creek, which flows parallel to the Santa Ysabel through the Santa Maria plain and joins San Dieguito River in San Pasqual Valley. Through a large part of its course the main stream flows over valley fill, but it has not cut so deeply into the fill as has the San Luis Rey in part of its valley.

San Diego Valley.—San Diego River rises on the table land near Julian, and all its headwaters flow west or northwest until they reach the deep canyon through which the main stream flows and which extends southwestward. Above El Cajon Valley no large streams enter the river on the north side, but on the south it receives many streams of considerable size. The area lying immediately north of the San Diego is drained by San Vicente Creek, which flows in a course roughly parallel to that of the San Diego, to its junction with the latter near Lakeside.

Sweetwater Valley and other valleys.—Sweetwater Valley and the valleys of Cottonwood and Pine Valley creeks, in the southern part of the area, are essentially like the valley of the Santa Ysabel. Sweetwater River rises just east of Cuyamaca Peak, on a table-land into which its headwaters have cut deep canyons, and flows southwestward to the ocean in a course parallel to courses of the Santa Maria and the San Dieguito. Between the headwaters and Dehesa the river receives several tributaries of considerable size on the south side but none at all on the north side, all the country between Sweetwater Valley and San Diego River being drained by tributaries of the San Diego.

Cottonwood Creek, to which Pine Valley Creek is tributary, rises somewhat farther south than Sweetwater River and flows in a more southerly direction to the eastern base of the San Ysidro Mountains where it joins the Rio del Tecate to form Tia Juana River.

The fall of Sweetwater River between its head and Sweetwater dam is 4,300 feet, or nearly 100 feet per mile. The fall between the head of Pine Valley Creek and the junction of Cottonwood Creek with Rio del Tecate is about 4,000 feet, or about 70 feet to the mile.

Peculiarities of drainage systems.—The drainage of the highland area as a whole presents a number of striking peculiarities. In all the principal valleys there are places where the bedrock floor is deeply buried beneath detritus. In several of the valleys the streams are flowing on the rock bottoms of narrow gorges at places farther downstream than those where there is so much filling. In some of the latter places the rock floor beneath the filling is so low as compared with the bottoms of the rock gorges farther downstream as to indicate either that the filled parts have sunk as compared with the gorges or that the gorges have been raised as compared with the filled parts, or, in other words, differential land movements have taken place. The drainage basins are unsymmetrical, so that most of the streams have more and longer tributaries on one side than on the other. This arrangement may have resulted from tilting of some of the blocks of the earth's crust as they were raised or lowered.

The pattern of the streams, as drawn on a map, shows that there is a tendency in parts of the region for the drainage to follow nearly parallel courses and to make rectangular changes of direction. These conditions are believed to be due to control of the drainage by faults or other structures in the rocks.

AN ANCIENT RIVER VALLEY.

It is believed that previous to the establishment of the present drainage systems at least the central part of the highland area was drained by an ancient stream a part of whose course is now indicated by a line of stream deposits (see Pl. III, in pocket), that extend from Witch Creek southwestward nearly to Foster. The evidences of this old drainage line are described by Fairbanks[1] as follows:

> It is not generally known that an acient auriferous gravel channel exists in the county. It begins about a mile north of the old stage station, and 3 miles west of Ballena post office, where there rises a hill shaped like a whale's back (hence the name Ballena), covered with washed gravel and boulders. The main portion of the channel which has escaped erosion begins south of the stage station, capping a hill which has an elevation above the sea of 2,400 feet, being a little lower than the so-called Whale Mountain. The gravel is 50 to 100 feet thick, and has a width of 2,000 feet or more. It rises 300 to 500 feet above the valleys and canyons on its sides. It extends in a direction a little south of west for about 4 miles, terminating on the south of Santa Maria Valley. A granite ridge runs 2 or 3 miles farther in the same direction, probably preserved by the gravels, which are now gone. A pretty valley, a mile long, has been eroded in the eastern end of the gravels, down to the underlying granite. Placer mining has been carried on for years here in a small way by Mexicans. Gold is said to be scattered everywhere through the gravels, which are often very firmly cemented. Lack of water, for the ridge is higher than any of the surrounding country, has prevented work on a large scale. Lately a mining district has been organized, and it is proposed to bring water 7 miles in pipe. In the gravels are washed boulders, many of them being 2 feet in diameter and well polished. The remarkable thing about them, however, is that they are nearly all porphyries. The most abundant is a red feldspar-quartz porphyry. Quartzite boulders of all colors are numerous, and there are a few of the basic diorite so common in portions of the county. Garnets are said to be very abundant in the gravels, and many boulders of a schist carrying them are also present. The matrix of this rock could not be made out in the field; it is very tough and heavy, and has never been seen in place. The red porphyry boulders resemble those on the mesa farther west, but have never been found in place. Never, in the mountains east or north, has porphyry of this kind been seen, either by myself or described by others. From the old stage station the upper course of the stream was north and south as far as it can be traced. There are indications that one branch

[1] Fairbanks, H. W., Geology of San Diego County, also of portions of Orange and San Bernardino counties: California State Min. Bur. Eleventh Ann. Rept., pp. 91-92, 1893.

extended easterly toward Julian. These gravels appear on a hill surrounded by deep canyons, about 2 miles east of the top of the grade above Fosters. At the top of the grade the hills on the west are flat-topped, and covered with gravels to a depth of 150 feet. These have much the same character, and probably belong to the same channel. More investigation is needed to determine whether the course of the old stream was down toward the San Diego River, in Cajon Valley, or west toward the high mesas south and southeast of Poway Valley. It seems probable, however, that the stream flowed west, and that the mesas have been formed partly from the bowlders which they brought down. This mesa, as well as the gravels at the head of the grade, has an elevation of 1,500 feet. The source of the porphyry boulders and the garnetiferous schists of this old river is a matter of great perplexity. The gravel deposit has every characteristic of an old river channel, and not that of an elevated arm of the sea; besides, the presence of gold in the gravels indicates their derivation from the country farther east. The gold may have been derived from Julian or Mesa Grande, or some more remote point. The river must have flowed across the gold belt, but then the question arises, how could a river of such magnitude have existed so near the summit? The only way out of the difficulty is to suppose that a great uplift has taken place along the crest and western slope, coupled with an enormous amount of erosion; and that this stream once, before this great change took place in the configuration of the country, headed many miles to the northeast, far beyond the drainage of the western slope. The boulders consist largely of hard rocks, and are very smoothly rounded and polished, indicating that they have been transported a long distance, and subjected to attrition through a protracted interval.

The peculiarities of the present drainage system, together with the evidence of an earlier drainage, indicate not only that the land surface in this area has undergone changes of level of considerable magnitude but also that these disturbances have been accompanied by warping and slight differential movements of the crust which have produced faults and folds throughout the area. It is probable that many of the present drainage lines have been developed in part along depressions created by crustal movements and in part along fault lines and zones of crushed and weakened rocks, caused by those movements.

HIGHLAND BASINS.

GENERAL FEATURES.

Comparatively flat tracts, some of them surrounded by steep mountain walls, cover many square miles within the highland area and form the broad valleys or basins that are referred to in this report as highland basins. El Cajon Valley (Pl. XIII), Santa Maria Valley (see fig. 2), and Warners Valley are typical examples. They bear about the same relation to the stream valleys that lakes ordinarily bear to rivers—that is, they form nodes or local enlargements which in size are out of proportion to the main stream valleys. Thus El Cajon Valley, a little more than halfway between the head and mouth of San Diego River, forms a broad, nearly square basin that extends 6 miles in the direction at right angles to the course of the river and more than 5 miles in the direction parallel to the river. The river valley both above and below this basin is in most places

FIGURE 2.—Sketch showing topography of Santa Maria Valley in vicinity of Ramona.

less than a quarter of a mile wide and does not exceed three-quarters of a mile in width even in Mission Valley, near the mouth of the river.

The floors of these valleys are comparatively smooth and slope gently toward the streams to which they are tributary, being in this respect distinctly in contrast to their rugged surroundings. Thin deposits of alluvium, with minor amounts of wind deposits, underlie all parts of these basins, except in Warners and San Felipe valleys, where lake deposits occur. In the central parts of the basins, where the alluvium has been spread out by flood waters, it ranges in thickness from only a few inches to several feet, but in the slopes near the borders of the basin the thickness of the deposit may be 30 feet or more. The alluvium is underlain by granite, which is thoroughly disintegrated at the surface, but becomes gradually firmer below the surface and is solid at a depth ranging in general from 50 to 100 feet. At some places south of Fallbrook this residuum is not more than 10 feet thick, and at a few places, especially northwest of Escondido, fresh granite outcrops at the surface.

Each of the highland basins is crossed by one or more streams, but there is apparently no genetic relation between the streams and the basins. San Diego River flows along the northern edge of El Cajon Valley; the headwaters of San Luis Rey River lie in the extreme northern part of Warners Valley, and in the lower part of its course this stream crosses near the middle of Fallbrook Plain; Escondido Creek crosses near the north end and San Dieguito Creek near the middle of the Escondido plains; and Los Penasquitos Creek flows along the south wall of Poway Valley; and there is no clear evidence that the general topography of any of the basins is due to erosion by these streams.

In accordance with their geographic distribution, the highland basins are grouped into three belts. The first belt, or lower basins, includes Fallbrook Plain, Escondido, Poway, and El Cajon valleys. Poway Mesa is also included in this belt of basins, because the rock floor on which the deposit that now forms the mesa was laid is believed to be similar to and genetically related to the basin floors on the north and south of it. The second belt, or intermediate basins, includes Bear Valley and Santa Maria Valley; and the third belt, or higher basins, includes Warners and San Felipe valleys.

LOWER BELT.

Fallbrook Plain.—Fallbrook Plain extends from Santa Margarita River, at the foot of Gavilan and neighboring mountains, southward to the valley of the San Luis Rey, and from Red Mountain westward to the eastern edge of the sedimentary rocks underlying the coastal belt. Its surface is gently rolling, but a few hills are scattered along its western edge. The bedrock is principally granite, which is decomposed at the surface, the residuum being 50 to 100 feet deep over most of the area, but only a few feet thick or entirely absent in some places, where fresh rocks lie near to the surface or are exposed. The elevation of Fallbrook Plain ranges from 500 feet to about 700 feet, the mean elevation being about 600 feet.

South of Fallbrook Plain and separated from it by the valley of the San Luis Rey another basin extends southward to San Marcos Creek and from San Marcos Mountains westward to the sedimentary rocks. This basin was originally of the same character and origin as Fallbrook Plain, although it has been made more rugged by erosion by the headwaters of seven or eight small streams that rise at the foot of San Marcos Mountains. The surface is covered by residuum, and the average elevation is about 500 feet. At its southern end this basin swings eastward along the northern base of Cerro de las Posas and joins Escondido Valley, where, owing to less favorable conditions for stream erosion, the surface becomes much smoother

Escondido and Poway valleys.—Escondido Valley is bounded on the north by the south ends of the San Marcos Mountains, Merriam Mountains, and Burnt Mountain, and extends southward (including Poway Valley) to Los Penasquitos River and the base of the cliff of Tertiary gravels that forms the side of Poway Valley. It is 4 to 8 miles wide. On the east it is bounded by highlands that are more than 2,000 feet in elevation and that include Las Lomas Muertas and Woodson mountains, and on the west by Mount Whitney, Black Mountain, and intermediate peaks. The topography of this basin is not essentially different from that of Fallbrook Plain, though the mountain wall on the west gives it a more basin-like appearance. The surface is much smoother in the vicinity of Escondido than elsewhere owing to deposits of alluvium which have filled many of the hollows. The surface rises slightly between Escondido and Poway, becoming rougher, like the area between the San Luis Rey and the San Marcos, and it is crossed by San Dieguito River, which has cut a narrow valley to the depth of about 400 feet below the level of Escondido. Twin Peak, rising to an elevation of 1,312 feet, and several lower granitic hills in its vicinity nearly separate Poway Valley from the northern part of the plain. The mean elevation of Escondido Valley is about 700 feet, and of Poway Valley about 500 feet above sea level.

The formation that lies at the surface over the greater part of the basin is residuum popularly known as decomposed granite. It extends to depths of from 40 to about 100 feet, and is underlain by solid granite. Along Escondido Creek beds of sand and gravel that occupy an old rock valley of the stream have been penetrated to depths of 30 to 40 feet by well borings that have failed to reach bedrock.

Poway and El Cajon valleys are separated by Poway Mesa, which is 1,000 to 1,200 feet in general elevation and is underlain by coarse gravels mixed with more or less sandy clay that stand in steep slopes. These gravels form most of the north slope of El Cajon Valley, and along this slope granite can be seen underlying the gravels at an elevation about 500 feet above the sea. The Beaver oil well (K 22, Pl. II and p. 68) was drilled almost exactly in the center of Poway Mesa at an elevation of 1,000 feet above sea level, and it was reported that granite was reached at a depth of about 800 feet. According to this information the elevation of the bedrock at this point between Poway and El Cajon valleys is about 300 feet above sea level. The position of the rocks here and under the gravels north of San Diego River indicates that there is no important break in the surface of the rock floor between Poway and El Cajon valleys.

Practically all the material penetrated by the Beaver oil well consisted of the gravels and sandy clays that are exposed in all the canyons in the Poway Mesa, but immediately overlying the bedrock the well encountered a deposit that probably corresponds to the marl in El Cajon Valley. If the meager information in regard to this material is correctly interpreted it indicates that previous to the deposition of the gravels of the mesa the underlying rock surface was submerged in the waters of a bay which for a long time was receiving very little sediment from the land on the east.

El Cajon Valley.—El Cajon Valley, which has a mean elevation of about 500 feet, is bounded on the north by Poway Mesa, on the east and south by granite walls that rise 500 to 1,500 feet above the valley floor, and on the west by a steep, wave-cut slope composed of Tertiary deposits. At least six terraces are preserved along this western wall at elevations of about 440, 570, 650, 688, 760, and 800 feet above sea level, respectively. Cowles Mountain, through which San Diego River has cut a gorge, forms a short stretch of the west boundary. This valley is not unlike the basins previously described, the only noteworthy difference being that, except where cut by the narrow gorge of San Diego River, it is completely inclosed by high walls, and from this fact it derives its Spanish name, meaning "the box." The length of the valley north and south is about 5 miles, and the average width east and west about 4 miles. A thin layer of alluvium covers the surface, but under this residuum or decomposed granite, in places extending to depths of 25 to 50 feet, has been encountered in a number of wells. At several places in this valley, however, wells passing through the alluvium at the surface have entered a calcareous clay resembling marl, which along San Diego River west of Lakeside was found to be more than 200 feet thick. This material is believed to have been deposited in quiet waters that occupied El Cajon Valley before and during the time that the gravel and clay of Poway Mesa was being deposited. That El Cajon Valley was not deeply filled by Tertiary deposits and later excavated by erosion is indicated by the absence of any identifiable remnants of such deposits along the eastern and southern walls of the valley and on the valley floor itself, and by the absence of any stream competent to remove so completely so large an amount of material. It is therefore concluded (1) that comparatively little sedimentation took place in the basin while it was submerged, and that Tertiary deposits along the west side were distributed by shore currents, and (2) that the distribution over this valley of the deposits which form Poway Mesa as well as other high terraces was prevented by the headland formed by San Miguel Mountain and the islands offshore, comprising what are now

Cowles Mountain, Black Mountain, Mount Whitney, and intermediate peaks, which directed the shore currents along their western sides.

When the land was elevated the bays were gradually drained, the water which occupied El Cajon Valley escaping through the narrow passage now occupied by San Diego River; and the terraces on the west wall of the valley indicate the successive stages of uplift while the waves in the bay were washing against the steep wall of sediments.

Origin of the basins of the lower belt.—All the highland basins thus far described, together with the rock surface underlying the gravels of Poway Mesa form a belt which may be regarded as a structural unit. The gravels of Poway Mesa are evidently marine deposits, as is indicated by their position and structure. At the time of their deposition the underlying crystalline rock basement was submerged. El Cajon Valley and Poway Valley were submerged at this time, together with the marls of marine origin underlying it, and by the marine deposit on the northwest side of Poway Valley; but no direct evidence that Escondido Valley and Fallbrook Plain were submerged has been obtained. No evidence was discovered in this area indicating that these basins might have been produced by marine erosion before the deposition of the gravels, but this present lack of evidence is not considered sufficient reason to abandon altogether the theory of marine erosion, and further study of this problem is highly desirable. However, other features of the highland area afford evidence that this surface is a part of a more extensive base level, and that it owes its present position relative to the adjacent highlands on the east to the earth movements which have characterized the geologic history of this region.

INTERMEDIATE BELT.

Approximately parallel to the belt of basins previously described and about 10 miles east of it there is a second belt of basins that show the same similarities in geology and topography that have been pointed out in regard to the western belt. This belt includes Bear Valley and the broad area of low relief that extends 5 or 6 miles northward nearly to the Pauma grant, the south half of the Guejito grant, and Santa Maria Valley. The basins in this belt are from 1,000 to 1,500 feet higher than those in the first belt, and they are more definitely separated by deeply eroded canyons. Nevertheless, they correspond very closely in their physical features and were obviously connected previous to the development of the canyons which now separate them.

Bear Valley.—The area lying south of the Pauma grant and including Bear Valley is an elevated table-land about 1,500 feet above sea level, very irregular in outline but definitely bounded in every direction except the southeast by deep valleys and sharp peaks and ridges, whose summits correspond in elevation with the general level of this area. Alluvium and residuum underlie the surface except where small rocky hills rise above the general level. In the southern part of the area is a deposit of valley fill, the extent and thickness of which was not ascertained, but it is neither so thick nor so extensive as the fill in El Cajon Valley or in Escondido Valley.

From the eastern end of Bear Valley the land surface rises gradually to the boundary of the Guejito grant, where it reaches a broad rolling table-land, 2,000 feet above sea level, that comprises about 7,000 acres, and extends 8 miles southward to San Pasqual Valley. The physical features of this basin are essentially like those of the area previously described. It is bounded on the north by Roderick Mountain and Pine Mountain, which rise to elevations of about 3,800 and 4,100 feet above sea level, respectively, but on the east and south it is bounded by deep valleys. On the west there is a broad area of very rugged topography but the summits of the peaks correspond in general elevation with this plain.

Santa Maria Valley.—Santa Maria Valley is separated from the Guejito basin by the canyon of Santa Ysabel River and San Pasqual Valley, which have been cut to a depth of about 1,000 feet below the level of Santa Maria Valley. The mean elevation of Santa Maria Valley is about 1,500 feet. Its surface is gently rolling and is formed by alluvium and decomposed granite, except along the course of Santa Maria Creek, which crosses about the middle of it, where sand and gravel of fluviatile origin occur. This basin is roughly circular in outline and is approximately 6 miles in diameter. It is bounded by broken country of high relief distinctly in contrast to the topography of the valley itself, in which granite hills that rise to elevations 500 to 1,000 feet higher than Santa Maria Valley are common.

Just east of this basin and separated from it by a narrow belt of rough country there is an area similar in character and nearly as large, which stands at an elevation of about 2,300 feet. This area includes Santa Teresa Valley. It is more indefinite in outline and somewhat rough, but its surface is distinctly more even than that of the country surrounding it.

Other basins.—In the southern part of the highland area there are a large number of smaller basins similar to those just described. Some of them are very definitely bounded by mountain walls; for example, Jamul Valley (elevation, 1,000 feet), whose sharp triangular shape is a striking feature, and Padre Barona Valley (elevation, 1,500 feet), which, although closely surrounded by high peaks and at least 500 feet above the base-level of its small drainage system, has a floor so nearly flat that it is almost marshy in places. Other basins are irregular and more or less indefinite in outline and stand at elevations successively higher from the edge of the coastal belt eastward to the divide.

HIGHER BELT.

East of Bear and Santa Teresa valleys is a third belt of characteristic basins which includes Warners, San Felipe, Dodge, and Oak Grove valleys. Of this group only Warners Valley was studied in the field, but the topographic map shows that all correspond rather closely in elevation, and particularly that Warners Valley and San Felipe Valley are essentially the same in their topographic relations to their surroundings. The logs of a few wells in San Felipe Valley and some general information in regard to that area (p. 206) support the topographic evidence.

Warners Valley is nearly square and comprises about 32 square miles. It is bounded on all sides by steep mountain walls that rise on the east, south, and west more than 1,000 feet, and on the north more than 3,000 feet above the valley floor. The valley floor comprises areas of rolling land, flat river floodplains, and a small group of low rocky buttes, called Monkey Hill, which lies a short distance from the southwestern side of the valley. Some granitic residuum occurs in the valley but most of the valley floor is formed by sediments that were deposited in an ancient lake. Shore features, beach ridges, deltas, and terraces, composed largely of gravel formed in this lake are preserved on all sides of the valley but are most definite on the northeastern, southeastern, and southwestern borders. The northeastern and southwestern edges of the valley coincide with fault lines, as shown by the California Earthquake Commission,[1] and characteristic evidences of faulting are displayed along the southwestern edge. It seems probable also that the valley is bounded on the northwest and southeast by faults, and that it was produced by faulting.

ORIGIN OF HIGHLAND BASINS.

The correspondence in the elevations of the basins in each of the three belts has been pointed out, and also the fact that the belts are successively higher from the coastal region eastward. There is, moreover, in all of the region lying east of the first belt of basins, a notable correspondence in elevation between the summits of most of the peaks in the broken areas and the basins. In fact, if, in the region east of Escondido and El Cajon valleys, all the canyons were filled up level with the basins of the highland belt there would be reconstructed an extensive rolling plain sloping gently toward the west. Along the eastern border of the area this plain would be broken by a range of mountains, including Palomar, Volcan, and Cuyamaca peaks, but farther west the summits of most of the peaks and ridges would coincide with the plain, so that only widely separated buttes would rise considerably above the general level. On the west

[1] Rept. California State Earthquake Commission, Andrew C. Lawson, chairman, 1910, Atlas, Map. No. 1.

this plain would be level with the summits of Monserate Mountain, the San Marcos and Merriam mountains, and with the heights all along the eastern borders of Escondido, Poway, and El Cajon valleys, but along the eastern edge of the first belt or lower basins it would suddenly end and the surface would fall in steep slopes 500 feet or more to the level of the Fallbrook, Escondido, and El Cajon basins.

These relations indicate that in an earlier geologic time a plain of this kind really existed here, that the present high, flat areas so widely distributed throughout the region are remnants of it, and that the present topography is due principally to stream erosion which progressed gradually as the region was elevated from its original low position to its present altitude. But as a result of a certain amount of faulting that took place while the land was being raised some land masses were elevated more than others. Thus Palomar Mountain and Volcan Mountain and some of the other peaks were raised high above their surrounding regions. According to Merrill[1] (see p. 37) faulting and folding have probably been important factors in the development of the present topography of the highland area. He states that this "is an anticlinal area including minor synclines. The various anticlinal and synclinal folds are intersected by parallel faults at right angles to their axes and consequently with northeast trend. These faults have cut the formation into blocks which pitch northwesterly." The differential elevation and tilting of fault blocks west of Smiths Mountain and Cuyamaca Mountain have not been so directly instrumental in producing the present topography as erosion has been; but indirectly by their effect on drainage, as suggested on page 37, they have probably been influential throughout the entire region. The presence of faults along the western edge of the highland area has not been established, but considering the general topographic and structural relations of the region as a whole and the present lack of definite indications of marine erosion in the basin areas, it seems extremely probable that the Fallbrook, Escondido, Poway, and El Cajon basins, and the rock basement of Poway Mesa, were originally parts of the extensive base level on the east, and if they were it is impossible reasonably to account for their present topographic relation to the highlands on the east except by the theory that, as a result of faulting or exceedingly sharp folding along their eastern borders, the land surface on the east was raised nearly 1,500 feet higher than it was west of those borders.

The range of mountains along the western edge of the highland area, including Otay, San Miguel, Cowles, and Black mountains, was probably brought into relief primarily by erosion previous to the

[1] Merrill, F. J. H., Geology and mineral resources of San Diego and Imperial counties: California State Min. Bur. Biennial Rept., 1913-14, p. 8, 1914.

elevation of the land farther east and, like the range including Cuyamaca and Laguna mountains, rose to a considerable height above the ancient base level, but it seems also to have been involved to some extent in differential crustal movements which may have included faulting, as is indicated by the fact that all the large streams cross this range through rock gorges floored with solid rock, whereas immediately east of the range these streams flow over débris-filled valleys whose rock bottoms lie much lower than the rock floors of their canyons through the felsite range.

GEOLOGY.

By A. J. Ellis.

GENERAL STATEMENT.

The area discussed in this report is divisible geologically into two provinces, one, comprising a region of crystalline rocks that extends from the eastern boundary of the area westward to the coastal section, practically coextensive with the highland area, and the other a region of sedimentary rocks that lies between the region of crystalline rocks and the ocean and is practically coextensive with the San Diego coastal belt. The boundary between these two provinces is a sinuous line roughly parallel to the coast at an average distance of about 15 miles inland. Throughout most of its length, and especially in the southern part of the area, where the edge of the crystalline rocks is marked by a range of mountains, the boundary is sharply defined by the abutment of the flat-lying sediments against steep walls of igneous rocks; but in most places, particularly in the northern part of the area, the sedimentary rocks overlap on the crystallines in such a way that the establishment of a boundary line between the two is more or less arbitrary. There are a few outlying masses of crystalline rocks in the sedimentary area (Pl. XIV, *B*), and scattered deposits of unaltered sediments occur in the crystalline area. Slates, quartzites, and schists of sedimentary origin are present in the crystalline area, but are so intimately associated with the granites and felsites that they are regarded as elements of the crystalline complex.

SEDIMENTARY FORMATIONS.

DISTRIBUTION AND CHARACTER.

The San Diego coastal belt has been the scene of deposition through a very long time. A drill hole near San Diego, which was begun practically at sea level, has penetrated sedimentary rocks to a depth of more than a mile, and more than a thousand feet of stratified deposits lie above sea level. On the east the sedimentaries overlap the

A. PALA CONGLOMERATE AT PALA.

B. PORPHYRITIC DIKE CUTTING TERTIARY SEDIMENTS, LOS PENASQUITOS CANYON.

crystalline rocks and become rapidly thinner until they disappear, but on the west they extend to an unknown depth. The formations consist of conglomerate, sandstones, shales, and limestones, but, owing to the close proximity to the highland area from which nearly all the material has been derived, coarse deposits are present in large proportions and in the upper part of the section they are predominant. Some of the finer-grained beds contain fossils, most of them poorly preserved and difficult to identify, but fossils of Cretaceous, Tertiary, and Pleistocene age have been distinguished. The oldest or Cretaceous beds are exposed in only a few low places along the coast. The widely distributed terrace formations are of Tertiary age. The Pleistocene occurs as a thin veneer on the older rocks along the shore.

TABLE 1.—*Sedimentary formations in the San Diego area, Calif.*

System.	Series.	Formation.	Material.	Thickness (feet).
Quaternary.	Recent.	Valley fill	Loam, sand, silt, and gravel	0–100–200
		—Unconformity—		
	Pleistocene.	San Pedro formation	Beach sands and mud	0–50±
		Pala conglomerate (relation to San Pedro formation undetermined; may be contemporaneous with San Pedro or may be older).	Coarse valley fill conglomerate.	0–200+
Unconformity—				
Tertiary.	Pliocene and Miocene.	Beach deposits		0–50
		San Diego formation	Interbedded sandstone, sandy marls, sandy shales, and conglomerates.	0–500
		Poway conglomerate (relation to San Diego formation undetermined; may be contemporaneous with San Diego).	Conglomerate, thin sand and clay beds.	0–1,000
		San Onofre breccia	Breccia	(?)
		—Unconformity—		
	Eocene.		Sandstone, shale, and limestone. Thin coal seams.	600–700
Cretaceous.	Upper Cretaceous.	Chico formation	Sandstones, shales	(?)

CRETACEOUS SYSTEM.

CHICO FORMATION.

The lower parts of the sea cliffs at the south end of Point Loma expose beds of dark shales and sandstones from which Fairbanks obtained about 60 species of Cretaceous fossils, most of which are characteristic of the Chico formation of the Upper Cretaceous. The exposed thickness of these beds is estimated at about 50 feet, but the estimate may be only roughly approximate, for the Cretaceous beds do not differ markedly in appearance from the overlying Tertiary, and the barrenness of many of the beds made it impossible accurately to determine the position of the contact. The Chico formation in this locality is overlain by Tertiary deposits that correspond in appearance much more closely with the later Tertiary or Miocene deposits back of San Diego than with the earlier Tertiary or Eocene deposits in the northern part of the area. Fossils indicating the age of beds in the upper part of this section could not be obtained, but there is little doubt that Eocene formations are entirely absent. About a mile north of the point, however, on the east side of the peninsula, the lower parts of the bluff expose sandstones which resemble the Eocene sandstones north of Los Penasquitos Canyon, and Eocene fossils have been found on the north end of Point Loma, so that apparently the later Tertiary was deposited unconformably on the underlying formations. Cretaceous beds that are similar to those on Point Loma and that carry similar fossils are exposed in the sea cliffs at La Jolla, but from La Jolla the beds dip both northward and southward and disappear within a short distance. Here also Cretaceous beds appear to be overlain by later Tertiary deposits, although Eocene beds are exposed in the cliffs a short distance north of La Jolla and at the mouth of Rose Canyon southeast of La Jolla. In both places the Cretaceous beds are exposed only in sea cliffs, and not at the surface, consequently in those places this formation is not shown on the geologic map (Pl. III, in pocket).

The area of Cretaceous rocks mapped as Chico formation in the northwest corner of the county was not surveyed in connection with the investigation here reported, but information furnished by R. T. Hill and E. S. Larsen, jr., indicates it as the probable extension of an area of Cretaceous rocks lying immediately north of this area.

TERTIARY SYSTEM.

DISTRIBUTION.

Two divisions of the Tertiary which are distinguished by lithologic as well as paleontologic difference have been recognized in this area—an earlier Tertiary, which is undoubtedly Eocene, and a later, which appears to be an inseparable assemblage of upper Miocene and Pliocene deposits. Both upper Miocene and Pliocene fossils have been obtained in the southern part of the area, but owing to the lack of continuity in the strata and to the barrenness of the beds in so many places, detailed correlation has not yet been possible, and no general stratigraphic distinction between Miocene and Pliocene has been made in this report.

As shown on the geologic map (Pl. III, in pocket), the earlier Tertiary or Eocene deposits appear at the surface from Los Penasquitos Canyon northward to Buena Vista Creek; the later Tertiary deposits are exposed from Las Penasquitos Canyon southward to the Mexican boundary and from Buena Vista Creek northward to the north boundary of the county.

EOCENE SERIES.

The earlier Tertiary or Eocene beds appear at the surface between Los Penasquitos Canyon and Buena Vista Creek and underlie the later deposits from Los Penasquitos Canyon southward, being exposed at low levels in Soledad, San Clemente, and Rose canyons. Fossils, possibly of Eocene age, were collected near the top of the mesa east of Chula Vista, and although none but late Tertiary deposits have as yet been definitely recognized, detailed paleontologic studies may establish the presence at the surface of Eocene deposits south of Mission Valley.

The top of the Eocene is characterized by a white sandstone, which in some places east of Delmar and Encinitas is nearly 100 feet thick. This white sandstone is underlain by alternating layers of shale, sandstone, and limestone, all of which, in contrast with the later Tertiary deposits, appear to be quite uniform over considerable areas. In the upper part of the section limestone is rare and the sandstones and shales are generally very light colored, the shales being usually decidedly greenish; but in the lower part of the section, as exposed along the shore line, the beds are somber colored, some of them very dark, and thin layers of limestone are common.

The following section is exposed in the sea cliffs 2 miles north of Delmar and just north of the mouth of San Dieguito River. The beds are undulating, but near the southern end of the exposure they dip 5° N. 25° E.

Section 2 miles north of Delmar.

	Feet.
Pleistocene:	
Yellow and reddish, slightly indurated sand, containing Pleistocene fossils	40
Eocene:	
Yellow to white sandstone	20
Shale; thin layers; greenish with rusty patches; contains a few fossil oysters	8
Limestone composed chiefly of oyster shells	.6
Greenish-white sandstone	3.5
Limestone composed chiefly of oyster shells	3
Greenish sandstone with a few thin (1 to 2 inch) streaks of fossil oysters	4

Among the fossils collected from the uppermost of these beds, W. H. Dall identified six Pleistocene forms. (See p. 69.) The basal members of the section yielded numerous specimens which Mr. Dall labels *Ostrea* sp. undet.

The following section is exposed 1 mile south of Delmar at the east side of the road near the mouth and on the north side of Soledad Canyon. The beds dip 6° 30′ N. 30° W.

Sections of Eocene beds 1 mile south of Delmar.

	Feet.
(Top) Friable white sandstone	10
Shale	.6
Brown to white sandstone	3
Shale	.4
Brown to white sandstone	3
Shale	.5
Varicolored sandstone—red, yellow, and white	3
Greenish shale, somewhat sandy	5

The following section is exposed 2 miles southeast of Delmar, on the east side of the railroad, at the mouth of Soledad Canyon. The beds dip 6° 30′ N. 75° W.

Section 2 miles southeast of Delmar.

	Feet.
Pleistocene: Silt, gravel, and pebbles, with Pleistocene fossils.	
Eocene: Friable sandstone with pebbles; rough bedded	15
Eocene: Massive argillaceous sandy layer containing *Ostrea* sp. undet.	
Greenish sandy shale.	

A richly fossiliferous outcrop of shale, sand, and gravel appears on the west side of the county road in the south wall of San Clemente Canyon, 6 miles east of its junction with Rose Canyon. The fossils collected here were submitted to Mr. Dall, who identified them as Eocene, closely resembling in the general assembly the fauna of the Arago group at Coos Bay, Oreg., but the species are represented by very poor casts, not determinable. The following genera are all represented:

Conus.	Acila.	Angulus.
Nassa.	Nucula.	Solen.
Turritella.	Glycymeris.	Diplodonta.
Trochita.	Ostrea.	Corbula.
Hipponix.	Cardium.	Terebratulina.
Modiolus.	Tellina.	Laquens.
Anomia.	Macoma.	
Leda.	Moerella.	

In the cliff on the south side of the mouth of San Elijo Lagoon, 3 miles south of Encinitas, the following section is exposed. The top bed dips 5° E., but the lower beds dip 4° 30′ S.

Section of Eocene beds at mouth of San Elijo Lagoon.

	Feet.
(Top) Yellow to white sand	30
Limestone composed of a mass of Eocene shells, a collection of which contained, as determined by Mr. Dall: *Ostrea* sp., *Scala* sp., *Venericardia planicosta* var. *horni* Gabb, *Pitaria* (?) sp., *Tellina* sp., *Cerithium* sp., *Ampullina* (?) sp., *Tochita* sp	.8
Yellow sandstone	4
Sandy limestone containing numerous oysters and a few other fossils	.3
Coarse yellow sandstone with a few scattered oysters at the top	3

A well drilled about 5 miles northeast of Encinitas, in sec. 26, T. 12 S., R. 4 W. (F 6, Pl. II), in search of oil, penetrated 2,126 feet of alternating beds of sandstone, shale, conglomerate, and limestone, as shown in the following well log. Eocene sandstones and shales immediately underlie the surface where this well was drilled, but it is not possible to determine from the reported log the depth to which the Eocene rocks extend. The log as given represents some unfortunately broad generalizations, as, for example, the first 700 feet of the section is reported merely as sandstone and shale, whereas a detailed record would undoubtedly show a succession of distinct beds, but it is especially remarkable that at the depth of 700 feet an 800-foot bed of conglomerate was encountered. Probably this also represents a rough grouping of very distinct layers, and it is possible that the other members of the section should also be regarded as more or less general.

TABLE 2.—*Log of Clark oil well* (*F 6*).

[Authority, K. V. Phoenix. Surface elevation about 200 feet above sea level.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Sandstone and shale	700	700	Sandy shale	25	1,875
Conglomerate	800	1,500	Limestone	35	1,910
Blue shale	125	1,625	"Brea sand"	105	2,015
Calcareous layer	? Thin	? Thin	Shale	(?) 1	2,016
Red shale	35	(?)	White sand with sulphur water	64	2,080
Conglomerate	(?)	1,750	Calcareous shale with fossils	(?) 1	2,081
Hard black sand	100	1,850	Hard sand layers	45	2,126

NOTE.—Work on this well was interrupted at the depth of 1,750 feet; when it was resumed the old boring was reamed out. Mr. Phoenix was employed on the second stage of the work and during the subsequent drilling, and this log was furnished by him from memory.

The following incomplete log of the Balboa oil well was furnished by Mr. H. A. Whitney, of the San Diego Department of Water:

TABLE 3.—*Log of Balboa oil well* (*K 37*).

[Surface elevation, 15 feet above sea level.]

	Thickness.	Depth.		Thickness.	Depth.
Pleistocene (valley fill):			Eocene—Continued.		
Quicksand, gravel, and shells	*Feet.* 80	*Feet.* 80	Water sand, fine gray, water fresh	*Feet.* 175	*Feet.* 900
Sand and boulders	6	146	Hot fresh water	100	1,000
Eocene:			Sand, shale, boulders	226	1,226
Shale, stratified, blue and brown	154	300	Sand, shell [limestone?] shale	74	1,300
Hard white shell lime	25	325	Hard shell [limestone?]	25	1,325
Shale (stratified)	175	500	Brown shale showing oil	625	1,950
Hard shell [limestone?]	?	?	Black sand (sulphur water with gas)	30	1,980
Water sand	?	525	Brown shale showing oil	230	2,210
Shale (mixed strata)	175	700	Hard limestone	37	2,247
Hard white shell lime [limestone?]	25	725	Water sand, brackish	63	2,310
			Blue limestone	100	2,410

A later record of this well is published by F. J. H. Merrill[1] as follows:

TABLE 4.—*Log of Balboa oil well (K 37) (1913).*

[Surface elevation, 15 feet above sea level.]

	Thickness.	Depth.
Pleistocene (valley fill):	*Feet.*	*Feet.*
Quicksand, gravel, and shells	80	80
Sand and boulders	66	146
Eocene:		
Shale, blue and brown	179	325
Hard white shell lime	10	335
Water sand (artesian flow)	15	350
Shale, blue and brown	150	500
Hard shell	10	510
Water sand	15	525
Shale mixed strata	175	700
Hard white shell lime	25	725
Water sand	175	900
Hot water	100	1,000
Sand, shell, and boulders	226	1,226
Sand and shale	74	1,300
Hard shell lime	25	1,325
Shale, brown (clay stiff enough to stand up)	885	2,210
Hard blue lime	37	2,247
Water sand, blue shale	63	2,310
Blue-black limestone gas?[a]	100	2,410
Hard shell, dark	144	2,554
Dark-gray, hard	5	2,559
Do	12	2,571
Dark-gray, softer	4	2,575
Dark-gray, very hard	16	2,591
Eocene—Continued.	*Feet.*	*Feet.*
Dark-gray, softer	15	2,606
Dark-gray, hard	12	2,618
Dark-gray, softer	4	2,622
Light-gray	15	2,637
Shell	9	2,646
Shale	4	2,650
Dark hard lime shell	22	2,672
Do	2	2,674
Blue shale	4	2,678
Dark hard lime shell	16	2,694
Blue shale	3	2,697
Alternating shale and limestone	18	2,715
Blue lime	145	2,860
Blue shale	2	2,862
Dark-blue lime	16	2,878
Hard blue lime	16	2,894
Dark-blue lime	26	2,820
Light-blue lime	22	2,942
Light-blue lime mixed with white lime	5	2,947
Hard black slate and lime	3	2,950
Black slate	28	2,978
Blue-black lime	7	2,985
Black slate	10	2,995
Gray sand rock	5	3,000

[a] New company began operations here.

The first 146 feet of the above log represents Quaternary valley fill. The underlying formations are no doubt Eocene but the depth to which the rocks of this age extend can not be ascertained from the log. It is probable that Cretaceous beds are reached at a depth less than 1,000 feet.

As compared with the later deposits, the Eocene beds in this area appear to have been laid down in comparatively deep water. The bedding is uniform and persistent, and the segregation of coarse and fine materials is thorough. Coarse deposits, such as conglomerate, are notably absent in the exposed section, and so far as known none of the deep wells north of San Diego, except the Clark oil well, have encountered conglomerates below sea level.

Beds belonging to the upper part of the Eocene can be recognized in the logs of wells south of Mission Valley, where they underlie later Tertiary deposits, but the base of the Eocene has not been recognized in these logs.

The thickness of the Eocene in the vicinity of San Diego and La Jolla is stated by Dickerson[2] to be 600 to 700 feet, and paleontologic studies of the strata have enabled him to conclude that

[1] Merrill, F. J. H., Geology and mineral resources of San Diego and Imperial counties: California State Min. Bur. Repts., 1913–14, 1914.

[2] Dickerson, R. E., Stratigraphy and fauna of the Tejon Eocene of California: California Univ. Dept. Geology Bull., vol. 9, No. 17, p. 437, May 2, 1916.

(1) The Tejon Eocene strata of San Diego County have yielded a fauna of over 90 forms, many of which are common species in the Tejon of Canada de las Uvas. (2) The same faunal stage is present in both localities—that is the *Rimella simplex* zone. (3) Orogenic movements in post-Eocene time have been far less vigorous in the vicinity of San Diego than in central California, although equivalent strata occur in both places.[1]

MIOCENE AND PLIOCENE SERIES.

SAN ONOFRE BRECCIA.

Most of the rocks of later Tertiary age north of Buena Vista Creek are essentially like those in the southern part of the area as described under San Diego formation (p. 58). The rocks forming the San Onofre Hills, however, are entirely different from any other Tertiary rocks in the area, for they consist of very coarse breccias or agglomerates, made up almost entirely of angular boulders and slabs of garnetiferous glaucophane schists and other schistose rock fragments. So far as known, none of the materials composing the mass were derived from rocks within the area, but rocks of this character occur in place in some of the islands off the coast, and it has been suggested that probably the material now exposed in the San Onofre Hills was derived from the west. These rocks are considered to be of early Miocene age and are older than the Tertiary formations which surround them. Fairbanks[2] describes their relation to the adjacent later formations as follows:

The Tertiary beds north of the Santa Margarita Creek are very different in outline from those south. Instead of their extending in a gradual slope from the older mountains to the ocean, there arises in them, near their western border, a range of mountains, known as the San Onofre Mountains. These extend parallel to the ocean at an average distance of 2 miles. They rise north of the Santa Margarita Creek and extend to the San Onofre Creek. They have a gradual slope on the west, rising to an elevation of 1,400 feet, but are quite abrupt on the east. Los Flores Creek cuts through the southern end of this range, showing that while the soft, clayey sandstones between it and the Santa Margarita Mountains slope only 5° to 10° southwest, the rocks of the range itself dip west at an angle of 35° to 40°. The formation is a breccia, the fragments of which are argillitic, micaceous, and hornblendic schists. Some of these fragments are of great size, one boulder of hornblende schist being 8 feet in diameter. Pebbles of white quartz and other hard metamorphics are also present. The soft, coarse sandstone in which the fragments are imbedded show no traces of any granitic matter. The range was ascended 2 miles north of the Los Flores ranch house and found to consist entirely of fragmental schists, such as those mentioned, dipping southwest at an angle of 45°. The mountains were also climbed at their northern end, near San Onofre Creek. Here there is a very abrupt escarpment on the eastern side. The strata dip toward the ocean at a high angle, while the irregular hills and ridges of soft light-colored sandstone lying east toward the Santa Margarita Mountains are nearly level. After a careful study of the range the conclusion was reached that its origin was due to a great fault, represented by the very abrupt eastern slope, tilting the elevated portion to the west at a high angle. I believe that this fault took place after the deposition of the Tertiary strata. As far as my observation

[1] Dickerson, R. E., op. cit., p. 440.

[2] Fairbanks, H. W., Geology of San Diego County; also of portions of Orange and San Bernardino counties: California State Min. Bur. Eleventh Ann. Rept., p. 98, 1893.

went the Tertiary beds on the east do not rise to meet the San Onofre range, as they would to a certain extent if it were present when they were deposited; on the contrary, they dip toward it.

SAN DIEGO FORMATION.

In the south wall of Los Penasquitos Canyon the Eocene rocks are overlain by a thin bed of conglomerate that increases in thickness southward, becoming separated from the Eocene by increasingly numerous lenses of sandstone and sandy shale until in Mission Valley the Eocene is overlain by more than 400 feet of these later Tertiary deposits. The stratigraphy of these later deposits is exceedingly complex. The beds are discontinuous and are generally very limited in extent, so that even in the small canyons it is commonly impossible to correlate the beds exposed in opposite walls. In many places there is exhibited an extremely intimate interbedding of coarse and fine material, thin layers of clay or shale separating thick layers of coarse conglomerate, and short layers of limestone only a few inches thick occurring within coarse sandstone.

As shown by the accompanying sections (pp. 61–69) the lithology of the later Tertiary deposits in this area presents most pronounced variations, both horizontally and vertically. The lithologic units commonly extend over small areas and either end abruptly with entirely different deposits, such as shale and conglomerate, in juxtaposition, as if the one had been laid down in a trough cut in the other, or they change gradually by giving way to increasing admixtures of other material until they appear as entirely different deposits, or they gradually diminish in thickness until they disappear. Some interesting sections were exposed just east of San Diego by excavations for the extension of city streets, in which cross sections of sand-filled channels in clay were very distinctly shown. Some beds are more extensive than others, and a few deposits of conglomerate cover comparatively large areas, but on the whole the discontinuity of beds is an outstanding characteristic of these deposits.

The beds are in general less indurated than the underlying Eocene beds. Excepting the very rare limestone lenses or concretions, the firmest beds are conglomerates, but these owe their firmness largely to the clay that fills the spaces between pebbles and boulders and serves as an effective cement. Wells have been dug by hand to depths of nearly a hundred feet without encountering rocks hard enough to require blasting.

Marl and calcareous material of a chalky appearance are common in the deposits. In some places, as, for example, in the vicinity of La Mesa, beds of marl several feet thick occur, but this material appears most commonly as friable lumps and disseminated particles in clay beds. A typical example is exhibited in an exposure along the road extending from the end of Sixth Street, San Diego, to

Mission Valley (see section of San Diego formation, p. 62), and a deposit almost identical with this is exposed in the south wall of San Luis Rey River about 1½ miles east of Oceanside. In both these exposures white lime is present in sufficient amounts to give the beds a pronounced gray color.

The sandy marls which are exposed around Mission Bay and in Mission Valley and that underlie the conglomerates east of San Diego have been referred to in the literature[1] as the San Diego beds. Fossils collected from these beds have been classified as Pliocene.

In the following quotation C. R. Orcutt[2] has assembled the data in regard to fossil collections obtained from these deposits in a well boring in the city of San Diego.

> In the early days of the present city of San Diego, Calif., a well was sunk to a depth of 160 feet, at the corner of Ash and Eleventh streets, which for a time formed the source of the water supply of the then small town. The depth reached was not far from the present sea level, and it may be well to add that the well is situated at the mouth of one of the small canyons, opening out upon the lower mesa, upon which is built the business portion of our city to-day.
>
> Mr. Henry Hemphill, the indefatigable student and collector of our west coast Mollusca, was then, as now, a resident of San Diego, and present to examine the débris as it was brought up from the well. At the depth of about 90 feet a stratum of indurated sandstone was passed through, in which was found casts of various shells, together with a few well-preserved fossil shells.
>
> At a greater depth, from 140 to 160 feet, came a rich variety of well-preserved shells, imbedded in a usually rather soft matrix, composed of loosely aggregated grains of sand or fine sandy mud, occasionally hardened by infiltration of lime-bearing water.
>
> The following is a list of the species obtained from this well by Mr. Hemphill, as they were identified and published in the Proceedings of the California Academy of Sciences, vol. 5, pp. 296–299, 1874, by Wm. H. Dall:

Glottidia albida Hinds.
Xylotrya sp. indet. (tubes only).
Cryptomya californica Conrad.
Dentalium hexagonum Sowerby.
 semipolitum Broderip and Sowerby.
Solen rosaceus Carpenter.
Solecurtus californianus Conrad.
Myurella simplex Carpenter.
Macoma expansa Carpenter.
Callista sp. indet. (smooth, thin, and inflated; much like C. newcombiana).
Cardium centifilosum Carpenter.
Venericardia borealis Conrad.
Lucina nuttallii Conrad.
 borealis Linné.
 tenuisculpta Carpenter.
Cryptodon flexuosus Montague.
Modiola recta Conrad.
Arca microdonta Conrad.
Nucula n. sp. Carpenter (like N. tenuis).
Acila lyalli Baird (frequently reported as A. castrensis Hinds).
Leda caelata Hinds.
Pecten hastatus Sowerby.
Amusium caurinum Gould.
Janira florida Hinds.
Ostrea conchaphila Carpenter.
Placunanomia macroschisma Deshayes.
Tornatina eximia Baird.
Cylichna cylindracea Linné.
Siphonodentalium pusillum? Gabb.
Calliostoma annulatum Martyn.
Galerus filosus Gabb.
Crepidula navicelloides Nuttall.
 princeps Conrad (not C. grandis of Middendorf).

[1] Dall, W. H., A table of the North American Tertiary horizons, correlated with one another and with those of western Europe, with annotations; U. S. Geol. Survey Eighteenth Ann. Rept., pt. 2, p. 337, 1898.
[2] West American Scientist, vol. 6, No. 46, p. 84, August, 1889.

Turritella jewettii Carpenter.
Bittium asperum Carpenter.
Drillia sp. indet.
sp. indet.
sp. indet.
sp. indet.
Surcula carpenteriana Gabb.
Mangilia variegata Carpenter.
sp. indet.
sp. indet.
sp. indet.
sp. indet.
Clathurella conradiana Gabb.
Odostomia straminea Carpenter.
sp. indet.
Turbonilla torquata Carpenter.
Eulima rutila Carpenter.
Scalaria subcoronata Carpenter.
Cancellaria sp. indet.
sp. indet.
sp. indet.
sp. indet.
Neverita reclusiana Petit.
Sigaretus debilis Gould.
Ranella mathewsonii Gabb.
Olivella boetica Carpenter.
Nassa fossata Gould.
mendica Gould.
Astyris tuberosa Carpenter.
sp. indet.
Ocinebra lurida Carpenter.
Pteronotus festivus Hinds.
Trophon orpheus Gould.
Fusus (Colus) dupetit-thouarsi? Kiener.
Chrysodomus diegoensis Dall, n. sp.
n. sp. (too imperfect to describe).

The following additions to the list of species from this well were reported by Dall.[1]

Venericardia monilicosta Gabb.
Janira dentata Sowerby.
Cylichna alba Brown.
Turritella cooperi Carpenter.
Turbonilla stylina Carpenter.

Other additions to the list are incorporated by Dall[2] in substantially the same list as was published in the Proceedings of the California Academy of Sciences, which I note as follows:

Clementia subdiaphana Carpenter.
Lucina acutilineata Conrad.
Nucula exigua Sowerby.
Volutopsis sp. indet.
Mamma nana Möller.
Cadulus fusiformis.
Pecten expansus Dall.

The stratum from which these fossils came is probably at least 70 feet in thickness in places, and the bed is of wide extent, as is shown by the fossils which have been found in nearly every well that has been sunk in San Diego.

The beds described by Orcutt are near the base of the later Tertiary section. They are best developed in the immediate environs of the city of San Diego, but they have been recognized by their lithologic character as far south as Otay and in the northern part of the area in the vicinity of Oceanside. They seem to be integral parts of a single formation and chronologically inseparable from the other lenticular strata with which they are interbedded. On this ground it is proposed to include all the later Tertiary marine deposits in this area under the name San Diego formation.

South of Otay Valley the San Diego formation is probably more than 500 feet thick, but between Otay River and Los Penasquitos River it is in most places less than 500 feet thick. The principal lithologic characteristics which distinguish this formation from the underlying Eocene are (1) lenticular bedding and deltoid structures; (2) lower degree of induration; (3) absence of limestone beds, but

[1] Dall, W. H., U. S. Nat. Mus. Proc., vol. 1, pp. 10-16.
[2] Idem, pp. 26-30.

large amounts of calcuim carbonate disseminated through the fine-grained deposit; (4) presence of large quantities of coarse material as thick beds of conglomerate, as beds of coarse gravel, and as mixtures of sand, gravel, and clay; (5) predominance of sandstones and coarser materials over clay.

The San Diego formation is essentially a shallow-water deposit, as is indicated by its deltoid structure and by the presence of fossil mud cracks. Most of the materials of which it is formed were derived from the highland area on the east, some of them being transported only short distances and others being brought from comparatively remote sources. The conglomerates are made up of well-rounded pebbles, some of which are derived from rocks that have not been found in place in San Diego County; and the presence of the large fluviatile deposits east of Foster suggests that some, but probably only a small part, of this material may have been transported from sources entirely outside the San Diego area.

The following well log shows the character of the strata on the north end of Point Loma, but no fossil evidence of the age of the successive beds was preserved. The surface deposits belong to the San Diego formation and the lowest beds may be Cretaceous.

TABLE 5.—*Log of well on pueblo lot 146, Point Loma, San Diego County, Calif.*

[Begun Aug. 18, 1900; completed Mar. 18, 1901. Authority, Katherine Tingley, owner. Elevation of mouth of well, 255.88 feet above high tide.]

	Thickness.	Depth.		Thickness.	Depth.
San Diego formation:	*Feet.*	*Feet.*	Eocene—Continued.	*Feet.*	*Feet.*
Surface clay	3	3	Water-bearing sand, good water	6	271
"Hardpan"	5	8	Dark-blue shale	27	298
Sandy clay	22	30	Water-bearing sand	2	300
Water-bearing sand	10	40	Dark-blue shale	20	320
Sandy shale and dry sand	20	60	White quartz } gold colors from panning.	1	321
Sandy shale	40	100	Blue granite	2	323
Sand	6	106	Light-blue shale	27	350
Eocene:			Alternate shale and sand	10	330
Dark-blue shale	84	190	Light-blue shale	10	370
Water-bearing sand	2	192	Water-bearing sand	2	372
Dark-blue shale	8	200	Light-blue shale	16	388
Water-bearing sand	2	202	Water-bearing gravel and sand	2	390
Dark-blue shale	58	260	Shale, gravel, and clay	10	400
Whitish clay	1	261			
Coal	1	262			
"Ore"	3	265			

Diameter of well, 6 inches, 0 to 40 feet; 5 inches, 40 to 400 feet. Water level, 253 feet below surface, or 2.88 feet above high tide. Estimated yield, 35,000 gallons daily if all water-bearing strata are used.[1]

[1] U. S. Geol. Survey Bull. 264, p. 79, 1905.

A well which was being drilled for Mr. L. K. Lanier, in South Las Choyas Valley, about 4 miles east of San Diego, penetrated the following beds:

TABLE 6.—*Log of L. K. Lanier's well (O 5).*

[Furnished by Wilkes James, driller. Surface elevation about 175 feet above sea level.]

	Thickness.	Depth.
San Diego formation:	*Feet.*	*Feet.*
Yellow sand with a few layers of clay	210	210
Very fine dark-colored sand containing a large admixture of fine black mica; quite fluid when wet. Abundant fossils	150	360

W. H. Dall examined a collection of fossils obtained from the lower member of this section and classified as upper Miocene or probably Pliocene, the following forms:

Cancellaria sp.
Olivella pedroana Conrad.
Tritonalia sp.
Nassa cf. N. mendica Gould.
Thais cf. T. lamellosa var.
Neverita cf. N. recluziana.
Dentalium sp. nov.
Leda cf. L. arca trilineata Conrad.
Pecten. 2 sp. indet.
Phacoides 2 sp.
Tellina ? sp.
Dosinia ponderosa.
Chione sp.?
Spisula sp.
Cardium sp.
Corbula sp.

The following section is exposed in the south wall of Mission Valley 2 miles east of North San Diego.

Section of San Diego formation.

	Feet.
(At top, elevation, 250 feet above sea level) fine to medium-grained sand, containing poorly preserved casts of shells	60
Conglomerate	20
Coarse sand, containing garnet grains and small flakes of black mica, generally white to brown but locally greenish, with irregular streaks and masses of marl. At the bottom the sand is locally thin bedded and dark colored. This member closely resembles the dark sand penetrated by Lanier's well (O 5) at the depth of 210 feet, and by the Y. M. C. A. well in San Diego (O 1) at the depth of 145 feet. It is presumably the same bed as that which yielded the fossils described on page 59	170+

Robert Dick's well, just northwest of Hollywood, penetrated the San Diego formation to the depth of 203 feet, encountering alternating beds of clay and conglomerate as follows:

TABLE 7.—*Log of Robert Dick's well (O 7).*

[Furnished by Wilkes James, driller. Surface elevation about 250 feet above sea level.]

	Thickness.	Depth.		Thickness.	Depth.
San Diego formation:	*Feet.*	*Feet.*	San Diego formation—Contd.	*Feet.*	*Feet.*
Clay loam	40	40	Hard conglomerate	11	136
Conglomerate	3	43	Gravel and clay	29	165
Clay	9	52	Coarse conglomerate	9	174
Conglomerate	7	59	Clay and gravel	12	186
Clay	31	90	Conglomerate	8	194
Clay and gravel; water at 114 feet	35	125	Clay and gravel	9	203

A well drilled at Angelus Heights to the depth of 375 feet penetrated the following beds:

TABLE 8.—*Log of the Angelus Heights well (O 8).*

[Authority, Wilkes James, driller. Surface elevation about 400 feet above sea level.]

	Thickness.	Depth.		Thickness.	Depth.
San Diego formation:	*Feet.*	*Feet.*	San Diego formation—Contd.	*Feet.*	*Feet.*
Top, hard yellow clay	25	25	Clay and conglomerate	93	310
Chalky formation, and boulders	50	75	Water-bearing sand	(?)	(?)
Clay and conglomerate with some sand	140	215	Clay and sand	(?)	370
Sand and gravel yielding water	2	217	Sand yielding salty water	5	375

About $3\frac{1}{4}$ miles east of Chula Vista and $1\frac{1}{4}$ miles southeast of Bonita the north wall of a small canyon, locally known as Fossil Canyon, exhibits a section of alternating lenticular deposits of sand and sandy clay containing large masses of concretionary limestone and lenticular beds of impure limestone. A collection of fossils, which were obtained principally from the limestones which are in place at an elevation of about 300 feet above sea level, are considered by W. H. Dall to be of upper Miocene age. The following forms were identified:

Cetacean bone.
Cancellaria sp.
Fasinus sp.
Turritella sp.
Pecten cf. P. diegensis Dall.
Mactra albaria Conrad.
Thracia n. sp.
Venerid genus undet.

Two miles east of Chula Vista a tributary to the Sweetwater has cut a deep canyon in the mesa formations. Conglomerates are less in evidence in the exposures here than north of Sweetwater River. About 2 miles east of Chula Vista and $1\frac{1}{2}$ miles south of Bonita, near the top of the south wall of the canyon, the following section is exposed:

Section of San Diego formation 2 miles east of Chula Vista.

	Feet.
(Top, elevation about 200 feet above sea level) loose gravel and clay	3+
Coarse impure sandstone, somewhat calcareous, containing fossil mud cracks, some of which are 16 inches deep	3
Calcareous sandstone containing a few fossils	40

A collection of fossils from the lowest member was submitted to Mr. Dall, who describes it as Eocene (?), like the collection obtained in San Clemente Canyon. (See p. 54.) The following genera are represented:

Ostrea.
Chione.
Phacoides.
Psammacema.
Sanguinolaria.
Siliqua.

Mr. Dall has indicated some doubt as to the age of these fossils and it is quite possible, considering the close proximity of upper

Miocene beds, $3\frac{1}{4}$ miles east of Chula Vista and $1\frac{1}{4}$ miles southeast of Bonita (p. 63), that they may be younger than Eocene. If they are Eocene there is practically an entire absence of the San Diego formation at this locality, and the contact between the Eocene and the San Diego is shown to be irregular, the top of the Eocene being more than 300 feet higher here than it is in the vicinity of San Diego, where, according to notes published in the West American Scientist [1] the later Tertiary deposits here designated San Diego formation extend at least to the depth of 110 feet below sea level. The following note relates to a well boring made on Coronado Island in 1886:

In boring for artesian water a stratum of sand was found containing numerous fossil shells of the later Tertiaries. The more prevalent species were *Phasianella compta*, *Ostrea lurida*, and *Anomia lampe*, in the order named. The stratum was found at a depth of nearly 70 feet.

These species, according to W. A. English, belong to the lower Pliocene.

The following note appears in the issue of the West American Scientist for July, 1890 (p. 24).

When the Coronado Beach Co. was boring an artesian well on Coronado Beach, San Diego, in 1886, a fossil tooth was found at a depth of 110 feet which was presented by H. L. Story to Mrs. R. S. Eigenmann. This has been examined by Prof. E. D. Cope, editor of the American Naturalist, who identifies it as a left upper molar of an extinct species of horse, *Equus excelsus*.

According to J. W. Gidley, of the National Museum, the evidence of one tooth is hardly sufficient to distinguish between *Equus excelsus* and *Equus occidentalis*, but either of these species may occur in the Pliocene.

The following well logs, particularly the logs of the Chula Vista Oil Co.'s borings, which, as shown on Plate II, are close together, illustrate the variable character of the deposits in this part of the area.

TABLE 9.—*Log of test well No. 1, Chula Vista Oil Co. (O 23).*

[Completed 1901. Surface elevation about 150 feet above sea level. Authority, Mrs. M. J. Herman.]

	Thickness.	Depth.		Thickness.	Depth.
San Diego formation:	*Feet.*	*Feet.*	Eocene—Continued.	*Feet.*	*Feet.*
Gravel, sand, clay	120	120	Shell	1	371
Conglomerate	15	135	Shale	83	454
White sand	16	151	Shell	5	459
Conglomerate	2	153	Blue clay, sand	105	564
Eocene:			Very hard shell	23	587
White sand	22	175	Clay	13	600
Sandstone	45	220	Shell	1	601
Blue sand	30	250	Shale (gas)	11	612
Shale	(?)	(?)	Sand	12	624
Water sand	(?)	270	Clay	28	652
Shell	4	274	Sand	8	660
Quicksand	56	330	Clay	9	669
Shell	3	333	Shell	1	670
Blue clay and sand	37	370	Clay (oily particles)	8	678

[1] West American Scientist, vol. 2, No. 15, p. 32, April, 1886.

TABLE 10.—*Log of test well No. 2, Chula Vista Oil Co. (O 24).*

[Completed 1901. Surface elevation about 150 feet above sea level. Authority, Mrs. M. J. Herman.]

	Thickness.	Depth.		Thickness.	Depth.
San Diego formation:	*Feet.*	*Feet.*	Eocene—Continued.	*Feet.*	*Feet.*
Surface clay and sand	116	116	Quicksand	23	312
Conglomerate	14	130	Shell	1	313
Eocene:			Clay	8	321
White sand	13	143	Shell	3	324
Shell	1	144	Sand and soft shale	4	428
Clay and sandstone	18	162	Shell	1	429
Shell	1	163	Sand	20	449
Blue sand	33	196	Clay	44	493
Shell	2	198	Shell	4	497
Clay, sandstone, and shale	42	240	Clay	9	506
Blue sand	15	255	Hard shell	5	511
Shell	2	257	Alternate sand and clay	57	568
Shale	30	287	Conglomerate	2	582
Shell	2	289			

TABLE 11.—*Log of test well No. 3, Chula Vista Oil Co. (O 26).*

[Completed 1902. Surface elevation about 150 feet above sea level. Authority, Mrs. M. J. Herman.]

	Thickness.	Depth.		Thickness.	Depth.
San Diego formation:	*Feet.*	*Feet.*	Eocene:	*Feet.*	*Feet.*
Surface soil	12	12	Clay	70	280
Cemented sand	10	22	Sand	30	310
Conglomerate	22	44	Clay	90	400
Clay	54	98	Hard shell	2	402
Sandstone	12	110	Shale (oil and gas)	18	420
Clay	30	140	Clay	30	450
Soft sandstone	30	170	Very hard shell	3	453
Clay	5	175	Blue clay	173	626
Water gravel	35	210	Conglomerate	19	645
			Light-yellow shale	15	660

TABLE 12.—*Log of test well No. 4, Chula Vista Oil Co. (O 27).*

[Completed in 1902. Surface elevation about 135 feet above sea level. Authority, Mrs. M. J. Herman.]

	Thickness.	Depth.		Thickness.	Depth.
San Diego formation:	*Feet.*	*Feet.*	Eocene—Continued.	*Feet.*	*Feet.*
Surface soil	12	12	Clay	78	271
Sand and boulders	9	21	Sand	33	304
Conglomerate	20	41	Clay	86	390
Clay	54	95	Hard shell	11	401
Sandstone	19	114	Shale	15	416
Clay	32	146	Blue clay	31	447
Sand and boulders	12	158	Shell	2	449
Eocene:			Blue clay	63	512
Sandstone	7	165	Hard shell	3	515
Clay	21	186	Blue clay	104	619
Shell	7	193	Conglomerate	24	643

115536°—19—WSP 446——5

TABLE 13.—*Log of the Chula Vista oil well* (*O 25*).

[Surface elevation about 150 feet above sea level. Authority, Mrs. M. J. Herman.]

	Thickness.	Depth.
	Feet.	*Feet.*
San Diego formation:		
Surface sand and clay	55.6	55.6
Sand	25	80.6
Clay	38.8	129.4
Sand with water	16.6	146
Boulders	5	151
Eocene:		
Sand	18	169
Blue clay and sand	32	201
Black water sand	9	210
Blue clay and sand	16	226
Sand	8	234
Hard shell	4	238
Sand	25	263
Blue clay and sand	87	350
White sand	12	362
Shale	7	369
Blue clay and sand	67	436
Shell	5	441
Sand	12	453
Blue clay and sand	38	491
Hard shell	3	494
Blue clay and sand	92.2	586.2
Conglomerate	25	611.2
Yellow clay	92.4	703.6
White sand	8.4	712
Clay	26	738
White sand and clay	3	761
Hard shell	3	764
Light clay and sand	12.5	776.5
Light clay	52.1	828.6
Sand	8.2	836.8
Light clay	4	840.8
White sand	13	853.8
Clay	9	862.8
Sand	8	870.8
Clay	4	883.8
Clay and sand	16.2	900
Hard shell	1	901
Hard sand	3.6	904.6
Light clay	3.4	908
White sand	?	?
Light clay	?	?
White sand	?	925
Light clay	?	?
Clay and sand	?	940
Dark sand and clay	8	948
Light clay and sand	10	958
Dark clay, sand, and gravel	10	968
Hard coarse sand and clay	32	1,000
Clay and sand	?	?
Coarse sand	?	1,030
Eocene—Continued.		
Light clay and sand	30	1,060
White fine sand	10	1,070
Clay sand and boulders	36	1,106
Clay and sand	20	1,126
Fine white sand	24	1,150
Light clay, sticky	5	1,155
Clay and sand	?	?
Coarse gravel and boulders	?	1,174
Hard shell	1	1,175
Fine white sand	40	1,215
Hard shell	1	1,216
Light clay and sand	12	1,228
Dark sand	8	1,236
White sand	40	1,276
Light clay	?	?
White sand	?	1,295
Light clay	5	1,300
Sand and gravel	25	1,325
Light clay and sand	23	1,348
Light clay	17	1,365
White sand	?	?
Light clay	?	1,380
White sand	5	1,385
Light clay	22	1,407
White sand	?	?
Light clay	?	1,440
White sand	?	?
Hard sand	?	1,457
White sand	?	?
Hard fine sand	?	1,460
White sand	?	?
White clay	?	1,475
Blue sand and clay	97	1,562
Blue clay and sand	28	1,590
Hard white sand	4	1,594
Blue clay and sand	28	1,622
Hard white sand	3	1,625
Blue clay and sand	11	1,636
Hard white sand	2	1,638
Blue clay and sand	?	?
Hard white sand	?	?
Blue clay and sand	?	1,657
Hard white sand	6	1,663
Blue clay and sand	17	1,680
Hard white sand	2	1,682
Dark clay and sand shale	100	1,762
Hard white sand	2	1,764
Dark clay and sand shale	9	1,773
Hard white sand	4	1,777
Blue clay and sand shale	35	1,812

Casing log of the Chula Vista oil well (*O 25*).

Diameter.	Depth cased.
Inches.	*Feet.*
16	0–270
14	130–385
12	0–1,115
7⅝	0–1,346
5⅝	0–1,485
4½	0–1,670
3⅝ [a]	0–1,760

[a] Stovepipe lining.

TABLE 14.—*Log of the Lo Tengo Oil Co.'s well* (*O 62*).

[Surface elevation, 375 feet above sea level.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
San Diego formation:			Eocene—Continued.		
Sandy clay	20	20	Brown shale	15	1,450
Sand and shale	20	40	Sand and conglomerate	37	1,487
Soft light yellow sand, water	200	240	Brown shale	15	1,502
Conglomerate	70	310	Sand and conglomerate	38	1,540
Eocene:			Dark soft shale, water	90	1,630
Hard shell	10	320	Brown shale, sand	50	1,680
Soft red sand	37	357	Sticky blue clay	38	1,718
Soft yellow sand	43	400	Blue shale	?	?
Blue shale	45	445	Red sand	?	1,758
Soft sand and blue shale	50	495	Blue clay, streaks of sand	185	1,943
Yellow clay	35	530	Hard calcareous rock	472	2,415
Yellow sand, water at top	42	572	Hard fine sand	40	2,455
Sticky clay	?	?	Calcareous sand rock	127	2,582
Blue clay	?	605	Dark sand rock	18	2,600
Gray sand shell, gray sand	35	640	Calcareous rock	200	2,800
Blue clay	25	665	Conglomerate and sand	32	2,832
Water	?	?	Conglomerate	16	2,848
Blue clay	?	720	Sand, gas	17	2,865
Blue shale	25	745	Gas and oil	?	?
Sandy shale	50	795	Soft sand	?	2,965
Blue shale and clay	?	?	Hard calcareous sand	?	?
Blue clay	?	860	Oil	?	?
Light brown shale, hard shell	?	?	Soft sand, oil	?	2,985
Brown shale and shells	?	1,365	Sand	50	3,035
Black sand, water	70	1,435	Soft sand, oil	?	?
			Hard, calcareous rock, streaks of sand in lower part	?	3,400

TABLE 15.—*Log of the Tia Juana oil well* (*O 63*).

[Authority, Capt. J. F. Scott. Surface elevation, about 85 feet above sea level.]

	Thickness.	Depth.		Thickness.	Depth.
	Feet.	*Feet.*		*Feet.*	*Feet.*
San Diego formation:			Eocene—Continued.		
Conglomerate	80	80	Shale and sand alternating	100	1,000
Water sand	2	82	Shale with streaks of oil sand	8	1,008
San Diego (?) formation:					
Quicksand with mica	500	582	Alternating hard and soft	92	1,100
Eocene:			sand and blue clay	1	1,101
Coal seam, thin	?	582	Hard fossil bed	249	1,350
Shale and sand alternating [a]	?	800	Sandstone with water [b]	12	1,362
			Hard sand, trace of oil		
Shale with trace of oil	4	804	Sands and black shales, showing oil	43	1,405
Hard sand	96	900			

[a] From a depth of 800 feet the sand bucket brought to the surface a specimen of *Spicula* sp.? (crushed) Miocene?

[b] Water encountered at 1,125 feet below surface; rose nearly to surface but leaked into higher formations; water of excellent quality.

POWAY CONGLOMERATE.

The rocks forming Poway Mesa are chiefly conglomerates, but lenses of cross-bedded sand and thin layers of marly clay are exposed in some of the canyon walls. Large deposits of similar materials occur in a narrow belt that extends from Poway Mesa eastward to Witch Creek, as shown on Plate III. They are also well exposed near the town of Poway and form the south wall of Poway Valley. The maximum thickness of the conglomerates west of Foster is about 1,000 feet. Two hypotheses have been advanced to account for the occurrence of these deposits. According to one of them, an arm of the sea extended from Foster eastward, in which coarse detritus from the surrounding land mass accumulated; the other, proposed by Fairbanks (see p. 40), suggests a fluviatile origin of the deposits.

The following well log exhibits a section of Poway Mesa.

TABLE 16.—*Log of the Beaver oil well (K 22).*

[Authority, F. C. Tower. Surface elevation, 975 feet above sea level.]

	Thickness.	Depth.
	Feet.	*Feet.*
Poway conglomerate:		
Coarse gravels	875	875
Crystalline complex:		
Granitic rock with thin covering of marl	175	1,050

NOTE.—Encountered water at 525 feet below surface which rose 100 feet in the casing. Said to be "soda water" and strongly mineralized.

No fossils were found in this formation, and its contact with the marine San Diego formation does not afford a definite interpretation of its relative age. But the materials of which it is composed, being practically the same as the coarser phases of the San Diego formation, suggest an age corresponding in a general way with that formation. Probably it is somewhat older than the upper part of the San Diego, since it is at a much higher elevation and must have emerged before the San Diego was raised above the sea, but it may correspond in age with the lower part of that formation.

LATE TERTIARY BEACH DEPOSITS.

The surface of Linda Vista Mesa is crossed by narrow bands of sandstone that represent ancient beach ridges. In most places the sandstone is brick-red, but it is locally mottled red and yellow, and near Mission Valley is gray. The texture of the rock is variable, ranging from very coarse to medium fine, and shows stratification only near the surface, where it is most indurated. In a few places fossil sun cracks were found in impure facies of the rock. The thickness of these deposits ranges from a few feet, south of Mission Valley, to 50 feet or more north of Los Penasquitos Canyon (see p. 30). They rest on the San Diego formation where these beds underlie the surface but continuing northward they rest on Eocene.

QUATERNARY SYSTEM.

Two types of Quaternary deposits, distinguished primarily by their geologic occurrence, are recognized in this region—the marine Pleistocene and the nonmarine Pleistocene and Recent valley fill. The marine Pleistocene occurs principally along the coast, resting unconformably on older formations, but the valley fill occupies the valleys of the principal streams in all parts of the region, and also forms the present floors of San Felipe Valley and Warners Valley.

PLEISTOCENE SERIES.

SAN PEDRO FORMATION.

Littoral deposits of fossiliferous sand and loam occur as a veneer on the older rocks in a narrow belt along the shore from San Onofre to the boundary (Pl. III). North of Soledad Canyon the terraces along the shore are surmounted by ridges of semi-indurated sand containing Pleistocene fossils, which reach elevations of about 100 feet, and Pleistocene fossils are distributed over the flat surfaces of the benches on which Oceanside, South Oceanside, and Carl are situated, as much as a mile inland from the present shore line.

Fossils collected in the NE. ¼ sec. 36, T. 11 S., R. 5 W., at an elevation of about 70 feet above sea level include, according to Mr. Dall, the following Pleistocene species:

Neverita recluziana var. alta Dall.
Pecten circularis Sowerby.
Chione gnidia Sowerby.
Chione fluctifraga Sowerby.
Chione neglecta Sowerby.

About a half mile southeast of this locality, on the south side of the salt marsh at the mouth of Buena Vista Creek, in the SW. ¼ sec. 31, T. 11 S., R. 4 W., a narrow band of black loam on the steep terrace slope 50 feet above sea level, contained numerous specimens of *Neverita recluziana* var. *alta* Dall.

The following species were identified in a collection of fossils obtained from an old beach ridge at the top of the cliffs 2 miles north of Delmar (see section, member a, p. 53):

Neverita recluziana var. alta Dall.
Pecten circularis Sowerby.
Chama mexicana Carpenter.
Tivela crassatelloides Conrad.
Chione gnidia Sowerby.
Chione neglecta Sowerby.

Small isolated deposits of Pleistocene sand and loam were found along Buena Vista Creek as far east as El Salto. Half a mile west of El Salto a collection was obtained from a small deposit of dark loam among which were the following Pleistocene forms:

Ostrea conchaphila Carpenter.
Anomia sp.
Pecten circularis Sowerby.
Donax laevigata Deshayes.
Chione gnidia Sowerby.
Chione fluctifraga Sowerby.
Chione neglecta Sowerby.

Such deposits are common along the shores of all the lagoons as far south as Soledad Canyon.

Pleistocene deposits occur on the shores of Bay and of San Diego Bay, as shown on Plate III, generally at elevations between 15 and 50 feet above sea level. A careful search failed to discover Pleistocene fossils between Mission Valley and Tia Juana Valley at a higher elevation than 50 feet, but south of Tia Juana Valley the high terraces along the shore reaching 100 feet in elevation are thickly strewn with Pleistocene shells.

Arnold [1] has described the beds in the vicinity of San Diego, and has correlated the Pleistocene deposits there with the San Pedro formation of Los Angeles County.

During the field work in connection with this investigation the Pleistocene beds near San Diego could not be distinguished from the other marine Pleistocene deposits along the coast in this county, so that in accordance with Arnold's correlation, all the marine Pleistocene in San Diego County has been mapped as San Pedro formation.

PALA CONGLOMERATE.

Valley fill of a type not common in this area occurs in the valley of the San Luis Rey, in the vicinity of Pala. This material is a conglomeritic mass of boulders and residuum, having a thickness of about 200 feet above and extending to an undetermined depth below the present level of the river. The boulders which make up a large part of this formation are all regular, most of them being prismatic blocks with slightly rounded corners showing that they have been transported only short distances. (See Pl. XIV, *A*.) The boulders are granite, and the country rock in the immediate vicinity of Pala is gabbro, but this gabbro is surrounded by granites, and the degree of corrosion exhibited by the boulders seems not inconsistent with the assumption that they were derived from granite masses within the drainage basin of the San Luis Rey.

This deposit is older than the valley fill which underlies the present valley floors, and it may be as old or even older than the San Pedro formation, but it has not been possible to ascertain definitely the relative ages of these formations.

LACUSTRINE DEPOSITS.

The lake deposits of Warners Valley are not exposed in section, and information as to the stratigraphic character of the deposits over the inner parts of the valley has not been obtained. The materials at the surface consist of sandy alluvium. It is probable that the sediments in Warners Valley are similar to those in San Felipe Valley, where wells drilled near the middle of the valley, to depths ranging from 90 to 280 feet, penetrated alternating beds of alluvial rock débris, sand, and clay, and ended in a bed of coarse rounded boulders. The deposits which form beach ridges and deltas around the margins of Warners Valley consist of gravel and coarse sand, generally poorly assorted and locally mixed and cemented with clay.

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[1] Arnold, Ralph, The paleontology and stratigraphy of the marine Pliocene and Pleistocene of San Pedro, Calif.: California Acad. Sci. Mem., vol. 3, p. 57, 1903.

RECENT SERIES.

VALLEY FILL.

The most recent geologic formation is the alluvium which occupies the valleys of all the principal streams. These valleys were excavated during a period in which the land stood possibly 800 or 1,000 feet higher than it does at present,[1] and the streams were able to cut their valleys to a depth between 100 and 200 feet below the levels of the present valley floors before the beginning of the submergence that obliged the streams to aggrade their valleys. The alluvium is composed of sand, clay, and gravel derived from the drainage basins of the streams. The areal distribution of the valley fill is shown on Plate III. The beds of the ancient channels underlying the alluvium are generally characterized by coarse boulder deposits. Overlying the boulders are alternate layers of gravel, sand, and clay, sand being predominant, especially at the surface.

These deposits comprise the principal ground-water reservoirs in the county. They are more fully described on pages 111–121.

RESIDUUM.

Most of the igneous rocks in San Diego County are coarse granites that yield readily to weathering. In the broad areas in which rocks of this kind occur the surface is immediately underlain by residuum, or disintegrated granite, in which the joint planes of the original rock are still preserved. Disintegration is most advanced at the surface, where the rock has been completely reduced to soil, and it decreases downward to the solid granite at depths ranging from a few inches to about 100 feet. Near the margins of valleys the residuum is covered by talus and alluvium washed from the slopes, and in some of the valleys alluvium has been spread over the entire valley floors.

IGNEOUS AND METAMORPHIC ROCKS.

Only a superficial study of the lithology of the region of crystalline rocks has been made in connection with this investigation, so that merely a general discussion of the character and distribution of these rocks is possible in this report. A large amount of specific and detailed information on this subject is, however, contained in the publications of the California State Mining Bureau, the most comprehensive paper being a report by H. W. Fairbanks [2] on the geology of San Diego County and portions of Orange and San Bernardino counties.

The rocks composing the crystalline complex include both igneous and metamorphosed sedimentary rocks of great age, together with

[1] Merrill, F. J. H., Geology and mineral resources of San Diego and Imperial counties, Calif.: California State Min. Bur. Bien. Rept., 1913–14, p. 11, 1914.

[2] California State Min. Bur. Eleventh Ann. Rept., p. 76, 1893.

numerous dike and vein rocks of somewhat more recent origin, and consist of gneisses, crystalline schists, quartzites, slates, and limestone, which have been intruded by granites, which in turn have been intruded by diorites and gabbros. The oldest formations occur particularly in a belt along the west side of the crest of the Peninsular Range, although isolated bodies are present in other parts of the area.

The igneous rocks include many holocrystalline varieties, together with porphyries, felsites, and amorphous lavas. Coarse granites, cut by dikes of fine-grained granite, are by far the most widely distributed and constitute the major portion of the crystalline complex. The coarser granites, both on the elevated plateaus and on the low valley plains, are deeply disintegrated and in many places completely reduced to a residual soil. Large masses of basic rocks, including gabbro and diorite, are intruded into the granites and metamorphic rocks in the eastern part of the area, and of these Cuyamaca Peak, Middle Peak, and North Peak, and several of the mountains in the vicinity of Pala are composed. The range along the western edge of the crystalline area, including Otay, San Miguel, and Cowles mountains and other lower hills, is composed of felsites and porphyries which are shown on the geologic map of the United States [1] as effusives of Tertiary or later age.

A description of these rocks together with a comment on their probable age is given by Merrill[2] as follows:

> On the southwestern flank of the granites is a volcanic area, a few miles wide, extending northwest some 40 miles from the Mexican boundary and often erroneously called "the porphyry dike." This is largely overlain by the Tertiary formations. The principal rocks exposed are felsite, quarried for crushed stone at Spring Valley and Sweetwater dam. With these, at various points, are tufas and volcanic conglomerates. The age of these volcanics is as yet somewhat indeterminate, but the specimen from Lo Tengo oil well, of black shale cut by felsite, suggests a post-Jurassic age for the latter.
>
> The felsites may belong to the same period of eruption as the volcanics of Coyote Mountain in Imperial County, which underlie the Miocene clays, but they are of different type, for the Coyote Mountain effusive rocks are basic and, though they are badly decayed and difficult to identify, were probably mostly andesites.

Fairbanks states that this rock "is without doubt an ancient intrusive, very greatly altered. * * * None of the other crystalline rocks in San Diego County appear so old or show so much alteration."

Samples were collected by the writer at three localities in the range, one in the SW. ¼ sec. 34, T. 17 S., R. 1 E.; one in the NE. ¼ sec. 4, T. 18 S., R. 1 E.; and one just north of the north boundary of the San Dieguito grant, at the center of sec. 16, T. 13 S., R. 3 W. These

[1] Willis, Bailey, and Stose, G. W., Geologic map of North America, U. S. Geol. Survey, 1911.

[2] Merrill, F. J. H., Geology and mineral resources of San Diego and Imperial counties; California State Min. Bur. Bien. Rept., 1913-14, p. 11, 1914.

rocks were examined and described by E. S. Larsen, of the United States Geological Survey, as quartz latites, greenish or grayish rocks which carry a moderate number of phenocrysts of oligoclase-andesine feldspar and a few of chloritized biotite in a very fine, indistinctly granular groundmass made up of quartz and orthoclase. The rocks are much altered flow breccias, secondary chlorite and calcite being abundant, and they carry many included fragments of andesitic and latitic rocks. The sample from sec. 16, T. 13 S., R. 3 W., contains phenocrysts of quartz and the groundmass is coarser. A sample collected by G. A. Waring from Morro Hill is described as a dense, aphanitic light-gray andesite or quartz latite. Small laths of andesine make up about half of the rock, and augite and magnetite are in small amount. The groundmass is glassy, and the rock is much less metamorphosed than the rocks described above, being possibly of later origin.

Probably the latest igneous rocks in the San Diego area are the lavas, described by Fairbanks, that cap sandstone hills in the extreme northern part of the county north of De Luz.

In an area of crystalline rocks of this character the order in which the different rocks were formed is indicated by the phenomena of intrusion, and the amount of weathering which the different rocks have undergone is a criterion of their ages, but since this is dependent as much on rock composition and structure as on the length of time that the rocks have been exposed, it is often unreliable as an indication of age. But neither of these criteria is in itself sufficient to define the geologic age of rocks, and in this area few other data bearing on the problem have been obtained. Fossils of Carboniferous age have been reported from metamorphic rocks correlative with those in the San Diego area, indicating that most of the crystalline rocks are post-Carboniferous, and Merrill suggested (see p. 72) a post-Jurassic age for the felsites on the west, which, so far as has been determined, are not considerably younger than the mass of crystallines. Conditions along the contact between the exposed Tertiary sediments and the crystallines indicate that the latter were old before the Tertiary deposits were laid down and are probably not younger than early Cretaceous. Fairbanks states that "although none but Carboniferous fossils have yet been found, it is probable that the metamorphic series contains rocks much older as well as younger," and that he believes "that the great convulsion which upheaved and metamorphosed the older rocks and intruded granite into them took place, as it did in central and northern California, between the Cretaceous and the Jurassic."

GEOLOGIC HISTORY.

PRE-CRETACEOUS SEDIMENTATION.

The early geologic history of western San Diego County is obscure, owing to the absence in the eastern part of recognizable time markers, and in the western part to the great thickness of the deposits beneath which the old formations are buried. The oldest rocks are in the eastern part of the region. No fossils have as yet been discovered in them, but they have been provisionally [1] correlated with the rocks of the Calaveras group, which are believed to be of Carboniferous age. In San Diego County these rocks include metamorphosed shales and sandstones and, in adjacent areas to the east, limestones. When these rocks were deposited, presumably during Carboniferous time at the latest, the region was covered by the sea. The materials of which the shales and sandstones were composed were probably derived from land not far to the east, and they were deposited in thick beds that probably extended over all the highland area. The rocks on which they were laid down may have been crystallines or ancient sediments which have been so thoroughly altered that they can not now be recognized as such.

PRE-CRETACEOUS OR EARLY CRETACEOUS DIASTROPHISM, VOLCANISM, AND METAMORPHISM.

Late in the Jurassic period or early in the Cretaceous period there was a time in which great geologic changes occurred. Many of the separate events were no doubt closely related, and some entirely obliterated the results of earlier action, so that the true sequence of events is hard to determine. Into the sedimentary formations great igneous masses were intruded, eventually forming the granite rock that underlies practically the whole region. This intrusion elevated the region, particularly the highland area, and crumpled and folded the rocks into anticlines and synclines. The sediments were changed by heat and pressure to schists, slates, quartzites, and marbles. Erosion of the land mass then began and became more vigorous as elevation progressed. As a culmination of the processes of volcanism great masses of basic magmas were intruded into the granites and overlying rocks. These basic masses produced the Cuyamaca peaks and other peaks in the eastern part of the area and possibly the porphyritic rocks along the western border.

CRETACEOUS (?) PENEPLANATION.

Erosion continued until the region was reduced practically to a base level. The metamorphosed sediments were in large part removed

[1] Merrill, F. J. H., Geology and mineral resources of San Diego and Imperial counties, Calif.: California State Min. Bur. Bien. Rept. 1913–14, p. 24, 1914.

from the elevated positions and were left only in the protected synclines, and the ridges and peaks of hard basic rocks were etched into relief by the removal of the softer materials into which they had been intruded. The débris stripped from the highland area was carried into the ocean, where it accumulated in stratified deposits now covered by younger sediments. It is probable that during the Cretaceous as well as the Tertiary period the shore line remained essentially in the same position—along the boundary between the present coastal section and the highland area. In fact it is presumable that a great fault line extended along the west edge of the present highland area, approximately coincident with that ancient shore line, and that the area of sedimentation west of the fault gradually subsided as the sediments accumulated, so that thousands of feet of sedimentary rocks were laid down at the very edge of the land mass.

EARLY TERTIARY UPLIFT, REJUVENATED EROSION, AND COASTAL SEDIMENTATION.

A period of uplift and mountain building followed the base-leveling, probably in early Tertiary time.[1] During this period the previously formed peneplain was in part broken up and high mountains were formed along the eastern border of the area. Streams readjusted themselves to new topographic conditions and began to carve the present drainage lines. A period of intermittent submergence followed, during which Tertiary sediments accumulated along the coast.

LATE TERTIARY AND QUATERNARY EMERGENCE AND OSCILLATION.

Toward the end of the Pliocene epoch the land movements were reversed and the sea slowly withdrew from the present coastal region, the periods of quiescence and relatively rapid emergence of the land being recorded by well-defined terraces separating successive wave-cut plains.

Oscillatory movements, or alternate elevations and depression of the land, characterized the succeeding Quaternary period. During an epoch of depression the west edge of the coastal region was submerged and received deposits of Pleistocene age. During a subsequent epoch of elevation these deposits were lifted high above the sea, and most of the deposits which had been laid down in the larger valleys were carried into the sea again by river erosion. The land was raised probably as much as 200 feet higher than it stands at present, and the principal streams excavated deep valleys. A still later subsidence of the land brought about a refilling of all these channels to the present levels of the valley floors.

[1] See Fairbanks, H. W., Oscillations of the coast of California during the Pliocene and Pleistocene: Am. Geologist, vol. 20, pp. 213-245.

These movements are believed to represent the principal events in the history of the region, but minor changes of which little or no record is preserved have no doubt been constantly taking place. The terraces along the coast show that the oscillations of the land have continued to the present time, and that changes of geologic importance, due in part to land movements and in part to the processes of degradation and aggradation, are now in progress.

PRECIPITATION.

By C. H. Lee.

GENERAL CONDITIONS.

Both the surface and the ground waters of San Diego County are derived from precipitation on the surrounding slopes. Of the water that falls as rain or snow on any area a part is immediately lost by evaporation; another part is directly absorbed by the soil or other porous material and percolates downward, and if it escapes evaporation from the soil or transpiration from plants this part may ultimately reach the water table and join the permanent body of ground water; the remaining part collects in stream channels and is either absorbed by the porous alluvial débris of the beds, and thus joins the permanent body of ground water, or flows onward to the ocean.

Determination of the source and quantity of the ground waters of San Diego County requires a knowledge of the quantity and distribution of precipitation from season to season and from year to year. A wealth of such information is available in the form of records of the daily, monthly, and annual precipitation at a great number of stations well distributed throughout both the mountainous parts of the county and the coastal region. The writer knows of no mountainous areas of equal size in the western United States for which records of precipitation are so full or so widely distributed.

CHARACTER OF STORMS.

Most of the precipitation that occurs in San Diego County is due to the great cyclonic storm areas, or "lows," from the north Pacific Ocean that appear off the coasts of southeastern Alaska, British Columbia, and northern United States. These lows, which are from 500 to 1,000 miles in diameter, have a general easterly movement as they reach the continent, but many are deflected southward. The frequency and intensity of these storms is greatest during the rainy season. Whether the rainy season is what is known locally as "wet" or "dry" depends upon the number of "lows" that are deflected to the south and the degree of deflection. If the percentage of "lows" deflected southward is large the season is wet;

in a dry season few or no "lows" reach far enough south to affect precipitation in San Diego County. The variation of rainfall from month to month during the year and also from year to year is thus largely controlled by the general movement of these great Pacific storms. Mr. Ford A. Carpenter, for many years stationed at San Diego as local forecaster of the United States Weather Bureau, states that 90 per cent of the rain falling in the vicinity of San Diego results from these storms.[1] It is stated by McAdie [2] and also by Carpenter that not one-tenth of the north Pacific "lows" have any appreciable effect on the climate of San Diego.

Another type of storm that occasionally brings precipitation during the rainy season approaches the San Diego Coast from the southwest. These storms do not move rapidly and many of them remain stationary over southern California and Arizona for several days. In some winters none of these storms appear and seldom more than two yield precipitation over San Diego County.

Besides storms of these two types, local thunder showers occur in the higher mountains of eastern San Diego County during the summer months, chiefly July and August. Such storms seldom reach the coast, and precipitation in the mountains is usually limited to a few hours in the afternoon. Their influence on the total annual precipitation at mountain stations is small. Stream flow is seldom affected by them.

A fourth type of local storm is the "sonora," which reverses the ordinary storm movement and, traversing the country from Sonora, Mexico, is heralded by northerly and northeasterly winds. This storm is cyclonic in character and extends over large areas. It occurs during the summer—May to September—but is very infrequent, and precipitation due to it is confined to the mountains and interior regions. It has little influence on monthly or annual variations in precipitation in San Diego County and seldom causes run-off.

Precipitation in San Diego County is mainly in the form of rain, although more or less snow falls every winter on the higher mountain slopes and occasionally at lower levels. Snow remains but a few days except in the most protected parts of the highest mountains.

OBSERVATIONS OF PRECIPITATION.

Records of precipitation are available for periods varying from one year to 65 years at 106 stations in San Diego County. Seventeen per cent of the records have been kept by the United States Weather Bureau, 32 per cent by the City of San Diego, 40 per cent by water companies and other organizations, and 11 per cent by private individuals. These stations are well distributed over the county,

[1] Carpenter, F. A., The climate and weather of San Diego, Calif., 1913.

[2] McAdie, A. G., Climatology of California: U. S. Weather Bureau Bull. L, 1903.

both vertically and longitudinally. Six per cent are more than 5,000 feet above sea level, 9 per cent are between 4,000 and 5,000 feet, 16 per cent are between 3,000 and 4,000 feet, 22 per cent are between 2,000 and 3,000 feet, 11 per cent are between 1,000 and 2,000 feet, and 39 per cent are less than 1,000 feet. Horizontally, there is an average of one station to about 30 square miles, although the more important run-off areas, such as the upper parts of the drainage areas of San Luis Rey and Santa Ysabel rivers, have two or more stations to the township. The United States Weather Bureau records presented in this report were obtained from the printed reports of the bureau. Other records were compiled by the writer from the original sources or from reliable secondary sources. So far as possible, each precipitation gage and its exposure was examined, and the character and methods of the observer and the probable accuracy of the record were ascertained from personal interview. Practically all observations have been made with the standard 8-inch gage in general use by the United States Weather Bureau. The writer believes that all private records presented in this report have been carefully and conscientiously kept and that the results are reasonably accurate and within the limits of error of carefully kept precipitation observations. The officers of private companies and individuals who had kept records were found ready to assist in every way possible in furnishing the original records and other information.

A summary of precipitation observations is presented in Table 17, which gives the map number, location, and elevation of the station, the authority for and period covered by the record, the average observed annual precipitation, and the corrected long-term average annual precipitation. The details of the records, in the form of monthly and annual depth of precipitation in inches, will be found in Table 64 of this report (pp. 290–313).

TABLE 17.—*Summary of precipitation records in San Diego County used as a basis for Plate X V.*

(For complete monthly and annual records see Table 64.)

No. of station.	Location.	Altitude in feet above sea level.	Authority.	Period of record.		Observed average annual precipitation.	Correction factor.	Corrected, long-term, average annual precipitation.
				Inclusive dates.	Number of years.			
						Inches.		*Inches.*
1	Warner dam site	2,702	V. L. & W. Co	1911-12 to 1914-15	4	30.34	1.03	29.46
2	Damron's	2,725	....do	....do	4	32.74	1.03	31.79
3	Monkey Hill	2,810	....do	....do	4	15.03	1.03	14.59
4	Warner's Summer Road	2,805	....do	....do	4	18.57	1.03	18.03
5	Puerta La Cruz	2,772	....do	....do	4	18.33	1.03	17.80
6	Deadman's Hole	3,200	....do	....do	4	21.63	1.03	21.00
7	Pamo	1,050	....do	1911-12 to 1912-13	2	16.21	.79	20.52
8	Santa Ysabel ranch house	3,000	S. Rotanzi and V. L. & W. Co	1900-1901 to 1914-15	15	24.68	1.03	23.96
9	Santa Ysabel store	2,983	V. L. & W. Co	1911-12 to 1914-15	4	27.39	1.03	26.59
10	Witch Creek store	2,800	J. Woods	1909-10 to 1914-15	6	27.19	1.01	26.92
11	Ramona	1,400	R. L. Verlague	1896-97 to 1914-15	19	17.25	.97	17.78
12	....do	1,400	Sentinel newspaper	1911-12 to 1914-15	4	18.28	1.03	17.75
13	Rose Glen	2,300	Mrs. S. Rotanzi	....do	4	23.26	1.03	22.58
14	Mesa Grande	3,450	Ed. H. Davis and U. S. W. B	1905-6 to 1907-8, 1908-9 to 1914-15	10	33.18	1.07	31.01
15	Mesa Grande (Angels)	3,448	V. L. & W. Co	1911-12 to 1914-15	4	35.12	1.03	34.10
16	Nellie	5,350	T. O. Bailey and U. S. W. B	1901-2, 1903-4 to 1905-6, 1908-9 to 1914-15	11	48.66	1.04	46.79
17	Mendenhall Valley	4,500	V. L. & W. Co	1911-12 to 1914-15	4	33.46	1.03	32.49
18	Oak Grove	2,750	U. S. W. B	1911-12 to 1912-13	2	14.20	.79	17.97
19	Chihuahua Mountain	4,200	V. L. & W. Co	1911-12 to 1914-15	4	22.08	1.03	21.44
20	Eagle's Nest	4,500	....do	....do	4	17.94	1.03	17.42
21	Warner's Springs	3,165	U. S. W. B	1906-7 to 1914-15	9	18.92	1.02	18.55
22	Warner's ranch house	2,894	V. L. & W. Co	1911-12 to 1914-15	4	18.95	1.03	18.40
23	San Felipe	3,600	....do	....do	4	24.00	1.03	23.30
24	Matagual	3,200	....do	....do	4	24.01	1.03	23.31
25	Volcan Mountain	4,800	....do	....do	4	36.36	1.03	35.30
26	Pine Mountain	2,500	....do	1911-12	1	19.81	.91	21.77
27	Aguanga	1,988	U. S. W. B	1908-9 to 1914-15	7	13.98	1.03	13.57
28	Julian	4,200	....do	1879-80 to 1883-84, 1891-92 to 1914-15	29	29.02	1.00	29.02
29	Cuyamaca	4,677	....do	1888-89 to 1914-15	27	40.78	1.01	40.37
30	Escondido	657	Newspaper and U. S. W. B	1875-76 to 1914-15	40	15.51	1.02	15.20
31	Head Escondido ditch	1,986	E. M. W. Co	1896-97 to 1900-1901, 1902-3, 1906-7 to 1914-15, incl.	15	20.92	.95	22.02
32	Hot Springs Mountain	6,200	V. L. & W. Co	1912-13 to 1914-15	3	17.79	1.07	16.62
33	Elsinore	1,234	U. S. W. B	1887-88, 1897-98 to 1911-12	16	13.34	.95	14.04
34	Oceanside	67	J. A. Tulip, U. S. W. B	1892-93 to 1914-15	23	11.15	.96	11.60
35	Poway	460	U. S. W. B	1879-80 to 1887-88, 1893-94 to 1908-9	25	14.01	1.00	14.01
36	Sweetwater dam	310	Sweetwater Water Co	1888-89 to 1914-15	27	10.88	1.01	10.76

TABLE 17.—*Summary of precipitation records in San Diego County used as a basis for Plate XV*—Continued.

No. of station.	Location.	Altitude in feet above sea level.	Authority.	Period of record.		Observed average annual precipitation.	Correction factor.	Corrected, long-term, average annual precipitation.
				Inclusive dates.	Number of years.			
						Inches.		*Inches.*
37	Descanso	3,400	U. S. W. B.	1895–96 to 1901–2, 1909–10 to 1914–15	13	22.35	.87	25.69
38	Valley Center	1,360	S. G. Anthony and V. L. & W. Co.	1872–73 to 1898–99, 1911–12, 1913–14, 1914–15.	30	19.74	1.04	18.98
39	San Diego	93	U. S. W. B.	1850–51 to 1914–15	65	9.69	1.00	9.69
40	El Cajon	570	do	1899–1900 to 1914–15	16	13.53	1.01	13.39
41	Lakeside	500	S. D. & S. E. Ry.	1909–10 to 1914–15	6	13.62	1.01	13.48
42	End of flume	640	C. W. Co.	1899–1900 to 1914–15	16	13.69	1.01	13.55
43	Los Coches Creek	710	do	1900–1901 to 1914–15	15	13.69	1.03	13.29
44	Chocolate Creek	760	do	1899–1900 to 1914–15	16	17.07	1.01	16.90
45	Diverting dam	820	do	do	16	16.99	1.01	16.82
46	East Cuyamaca	4,600	do	1912–13 to 1914–15	3	21.93	1.07	20.49
47	Schilling's ranch	4,550	do	do	3	27.91	1.07	26.08
48	Campo	2,543	U. S. W. B.	1877–78 to 1881–82, 1889–90 to 1893–94, 1900–1901 to 1914–15.	25	20.33	1.04	19.55
49	Buckman's Springs	5,450	C. W. Co.; see No. 86	1914–15	1	31.63	1.47	21.52
50	Morena dam	3,000	S. C. M. W. Co. and city of San Diego	1907–8 to 1914–15	8	21.79	1.01	21.57
51	La Jolla reservation	3,800	U. S. W. B.	1911–12 to 1914–15	4	31.26	1.03	30.44
52	Laguna	5,440	Arch Campbell	1894–95 to 1903–4	10	18.59	.82	22.67
53	Barrett dam site	1,600	S. C. M. W. Co. and City of San Diego	1909–10 to 1914–15	6	20.66	1.01	20.45
54	Jamul	1,040	S. C. M. W. Co.	Incomplete season				
55	El Cajon Valley, Southwest Pass.	670	C. W. Co.	1908–9 to 1914–15	7	12.07	1.03	11.72
56	Pine Hills hotel	4,100	V. L. & W. Co.	1913–14 to 1914–15	2	42.88	1.27	33.77
57	Fallbrook	700	U. S. W. B.	1876–77 to 1902–3	27	17.27	1.00	17.27
58	Divide between Santa Ysabel and Warner's.	3,200	V. L. & W. Co.	1912–13 to 1914–15	3	31.53	1.07	29.47
59	Rincon of Warner's ranch	2,975	do	do	3	29.20	1.07	27.29
60	La Mesa dam	500	C. W. Co.	do	3	14.25	1.07	13.31
61	Sutherland dam site	1,900	V. L. & W. Co.	1914–15	1	37.37	1.47	24.42
62	Santa Maria dam site	1,400	do	1914–15	1	28.42	1.47	19.33
63	Pamo camp	975	do	1914–15	1	28.18	1.47	19.17
64	Carroll dam site	250	do	Incomplete season				
65	Point Loma	302	U. S. W. B.	1904–5 to 1914–15	11	11.39	1.11	10.26
66	Otay	90	Geo. G. Downes	1908–9 to 1914–15	7	11.07	1.03	10.74
67	Lower Otay reservoir	486	S. C. M. W. Co. and City of San Diego	1906–7 to 1914–15	9	11.80	1.02	11.57
68	Los Padres ranch	490	M. G. Allen	1901–2 to 1910–11, 1912–13 to 1914–15	13	15.87	1.05	15.11
69	Bonita	110	G. A. Norton, R. M. Allen, U. S. W. B.	1899–1900 to 1914–15	16	10.61	1.01	10.51
70	Rockwood ranch	430	L. D. Rockwood	1893–94 to 1914–15	22	13.04	.96	13.58
71	Boulder Creek	2,990	V. L. & W. Co.	Incomplete season				

72	Harvey ranch	514	City of San Diego	...do				
73	Jamul ranch	800	...do	1912–13 and 1914–15	2	16.77	1.07	15.67
74	Dulzura	1,075	...do	1914–15	1	24.03	1.47	16.34
75	Marron Valley	575	...do	1914–15	1	18.19	1.47	12.37
76	Winetka Valley	2,500	...do	Incomplete season				
77	Lyon Peak	3,755	...do	1914–15	1	30.02	1.47	20.42
78	Lyon Valley	2,200	...do	1914–15	1	36.59	1.47	24.89
79	The Willows	2,300	...do	Incomplete season				
80	Cottonwood	875	...do	1914–15	1	22.65	1.47	15.41
81	Tecate	1,775	...do	1914–15	1	23.73	1.47	16.14
82	Potrero	2,390	...do	1914–15	1	27.34	1.47	18.60
83	Skye Valley	2,550	...do	1913–14	1	19.45	1.47	13.23
84	Grigsby's ranch	2,690	...do	1913–14 to 1914–15	2	25.36	1.27	19.97
85	El Cajon City	482	T. J. Cox	1882–83 to 1893–94	12	14.78	1.17	12.63
86	Buckman Springs	3,400	City of San Diego	1914–15	1	30.47	1.47	20.71
87	Descanso Valley	3,500	...do	1914–15	1	40.31	1.47	27.42
88	Laguna ranger station	5,475	...do	Incomplete season				
89	Bonita	60	...do	1914–15	1	13.97	1.47	9.50
90	Chollas Heights	350	...do	1914–15	1	19.30	1.47	13.13
91	Campbell's ranch	2,575	...do	Incomplete season				
92	Kitchen Valley	5,250	...do	...do				
93	Dehesa	580	...do	1914–15	1	25.59	1.47	17.41
94	La Presa	300	...do	1914–15	1	17.13	1.47	11.63
96	Nobles mine	4,200	...do	1913–14	1	19.54	1.47	13.29
97	Japatul	2,725	...do	1914–15		28.88	1.47	19.64
98	Pueblo farm	400	...do	Incomplete season				
99	Modicajuat	3,150	...do	1914–15	1	28.38	1.47	19.30
100	Rattlesnake Valley	4,775	...do	Incomplete season				
101	La Posts	3,300	...do	...do				
102	Viejas		...do	...do				
103	Miramar	660	G. A. Riley	1901–2 to 1914–15	14	14.15	1.04	13.60
104	Santa Fe ranch	60	M. H. Crawford	1911–12 to 1914–15	4	10.61	1.03	10.30
105	Scripps Biological Institute	50	G. F. McEwen	Incomplete season				
106	Lauterbachs		City of San Diego	1914–15	1	25.64	1.47	17.44

NOTE.—Abbreviations were used for the following authorities quoted in the table: Volcan Land & Water Co., United States Weather Bureau, Escondido Mutual Water Co., San Diego & Southeastern Ry., Cuyamaca Water Co., Southern California Mountain Water Co.

The precipitation year has been considered as extending from July 1 to June 30, so as to cover the rainy season and the period of run-off resulting therefrom. The location of all stations is shown on Plate XV (in pocket).

The records published by the United States Weather Bureau cover long periods and are among the most valuable available. Most of the stations at which observations were made by the city of San Diego were installed in 1914 and maintained under the direction of Mr. H. A. Whitney, hydraulic engineer, department of water, city of San Diego. Among the records kept

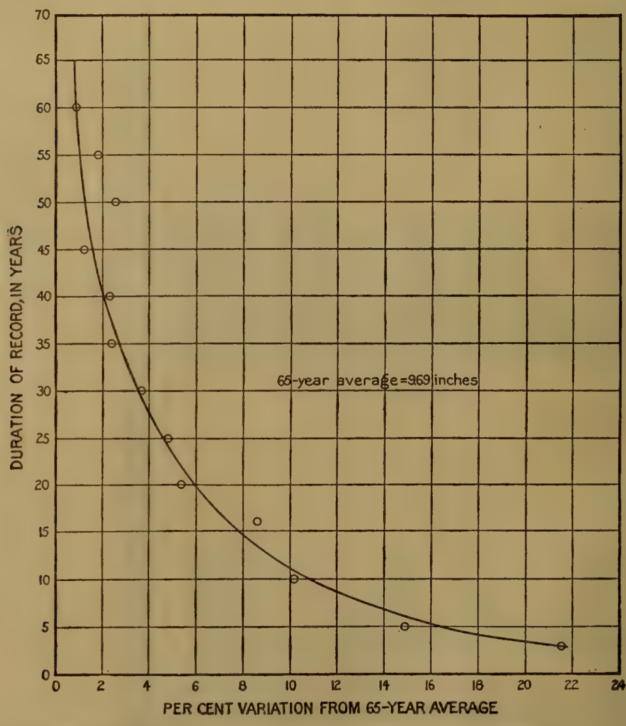


FIGURE 3.—Relation of length of record of precipitation to variation from the average at San Diego, Calif.

by water companies, 80 per cent were furnished by the Volcan Land & Water Co. and the Cuyamaca Water Co., and great credit is due Mr. W. S. Post, chief engineer for both companies, for the thoroughness and care with which the data have been obtained and compiled, as well as to the companies for the public spirit displayed in making the records available. Most of these gages were installed in 1911, although several stations have been maintained by the Cuyamaca Water Co. since 1899. Other companies maintaining precipitation stations, to whom credit is due for furnishing records, are the Sweetwater Water Co., the Escondido

Mutual Water Co., and the San Diego & Southeastern Railway Co. A number of valuable records were also furnished by private individuals, some of them covering considerable periods. These individuals are too numerous to be mentioned by name, but the writer wishes to express his appreciation of their scientific interest in this subject and their public spirit in making the records available for publication.

By summarizing the data obtained at the stations listed in Table 17 according to the number of complete seasons of record available, it appears that 8 per cent of the records are over 25 years long, 2 per cent are from 25 to 20 years, 9 per cent are from 20 to 15 years, 7 per cent are from 15 to 10 years, 10 per cent are from 10 to 5 years, 50 per cent are less than 5 years, and 27 per cent are less than 3 years in length. As precipitation in San Diego County is notoriously subject to wide annual variations, large deviations from the mean, sometimes extending over several years, it is apparent that the true averages for the depth of annual precipitation could not be determined at many of the stations by simply averaging the observed quantities. In order to determine to some extent the short-term records the following procedure was followed: The whole period of record at San Diego was divided into periods of 3, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, and 60 years each, and the average annual precipitation was computed for each of these periods. The relation, in percentage, of the average annual precipitation during each of the short periods to the average annual precipitation for the whole 65-year period was next computed, and the results were averaged for periods of equal length. The results thus obtained were represented diagrammatically on figure 3, and a smooth curve was drawn to fit the points.

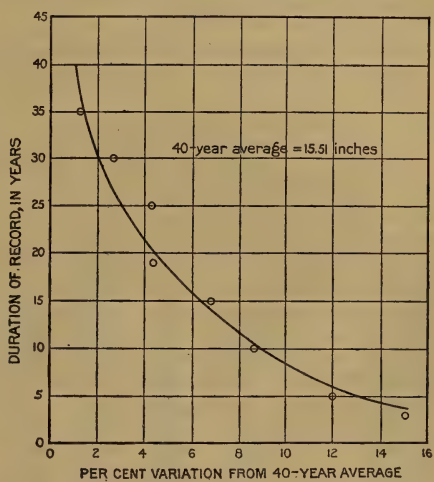


FIGURE 4.—Relation of length of record of precipitation to variation from the average at Escondido, Calif.

Inspection of this curve shows that the average of 25-year periods differs by 4.6 per cent from the 65-year period. Similarly, for Escondido, it was found that the average of the 25-year records differs but 3 per cent from the 40-year period.

There are nine stations in the county at which records are available for 25 years or more. These stations are well distributed, both vertically and geographically (Pl. XV), and are as follows: San Diego, at which the record covers 65 years; Escondido, 40 years; Valley Center, 30 years; Julian, 29 years; Fallbrook, Cuyamaca, and Sweetwater, each 27 years; and Campo, 25 years. These stations are termed "control stations" in this report because of their use in evaluating the short-term records.

Examination of the annual variations from the normal at the nine control stations, as tabulated by percentages in Table 18, indicates a general concordance in the variations at the different stations, which is due, at least in part, to the fact that most of the precipitation results from general storms that at any given time cover areas many times greater than San Diego County. This condition is well known to the inhabitants of San Diego County and other parts of southern California, as is shown by the popular terms "wet," "dry," and "average," as applied uniformly throughout the region to specific rainfall seasons.

TABLE 18.—*Precipitation index and annual variation of precipitation at nine control stations in San Diego County, expressed as per cent of average of observed precipitation.*

Year (July 1 to June 30).	Julian (28).[a]	Escondido (30).[a]	Valley Center (38).[a]	Fallbrook (57).[a]	Cuyamaca (29).[a]	Poway (35).[a]	San Diego (39).[a]	Sweetwater (36).[a]	Campo (48).[a]	Average all control stations.
										Per cent.
1872–1873			59				67			63
1873–1874			191				174			182
1874–1875			67				59			63
1875–1876		134	98				104			112
1876–1877		54	45	50			39			47
1877–1878		173	134	144			166		99	143
1878–1879		56	43	44			82		52	55
1879–1880	106	128	124	118		110	148		88	117
1880–1881	89	69	81	78		76	100		78	81
1881–1882	101	66	84	71		95	98		62	82
1882–1883	143	50	60	77		60	51			74
1883–1884	212	207	256	236		210	268			232
1884–1885		61	68	73		76	90			74
1885–1886		135	155	152		120	175			147
1886–1887		68	69	63		68	86			71
1887–1888		102	116	117		112	101			110
1888–1889		119	134	136	130		114	129		127
1889–1890		135	154	156	183		155	157	147	155
1890–1891		96	135	114	153		108	116	132	142
1891–1892	77	75	91	78	97		90	91	160	95
1892–1893	87	118	104	123	108		96	105	87	103
1893–1894	142	38	50	57	55	59	51	59	125	71
1894–1895	109	120	125	138	140	134	123	149		129
1895–1896	41	51	61	54	62	77	64	67		60
1896–1897	77	100	122	125	103	126	122	111		111
1897–1898	47	56	55	64	78	65	52	65		60
1898–1899	37	61	59	50	64	57	54	53		54
1899–1900	70	89		78	70	80	62	60		73
1900–1901	85	93		96	105	94	108	85	86	94
1901–1902	84	75		72	88	70	64	65	86	76
1902–1903	106	114		136	90	118	121	96	98	110
1903–1904	53	53			57	59	45	47	43	51
1904–1905	140	151			142	141	148	142	155	145
1905–1906	152	164			138	155	152	153	133	150
1906–1907	112	115			110	119	110	120	125	116
1907–1908	85	87			74	91	88	97	76	85
1908–1909	96	117			112	128	106	111	113	112
1909–1910	82	121			82		101	95	86	94
1910–1911	98	100			79		124	104	100	101
1911–1912	92	95	62		78		111	105	94	91
1912–1913	72	67			76		62	66	63	68
1913–1914	122	123	105		85		102	109	99	106
1914–1915	180	163	141		137		150	145	115	147
Number of years observed	29	40	30	27	27	25	65	27	25	
Average annual precipitation, in inches, as observed	29.02	15.51	19.74	17.27	40.78	14.01	9.69	10.88	20.33	

[a] Number of stations in Tables 17 and 64.

The method of estimating the average annual precipitation at stations for which only short-period records are available is essentially that used by Hann and has been adopted as more or less standard by European and American meteorologists.[1] The procedure may be indicated algebraically as follows:

Let m = period of years represented by short-time record at precipitation station A.

a = average annual precipitation at A as observed for period m.

N = computed average annual precipitation at A for long period of years (normal).

Sn = average annual precipitation as observed at one of the nine San Diego County control stations near A (normal).

Sm = average annual precipitation as observed at same control station for period m.

K = ratio Sm/Sn, or correction factor.

Then, according to the method used by Hann, $Sm/Sn = a/N$ or $K = a/N$, from which it follows that $N = a/K$.

The value of K for any group of years can be obtained from the last column of Table 18 by merely averaging the precipitation indices for the years. The computation of the estimated normal precipitation at any short-period station is thus simplified to a substitution in the equation $N = a/K$ of values for a and K. These values have been computed for all precipitation stations listed in Table 17 and are tabulated in the next to the last column of that table. The computed normal precipitation for all stations of less than 25 years' record is entered in the last column of Table 17. These quantities are comparable with each other and with the averages at the nine control stations, and they form the basis for the study of the geographical distribution of average annual precipitation.

DISTRIBUTION OF PRECIPITATION BY TIME.

The distribution of precipitation by days (storms), by months, and by years affects materially the ground-water supply in San Diego County. Records of daily precipitation are essential to a detailed study of fluctuations of the water table due to direct rainfall and flood run-off. Records of monthly precipitation are useful in studying precipitation as a direct source of ground water and its effect on monthly fluctuations of the water table. Records of annual precipitation are necessary in studying variations in annual run-off and the more general fluctuations of the water table.

The distribution of precipitation by storms in San Diego County is well shown by the graphic record of daily precipitation at six typical

[1] On working up precipitation observations; translated from Dr. Hugh Meyer's "Guide to the working up of meteorological observations for the benefit of climatology": U. S. Weather Bureau Monthly Weather Review, April, 1917.

stations for the season 1914–15 (Pl. XVI). The rainfall for each day is shown by an inclined line crossing the space represented by a day and reaching a vertical height representing the precipitation for the day, according to the scale at the left of the diagram. For a storm that lasts several days, continuous lines are drawn, one above the other, the end of the line representing the aggregate precipitation for the storm. It should be noted that few single storms last more than four days, and that during the rainy season they occur at intervals

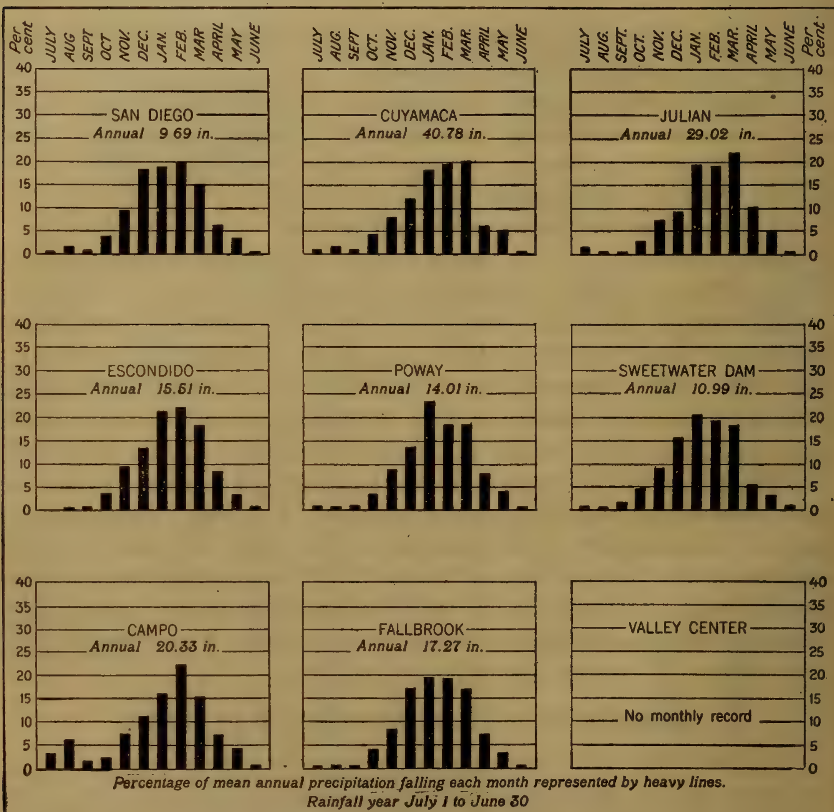
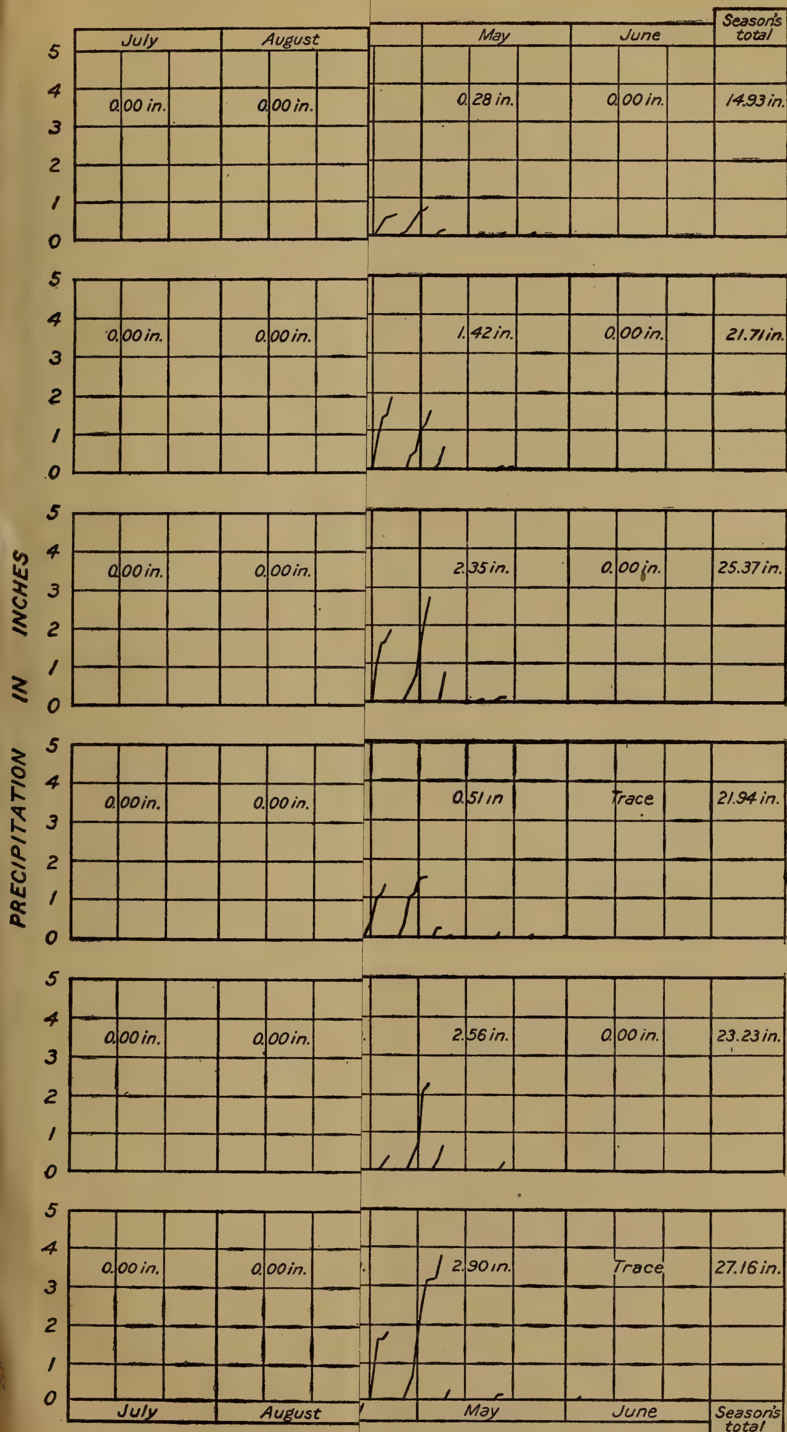


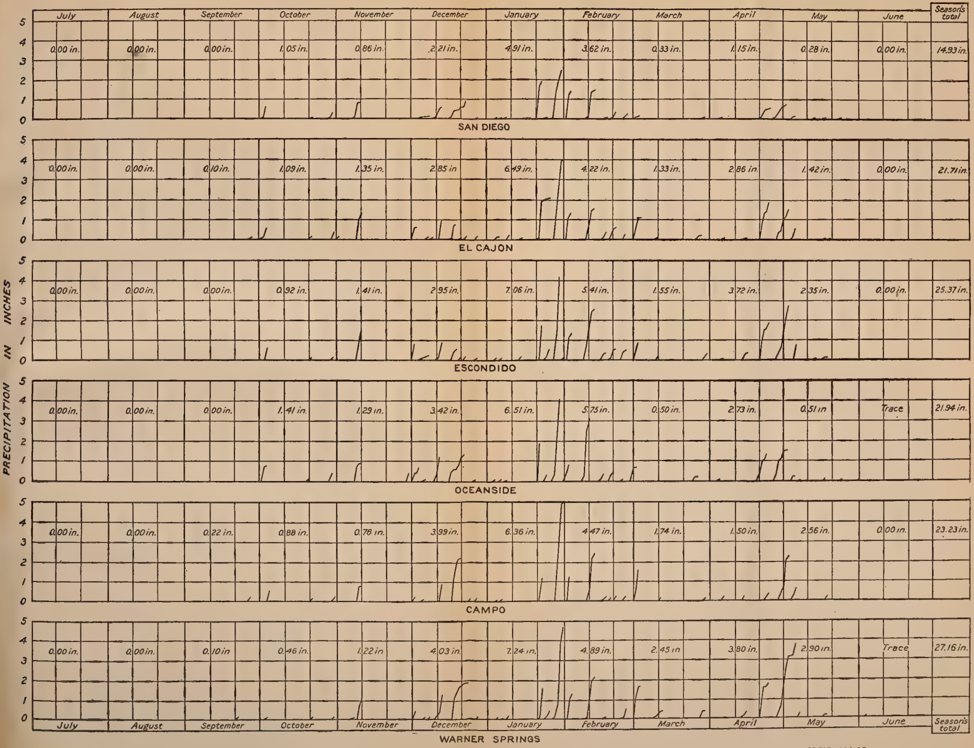
FIGURE 5.—Monthly distribution of precipitation in San Diego County.

of 1 to 20 days. The frequency was greater than usual in 1914–15, which was a very wet year (Table 18). The dry season is without rainfall.

The monthly distribution is well shown by figure 5, on which the percentage of the average annual precipitation occurring each month at each of the nine control stations is represented. From these diagrams it appears that 70 per cent of the precipitation occurs from December to March, inclusive, and practically none from June to September. At mountain stations, however, such as Campo and



DIAGRAMS GO COUNTY IN 1914-15.

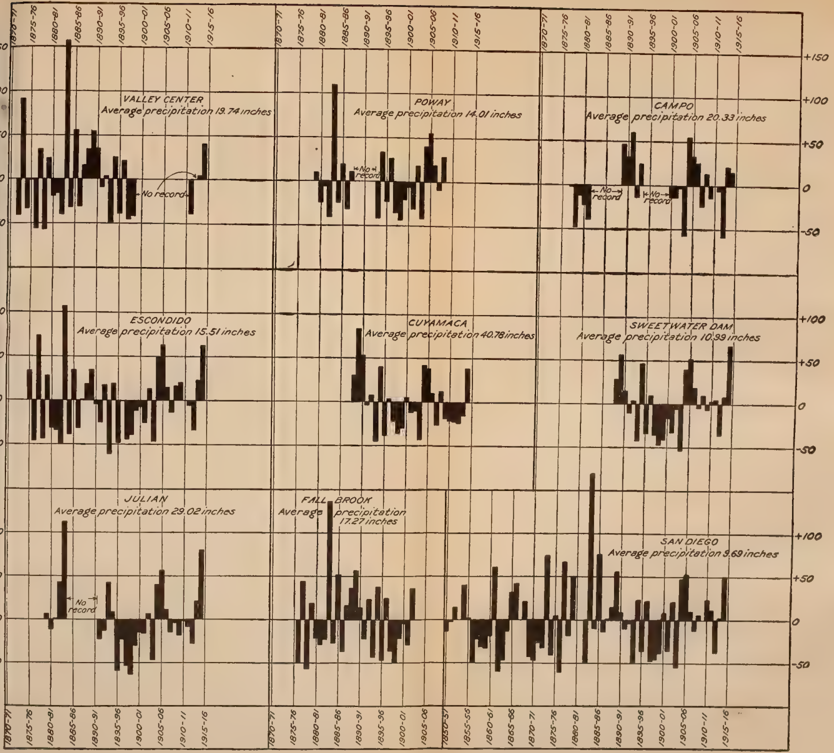


DIAGRAMS SHOWING DURATION, INTENSITY, AND TOTAL PRECIPITATION OF STORMS AT TYPICAL STATIONS IN SAN DIEGO COUNTY IN 1914-15.

PERCENT ABOVE OR BELOW AVERAGE

PERCENT ABOVE OR BELOW AVERAGE

PERCENT ABOVE OR BELOW AVERAGE



DIAGRAMS SHOWING VARIATION IN ANNUAL PRECIPITATION AT NINE CONTROL STATIONS IN SAN DIEGO COUNTY.

Cuyamaca, local thunderstorms occur during the summer. Rainfall during October, November, April, and May has little direct effect on run-off or ground water.

Variations in annual precipitation are shown diagrammatically by Plate XVII for the nine control stations in San Diego County for the full period of record at each. The departure from the average is expressed as a percentage and is plotted up or down from a zero line representing the average. The most striking feature of the diagram is the wide variation from year to year and the tendency for wet and particularly for dry years to occur in groups or cycles. The maximum range of variation is from about twice to one-half the average. The longest consecutive cycle of dry years comprises about six years, and the longest consecutive cycle of wet years comprises three years. Precipitation in the year beginning July 1, 1914, and ending June 30, 1915, during which most of the field observations were made in connection with this report, was 47 per cent above the average.

GEOGRAPHIC DISTRIBUTION OF PRECIPITATION.

A knowledge of the geographic or horizontal distribution of precipitation is important in connection with the study of run-off from specific areas and of absorption of water by porous alluvium and residium. The ground-water supply is annually replenished by absorption from both direct rainfall and run-off. The amount of precipitation over any given area, therefore, has a direct effect on the ground-water supply of that area and of lower areas through which the run-off passes.

The horizontal distribution of precipitation in San Diego County is largely controlled by the topography. The situation is typical of that in regions characterized by a range of mountains paralleling a coast toward which cyclonic storms move from the bordering ocean. The slope leading up to the crest of the range elevates the whole body of moisture-laden air during its movement inland and thus induces more rapid condensation of moisture as a result of the cooling which accompanies gaseous expansion. As soon as the air reaches the crest and begins movement down the opposite slope condensation of moisture stops as a result of compression and increasing temperature of the air. These conditions are found on all humid continental borders throughout the world, although in many of them the depth of annual precipitation exceeds that in San Diego County. On the west slope of the Sierra Nevada in California[1] there is a zone of maximum precipitation between altitudes 3,500 and 5,500 feet above

[1] Henry, A. H., Average annual precipitation in the United States for the period 1871 to 1901: U. S. Weather Bur. Monthly Weather Review, vol. 30, p. 208, 1902.
Lee, C. H., Water resources of a part of Owens Valley, Calif.: U. S. Geol. Survey Water-Supply Paper 294, 1912.

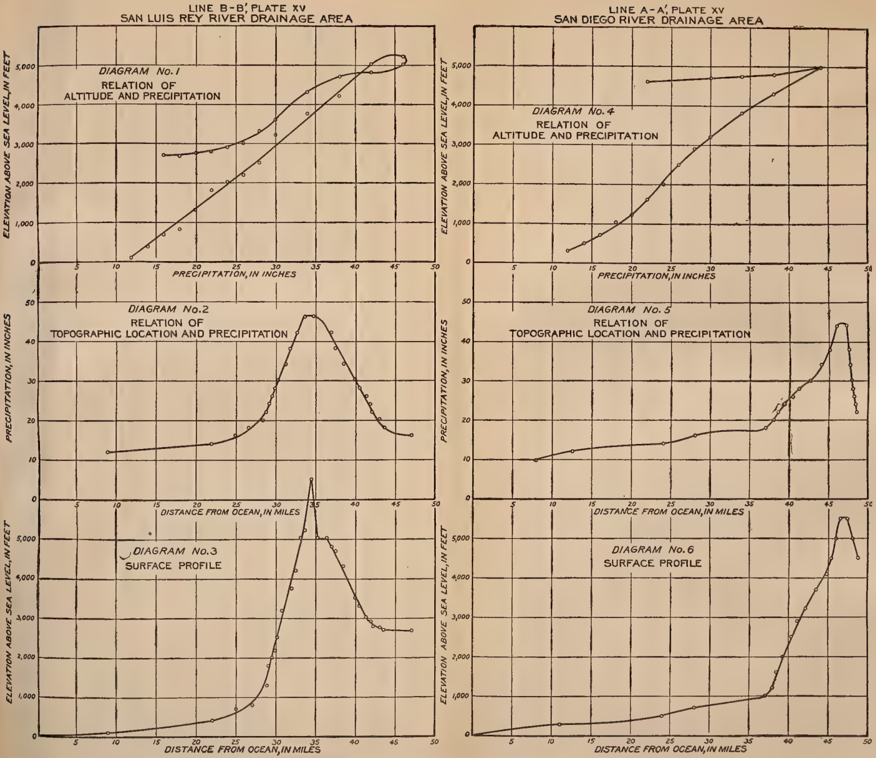
sea level, the amounts decreasing above the higher level. In San Diego County, however, the highest peaks barely reach 6,000 feet above sea level, so that the maximum precipitation occurs at or near the crest of the first range from the west.

The great number of precipitation stations in San Diego County makes it feasible to study the influence of topography on precipitation in greater detail than is ordinarily possible. The results of this study are embodied in the map of the Pacific slope drainage areas of the county (Pl. XV), which shows lines of equal average annual precipitation with 2-inch intervals. This map shows that the average annual precipitation increases regularly from about 10 inches at the coast to about 45 inches at the crest of the first range, and that the amount of precipitation in any locality follows very closely the local slopes and elevations.

The general relations of precipitation, elevation, and slope are well shown by the diagrams in Plate XVIII, which were prepared from Plate XV along vertical sections represented by lines *A–A* and *B–B*. The first pair of diagrams shows the relation of average annual precipitation and altitude and indicates a more or less uniform rate of increase from the coast to the highest elevation of the range of about 0.6 inch in depth per 100 feet increase in elevation. East of the crest precipitation decreases rapidly. The second and third pairs of diagrams show very clearly the close relation between precipitation and slope.

The method of indicating on the plate the position of lines of equal annual precipitation was as follows: First a diagram was prepared (fig. 6) on which the corrected average annual precipitation at each station (Table 17) was plotted against the elevation of the station (Table 17). Examination of this diagram showed that for all stations west of the first mountain crest precipitation and elevation maintained a more or less consistent relation which could be approximately expressed by a straight line with a slope of 0.56 inch of rain per 100 feet of elevation. Variations from this line were considerable but exceeded 20 per cent at only four stations.

The first step in plotting a line of equal precipitation for a locality was to select pairs of stations which were not separated by pronounced ridges and at which precipitation was greater and less, respectively, than that desired. Each pair of points was then picked out on figure 6 and connected by a straight line. The average of the elevations at which these lines cross the given precipitation line was then plotted on the map. By covering the whole area in this manner numerous points were plotted for each line of equal precipitation, and these points were then connected, the connecting line following the general course of the proper surface contours between the points of control. For areas east of the crest of the culminating range this



DIAGRAMS SHOWING INFLUENCE OF TOPOGRAPHY, LOCATION, AND ALTITUDE ON PRECIPITATION IN SAN DIEGO COUNTY.

method was combined with straight interpolation. In studying the area west of the crest it was found that the same precipitation occurs at progressively higher elevations from north to south across the county. Thus, whereas an average annual precipitation of 20

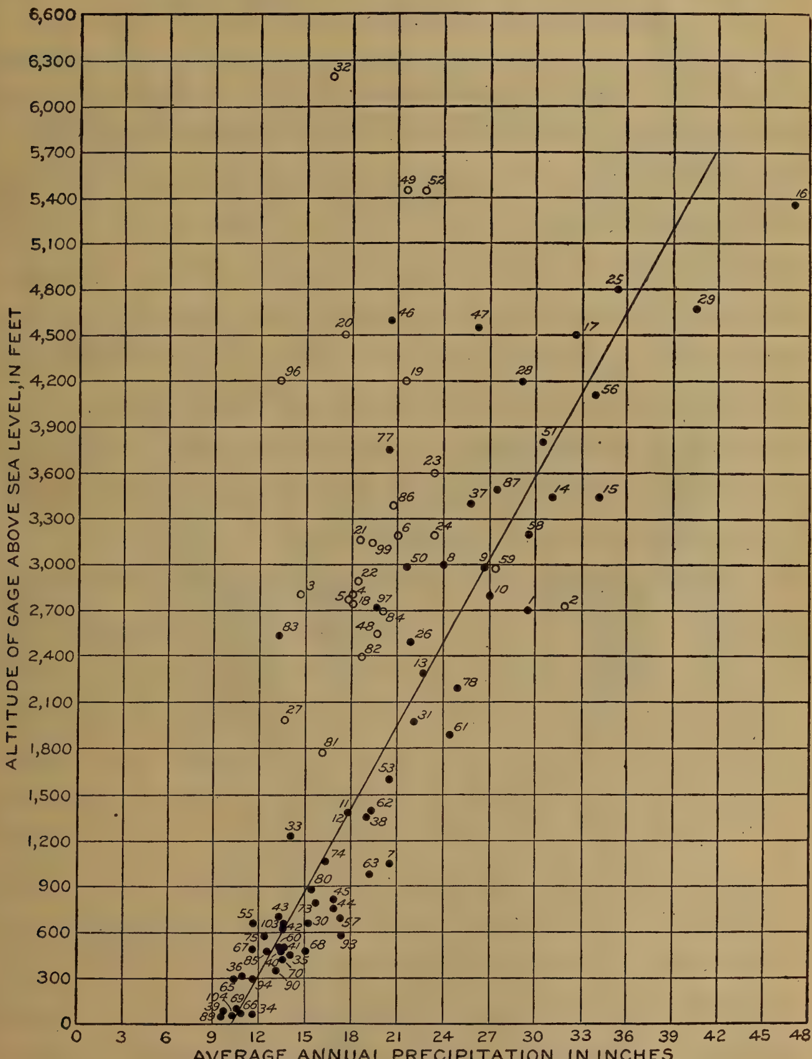


FIGURE 6.—Relation of altitude to long-term average annual precipitation for all stations in San Diego County.

inches occurs at an elevation of about 1,500 feet at the north county line, at the international boundary the line of 20-inch average annual precipitation rises to about 2,500 feet. Similar differences in elevation occur in all contours of precipitation exceeding 16 inches. This fact explains much of the variation from the average straight line as noted in figure 6. Although the lines of equal annual precipitation as shown in Plate XV are doubtless inaccurate in many details, it is believed that the map is sufficiently reliable to be useful to engineers in connection with investigations of water-supply.

RELATION OF RUN-OFF TO PRECIPITATION.

Two relations of run-off to precipitation are significant in connection with the subject of ground-water supply as discussed in this report—variation in regard to time and percentage of precipitation appearing as run-off.

Seasonal variations in run-off and precipitation are readily compared by means of figure 7, on which the average annual variation of precipitation at the nine control stations has been plotted together with the annual variation of flow of Sweetwater River at Sweetwater dam, San Diego River at diverting dam, and San Luis Rey River near Pala. (See also Table 20, p. 95.) The variation in flow of San Gabriel River near Azusa, in Los Angeles County, for which a 19-year record is available, is also shown. These diagrams show that although run-off follows in general the same variations as precipitation, it is subject to wider seasonal fluctuations than precipitation, the maxium run-off being from 2½ to 3 times the average run-off and the minimum being almost zero.

The relation between daily run-off and precipitation may be seen by comparing Plates XVI (p. 86) and XIX (in pocket). An important difference at once apparent is that, although precipitation began late in September or early in October, 1914, the first flood run-off occurred January 29, 1915, by which date about 7 inches of the season's precipitation had fallen. After this date every storm in which the precipitation was an inch or more yielded large run-off. Even smaller storms, such as that of March 27–29, when about 0.3 inch of rain fell, affected stream flow. The failure of precipitation to produce run-off early in the season was due to lack of moisture in the ground—a lack that existed both in the alluvium of the valleys and in the thin but widespread unconsolidated surface materials of other parts of the drainage areas. When the surface materials had absorbed a certain quantity of moisture they became saturated more easily, and the precipitated water then began in part to flow off the surface. Run-off continued, in diminishing quantity, after the last storm in May for two or three months, and then the streams dried up. The source of this flow was ground water, which continued to percolate to the stream channels in diminishing quantities until most of that above levels of the stream channels had drained out.

A comparison of daily run-off and precipitation in seasons prior to to that of 1914–15 shows that the amount of precipitation before the date of the first flood run-off varies widely and depends largely on

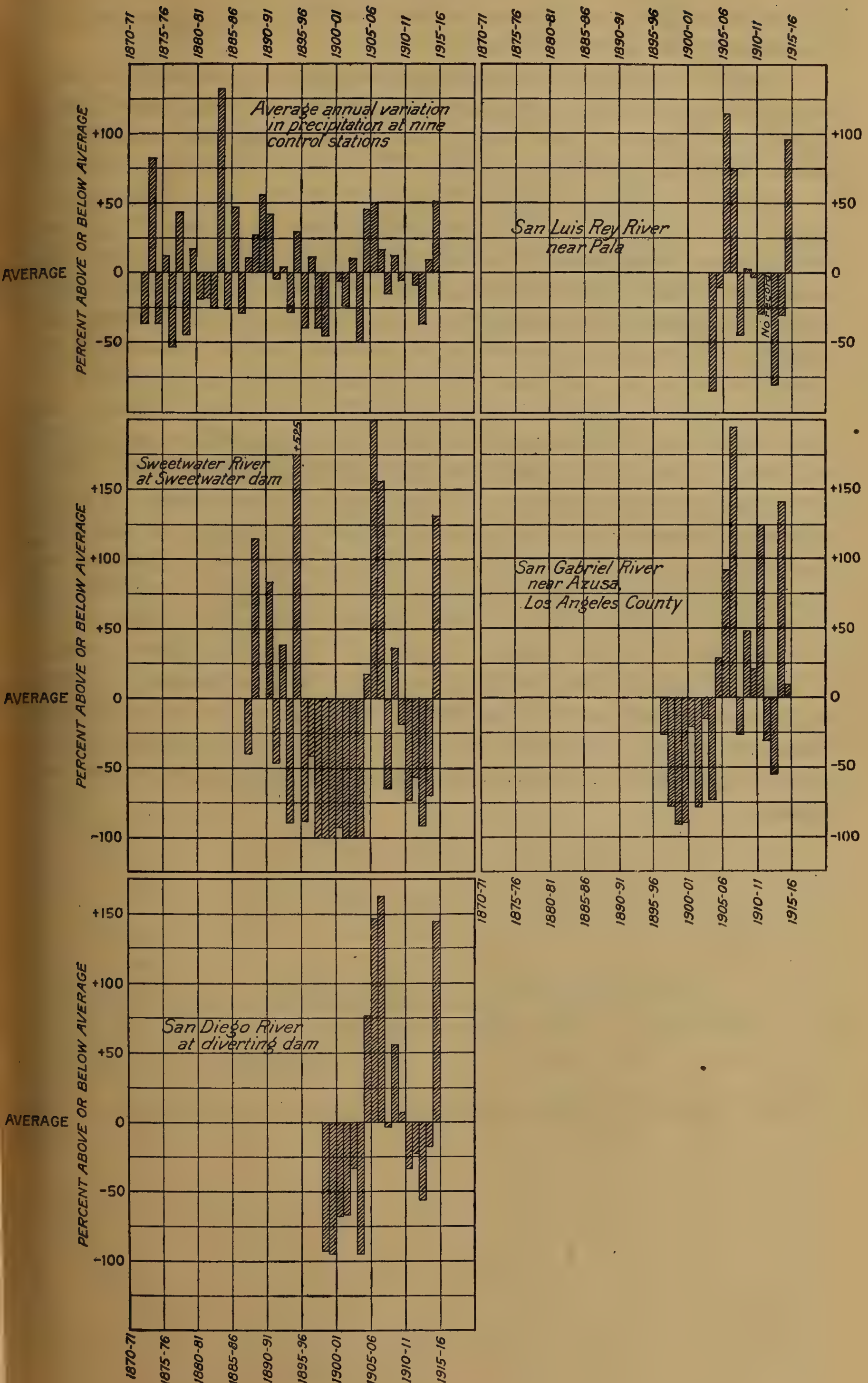


FIGURE 7.—Variation in annual discharge of streams in San Diego County.

the degree of the precipitation in the preceding year or years and on the intensity of the early rains.

In order to analyze the conditions Table 19 was prepared for four typical gaging stations—San Luis Rey River near Pala, Santa Ysabel River near Ramona, San Diego River at diverting dam, and Sweetwater River at Sweetwater dam. This table covers the period of record at each station and shows the precipitation index for each year, beginning July 1 (Table 18), the date of first flood run-off, the approximate average depth of precipitation on the drainage area for each year, the per cent of precipitation prior to the date of first flood run-off, and the average depth of precipitation on the drainage area prior to the date of first flood run-off separated with respect to the character of the precipitation in the previous year, into three groups, determined for (1) dry years, or years following those with precipitation index less than 90 per cent or the second year following a year with an index of 70 per cent or less; (2) average years, or years following those with a precipitation index of 90 to 110 per cent; (3) wet years, or years following those with a precipitation index exceeding 110 per cent, except the second year after one with an index of 70 per cent or less. The purpose of the segregation into groups was to show the hold-over effect, if any, of a dry or wet year on the quantity of moisture stored in the earth. Inspection of the last three columns of Table 19 shows a similarity in the depths of precipitation required to produce run-off under these three conditions and thus an evident hold-over effect. The effect of a year in which precipitation is less than 70 per cent of the average appears to be noticeable for two years.

TABLE 19.—*Precipitation required to produce flood run-off in typical streams of San Diego County.*

San Luis Rey River near Pala.[a]

[Drainage area, 322 square miles.]

Year (July 1 to June 30).	Precipitation index (percentage of average for nine control stations; table 18).	Date of first flood run-off at gaging station.	Average precipitation on drainage area.	Per cent of annual precipitation prior to date of first flood run-off, as obtained from precipitation stations on drainage area.	Average depth of precipitation required to produce run-off following— A year with index of 89 per cent or less, or the second year following one with index of 70 per cent or less.	A year with index of 90 per cent to 110 per cent.	A year with index of 111 per cent or more except second year after one with index years of 70 per cent or less.
			Inches.	*Per cent.*	*Inches.*	*Inches.*	*Inches.*
1902–03	110						
1903–04	51	Mar. 23, 1904	12.8	48.7		6.2	
1904–05	145	Jan. 9, 1905	36.4	12.1	4.4		
1905–06	150	Jan. 19, 1905	37.7	21.4	8.1		
1906–07	116	Nov. 23, 1906	29.2	6.8			2.0
1907–08	85	Oct. 16, 1907	21.3	5.3			1.1
1908–09	112	Dec. 3, 1908	28.1	23.6	6.6		
1909–10	94	Nov. 11, 1909	23.6	4.5			1.1
1910–11	101	Jan. 10, 1911	25.4	16.2		4.1	
1911–12	91	Dec. 29, 1911	22.8	8.7		2.0	
1912–13	68	Jan. 15, 1913	17.1	28.2		4.8	
1913–14	106	Jan. 16, 1913	26.6	23.0	6.1		
1914–15	147	Jan. 22, 1915	36.9	23.1	8.5		
Average			(b)		6.7	4.3	1.4
Santa Ysabel River near Ramona.[c]							
1904–05	145						
1905–06	150	Jan. 19, 1906	39.2	22.4	8.8		
1906–07	116	Dec. 7, 1906	30.3	13.1			4.0
1907–08	85	Dec. 7, 1907	22.2	20.1			4.5
1908–09	112	Jan. 9, 1909	29.2	19.2	5.6		
1909–10	94	Nov. 11, 1909	24.5	11.0			2.7
1910–11	101	Jan. 9, 1911	26.4	17.8		4.7	
1911–12	91	Mar. 2, 1912	23.8	19.7		4.7	
1912–13	68	Jan. 16, 1913	18.3	28.9		5.3	
1913–14	106	Jan. 19, 1914	28.5	25.1	7.2		
1914–15	147	Jan. 22, 1915	39.5	21.8	8.6		
Average			(d)		7.6	4.9	3.7

a Date of first flood run-off at gaging station determined from records of U. S. Geological Survey and Volcan Land & Water Co.; flood flow considered as flow in excess of 14 second-feet.
b Average for these areas, derived from Pl. XV, is 24.3 inches.
c Date of first flood run-off at gaging station determined from records of U. S. Geological Survey. Flood flow considered as flow in excess of 12 second-feet.
d Average depth of seasonal precipitation from Pl. XV is 26.1 inches for area of 128 square miles, and 26.9 inches for area of 110 square miles.

NOTE.—Station on Santa Ysabel Creek near Escondido, with drainage area of 128 square miles from Dec. 17, 1905, to June 30, 1912. Station moved to Pamo, with drainage area of 110 square miles on July 1, 1912.

TABLE 19.—*Precipitation required to produce flood run-off in typical streams of San Diego County*—Continued.

San Diego River at diverting dam.[a]

[Drainage area, 90 square miles.]

Year (July 1 to June 30).	Precipitation index (percentage of average for nine control stations; table 18.)	Date of first flood run-off at gaging station.	Average precipitation on drainage area.	Per cent of annual precipitation prior to date of first flood run-off, as obtained from precipitation stations on drainage area.	Average depth of precipitation required to produce run-off following— A year with index of 89 per cent or less, or the second year following one with index of 70 per cent or less.	A year with index of 90 per cent to 110 per cent.	A year with index of 111 per cent or more except second year after one with index years of 70 per cent or less.
			Inches.	*Per cent.*	*Inches.*	*Inches.*	*Inches.*
1897–98	60						
1898–99	54	Feb. 1, 1899	15.4	45.0	6.8		
1899–1900	73	Jan. 2, 1900	20.8	38.0	7.9		
1900–1901	94	Jan. 5, 1901	26.8	29.1	7.8		
1901–2	76	Jan. 24, 1902	21.7	26.4		5.7	
1902–3	110	Jan. 26, 1903	31.4	37.0	11.6		
1903–4	51	Mar. 17, 1904	14.5	44.0		6.4	
1904–5	145	Feb. 1, 1905	41.3	22.1	9.2		
1905–6	150	Nov. 25, 1905	42.8	17.0	7.3		
1906–7	116	Dec. 1, 1906	33.1	15.0			5.0
1907–8	85	Oct. 13, 1907	24.2	5.0			1.2
1908–9	112	Jan. 9, 1909	32.0	22.0	7.1		
1909–10	94	Nov. 13, 1909	26.8	12.0			3.2
1910–11	101	Jan. 8, 1911	28.8	19.5		5.6	
1911–12	91	Feb. 28, 1912	25.9	16.0		4.2	
1912–13	68	Jan. 8, 1913	19.4	24.7		4.8	
1913–14	106	Dec. 22, 1914	30.2	21.3	6.4		
1914–15	147	Jan. 29, 1915	41.8	29.9	12.5		
Average			(b)		8.5	5.3	3.1

Sweetwater River at Sweetwater dam.[c]

[Drainage area, 181 square miles.]

1886–87	71						
1887–88	110		21.9				
1888–89	127	Dec. 23, 1888	25.3	23.2		5.8	
1889–90	155	Dec. 23, 1889	30.9	21.7			6.7
1890–91	142	Dec. 4, 1890	28.3	15.2			4.3
1891–92	95	Jan. 25, 1892	18.9	32.2			6.1
1892–93	103	Mar. 4, 1893	20.5	48.3		9.9	
1893–94	71	Feb. 6, 1894	14.1	60.5		8.6	
1894–95	129	Jan. 14, 1895	25.7	46.8	12.1		
1895–96	60	Jan. 26, 1896	12.0	52.5			6.3
1896–97	111	Feb. 18, 1897	22.1	66.4	14.7		
1897–98	60	No run-off	12.0	100.0	12.0		
1898–99	54	Jan. 10, 1899	10.8	27.5	3.0		
1899–1900	73	No run-off	14.6	100.0	14.6		
1900–1901	94	Feb. 5, 1901	18.8	52.0	9.8		
1901–2	76	No run-off	15.2	100.0	15.2		
1902–3	110	Mar. 25, 1903	21.9	75.0	16.4		
1903–4	51	No run-off	10.2	100.0		10.2	
1904–5	145	Feb. 3, 1905	28.9	38.8	11.2		
1905–6	150	Feb. 10, 1906	29.9	37.2	11.1		
1906–7	116	Dec. 27, 1906	23.1	28.2			6.5
1907–8	85	Jan. 22, 1908	17.0	29.8			5.1
1908–9	112	Jan. 22, 1909	22.3	40.4	9.0		
1909–10	94	Dec. 5, 1909	18.8	27.3			5.1
1910–11	101	Feb. 1, 1911	20.1	45.9		9.2	
1911–12	91	Mar. 3, 1912	18.2	25.1		4.6	
1912–13	68	Jan. 20, 1913	13.5	38.2		5.2	
1913–14	106	Jan. 26, 1914	21.1	42.3	9.0		
1914–15	147	Jan. 29, 1915	29.3	31.3	9.2	9.2	
Average			(d)		11.3	7.8	5.7

[a] Date of first flood run-off at gaging station determined from records of Cuyamaca Water Co. Flood flow considered as flow in excess of 12 second-feet.
[b] Average depth of seasonal precipitation from Pl. XV is 28.5 inches.
[c] Dates of first flood run-off at gaging station obtained from charts showing water stage at Sweetwater reservoir, furnished by Sweetwater Water Co., J. F. Covert, engineer.
[d] Average depth of seasonal precipitation from Pl. XV is 19.9 inches.

TABLE 20.—*Run-off from and precipitation on drainage basins of streams in San Diego County.*

San Luis Rey River near Pala.

[Drainage area, 322 square miles.]

Year (July 1 to June 30).	Run-off.				Average precipitation on drainage area (inches).	Run-off in per cent of precipitation.
	Total in acre-feet.*a*	Acre-feet per square mile.	Depth on drainage area (inches).	Per cent of 12-year average.		
1903–4	7,526	23.4	0.44	16	12.4	3.5
1904–5	45,303	140.7	2.63	94	35.2	7.5
1905–6	108,224	336.0	6.30	224	36.5	17.3
1906–7	86,753	269.4	5.05	180	28.2	17.9
1907–8	28,323	88.0	1.65	59	20.6	8.0
1908–9	52,192	162.1	3.04	108	27.2	11.2
1909–10	50,132	155.7	2.92	104	22.8	12.8
1910–11	36,279	112.7	2.11	75	24.6	8.6
1911–12	19,003	59.0	1.11	39	22.1	5.0
1912–13	9,350	29.0	0.54	19	16.5	3.3
1913–14	35,874	111.4	2.09	74	25.8	8.1
1914–15	100,011	310.6	5.80	207	35.7	16.2
12-year average	48,248	149.9	2.81	100	25.6	10.0

Santa Ysabel Creek near Ramona.

1905–6	*b c* 60,471	....	....	....	39.2	....
1906–7	*b* 35,756	279.0	5.23	131	30.3	17.3
1907–8	*b* 12,389	96.8	1.82	45	22.2	8.2
1908–9	*b* 45,765	357.0	6.70	168	29.2	22.9
1909–10	*b* 35,191	274.5	5.16	129	24.5	21.0
1910–11	*b c* 2,927	....	....	....	26.4	....
1911–12	*b* 15,352	119.9	2.25	56	23.8	9.5
1912–13	*d* 5,965	54.2	1.02	22	18.3	5.6
1913–14	*d* 19,814	180.0	3.37	73	28.5	11.8
1914–15	*d* 48,069	437.0	8.20	176	39.5	20.7
8-year average	27,288	224.8	4.22	100	*e* 28.2	14.6

San Diego River at diverting dam.

[Drainage area, 90 square miles.*f*]

1898–99	909	10	0.19	7	15.4	1.2
1899–1900	609	7	.13	5	20.8	.6
1900–1901	4,023	45	.84	32	26.8	3.1
1901–2	4,122	46	.86	33	21.7	4.0
1902–3	8,375	93	1.74	67	31.4	5.5
1903–4	638	7	.13	5	14.5	.9
1904–5	22,036	248	4.65	176	41.3	11.3
1905–6	30,837	343	6.43	246	42.8	15.0
1906–7	32,816	365	6.85	262	33.1	20.7
1907–8	12,091	134	2.51	96	24.2	10.4
1908–9	19,455	216	4.05	155	32.0	12.6
1909–10	13,461	149	2.79	107	26.8	10.4
1910–11	8,345	93	1.74	66	28.8	6.0
1911–12	9,620	107	2.01	77	25.9	7.8
1912–13	5,378	59	1.11	43	19.4	5.7
1913–14	10,261	114	2.14	82	30.2	7.1
1914–15	30,593	340	6.38	244	41.8	15.3
17-year average	*g* 12,563	139	2.62	100	*h* 27.8	8.1

a For authority see Table 23.
b Data compiled from U. S. Geol. Survey Water Supply Paper 300.
c Part of season only.
d Data furnished by district engineer, U. S. Geological Survey.
e Average depth of seasonal precipitation from Pl. XV is 26.1 inches for area of 128 square miles and 26.9 inches for area of 110 square miles.
f Exclusive of drainage area of 12 square miles tributary to Cuyamaca reservoir.
g Authority for run-off, Cuyamaca Water Co., W. S. Post, engineer.
h Average depth of seasonal precipitation from Pl. I is 28.5 inches.

NOTE.—Station on Santa Ysabel Creek near Escondido, drainage area of 128 square miles, from Dec. 17, 1905, to June 30, 1912. Station moved to Pamo, drainage area of 110 square miles, on July 1, 1912.

TABLE 20.—*Run-off from and precipitation on drainage basins of streams in San Diego County*—Continued.

Sweetwater River at Sweetwater dam.

[Drainage area, 181 square miles.]

Year (July 1 to June 30).	Run-off.				Average precipitation on drainage area (inches).	Run-off in per cent of precipitation.
	Total in acre-feet.	Acre-feet per square mile.	Depth on drainage area (inches).	Per cent of 12-year average.		
1887–88	7,048	38.9	0.73	60.0	21.9	3.3
1888–89	25,253	139.5	2.61	214.9	25.3	10.3
1889–90	20,532	113.2	2.12	174.7	30.9	6.9
1890–91	21,565	119.0	2.23	183.6	28.3	7.9
1891–92	6,198	34.2	.64	52.7	18.9	3.4
1892–93	16,261	90.0	1.69	138.4	20.5	8.2
1893–94	1,338	7.4	.14	11.4	14.1	1.0
1894–95	73,412	405.0	7.60	624.7	25.7	29.6
1895–96	1,321	7.3	.14	11.2	12.0	1.2
1896–97	6,891	38.1	.72	58.6	22.1	3.3
1897–98	4	.0	.00	.0	12.0	.0
1898–99	245	1.4	.03	2.1	10.8	.3
1899–1900	0	.0	.00	.0	14.6	.0
1900–1901	828	4.6	.09	7.0	18.8	.5
1901–2	0	.0	.00	.0	15.2	.0
1902–3	0	.0	.00	.0	21.9	.0
1903–4	0	.0	.00	.0	10.2	.0
1904–5	13,760	76.2	1.43	117.0	28.9	5.0
1905–6	35,000	193.3	3.63	297.8	29.9	12.1
1906–7	30,000	165.8	3.11	255.3	23.1	13.5
1907–8	4,140	22.8	.43	35.2	17.0	2.5
1908–9	16,007	88.5	1.66	136.2	22.3	7.4
1909–10	9,619	53.2	1.00	81.8	18.8	5.3
1910–11	3,160	17.5	.33	26.9	20.1	1.6
1911–12	5,017	27.7	.52	42.7	18.2	2.9
1912–13	915	5.0	.09	7.8	13.5	.7
1913–14	3,525	19.5	.37	30.0	21.1	1.7
1914–15	27,026	149.5	2.80	30.0	29.3	9.6
28-year average	[a] 11,752	64.9	1.22	100.0	[b] 20.2	4.9

San Gabriel River near Azusa.

[Drainage area, 222 square miles.]

Season.	Run-off.			
	Total acre-feet.[c]	Acre-feet per square mile.	Depth on drainage area (inches).	Per cent of average.
1895–96	[d] 28,661	140.4	2.63	....
1896–97	88,122	396.9	7.45	74
1897–98	26,628	120.0	2.25	22
1898–99	10,490	47.2	.89	9
1899–1900	12,002	54.1	1.01	10
1900–1901	92,976	418.8	7.85	78
1901–2	26,518	119.4	2.24	22
1902–3	101,623	457.7	8.59	85
1903–4	32,295	145.4	2.73	27
1904–5	153,048	689.4	12.92	128
1905–6	228,470	1,029.1	19.32	192
1906–7	349,800	1,575.7	29.55	[illegible]
1907–8	88,280	397.7	7.45	[illegible]
1908–9	176,460	794.9	14.90	14[illegible]
1909–10	144,040	648.8	12.17	121
1910–11	266,780	1,201.7	22.53	224
1911–12	82,400	371.1	6.95	69
1912–13	53,141	239.4	4.49	45
1913–14	287,172	1,293.5	24.25	241
1914–15	129,462	583.1	10.92	109
20-year average	[c] 119,044	536.2	10.05	100

[a] Authority for run-off, Sweetwater Water Co., John F. Covert, engineer.
[b] Average depth of seasonal precipitation from Pl. I is 19.9 inches.
[c] Authorities: U. S. Geol. Survey Water-Supply Paper 300, August 8, 1895, to June 30, 1912; district engineer, U. S. Geol. Survey, July 1, 1912, to June 30, 1915.
[d] Part of year only.

The last three columns of Table 19 are summarized in the following table:

TABLE 21.—*Average depth of precipitation, in inches, required to produce run-off.*

Stream.	First year after year with less than 90 per cent of average rainfall or second year after one with 70 per cent or less.	Following an average year (90 to 110 per cent of average rainfall).	Following a year with more than 110 per cent of average rainfall except second year after one with 70 per cent or less.
San Luis Rey River near Pala	6.7	4.3	1.4
Santa Ysabel Creek near Ramona	7.6	4.9	3.7
San Diego River at diverting dam	8.5	5.3	3.1
Sweetwater River at Sweetwater dam	11.3	7.8	5.7

For the three mountain drainage basins that do not include any major river valley (the first three in Table 21) the average depth of precipitation required to produce run-off is 7.5 inches after a dry year, 4.8 inches after an average year, and 2.7 inches after a wet year. For Sweetwater River, however, which traverses a long alluvium-filled valley before it reaches the point of measurement, the depths are 11.3, 7.8, and 5.7 inches respectively. The depths for Sweetwater Valley are probably greater than those of other major river valleys at corresponding points of measurement. In applying these determinations it is to be remembered that they are averages for whole drainage areas and that they do not necessarily represent the amount of precipitation at any single station.

The per cent of precipitation appearing as run-off in the four drainage basins for which the above study was made is given in Table 20. Wherever possible the total run-off was obtained from records of stream-gaging stations of the United States Geological Survey. For the San Luis Rey near Pala the quantity diverted by the Escondido Mutual Water Co. (Table 22) was added to the measured flow to determine the total run-off (Table 23). The record of run-off of Sweetwater River was furnished by the Sweetwater Water Co.

TABLE 22.—*Monthly discharge, in acre-feet, of Escondido Mutual Water Co.'s canal at heading near Nellie, for years ending June 30, 1904–1915.*[a]

Month.	1904–5	1905–6	1906–7	1907–8	1908–9	1909–10	1910–11	1911–12	1912–13	1913–14	1914–15
J[illegible]	0	0	0	65	0	101	32	0	0	0	0
[illegible]ust	0	0	0	0	0	0	22	0	0	0	0
[illegible]eptember	0	0	0	0	0	0	0	0	0	0	0
October	0	0	128	0	0	0	0	0	0	0	0
November	0	0	64	88	77	0	0	0	0	0	0
December	0	0	1,055	588	414	0	166	0	182	240	541
January	0	448	153	612	544	502	478	494	222	676	896
February	0	1,192	0	299	397	797	543	305	530	924	1,773
March	1,138	282	0	432	852	754	1,161	487	1,294	1,951	1,194
April	1,621	0	0	714	798	392	1,151	458	716	891	918
May	676	0	278	622	627	395	469	1,332	16	1,020	412
June	0	0	504	53	363	105	0	12	0	230	793
Total	3,435	1,922	2,182	3,473	4,072	3,046	4,022	3,088	2,960	5,932	6,527

[a] Compiled from records in U. S. Geol. Survey Water-Supply Paper 411, and furnished by H. D. McGlashan, district engineer.

TABLE 23.—*Annual discharge of San Luis Rey River near Pala, including Escondido Mutual Water Co.'s canal, for years ending June 30, 1904–1915.*

[Drainage area, 322 square miles.]

Year.	Observed run-off at gaging station near Pala (acre-feet).	Discharge of canal at heading (acre-feet).	Total discharge of San Luis Rey River above gaging station near Pala.	
			Acre-feet.	Acre-feet per square mile.
1903–4	[a] 7,526	No record.		
1904–5	[b] 41,868	3,435	45,303	140.7
1905–6	[b] 106,302	1,922	108,224	336.0
1906–7	[b] 84,571	2,182	86,753	269.4
1907–8	[b] 24,850	3,473	28,323	88.0
1908–9	[b] 48,120	4,072	52,192	162.1
1909–10	[b] 47,086	3,046	50,132	155.7
1910–11	[c] 32,257	4,022	36,279	112.7
1911–12	[d] 15,915	3,088	19,003	59.0
1912–13	[e] 6,390	2,960	9,350	29.0
1913–14	[f] 29,942	5,932	35,874	111.4
1914–15	[f] 93,484	6,527	100,011	310.6

[a] Discharge for July, August, September, and Oct. 1–8, inclusive, estimated by C. H. Lee; Oct. 9 to June 30, inclusive, from U. S. Geol. Survey Water-Supply Paper 300, 1913.
[b] From record in U. S. Geol. Survey Water-Supply Paper 300, 1913.
[c] July 1 to Dec. 31, inclusive, estimated by C. H. Lee; Jan. 1 to June 30, from U. S. Geol. Survey Water-Supply Paper 300, 1913.
[d] July 1, 1911, to Mar. 31, 1912, estimated by C. H. Lee; Apr. 1 to May 31, from U. S. Geol. Survey Water-Supply Paper 331, p. 45, 1914; June, from records of Volcan Land & Water Co.
[e] July 1 to Nov. 13, inclusive, from records of Volcan Land & Water Co.; Nov. 14 to June 30, data furnished by H. D. McGlashan, district engineer, U. S. Geol. Survey.
[f] Record furnished by H. D. McGlashan, district engineer, U. S. Geol. Survey.

NOTE.—Canal record compiled from data in U. S. Geol. Survey Water-Supply Paper 411 and furnished by H. D. McGlashan, district engineer.

The following table summarizes the data presented in Table 20:

TABLE 24.—*Summary of data showing ratio, in percentage, of run-off to precipitation on drainage area.*

Year.	San Luis Rey River near Pala.	Santa Ysabel Creek near Ramona.	San Diego River at diverting dam.	Sweetwater River at Sweetwater dam.
1887–88				3.3
1888–89				10.3
1889–90				6.9
1890–91				7.9
1891–92				3.4
1892–93				8.2
1893–94				1.0
1894–95				29.6
1895–96				1.2
1896–97				3.3
1897–98				
1898–99			1.2	.3
1899–1900			.6	.0
1900–1901			3.1	.5
1901–2			4.0	.0
1902–3			5.5	.0
1903–4	3.5		.9	.0
1904–5	7.5		11.3	5.0
1905–6	17.3		15.0	12.1
1906–7	17.9	17.3	20.7	13.5
1907–8	8.0	8.2	10.4	2.5
1908–9	11.2	22.9	12.6	7.4
1909–10	12.8	21.1	10.4	5.3
1910–11	8.6		6.0	1.6
1911–12	5.0	9.5	7.8	2.9
1912–13	3.3	5.6	5.7	.7
1913–14	8.1	11.8	7.1	1.7
1914–15	16.2	20.7	15.3	9.6
Average	10.0	14.6	8.1	4.9

The run-off shown in this table for the mountain drainage areas above the major river valleys ranges from 0.6 to 22.9 per cent of the precipitation, the average being about 11 per cent. The per cent of run-off is largest on Santa Ysabel Creek near Ramona, where the average is 14.6 per cent.

The run-off from the combined mountain and foothill area drained by Sweetwater River above Sweetwater dam varies in different years from 0 to 29.6 per cent of the precipitation and averages 4.9 per cent; it certainly does not exceed the average run-off from mountain and foothill areas of other major river basins in San Diego County.

SUMMARY.

The average annual precipitation in western San Diego County ranges from about 10 inches along the coast to 45 inches at the crest of the first range of mountains, increasing about 0.56 inch for each 100 feet of increase in elevation. East of the first range the precipitation rapidly decreases to an annual average of about 18 inches in the high mountain valleys and is only slightly more than 18 inches on the second mountain crest. The range in annual precipitation is from about twice to one-half the average, and the range in annual run-off is from about three times to less than one-tenth the average.

The aggregate depth of precipitation required to produce the first run-off in any season varies, so far as indicated by the records, from 1.4 to 11.3 inches, the amount depending on the character of the stream, on the precipitation in the preceding year or years, and on the intensity of the early storms.

The data indicate that the proportion of the precipitation in mountain areas that is discharged as run-off ranges from 0.6 to 22.9 per cent and averages about 9 per cent. From one area that includes mountains, foothills, and valleys, the average is about 5 per cent.

EVAPORATION.

By C. H. Lee.

EVAPORATION FROM WATER SURFACES.

Records of evaporation from large water surfaces have been kept at several places in San Diego County. The earliest published record was obtained in the years 1889 to 1892 by the San Diego Land & Town Co. from a pan floating on the surface of Sweetwater reservoir near National City. The method of observation is well described in the following extract from a letter sent to the writer by Mr. Charles L. Fulton, who was at the reservoir during a part of the period and who made some of the observations. For a number of years Mr. Fulton has been the resident keeper of the Sweetwater dam and reservoir for the Sweetwater Water Co., the successor to the San Diego Land & Town Co.:

The pan consisted of a section of 36-inch pipe closed at the bottom and securely fastened to a float or raft in the reservoir, and so arranged as to guard against ordinary stormy or rough water. In the center of this pan was an iron rod, the upper end of which was pointed. The zero point of the pan then was the top of this pointed rod, and at the beginning of the week the pan was filled to the point. At the end of the week the pan was filled to the point again by dipping water from the lake with a quart measure, careful account being kept of the number of quarts needed to fill the pan to the required point, this later being referred to a table for conversion to inches. If the rainfall was less than the evaporation, rainfall would be added to the measured evaporation for total evaporation. If the rainfall was in excess of evaporation the excess was dipped out and measured to the zero point of the pan. Then this was deducted from the weekly precipitation to calculate the evaporation.

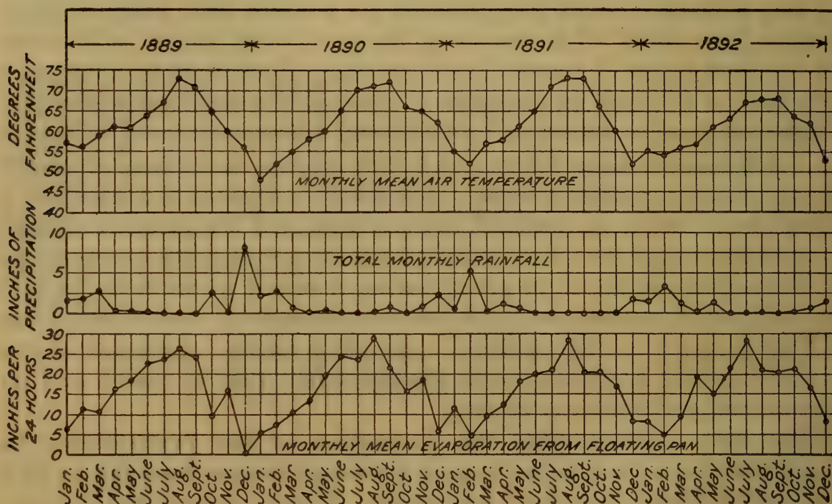


FIGURE 8.—Comparison of evaporation with temperature and precipitation at Sweetwater dam.

The record as originally published[1] is reproduced in Table 25 and shows an average annual depth of evaporation of 58.7 inches during the four years 1889–1892. The record indicates that annual variations in depth of evaporation are of very minor importance. The variations from month to month, however, are considerable, the depth of evaporation changing in conformity with the annual change in temperature and to a slight extent with humidity during storm periods. (See fig. 8.)

[1] U. S. Geol. Survey Water-Supply Paper 81, p. 334, 1903.

TABLE 25.—*Evaporation from free water surface at Sweetwater reservoir, 1889–1892.*

[Pan floating on surface of reservoir at elevation of 200 feet.]

Month.	1889		1890		1891		1892		Average.	
	Depth in inches.	Per cent of year's total.	Depth in inches.	Per cent of year's total.	Depth in inches.	Per cent of year's total.	Depth in inches.	Per cent of year's total.	Depth in inches.	Per cent of year's total.
January	1.99	3.46	1.59	2.65	3.61	6.22	2.54	4.26	2.43	4.15
February	3.34	5.82	2.21	3.70	1.35	2.33	1.39	2.34	2.07	3.55
March	3.38	5.90	3.28	5.48	3.08	5.30	3.08	5.18	3.20	5.46
April	4.96	8.65	4.14	6.92	3.71	6.39	5.82	9.77	4.65	7.93
May	5.82	10.14	6.14	10.26	5.60	9.64	4.67	7.84	5.56	9.47
June	6.81	11.89	7.30	12.21	6.03	10.38	6.48	10.89	6.66	11.34
July	7.40	12.89	7.38	12.35	6.50	11.19	8.81	14.80	7.52	12.81
August	8.25	14.40	9.02	15.06	8.89	15.30	6.54	11.00	8.18	13.94
September	7.36	12.84	6.48	10.83	6.15	10.59	6.27	10.52	6.57	11.19
October	[a] 3.00	5.23	4.92	8.21	6.31	10.85	6.56	11.02	5.20	8.83
November	4.80	8.35	5.54	9.25	4.10	7.07	4.77	8.00	4.80	8.17
December	[a] .25	.43	1.85	3.08	2.75	4.74	2.61	4.38	1.87	3.16
	57.36	100.00	59.84	100.00	58.08	100.00	59.54	100.00	58.71	100.00

[a] Heavy rains these months.

Observations by San Diego Land & Town Co. (See U. S. Geol. Survey Water-Supply Paper 81, p. 344, 1903.)

Under the direction of Mr. W. S. Post, chief engineer of the Cuyamaca Water Co., records of evaporation have been kept at La Mesa reservoir, about 8 miles northeast of San Diego, and at Cuyamaca reservoir, about 35 miles northeast of San Diego. The method of obtaining the records was the same as that used at Sweetwater reservoir, except that the pans were square instead of circular. The records as published,[1] with the addition of data more recently obtained by the company, are shown by Tables 26 and 27. The average annual depth of evaporation at the two stations is 66.1 and 76.0 inches, respectively, during the three-year period 1913 to 1915. These records indicate somewhat greater annual fluctuation than at Sweetwater reservoir, but the monthly variations closely correspond. The evaporation is apparently greater at La Mesa reservoir than at Sweetwater, possibly because of lower humidity and higher temperature at the former station, although no observations are available definitely to show this condition. The greater evaporation at Cuyamaca reservoir is obviously due to the proximity of the desert and its low humidity.

[1] Am. Soc. Civil Eng. Trans., vol. 80, p. 1909, 1916.

TABLE 26.—*Evaporation from free water surface at La Mesa reservoir.*

[Pan floating on surface of reservoir.]

Month.	1913		1914		1915		Average.	
	Depth in inches.	Per cent of year's total.	Depth in inches.	Per cent of year's total.	Depth in inches.	Per cent of year's total.	Depth in inches.	Per cent of year's total.
January	1.59	2.3	2.37	3.6	1.73	2.8	1.90	2.9
February	4.23	6.0	2.94	4.5	2.40	3.8	3.19	4.8
March	4.51	6.4	6.15	9.3	4.99	8.0	5.22	7.9
April	6.19	8.9	6.16	9.4	5.15	8.2	5.83	8.8
May	7.54	10.8	5.48	8.3	6.45	10.3	6.49	9.8
June	6.98	10.0	7.76	11.8	8.01	12.8	7.58	11.5
July	9.64	13.8	9.03	13.7	9.34	14.9	9.34	14.1
August	8.45	12.1	8.26	12.5	7.89	12.6	8.20	12.4
September	8.21	11.7	6.54	9.9	6.02	9.6	6.92	10.4
October	6.46	9.2	4.47	6.8	5.10	8.2	5.34	8.1
November	3.42	4.9	4.34	6.6	4.11	6.6	3.96	6.0
December	2.70	3.8	2.37	3.6	1.44	2.3	2.17	3.2
Year	69.92	100.0	65.87	100.0	62.63	100.0	66.14	100.0

NOTE.—Pan is a 3 by 3 foot standard pan 18 inches deep. Elevation, 480 feet. Observations by Cuyamaca Water Co.

TABLE 27.—*Evaporation from free water surface at Cuyamaca reservoir.*

[Pan floating on surface of reservoir.]

Month.	1913		1914		1915		Average.	
	Depth in inches.	Per cent of year's total.	Depth in inches.	Per cent of year's total.	Depth in inches.	Per cent of year's total.	Depth in inches.	Per cent of year's total.
January	....	....	[a] 3.28	4.12	3.47	4.73	3.38	4.45
February	....	....	[a] 5.46	6.85	3.97	5.42	4.72	6.21
March	....	....	7.20	9.05	4.56	6.23	5.88	7.74
April	....	....	5.60	7.03	3.75	5.11	4.68	6.16
May	....	....	7.53	9.47	4.52	6.16	6.02	7.92
June	9.25	....	8.99	11.29	9.66	13.18	9.30	12.23
July	8.18	....	9.90	12.46	8.74	11.91	8.94	11.77
August	7.94	....	10.76	13.53	10.30	14.05	9.67	12.73
September	9.68	....	7.53	9.46	7.16	9.78	8.12	10.69
October	6.86	....	6.08	7.66	8.30	11.31	7.08	9.32
November	5.63	....	3.28	4.12	3.99	5.45	4.30	5.66
December	2.85	....	3.94	4.96	4.88	6.67	3.89	5.12
Year	....	....	79.55	100.00	73.30	100.00	75.98	100.00

[a] Excessive rains overflowed pans; interpolated Jan. 13–20, 20–28, and Feb. 17–24.

NOTE.—Pan is a 3 by 3 foot standard pan 18 inches deep. Elevation, 4,620 feet. Observations by the Cuyamaca Water Co.

An interesting comparison of the depth of evaporation from a pan floating on the surface of a large reservoir with that from a whole reservoir surface, considered as an immense evaporating pan, can be made in connection with the record obtained at La Mesa reservoir. The Upper Otay reservoir, situated at about the same elevation and the same distance from the coast as La Mesa reservoir and 11 miles farther southeast, was not drawn upon nor did it receive accessions during the period January, 1913, to December, 1915. A record of the water level was kept at the reservoir and observations of rainfall were made at Lower Otay dam about 2½ miles away. The net movement of the reservoir surface after correcting for rainfall is considered due to evaporation from the surface of the reservoir, since the formation surrounding the reservoir is practically water-tight. The data have been compiled by H. A. Whitney[1] and are reproduced in Table 28. The depths of evaporation as measured in the pan at La Mesa reservoir and computed from reservoir levels as Upper Otay reservoir have been placed in parallel columns, together with the monthly and annual per cent of the former to the latter. The average for the three-year period is 94 per cent. Assuming that the factors affecting evaporation were the same at the two reservoirs, that there was no underflow into or out from the Upper Otay reservoir, and that the rainfall on the Upper Otay reservoir was the same as at the point where the rain gage was maintained, it would appear that the rate of evaporation is slightly greater from a floating pan than from the whole of the large surface upon which the pan is floating. In a similar comparison in Owens Valley, Calif., between the evaporation from the surface of Owens Lake and a pan floating on the surface of Owens River, 20 miles north of the lake, conditions of evaporation being similar, the writer found the two to agree within 1 per cent. This subject requires further investigation, but the writer believes that a comparison made between a whole reservoir surface and a pan floating upon the surface of the same reservoir, if carried out under favorable conditions for measurement of reservoir stage, draft, and accession, would show the rate of loss from the whole reservoir surface to be very little less than that from the pan. The most important factor tending to make a difference is probably the higher temperature of water in the pan during the day, as compared with that of the surrounding water, resulting from the absorption of solar heat by the pan. Observations of temperatures made by the writer have indicated that water temperatures in and surrounding the pan do not differ by more than 1° or 2° F. during the hot part of the day.

TABLE 28.—*Comparison of depths of evaporation, in inches, measured by floating pan at La Mesa reservoir with those computed from reservoir levels at Upper Otay reservoir.*

Month.	1913			1914			1915			Average.		
	A. La Mesa reservoir.	B. Upper Otay reservoir.	Ratio of $\frac{B}{A}$ (per dent).	A. La Mesa reservoir.	B. Upper Otay reservoir.	Ratio of $\frac{B}{A}$ (per cent.)	A. La Mesa reservoir.	B. Upper Otay reservoir.	Ratio of $\frac{B}{A}$ (per cent).	A. La Mesa reservoir.	B. Upper Otay reservoir.	Ratio of $\frac{B}{A}$ (per cent).
January	1.59	2.50	157	2.37	2.70	114	1.73	2.40	139	1.93	2.53	131
February	4.23	3.00	71	2.94	3.40	116	2.40	2.90	121	3.19	3.10	97
March	4.51	3.00	66	6.15	5.90	96	4.99	2.90	58	5.22	3.93	75
April	6.19	4.30	70	6.16	6.70	109	5.15	4.10	80	5.83	5.03	86
May	7.54	5.00	66	5.48	7.20	131	6.45	7.90	123	6.49	6.70	103
June	6.98	5.80	83	7.76	6.70	86	8.01	6.00	75	7.58	6.17	81
July	9.64	8.70	90	9.03	8.80	98	9.34	8.00	86	9.34	8.50	91
August	8.45	8.00	95	8.26	8.00	97	7.89	8.00	101	8.20	8.00	98
September	8.21	6.00	73	6.54	7.00	107	6.02	5.00	83	6.92	6.00	87
October	6.46	5.00	77	4.47	5.00	112	5.10	4.00	78	5.34	4.67	88
November	3.42	6.10	179	4.34	3.40	78	4.11	4.70	114	3.96	4.73	119
December	2.70	3.70	137	2.37	2.70	114	1.44	2.30	160	2.17	2.90	134
	69.92	61.1	87.5	65.87	67.50	102.5	62.63	58.20	92.9	66.17	62.26	94.2

[1] Am. Soc. Civil Eng. Trans., vol. 80, pp. 1894–1989, 1916.

In conclusion, it can be stated that the average annual depth of evaporation observed during short periods in floating pans at the three localities in San Diego County ranged from about 58 inches near the coast to about 76 inches in a high valley that opens toward the desert at the crest of the divide. Variations in annual evaporation are very small. Variations in monthly evaporation generally follow variations in air temperature, with slight modifications resulting from abnormal humidity during stormy weather.

EVAPORATION FROM SOIL.

The relation between the depth of evaporation from a large water surface and from damp bare soil is not direct, since the rate of evaporation from soil varies widely, depending on the depth of the zone of saturation below the land surface and the height to which water is drawn by capillary action. The maximum depth from which water is drawn by capillarity ranges for most soils between 4 and 9 feet, depending on the character of the soil. If the depth to ground water is more than 9 feet, the evaporation from the soil is zero,[1] according to the best experimental evidence, except as the surface is temporarily moistened by precipitation or flooding. If, on the other hand, the surface soil is permanently saturated, the rate of evaporation is but slightly less than, or possibly equal to that from a free water surface. This fact has been shown by the experiments of Ebermayer[2] and also recent experiments by the United States Department of Agriculture and by the writer. If the surface is covered by close-growing plants or trees, the combined rates of evaporation and transpiration differ from that of bare soil. The determination of evaporation from soil moistened by ground water and of transpiration is thus impossible without detailed information of conditions of surface and soil and depth to ground water throughout the area. Such information can be obtained only by careful and extended field surveys, and is beyond the scope of this report.

In this connection, however, the data presented later in this report (pp. 143–146) with regard to the annual replenishment of the closed basins represented by the major river valleys is of interest. As is shown, the porous alluvial fill of these valleys absorbs water from precipitation directly and from the streams that flow over the surface of the fill. It loses this water by evaporation from the surface layer of the fill as moistened by capillary water drawn up from the zone of saturation and by transpiration from vegetation. Considered for a period of years, the average annual absorption equals the average annual loss. The average annual absorption can

[1] Lee, C. H., U. S. Geol. Survey Water-Supply Paper 294, 1912.
[2] Hough, F. B., Report on forestry, U. S. Dept. Agr., 1877.

be computed for the various major valleys, as explained on pages 143–146. In San Luis Rey Valley the average annual absorption has been determined as 14,450 acre-feet. The writer has made a detailed field examination of the surface of the valley fill of this valley below the gaging station of the United States Geological Survey near Pala and has segregated and mapped all lands from which soil evaporation and transpiration occur through part or all of the year. The total area of such lands was found to be 6,640 acres. The remaining 1,006 acres of valley fill was bare land beneath which the zone of saturation was at too great a depth for ground water to be drawn to the surface by capillarity. By dividing the average annual absorption of the valley fill by the land area from which this volume is annually dissipated into the atmosphere, it appears that the average depth of water lost each year is 2.19 feet. This result checks within 10 per cent that reached independently from a detailed study of evaporation and transpiration from soil in this valley by using the principles developed by work in Owens Valley [1] and other experiments, but modifying their application to conform with the local conditions as to soil, evaporation from free water surface, and type and density of vegetation. The natural conditions in other major valleys of San Diego County are similar to those in San Luis Rey Valley, although the ground-water supply has been more extensively used in some of them. This determination, however—2.19 feet—can be considered as approximately representing the average annual depth of water discharged by evaporation from moist lands and transpiration from natural vegetation in the major river valleys of the county.

METHOD OF DISCUSSING GROUND WATER BY AREAS.

To facilitate discussion San Diego County may be divided into the following groups of areas with respect to the occurrence of ground water: (1) Major valleys, comprising the valleys of the six largest streams of the county; (2) minor valleys of the coastal belt; (3) minor valleys of the highland area; (4) Nestor and Chula Vista sea terraces, adjacent to San Diego Bay; (5) interstream areas underlain by Tertiary and older sedimentary formations; (6) highland areas underlain by crystalline rocks not covered by residuum; (7) highland areas in the gently sloping and level parts of which the crystalline rocks are overlain by water-bearing rock waste.

Although areas belonging to the first group constitute only a small part of the total area of the county, they are by far the most important as sources of water supply. The other areas possess in the aggregate a greater quantity of stored ground water, but are not capable of yield-

[1] Lee, C. H., The determination of safe yield of underground reservoirs of the closed-basin type: Am. Soc. Civil Eng. Trans., vol. 78, p. 148, 1915.

ing large quantities at any one point, and hence are not adapted to utilization by big single plants. At many localities in these areas, however, small but reliable supplies of ground water can be obtained.

The discussion of the ground water of the major river valleys includes descriptions of the topography and drainage of the valleys, underground reservoirs, the valley fill, form and fluctuations of the water table, yield of ground water, and methods of constructing wells, and it is followed by descriptions of the ground-water supply in the minor valleys and in other areas.

WATER IN THE MAJOR VALLEYS.

By C. H. Lee.

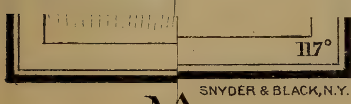
TOPOGRAPHY AND DRAINAGE OF THE VALLEYS.

RELATION OF VALLEYS TO ADJACENT AREAS.

The major valleys of San Diego County, as here described, are the narrow, flat-bottomed valleys that extend inland from the coast 20 to 25 miles and are traversed by streams that rise in the culminating mountain ranges and discharge into the Pacific Ocean. The desert region east of the culminating ranges is drained in part into the Salton Sea and in part into the Gulf of California.

The streams that occupy the major valleys west of the divide, named in order from north to south, are Santa Margarita, San Luis Rey, San Dieguito, San Diego, Sweetwater, and Tia Juana rivers. (See Pls. XX to XXV.) From the valleys of these streams steep slopes lead up to the bordering terraces or mountains. The range in which these streams rise has an average elevation above sea level of about 5,500 feet, and in a few places exceeds 6,000 feet. It is dissected by valleys and wide canyons into more or less isolated mountains, such as the Agua Tibia Mountains, the Palomar Mountains, and the Ysidro Mountains at the head of San Luis Rey River, the Volcan Mountains at the head of Santa Ysabel Creek, and the Cuyamaca Mountains at the head of Cottonwood Creek, which is a tributary of Tia Juana River in the United States.

The major valleys trend from northeast to southwest and in general parallel one another, at intervals ranging from 3 to 15 miles, from the vicinity of the north line of the county to the international boundary (Pl. II). Most of the valleys head in the highland area and extend more or less continuously to the coast. For the upper 12 to 18 miles of their length they are bordered by the mountains and foothills of the highland area, and for the lower 6 to 8 miles by the terraces or "mesas" of the coastal belt. The unconsolidated alluvial material that underlies the floors of these valleys is porous and contains much ground water.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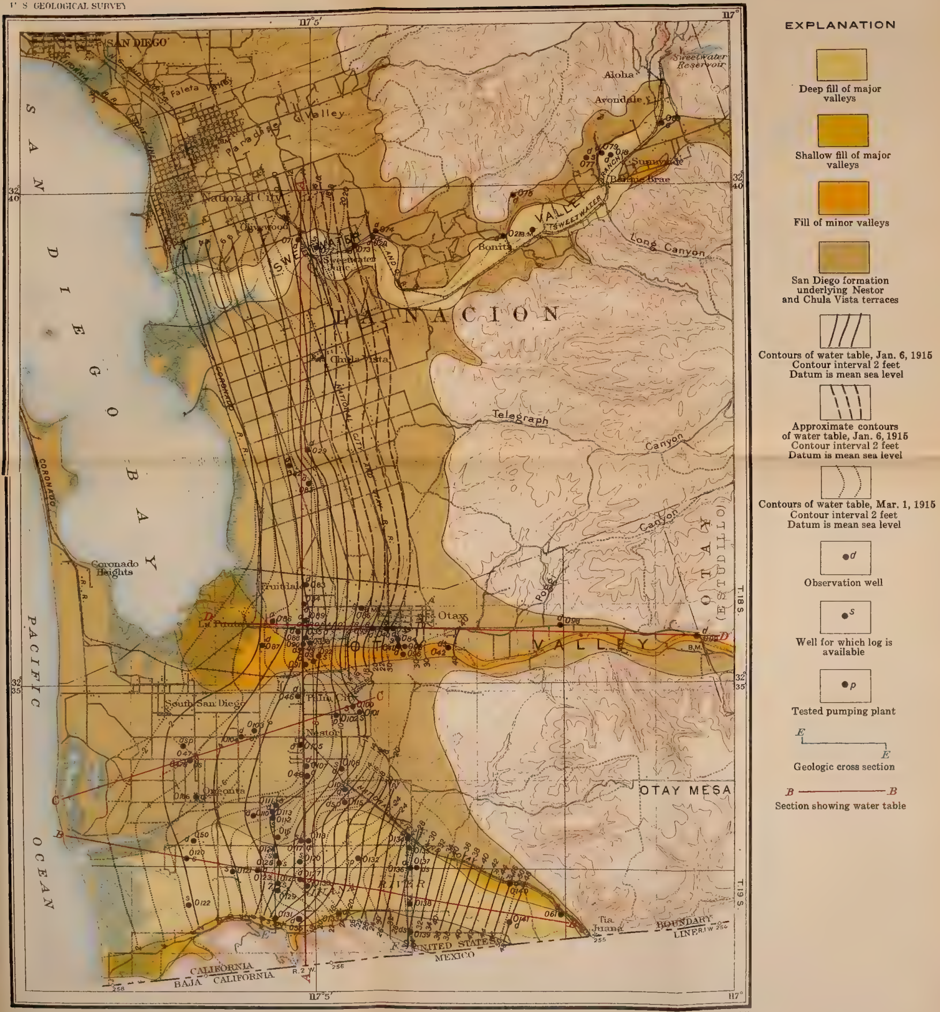


SNYDER & BLACK, N.Y.

MAP OF PART OF SAN DIEGO BAY REGION, CALIFORNIA

Showing principal water-bearing formations, contours of water table, and tested pumping plants

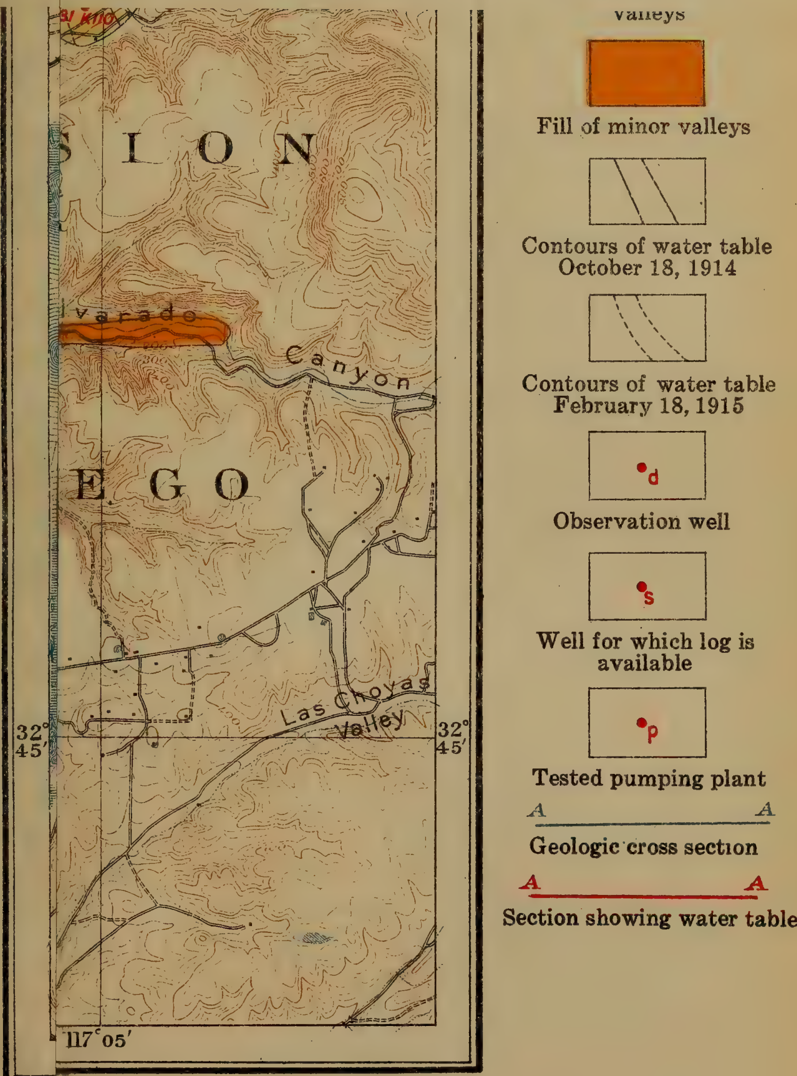
Scale $\frac{1}{62500}$

1 ½ 0 1 2 Miles

Contour interval 25 feet

Datum is mean sea level.

1919.



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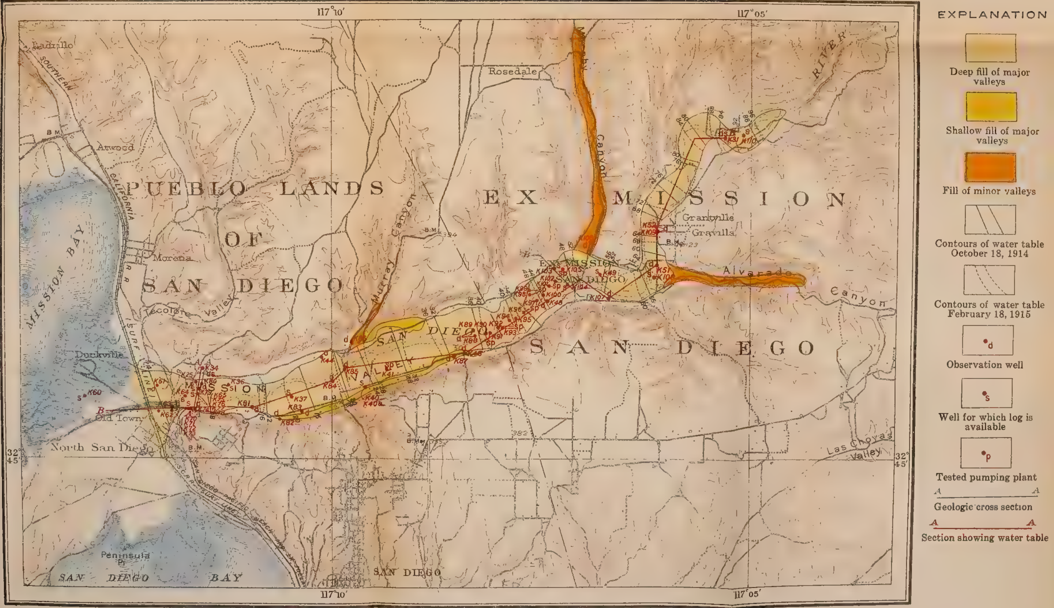

MAP OF MISSION VALLEY, CALIFORNIA

Showing principal water-bearing formations, contours of the water table, observation wells, and tested pumping plants

Scale $\frac{1}{62,500}$

1 ½ 0 1 2 Miles

Contour interval 25 feet.

Datum is mean sea level

1919.

The major valleys and their streams are among the valuable assets of San Diego County. The valley floors, though not desirable as places of residence because of their low elevation and liability to be overflowed, are well adapted to the raising of such field crops as alfalfa and vegetables and also to dairying. They comprise, in fact, the largest single bodies of land in the county adapted to such uses, and the local demand for their products will increase rapidly with increase in the population of the adjacent slopes. The water, both surface and underground, which these valleys afford, is their greatest element of value to the county. The most thickly populated parts of the county and the most productive agricultural lands depend either directly or indirectly on this water supply. The foothills and terrace lands are largely supplied by gravity from surface storage reservoirs which are filled from the winter flow of the streams that traverse the valleys. In periods of severe drought, when the supply of surface water has proved insufficient, heavy drafts have been made on the ground water stored in the fill of these valleys. In recent years pumping plants utilizing the ground waters have been established in these valleys to provide water not only for the irrigation of the valley lands, but for domestic use and irrigation on the adjacent "mesas" or terraces. Without the water supply available from these valleys, therefore, the foothills and coastal "mesas" of San Diego County would be practically uninhabitable.

COASTAL VALLEYS.

As shown by Plates XX to XXV, the major valleys consist of several more or less distinct parts. Where they cross formations of resistant rock they are narrow and in some places are deep canyons; where they traverse softer formations they are wide and flat-bottomed. Each of the principal rivers, therefore, passes alternately through narrow gorges and wide, steep-walled basins. A few of the canyons contain some valley fill; others, such as the canyon at the head of Mission Valley, have floors of bedrock. The wide parts of the major valleys, formed where they cross the coastal belt, are referred to in this report as coastal valleys; those that are situated in the highland area are referred to as highland valleys. The coastal valleys extend inland from 6 to 8 miles from the coast and as a rule are broader than the highland valleys. The narrow, sand-floored canyons or rocky gorges that separate the coastal from the highland valleys are 4 to 6 miles long.

The principal coastal valleys are Santa Margarita Valley below Deluz station on the abandoned Fallbrook branch of the Santa Fe Railway, San Luis Rey Valley below Guajome ranch, San Dieguito Valley, Mission Valley (on San Diego River), Sweetwater Valley below Sweetwater dam, and Tia Juana Valley. These valleys lie entirely within the area underlain by sedimentary rocks (see Pl. III). They vary in width from a quarter of a mile to 1½ miles and are sharply separated from the bordering terraces or "mesas" by steep slopes and bluffs 200 to 400 feet high. Their floors are nearly level but slope downstream 9 to 12 feet per mile. Some of the valleys, such as Tia Juana, open directly into the ocean; others, such as San Luis Rey, are contracted at the mouth, so that the stream finds its outlet to the ocean through a canyon. The areas of these valleys range from 4,380 acres in Tia Juana Valley to 1,532 acres in Sweetwater Valley, the aggregate area of coastal valleys in the county being 17,500 acres. (See Table 40, p. 151.) These figures represent the areas underlain by the main body of valley fill but do not include small tributary valleys.

HIGHLAND VALLEYS.

The highland valleys traversed by the major streams comprise the valley of San Luis Rey River between the east boundary of the Pala Indian Reservation and Bonsall, and possibly also the river valley within and between the Pauma land grant and the Rincon Indian Reservation, San Pasqual Valley and Santa Ysabel Creek Valley to Bernardo, the valley of San Diego River from the east boundary of El Cajon land grant to the Old Mission dam (including the valley of San Vicente Creek below Foster), and Dehesa and Jamacho valleys on Sweetwater River. These valleys lie wholly within the highland area and are underlain by granitic rocks. Most of them are definitely outlined by steep rocky slopes and are surrounded by the irregular mountains and high valleys of the highland area. The valleys vary from a few hundred feet to half a mile in width. Some of the connecting gorges are barely 400 feet wide. The valley floors are nearly level but have slopes downstream of 13 to 25 feet per mile, the steepest slope being at the head of the highest valley on each stream. At the same relative distance from the coast the slopes in different valleys closely correspond. The areas of these valleys range from 4,476 acres for the valley of San Luis Rey River to 1,065 acres for the upper Sweetwater Valley, the aggregate area of the highland valleys being 10,540 acres. (See Table 40, p. 151).

SURFACE WATERS.

The streams obtain most of their water from the upper parts of the highland area. Tributaries that enter farther downstream seldom add greatly to the flow of the stream. The main streams range in length from 40 to 55 miles. Their drainage basins, including highland area and coastal belt, range in size (excluding Tia Juana River, for which data are incomplete) from 780 square miles for Santa Margarita River to 181 square miles for Sweetwater River. The total area tributary to all the principal rivers (excluding Tia Juana River) is 2,280 square

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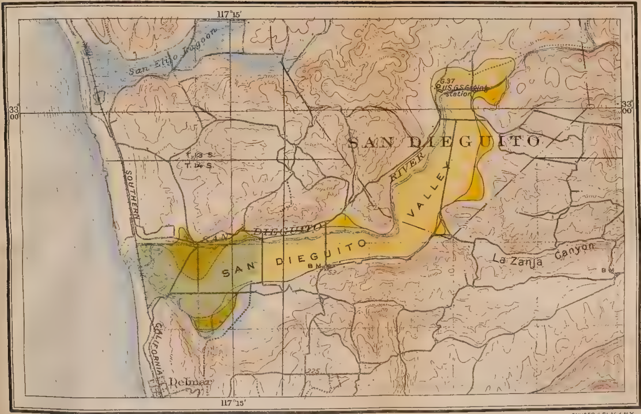

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MAP OF SAN DIEGUITO VALLEY, CALIFORNIA

Showing valley fill and location of observation well and gaging station

Scale $\frac{1}{62500}$

1 ½ 0 1 2 Miles

Contour interval 25 feet.
Datum is mean sea level
1919.

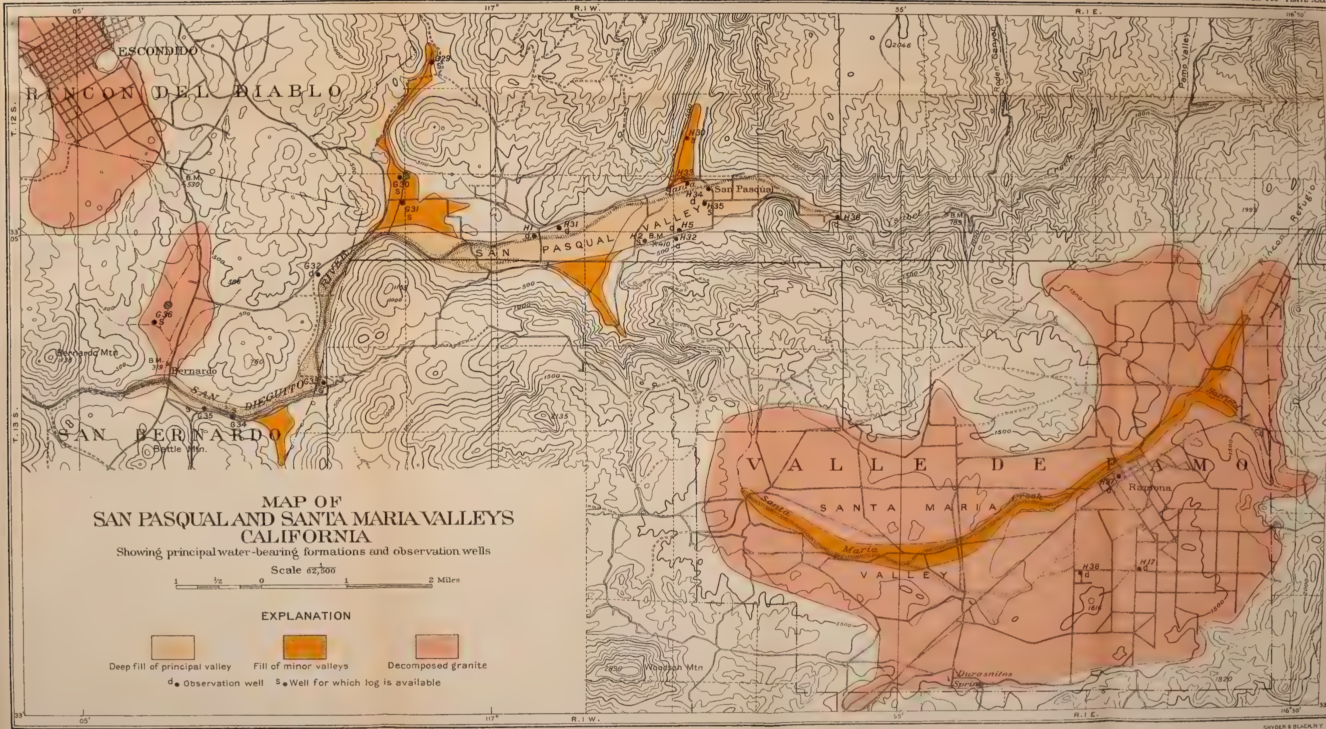
EXPLANATION

Deep valley fill

Shallow valley fill

G37 Observation well


A


MAP OF
SAN PASQUAL AND SANTA MARIA VALLEYS
CALIFORNIA
Showing principal water-bearing formations and observation wells
Scale 1/62,500
1 1/2 0 1 2 Miles
EXPLANATION
Deep fill of principal valley
Fill of minor valleys
Decomposed granite
d Observation well
S Well for which log is available
ESCONDIDO
RINCON DEL DIABLO
SAN PASQUAL VALLEY
San Pasqual
SAN DIEGUITO RIVER
Bernardo
Bernardo Mtn
SAN BERNARDO
Battle Mtn.
VALLE DE PAMO
SANTA MARIA VALLEY
Santa Maria Creek
Ramona
Woodson Mtn
Durasnitos Spring
Rincon Refugio
Ysabel Creek
Pamo Valley
Rodeo Canyon
SNYDER & BLACK, N.Y.

miles (Table 29 and Pl. XV). Comparison of this area with the total area of the major valleys shows that the latter comprise only 2 per cent of the tributary drainage basins.

TABLE 29.—*Areas of drainage basins tributary to streams at gaging stations in San Diego County.*

Stream.	Gaging station.	Total area above gaging station.
		Square miles.
Temecula Creek	Near Temecula	420±
Santa Margarita River	Near Ysidora	780±
San Luis Rey River	Near Mesa Grande	209
Do	Near Nellie (Escondido intake)	240
Do	Near Pala	a322
Do	Bonsall	465
Do	Oceanside (opposite Oceanside pumping plant).	563
Santa Ysabel Creek	Near Santa Ysabel	12.8
Do	Near Ramona	b110
Do	Near Escondido	128
Do	Bernardo	266
San Dieguito River	Near Del Mar	328
Santa Maria Creek	Near Ramona	57.3
Guejito Creek	Near Escondido	27.6
Boulder Creek	Cuyamaca	12.0
San Diego River	Diverting dam	c102.0
Do	Lakeside	d203
Do	Near Santee (Old Mission dam)	375
Do	Near San Diego (Murray ford)	431
San Vicente Creek	Foster	74.9
Sweetwater River	Near Descanso	e43.7
Do	Near Dehesa	112
Do	Sweetwater dam	f181
Otay River	Lower Otay dam	98.6
Cottonwood Creek	Barrett dam	246
Tia Juana	Near Nestor	

a Formerly published as 318 square miles.
b Formerly published as 113 square miles.
c Area above diverting dam exclusive of 12 square miles tributary to Cuyamaca reservoir is 90 square miles.
d Formerly published as 208 square miles.
e Formerly published as 40 square miles.
f Formerly published as 186 square miles.

Precipitation of sufficient magnitude to produce run-off is largely confined to the winter months—January to April—when the county is visited by the general storms that are common to the whole Pacific coast. Run-off is rapid and stream flow is at its maximum during the storms. The principal streams seldom flow after the first of July, except San Luis Rey River near Pala. As a result of the similarity of surface conditions and precipitation, the run-off of the streams is similar. The records of daily flow of San Luis Rey, Santa Ysabel, San Diego, and Tia Juana rivers in this region (Pl. XIX), show a remarkable agreement both as to dates of critical stages of flow and relative rates of discharge.

SOILS AND VEGETATION.

The soil of all the valleys is composed of sand and silt derived mainly from the granitic rocks of the highland area but in part from the Tertiary formations of the coastal belt. Silty soils cover larger areas in the coastal valleys than in the highland valleys. This material has all been deposited at some time by the river that traverses the valley, and the fertility of the soil depends largely on the decomposition that has taken place.

Before they were settled and cultivated the valleys supported growths of willow, cottonwood, alder, and sycamore trees, and more or less underbrush. Salt grass, yerba mansa, and swamp vegetation occupied open areas where the water table (see p. 123) commonly stood within 5 feet of the surface. As a result of settlement and cultivation much of the original vegetation has been removed and replaced with field crops, but there still remain considerable areas of natural vegetation, especially in the upper San Luis Rey and Sweetwater valleys. The destructive effect in times of flood of removing trees along the river channels is becoming more and more apparent.

The slopes of the culminating range are covered by brush of varying density but the valleys are bare except for range grasses. Groves of coniferous trees grow at elevations of 5,000 feet and higher. Scattered oak trees are common at all levels along the margins of valleys and in canyons and in all other localities where soil and water supply are favorable.

The surface of the coastal area is only gently undulating, the formations that underlie it consist largely of gravel and sand interbedded with clay, and the soils do not readily absorb water. There is little vegetation other than the short range grass which grows during the rainy season.

UNDERGROUND RESERVOIRS.

SOURCES OF WATER.

As compared with the valley fill, the rocks surrounding both the highland and coastal valleys are practically impervious to the passage of water. The crystalline rocks of the highland area are dense and contain recoverable water only in the fissures that traverse them. The voids in the conglomerate and some of the sandstones of the sedimentary formations are filled with clay or other impervious material. Well logs and other data show that hard, impervious formations, undoubtedly the same as those that underlie the uplands adjoining the valleys lie beneath the valleys at depths nowhere exceeding 215 feet. These logs also show that underlying the valleys and filling the basins formed by the bedrock there are bodies of porous, unconsolidated alluvial material which is composed of silt, sand, and gravel and is saturated with water almost to the surface. The water is derived chiefly by absorption and percolation of surface water as it flows over the valley fill; it escapes either by seeping into the stream channels at the lower ends of the basins, by underflow through the fill into the next lower basins, by evaporation from the soil, or by transpiration from plant surfaces. Additions to the supply are accompanied by a rise of the water table; withdrawals from the supply lower the water table. These relatively water-tight bedrock basins filled with porous material constitute reservoirs of underground water. It is as though the present valleys and canyons were to be closed at their lower ends by high dams and the reservoirs thus formed were to be filled with sand and gravel transported by the tributary streams. The capacity of such reservoirs to store water would be reduced thereby, but the action of the reservoir, its filling and emptying, and the rise and fall of its water surface, would differ but little from that of a surface reservoir.

The following discussion of these ground-water reservoirs includes descriptions of the valley fill, the form and fluctuations of the water table, yield of ground water, and methods of reconstructing wells.

THE VALLEY FILL.

COASTAL VALLEYS.

Origin of the deposits.—Information concerning the valley fill is obtained from geologic formations, structural features exposed at the surface, and the records of materials penetrated in wells.

The geology and physiography of San Diego County indicate that the present position of the land with respect to the ocean level is one of many that it has occupied at various times. (See pp. 21–34.) The land surface has been both higher and lower than at present. At the time of its greatest elevation deep valleys were excavated, of which the present valleys are only the upper portions. The bottoms of these ancient valleys, though having the same general shape as at present, were narrower and deeper than those of the present valleys, and they were traversed by rapidly flowing streams that were actively cutting and widening the canyons in which they flowed. In some places the streams flowed near the middle of the canyon bottoms without much tendency to work toward either side; in other places the current was so directed that it undercut one of the canyon walls. At such places steep slopes or cliffs were created, the upper parts of which can still be identified by the configuration of the valley and the steep slope of the bluff above the present valley floor, as, for example, at the north end of geologic section B–B (Pl. XXI) in Mission Valley (fig. 11, p. 114), at the south end of section A–A (Pl. XXI) in the same valley (fig. 12), and at and directly west of the south end of geologic section A–A (Pl. XXI) in San Luis Rey Valley (fig. 14). As explained later (p. 115) these indications are of great assistance in determining the best places for wells in the valley fill.

When these valleys had been cut to depths of 400 to 500 feet the sea began to advance inland, submerging the land and converting the river valleys into narrow estuaries or salt-water bays. The rivers which formerly flowed rapidly through the valleys, carrying their loads of gravel, sand, and silt to the old shoreline, now deposited great quantities of alluvial débris on the submerged valley bottoms. Most of the coarse sand and gravel was deposited at the heads of the bays, but the fine sands and silts were carried farther. Submergence continued followed by emergence of the land, with the result that to-day these inland bays are completely filled with alluvial material which at the heads of some of the valleys has been built up to an elevation 100 feet above the present sea level. Thus have the ancient coastal stream valleys been converted into the modern underground reservoirs.

Tia Juana Valley.—Prior to its submergence Tia Juana Valley was the largest of the coastal valleys, the bottom being nearly a mile wide for a distance of 4 miles back from the present coast line (figs. 9 and 10). The bedrock floor of the valley was almost level trans-

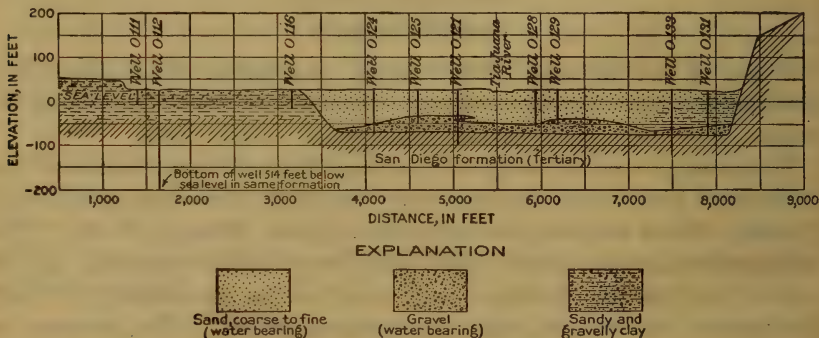
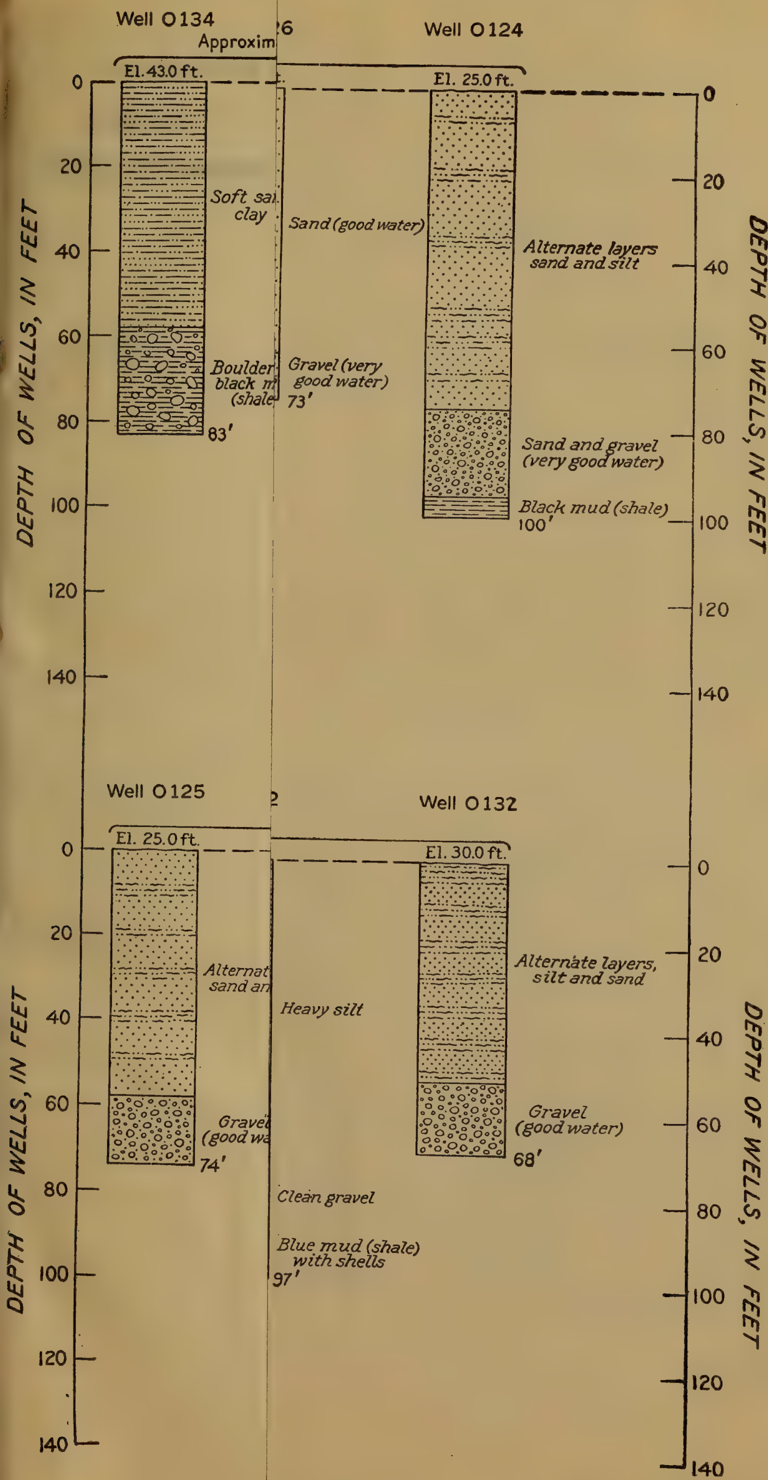
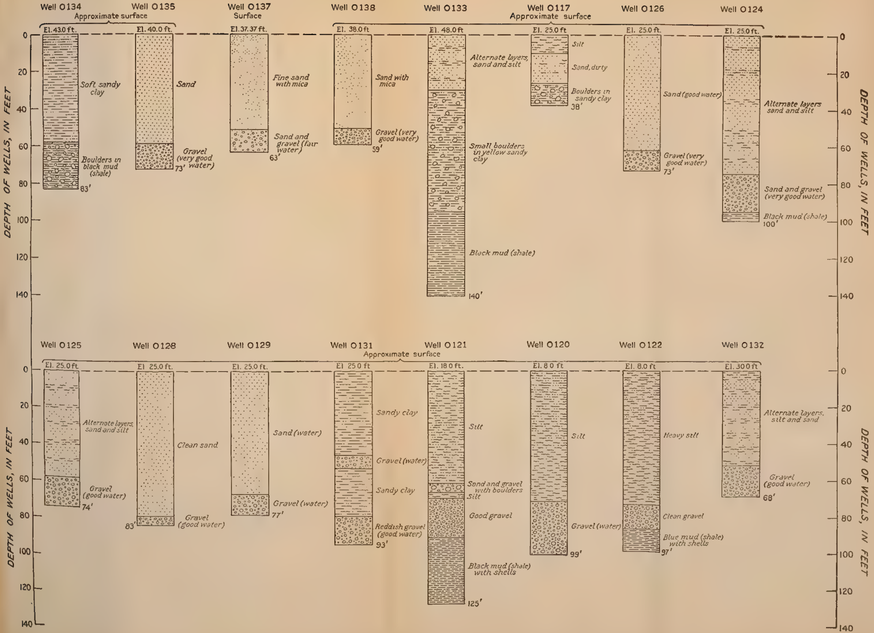


FIGURE 9.—Diagrammatic cross section of Tia Juana Valley along line E-E, Plate XX.

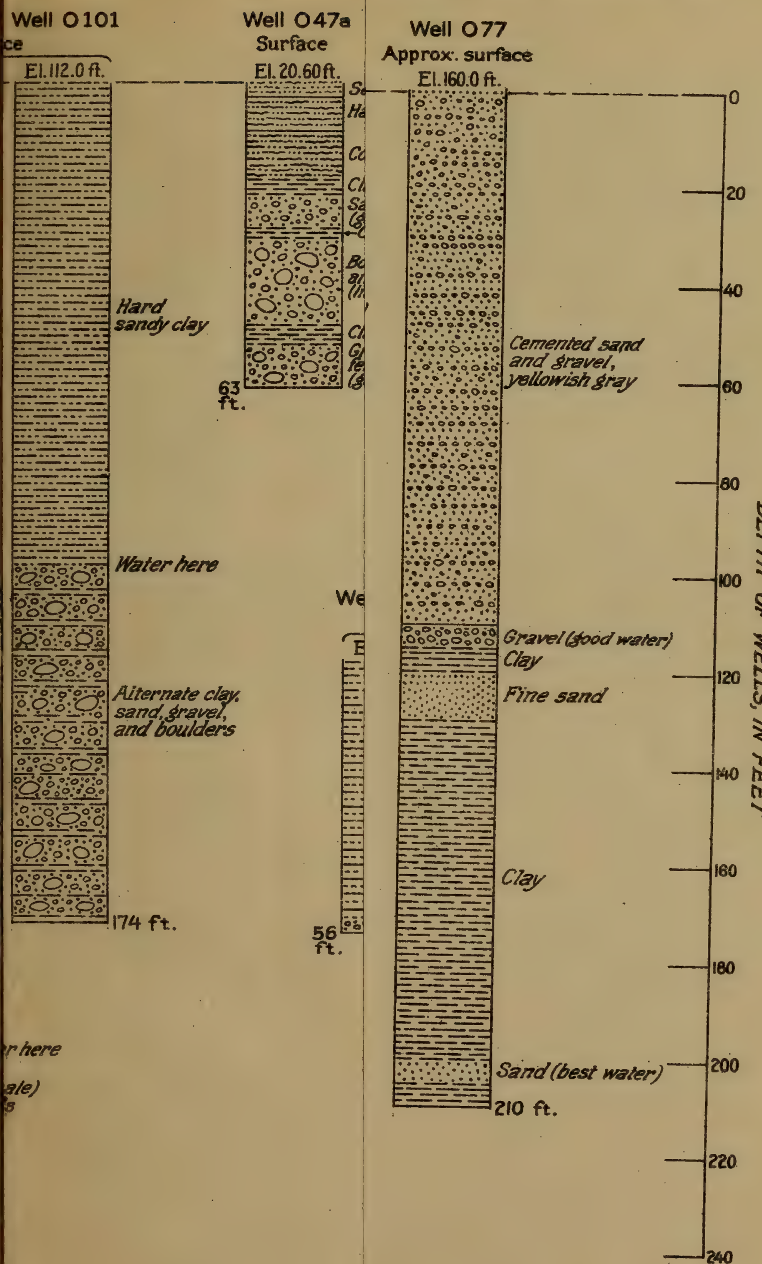
versely and consisted of the upper surface of a layer of dark-colored shale which contains many fossil shells and which, because of its consistency when brought to the surface in drilling operations, the well drillers call "black mud." This material underlies a considerable portion of the valley and adjacent areas, as shown by logs of wells O 133, O 121, O 124, O 112, O 42, and others (Pls. XXVI and XXVII). The valley fill consists of a continuous layer of coarse gravel and boulders of the size of cobblestones, from 10 to 35 feet thick, overlain by layers of sand and silt. The sand grains range from coarse to fine, the percentage of coarse sand being much greater at the upper end of the valley than at the lower. The sand and silt are roughly bedded, although the beds do not appear to be continuous over large areas. The thickness of the sand varies from a maximum of 90 feet at the lower end of the valley to less than 50 feet at the upper end. The total depth of the fill in the lower part of the valley is about 100 feet; its depth in the upper part of the valley is not known, but is probably somewhat less than in the lower part.



Well O134
Approxim
El. 43.0 ft.
Soft sa
clay
Boulder
black m
(shale
83'
Sand (good water)
Gravel (very
good water)
73'
Well O124
El. 25.0 ft.
Alternate layers
sand and silt
Sand and gravel
(very good water)
Black mud (shale)
100'
DEPTH OF WELLS, IN FEET
Well O125
El. 25.0 ft.
Alternat
sand an
Gravel
(good wa
74'
Heavy silt
Clean gravel
Blue mud (shale)
with shells
97'
Well O132
El. 30.0 ft.
Alternate layers,
silt and sand
Gravel
(good water)
68'
DEPTH OF WELLS, IN FEET



SECTIONS OF WELLS IN TIA JUANA VALLEY.



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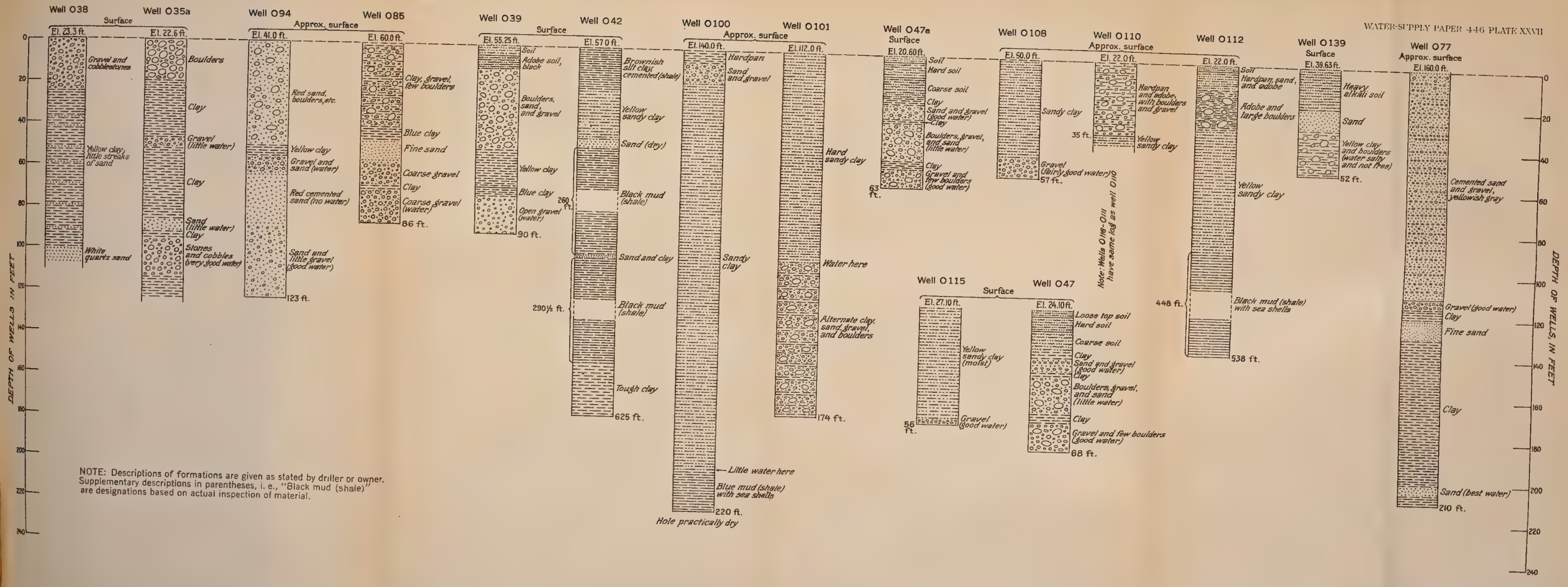


SECTIONS OF WELLS IN SAN DIEGO FORMATION IN VICINITY OF SAN DIEGO BAY.

The fill of the main valley has obviously been deposited by the main Tia Juana River. Along the margin of the valley, particularly opposite tributary canyons from the "mesas," clay and fine wash material are intermingled and interbedded with the fill of the main valley, as shown by logs of wells O 139, O 134, O 133, O 131, and others (Pl. XXVII). In some places accumulations of boulders, more or less embedded in clay or mud, have been encountered in drilling at the mouths of these canyons. These deposits do not extend far out into the valley and are to be expected opposite and just below the mouths of tributary canyons. Along the north edge of the valley, beginning at a point about a mile southeast of Nestor and extending west (Pl. XX), the valley floor is underlain by bedrocks like those that underlie the "mesa" to the north, as illustrated in the geological cross section along the line E–E of Plate XX, figure 9.

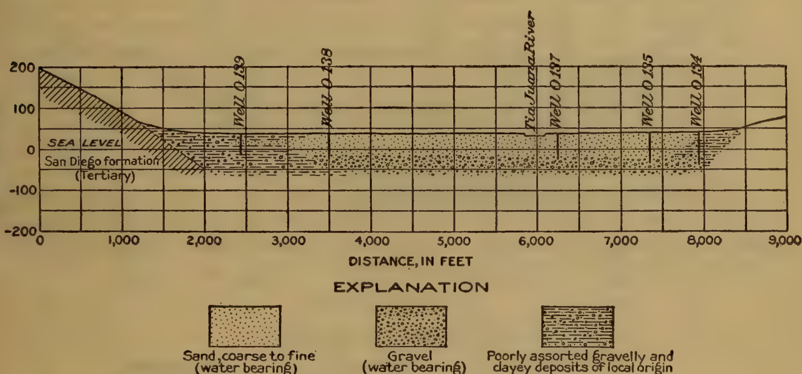


FIGURE 10.—Diagrammatic cross section of Tia Juana Valley along line F–F, Plate XX.

The entire valley fill is saturated with water, as are also the bedrocks adjacent to the valley on the north and lying below the water table in the main valley. All these materials, however, do not yield water with equal readiness. The best water-bearing material is the layer of gravel underlying the main valley and far enough away from the margin to be free from fine material washed in from small lateral canyons. This is the formation from which most of the best wells in the valley draw their water. The coarser sands that overlie the gravels are next in value as water bearers, particularly in the upper part of the valley, although good wells drawing from both gravel and sand have been obtained west of the north-south road that crosses the valley south of Nestor. The most successful wells obtaining water from sand are those around which gravel has been worked down so as to increase the intake area and to prevent sand from entering and clogging the wells.

The limits of the deep valley fill of Tia Juana Valley are indicated on Plate XX. Wells near the margins of this area on the north and south side of the valley may encounter poor water-bearing material. Wells out in the main valley, however, will encounter materials such as have been described above and are shown in figure 19 and figure 10. The logs of 16 typical wells in the deep fill of the valley (shown in Plate XXVI) indicate very clearly the different formations to be found in various parts of the valley. The water-bearing possibilities of the formations underlying the mesa to the north of the valley are described under "Ground water on Nestor and Chula Vista terraces," page 181.

Sweetwater Valley.—Prior to submergence Sweetwater Valley was very narrow, the bottom being only a few hundred feet wide. In general the fill resembles that of Tia Juana Valley. In the lower part of the valley the depth of sand is about 60 feet. The layer of

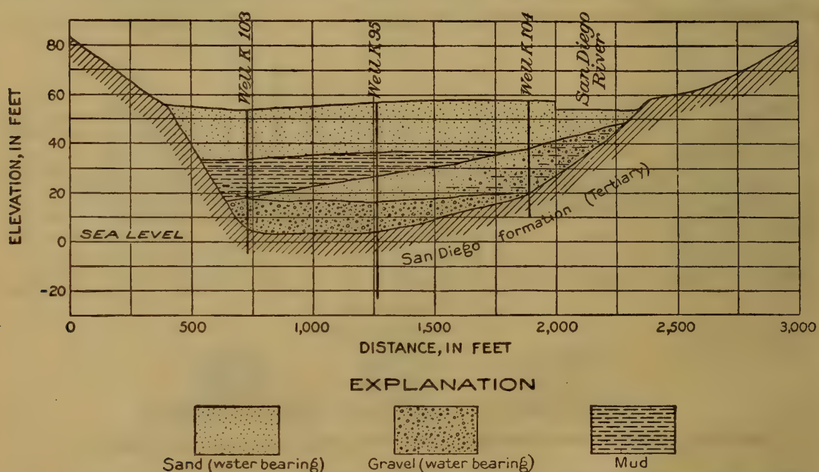


FIGURE 11.—Diagrammatic cross section of Mission Valley along line B–B, Plate XXI.

gravel and boulders beneath the sand in the bottom of the ancient valley exceeds 7 feet in depth. In five wells near Sweetwater Junction (O 72) the total depth of the fill was found to be more than 67 feet but less than 80 feet. In the upper part of the valley the sands are much coarser but no logs were obtained of wells that penetrated to the gravels. The total depth of the fill is probably less than in the lower part of the valley. The limits of the valley fill are shown on Plate XX. The best places for wells will be found in areas underlain by coarse sands or by gravels lying at the bottom of the ancient valley.

Mission Valley.—Prior to submergence, Mission Valley had a bottom width varying from 900 feet just below San Diego Mission (fig. 11 to 1,500 feet at Old Town (fig. 12). Above the mission the width is probably less than 500 feet. The floor of the ancient valley was formed by the relatively impervious formations that underlie the mesa on either side of the valley, as is shown by the logs of wells K 64, K 93, K 95, K 97, and K 105 (Pl. XXVIII, fig. 13, and Pl. XXI). The valley fill is similar to that of Tia Juana Valley as is shown by figures 11, 12, and 13. The gravels lie on the floor of the ancient valley, just as in the Tia Juana Valley. The depth of the gravels ranges in general from 10 to 20 feet, the depth of the overlying sand from about 20 feet at the upper end of the valley to about 65 feet at the lower end and the total depth of the fill from about 40 feet at the upper end of the valley to nearly 80 feet at the lower end (fig. 13). The existence of interbedded clay and other fine material in the valley fill opposite lateral canyons is shown by the log of well K 75 near Old Town (fig. 12). Deposits of this kind may be encountered in the vicinity of other lateral canyons. This material does not yield water readily and is to be avoided in locating wells. The bottom of the

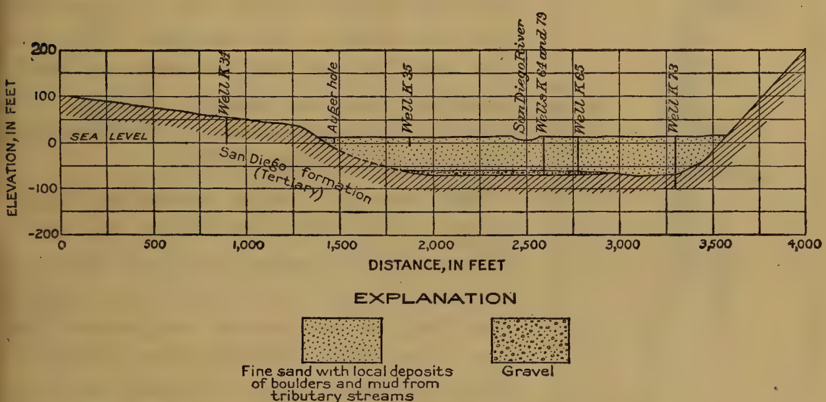


FIGURE 12.—Diagrammatic cross section of Mission Valley along line A–A, Plate XXI.

old valley does not, as a rule, lie beneath the middle of the present valley, but swings from side to side, its position depending on the direction of the current of the ancient stream. Its probable position can be determined in some places by a study of the walls of the present valley. Where it is not possible to do this, the logs of adjacent wells are the only guide. Wells that do not penetrate the gravels at the bottom of the old valley yield small supplies and are not so satisfactory as the deeper ones.

It is much more difficult to determine the best places for wells in Mission Valley than in Tia Juana Valley, because the ancient Mission Valley was narrower and more winding. The logs of 21 wells in the deep fill of Mission Valley, shown in Plate XXVIII, indicate the different formations to be found in various parts of the valley. The limits of the deep valley fill are shown in Plate XXI. It should be noted, however, that these limits are considerably wider than the bottom of the ancient valley and that all wells put down within these

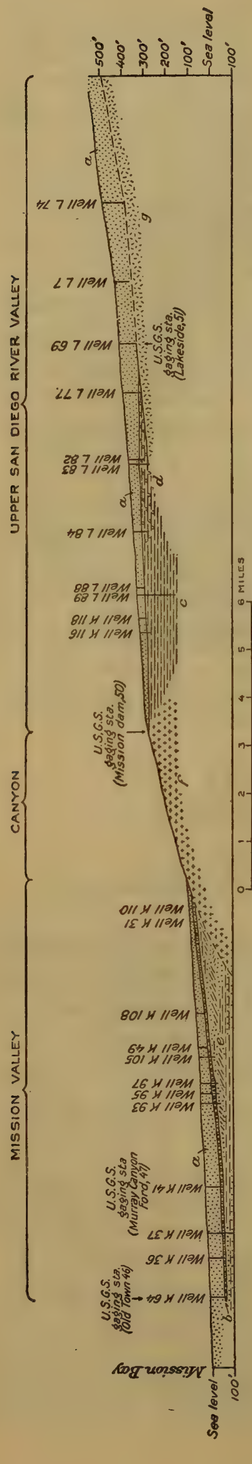
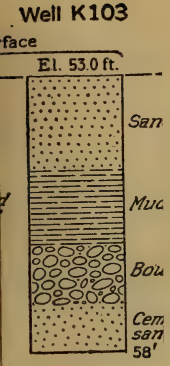


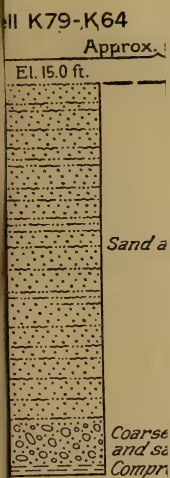
FIGURE 13.—Diagrammatic longitudinal section of San Diego River valley following approximately the deepest portion of the ancient river valley.

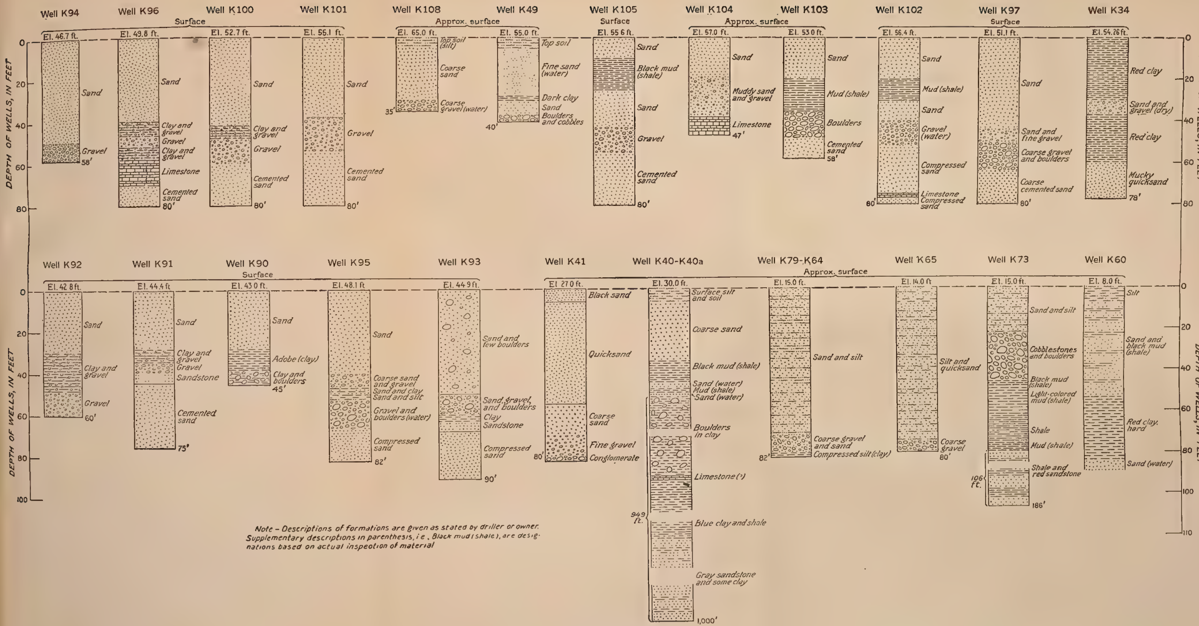
limits will not penetrate the gravels. Other wells not shown on Plate XXVIII, of which incomplete information was obtained, are as follows: Well K 31, 26 feet deep, passes through sand and ends in coarse gravel; well K 110, 20 feet deep, also passes through sand and ends in coarse gravel; well K 36, consisting of a group of five wells, said to be from 62 to 78 feet deep, all end at a bed of cobblestones cemented with clay.

San Dieguito Valley.—San Dieguito Valley is much shorter than Mission Valley, but the conditions in it are similar. No well logs were obtained, but it is probable that the width of the ancient valley bottom and the depth and character of the fill resemble those of Mission Valley. The limits of the deep valley fill are shown approximately on Plate XXIII.

San Luis Rey Valley.—Prior to the submergence San Luis Rey Valley was deeper than any of the coastal valleys to the south and had, in fact, the character of a canyon. The floor of the ancient canyon and that part of its walls which is now covered by valley fill were formed by strata which underlie the beds that outcrop in the walls of the present valley and which are in general similar to these beds. (See pp. 53-66.) The width of the old canyon bottom is approximately 1,500 feet, as is indicated in the cross section along the line A–A, Plate XXV (fig. 14). The fill resembles generally that of the other valleys to the south. At the section along the line A–A a more pronounced segregation of fine material is exhibited than in any other valley. At the bottom is a layer of water-bearing gravel about 20 feet thick; above this is a layer of sand and fine gravel about 70 feet thick; and above this a layer of fine sand, quicksand, or mud 125 feet thick extends across the full width of the valley. The maxi-


Well K103
face
El. 53.0 ft.
San
Muc
Bou
Cem
san
58'


ll K79-K64
Approx.
El. 15.0 ft.
Sand a
Coarse
and sa
Compr



SECTIONS OF WELLS IN MISSION VALLEY.

mum depth of the fill along this line is 215 feet. (See also fig. 15.) The log of well F 12, as recalled from memory by the driller, showed bedrock at a depth of about 200 feet overlain by 40 feet of gravel, the material above the gravel being sand and silt. Wells west of San Luis Rey Mission are reported to have reached a depth of about 200 feet in the valley fill. Well F 4 is said to have encountered 16 feet of gravel at the bottom of the fill, the fill being overlain by sand and resting on bedrock at a depth of 168 feet. A well 4 miles up the canyon, near the mouth of Gopher Canyon, encountered bedrock at 58 feet, the material of the fill being sand with two shallow layers of gravel down to a depth of 46 feet, followed by a 12-foot layer of gravel and boulders. Apparently the fill ranges in maximum depth from about 170 feet at the head of the valley just west of the Guajome ranch to about 215 feet in the lower part of the valley. The narrow

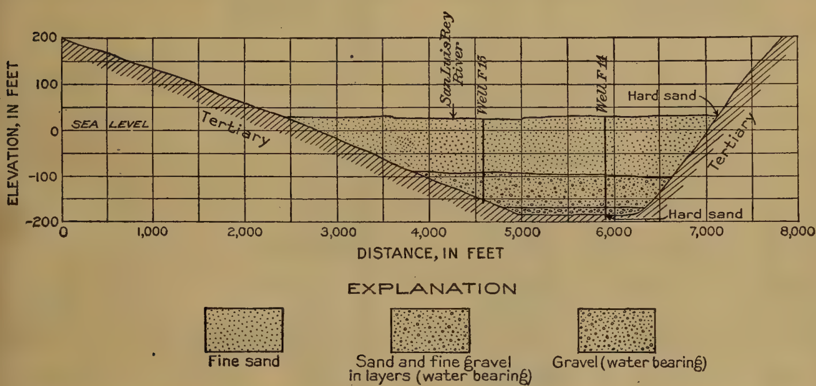


FIGURE 14.—Diagrammatic cross section of San Luis Rey Valley along line A–A, Plate XXV.

width of the old canyon bottom, the resulting small area covered by the gravels, and the unusually large proportion of overlying fine material render it very difficult to place successful wells. The only wells from which a good yield is assured are those that penetrate to the gravels. The same methods can be followed in determining the position of the channel as were suggested for Mission Valley, but owing to the greater width of the modern valley, however (Pl. XXV), the problem is more difficult than in Mission Valley.

Santa Margarita Valley.—Although Santa Margarita Valley was not carefully studied, conditions in it are supposed to be similar to those in San Luis Rey Valley. Wells in this valley are said to reach bedrock at a depth of about 200 feet, a fact indicating that the depth of the fill is about the same as in San Luis Rey Valley. Inspection of the limits of the valley fill as shown on Plate XXV suggests that the bottom of the old canyon is little if any wider than in that valley.

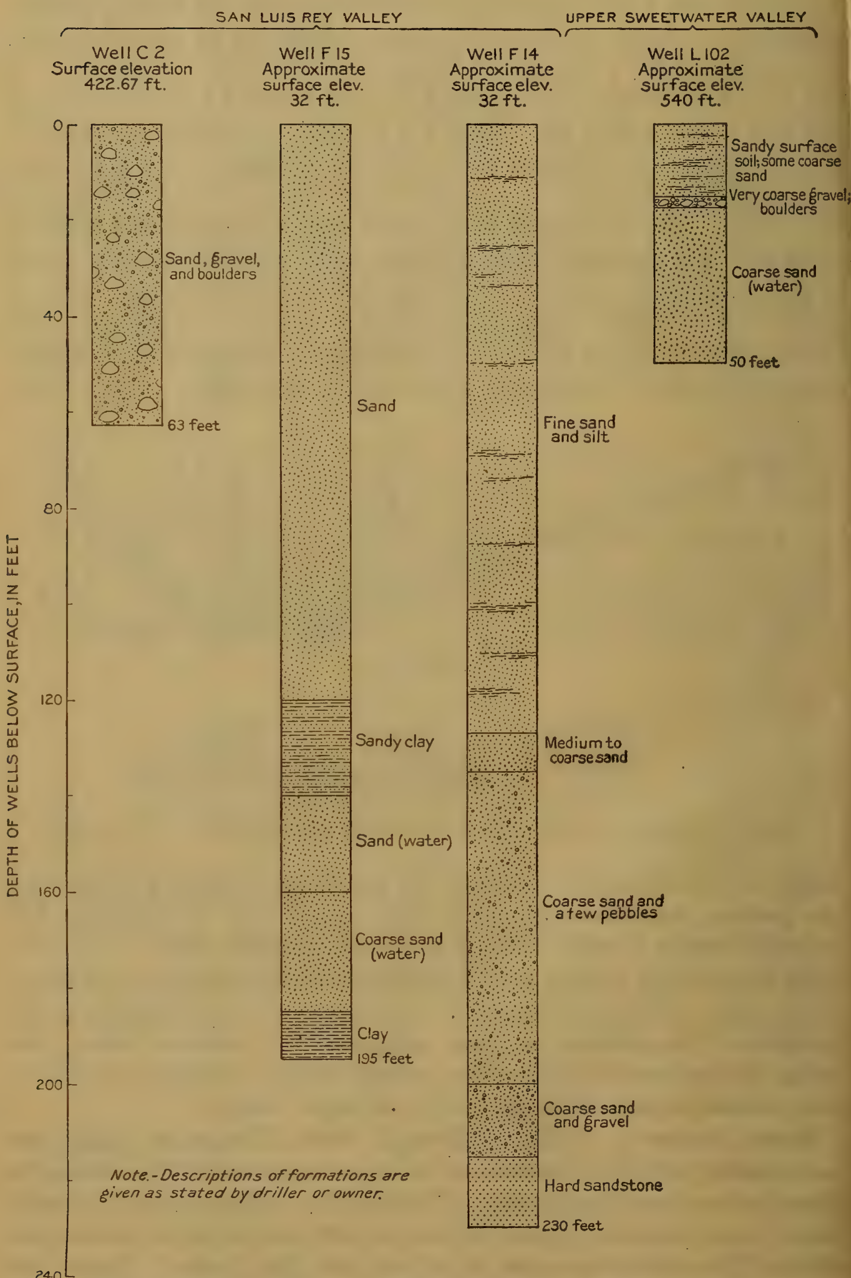


FIGURE 15.—Sections of wells in upper San Luis Rey and upper Sweetwater valleys.

HIGHLAND VALLEYS.

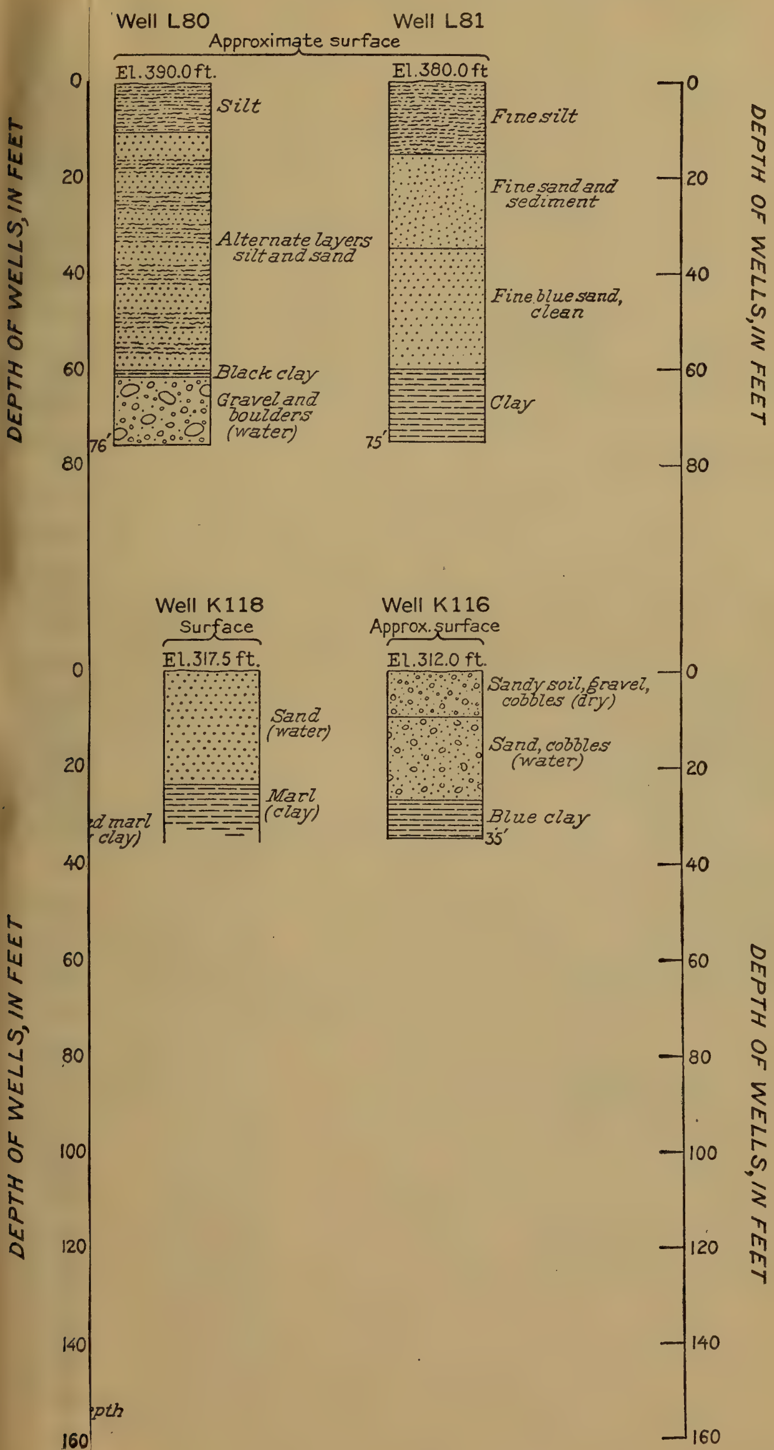
The major river valleys of the highland area are ancient valleys which at some stage of their geologic history were mountain canyons and which have been filled to their present levels with alluvial débris deposited by the streams that enter and traverse them. The ancient canyons were cut into the granite rocks that underlie the modern fill. These canyons were more or less winding and of varying width. They were, in fact, similar to the many canyons that can be seen to-day in the highland area. The filling of the ancient canyons resulted from diverse causes, and they will be described separately.

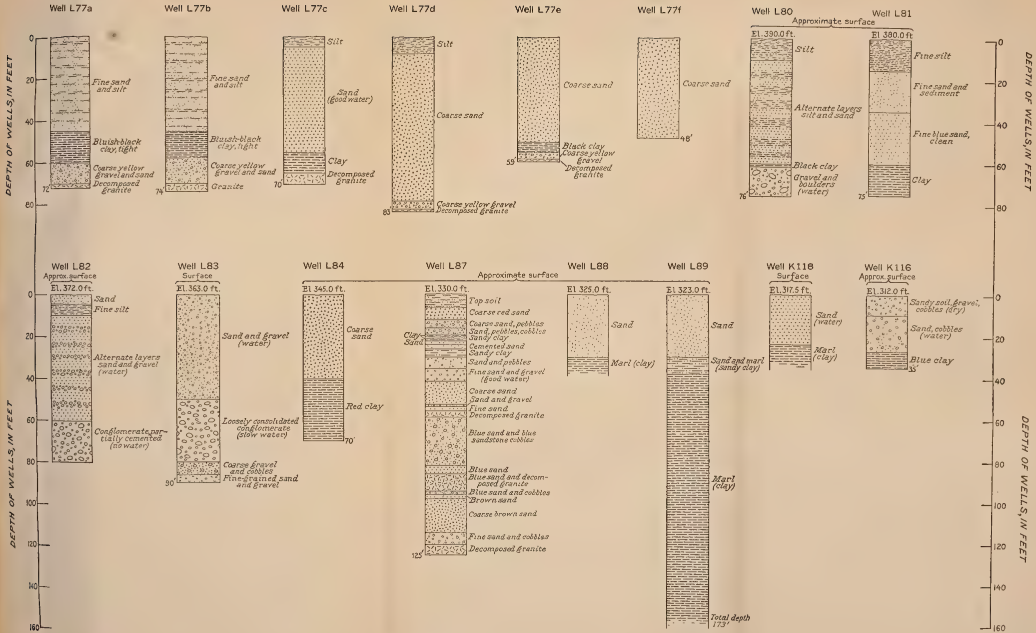
Upper Sweetwater Valley.—On the west upper Sweetwater Valley is limited by the chain of hills, composed of porphyry, which extends along the margin of the coastal plain from the international boundary almost to the San Luis Rey River. The porphyry is exposed in the present bed of Sweetwater River in the canyon at the Sweetwater dam, where the stream cuts through the formation, but above the canyon the old rock bed of the stream is covered by valley fill. No logs of wells that penetrate the entire thickness of the fill have been obtained in this valley. Well L 102 (fig. 15) passed mostly through coarse water-bearing sand, and reached a depth of 50 feet without encountering bedrock. The four wells designated L 100 are spaced 100 feet apart in a line across the channel of Sweetwater River. They are 45 feet deep and only the well nearest the hill on the south reached bedrock. The material was coarse sand and silt in layers. Well L 41 reached a depth of 34 feet in coarse sand and gravel without reaching bedrock. The 18 wells designated P 24 are 38 feet in average depth, but no information was obtained as to bedrock. So far as known, the fill consists chiefly of fine and coarse sand with occasional layers of fine gravel. The coarse sand predominates, particularly in the upper part of the valley. The total depth of fill is probably not more than 80 feet at the upper end of the valley and probably much less toward the lower end, below Jamacho.

Upper San Diego River valley.—The geologic history of upper San Diego Valley is probably somewhat similar to that of upper Sweetwater Valley. (See fig. 13 and Pl. XXIX.) An interesting feature of the fill is a deposit of clay, merging upstream into gravel and boulders more or less cemented with clay, that underlies the sand for the first 5 miles above the Old Mission dam. This deposit suggests the former existence of a body of still water behind the range of porphyritic rocks, into which the river discharged. The coarser material transported by the river would naturally be deposited at the upper end of the lake and the finer material would be carried out and spread over the lake bottom. The filling of the lake and subsequent aggradation would result in the accumulation of coarse débris over the surface formerly occupied by the lake, while the fine material, held in suspension by the flowing water, would be carried on through the basin. This process would ultimately build up alluvial débris to the new grade of the river under the changed conditions. This action is suggested by the profile of the valley fill as shown by figure 13. The water-bearing part of the valley fill—the sand and fine gravel overlying the clay and cemented gravel—varies in depth from a few feet at the lower end of the valley to more than 100 feet above the mouth of San Vicente Creek, opposite Lakeside. Four drilled wells, designated L 74 (Pl. XXII), pass through coarse sand and gravel. One of these wells is said to be 111 feet and another 129 feet deep. Three wells designated L 73 are about 45 feet deep and end in coarse sand. Wells L 7 *a* to L 7 *d* are 70 feet deep and end in coarse sand. Five wells designated L 69 are reported by the driller to be 80 to 85 feet deep and to end in coarse sand. The logs of other wells are shown on Plate XXIX. The sand becomes finer toward the lower end of the valley, particularly below Riverview Station, and in some wells considerable trouble is caused by clogging of screens with fine material.

The character and depth of material in the fill of Foster Valley along San Vicente Creek are indicated by the following information furnished by owners or drillers of wells. The five drilled wells designated L 60 (Pl. XXII) end in clean coarse sand mixed with gravel and at an average depth of 95 feet. Well L 61, 78 feet deep, passes through 40 feet of sand and gravel, 10 feet of black mud or silt and 28 feet of sand, gravel, and boulders. Well L 62, 77 feet deep, penetrates about 30 feet of black mud similar to that in well L 61. Well L 64, 78 feet deep, passes through 40 feet of silt and sand, fine to coarse, merging into boulders 8 to 10 inches in diameter at the bottom.

San Pasqual Valley.—The history of San Pasqual Valley is similar to that of the upper Sweetwater and San Diego river valleys, although it affords no indications of the existence of such a body of still water as may have existed in upper San Diego River valley. The depth to bedrock has not been determined, as few if any of the wells in the open valley reach the granite. The following wells, whose location is shown on Plate XXIV, indicate the character of the fill. Well H 30, 150 feet deep, passed through sand and silt to a hard boulder or bedrock which was too hard to drill with the sand bucket. The depth of the fill in the main valley probably exceeds that of the tributary canyon in which this well is located. The material encountered was much finer in this well than in the main valley and the well has never been used on account of its small yield. Well H 33, 60 feet deep, penetrated sand and gravel. Well H 35, 86 feet deep, passed through sand, gravel, and silt, with boulders at


Well L80
Well L81
Approximate surface
El. 390.0 ft.
Silt
Alternate layers silt and sand
Black clay
Gravel and boulders (water)
76'
El. 380.0 ft
Fine silt
Fine sand and sediment
Fine blue sand, clean
Clay
75'
Well K118
Surface
El. 317.5 ft.
Sand (water)
Marl (clay)
Well K116
Approx. surface
El. 312.0 ft.
Sandy soil, gravel, cobbles (dry)
Sand, cobbles (water)
Blue clay
35'
DEPTH OF WELLS, IN FEET
0
20
40
60
80
100
120
140
160



SECTIONS OF WELLS IN UPPER SAN DIEGO RIVER VALLEY.

the bottom. Well H 2, 40 feet deep, passed through sand which was coarse at the bottom. Well G 31, 77 feet deep, passed through 6 feet of clay and then through sand and gravel, with large boulders at the bottom. Well G 30, 52 feet deep, penetrates sand, silt, and gravel, the formation at the bottom being coarse sand and boulders. Well G 29, 80 feet deep, encountered silt for the first 10 feet, very coarse sand for 30 feet, coarse to medium sand rather sticky and yielding water slowly for 30 feet, and decomposed granitic bedrock for the last 10 feet. Wells G 31, G 30, and G 29 are all in a tributary valley, but their records give information in connection with the probable depth of the main valley. Well G 33 is 93 feet deep and passed through silt and sand, the latter being coarse at the bottom. Wells G 35 and G 34 are 45 feet deep and pass through sand and gravel. The sand of the main river valley yields water readily.

Upper San Luis Rey Valley.—The fill of upper San Luis Rey Valley has unbroken connection with the fill of the coastal valley (Pl. XXV) and evidently occupies a deeper valley or canyon which was formerly a continuation of the ancient coastal valley. Filling has resulted from submergence. Well logs show that the depth of the fill in the canyon below Bonsall is 60 feet. Well C 41 is 75 feet deep and passes through coarse sand and fine gravel. According to the driller the eight wells designated C 8 encountered bedrock at 60 feet and penetrated sand with boulders at the bottom. Well C 2 (fig. 15) encountered coarse gravel and boulders to a depth of 63 feet without reaching bedrock. Where the present valley is wide the best water-bearing material would probably be found near the old channel.

POROSITY.

The voids between the particles of silt, sand, and gravel composing the valley fill of the principal river valleys contain the stored ground water. The percentage of porosity varies in different materials and even in different parts of the same material, according to the relative size and arrangement of the individual particles. Experiments made by the writer on 36 samples from the fill of the major river valleys of San Diego County, the material varying from coarse sand to silt, indicated total voids expressed as per cent by volume as follows: Coarse sand, 39 to 41 per cent; medium sand, 41 to 48 per cent; fine sand, 44 to 49 per cent; fine sandy loam, 50 to 54 per cent. The average porosity of all 36 samples was 45.1 per cent. The classification of materials is that used by the Bureau of Soils of the United States Department of Agriculture. These percentages represent the porosity of the material under natural condition as to size and arrangement of grains. The method of determining porosity was as follows:

A pit was dug to the level from which it was desired to take the sample, a part of the bottom being excavated to a further depth of about a foot so as to leave a vertical face; a metal cylinder $5\frac{5}{8}$ inches in inside diameter and 9 inches long, the lower edge being beveled from the outside so as to make a cutting edge, was pressed down vertically, cutting out a core of undisturbed material; the material was then carefully dug away from the front of the cylinder and a stiff sheet of metal pushed under to cut off the sample at the bottom of the cylinder; the metal plate and cylinder were then removed and the top of the sample was leveled off. This method gave a sample of the known volume as it existed in its natural state. The sample was then oven-dried and the specific gravity of a selected portion determined. The porosity was then computed by the following formula:

$$P=100\left(1-\frac{w}{W}\right)$$

in which P = Porosity expressed in percentage
w = Specific gravity of the dried sample
W = Average specific gravity of the minerals comprising the sample.

A certain proportion of the moisture that occupies the voids of any saturated porous material does not readily drain out, even when the zone of saturation has fallen below the depth from which the capillary rise of water is rapid. This moisture can not be extracted by pumping nor does it represent water that drains out and is replenished during the natural fall and rise of the water table. To determine the water-retaining capacity of various valley-fill materials, six experiments were made after the annual summer lowering of the water table had taken place. The water-retaining capacity was found to range from 6 to 10 per cent in the coarse, medium, and fine sands, but no finer materials were examined where the depth to the water table was great enough to enable the field capacity to be determined with certainty. Etcheverry,[1] quoting from Widtsoe's extensive experiments, gives the water-retaining capacity of sandy loam as $14\frac{1}{2}$ per cent by weight, which is equal to about 22 per cent by volume, and this percentage can be considered as representing roughly the condition in sandy loam soils of the major river valleys under consideration. The total volume of water that might be drained from the valley fill by the slow lowering of the water table can be estimated as ranging from about 33 to 37 per cent by volume. Such complete drainage, however, requires considerable time, and the relatively quick drainage resulting from the artificial lowering of the water table by pumping

[1] Etcheverry, B. A., Irrigation practice and engineering, vol. 1, p. 4, New York, McGraw-Hill Book Co., 1915.

undoubtedly represents the extraction of far less of the total water content. In practice the proportionate volume that could be extracted from the valley fill of the major valleys probably does not exceed 20 to 25 per cent. In other words, a general lowering of the water table of 1 foot by pumping would represent, on the average, an extraction of 65,000 to 81,000 gallons from each acre of valley fill.

The method used by the writer for determining the water-retaining capacity was as follows: Pits were sunk to the ground water at points selected so as to give differing distances to the water table and differing types of material. Samples of the material were taken at intervals of a foot from the surface down to the water table, as described above for porosity samples. The initial weight of the samples with the contained moisture was ascertained immediately after removal from the pit, and the dry weight was obtained after oven drying; the difference in weight, representing the retained water expressed as a percentage by volume, gave the percentage of retained water by volume when divided by the initial volume of the sample. This percentage was found to vary at different distances above the water table. The maximum was at the water table, where the material was saturated and the percentage of initial moisture was practically equal to the total porosity of the material; the minimum occurred near the surface of the ground but at a depth sufficiently great to be beyond the range of evaporation. It was found that by representing the data graphically, the water-retaining capacity of samples ranging from coarse to fine sand could be approximately ascertained by inspection. The zone of saturation was too near the surface, however, to enable this to be done with finer materials.

The volume of water represented by the annual rise and fall of the zone of saturation was computed from these same diagrams. For the average annual fluctuation of approximately 3.5 feet, it was found that the effective porosity—that is, the difference between the total porosity and the water-retaining capacity—ranged from an average of 41 per cent for sand of differing grades and with differing depths to the water table, to 16 per cent for fine sandy loams. The average for the six typical conditions studied was 34 per cent.

THE WATER TABLE.

FORM AND SLOPE.

The water table is the surface below which the voids of any extended body of porous material are completely filled with water. Although the voids above the surface usually contain either capillary or hydroscopic water, such water occupies only a portion of the total void space. The water table of an underground reservoir corresponds to the surface of an ordinary lake or reservoir. It is seldom a level surface, however, as is an ordinary water surface, but has an appreciable slope which varies at different places and at the same place at different times of the year. In general, in the major valleys, it has the slope and to some extent the form of the ground surface, although important differences exist. Its depth below the surface in the major valleys of San Diego County varies at different times of the year and in different parts of the valleys from a few inches to as much as 20 feet, but the average depth is close to 5 feet. The position of the water table is represented by the level of standing water in wells.

Knowledge of the position, slope, and fluctuation of the water table is essential in the study of ground-water problems. To obtain such information the writer selected 87 wells in the major river valleys of San Diego County, and made observations of the depth to the water level at intervals of one month or less from September, 1914, to August, 1915. In upper Sweetwater Valley the Sweetwater Water Co. cooperated in making observations on the selected wells. Observations were also made by the writer at 34 wells that had been more or less regularly observed since 1912 by the United States Geological Survey, the Vulcan Land & Water Co., and the Cuyamaca Water Co. Observations were also made at a well observed prior to September, 1914, by Mr. Lebert, of San Diego. The total number of wells observed during the season 1914–15 was 122. The location of each of these wells is shown on Plates XX to XXV. Wells were selected which were representative of ground-water conditions in the vicinity and which, with other wells, would give comprehensive information in regard to the water table over whole valleys. Wells that were not likely to be influenced by abnormal local conditions, such as pumping or irrigation, were preferred to others. A permanent bench mark was chosen at each well from which vertical measurements to the water surface could be made with a steel tape. The accurate elevation above sea level of all bench marks was determined instrumentally from the nearest bench mark of the United States Geological Survey, and all water-level observations were referred to sea level.

A complete list of wells in which a series of water level measurements were made is given by number, in Table 45 (p. 209), together with the location, owner's name, class of well, depth of well, elevation of ground surface, description and elevation bench mark, geologic source of water, and local conditions of surface and vegetation. This table includes records of all wells observed by the writer, not only in the fill of major valleys but also in other water-bearing formations. The column headed "geologic source of water" designates the formation from which the well derives its water, the terms "deep valley fill" and "shallow fill or major river valleys" both applying to wells in the major river valleys. These terms are used to distinguish the deeper parts of the fill or major river valleys, in which the best water-bearing formations occur, from the shallower parts in which the fill is thin and contains but little gravel or coarse sand. The approximate limits of each of these formations is shown on Plates XX to XXV.

The individual observations at all record wells are too numerous to be presented in this report, but summaries and typical records are given in Table 30, covering observations during the period September, 1914, to August, 1915, and Table 31, which covers the period March, 1912, to August, 1915. The fluctuations are shown graphically in Plates XXX to XLII and figures 16 to 18.

TABLE 30.—*Summary of observations of water level at wells in San Diego County during season of 1914–15.*

[For summary for wells observed prior to 1914–15, see Table 31.]

Well No.	Geologic source of water.	Elevation of ground surface.	Lowest level observed.		Highest level observed.		Rise during season 1914–15.	Remarks.
			Date.	Elevation.	Date.	Elevation.		
		Feet.		*Feet.*		*Feet.*	*Feet.*	
C 2	Deep fill of major valley	422.67	Jan. 10, 1915	411.37	Mar. 2, 1915	412.56	1.19	Record started Jan. 10, 1915.
C 5	do							Destroyed before elevations determined.
C 6	do	165.24	Nov. 13, 1914	159.73	Feb. 24, 1915	161.32	1.59	
C 7	do	155.00	do	153.62	May 5, 1915	155.14	1.52	U. S. G. S. river gage at Bonsall.
D 2	do	863.07	Nov. 12, 1914	847.61	May 6, 1915	850.97	3.36	
D 3	do	874.74	Jan. 8, 1915	862.35	Mar. 3, 1915	867.67	5.32	
F 4	do	72.70	Jan. 9, 1915	61.95	May 5, 1915	70.06	8.11	
F 10	do	7.08	July 29, 1914	4.17	do	6.12	1.95	
F 18	do							Destroyed before elevations determined.
H 17	Residuum	1,436.16	Jan. 8, 1915	1,426.59	Feb. 25, 1915	1,433.37	6.78	
H 34	Deep fill of major valley	425.00	Nov. 11, 1914	422.87	Mar. 11, 1915	426.42	3.55	River channel.
H 36	do	462.27	do	450.24	Feb. 25, 1915	460.36	10.12	
H 37	Residuum	1,438.01	Nov. 10, 1914	1,410.26	June 1, 1915	1,413.26	3.00	
H 38	do	1,424.65	do	1,411.39	Mar. 11, 1915	1,418.47	7.08	
K 31	Deep fill of major valley	94.00	Jan. 25, 1915	84.80	Feb. 18, 1915	92.81	8.01	
K 33	do	11.23	Nov. 7, 1914	3.95	Feb. 12, 1915	8.65	4.70	
K 34	San Diego formation	54.26	do	7.46	Mar. 31, 1915	9.80	2.34	
K 35	Deep fill of major valley	14.82	do	6.15	Feb. 12, 1915	12.47	6.32	
K 44	do	23.54	Oct. 1, 1914	17.33	Feb. 27, 1915	23.10	5.77	
K 46	Shallow fill of major valley	44.00	Oct. 22, 1914	33.96	Feb. 18, 1915	37.59	3.63	
K 48	Deep fill of major valley	54.40	Jan. 7, 1915	44.08	do	49.74	5.66	
K 51	do	72.67	Oct. 22, 1914	59.18	do	65.07	5.89	
K 52	do	72.00	Nov. 7, 1914	67.89	May 3, 1915	71.33	3.44	
K 61	do	14.07	do	4.09	June 2, 1915	6.42	2.33	
K 62	do	14.19	do	4.50	Feb. 12, 1915	9.06	4.56	
K 65	do	13.55	do	6.96	Feb. 27, 1915	13.15	6.19	
K 70	do	15.34	do	7.01	Jan. 31, 1915	11.47	4.46	
K 71	do	13.86	do	6.98	do	11.47	4.49	
K 72	do	11.86	do	6.96	Feb. 12, 1915	12.08	5.12	
K 73	do	14.34	do	7.10	do	13.20	6.10	
K 74	do	18.22	do	6.97	Jan. 31, 1915	11.41	4.44	
K 75	do	10.75	do	6.90	Feb. 27, 1915	10.84	3.94	Submerged Jan. 29 to Feb. 27, 1915.
K 76	do	8.75	do	6.91	do	10.74	3.83	Do.
K 77	do	9.25	do	6.92	do	10.70	3.78	
K 78	do	12.55	do	6.85	Feb. 12, 1915	12.08	5.23	
K 79	do	15.00	do	7.00	do	12.58	5.58	
K 80	do	14.82	do	7.49	do	14.30	6.81	
K 81	do	17.54	do	11.10	Feb. 4, 1915	15.66	4.56	

K 82	Shallow fill of major valley	22.64	do	14.44	Feb. 18, 1915	20.47	6.03	
K 83	Deep fill of major valley	23.98	do	14.60	do	20.63	6.03	
K 84	do	28.39	Oct. 21, 1914	17.88	do	23.39	5.51	
K 85	do	25.00	Nov. 7, 1914	22.21	Feb. 12, 1915	27.43	5.22	U. S. G. S. river gage at Murray Ford.
K 86	Fill of minor valley	34.80	Jan. 7, 1915	22.60	Feb. 27, 1915	32.05	9.45	
K 87	Shallow fill of major valley	57.53	Dec. 7, 1914	32.14	Feb. 18, 1915	35.92	3.78	
K 88	Deep fill of major valley	41.16			May 3, 1915	39.10		Record started Mar. 17, 1915.
K 89	do	41.93			Mar. 17, 1915	38.91		Do.
K 98	do	46.69	Jan. 27, 1915	42.13	Feb. 4, 1915	47.43	5.30	
K 99	do	47.79	do	42.03	Jan. 31, 1915	47.67	5.64	
K 106	Fill of minor valley	68.00	Jan. 7, 1915	61.49	Feb. 27, 1915	63.68	2.19	
K 109	San Diego formation	76.00	Oct. 22, 1914	64.94	Feb. 18, 1915	71.88	6.94	
K 115	Fill of minor valley	304.00	do	296.63	Feb. 26, 1915	302.17	5.54	
L 5	Deep fill of major valley	412.00	Nov. 10, 1914	400.13	Mar. 11, 1915	405.55	5.42	
L 7e	do	437.20	Oct. 23, 1914	426.67	Feb. 13, 1915	431.92	5.25	
L 7f	do	437.25	do	426.62	do	431.87	5.25	
L 7g	do	438.00	do	426.71	do	431.94	5.23	
L 7h	do	438.20	do	426.75	May 4, 1915	431.77	5.02	
L 7i	do	438.60	do	426.44	do	432.02	5.58	
L 7j	do	438.50	do	426.42	do	431.92	5.50	
L 7k	do	438.50	do	426.87	do	431.94	5.07	
L 7l	do	438.20	do	426.51				Buried after Jan. 8, 1915.
L 7m	do	437.80	do	426.33	May 4, 1915	432.01	5.68	
L 7n	do	438.00	do	426.29	do	432.04	5.75	
L 7o	do	437.60	do	426.64	do	432.06	5.42	
L 7p	do	437.60	do	426.86	do	432.20	5.34	
L 7q	do	437.40	do	427.04	do	432.23	5.19	
L 7r	do	437.60	do	427.04	Feb. 13, 1915	432.26	5.22	
L 24	Residuum	435.00						
L 40	do	501.00	Dec. 31, 1914	483.95	May 10, 1915	494.95	11.00	
L 41	Deep fill of major valley	405.87	Dec. 5, 1914	396.84	do	401.70	4.86	
L 42	do	386.85	Oct. 6, 1914	378.19	June 8, 1915	382.18	3.99	
L 63	do	428.28	Nov. 10, 1914	417.83	Mar. 10, 1915	424.78	6.95	
L 68a	do	408.44	do	397.59	Feb. 13, 1915	403.04	5.45	
L 71	do	454.02	Oct. 23, 1914	447.00	Feb. 3, 1915	450.98	3.98	Maximum elevation is for flood peak between Jan. 29, 1915, and Feb. 8, 1915.
L 72	do	467.40	Dec. 7, 1914	458.92	Mar. 11, 1915	461.11	2.19	
L 78	Fill of minor valley	400.85	Nov. 10, 1914	387.52	June 1, 1915	392.85	5.33	
L 79	do	400.00			do	395.79		Record started Apr. 6, 1915.
L 83	Deep fill of major valley	363.00	Nov. 10, 1914	353.64	May 4, 1915	360.44	6.80	Maximum elevation at time of late flood in river.
L 85	Shallow fill of major valley	335.00			Mar. 10, 1915	328.14	5.74	Substituted for well L 86 Mar. 10, 1915.
L 86	do	328.00	Nov. 10, 1914	322.40			5.74	Destroyed between Feb. 26 and Mar. 10, 1915.
L 96	Residuum	441.58	Jan. 17, 1915	427.31	Mar. 10, 1915	436.72	9.41	
L 99	Deep fill of major valley	450.89	Oct. 7, 1914	436.75	May 10, 1915	440.37	3.62	Maximum elevation when river flowing.
L 101	do	507.32	Nov. 16, 1914	486.92				
L 103	do	512.00						Varies about 5 feet.
L 104	do	516.07	Dec. 31, 1914	502.57	May 10, 1915	511.07	8.50	Maximum elevation when river flowing.
L 105	Shallow fill of major valley							Varies about 4 feet.
O 18	Deep fill of major valley	89.48	Jan. 7, 1915	81.24	Feb. 19, 1915	84.13	2.89	Maximum elevation when river flowing.
O 21	do	57.78	Nov. 6, 1914	54.20	Feb. 1, 1915	55.30	1.10	
O 26	do	28.29	do	22.28	Mar. 13, 1915	25.61	3.33	

TABLE 30.—*Summary of observations of water level at wells in San Diego County during season 1914–15*—Continued.

Well No.	Geologic source of water.	Elevation of ground surface.	Lowest level observed.		Highest level observed.		Rise during season 1914–15.	Remarks.
			Date.	Elevation.	Date.	Elevation.		
		Feet.		*Feet.*		*Feet.*	*Feet.*	
O 29	San Diego formation	61.44	Dec. 5, 1914	10.88	June 4, 1915	11.52	0.64	
O 34	do	53.08	Oct. 2, 1914	3.80	Mar. 15, 1915	7.32	3.52	
O 35	do	22.60	do	4.20	Feb. 14, 1915	11.11	6.91	
O 35a	do	22.60	Oct. 12, 1914	6.76	do	12.26	5.50	Seriously affected by pumping in vicinity.
O 38 (Pit.)	Fill of minor valley	23.30	Oct. 9, 1914	6.20	do	14.95	8.75	
O 39	San Diego formation	55.25	Oct. 30, 1914	20.80	Mar. 3, 1915	23.56	2.76	Affected by pumping in vicinity.
O 40	do	55.17	do	19.56	do	28.32	8.76	
O 41	Fill of minor valley	41.00	do	27.08	Mar. 15, 1915	34.39	7.31	
O 42	do	57.00	Oct. 2, 1914	38.25	do	45.97	7.72	Maximum elevation when river flowing.
O 46	San Diego formation	41.60	Oct. 30, 1914	6.59	June 4, 1915	8.43	1.84	
O 47	do	24.10	Sept. 25, 1914	1.91	Mar. 30, 1915	3.47	1.56	
O 47a	do	20.60	do	1.90	June 5, 1915	3.50	1.60	
O 48	do	33.00	Oct. 8, 1914	6.77	May 1, 1915	8.72	1.95	
O 50	Deep fill of major valley	9.82	Oct. 12, 1914	1.52	Mar. 15, 1915	7.28	5.76	
O 55	do	24.20	Jan. 21, 1915	15.94	June 29, 1915	20.90	4.96	
O 61	do	58.10	Jan. 6, 1915	50.74	May 1, 1915	54.46	3.72	
O 70	Dan Diego formation	112.20	Oct. 29, 1914	10.75	July 30, 1915	11.68	0.93	
O 71	Deep fill of major valley	17.36	Oct. 9, 1914	10.44	Feb. 19, 1915	13.66	3.22	
O 73	do	29.14	Dec. 5, 1914	20.33	Mar. 13, 1915	23.09	2.76	
O 74	San Diego formation	31.00	Oct. 29, 1914	23.42	Mar. 25, 1915	25.88	2.46	
O 75	do	131.39	do	91.54	Feb. 27, 1915	92.08	0.54	
O 76	Deep fill of major valley	63.80	do	59.42	Feb. 1, 1915	60.74	1.32	
O 78	do	83.16	Nov. 6, 1914	78.69	Feb. 27, 1915	79.62	0.93	
O 79	do	86.94	Dec. 5, 1914	80.59	Feb. 19, 1915	83.17	2.58	
O 80	do	101.57	Jan. 7, 1915	87.86	Feb. 27, 1915	94.12	6.26	
O 81	San Diego formation	59.42	Oct. 30, 1914	7.93	July 30, 1915	8.10	0.17	
O 82	do	45.50	Nov. 6, 1914	7.15	June 28, 1915	7.47	0.32	
O 83	do	57.70	do	7.50	Aug. 1, 1915	7.88	0.38	
O 84	do	51.62	Oct. 2, 1914	6.57	June 4, 1915	7.39	0.82	
O 86	do	12.00	Oct. 8, 1914	2.42	Apr. 30, 1915	6.60	4.18	
O 87	Fill of minor valley	10.90	do	1.60	Mar. 1, 1915	5.59	3.99	
O 88	San Diego formation	20.20	Oct. 9, 1914	4.03	Mar. 15, 1915	8.72	4.69	
O 89	do	22.38	Oct. 2, 1914	4.00	Mar. 24, 1915	8.16	4.16	
O 90 (Casing.)	do	22.60	Oct. 9, 1914	6.10	Feb. 14, 1915	11.84	5.74	Seriously affected by pumping in vicinity.
O 91	Fill of minor valley	21.73			Apr. 8, 1915	10.43		Record started Apr. 8, 1915.
O 93	San Diego formation	50.96	Oct. 2, 1914	17.51	Apr. 30, 1915	20.42	2.91	
O 97	do	83.78	Feb. 1, 1914	37.22	June 28, 1915	38.70	1.48	
O 98	do	125.80	Jan. 6, 1915	82.68	Mar. 3, 1915	83.26	0.58	

O 99	Fill of minor valley	139.00	Nov 6, 1914	127.90	Feb. 12, 1915	134.66	6.76	Maximum elevation when river flowing.
O 103	San Diego formation	28.60	Nov. 5, 1914	5.09	Mar. 3, 1915	29.18		Becomes flooded with surface water and is not true ground water surface.
O 104	do	52.30	do	4.66	June 29, 1915	6.04	1.38	
O 105	do	26.00	Oct. 9, 1914	7.12	do	8.84	1.72	
O 106	do	32.40	Nov. 5, 1914	1.95	Mar. 15, 1915	5.23	3.28	
O 107	do	28.30	Oct. 8, 1914	7.05	May 1, 1915	8.68	1.63	
O 109	do	26.87	Sept. 25, 1914	14.18				Destroyed Nov. 5, 1914.
O 113	do	22.40	Oct. 12, 1914	7.08	Mar. 30, 1915	11.80	4.72	
O 114	do	22.30	Oct. 19, 1914	8.80	Feb. 11, 1915	20.66	11.86	Subject to flood from Tia Juana Valley.
O 115	do	27.10	Jan. 6, 1915	15.01	June 7, 1915	19.29	4.28	
O 118	Deep fill of major valley	25.00	Oct. 30, 1914	10.62	Apr. 10, 1915	19.65	9.03	
O 123	do	19.83	Oct. 12, 1914	3.34	Mar. 15, 1915	15.80	12.46	
O 127	do	25.50	Sept. 11, 1914	9.50	Mar. 3, 1915	23.19	13.69	
O 130	do	21.00	Jan. 6, 1916	(11.00)	Feb. 11, 1915	25.60	14.60	
O 136	do	38.47			Mar. 15, 1915	34.89		Substituted for well 92 on Feb. 9, 1915.
O 137	do	(38.00)	Nov. 5, 1914	29.00				Destroyed Jan. 6, 1915.
O 139	San Diego formation	39.63	Jan. 21, 1915	30.21	June 7, 1915	36.04	5.83	
O 140	Shallow fill of major valley	53.40	Jan. 19, 1915	45.94	June 5, 1915	49.52	3.58	
O 141	Deep fill of major valley	54.99	do	48.06	Mar. 1, 1915	52.75	4.69	
P 2	Residuum	363.16	Dec. 5, 1914	331.68	July 9, 1915	335.11	3.43	
P 20	Deep fill of major valley							Insufficient measurements.
P 21	Residuum	356.39	do	338.59	Feb. 19, 1915	342.34	3.75	
P 22	Deep fill of major valley	331.60	Oct. 7, 1914	325.15	do	328.54	3.39	
P 23	do	322.73	do	316.88	do	321.17	4.29	Maximum elevation when river flowing.
P 25	do	349.25			Apr. 5, 1915	341.99		
P 26	do	313.00	Oct. 7, 1914	298.57	Feb. 19, 1915	300.11	1.54	
P 26a	do	308.24	do	297.52	do	300.18	2.66	

TABLE 31.—*Summary of observations of water*

[For summary for wells observed

Well No.	Geologic source of water.	Elevation of ground surface (feet).	1912		1912–13			
			Highest level observed.		Lowest level observed.		Highest level observed.	
			Date.	Elevation (feet).	Date.	Elevation (feet).	Date.	Elevation (feet).
L 90	Deep fill of major valley	317.50			Sept. 25, 1912	308.80	Apr. 12, 1913	311.98
L 76	do	394.00			Oct. 18, 1912	386.60	do	387.60
L 65	do	412.00			do	400.30	do	402.30
L 67	do	414.00			Oct. 19, 1912	405.55	Dec. 27, 1912	406.87
L 68–b	do	408.44						
K 63[a]	do	5.70			Nov. 23, 1912	5.38	Apr. 14, 1913	6.01
K 107[b]	do	54.00			Dec. 27, 1912	53.46	Apr. 12, 1913	54.27
K 114[c]	Shallow fill of major valley	270.00			June 25, 1912	272.40	Jan. 28, 1913	272.64
L 70[f]	Deep fill of major valley	410.00			Nov. 13, 1912	406.25	May 12, 1913	407.42
L 92	Residuum	325.00			Dec. 27, 1912	314.45	May 15, 1913	315.86
K 117	Fill of minor valley	318.80			Jan. 28, 1913	312.15	Apr. 12, 1913	313.08
L 11[e]	Residuum	354.00					May 15, 1913	338.61
L 66	Deep fill of major valley	412.00			Nov. 13, 1912	402.59	Apr. 12, 1913	403.90
H 5	do	419.14			Sept. 24, 1912	413.17	Apr. 10, 1913	416.21
H 32	Residuum	420.28			July 13, 1912	407.78	Mar. 13, 1913	413.93
H 31	Deep fill of major valley	381.97			Sept. 24, 1912	380.05	do	381.90
H 1	do	379.23			do	375.96	do	377.71
G 32	Residuum	(350.)			Jan. 20, 1913	338.66	June 16, 1913	343.10
L 7–a	Deep fill of major valley	438.20			Oct. 9, 1912	427.80	Mar. 15, 1913	430.43
L 7–b	do	437.80			do	427.85	do	430.87
L 7–c	do	437.70			do	428.05	do	430.83
L 7–d	do	437.00			July 22, 1912	428.70	do	431.45
L 75[i]	do	498.40						
C 10	do	313.00	Apr. 19, 1912	307.43	Sept. 20, 1912	306.14	Feb. 20, 1913	306.69
C 9	do	265.00	Apr. 12, 1912	264.64	do	261.34	Jan. 2, 1913	263.85
B 10	Fill of minor valley	111.50	Apr. 15, 1912	102.03	Jan. 2, 1913	97.61	Mar. 8, 1913	101.19
B 11	Shallow fill of major valley	79.30	Apr. 19, 1912	70.96	Jan. 18, 1913	65.59	do	70.54
F 21[j]	Deep fill of major valley	66.90	May 21, 1912	62.88	do	55.94	Apr. 8, 1913	62.94
F 20[j]	do	63.55	do	58.99	do	53.69	do	60.30
F 19	do	54.00	Apr. 15, 1912	55.38	Dec. 18, 1912	52.15	Mar. 21, 1913	54.73
F 17	do	47.82	Apr. 19, 1912	42.16[d]	Oct. 31, 1912	40.48	do	41.40
F 16	do	41.00	Apr. 13, 1912	39.57	Sept. 22, 1912	35.66	Mar. 8, 1913	36.77
F 3	do	32.10	Apr. 19, 1912	28.68	Oct. 31, 1912	26.61	Apr. 8, 1913	27.98
F 13	do	26.80	Apr. 13, 1912	24.59	Sept. 22, 1912	21.41	do	23.20
F 11	do	12.22						

[a] U. S. Geological Survey gaging station at San Diego (Old Town).
[b] In river channel.
[c] U. S. Geological Survey gaging station at Mission dam.
[d] Continually.
[e] Rising.

NOTE.—Observations by U. S. Geological Survey in cooperation with Volcan Land & Water Co. and Cuyamaca Water Co., except as otherwise noted. For rise and fall each year, see Table 33.

level, in feet, at wells in San Diego County, 1912–1915.

during 1914–15, see Table 30.]

1913–14				1914–15			
Lowest level observed.		Highest level observed.		Lowest level observed.		Highest level observed.	
Date.	Elevation (feet).	Date.	Elevation (feet).	Date.	Elevation (feet).	Date.	Elevation (feet).
....	....	....	....	Oct. 13, 1914	313.60	May 3, 1915	315.01
Oct. 30, 1913	385.15	Mar. 5, 1914	389.65	.....do......	385.25	.....do......	391.62
.....do......	399.38	May 12, 1914	402.34	Nov. 10, 1914	398.90	Mar. 11, 1915	405.31
Oct. 1, 1913	404.15	Mar. 5, 1914	407.55	.....do......	404.01	.....do......	408.52
Oct. 30, 1913	398.13	.....do......	401.68	.....do......	397.76	Feb. 13, 1915	403.29
....	....	....	....	Nov. 7, 1914	4.84	Feb. 12, 1915	10.31
Oct. 29, 1913	52.37	Mar. 3, 1914	55.25	Oct. 13, 1914	52.32	May 3, 1915	57.57
Apr. 12, 1913	272.49	(*d*)	(*d*)	(*e*)	(*e*)	Feb. 13, 1915	276.73
Aug. 24, 1913	404.59	May 1, 1914	407.40	Nov. 10, 1914	404.45	Feb. 3, 1915	409.08
Jan. 21, 1914	313.46	Mar. 6, 1914	315.37	Dec. 7, 1914	313.16	Mar. 10, 1915	317.31
.....do......	310.61	May. 13, 1914	317.25	.....do......	311.82	.....do......	318.98
July 23, 1913	335.56	Apr. 4, 1914	337.14	Jan. 17, 1915	336.20	July 5, 1915	340.54
Oct. 30, 1913	400.96	Apr. 20, 1914	403.60	Dec. 7, 1914	400.55	Mar. 11, 1915	405.82
Oct. 29, 1913	412.50	Feb. 27, 1914	416.43	Oct. 14, 1914	412.91	Feb. 25, 1915	416.99
July 28, 1913	409.15	.....do......	417.12	.....do......	408.26	Feb. 1, 1915	418.06
Oct. 29, 1913	379.52	.....do......	382.06	.....do......	380.07	May 4, 1915	382.17
.....do......	375.33	Mar. 27, 1912	378.12	.....do......	375.73	.....do......	378.77
Aug. 20, 1913	337.99	Mar. 27, 1914	344.96	Jan. 25, 1915	338.39	(*h*)	(*h*)
Oct. 30, 1913	426.48	Mar. 3, 1914	430.81	Oct. 23, 1914	424.70	May 4, 1915	431.70
.....do......	426.63	.....do......	431.19	.....do......	424.71	.....do......	431.99
.....do......	427.13	.....do......	431.69	.....do......	426.71	.....do......	432.17
....	....	....	....	.....do......	427.00	Feb. 3, 1915	432.57
Dec. 12, 1913	479.42	July 1, 1914	488.42	Jan. 16, 1915	479.22	May 10, 1915	491.42
June 13, 1913	305.92	Mar. 1, 1914	307.60	Aug. 19, 1914	305.91	Feb. 24, 1915	308.24
July–Aug. 1913	(261.00)	Jan. 23, 1914	263.82	.....do......	261.50	May 5, 1915	264.82
Dec. 9, 1913	97.35	May. 9, 1914	101.53	Nov. 25, 1914	97.53	May 31, 1915	101.36
....do......	65.26	Mar. 9, 1914	70.73	Jan. 9, 1915	66.09	Feb. 24, 1915	72.05
....do......	55.44	May 9, 1914	62.90	.....do......	56.35	May 5, 1915	63.30
....do......	53.23	.....do......	60.99	.....do......	54.04	.....do......	59.77
....do......	51.30	Mar. 9, 1914	56.28	Dec. 9, 1915	52.25	.....do......	56.08
Sept. 29, 1913	39.96	Feb. 28, 1914	43.02	Nov. 13, 1914	40.69	Feb. 24, 1915	44.18
Aug. 19, 1913	34.53	Jan. 30, 1914	39.13	.....do......	36.07	Feb. 5, 1915	40.93
Nov. 1, 1913	26.42	Mar. 9, 1914	29.44	Dec. 14, 1914	26.50	Feb. 24, 1915	30.14
Sept. 29, 1913	21.24	Jan. 30, 1914	24.89	Aug. 19, 1914	21.19	.....do......	26.14
Dec. 9, 1913	13.20	.....do......	15.46	Nov. 14, 1914	13.45	....	....

f U. S. Geological Survey gaging station at Lakeside.
g Well affected by pumping.
h Record ended Jan. 25, 1915.
i Observed by Mr. Lebert.
j Affected by ditch.

In addition to the above data, contours of the water table, or lines connecting all points at which the ground water has the same elevation, have been drawn from the original observations to show the position of the water table in Mission Valley October 22, 1914, and February 18, 1915 (Pl. XXI), and in Sweetwater, Otay, and Tia Juana valleys and the intervening low terraces January 6 and March 1, 1915 (Pl. XX).

The ground-water profiles and cross sections (Pls. XXX to XXXV, fig. 9), and the contours of the water table (Pls. XX and XXI), show that in the major river valleys the water table slopes downstream, with a slight tendency outward from the stream channel toward the edge of the valley during the period of river flow, but with practically no transverse slope at other times of the year and particularly not during the last part of the year.

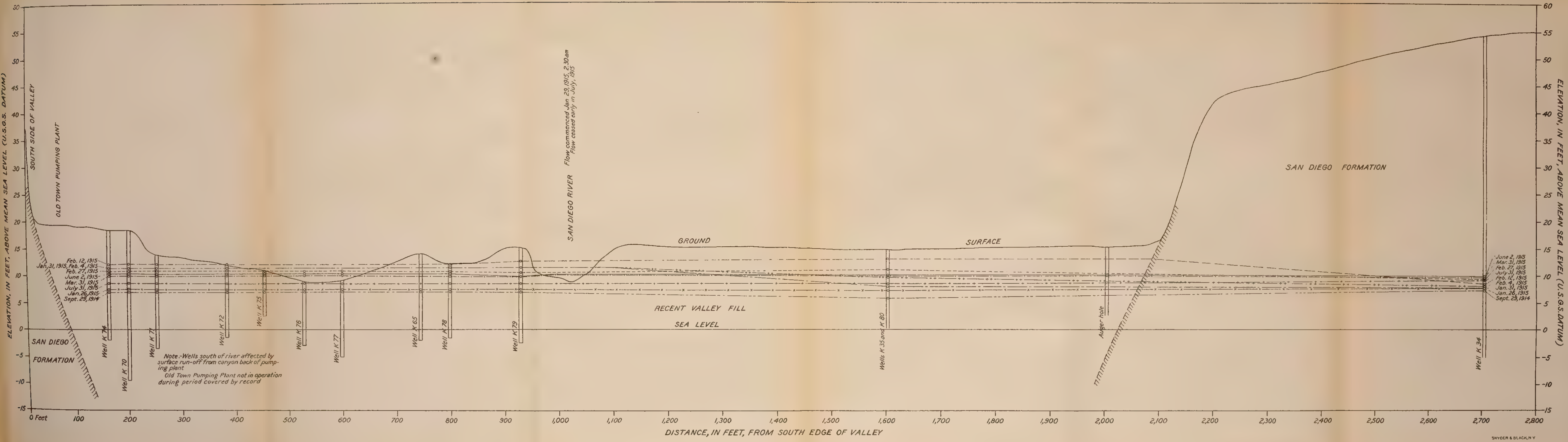
FLUCTUATIONS OF THE WATER TABLE.

The water table at any point is constantly either rising or falling. The rate of rise or fall varies widely at different places and times, depending on the position of the place with respect to the sources or outlets of the ground water and the rapidity of the accretion and depletion of the supply. The fluctuation of the water table is an index to the relative rates of supply and loss of ground water and in this respect corresponds to the rise and fall of water level in a reservoir.

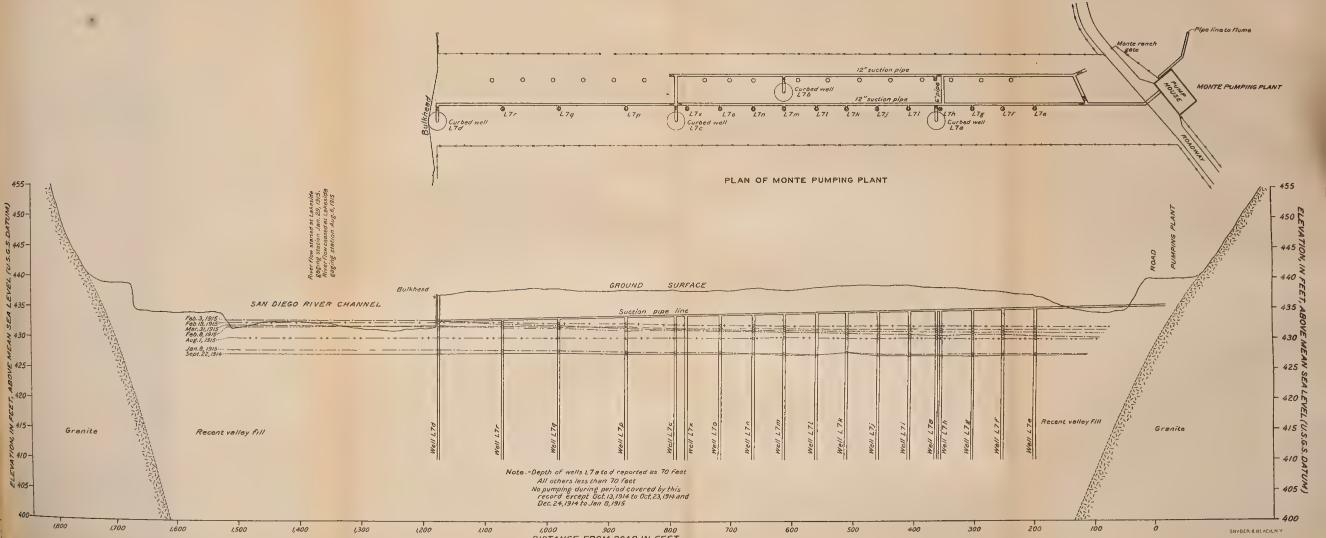
The water table in the fill of the major valleys fluctuates annually, and this fluctuation was observable in all the wells studied during the years 1912 to 1915. The annual fluctuation is the result of the annual variation in rainfall, stream flow, evaporation, transpiration, and other conditions affecting ground-water levels. The water table reaches its lowest stage during the months October to January preceding the first storm heavy enough to produce run-off. The average date of minimum level in 1914 was November 7 (Table 32), and this is nearly the average date for other years. Coincident with the first heavy storm producing run-off, usually occurring in January (Table 34), water levels rise more or less sharply, reaching their maximum level during the months January to April. The average date of maximum level in 1914 was March 19 (Table 32); taking all seasons into consideration April 1 is probably about the average. From the date of maximum level to the last part of the year levels are gradually lowered, the rate of lowering being greatest from April to August. The average fluctuation for the year 1914–15 at all observation wells in the major valleys was 4.70 feet (Table 32). That this range is greater than the annual average is indicated by the records at wells in upper San Diego and San Luis Rey River valleys during the period 1912 to 1915 (Table 33). Judging by the conditions in these two valleys, the average annual fluctuation of the water level in the major valleys is about 3.6 feet.

E

ELEVATION IN FEET ABOVE MEAN SEA LEVEL (U.S.G.S. DATUM)

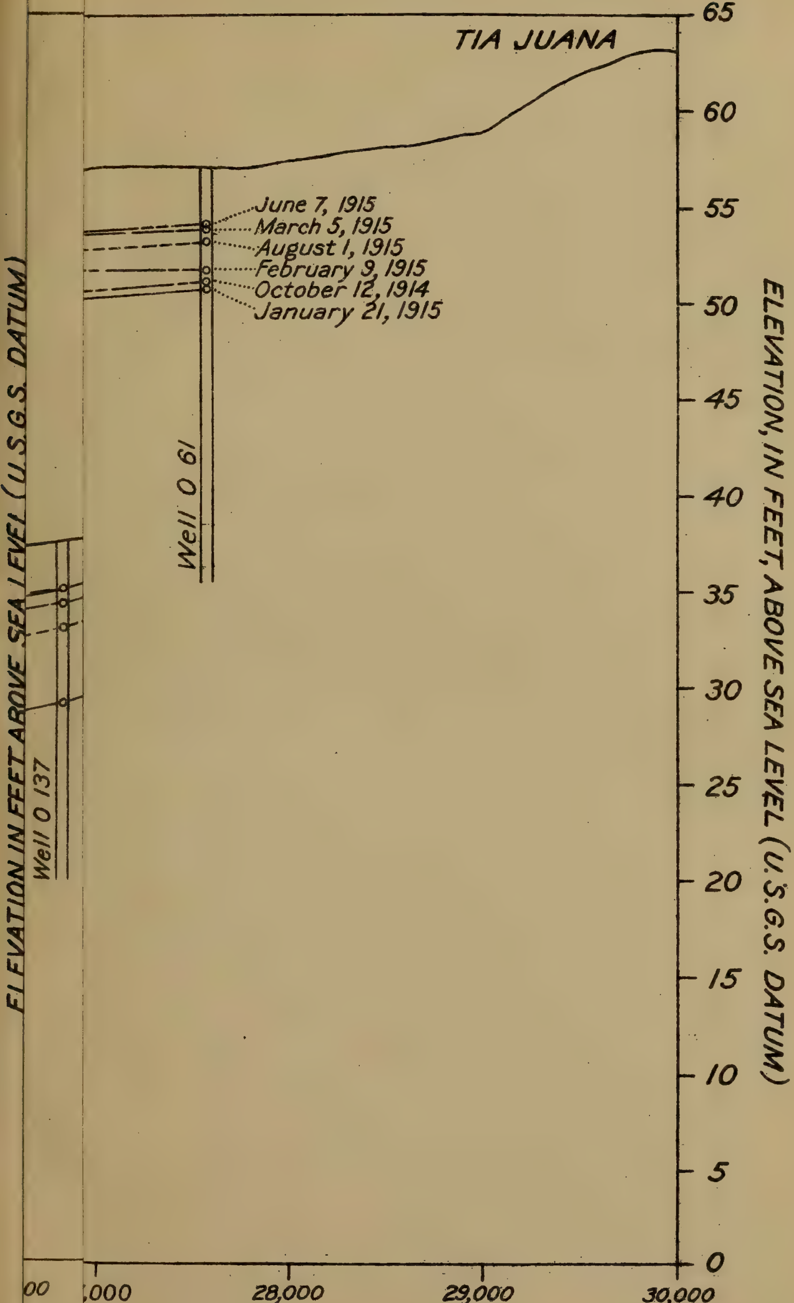


SECTION ACROSS MISSION VALLEY AT OLD TOWN PUMPING PLANT, SHOWING PROFILES OF WATER TABLE IN DIFFERENT SEASONS OF THE YEAR, 1914-1915. (Red line A-A, Plate XXI)

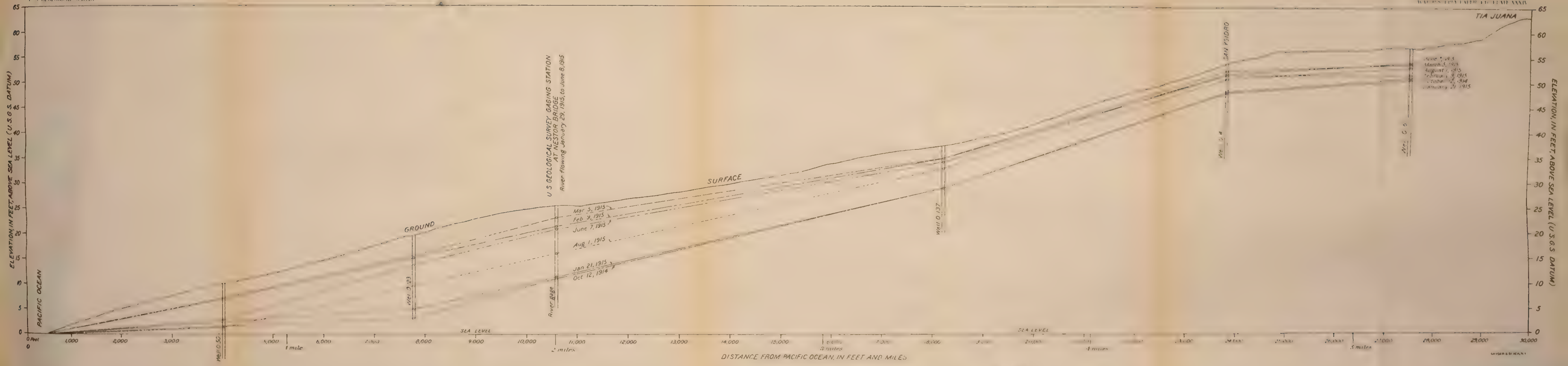


SECTION ACROSS UPPER SAN DIEGO RIVER VALLEY AT MONTE PUMPING PLANT, SHOWING FLUCTUATIONS OF WATER TABLE, SEASON 1914-1915, AND PLAN OF PUMPING PLANT.

(Line A-A, Plate XXII)



SNYDER & BLACK, N.Y.



LONGITUDINAL PROFILES OF TIA JUANA VALLEY, SHOWING FLUCTUATIONS OF WATER TABLE, SEASON 1914-1915.

Red line B-B, Plate XX

TABLE 32.—*Annual range of fluctuation of water level in record wells in San Diego County, 1914–15.*

Geologic source of water.	Valley.	Number of wells observed.	Annual range of fluctuation.				
			Average date of maximum level.	Average date of minimum level.	Maximum in any well.	Minimum in any well.	Average in all wells.
					Feet.	*Feet.*	*Feet.*
Deep fill of major valley.	Tia Juana	9	Apr. 11, 1915	Nov. 25, 1914	13.69	3.72	7.08
Do	Upper Sweetwater	8	Apr. 4, 1915	Oct. 25, 1914	8.50	1.54	4.11
Do	Lower Sweetwater	9	Feb. 21, 1915	Nov. 11, 1914	6.26	.93	2.71
Do	Upper San Diego	17	Mar. 22, 1915	Nov. 12, 1914	12.20	1.41	5.57
Do	Lower San Diego	22	Feb. 22, 1915	Nov. 13, 1914	8.01	2.33	5.16
Do	San Pasqual	5	Mar. 22, 1915	Oct. 20, 1914	10.12	2.10	4.58
Do	San Luis Rey	14	Mar. 25, 1915	Nov. 4, 1914	8.11	1.19	3.61
Average			Mar. 19,——	Nov. 7,——			4.69
Fill of minor valleys	Otay	5	Feb. 28, 1915	Oct. 22, 1914	8.75	3.99	6.91
Do	Murphy Canyon	1	Feb. 27, 1915	Jan. 7, 1915	2.19	2.19	2.19
Do	Murray Canyon	1	do	do	9.45	9.45	9.45
Do	Miscellaneous	4	Apr. 16, 1915	Nov. 1, 1914	5.54	5.33	5.46
Average							6.18
Residuum (decomposed granite).		10	Apr. 11, 1915	Dec. 16, 1914	11.00	3.43	6.31
San Diego formation less than 200 feet below sea level.	Vicinity of Nestor	11	May 21, 1915	Nov. 18, 1914	5.83	1.38	2.59
Do	Vicinity of Otay	10	Mar. 27, 1915	Oct. 31, 1914	8.76	.58	4.32
Do	Vicinity of Chulavista.	5	July 1, 1915	Nov. 7, 1914	.82	.17	.47
Do	National City	1	July 30, 1915	Oct. 29, 1914	.93	.93	.93
Do	Vicinity of Old Town.	1	Mar. 31, 1915	Nov. 7, 1914	2.34	2.34	2.34
Average							2.76

TABLE 33.—*Annual range of fluctuation, in feet, of water level in record wells in San Diego County, 1912–13 to 1914–15.*

Upper San Diego River Valley (deep valley fill.)

Well No.	Lowering of 1912.	Rise of 1912–13.	Lowering of 1913.	Rise of 1913–14.	Lowering of 1914.	Rise of 1914–15.	Average lowering.	Average rise.
L 75				9.00	9.20	12.20	9.20	9.00
L 7-d		2.75				5.57		4.16
L 7-c		2.78	3.70	4.56	4.98	5.46	4.34	4.27
L 7-b		3.02	4.24	4.56	6.48	7.28	5.36	4.95
L 7-a		2.63	3.95	4.33	6.11	7.00	5.03	4.65
L 70		1.17	2.83	2.81	2.95	4.63	2.89	2.87
L 67		1.32	2.72	3.40	3.54	4.51	3.13	3.08
L 66		1.31	2.94	2.64	3.05	5.27	3.00	3.07
L 65		2.00	2.92	2.96	3.44	6.41	3.18	3.79
L 68-b				3.55	3.92	5.53	3.92	4.54
L 76		1.00	2.45	4.50	4.40	6.37	3.43	3.91
Average		2.12	3.29	4.23	4.81	5.97	4.35	4.22

Lower San Diego River valley (deep valley fill).

K 107		0.81	1.90	2.88	2.93	5.25	2.42	2.98
K 63		0.63				5.47		3.05

TABLE 33.—*Annual range of fluctuation, in feet, of water level in record wells in San Diego County, 1912–13 to 1914–15*—Continued.

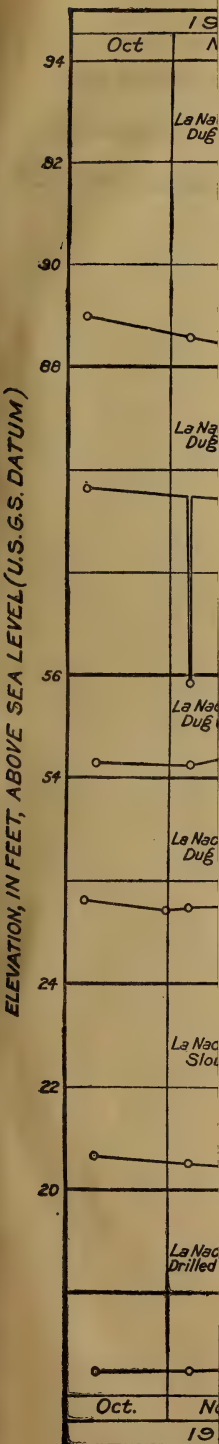
Well No.	Lowering of 1912.	Rise of 1912–13.	Lowering of 1913.	Rise of 1913–14.	Lowering of 1914.	Rise of 1914–15.	Average lowering.	Average rise.
San Pasqual Valley (deep valley fill).								
H 5	....	3.04	3.71	3.93	3.52	4.08	3.61	3.68
H 31	....	1.85	2.38	2.54	1.99	2.10	2.19	2.16
H 1	....	1.75	2.38	2.79	2.39	3.04	2.39	2.52
Average	....	2.21	2.83	3.09	2.63	3.07	2.79	2.72
San Dieguito Valley (deep valley fill).								
G 37	....	....	....	10.80	8.10	9.40	....	....
San Luis Rey River Valley (deep valley fill).								
C 10	1.29	0.55	0.77	1.68	1.69	2.33	1.25	1.52
C 9	3.30	2.51	2.85	2.82	2.32	3.32	2.82	2.89
B 11	5.37	4.95	5.28	5.47	4.64	5.96	5.10	5.46
F 21[a]	6.94	7.00	7.54	7.46	6.55	6.95	7.01	7.14
F 20[a]	5.30	6.61	7.07	7.76	6.95	5.73	6.44	6.70
F 19	3.23	2.58	3.43	3.98	3.03	3.83	3.23	3.46
F 17	1.68	0.92	1.44	3.06	2.33	3.49	1.82	2.49
F 16	3.91	1.37	2.24	4.60	3.06	4.86	3.07	3.61
F 3	2.07	1.37	1.56	3.02	2.94	3.64	2.19	2.68
F 13	3.18	1.79	1.96	3.65	3.70	4.95	2.61	3.46
F 11	....	....	....	2.26	2.01	....	2.01	2.26
Average	3.00	2.00	2.44	3.39	2.87	4.04	2.68	3.09

[a] Affected by Libby ditch, not used in averages.

Well No.	Lowering of 1912.	Rise of 1912–13.	Lowering of 1913.	Rise of 1913–14.	Lowering of 1914.	Rise of 1914–15.	Average lowering.	Average rise.
Fill of minor valleys.								
B 10	4.42	3.58	3.84	4.18	4.00	3.83	4.09	3.86
L 91	....	0.93	2.47	6.64	5.43	7.16	3.95	4.91
Decomposed granite.								
L 92	....	1.41	2.40	1.91	2.21	4.15	2.31	2.49
L 11	....	....	3.05	1.58	0.94	4.66	2.00	3.12
H 32	....	6.15	4.78	7.97	8.86	9.80	6.82	7.97

The diagrams illustrating fluctuations of the water table (Pls. XXXVI to XLII and fig. 18) show four types of annual fluctuation that can be associated with (1) the location of the observation wells, (2) the depth to ground water just prior to the first heavy storm producing run-off, or (3) the permanence of flow of the stream traversing the valley in which the well is located. These types are described as follows:

1. Annual fluctuations of wide range, varying from about 4 to 9 feet and averaging about 7 feet, the fall of the water table continuing until the first heavy storm accompanied by run-off. Observation wells exhibiting this wide range are those in the upper parts of valleys traversed by streams that normally do not flow throughout the year. Examples are wells numbered F 4, B 11, L 75, L 63, K 31, L 104, O 80, and O 61.


19
Oct
94
La Na
Dug
82
90
88
La Na
Dug
56
La Na
Dug
54
La Nac
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24
La Nac
Slou
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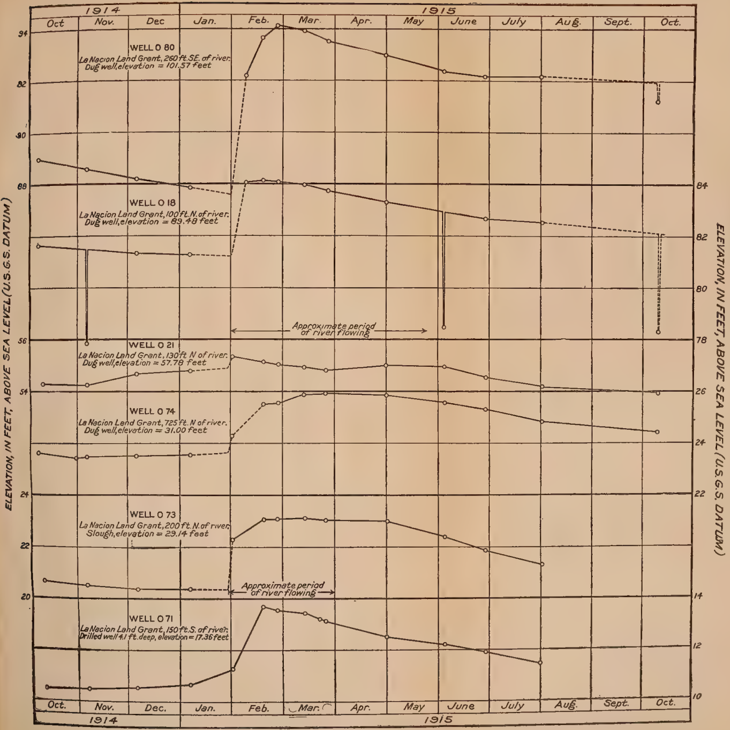
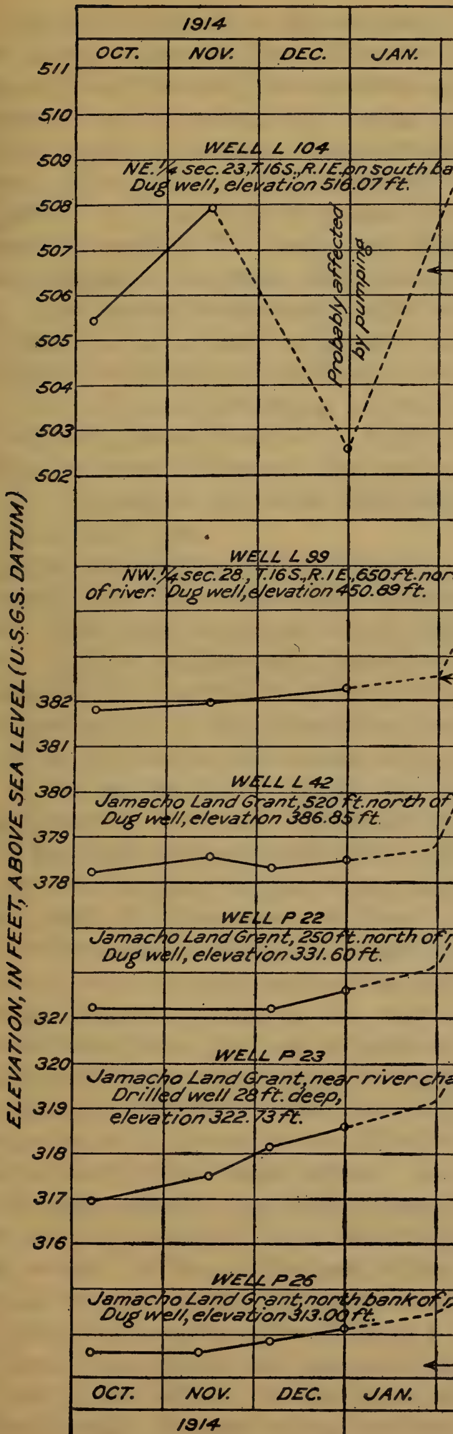
Drilled
Oct.
N
19
ELEVATION, IN FEET, ABOVE SEA LEVEL (U.S.G.S. DATUM)

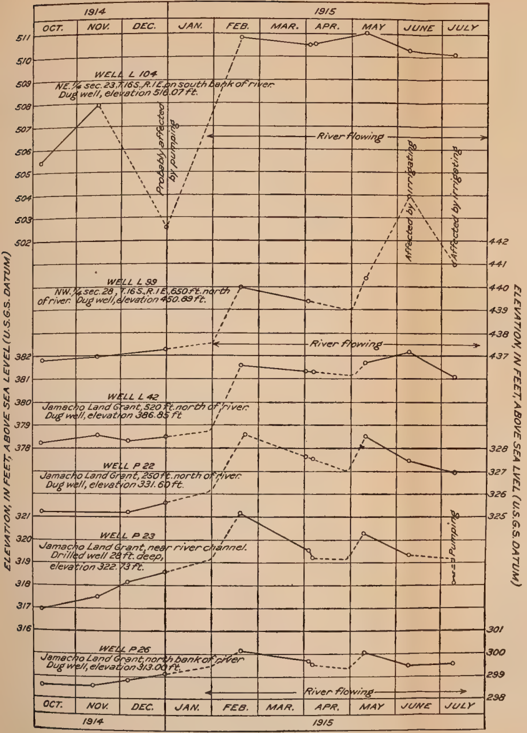
DIA



DIAGRAMS SHOWING FLUCTUATION OF WATER TABLE IN OBSERVATION WELLS IN SWEETWATER VALLEY.



DIAGRAMS SHOWING FLUCTUATIO
JAMACHO



DIAGRAMS SHOWING FLUCTUATION OF WATER TABLE IN OBSERVATION WELLS IN JAMACHO AND DEHESA VALLEYS.

2. Annual fluctuations of approximately the average range for the major valleys—about 3.6 feet, the water table remaining practically stationary from October 1 to the first big storm producing run-off. Observation wells showing the average range are in the middle of valleys traversed by streams that normally do not flow throughout the year. Examples are wells numbered F 17, F 16, F 3, H 5, L 67, L 66, L 65, L 42, P 22, O 76, O 20, and O 55. Exceptions to this rule are found in parts of Tia Juana and Mission valleys, where heavy pumping depresses the water table locally in the middle part of the valley. The annual fluctuation in the middle part of Tia Juana Valley was 7 to 12 feet and in Mission Valley 5 to 6 feet.

3. Annual fluctuations of small range, varying in the wells observed from 1.1 to 2.3 feet and averaging 1.8 feet, the annual rise of the water table beginning about October 1. Such wells are in the lower parts of valleys traversed by streams that normally do not flow throughout the year. Examples are wells numbered C 6, F 10, H 31, L 72, K 61, O 21, and P 26a.

4. Annual fluctuations of small range, averaging about 1.5 feet, the annual rise of the water table beginning sometime during September. Such wells are found in all parts of valleys traversed by streams that flow continuously throughout the year. Examples are wells numbered C 2 and C 10 in San Luis Rey Valley near Pala.

The explanation of the fluctuations described in paragraphs 1, 2, and 3 is to be found in the annual filling and draining of a shallow layer of the porous fill of valleys traversed by streams that flow during a part of the year. The range of fluctuations is relatively large in the upper parts of such valleys and small in the lower parts, owing to the tendency of the water table to assume a horizontal position after the river ceases to flow. The natural movement of ground water is from the upper toward the lower end of the valley. The limited cross-sectional area of the fill at the lower end prevents free escape of ground water at this point, and the continued arrival of ground water from the broader parts of the valley above tends to replenish local losses, consisting of seepage return to stream channel evaporation, or underflow to the next lower valley. The water table at the lower end of the valley thus falls but little during the summer, even after the river has ceased to flow. At the upper end of the valley, however, replenishment practically ceases as soon as the river ceases to flow, and all conditions favor local depletion and lowering of the ground water. In the middle part of the valley conditions lie between the two extremes. The slow rising of the water level in the lower part of the valley after October 1 is due to the diminishing losses from evaporation and the accumulation of water from the upper end of the valley. In the upper end water levels continue to fall slowly until the first storm producing flood run-off. In the middle part loss and gain balance each other, and the water level remains stationary from about October 1 to the first big storm producing flood run-off. Thus the observed fluctuations are the effects of gain and loss and the tendency of the water surface to assume a horizontal position in each ground-water reservoir.

In the fourth group the continued flow of the stream replenishes the ground-water supply at the head of the basin throughout the year and thus counteracts the tendency of the water table to fall. The rate of evaporation begins to decrease in September (Tables 25, 26, and 27, pp. 101, 102), at which time the water table begins to rise through replenishment by lateral percolation from the near-by stream.

TABLE 34.—*Duration of flow of principal streams in San Diego County at typical gaging stations.*

San Luis Rey River near Pala.

Year (July 1 to June 30).	Date that continuous flow commenced.	Date that flood flow commenced.[a]	Date of last flood flow.[a]	Date that continuous flow ceased.	Number of days of continuous flow.	Number of days of flood flow.[a]	Minimum flow of stream during nonflood period.
							Sec. ft.
1903-4	July 1	Mar. 23	May 25	June 30	365	61	1.0
1904-5	...do	Jan. 9	(June 12)	...do	365	(154)	2.0
1905-6	...do	Jan. 19	June 30	...do	365	143	2.5
1906-7	...do	Nov. 23	June 26	...do	365	209	3.0
1907-8	...do	Oct. 16	Apr. 26	...do	365	144	0.6
1908-9	...do	Jan. 13	May 28	...do	365	135	2.0
1909-10	...do	Nov. 11	May 4	...do	365	159	5.0
1910-11	...do	Jan. 10	May 2	...do	365	106	(4.0)
1911-12	...do	Dec. 29	May 20	...do	365	74	....
1912-13	...do	Jan. 15	Apr. 19	...do	365	37	3.0
1913-14	...do	Jan. 16	May 16	...do	365	118	2.0
1914-15	...do	Jan. 22	June 30	...do	365	160	1.0
Observed average		Jan. 2	May 25		365	125	
Corrected average[b]					365	100	

San Luis Rey River at Bonsall.

Year (July 1 to June 30).	Date that continuous flow commenced.	Date that flood flow commenced.[a]	Date of last flood flow.[a]	Date that continuous flow ceased.	Number of days of continuous flow.	Number of days of flood flow.[a]	Minimum flow of stream during nonflood period.
1911-12	....	(Mar. 6)	May 16	June 17	....	(67)	0
1912-13	Dec. 12	Jan. 10	Mar. 30	June 14	177	51	0
1913-14	Dec. 1	Jan. 18	May 8	June 25	207	107	0
1914-15	Nov. 15	Jan. 22	June 30	June 30	227	160	0
Observed average						96	
Corrected average[b]						96	

[a] Flood flow considered as flow in excess of 14 second feet.
[b] Observed average multiplied by ratio of observed 17-year average on San Diego River at diverting dam to observed average for period 1903-4 to 1914-15.

TABLE 34.—*Duration of flow of principal streams in San Diego County at typical gaging stations*—Continued.

Santa Ysabel Creek near Escondido and Ramona.

Year (July 1 to June 30).	Date that continuous flow commenced.	Date that flood flow commenced.[a]	Date of last flood flow.[a]	Date that continuous flow ceased.	Number of days of continuous flow.[b]	Number of days of flood flow.[a]	Minimum flow of stream during nonflood period (second-feet).
1905-6	July 1	Jan. 19	June 30	June 30	365	150	0.5
1906-7	...do	Dec. 7	...do	...do	365	212	3.0
1907-8	...do	...do	May 17	...do	365	150	1.0
1908-9	Oct. 12	Jan. 10	(June 30)	...do	269	170	0
1909-10	Sept. 23	Nov. 11	May 11	...do	358	163	0
1910-11	(Jan. 9)	Jan. 9	June 4	...do	180	135	0
1911-12	Oct. 15	Mar. 2	May 29	...do	264	85	0
1912-13	Oct. 3	Jan. 16	Apr. 21	...do	304	63	0
1913-14	Nov. 5	Jan. 19	June 9	...do	278	129	0
1914-15	Oct. 11	Jan. 22	June 30	...do	278	157	0
Observed average		Jan. 6	June 6		303	141	
Corrected average						103	

San Dieguito River at Bernardo.

Year (July 1 to June 30).	Date that continuous flow commenced.	Date that flood flow commenced.[a]	Date of last flood flow.[a]	Date that continuous flow ceased.	Number of days of continuous flow.[b]	Number of days of flood flow.[a]	Minimum flow of stream during nonflood period (second-feet).
1911-12		(Mar. 7)	May 22	June 30		(72)	0
1912-13	Feb. 1	Feb. 23	Apr. 5	May 31	120	28	0
1913-14	Dec. 20	Jan. 26	May 17	June 28	190	73	0
1914-15	Jan. 22	Jan. 29	June 23	June 30	159	146	0
Observed average						80	
Corrected average						80	

[a] Flood flow considered as flow in excess of 12 second-feet.
[b] Includes number of days flow after July 1, prior to drying up of stream during late summer.

San Diego River at diverting dam (excluding draft from Cuyamaca reservoir).

Year (July 1 to June 30).	Date that continuous flow commenced.	Date that flood flow commenced.[a]	Date of last flood flow.[a]	Date that continuous flow ceased.	Number of days of continuous flow.[b] [c]	Number of days of flood flow.[a]	Minimum flow of stream during nonflood period (second-feet).
1898-99	(Feb. 1)	Mar. 17	Mar. 30	(May 12)	101	8	0
1899-1900	Jan. 2	May 5	May 6	(May 31)	149	2	0
1900-1901	Nov. 21	Feb. 2	May 1	(June 18)	209	41	0
1901-2	Jan. 23	Feb. 24	Apr. 23	(June 7)	135	40	0
1902-3	Jan. 26	Jan. 30	May 22	(June 16)	141	97	0
1903-4	Mar. 10	Mar. 22	Mar. 30	Apr. 9	30	5	0
1904-5	Jan. 9	Feb. 1	June 10	June 30	172	121	0
1905-6	Nov. 5	Nov. 5	June 30	...do	237	170	0
1906-7	July 1	July 5	June 27	...do	365	201	(2)
1907-8	...do	Oct. 3	May 16	...do	365	166	(2)
1908-9	Dec. 1	Dec. 1	May 31	...do	257	150	0
1909-10	Nov. 13	Nov. 13	May 5	...do	229	141	0
1910-11	Jan. 8	Jan. 8	May 1	June 6	149	97	0
1911-12	Dec. 30	Mar. 5	June 2	(June 30)	182	80	0
1912-13	Jan. 9	Jan. 16	Apr. 22	(June 5)	147	54	0
1913-14	Dec. 20	Dec. 22	June 12	June 19	191	106	0
1914-15	Dec. 12	Jan. 29	June 20	June 30	200	143	0
Observed average		Jan. 20	May 17		192	96	
Corrected average						96	

[a] Flood flow considered as flow in excess of 12 second-feet at diverting dam.
[b] Includes number of days flow after July 1, prior to drying up of stream during late summer.
[c] Includes period of Cuyamaca Water Co. flume diversion, excepting Cuyamaca draft.

TABLE 34.—*Duration of flow of principal streams in San Diego County at typical gaging stations*—Continued.

San Diego River at Mission dam.

Year (July 1 to June 30).	Date that continuous flow commenced.	Date that flood flow commenced.[a]	Date of last flood flow.[a]	Date that continuous flow ceased.	Number of days of continuous flow.[b]	Number of days of flood flow.[a]	Minimum flow of stream during nonflood period (second-feet).
1911-12		Mar. 10	May 27	June 20		(73)	0
1912-13	Dec. 19	Jan. 30	Apr. 7	June 30	193	27	0
1913-14	Jan. 1	Jan. 26	Apr. 1	May 30	150	31	0
1914-15	Jan. 22	Jan. 22	June 22	June 30	159	135	0
Observed average						66	
Corrected average						66	

a Flood flow considered as flow in excess of 10 second-feet at Mission dam.
b Includes number of days flow after July 1, prior to drying up of streams during late summer.

Sweetwater River near Descanso.

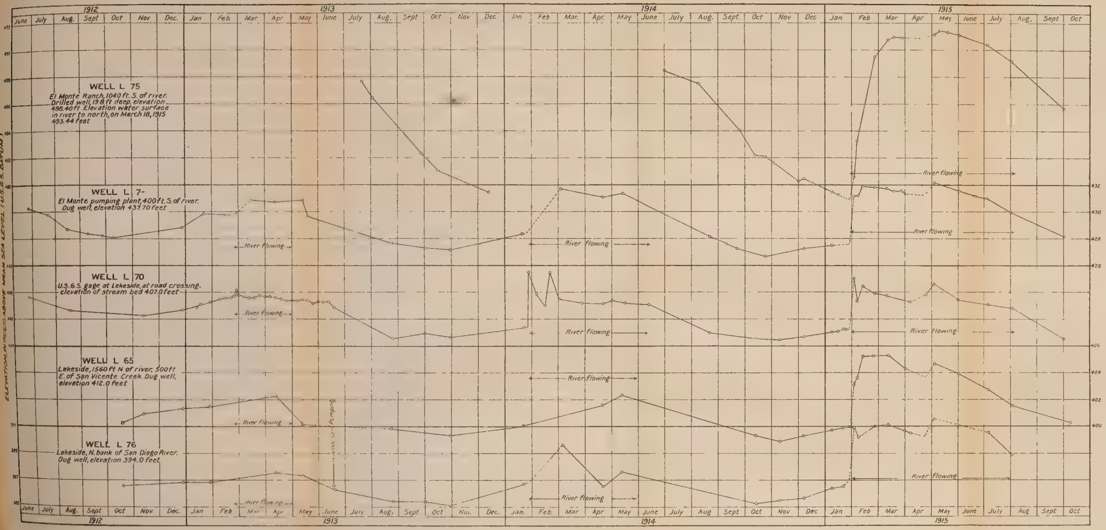
Year (July 1 to June 30).	Date that continuous flow commenced.	Date that flood flow commenced.[a]	Date of last flood flow.[a]	Date that continuous flow ceased.	Number of days of continuous flow.	Number of days of flood flow.[a]	Minimum flow of stream during nonflood period (second-feet).
1905-6	July 1	Jan. 19	June 8	June 30	365	128	0.4
1906-7	...do...	Dec. 12	June 15	...do...	365	172	1.1
1907-8	...do...	Jan. 25	Apr. 24	...do...	365	34	0.8
1908-9	...do...	Jan. 14	May 28	...do...	365	117	0.3
1909-10	...do...	Nov. 15	Apr. 15	...do...	365	96	0.8
1910-11	...do...	Jan. 10	Apr. 17	...do...	362	58	0.0
1911-12	...do...	Mar. 2	May 12	...do...	365	54	0.4
1912-13	...do...	Jan. 15	Mar. 28	...do...	365	28	0.4
1913-14	Aug. 16	Jan. 26	Apr. 22	...do...	319	22	0.0
1914-15	July 1	Jan. 29	June 23	...do...	365	146	0.05
Observed average		Jan. 13	May 11		360	86	
Corrected average						63	

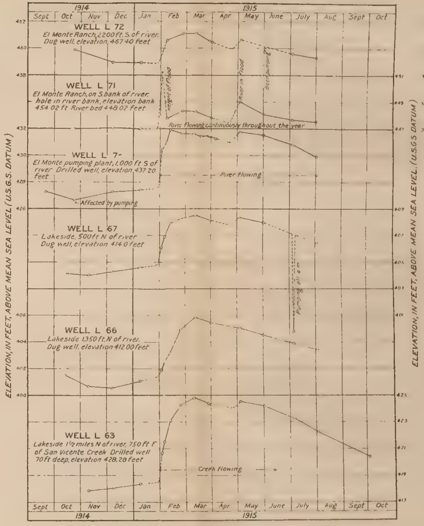
a Flood flow considered as flow in excess of 10 second-feet.

The diagrams (Pls. XXXVI to XLII) also illustrate differences in conditions with respect to the rise of the water table, as follows:

1. In wells somewhat remote from stream channels and in places not subject to floods maximum ground-water level is attained within about seven days of the first heavy storm producing flood run-off and with no relation to the distance of the well from the river channel. At the observed wells of this class the depth to water just previous to the storm was 6.6 feet or less (Table 35). Such wells are numbers H 31, O 76, F 13, F 16, L 86, H 5, K 82, and C 10.

2. In wells somewhat remote from stream channels and in places not subject to flooding maximum ground-water level each year is attained gradually after the first heavy storm producing flood run-off, the time varying in the wells observed from 15 to 161 days and averaging 52 days, and depending somewhat on the distance of the





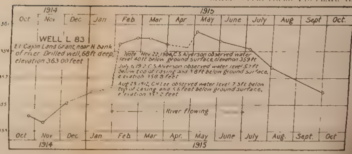


DIAGRAM SHOWING FLUCTUATIONS OF WATER TABLE IN OBSERVATION WELLS IN UPPER SAN DIEGO RIVER VALLEY

1912 - 1915

NOTE. Dotted lines connecting observations indicate approximate fluctuations during periods for which record is insufficient to show detail

well from the river channel. At such wells the depth to water just before the storm is more than 6.6 feet (Table 35). Such wells are those numbered O 61, O 55, K 31, L 67, K 62, K 83, F 20, K 61, F 21, L 66, L 5, L 7–a, O 118, B 11, O 80, and L 75.

3. In wells near a stream or in places subject to flooding maximum ground-water level is reached either during the period of greatest flood flow of the season or immediately thereafter. Such wells are numbers C 7, F 19, H 36, H 34, L 71, L 7–d, L 70, L 76, K 118, K 107, K 85, K 63, P 23, O 78, O 127, O 130, and O 123.

The conditions represented by the first and second groups are explained as follows: The precipitation from a storm that produces the first flood run-off usually amounts to 2 to 4 inches on the valley floor and has generally been preceded by several inches of rain during the current rainy season. If a porous material contains capillary moisture from the zone of saturation up to the surface of the ground, water applied to the surface passes down rapidly to the zone of saturation. If, however, the surface layers of the material are dry to an appreciable depth below the surface, the water that is absorbed must cover the dry soil grains with a film of moisture and fatten the depleted water films of the soil grains below the surface before it will pass down to the zone of saturation. The vertical distance through which the materials composing the fill of the valleys in San Diego County will draw capillary moisture from the zone of saturation ranges from 2.5 feet in the coarsest sands to 7 or 8 feet in the fine silts. For average porous materials, in which the zone of saturation is less than 7 feet below the surface and the moisture films in the upper layers have already been somewhat replenished by recent storms, the conditions are ideal for rapid absorption and transmission to the zone of saturation of the water of the first big storm that produces flood run-off. This is the condition at the first group of wells (Table 35). The immediate rise of the water table to maximum, as observed in most of these wells is due to replenishment from direct rainfall during the storm that produces the first flood run-off and not to transmitted pressure or absorption from run-off. This conclusion is confirmed by study of the second group of wells, in which the depth to water exceeded 7 feet.

TABLE 35.—*Time required for water table to reach maximum levels after first storm that produces run-off.*

Well No.	Major valley.	Depth to water table just prior to first storm that produced flood run-off.	Distance of well from river channel.	Date of beginning of first storm that produces flood run-off.	Date of arrvial of first flood.	Approximate date of highest level of water table.	Period between first flood and highest water level.
		Feet.	*Feet.*				*Days.*
H 31	San Pasqual	1.2	520	Jan. 27, 1915	Jan. 29, 1915	Feb. 1	2
O 76	Sweetwater	2.7	150	do	do	do	2
F 13	San Luis Rey	4.0	2,100	do	do	Feb. 5	7
F 16	do	4.7	2,200	do	do	do	7
L 86	Upper San Diego	4.8	1,500	do	do	Feb. 3	5
H 5	San Pasqual	6.1	2,200	do	do	Feb. 1	2
K 82	Mission	6.6	1,700	do	do	Feb. 4	6
C 10	San Luis Rey	6.6	520	do	do	Feb. 5	7
O 61	Tia Juana	7.4	900	do	do	May 1	92
O 55	do	8.2	2,150	do	do	June 29	161
K 31	Mission	9.2	300	do	do	Feb. 18	20
L 67	Upper San Diego	9.2	500	do	do	Mar. 11	41
K 62	Mission	9.3	150	do	do	Feb. 12	14
K 83	do	9.4	1,000	do	do	Feb. 18	20
F 20	San Luis Rey	9.6	1,500	do	do	Mar. 12	42
K 61	Mission	9.8	1,000	do	do	Mar. 31	61
F 21	San Luis Rey	10.5	1,300	do	do	Feb. 24	26
L 66	Upper San Diego	10.6	1,350	do	do	Mar. 11	41
L 5	do	11.0	1,000	do	do	do	41
L 7-a	do	11.7	820	do	do	Feb. 13	15
O 118	Tia Juana	13.0	2,340	do	do	Mar. 30	60
B 11	San Luis Rey	13.3	500	do	do	Feb. 24	26
O 80	Sweetwater	13.9	260	do	do	Feb. 27	29
L 75	Upper San Diego	19.4	1,040	do	do	Mar. 18	48

NOTE.—Wells not surrounded by or near to standing or flowing surface water were protected from inflow of surface water by curbing or otherwise.

At no wells of this group, whether relatively near or at a considerable distance from the river, was the maximum water level attained within a period less than 14 days, the average being 52 days, whereas the longest period among the wells of the first group was 7 days. The time elapsing does not necessarily vary proportionally to the distance of the well from the river, because in some places the maximum level occurs with the arrival of the crest of the ground-water wave traveling outward from the river, whereas in others it occurs with the arrival of the absorbed rainfall from above. The facts are brought out by Table 35, on which the wells are arranged in order of their depth to the water table just prior to the first storm producing flood run-off. The conclusion is that the attainment of maximum ground-water level at the time of the first storm producing flood run-off in wells not influenced directly by the river or overflow water is due to the absorption and immediate transmission of rainfall directly to the zone of saturation, made possible by an initial moist condition of material from the zone of saturation to the surface of the ground.

In the third group the quick rise of the water table to maximum level in wells near a stream or on ground that is subject to flooding is obviously due to direct contact of surface water with the adjacent porous formation.

In some ground-water reservoirs the water table undergoes broad periodic fluctuations, the periods covering several years, upon which the annual fluctuations are superimposed. Examination of the diagrams showing fluctuations of the water table in the observation wells since 1912 (Pls. XXXIX to XLII) and consideration of other more general information indicate that in the ground-water reservoirs of San Diego County, however, the broader periodic fluctuations are unimportant as compared with the annual fluctuations. The maximum level attained in dry years, as shown by the diagrams, is in most wells less than a foot lower than the maximum level in wet years, and the minimum level of dry years is always less than a foot lower than the minimum level of wet years. This variation in the maximum and minimum levels of wet and dry years is but a fraction of the total annual fluctuation. The only water-level observation available for the protracted period of drought from 1897–98 to 1903–4 is a measurement at well numbered L 83, in the upper San Diego River valley at Riverview, reported by Mr. C. S. Alverson. This measurement was made November 22, 1904, at practically the end of the dry period, and indicated a level several feet higher than the minimum of 1914 (Pl. XL). The ground-water levels in the vicinity of well L 83 have been affected since 1911 by pumping at well L 82, which is about 750 feet upstream. This measurement indicates that with natural conditions a protracted drought results in only a minor depression of the water table, a conclusion that is also confirmed by the statements of cattlemen who during this same dry period found it possible to obtain water for stock at many points in the river beds by merely scooping out basins 2 to 4 feet in depth. The only unusual depressions of the water table reported in this period were in the immediate vicinity of pumping plants making heavy drafts.

The explanation for this stability of the water table in periods of severe drought is to be found in the very slight opportunity for escape of ground water when its surface has fallen below the comparatively shallow depth within which moisture is lost by evaporation. The slope downstream is so gradual and the material through which the water must move is so fine that the velocity of underflow is very small and permits but slight depletion of the ground-water reservoirs after the normal low-water stage of November 1 has been reached. This condition serves greatly to enhance the value of the ground-water reservoirs as sources of reserve supply in dry years.

GROUND-WATER YIELD.

ECONOMIC REQUIREMENTS.

The quantity of water that can be drawn from a ground-water reservoir—the ground-water yield—may be considered either as the net quantity that can be withdrawn during average or wet years and completely restored to the reservoir in immediately following average or wet years, or as the net quantity that can be withdrawn during every year, including years of extreme and protracted drought, and completely restored within a period of one or two years.

The first quantity, which may be termed the average yield, can be considered as the quantity available to the irrigator as distinguished from the user of water for domestic supply, whose needs limit him to the second quantity, termed the safe yield.

Two classes of irrigation enterprises in San Diego County may depend on underground reservoirs for water—one designed for the cultivation of field crops of moderate value, such as vegetables, sugar beets, or alfalfa, chiefly in the valley land overlying or bordering the underground reservoirs, the other designed for the cultivation of orchards, chiefly on mesa and foothill lands. The permanent investment, other than that for land, buildings, and equipment, represented by enterprises of the first class, is small, and the inability to obtain an adequate water supply during any season involves little loss except the crop for that year. This loss can be better afforded than the loss which would result from permitting the land to lie fallow, as exceptional droughts ordinarily occur only once in 7 to 10 years. The orchards irrigated consist almost entirely of citrus fruit trees, which represent a large investment and produce a valuable crop. A full supply of water is required to produce an income-yielding crop from fruit trees, although the trees can be kept alive and the investment saved from destruction with only one-half a full supply. Furthermore, the seepage water from orchard lands is usually considerably less than that from lands devoted to field crops, and unlike the water applied to field crops seldom finds its way directly back to the valley from which it was drawn. Thus the amount of water developed from an underground reservoir for the supply of orchard trees must be less than for field crops. Considering irrigation in general, however, it is not absolutely necessary that a full supply be obtainable in dry years, and with proper modifications the average yield may be considered a safe basis for planning irrigation systems.

For domestic and general municipal uses, however, a full supply of water must be available every year and at all times of the year to assure protection from fire and to avoid the dangers of water famine. To meet these requirements and to insure an absolutely reliable supply through the most severe droughts sufficient available ground water must be in storage in the valley fill to supply the draft during a period of at least three years in which the reservoir receives practically no replenishment from rainfall and run-off, such periods of drought as are indicated by Tables 18 and 20, pages 84 and 95.

The cost of pumping is not so vital a limitation on the safe yield as on the average yield. The greatest depth from which the water can be economically pumped for irrigation depends on the amount the irrigator can afford to pay for pumped water. Generally speaking, this depth is less than that of the water-bearing formations of the major valleys. The greatest depth from which water can be economically raised for domestic supplies is determined largely by the depth of the water-bearing formations and the percentage of the voids or spaces in them that can be drained at different levels. The water-bearing formations of the major valleys of San Diego County lie at comparatively shallow depths, and the operation of the pumping plants should present no insuperable difficulty even if the draw-down in wells should reach to the bottom of the valley fill.

AVERAGE YIELD.

Replenishment of reservoirs.—The average yield of the ground-water reservoirs of San Diego County—the net quantity that can be withdrawn during an average or wet year and completely restored during a following average or wet year—is about equal to the average natural replenishment of the ground water, which can be more or less definitely computed for each major valley. The accurate computation of the annual replenishment requires a clear knowledge not only of the various sources of ground-water supply and of ground-water losses, but a knowledge of the time of supply and loss in the annual cycle and of their quantities and proportions.

The ground-water reservoirs under consideration are replenished by absorption (1) from rain that falls on the valley fill, (2) from streams that flow through the valleys, and (3) from the run-off from adjacent hill slopes. Water absorbed from precipitation percolates downward to the zone of saturation and gradually raises all parts of the water table. Water absorbed from a stream flowing through the valley builds up a ground-water ridge that widens in each direction from the channel and raises the water table as it moves.

The heaviest rains in the major valleys occur during December to March (fig. 5). The most effective replenishment of ground-water storage, however, is during January to March (Pls. XXXVI to XXXIX, XLII, and Table 35). The proportion of the ground-water replenishment derived directly from rainfall under average conditions is estimated at 35 per cent, although it varies widely, depending on the amount of the annual rainfall and the intensity and time of occurrence of individual storms.

Absorption from stream flow is most rapid during the early part of the flood-flow period (Pls. XXXVI to XLII, and Pl. XIX) but continues until the flow entirely ceases. The flood-flow period normally begins in January and lasts about 100 days. The following table (table 36) summarizes the data regarding the flood-flow period on different streams as given in greater detail in Table 34, page 136.

TABLE 36.—*Summary of data showing duration of flood flow, in days, for principal rivers in San Diego County.*

Season.	San Luis Rey River near Pala.	San Luis Rey River at Bonsall.	Santa Ysabel Creek near Ramona.	San Dieguito River at Bernardo.	San Diego River at diverting dam.	San Diego River at Mission dam.	Sweetwater River at Descanso.
1898–99					8		
1899–1900					2		
1900–01					41		
1901–02					40		
1902–03					97		
1903–04	61				5		
1904–05	154				121		
1905–06	143		150		170		128
1906–07	209		212		201		172
1907–08	144		150		166		34
1908–09	135		170		150		117
1909–10	159		163		141		96
1910–11	106		135		97		58
1911–12	74	(67)	85	(72)	80	(73)	54
1912–13	37	51	63	28	54	27	28
1913–14	118	107	129	73	106	31	22
1914–15	160	160	157	146	143	135	146
Observed average.	125	96	141	80	96	66	[illegible]
Corrected average.	100	96	103	80	96	66	[illegible]
Average date of first flood flow.	Jan. 2		Jan. 6		Jan. 20		Jan. 13.
Flood flow considered as any flow in excess of.	14 sec.-ft.	14 sec.-ft.	12 sec.-ft.	12 sec.-ft.	12 sec.-ft.	12 sec.-ft.	10 sec.-ft.

The flow of San Luis Rey River at the head of its major valley is continuous throughout the year but reaches a minimum ranging in different years from 1 to 5 second-feet. The flow of other streams is continuous in some years, but usually ceases during the summer and fall (Table 34). Flow other than flood flow is completely absorbed by the valley fill before it reaches the ocean. It is interesting to observe the advance of the end of San Luis Rey River after September 15. During the summer the end of visible flow is usually just above the well numbered C 9 on Plate XXV; in September it begins to advance downstream at a rate of about 170 feet a day, the water filling the depleted sands beneath and adjacent to the channel, and thus building up a broad ground-water ridge. In the canyon below Bonsall the advance is more rapid, for the depth to the water table is small. The rate of advance in 1914, as observed by the writer, was 1,360 feet a day. If not previously overtaken by flood flow the end of this stream advances to the head of Mission Valley by the middle of January.

The rate at which the ground absorbs water from stream flow at any time depends, among other things, on the relative elevations of the water surface in the channel and in the subjacent valley fill and on the area of channel in contact with the flowing stream. The total volume annually absorbed from run-off depends, in addition, on the length of the period of flow, which in the major valleys usually far exceeds the period required to bring the water table to its maximum elevation. The average date of latest flood flow is sometime late in May or early in June (Table 34, p. 136), whereas the date of maximum ground-water level is late in March or early in April (Tables 32 and 33, p. 133). When evaporation becomes more effective than recharge the water table begins to go down. The quantity of water normally absorbed from flood run-off is only a small proportion of the total run-off, and large quantities of water annually flow unused into the ocean.

Table 37.—*Comparative discharge measurements of principal streams of San Diego County in 1914–15.*

Tia Juana River.

Point of measurement.	Distance between points of measurement (miles).	Date.	Measured flow of river (second-feet).	Total gain (+) or loss (−) in second-feet.	Gain (+) or loss (−) in second-feet per mile.
2½ miles above international boundary	2.5	Jan. 19, 1915	0.86	− 0.86	....
International boundary					
Do	2.8	....do	0	0	0
Nestor bridge		....do	0		
Do	1.5	....do	0	0	0
Near Pacific Ocean		....do	0		
International boundary	2.8	Apr. 6, 1915	44.0	+ 3.0	+1.1
Nestor bridge		....do	47.0		
Do	1.5	....do	47.0	−10.0	−6.7
Near Pacific Ocean		....do	37.0		
Total	4.3	....	....	− 7.0	−1.63
International boundary	2.8	Apr. 10, 1915	36.0	− 4.0	−1.4
Nestor bridge		....do	32.0		
Do	1.5	....do	32.0	− 6.0	−4.0
Near Pacific Ocean		....do	26.0		
Total	4.3	....	....	−10.0	−2.33

Sweetwater River.

Point of measurement.	Distance between points of measurement (miles).	Date.	Measured flow of river (second-feet).	Total gain (+) or loss (−) in second-feet.	Gain (+) or loss (−) in second-feet per mile.
Dehesa	7.5	Apr. 5, 1915	26.2	− 2.2	−0.29
Jamacho bridge		....do	24.0		

San Diego River.

Point of measurement.	Distance between points of measurement (miles).	Date.	Measured flow of river (second-feet).	Total gain (+) or loss (−) in second-feet.	Gain (+) or loss (−) in second-feet per mile.
El Capitan	5.8	Mar. 31, 1915	51.0	− 6.0	−1.03
Lakeside		....do	45.0		
Do	8.0	Apr. 3, 1915	37	+ 1.0	+0.13
Old Mission dam		....do	[a] 51		
Do	11.5	....do	[a] 51	0	0
Old Town		Apr. 4, 1915	[b] 56.0		
Total	19.5	....	....	+ 1.0	+0.05
Old Mission dam	9.0	June 2, 1915	72.2	− 2.1	−0.23
Near San Diego		....do	[c] 64.8		

[a] Includes inflow into river from San Vicente Creek (Mar. 3, 1915) of 13.0 second-feet.
[b] Includes net effect of inflow into river from Alvarado Canyon (Mar. 4, 1915) of 12.0 second-feet, and loss by diversion at city pumping plant (Mar. 4, 1915) of 7.0 second-feet.
[c] Includes net effect of inflow into river from Alvarado Canyon (June 2, 1915) of 3.0 second-feet estimated), and loss by diversion at city pumping plant (June 2, 1915) of 8.3 second-feet.

TABLE 37—*Comparative discharge measurements of principal streams of San Diego County in 1914–15*—Continued.

San Vicente Creek.

Point of measurement.	Distance between points of measurement (miles).	Date.	Measured flow of river (second-feet).	Total gain (+) or loss (−) in second-feet.	Gain (+) or loss (−) in second-feet per mile.
Foster	3.3	Apr. 5, 1915	10.0	0	0
Near Lakeside		....do	10.0		

San Luis Rey River.

Point of measurement.	Distance between points of measurement (miles).	Date.	Measured flow of river (second-feet).	Total gain (+) or loss (−) in second-feet.	Gain (+) or loss (−) in second-feet per mile.
Bonsall	12.0	Feb. 5, 1915	268	+57	+4.8
Oceanside		....do	325		
Pala (800 feet east of bridge)	8.0	Mar. 17, 1915	71	+ 2	+0.25
Monserate		....do	73		
Do	9.0	....do	73	− 6	−0.67
Canyon above mission		Mar. 18, 1915	67		
Total	17.0			− 4	−0.23

Depletion of the reservoirs.—Ground-water reservoirs lose water naturally (1) by evaporation of moisture raised by capillarity from the zone of saturation to the surface soil, (2) by transpiration from vegetation drawing moisture from the zone of saturation, (3) by return of water to the channel of the river or by underflow through the fill in the contracted neck at the lower end of the valley, and (4) by leakage into surrounding formations.

Losses due to evaporation occur wherever the zone of saturation is sufficiently close to the surface to permit the continued upward capillary movement of water to replace that lost by evaporation. The capillary limit varies from about 2½ to 8 feet, depending on the type of soil and the relative sizes of sand grains. Loss continues so long as the zone of saturation is within the capillary limit and is greatest between the middle of April and the middle of September. The rate of capillary movement of the water varies with the depth to the water table, so that the rate of loss is not the same in different parts of the areas of discharge nor at the same point at different times of the year, because of the lowering of the water table as the season advances. In this connection it has been suggested that losses due to evaporation might be eliminated by artificially lowering the water table below the capillary limit.

Transpiration in the area underlain by the valley fill occurs principally from native trees, such as willow, sycamore, and alder; from natural grasses and close-growing plants, such as saltgrass, yerba mansa, and samphire; and from growing crops, such as alfalfa, sugar beets, and grain. The moisture may be either absorbed by the roots from capillary water drawn directly from the zone of saturation or from water applied to the surface in irrigation. The rate of transpiration in any area depends on the kinds of plants and on the luxuriance and density of their growth. The losses are confined to the growing season and are most active while the leaves are green.

The losses from the underground reservoirs by return of water to the streams are negligible. During the flood-flow period such losses may occur at the borders of the channels where the material becomes saturated to the level of the flood crests, the moisture draining out to the level of the permanent stream within a few days after the flood peak has passed. Comparative discharge measurements made by the writer during March to June, 1915, at critical points on Tia Juana, Sweetwater, San Diego, and San Luis Rey rivers (Table 37) show no increase in the flow of the streams as they pass through the different valleys and indicate that during the summer and fall the return flow is practically zero. The same fact is also shown by the following tables (38 and 39) compiled from records of the United States Geological Survey of the flow at critical points on San Luis Rey, Santa Ysabel, San Dieguito, and San Diego rivers.

Table 38.—*Monthly discharge, in acre-feet, at gaging stations on three rivers in San Diego County for the period June to December, 1914, following a rainy season in which run-off was less than the average.*

Stream and point of measurement.	June.	July.	August.	September.	October.	November.	December.
San Luis Rey near Pala	298	252	117	89	257	314	515
San Luis Rey at Bonsall	77	0	0	0	0	32	385
San Luis Rey at Oceanside	0	0	0	0	0	0	0
Santa Ysabel near Ramona	522	20	6	6	35	125	397
San Dieguito at Bernardo	24	0	0	0	0	0	0
San Dieguito near Del Mar	0	0	0	0	0	0	0
San Diego at Lakeside	29	0	0	0	0	0	0
San Diego at Mission dam	0	0	0	0	6	6	6
San Diego at San Diego	0	0	0	0	0	0	0

Table 39.—*Monthly discharge, in acre-feet, at gaging stations on three rivers of San Diego County, for the period June to September, 1915, following a rainy season in which run-off exceeded the average.*

Stream and point of measurement.	June.	July.	August.	September.
San Luis Rey near Pala	4,020	588	432	387
San Luis Rey at Bonsall	4,480	300	13	0
San Luis Rey at Oceanside	5,370	0	0	0
Santa Ysabel near Ramona	2,800	959	569	232
San Dieguito at Bernardo	1,760	54	53	0
San Diego at Lakeside	1,620	66	1	0
San Diego at Mission dam	696	0	0	0
San Diego at Old Town	74	0	0	0

The data obtained at these stations, all of which are at contracted places in the valleys, show that during the summer and fall the ground-water reservoirs do not, as a rule, lose by surface flow at the lower end, even in a wet year, but rather that they absorb all water entering them. The increased flow during June, 1915, at lower stations on San Luis Rey River is due largely to inflow from lateral tributaries but in part to return water caused by the draining out of water absorbed by the channel bank during the protracted floods of early May.

Loss by underflow through the fill of the contracted neck at the lower end of the valleys is also very small. In San Pasqual, upper San Diego, and upper Sweetwater valleys, no such loss can occur, because at their lower ends these streams flow through rock-bottomed canyons. The fill of upper San Luis Rey Valley is connected with that of the lower valley by a neck of sand about 5 miles long, which fills an old canyon in the granite. The fill in this canyon is 60 feet thick at the deepest point and ranges in width from 400 to 800 feet. The slope of the water table is about 12 feet to the mile. The average velocity of underflow at a selected cross section of this canyon fill near Bonsall was determined by the writer from 11 separate observations made by the Slichter method at points well distributed through the section, and was found to have an average value of 5.14 feet a day, or about one-third of a mile a year. The rate of underflow in the entire section was 0.47 cubic feet a second, or 340 acre-feet a year. The conditions were probably favorable for a rate of flow greater than the average for the year for there was flow on the surface during the period of measurement. The loss by underflow from the upper San Luis Rey Valley can thus be set down as less than 340 acre-feet per annum. This loss, however, is without doubt more than offset by the underflow into the valley at the gaging station near Pala.

The conditions for underflow from the coastal valleys into the ocean are even less favorable than the conditions at the section near Bonsall. The sands of the valley fill near the coast are much finer than those in the upper valleys, the slope is gentler, and there is back pressure from the ocean. All the valleys except Tia Juana visibly contract in cross section before reaching the ocean, and if well logs were available it might be found that this valley also closes up below the surface. Thus the conditions do not indicate appreciable loss by underflow from the coastal valleys.

Loss from ground-water reservoirs in San Diego County by leakage into the surrounding formations is, in general, impossible, for those formations are relatively impervious. Moreover, the valleys lie far below the adjacent general surface and below the bottoms of tributary valleys. The conditions are therefore more favorable for receiving water from the adjacent formations than for yielding water to them. However, the contours of the water table (Pl. XX) north of the lower half of Tia Juana Valley and on both sides of the lower part of Sweetwater Valley, as drawn for January 6 and March 1, 1915, apparently show some loss of ground water, but the amount is only a small percentage of the total replenishment for Tia Juana Valley south of Nestor. This is the only valley, however, in which any evidences of loss by lateral percolation were observed.

Summarizing the discussion of ground-water losses, it may be said, first, the only large natural ground-water losses from the major valleys of San Diego County, except the possible leakage out of Tia Juana Valley, are due to evaporation and transpiration; and, second, that the ground-water losses during the annual period of the lowering of the water table (about Apr. 1 to Nov. 1) are nearly equal to the volume of water represented by the lowering of the water table plus the volume of water absorbed from streams during the same period.

Relation of replenishment to loss.—The additions to the ground-water supply during any season tend either to raise the water table or to retard its lowering. The losses, on the other hand, tend either to lower the water table or to retard its rise. The difference in level of the water table at any two dates is directly proportional to the difference in the accretions and losses during the period between these dates. If the accretions are in excess the water levels rise; if the losses are in excess the water levels fall; if accretions and losses are equal the water levels remain stationary. Table 33, which summarizes observations on fluctuations of ground water in the major valleys since 1912, shows that for a series of three years, including one dry, one average, and one wet year, the average annual rise of the ground-water is practically equal to the average annual lowering. The stability of the water table over long periods is also indicated by the statements of local residents. Hence it can be concluded that over a series of years the ground-water rise is nearly equal to the ground-water lowering and therefore that average annual additions to ground-water supply about equal average annual losses.

Method of computing annual additions to supply of ground water.—The conclusions presented in the last two paragraphs can be made the basis of a simple method of computing the volume of the average annual additions to the ground-water supply of the underground reservoirs. For simplicity in analysis the following terms will be used:

A=average volume, in acre-feet, annually absorbed from run-off (both stream flow and run-off from adjacent slopes).

B=average volume, in acre-feet, annually absorbed from direct rainfall on the surface of the valley fill.

C=average volume, in acre-feet, annually lost by evaporation and transpiration.

D=average volume, in acre-feet, annually lost by leakage into adjacent formations.

E=average annual fluctuation of water table, in feet, throughout the areas underlain by valley fill.

K=effective porosity; that is, the ratio of depth of actual water represented by fluctuation of water table, if spread over an equal area, to observed fluctuation.

S=area underlain by valley fill, in acres.
a=average volume, in acre-feet, annually absorbed from run-off during period of lowering of the water table (Apr. 1 to Nov. 1).
c=average volume, in acre-feet, annually lost by evaporation and transpiration during period of lowering of the water table (Apr. 1 to Nov. 1).
m=ratio of loss by evaporation and transpiration in the period April 1 to October 31, to the loss during the whole year.

The two following relations exist among the above quantities as a result of the conclusions stated:

(1) $c=(E\times K\times S)+a$.

(2) $A+B=C+D$.

A third relation exists by reason of the definitions of terms used.

(3) $c=m\times C$.

As a result of these relations and by performing simple algebraic operations the following relation exists:

(4) $A+B=\frac{EKS+a}{m}+D$.

Values for all elements of the second member of this equation are available from observations made during the years 1912 to 1915, as follows:

E, the average annual fluctuation of the water table, is known from direct observation for the period 1912–1915 in upper San Diego, San Pasqual, and San Luis Rey valleys (Table 33). The average rise is determined from observations for the season 1914–15 in all major valleys (Table 32). The ratio of the average rise for the season 1914–15 to the average annual fluctuation for the three valleys for which complete data are available is 1.30 (Table 33). The average annual fluctuation for other valleys can be approximately obtained by applying this ratio.

K, the effective porosity—that is, the percentage by volume of the porous valley fill drained and filled by the annual fall and rise of the water table—has been estimated from the results of several porosity tests, described on pages 121–123, at 34 per cent. This percentage undoubtedly varies considerably in different valleys and was determined approximately for each valley by a study of local conditions.

D, the average quantity lost by leakage into adjacent formations, is believed to be negligible for all the valleys except Tia Juana Valley, for which 500 acre-feet was adopted as more nearly the average than the quantity lost in 1915 (pp. 146–149).

a, the average quantity absorbed during the lowering of the water table, was computed from run-off data obtained by the United States Geological Survey at gaging stations in each valley during the years 1912 to 1915, and was averaged for each valley. The results should be very close to an average for a long period. (See Table 20.)

m, the ratio of loss by evaporation and transpiration from April 1 to October 31 to the loss during the year, was computed from the three-year record of evaporation obtained from a floating pan at La Mesa reservoir (Table 26, p. 102). The average ratio of the loss by evaporation from this reservoir from April 1 to October 31 to the loss for the whole year for the three years 1913 to 1915 is 0.752.

S, the area, in acres, underlain by the valley fill, was computed by planimeter from Plates XX to XXV, and included the area of both deep and shallow fill in the major valleys. The area of valley fill at the head of Tia Juana Valley in Mexico, about 690 acres, is included.

TABLE 40.—*Observed and computed data regarding ground-water intake in major valleys of San Diego County, Calif.*

Valley.	S.	E.	K.	D.	a.	m.	A+B.
	Acres.	*Feet.*	*Per cent.*	*Acre-feet.*	*Acre-feet.*		*Acre-feet.*
Santa Margarita	3,640	(3.00)	(0.33)	0	(1,000)	0.752	6,115
San Luis Rey (upper)	4,376	3.00	.38	0	1,910	.752	9,180
San Luis Rey (lower)	3,270	3.00	.32	0	820	.752	5,270
San Pasqual	1,880	3.60	.38	0	2,220	.752	6,380
San Dieguito	2,210	(3.00)	.33	0	360	.752	3,390
San Diego (upper)	3,120	4.28	.38	0	1,040	.752	8,130
Mission	2,470	4.00	.33	0	200	.752	4,600
Sweetwater (upper)	1,065	3.16	.38	0	420	.752	2,260
Sweetwater (lower)	1,532	2.08	.33	0	0	.752	1,400
Tia Juana	4,380	5.45	.31	700	910	.752	11,550
	27,943	....	....	....	....	....	58,275

NOTE.—The quantities in the last column of the table (the term A+B of equation 4) represent the average annual additions to ground water from all available sources. The quantities in parentheses are approximate.

Accuracy of computations.—As several of the factors in the computations are based on inadequate data the determinations contain a large percentage of error. The greatest uncertainty exists in regard to the effective porosity (K), on account of the small number of porosity tests that were made, in regard to the average annual fluctuation of the water table (E), and the volume of stream water (a) absorbed from April 1 to November 1, on account of the shortness of the periods of observation.

The average annual yield—that is, the maximum quantity that can be withdrawn for use from year to year without depleting the supply—is not the same as the intake, which is shown in the last column of Table 40. The yield can be definitely determined only by large development and use of the water for a period of years. One of the principal elements of uncertainty in the relation of intake to yield is the extent to which the installation and use of pumping plants will reduce evaporation and transpiration from uncultivated land. Pumping at wells whose circle of influence includes the stream channel at a period when the stream is still flowing draws some water directly from the stream. Table 34 (p. 136) shows that this period usually includes the months April, May, and June. By lowering the water table below its normal level at the end of the season (Nov.

1), pumping withdraws water that would otherwise remain in the ground, and this water is replaced during the succeeding rainy season. These processes represent absorption from run-off in excess of the natural absorption. By prematurely lowering the water table over more or less extended areas during May to October, pumping reduces natural losses from evaporation, for it withdraws ground water that would otherwise be lost into the atmosphere. This process substitutes evaporation and transpiration from cultivated fields for that from uncultivated land. Where most of the large wells are within about 500 feet of the stream channel and the normal period of flow of the stream extends well into June, the yield may be greater than the natural ground-water recharge; where most of the large wells are more than 500 feet from the stream channel and the normal period of flow of the stream ends in April or earlier, the yield may be less than the natural recharge. If the wells draw extensively from a large body of open gravels that lie under finer materials, as in Tia Juana Valley, and if the gravels receive much water directly from the stream in the upper part of the valley, as they may in this valley, the yield may exceed the natural recharge. It is not possible with the available data to classify more definitely the valleys with respect to relation of yield to normal recharge.

If the total intake (see last column of Table 40) could be completely utilized for irrigating alfalfa and general field crops on valley lands, and with an average net duty of the water of 1.5 acre-feet per acre, the supply would be sufficient to irrigate about 36,000 acres, an area larger than the total area of these valleys, as shown in the second column of Table 40, page 151. In the estimate of the duty of water it is assumed that one-half the land is planted in alfalfa and requires 3 acre-feet per acre, and that the other half is in general crops requiring 1 acre-foot per acre, and that one-third of the water applied in irrigation of alfalfa is returned to the ground-water reservoir. For irrigating citrus crops on the mesa and foothill lands less water would be required to the acre but practically none of it would percolate back to the ground-water reservoir. The available supply could not be completely utilized on mesa lands, however, by pumping from a few groups of wells in each valley for, on account of the configuration and shallow depth of the valley fill, complete utilization would require many groups of wells and many widely distributed pumping plants feeding one or more "booster" plants in each valley. For economic reasons the available ground-water supply of the major valley therefore can not now be used exclusively in the irrigation of mesa lands. It will doubtless ultimately serve a large proportion of the arable valley lands, the best agricultural lands along the margins of these valleys, and a number of favorably situated blocks of mesa land. Data contained in the report of the Conservation Commission of California[1] show that in 1912 3,050 acres in San Diego County were irrigated with water derived from the major valleys. The area has been considerably increased since 1912, but the writer's investigations indicate that in 1915 it did not exceed 8,000 acres. Making allowances for inaccuracies in the computations, the writer believes that the ground waters of these valleys are adequate to serve much more land than has hitherto beer brought under cultivation.

SAFE YIELD.

The safe yield of ground-water reservoirs in San Diego County for domestic and municipal supplies, as defined on page 154, depends on their ability to meet withdrawals during periods of severe drought extending over several years during which they may receive little or no replenishment. In computing the safe yield the volume of water that is normally held in the valley fill and that can be extracted during a three-year period was determined, it being assumed that no replenishment takes place during this period, that adequate replenishment will take place during the next year, and that complete replenishment will take place before the occurrence of another three-year drought. Since safe yield is that required for domestic and municipal uses the effect of pumping on the lowering of the water table and the practicable draw down in wells need not be considered so carefully as, for reasons of economy, it must be in pumping for irrigation. The allowable depression of the water table in each valley was estimated from a study of the logs of wells (figs. 8, 15, and Pls. XXVI to XXIX), the profiles and cross sections (figs. 9–14), and the probable draw down in wells as determined from pumping tests. The quantity of water that could be drained by pumping from the valley fill was assumed to be 25 per cent in the upper valleys and 20 per cent in the coastal valleys except lower San Luis Rey Valley and Santa Margarita Valley, where, on account of the large proportion of fine materials, 15 per cent was considered more nearly correct. Table 41 shows the results of the study for each valley, the last column giving the approximate annual safe yield in acre-feet. The figures in the column headed "Effective area of valley fill" were obtained from those in the first column by deducting areas of shallow valley fill that will yield little water and areas in which the water probably contains so much mineral matter that it is unsuitable for domestic uses. In Sweetwater Valley, from which all but local run-off is withheld by Sweetwater reservoir, the safe yield as thus computed was reduced 50 per cent because the only sources of ground-water replenishment are direct rainfall, local run-off, and seepage returned

[1] Tait, C. E., Irrigation resources of southern California: Rept. Conservation Comm. of California, pp. 29-305, 1912.

from irrigation by gravity under the Sweetwater Water Co.'s system. The quantities of water indicated by the last column of the table could probably be removed from the valleys every year without causing serious depletion during long periods of drought. The utilization of the water for domestic and municipal supplies reduces, of course, the quantity available for irrigation.

TABLE 41.—*Estimated annual safe yield of ground water available for domestic and municipal supplies from major valleys of San Diego County, Calif.*

Valley.	Area underlain by valley fill.	Effective area of valley fill.	Assumed average depth water table could be lowered by end of 3 years.	Per cent of volume that could be drained.	Total volume extracted by pumping during 3-year period.	Approximate annual safe yield.	
						Acre-feet.	Million gallons per day.
	Acres.	*Acres.*	*Feet.*		*Acre-feet.*		
Santa Margarita	3,640	1,820	50	15	13,700	4,570	4.1
San Luis Rey (upper)	4,376	3,060	30	25	23,000	7,640	6.8
San Luis Rey (lower)	3,270	1,635	50	15	12,300	4,100	3.7
San Pasqual	1,880	1,320	40	25	13,200	4,400	3.9
San Dieguito	2,210	1,220	30	20	7,300	2,430	2.2
San Diego (upper)	3,120	2,180	30	25	16,400	5,470	4.9
Mission	2,470	1,480	30	20	8,880	2,960	2.6
Sweetwater (upper)	1,065	750	30	25	5,620	1,870	1.7
Sweetwater (lower)	1,532	920	30	20	5,500	1,100	1.0
Tia Juana	4,380	2,630	45	20	23,700	7,900	7.1
	27,943					42,470	37.9

For large single projects, for either domestic supply or for irrigation, the ground-water reservoirs can be used most advantageously in connection with surface-water reservoirs that intercept and hold the winter run-off. Indeed the relatively small yield of the ground-water reservoirs makes such procedure imperatively necessary. The principal advantage of the procedure, other than that of increasing the supply, is that the ground-water reservoir provides a dependable reserve which is free from loss by evaporation or catastrophe and, for the most part, from danger of pollution, which can be drawn upon heavily in emergency, and which is available after the surface reservoirs have been polluted or depleted by extended drought. If the cost of pumping is not great, the operation of the pumps to full capacity during the period of river flow will save the surface water held in storage without depleting the ground-water storage, the effect being that of increased diversion from the stream. This method also has the advantage of providing a clear, potable water at a time when surface waters are likely to be turbid.

There is a popular belief, which is held even by some engineers, that wells in the valley fill draw from a large underground stream that follows more or less closely the course of the river channel and maintains the level of the ground-water surface under adjacent lands by lateral percolation. According to the popular conception, this stream, although perhaps not moving so rapidly as a surface stream, has a very noticeable velocity, and the withdrawal of water at any point by pumping from a well is equivalent to a diversion from a surface stream and reduces the volume of underflow and the supply available to other wells downstream. The writer's investigations, however, indicate that such a belief is entirely unwarranted. As has already been shown (see p. 148) the ground water in the valley fill moves downstream very slowly, the measured advance at a narrow cross section where conditions were favorable for rapid movement being only one-third of a mile a year. The ground water, in fact, occupies a series of reservoirs represented by the valley fill and does not move in distinct streams any more than does the water in a surface reservoir or lake. When filling of these reservoirs ceases, late in the spring, there is a very slow general movement of water from the upper toward the lower part of each reservoir, but there is no particular segregation into bodies of moving and standing ground water, and certainly there is no continuous underflow through the basins. The effect of pumping from a well in the valley fill is indicated by the lowering of the water level in the vicinity of the well, just as pumping from a surface reservoir lowers the water level. The lowering does not, however, occur over the whole surface of an underground reservoir but is confined to a circle whose center is near the well. The diameter of this circle gradually increases if heavy pumping is carried on without intermission, and during the course of a long pumping season the circle of influence may extend out 1,000 feet or more from the well. The effect of intermittent pumping, however, does not extend far from the well, as the circle of influence shrinks when pumping ceases. The only wells that are affected by pumping are those within the circle of influence. The lowering of the water table that occurs around a well during any pumping season will normally be counteracted during the following winter by replenishment of the local ground-water supply from precipitation and run-off, so that the effect of the previous season's pumping is thus entirely overcome. It is therefore obvious that the effect of pumping is confined to the vicinity of the well from which water is drawn and is not a diversion from an underground stream on which all lower wells are depending for their supplies.

YIELD OF WELLS.

CONDITIONS AFFECTING YIELD.

The yield of wells in the fill of the major valleys of San Diego County depends mainly on (1) the capacity of the material of the water-bearing stratum to transmit water, (2) the thickness of the water-bearing stratum, (3) the drawdown, or lowering of the water level in the well during pumping, (4) the size and shape of the well, and (5) the length and kind of the screen or perforated area and the methods of cleaning and developing the well.

The capacity of the material of the water-bearing stratum to transmit water—the condition having the greatest effect on the yield of wells—depends mainly on the effective size of grain and on the porosity of the water-bearing material. Experiments have shown that the flow of water through any material varies as the square of the effective size of grain; hence doubling the effective size of grain will quadruple the flow of water. Likewise, the flow of water is also greatly increased with an increase in porosity. The alluvial materials composing the valley fill in San Diego County are made up of particles nonuniform in size, the smaller filling the voids or spaces between the larger. The porosity of such materials is much smaller than that of a material composed of particles uniform in size. Thus although large boulders or cobblestones scattered through a sand or fine gravel increase the effective size of grain they decrease rather than increase the transmission capacity of the sand or fine gravel, because the decrease in porosity of the material more than offsets the increase in effective size of grain. Slichter [1] has expressed the capacity of a water-bearing material to transmit water by means of a coefficient which he has termed the "transmission constant." This constant varies mainly with the size of grain and the porosity of the material and is defined as the quantity of water, in cubic feet, that is transmitted in one minute through a cylinder of material 1 foot long and 1 square foot in cross section, under a difference in head at the ends of 1 foot of water. Other things being equal, the yield of a well is directly proportional to the transmission constant of the water-bearing material.

In its effect on yield the thickness of the water-bearing stratum is closely allied to its transmission capacity. If the water-bearing strata penetrated in two wells are of the same material, the well in which the water-bearing material is thickest will yield the greater quantity of water, provided, of course, that the casing of the well permits the water to enter along the entire depth of the stratum.

Nearly equal to transmission capacity in its effect on yield of wells is the lowering of the water level during pumping, for the amount of lowering, or the "drawdown," determines the head under which water flows into the well. Other things being equal, the yield of a well varies directly with the drawdown. If, however, the drawdown is so large that the water level is forced below the top of the intake of the well, the resulting decrease in area available for the entrance of water obviously affects the yield and changes the relation. The amount of drawdown is specially significant in shallow wells, where

[1] Slichter, C. S., The rate of movement of underground waters: U. S. Geol. Survey Water-Supply Paper 140, pp 10-15, 1905.

it directly limits the entrance area. The yield of a well will not vary directly with the drawdown if an appreciable part of the drawdown is due to entrance head. Entrance head represents the pressure of water necessary to produce flow through the perforations of the well casing and depends on the size and shape of the perforations and their freedom from obstructions, as, for example, by particles of sand and gravel. The amount of drawdown that is desirable must be determined by carefully considering the relation of value of yield to cost of pumping. The value of the greater yield obtained by an increase in drawdown may be more than offset by the increase in the cost of pumping due to the greater lift. The economical draw-down in any well can be determined only by studying the local conditions.

Size has greatest effect in shallow wells, which are relatively large in diameter as compared with depth, as, for example, in dug wells of the pit type. In such wells the yield seems to be directly propor-tional to the diameter. In drilled wells, most of which are less than 12 inches in diameter, the effect of diameter on yield is not so direct, but greater diameter permits the water to enter at a lower velocity, thus decreasing the head lost in friction in passing through the water-bearing material. If the water-bearing stratum is composed of fine material the dependence of yield on diameter of the well is much less than is commonly supposed; but if the material is fine sand the larger well is more advantageous because, owing to the lower entrance velocity of the water, the well is less likely to become clogged with sand. In California 10-inch or 12-inch casing is com-monly used in irrigation wells. Some authorities recommend that 8-inch casing should be the largest used in ordinary irrigation wells, but for the conditions usual in California, where the wells are drilled in soft material and the price per foot is practically the same for wells from 7 inches to 14 inches in diameter, the only advantage of an 8-inch over a 12-inch well is the difference in the cost of casing, a difference that would be comparatively small except for very deep wells. The advantages of the 12-inch well over the 8-inch are some-what greater yield for the same water-bearing stratum, less likeli-hood of clogging through entrance of sand, and greater ease of sinking by the methods of drilling ordinarily used. This last advantage is particularly great in drilling in formations containing cobbles or boulders, in which it may be impossible to use casing smaller than 12 inches in diameter. The use of casings as large as 16 to 24 inches in diameter is usually advantageous only where the water-bearing material is very coarse and it is not recommended for wells in San Diego County.

The area and design of the screen affect the yield of a well because of the head lost through entrance of water into the well. If the screen is clogged, or if the perforations are not ample the yield is decreased. Other conditions remaining the same, the yield of a well will be increased by installing a screen or putting in perforations designed to reduce the entrance head as much as possible; at the same time clogging of the well must be prevented.

TESTS OF YIELD OF WELLS.

PURPOSE AND METHODS OF TESTS.

The best method of estimating the probable yield of a well before it is sunk is from tests of wells sunk in the same neighborhood or in similar formations. The nearer the position of the prospective well to the tested well the closer can its yield be estimated, because of the greater probability that it will penetrate similar water-bearing strata. If the prospective well is not near a tested well its probable yield can best be estimated from tests of wells sunk in formations of the same type.

The yield of wells can not be compared directly unless their draw down is the same. To make such a comparison it is necessary to determine for each well its "specific capacity," or the quantity of water furnished by the well for a unit lowering of the water level in the well by pumping. Specific capacity is usually expressed in gallons per minute per foot of draw down. For wells which are similarly perforated and which penetrate similar water-bearing strata the specific capacities will be found about the same. The specific capacity of wells, determined by test, is the best index of the yield of proposed wells drawing from the same formation.

Another term used in expressing the yield of wells is the "specific capacity of the formation." It is defined as the yield in gallons per minute per foot of drawdown for each square foot of perforated or strainer area, and it is perhaps a more accurate term for comparing the yield of wells than "specific capacity," as it takes into account the available area for entrance of the water.

Many of the wells that have been drilled in San Diego County do not yield as much water as they would if they had been properly constructed, and in order that those who contemplate sinking wells may benefit by the knowledge already gained, the writer made pumping tests to determine the yield and the specific capacity of several typical wells. In each of the tests the installed pumping equipment was used, and the runs were continued until the draw-down ceased to increase. Most of the tests covered an hour or more. The discharge from the pump was measured with a 2-foot Cippoletti weir, with a current meter, or with a tank of known dimensions. The drawdown was measured with a tape or was estimated from the vacuum gage readings after making due allowance for head lost in the suction lines.

RESULTS OF TESTS.

Well K 41.—The pumping plant owned by C. A. Van Houten, in Mission Valley, about 3 miles northeast of San Diego, comprises five drilled wells, 60 feet apart, connected with the same pump. Each well is provided with 10-inch standard screw casing sunk to an average depth of 80 feet. The principal water-bearing stratum is fine, clean gravel, between the depths of 70 and 80 feet. The section of the casing that penetrates the water-bearing stratum is perforated with drilled holes. (For logs of wells see Pl. XXVIII.) The normal water level in the wells varies during the year from 6 to 8 feet below the surface, and at the time of the test was about 8 feet.

During the test, which lasted five hours, the wells were pumped at the rate of 614 gallons a minute. The drawdown was estimated at 22 feet, which carried the water level to about 30 feet below the surface. The yield of each well was therefore about 6 gallons per minute per foot of drawdown or, for a perforated area of 131 square feet, about 0.21 gallon per minute per foot of drawdown for each square foot of perforated area. The low specific capacity of these wells suggests that they were not drawing freely from the water-bearing stratum.

Well L 82.—The pumping plant owned by J. Johnson, jr., in the upper San Diego River valley, about 3 miles west of Lakeside, comprises 10 drilled wells, 60 feet apart, interconnected to the same pump. In each well 12-inch double stovepipe casing is sunk to an average depth of 60 feet. The log of the wells (Pl. XXIX) shows that the principal water-bearing stratum extends from 10 feet below the surface to 60 feet below the surface. The normal water level in the wells ranges during the year from about 8 feet to 12 feet below the surface, and at the time of the test was about 8 feet below.

The wells were pumped 48 minutes at the rate of 2,475 gallons per minute. The full drawndown, estimated at 12 feet (making the water level 20 feet below the surface of the ground) was reached almost immediately after pumping was started. The yield of each well was therefore about 21 gallons per minute per foot of drawdown or, for an estimated perforated area of 400 square feet, about 0.53 gallon per minute per square foot of perforated area.

Well O 132.—The pumping plant owned by C. M. Richardson, in sec. 34, T. 18 S., R. 2 W., in Tia Juana Valley, about 2 miles southeast of Nestor, comprises two drilled wells, 72 feet apart, connected to the same pump. In these wells 12-inch casing is sunk to a depth of 68 feet, the last 17 feet in gravel, which is the principal source of the water. (For logs of wells see Pl. XXVI.) The lower ends of the casings are perforated along a length of 12 feet. The water level in the wells, according to the owner, is normally 9 feet below the surface of the ground.

For a period of one hour the wells were pumped at the rate of 1,120 gallons per minute. During the first 15 minutes the water level was drawn down an estimated distance of 27 feet below its normal level, or 36 feet below the surface of the ground, where it remained to the end of the test. Each well yielded, therefore, a little more than 20 gallons per minute for each foot of drawdown, or about 0.55 gallon per minute per square foot of perforated area per foot of drawdown. This well appears to be typical of wells in Tia Juana Valley, which penetrate the gravel that underlies most of the valley at depths ranging from 50 to 75 feet (figs. 9 and 10, pp. 112, 113).

Wells at Mission Valley pumping plant of San Diego city.—The wells at the Mission Valley pumping plant owned and used by the city of San Diego for municipal water supply were tested for yield

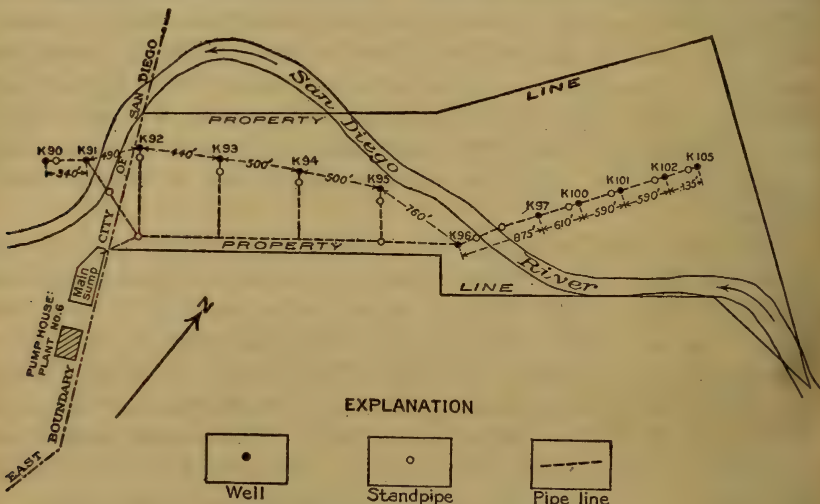


FIGURE 16.—Plan of Mission Valley pumping plant of the city of San Diego.

from November 16 to December 27, 1914, by H. A. Whitney, hydraulic engineer of the city water department. The tests are reported here because they furnish additional information as to the yield of wells in Mission Valley. The only test made by the writer in this valley was that on well K 41 (p. 159), whose yield is apparently not representative of that which should be expected from wells that penetrate the gravel underlying this valley.

The relative positions of the city wells are shown in the sketch map forming figure 16 and the logs of the wells in Plate XXVIII (p. 116). The principal water-bearing stratum in each well is gravel and ranges in thickness from 5 to 16 feet. In some of the wells, notably in well K 90, the stratum of gravel from which the water is drawn contains some clay, and wells K 93, K 96, and K 91 draw partly from such a formation. These drilled wells are lined with 12-inch stovepipe casing and are perforated where they pass through the water-bearing stratum. Each well was equipped with a pump. The results of the tests and the computations of specific capacity are given in Table 42. The drawdown recorded in the table was reached about 10 minutes after pumping was started in all the wells except K 105, in which the maximum drawdown was reached in about 20 minutes. For many of the wells the length of the perforated casing was not known, but for these it was assumed to equal the thickness of the water-bearing stratum, and that asumption was used in computing the specific capacity of the gravels.

TABLE 42.—*Summary of tests of San Diego city wells at Mission Valley pumping plant.*

[Tests made Nov. 16 to Dec. 27, 1914, by H. A. Whitney, hydraulic engineer, Department of Water, city of San Diego.]

Well No.	Duration of test (hours).	Total depth of well (feet).	Thickness of water-bearing, stratum.	Drawdown (feet).	Total yield (gallons per minute).	Specific capacity of well (gallons per minute per foot of drawdown).	Area of perforated or strainer surface (square feet).	Specific capacity of gravels (gallons per minute per foot of drawdown per square foot of strainer surface).
K 93	24	90	[a] 8	18.50	477	25.8	25.1	1.027
K 95	24	82	15	12.80	477	37.2	56.6	.658
K 96	24	80	[a] 11	25.40	432	17.0	47.2	.360
K 100	24	80	12	10.40	477	45.9	37.7	[b] 1.219
K 102	24	80	12	....	477	....	25.1	....
K 97	24	80	14	12.70	477	37.6	44.0	.855
K 94	24	58	9	11.60	504	43.5	28.3	[b] 1.538
K 92	24	60	12	16.20	504	31.1	37.7	[b] .825
K 91	24	75	[a] 11	30.10	407	13.5	15.7	[b] .860
K 90	24	45	7	24.20	477	19.7	22.0	[b] .896
K 105	24	80	12	33.50	369	11.0	25.1	.439

[a] Gravel, 5 feet; remainder gravel and clay.
[b] Figures obtained by assuming the length of perforated area equal to the depth of water-bearing stratum.

The records show clearly that wells sunk near each other in the fill of the major valleys may differ greatly in yield. For example, well K 100 yielded nearly 46 gallons per minute per foot of drawdown, whereas K 105 yielded only 11 gallons per minute per foot of drawdown, though each well, according to the driller's log, penetrated 12 feet of gravel. Other variations in yield are almost as striking. As the wide difference in yield between wells K 100 and K 105 can not be ascribed entirely to differences in the gravel stratum, it must be concluded that well K 105 was, for some reason, not drawing freely from the gravels. Employees in charge of the pumping plant report that well K 105 has always produced poorly.

The specific capacity of the gravels in the water-bearing formations of Mission Valley, as expressed by the yield of the wells in gallons per minute per foot of drawdown per square foot of perforated area, is shown in Table 42 to vary from 0.360 to 1.538. The lowest capacity was obtained in the test of well K 96, which passed through only 5 feet of gravel and draws partly from a formation including gravel and clay.

DISCUSSION OF WELL TESTS.

A summary of the results of tests for yield of wells in the fill of the major valleys of San Diego County, including the observations and the computations of specific capacity, is given in Table 43. Results obtained from tests of the San Diego city wells in Mission Valley are recorded in Table 42.

These tests show in general the dependence of yield on the character and thickness of the water-bearing material. The specific capacity of the wells tested ranged from 6 to 45 gallons per minute per foot of drawdown. The smallest and largest yields were obtained from wells K 41 and K 100, respectively, which are in Mission Valley and are only about 2 miles apart and which draw their water from gravels that are similar in character and thickness. The great difference in yield is probably due to clogging of well K 41, so that water from the gravels does not enter freely. Clogging no doubt also accounts for the low specific capacity—only 11 gallons per minute—of well K 105, in which, according to the driller's log, the stratum of gravel is as thick as in well K 100 (Pl. XXVIII). All the other wells tested in Mission Valley yielded more water than either well K 41 or K 105, though many of them, according to the driller's logs, draw water from strata inferior to those supplying K 41 and K 105. Except for these two wells the tests indicate that the specific capacity of the wells depends on the character and thickness of the water-bearing strata, being largest for wells that draw water from the thickest and most open gravels.

TABLE 43.—*Summary of tests of typical wells in San Diego County.*

Well No.	Owner.	Location.	Formation.	Thickness of water-bearing stratum (feet).	Drawdown (feet).	Total yield (gallons per minute).	Specific capacity of well (gallons per minute per foot of drawdown).	Area of perforated or strainer surface (square feet).	Specific capacity of gravels.[e]
Wells in fill of major valleys.									
O 132	C. M. Richardson..	Tia Juana Valley.	Valley fill.	17	27	[a]1,120	20	75.4	0.55
K 41	C. A. Van Houten.	Mission Valley.	.....do.....	10	22	[b]614	6	[d]131	[d]0.21
L 82	J. Johnson, jr.....	Upper San Diego River.	.....do....	50	12	[c]2,475	21	[d]400	[d]0.53
Wells on Nestor and Chula Vista terraces.									
O 115	W. E. Williams..	Tia Juana Valley.	San Diego formation.	3	15.25	231	15	....	....
O 47	Tucker & Evans..	2 miles west of Nestor.	.....do.....	14	21	373	18	....	....
O 102	R. J. Jaeger.......	One-half mile east of Nestor.	.....do.....	....	none.	116.5	....	....	....
Wells in residuum.									
L 24	J. Miller..........	1 mile north of El Cajon.	Residuum.	32	20.8	156	7.5	....	....
L 98	Chas. Bentley....	2 miles east of El Cajon.	.....do.....	62.5	24.7	79	3.2	....	....

[a] 2 wells. [b] 5 wells. [c] 10 wells. [d] Estimated. [e] Gallons per minute of drawdown per square foot of strainer surface.

The specific capacity of the water-bearing materials is shown by the tests to vary from 0.21 to 1.538, the larger capacities being found, as before, in wells drawing water from the more open and thicker gravels, although a few exceptions may be noted. On the whole, the specific capacities of these gravels may be said to be high, for in many sections of the country a yield of 0.33 gallon per minute per foot of drawdown per square foot of perforated area would be considered good.

The tests indicate that wells sunk in the major valleys of San Diego County, penetrating a considerable depth of coarse sand or from 10 to 15 feet of open gravel, such as lies at the bottom of the ancient river valleys, if properly perforated or equipped with strainers, may be expected to yield at least 20 gallons per minute per foot of drawdown. Where conditions are most favorable—that is, where the well passes through open gravel more than 10 feet thick and the casing is skillfully perforated—the specific capacity may amount to at least 30 gallons per minute per foot of drawdown; where conditions are poor—where the water-bearing formation contains little or no gravel and only a moderately thick stratum of coarse sand and the perforations are too large, too small, or too few—the specific capacity of the wells may be considerably less than 20 gallons. For a drawdown of 10 feet in drilled wells provided with 10 or 12 inch casing, a very good well should yield 300 gallons per minute or more, an average well 250 gallons per minute, and a poor well less than 200 gallons per minute; for a drawdown greater or less than 10 feet the total yield would be proportionally larger or smaller if other conditions remained the same.

The drawdown to be assumed in estimating the yield of wells depends on the relation of yield desired to the saving in cost to be effected and should be carefully computed for each pumping plant. A drawdown as great as 20 feet will rarely be found profitable. If the estimated yield of a single well for a moderate drawdown is too small, the desired yield can perhaps best be obtained by sinking two or more wells, 60 to 100 feet apart, and connecting them with the same pump. Pumping plants of this type are very common in the valley areas and are usually successful. For example, if the specific capacity is estimated at 20 gallons per minute, a total yield of 400 gallons per minute may be obtained either from a single well with 20-foot drawdown or from two wells with a drawdown of about 10 feet, allowance being made for a small additional drawdown to counteract interference. The choice must be based on comparison of the annual cost of pumping and the interest on the cost of sinking the well or wells.

The practical difficulty of closely estimating the yield of a well before sinking it must, however, be clearly remembered. Though the material composing the fill of the major valleys is fairly uniform in character and distribution, the logs of individual wells show marked variations, some of them within rather short distances; therefore the probable yield can be only roughly estimated. In other words, the generalized figures given in the preceding paragraphs are intended for use only as a guide.

METHODS OF SINKING WELLS.

The common method of sinking wells in the major valleys of San Diego County is the well-known California or stovepipe method,[1] which is well adapted for use in the loose sand and gravel (in few places exceeding 100 feet in thickness) that form the water-bearing strata in these valleys. Good wells range in depth from 50 to 100 feet, except in the lower part of San Luis Rey Valley and possibly of Santa Margarita Valley, where the valley fill in places exceeds 200 feet in thickness and the best wells are 160 to 210 feet deep.

No particular difficulty is experienced in drilling, although in some places beds of cobblestones and boulders, that are hard to penetrate, are encountered at the bottom of the valley fill. Such beds are usually open, however, and yield water so freely that there is seldom any reason for drilling through them. In Tia Juana Valley a number of very good wells draw their entire supply from such a bed at the bottom, the casing being without perforations. It is customary, however, to perforate the well casing at all strata of coarse sand and gravel in order to increase the yield. The perforations consist of vertical slits from three-sixteenths to five-sixteenths inch wide and about 8 inches long. The cuts are made with a knife that is thrust through the casing at the position desired and then slowly drawn upward the desired length with hydraulic jacks. For wells entirely in fine sand or material which does not readily yield water, it has been found possible to increase the yield greatly by running coarse gravel down around the outside of the casing. This is done by depositing the gravel around the casing at the surface, and then withdrawing material from the bottom of the casing with the sand bucket. The sand around the casing gradually settles, carrying the gravel down with it. There is thus created around the well a cylinder of coarser material which, when the casing is perforated and the well cleaned, gives a greatly enlarged percolating surface and also prevents fine material from entering the perforations and clogging the well. Wells which would be classed as failures have by this method been made to yield as much as those in more favorable formations. An experienced local driller who has used this method extensively states that it is not wise to employ it where the casing passes through one or more layers of clay in the sand, as the clay has a tendency to plaster the outside of the casing and shut out the water.

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[1] Slichter, C. S., The rate of movement of underground waters: U. S. Geol. Survey Water-Supply Paper 140, p. 98, 1905.

Prices for well drilling by this method vary somewhat, depending on the local conditions and the cost of well casing. In August and September of 1914 a number of wells were put down in Mission Valley for the city of San Diego by Mr. A. H. Hatherly, a local driller, who has had more than 10 years' experience in San Diego County. The contract price was $2.95 per foot for ordinary material and $4 per foot for boulders or rock. A charge of $15 per day additional was made for perforating, cleaning, and similar work. The price per foot included 12-inch stovepipe casing at $1 per foot. The average cost to the city of five of these wells 80 feet deep, sunk mostly in sand and gravel, and perforated with 40 to 90 cuts five-sixteenths inch by 8 inches was $263. The prices are typical of similar wells in other parts of this valley and in such valleys as Tia Juana, where most of the wells are about 80 feet deep. In the low mesa immediately north of Tia Juana Valley the cost of drilled wells 35 feet deep is almost as great as that of deeper wells in the valley on account of the formation, which consists of gravel and cobblestones cemented with clay. The prices will differ with the changes in the price of well casing, which varies with general market conditions and has advanced very much since these wells were sunk.

The casing commonly used for wells in the valley fill is the double slip-joint or stovepipe casing made of lap-riveted cylinders of sheet iron or steel. The cylinders are in 2-foot lengths and are of two sizes, one fitting inside the other. The larger sizes overlap the smaller by 1 foot, thus breaking the joints. The size most generally used is 12 inches in diameter and is made of No. 14 gage metal.

A casing of unusual type, devised by Mr. G. M. Hawley, of Jamacho, was found in recently constructed wells in the upper Sweetwater and San Diego River valleys. The casing is made of long strips of surfaced redwood nailed together with spacers so as to form a long open cylinder with many narrow slits extending full length, except where interrupted by the spacers at intervals of about 3 feet. The cross section of the strips was trapezoidal, the dimension varying somewhat with the size of casing. A specimen of 10-inch casing examined by the writer was composed of 32 staves, 1 inch thick, with edges three-fourths and one-half inch wide. The strips were placed with the three-fourths-inch face outward, and half-inch face inward. The outside width of the slits is varied to suit the formation, and in several wells examined by the writer it was only one-sixteenth inch. In some wells the outside of the casing is wrapped with copper wire or screen. The casing is manufactured at El Cajon, the price in 1914 being $1 per foot. The casing was devised to increase the percolating area of the well without cutting the relatively wide slits necessary in perforating metal casing with a knife and at the same time to avoid the more costly metal screens. In using this casing a metal casing of larger diameter is first driven down and the wooden casing is dropped inside the metal casing, which is then removed. The casing is being used in wells not more than 50 feet deep sunk in sand and fine gravels and is not adapted for use in silt, which enters the slits and clogs the well. It has not the strength and durability of a metal casing, but seems to be filling a local need very satisfactorily.

WATER IN THE MINOR VALLEYS.

By A. J. Ellis and C. H. Lee.

DISTRIBUTION OF MINOR VALLEYS.

In the broad tracts of the coastal belt between the deeply filled canyons of the major streams the principal sources of ground water are the relatively thin and narrow deposits of valley fill that cover the floors of many of the minor valleys. In the highland area, also, some of the minor valleys contain deposits that are capable of furnishing water. The supplies obtainable from these deposits, therefore, although meager compared with those obtainable from the fill of the major valleys, are nevertheless exceedingly valuable, for most of the valleys are bordered by large areas in which it is very difficult to obtain satisfactory supplies.

The distribution of the minor valleys is shown on the topographic maps published by the United States Geological Survey. The San Diego, La Jolla, Oceanside, Escondido, and El Cajon maps cover the coastal belt and western parts of the highland area and show by means of contour lines representing 25-foot intervals the widths of the valley floors and their depths below the levels of the mesas; the scale of these maps is about 1 mile to the inch (1:62,500). The Capistrano, San Luis Rey, Ramona, and Cuyamaca sheets also cover the highland area and parts of the coastal belt, but their scale is about 2 miles to the inch (1:125,000) and their contour interval is 100 feet. The map forming Plate II shows all these valleys, but on account of its small scale and large contour interval it shows little of the detail of width and depth.

The streams of the minor valleys of the coastal belt rise within 25 miles of the ocean, either on the coastal belt itself or on the first prominent mountain slopes, and they drain the areas between the major valleys. The largest, named in order from north to south, are Arroyo San Mateo, Arroyo San Onofre, and Las Pulgas, Buena Vista, San Marcos, Escondido, McGonigle, Soledad, San Clemente, Las Choyas, and Otay creeks (Pls. XV, XX, XXIII, and XXV).

The largest of the minor valleys in the highland area are Escondido Valley, along Escondido Creek, the valley of Santa Maria Creek, the upper part of the valley of San Luis Rey River, in Warner Valley, and the valley of Los Penasquitos Creek in Poway Valley.

Many of the minor valleys are very attractive for residence and contain tracts of bottom land well adapted to raising field crops or vegetables and to dairying. In many places these bottom lands have been brought under cultivation and irrigation by means of water from the underlying valley fill. The lands of the upper slopes and foothills in the highland valleys, such as Escondido and El Cajon valleys, are adapted to citrus culture, and where surface water is available for irrigation orchards have been planted. Although most of these valleys are small and widely scattered, they contain in the aggregate considerable agricultural land.

MINOR VALLEYS OF THE COASTAL BELT.

TOPOGRAPHY.

The minor valleys of the coastal belt extend back from the coast 6 to 8 miles, range in width from 200 feet to half a mile, and are connected with the level mesas by steep slopes 200 to 400 feet high. They slope downstream at rates ranging from 20 to 40 feet per mile, but in most places are level transversely. In area they seldom exceed a few hundred acres. They are underlain and bordered by sedimentary rocks.

MATERIALS OF THE FILL.

All the minor valleys contain alluvium and other fill in their lower but not in their upper parts. The fill is composed of materials washed in from the mesas in times of heavy rainfall and of similar materials which are blown into the valleys by the strong winds that at certain times of the year sweep the mesas. Most of it is rather coarse though poorly assorted, and water passes through it freely. It is inclosed on the sides and bottom by formations that contain little or no water above sea level and that apparently do not absorb water so readily as the fill itself. These minor valleys may therefore be regarded as rather steeply inclined troughs partly filled with loose material through which the drainage passes.

The quantity of water that can be obtained from a well in the fill of a minor valley depends on the thickness of the fill, the depth of the valley floor below the top of the mesa, and the distance of the well from the mouth of the stream. In most of the valleys the fill is deepest and broadest farthest below the mesa level and is most highly water bearing near the mouths of the valleys, and it gradually diminishes in depth, breadth, and water-bearing capacity toward the heads of the valleys. It is probably not more than 50 feet thick in any of the minor valleys.

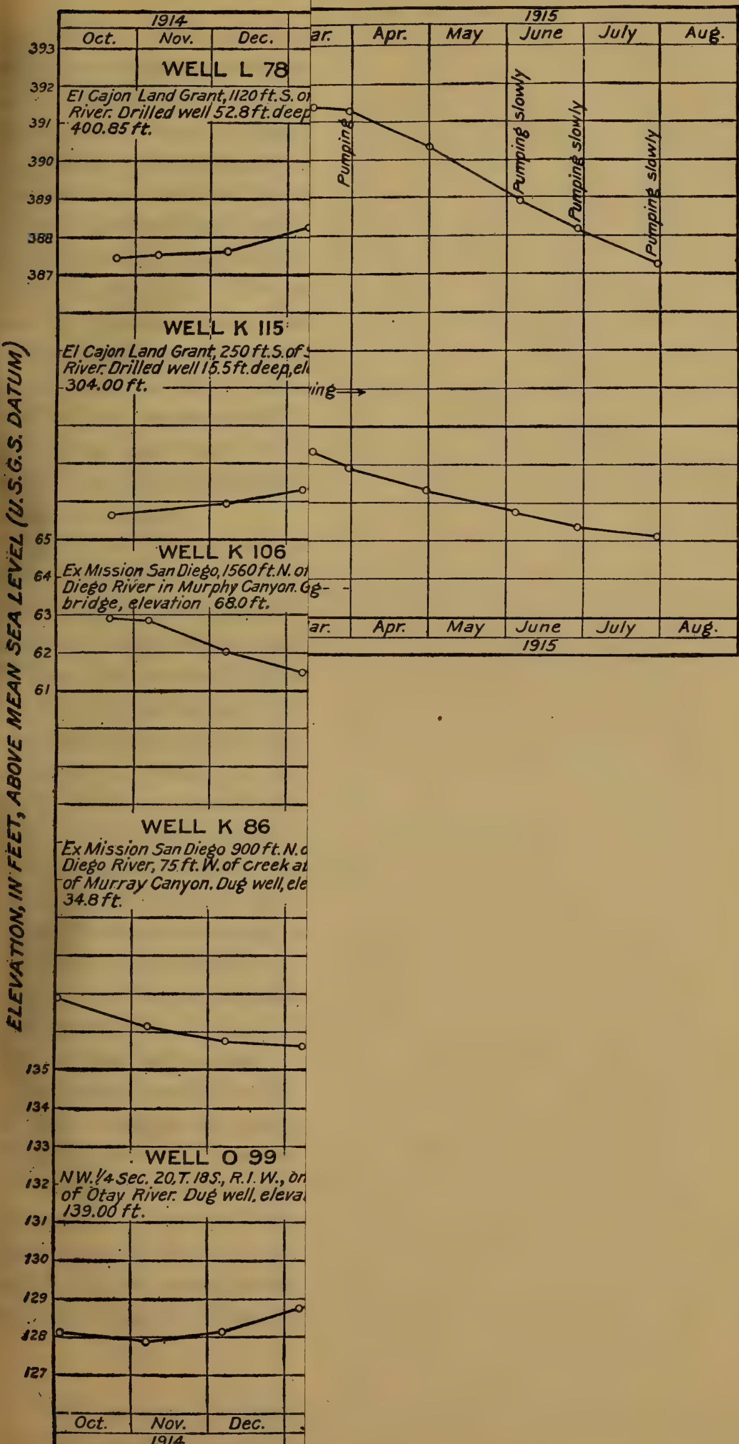
WATER TABLE.

The water table in the minor valleys of the coastal belt lies farther beneath the surface than in the major valleys. In general shape and position, however, it corresponds to that in the major valleys, having little slope across the valleys but an appreciable slope downstream. Its fluctuations within each year are similar to those in the major valleys of the coastal belt but of wider range (Pls. XLIII and XLIV). The fluctuations from year to year are also probably greater than in the major valleys, owing to the small run-off during dry years.

Observations of ground-water level were made at well K 106, in Murphy Canyon; K 86, in Murray Canyon; K 117, at the mouth of Sycamore Canyon; K 115, in the fill of a small canyon entering upper San Diego River from the south and a little west of Sycamore Canyon; and B 10, at the mouth of a tributary entering San Luis Rey River from the north between Bonsall and Mission San Luis Rey. A study of water level was also made at six wells in Otay Valley, the largest of the minor valleys of the coastal belt—Nos. O 90, O 42, O 87, O 38, O 41, and O 91—during the season of 1914–15. The position of all these wells is shown on Plate XX and the wells are fully described in Table 45. A summary of dates of maximum and minimum water level and the range of fluctuation is given in Table 32 (p. 133). Details of the observations at wells K 106, K 86, K 115, and B 10, at well L 78 at Lakeside, in El Cajon Valley, and of wells O 99, O 87, and O 41 are shown graphically in Plate XLIII, A profile of the water table along the line D–D of Plate XX is shown in Plate XLIV, but this profile, although drawn for Otay Valley, does not show the ground-water profile in the valley fill but in the San Diego formation to the north. In order to indicate the relations of the ground-water surface in these two adjacent formations, two cross sections of the valley are shown in Plate XLIV—one at wells O 42 and O 97, the other at wells O 96, O 95, and O 40. These two diagrams illustrate the greater fluctuation of the water table in the valley fill and its elevation compared with that in the adjacent Tertiary formations. The conditions indicated by these diagrams are typical of those found in the minor valleys of the coastal belt.

GROUND-WATER YIELD.

The quantity of ground water available in the minor valleys of the coastal belt is small, owing to the narrow width and shallow depth of the fill and the small run-off and short period of flow of the streams that traverse the valleys. Supplies adequate for domestic use can, however, be obtained in most of them. The safe yield of most of the wells is very small because the run-off in dry years is almost


1914
1915
Oct.
Nov.
Dec.
ar.
Apr.
May
June
July
Aug.
WELL L 78
El Cajon Land Grant, 1120 ft. S. o
River. Drilled well 52.8 ft. deep
400.85 ft.
Pumping
Pumping slowly
Pumping slowly
Pumping slowly
WELL K 115
El Cajon Land Grant, 250 ft. S. of
River. Drilled well 15.5 ft. deep, el
304.00 ft.
ing
WELL K 106
Ex Mission San Diego, 1560 ft. N. o
Diego River in Murphy Canyon. Gg-
bridge, elevation 68.0 ft.
WELL K 86
Ex Mission San Diego 900 ft. N. c
Diego River, 75 ft. W. of creek a
of Murray Canyon. Dug well, ele
34.8 ft.
WELL O 99
N.W. 1/4 Sec. 20, T. 18 S., R. 1. W., on
of Otay River. Dug well. eleva
139.00 ft.
ELEVATION, IN FEET, ABOVE MEAN SEA LEVEL (U.S.G.S. DATUM)
393
392
391
390
389
388
387
6
5
4
3
2
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65
64
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135
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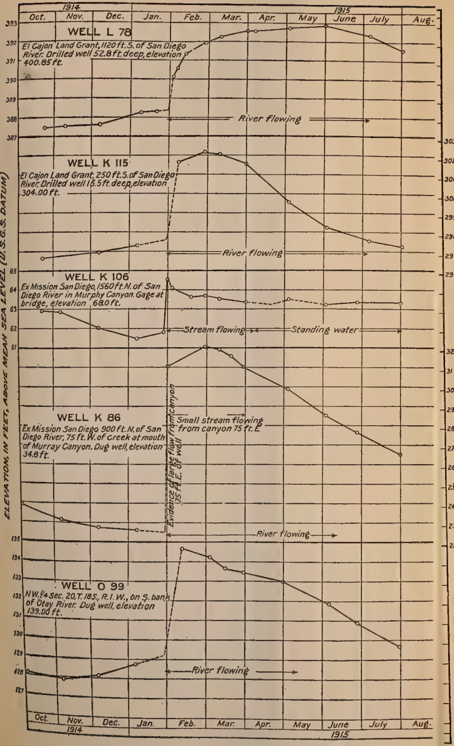
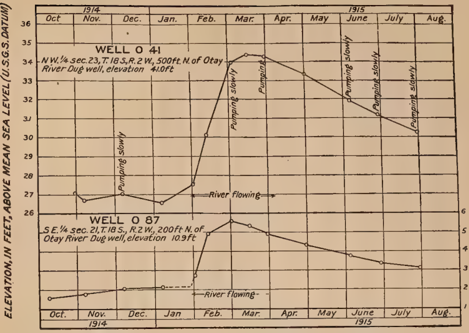
130
129
128
127

LEYS.





DIAGRAMS SHOWING FLUCTUATION OF WATER TABLE IN OBSERVATION WELLS IN FILL OF MINOR VALLEYS.

negligible. The use of ground water for irrigation in these valleys must as a rule be restricted to lands on the floors of the valleys, but even with this restriction the supply in many places will be insufficient to serve all the overlying land, particularly in dry years. The largest and most permanent yields will be obtained from wells sunk in the deepest and widest parts of the valleys that are traversed by the larger streams having the longest periods of flow, but they will be much smaller than the yields of good wells in the major valleys of the coastal belt. The best sites for wells are near stream channels and in places where the fill is deepest, but care must be taken to protect wells and pumping plants from damage by floods. Wells sunk too near the mouths of valleys that open to the ocean may yield salt water; consequently well sites should be chosen far enough from the ocean and from the lagoons and salt marshes along the shore to avoid the effects of backwater that during long droughts extends some distance inland.

Both for domestic use and for irrigation where the valley fill is very thin or absent dug wells of large diameter are likely to be the most satisfactory, because of their storage capacity and because the large area of wall surface permits rapid infiltration of water into the wells. Where the known thickness of the fill justifies drilling, drilled wells may be used to advantage, but where the fill is shallow it is wiser not to depend on the water that may be found in the fill but to drill deep enough to obtain a supply from the underlying Tertiary beds. Deep drilling should not be attempted, however, except where the valley floors are 200 or 300 feet below the level of the mesa. The usual practice, where the fill is 25 feet or more in depth, is to sink small cased wells, 6, 8, or 10 inches in diameter. The largest and most permanent supply at any single pumping plant will be obtained by sinking several small wells at intervals of 75 to 100 feet, and the largest and most reliable aggregate supply from one of the minor valleys will be obtained by installing a number of small plants rather than a few large ones.

At present wells in the minor valleys are widely separated and there is little danger of contamination of well water except from some local source. If, however, as is likely, settlements should increase in the valleys or on the adjacent heights, considerable care must be exercised to protect domestic wells from contamination by water that is polluted in its course past dwellings. The use of fertilizers must also be considered a possible source of pollution, because the ground water in these valleys is so definitely restricted.

WELLS.

Wells between Oceanside and Delmar.—Well F 5 is on the edge of the tidal marsh about 2 miles from the mouth of Buena Vista Creek, about 20 feet above sea level. It is a dug well, 13.9 feet deep, in which on October 25, 1914, the water level stood 10.1 feet below the surface of the ground. Water is lifted by a windmill to an elevated tank having a capacity of about 1,000 gallons. The water is used for domestic supply and to a small extent for irrigating a small vegetable garden. This well is on the flood plain of Buena Vista Creek at the mouth of a small tributary canyon which heads near the summit of Mount Kelly. A few rods east of the well there is a sharp bend in the creek valley, and the body of valley fill is locally constricted. The water in the well is derived from the shallow fill in the canyon which receives both seepage and underground drainage from the adjacent mesa.

Well F 8 is 2½ miles northeast of Encinitas, in the bottom of the canyon of a small intermittent stream tributary to Batiquitos Lagoon. The surface of the well is about 65 feet above sea level and about 350 feet below the surface of the mesa in which the steep-walled canyon is cut. This is a dug well 17 feet deep and 2.5 feet square. On October 25, 1914, the water level was 12 feet below the surface. The well is at the roadside some distance from any dwelling and is apparently little used. Water is lifted by means of a rope and bucket. The water is derived from the shallow fill in the canyon, which receives both the surface and underground drainage from the adjacent mesa.

The Cardiff municipal water supply is obtained from wells (F 9) 12 feet apart in a small valley just northeast of Encinitas. The following information was furnished by D. C. Ingersoll: Two wells, 8 inches in diameter, have been drilled to depths of 60 and 160 feet, respectively. Water was obtained at depths of 15, 30, 75, 125, and 160 feet, but in the shallower well the principal supply of water is obtained in fine sand between the depths of 30 and 60 feet and in the deeper well in sand between the depths of 140 and 160 feet. Both wells are cased to the bottom and are finished with screens. In the shallow well the water stands 20 feet and in the deep well 60 feet below the surface. The pumping plant consists of a gasoline engine and a lift pump, with cylinder 3½ inches in diameter and 16 inches long, used in the deeper well, and a windmill and lift pump with cylinder, 3½ inches diameter and 14 inches long, in the shallower well. The maximum yield by pumping is, for the deeper well, 25 gallons a minute and for the shallower well 10 gallons a minute, the lower yield in this well being attributed to the fineness of the screen, which does not allow the water to enter rapidly enough. The water is used for domestic supply. The water from the shallow well is of good quality but somewhat hard; that from the deeper well is very hard and slightly brackish and is therefore no longer used.

In 1914 a third well was being dug. If completed as planned, this well is 10 feet in diameter at the top and is reduced to 32 inches at the depth of 34 feet. The plans provided for a 32-inch steel casing to be sunk to a depth of 50 feet below the surface, the insertion of a 6-inch perforated point about which gravel was to be filled in, and the withdrawal of the large casing, leaving the point embedded in gravel to exclude sand from the well. It was estimated that this well would yield at least 50 gallons a minute, as the material between the depths of 28 and 60 feet apparently holds an abundant supply of water. The material penetrated by this well consists principally of fine sand interbedded with two or three layers of blue clay, each about 2 feet thick.

Well G 15 is a stock well, on Encinitas Creek about 2 miles north of Olivenhain. It is 15.6 feet deep and the depth to water on October 25, 1914, was 4.4 feet. Water is pumped by means of a windmill. There are no dwellings or other buildings in the immediate vicinity. The stream branches at this locality and forms a triangular area near the center of which the well was sunk. The bedrock in which the valley is cut is a white sandstone underlain by a green shale that outcrops north of Olivenhain. The valley contains a moderate depth of fill into which the drainage sinks. There is no doubt an adequate supply of water in this valley to supply a considerable number of such wells if they were needed, but the water stands so near the surface that irrigation is hardly necessary on the few acres of tillable and irrigable land in this locality.

Wells in McGonigle Canyon (K 3 to 9, inclusive).—The wells in McGonigle Canyon range in depth from 9 to 40 feet. Two of these are drilled wells, one 18 and the other 40 feet deep, both cased with cement tiles. The depth to water in the wells of this valley ranges from 7 to 37 feet below the surface, and each well yields a supply adequate for domestic use. Mr. John Stilling's well (K 4) is on the side of the valley and penetrates green shale. Definite information in regard to the well log was not available, but it is probable that the water enters the well above the shale bed. The other wells derive their supplies from the shallow alluvium in the canyon. The valleys tributary to McGonigle Canyon near its head carry the drainage from the west slopes of Black Mountain. From the foot of Black Mountain to the coast the canyon cuts through sandstones containing a few comparatively thin beds of shale. The valley fill probably does not exceed 25 feet in thickness anywhere in this canyon and in most places is much less. Though the supply of ground water in this canyon is not large, it is no doubt ample for domestic use. Information concerning the quality of the water from wells K 3 and K 8 is given in the table on page 260.

Wells between Los Penasquitos Canyon and Mission Valley.—Well K 11 is a dug well, 13.6 feet deep, the water level being 8.9 feet below the surface. It is on Los Penasquitos Creek about a mile below Poway Valley. It is pumped by a windmill that delivers water to a tank 400 feet west of the well. The valley fill at this place is partly coarse granitic alluvium and partly sand and gravel. The north slope of the valley is formed by granite thinly covered by alluvium and soil, but the south wall is formed by gravel. All the drainage from Poway Valley passes this locality, and conditions appear to be particularly favorable for procuring water from shallow wells. There are no wells below this place in Los Penasquitos Canyon, but sufficient water for domestic use could be obtained by sinking wells almost anywhere on the canyon floor. A body of basaltic rock crops out in the center of sec. 27, T. 14 S., R. 3 W., through which the creek has cut a short, narrow gorge. This rock forms an underground dam that brings the ground water to the surface and produces a surface stream in the little gorge. On October 24, 1914, an estimated flow of about half a second-foot was passing through the gorge. The canyon floor just above the gorge should be a particularly favorable site for shallow wells. Los Peñasquitos ranch, of which Mr. Charles Brown is proprietor, includes practically the entire valley of Los Penasquitos Creek. The ranch house is supplied with water from a spring (K 10), near the house and the stock is watered from the stream. A small irrigation system is supplied with water from a reservoir at the mouth of a small intermittent stream in the west-central part of sec. 24, T. 14 S., R. 3 W.

Wells in Soledad Canyon.—A tidal marsh extends into the lower part of Soledad Canyon. Well K 18, which is 1 mile above Sorento or 3 miles above the marsh, yields water which, although used for domestic supply, is said to be saline and of very poor quality. This well is 12.4 feet deep and 3 feet square, and its water level is 9.5 feet below the surface. On October 24, 1914, water was standing in pools on the surface at several places within 200 feet of this well and appeared to be at very shallow depths everywhere on the valley floor as far east as the mouth of Carroll Canyon.

Well K 19 is about 1 mile above K 18, on the south side of the canyon. The owner, W. T. Melbourne, stated that it yields an ample supply for domestic use but not sufficient for irrigation. It was originally 12 feet deep but has silted up somewhat and in October 24 was found to be only 8.9 feet deep, with a water level only 3.6 feet below the surface. Water is pumped by means of a windmill and a suction pump, with 3-inch cylinder and 8-inch stroke, to an elevated tank having a capacity of 1,000 gallons. The yield of the well was not ascertained but Mr. Melbourne stated that with the windmill running at a rapid rate the water level was lowered about 2 feet in two or three hours. The well has never been dry and the water level fluctuates only slightly. A short gully in the canyon wall debouches on the canyon floor just south of the well and the stream channel from the mouth of the gully swings to the west and joins the main channel a short distance below the well. A hole 2 feet deep and about 10 feet square in this channel contained several inches of water when it was visited and Mr. Melbourne stated that he had never known it to be entirely dry. Water is pumped from this hole to irrigate 4 acres of alfalfa and 4 acres of apricots. The pumping plant consists of a 6-horsepower gasoline engine and a small centrifugal pump. It can be run about 15 minutes before the hole is pumped dry.

Well K 20, owned by Mr. Max Dietrich, is about a mile east of well K 19, near the mouth of Carroll Canyon, which is tributary to Soledad Canyon. It is a dug well, 9 feet in diameter and 20 feet deep, and its water level is 4.5 feet below the surface. It is pumped by a windmill and supplies water for domestic use.

Soledad and Carroll canyons are very narrow, as is shown on Plate II, and their floors lie 100 to 400 feet below the level of the mesa through which they are cut. Gravels, shales, and sandstones outcrop in the canyon walls, the gravels being at the top. The valley fill east of Sorrento is probably 30 or 40 feet deep but it gradually diminishes in depth toward the east until in the upper parts of Soledad and Carroll canyons the bedrocks appear at the surface on the canyon floors. The streams that occupy these canyons are intermittent, but even during dry seasons considerable water from the adjacent formations accumulates in the valley fill and percolates down the canyons, constituting an important source of domestic water supply.

Wells in San Clemente County.—San Clemente Canyon, like Soledad and Carroll canyons, is very narrow and deep but contains a shallow deposit of valley fill into which water seeps from the gravels, shales, and sandstones that form the canyon walls, thus maintaining a ground-water supply during the long periods in which no surface water passes down the canyon. This canyon joins Rose Canyon at the foot of Soledad Mountain.

On the canyon floor $2\frac{1}{4}$ miles from Rose Canyon is a shallow dug well (K 23) formerly used for stock but apparently abandoned at the time it was visited in 1914. No measurements of this well were obtained, but the water stood at the surface of the ground. There were also several shallow pools of water in the streamway in the vicinity of the well, indicating that shallow water is general. The surface is not marshy, as it is in the lower part of Soledad Canyon, but trees and grasses grow rank and show no evidence of drought.

Well K 24, $2\frac{1}{2}$ miles east of K 23, is a dug well 9.9 feet deep, in which the water level, on October 24, 1914, stood 4.5 feet below the surface. Water is pumped by a windmill to a stock trough. There are no dwellings within several miles. The canyon walls near this well are composed entirely of gravel, the top of which is cemented into a hard layer; but three-eighths of a mile west of the well these gravels are underlain by at least 12 feet of clay.

Well K 25, owned by Mr. W. D. Bryson, is 2¾ miles northeast of K 24 and 1½ miles south of Miramar. It is dug 6.7 feet deep and 2½ feet square, and when visited its water level was 4 feet below the surface. The well was dry during the summer of 1913 but furnished sufficient water for domestic use and for a few head of stock during all of 1914. The water is pumped by means of a windmill to a tank at the house. The well is in the dry creek bed 460 feet above sea level and 40 feet below the level of the ground at the house. The water tank at the house is 10 feet above the ground. There is very little fill in the valley at this place and the quantity of water available is very small. Well K 26, a little less than half a mile east of K 25, is a small spring which is said to have been dry only three times in the last 23 years, the last occasion being in 1911. There was no flow at the surface when this spring was visited but water stood in a little pool and there may have been some underflow.

Wells south of Mission Valley.—Well O 9 is in Spring Valley, about 3 miles southeast of Lemon Grove. It is 24 feet deep, 8 feet in diameter, and, on October 5, 1914, the water stood 10 feet below the surface. It is pumped by a windmill and supplies a stock trough but the water is regarded as too brackish for any other use.

All the shallow water in the middle and lower parts of Spring Valley is said to be brackish and no deep wells have been sunk. The upper part of the valley is cut in crystalline rocks, but the middle part, down to about a mile from the mouth, is cut in Tertiary sedimentary rocks. The water, therefore, is obtained in part from areas underlain by crystalline rocks and in part from surface drainage from areas underlain by the sedimentary rocks and by seepage from these rocks.

MINOR VALLEYS IN THE HIGHLAND AREA.

Topography.—Along the stream channels throughout the highland area are numerous small valleys, formed where widening of canyon bottoms for short distances have afforded opportunity for the deposition of alluvial material. Many of these valleys are only a few acres in extent; others comprise 20 to 50 acres. Most of them are at elevations higher than those of the highland valleys traversed by the major streams.

The floors of these valleys consist largely of valley fill which in many places merges imperceptibly into the residuum of the surrounding hill slopes. The drainage system of one of the more important minor valleys is made up of several streams that drain the surrounding slopes and meet in the valley to form a single stream leading to the drainage outlet.

Materials of the valley fill.—The rocks surrounding all highland valleys are practically impervious. In the larger valleys alluvial material accumulates along the stream channels, in many places merging gradually into the residuum which, as a rule, is present over all but the steepest parts of the highland areas. The depth of the fill at the lower ends of minor valleys that are tributary to major valleys equals that of the adjacent fill of the larger valleys, but decreases upstream at a rate depending on the steepness of the ancient canyon. Thus, at the mouth of Guejito Creek, in San Pasqual Valley, the fill is at least 150 feet deep (well H 30), but bedrock appears in the canyon bottom not more than 1½ miles up this creek. In Moosa Canyon the fill is about 60 feet deep at the lower end and the bedrock appears in the valley bottom about 4 miles upstream. As a rule also, the alluvial material near the main valley is very fine and yields little water. This is illustrated by well H 30 in a branch of San Pasqual Valley, which penetrated 150 feet of sand and silt with a 12-inch casing, and when tested is reported to have yielded only 90 gallons a minute, in marked contrast with the large yields from wells in the main valley near by. The fill of a typical highland valley, however, consists largely of medium and coarse sand with occasional layers of fine gravel. It contains ground water in its pore spaces and in every respect constitutes a small ground-water reservoir, but the depth of the fill seldom exceeds 50 feet and in the smaller valleys is much less.

Water table.—The water table in a minor highland valley behaves much like that in a minor valley of the coastal belt, but as a rule it is nearer the surface and its slope downstream is less. Its annual fluctuations and its fluctuations from year to year are probably also less, owing to the longer period of stream flow and the greater probability of run-off in dry years.

Ground-water yield.—The quantity of ground water obtainable in these valleys varies with the dimensions of the fill and the permanence of stream flow.

The types of wells to be used and the method of selecting well sites are the same as in the minor valleys of the coastal belt. (See p. 169.)

WATER IN TERTIARY AND OLDER SEDIMENTARY FORMATIONS.

By A. J. Ellis and C. H. Lee.

WATER-BEARING CAPACITY OF THE FORMATIONS.

Tertiary and older sedimentary formations underlie the southern part of the San Onofre Hill district, between the northern boundary of San Diego County and Santa Margarita River, and the Linda Vista terrace district, and include also the relatively small Tertiary stream deposits that occur at irregular intervals on the hills between Miramar and Witch Creek. (See Pl. III.)

The Tertiary rocks consist of conglomerate, sandstone, sandy shale, clay, and limestone. (See p. 52.) From Los Penasquitos Canyon southward thick beds of conglomerate, which constitute the upper part of the San Diego formation, lie at or near the surface wherever the elevation exceeds 200 feet above sea level, and these beds are underlain by and in some places interbedded with alternating lenticular layers of sandstone, sandy shale and clay, all of which are small. From Los Penasquitos northward to Buena Vista Creek the surface formation is a porous sandstone that is underlain by alternating layers of shale, sandstone, and limestone that are ordinarily continuous over wide areas. North of Buena Vista Creek the rocks are similar to those in the southern part of the area.

The conglomerates are composed of rounded pebbles and small boulders, most of which are less than 4 inches in diameter, cemented together by hard calcareous clay. Where these conglomerates lie at the surface they are, as a rule, covered by a thin soil of sandy or gravelly clay. This formation differs from most coarse deposits in being nearly impervious and incapable of absorbing much water. The clay soil, by resisting the descent of water into the ground, serves as an additional obstacle to the absorption of water.

The shales also are practically impervious and usually yield water at a rate too slow to afford satisfactory supplies to wells.

The most favorable sources of water in the Tertiary rocks are the layers of sand. Their porosity is high, and the water circulates in them freely enough to supply wells wherever they are saturated. But a condition most unfavorable to the storage of water, even in the most porous of the strata, is the deep dissection of the region, which favors rapid drainage of all the beds that lie above the levels of the canyon floors. As all the principal streams have cut their valleys practically to sea level, the deposits that lie above the levels of the valley floors are completely drained during the annual periods of drought that characterize the climate of this region. Generally speaking, therefore, available water does not occur in the Tertiary rocks at elevations exceeding 100 feet above sea level in interstream areas, and in areas adjacent to the valley walls it is probably not above the level of the canyon floors.

SAN ONOFRE HILL DISTRICT.

In the San Onofre Hill district, north of Santa Margarita River, the rock formations consist of breccia, coarse gravels, and layers of sandstone and shale. They are thoroughly and deeply dissected, so that there is very little tillable land between the streams. All these lands are included within the Santa Margarita y Las Flores land grant, which has not been subdivided or opened to settlement, and, so far as known, no attempts have been made to obtain supplies of ground water except near the mouth of Arroyo San Mateo. On account of the thorough dissection of interstream areas, the formations, especially the slightly indurated conglomerates, are probably quite thoroughly drained above the stream levels. It is possible, however, that drilling will disclose conditions more favorable for the storage of ground water than are now known. In general, the breccia of the district is, with respect to the occurrence of ground water, probably comparable to other crystalline rocks (see p. 189); the surrounding formations probably contain water below levels corresponding approximately to the levels of the streams.

TERTIARY GRAVEL TRACTS.

The stream gravels that occur in discontinuous patches from Miramar to Witch Creek stand in high ridges capping crystalline rock hills and are in general very thoroughly dissected. At present there is practically no settlement in areas underlain by these deposits, and, so far as known, no attempts have been made to obtain from them supplies of ground water. Because of the ease with which they may be drained, they probably do not, as a rule, contain permanent supplies of ground water; it is possible, however, that in some places wells drilled to bedrock would obtain lasting supplies. The well (K 23; see log, p. 68) drilled for oil on the Poway terrace is said to have encountered at a depth of 525 feet a very strongly mineralized water that rose 100 feet in the casing. Failing to obtain oil, the well was abandoned. It was remote from any settlement, and no attempt was made to use the water, which was, however, said to be unfit for drinking.

LINDA VISTA TERRACE DISTRICT.

GENERAL CONDITIONS.

As described on pages 52–67, the coastal belt south of Santa Margarita River is underlain mainly by Tertiary formations comprising rocks of Eocene age and by the Miocene and Pliocene strata that are designated in this report the San Diego formation. As shown on the geologic map (Pl. III), the Eocene deposits appear at the surface from Los Penasquitos Canyon northward to Buena Vista Creek; the San Diego formation is exposed at the surface from Buena Vista Creek northwestward and from Los Penasquitos Creek southward; but where the San Diego formation is exposed at the surface it is generally underlain by Eocene strata. In the major valleys the Tertiary bedrocks are overlain by alluvium, as shown on Plate III, and although the alluvium is the principal source of ground water, some wells pass through it and draw their supplies from underlying Tertiary beds.

Most of the area between Los Penasquitos Canyon and Mission Valley, locally called Linda Vista Mesa, is uncultivated and unsettled and is covered only by sparse native vegetation. Several of the attempts that have been made to procure supplies of ground water have failed because of difficulties encountered in drilling through conglomerates and inability to reach water within a few hundred feet of the surface. So far as known, however, none of the wells reached within 100 feet of sea level, at which depth water might have been obtained.

In the western part of the coastal belt, between Mission Valley and Otay Valley, the upper part of the San Diego formation, including much of the conglomerate, has been removed by the cutting of marine terraces. A number of wells sunk in this area have obtained water at depths within about 100 feet of sea level. Conditions most favorable for the occurrence of ground water were found on terraces less than 200 feet above sea level, including Chula Vista and Nestor terraces. (See p. 26.)

South of Otay Valley the principal terrace, which corresponds to Linda Vista Mesa, has been raised to an elevation about 500 feet above sea level. This terrace is Otay Mesa. Here a few drilled wells furnish meager quantities of water, as described on page 179.

WELLS ON THE HIGH TERRACES.

K 1.—John Haflie's well is about 5 miles northeast of Delmar, at the top of the bluffs along the east side of San Dieguito Valley, 275 feet above sea level. The well is 6 inches in diameter and 200 feet deep, and although definite information was not obtained it is probably largely in granite, as this rock outcrops only a short distance from the well. This well does not, therefore, represent supplies available in the sedimentary rocks. Water is lifted by means of a windmill and not more than 150 gallons per day is pumped.

K 21.—A well drilled about 1 mile northeast of Miramar reached the depth of 300 feet, finding no trace of water. It penetrated loose red clay and gravel and ended in a light-colored shale. The casing was withdrawn and the well abandoned.

K 29.—A well belonging to Mr. Rodger Topp, on Linda Vista Mesa, about 4 miles north of Mission Valley and 2 miles northwest of Rosedale, at an elevation of 400 feet, penetrated conglomerate to the depth of 260 feet without reaching water and ended in a white sandstone, which is probably the Eocene rock that crops out in Los Penasquitos Canyon. (See p. 53.) A rotary drill 12 inches in diameter, which was used, was unable to penetrate a hard layer encountered at the depth of 260 feet.

O 8.—The community well drilled at Angelus Heights for the San Diego Homebuilders' Association is 375 feet deep, 10 inches in diameter, and cased throughout with standard casing. The elevation of the well is said to be about 400 feet and potable water was reached at the depth of 215 feet. Water-bearing sand was reached at 370 feet, but the water was salty and had to be cut off. The present supply, about 36 gallons a minute, is obtained from the 2-foot layer of sand and gravel at the depth of 215 feet.

P 8, P 9, P 10.—Three wells drilled on Otay Mesa, at elevations of about 500 feet, produced water suitable for domestic use. According to Mr. Wilkes James, who furnished the information, one of the wells (P 8) was being drilled at Loma Alta school, at the middle of the south line of sec. 27, T. 18 E., R. 1 W., and on November 10, 1914, had reached a depth of about 700 feet, obtaining a small quantity of water. Mr. Roul's well (P 9), drilled in the SW. ¼ sec. 35, T. 18 S., R. 1 W., is 310 feet deep and yields about 12 gallons a minute of water of good quality for domestic and stock use. Mr. Willpot's well, in the northeast corner of sec. 2, T. 19 S., R. 1 W., is 280 feet deep and yields a few hundred gallons of water a day, the water being of good quality for domestic use.

O 1.—A well, 8 inches in diameter, owned by the San Diego Young Men's Christian Association, was drilled at the corner of Eighth and C streets, San Diego, to the depth of 200 feet. Salt water was encountered at the depths of 85 feet and 100 feet, but was cased out, and fresh water was struck 140 feet below the surface in a 5-foot bed of sand that yielded 45 gallons a minute. It is said to be unsatisfactory in quality, however, because it discolored the tile lining of a swimming tank that the well was intended to supply.

O 1a.—Mr. Wilkes James's well, 2 miles east of San Diego, is about 160 feet above sea level. It was drilled 8 inches in diameter and 248 feet deep. Water was reached at the depth of 129 feet, but only a small quantity was obtainable between this depth and the depth of 190 feet. At 190 feet the drill penetrated a bed of coarse sand and gravel that yielded water freely. On November 19, 1915, the water level stood about 118 feet below the surface. No pump had been installed.

O 3.—The well of B. G. Estes, situated about 3 miles east of San Diego at an elevation of 175 feet above sea level, was dug to the depth of 155 feet. A perforated casing, 6 inches in diameter, is driven in the bottom to a total depth of 178 feet. Water encountered in small quantity in a bed of sand between the depths of 145 and 155 feet rose 4 feet above the top of the sand. The driven point penetrated a 3-foot layer of hardpan about 168 feet below the surface, under which it entered a water-bearing sand from which water rose 2½ feet above the bottom of the dug part of the well, or to a level 155½ feet below the surface of the ground. The pumping plant consists of a deep-well pump and a distillate engine, which are operated at a cost of 6 cents per 1,000 gallons of water pumped. About 35 acres of orchard, chiefly lemons, are irrigated.

O 14. A well owned by Mr. L. Wiese was dug to the depth of 76 feet and drilled from that depth to 104 feet. The material penetrated consists of alternating layers of blue and gray clay with a few beds of gravel. On October 8, 1914, the water stood 62 feet below the surface. The yield is too small to afford water for irrigation but an ample supply of water for domestic use is obtained. The cost of this well was $1 per foot for digging and $3 per foot for drilling, making a total of $160. The pumping plant consists of a windmill and a suction pump.

O 7. A well owned by Robert Dick, about 5 miles east of San Diego on the south side of Las Chouas Valley and about 250 feet above sea level, is 10 inches in diameter and 203 feet deep and affords a satisfactory domestic supply of water which was struck at a depth of 114 feet. (See log, p. 62.)

DEEP WELLS ENDING IN SEDIMENTARY ROCKS UNDER VALLEY FILL.

F 7. A well was drilled for oil by the Pacific Laguna Oil Co., on the valley floor of Batiquitos Lagoon, 4 miles north of Encinitas, at an elevation of about 20 feet above sea level. No detailed information could be obtained in regard to the log of this well. The well is said to be about 1,300 feet deep and to end in "black sand which was overlain by red rock." It was reported that at a depth of about 800 feet a water-bearing bed was penetrated from which water rose to the surface. When the well was visited, November 25, 1914, it was flowing about 5 gallons a minute over the top of the casing, which stood about 1 foot above the ground level. This well apparently has been abandoned.

K 16. The first McNeese oil boring, which was abandoned because it became crooked at a depth of 1,700 feet, is in Soledad Canyon, at Sorrento, at an elevation of about 35 feet above sea level. Water that flows at the surface was reached at a depth of about 600 feet. This water is said to be warm, but neither the temperature nor the flow could be determined when the well was examined, because the exhaust from the engine which is working on the new hole discharges into the well. The new hole is less than 200 feet from the old one and was 1,000 feet deep when it was visited September 22, 1914, but no information could be obtained in regard to water encountered.

K 30. When K 29 failed to reach water, a second well was drilled in Murphy Canyon just east of Rosedale, at an elevation of about 150 feet above sea level. This well is 618 feet deep and 10 inches in diameter. Water was reached first in a thin layer of sand at the depth of 125 feet, and at the depth of 250 feet a bed yielding warm sulphur water was encountered. The water stood about 15 feet below the surface of the ground October 10, 1914. Water is reported to have been pumped at the rate of 270 gallons a minute without apparent effect on the yield. It was said that the water is to be used for domestic supplies in Rosedale, which is 425 feet above sea level or 275 feet above the well site.

K 37. The Balboa oil boring (see log, p. 55), encountered artesian water at the depth of 900 feet. On August 31, 1912, the measured flow was 45 gallons a minute. This water was warm and had a brackish taste. Other water-bearing beds were reached at depths of 2,300, 4,152, and 4,217 feet, respectively, but little is known concerning these beds. As neither the quality nor the quantity of the flowing water changed greatly after drilling below 1,000 feet, it is believed that none of the lower formations yield artesian water. According to the well log published by Merrill (p. 56), an artesian flow was obtained at the depth of 335 feet, and other water-bearing beds were penetrated at depths of 510 feet and 725 feet.

K 53. The well belonging to Mr. J. L. Haughawout is in Alvarado Canyon, about 1½ miles northwest of La Mesa. It is a dug well 74 feet deep, all in Tertiary conglomerate. In the upper 70 feet the interstices between the gravels are filled with clay, but in the lower 4 feet the spaces are filled with sand. The water usually stands about 25 feet below the surface, but in wet seasons it sometimes rises within 2 feet of the top of the well. The average yield is about 2 gallons a minute and the well has been pumped dry by drawing water at the rate of 18 gallons a minute. The well is not used except in dry seasons when other sources of water fail.

NESTOR AND CHULA VISTA TERRACES.

SOURCES OF WATER.

The Nestor and Chula Vista terraces are underlain by deposits belonging to the middle part of the San Diego formation (see pp. 58–67), which in some places is overlain by a thin mantle of Pleistocene, as shown on Plate II. As a rule, this part of the San Diego formation contains no conglomerates; the beds consist of sandy clay, sand, and gravel, all in more or less lenticular and irregular layers, as shown in Plates XXVI and XXVII, wells numbered O 133, O 124, O 121, and O 122.

A study of fluctuations of ground water and the general shape and position of the water table was made in the region between Tia Juana and Sweetwater valleys, which is less than 100 feet above sea level (Pl. XX). The elevation of the water table from September, 1914, to August, 1915, was observed in 30 wells in this area, and records were kept at 25 wells in the three adjacent river valleys. The positions of these wells are shown on Plate XX, and other information in regard to them is given in Table 45 (p. 209). A summary of observations, with dates and elevations of maximum and minimum water levels is given in Table 30 (p. 126). The depth to the water table ranges from about 10 feet on a low terrace in Tia Juana Valley to 20 feet or more on the terrace near Nestor, 40 feet or more at Chula Vista and Otay, and 100 feet or more beneath the higher terraces. The maximum, minimum, and average annual range of fluctuations in wells under observation is shown in Table 32 (p. 133). The observations indicate an annual range of 0.17 to 8.76 feet, with an average of 2.76 feet, although this average is not representative of the formation as a whole. The type of fluctuation is shown in Plate XLV, and, with the exception of wells near Otay River, is remarkable for the late date—about May 1—at which the highest ground-water level occurs and also for the slight range of fluctuation.

Ground-water contours at the approximate dates of lowest and highest ground-water level in the adjacent river valleys are shown on Plate XX. Ground-water profiles along lines A–A, B–B, C–C, and D–D (Pl. XX) are shown in Plates XXXIV, XXXV, XLIV, and XLVI, respectively. The ground-water contours and profiles show a general slope of the water table from the hills toward the bay and ocean, but that this slope is not so steep as that in the river valleys. It shows also that in the period of lowest ground-water level in the river valley the water table beneath the mesa lands is little if any lower than that in the river valleys, but in the period of highest level in the river valleys it is considerably lower, and that a steep ground-water slope then exists from the river valleys into the adjacent mesa areas.

The ground-water in these low mesa areas is derived by percolation (1) directly from rainfall, (2) from small canyons debouching onto the slopes from the higher mesa areas to the east, (3) from irrigated areas, (4) laterally from adjacent river valleys, and possibly by underground drainage from the higher terraces on the east. The percolation of water from valley fill into the Tertiary beds is believed to account for the fact that the rise in ground-water during the period of replenishment was greatest adjacent to the river valleys, and that between Sweetwater and Otay valleys there was little or no rise except opposite the mouth of Telegraph Canyon, where the rise was far less than that taking place near the river valleys (Pl. XX). The greatest rise in ground-water was observed in wells on the mesa immediately north of Tia Juana Valley, and percolation from that valley may be the most active single source of supply of ground-water. The time elapsing between the first flood in Tia Juana Valley, January 29, 1915, and the maximum height of the ground-water level in six wells within a mile north of the edge of the valley indicates an average daily advance of the crest of the ground-water wave of 20 feet. The height of the crest at the edge of the valley was 6 to 8 feet. The height of the crest at a distance of a mile was about a foot. At Otay and Sweetwater valleys, where the rise of ground-water was only 4 feet, the effect was barely noticeable at a distance of a mile. In ordinary years, when there is little or no stream flow in these two valleys, the distance would be even less. Percolation from river valleys as a source of supply for this formation is thus very small at distances of a mile or more.

YIELD OF WELLS.

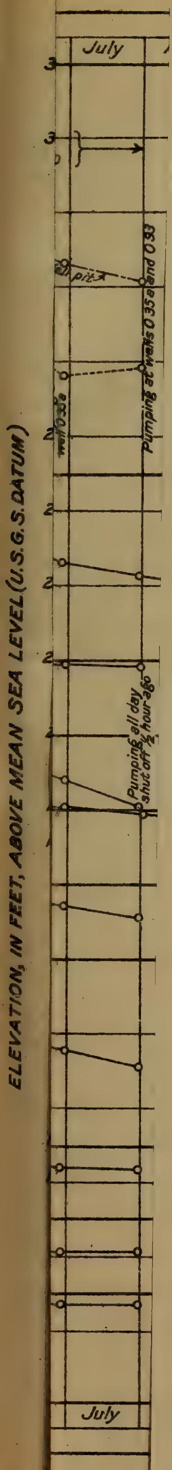
Conditions affecting yield.—The quantity of water obtainable from the San Diego formation underlying the Nestor and Chula Vista terraces between Sweetwater and Tia Juana rivers by pumping from wells depends chiefly on the distance of the wells from the nearest major river valley. Even at a distance of several miles from a river wells in this formation should yield sufficient water for farm, domestic, and stock use and the irrigation of small gardens. In order to supplement a deficient gravity supply in very dry years, in districts such as those about National City and Chula Vista, successful wells may yield sufficient water to irrigate small orchards if used in connection with a small tank or reservoir. As a rule, however, a well more than a mile from a river valley will yield only a small supply, and protracted pumping from many wells in the same vicinity will seriously lower the water level.

Successful wells in the San Diego formation within a mile north of Tia Juana Valley will yield sufficient water in average and wet years to irrigate alfalfa and garden truck, but the cost of installation and expense of pumping are greater than in the Tia Juana Valley, from which this area probably receives its supply of water. Where good water-bearing gravels are within reach, a single plant of one or two wells will furnish sufficient water, as indicated by the test of well O 47 (p. 270); where the water-bearing strata consist of sandy or gravelly clay, several wells may be necessary (see wells O 110, O 116, and O 111). From the rise of the zone of saturation (Pl. XX) it is estimated that in 1915, between January 6 and May 1, approximately 700 acre-feet of water was absorbed, a quantity probably in excess of that usually absorbed, as the flood flow of Tia Juana River was exceptionally large and prolonged and water was carried by an overflow channel that crosses the low terrace lying at the general level of the valley floor south of Nestor. In dry years the yield of wells in this area would probably not be sufficient for the irrigation of alfalfa, particularly if the cultivation of a large proportion of the land is attempted; it should be ample, however, for domestic use and for the irrigation of small tracts in vegetables or trees.

Conditions that affect the rate of yield of wells in the San Diego formation are in general the same as those that have been fully discussed for wells in the fill of the major valleys (p. 155).

Interference of wells.—The yield of wells on these low terraces occasionally shows strongly the effect of pumping at one well on the water level and yield of other wells drawing from the same water-bearing stratum. This effect is noticeable in wells in valley fill that are spaced at intervals of less than 1,000 feet but not at greater distances unless the pumps are of large capacity and the pumping is long continued. However, within a lens of gravel or sand surrounded by relatively tight materials this effect may appear instantly at distances exceeding 1,000 feet; it is not due to a lowering of the zone of saturation within the area of influence but to a decrease of hydraulic pressure within the gravel lens. The degree of lowering in each well varies with the facility with which changes in pressure are transmitted through the ground water. If there is sand or clay in the voids of the gravel, changes in pressure are not transmitted as far as if the voids are open.

A striking illustration of well interference of this kind was observed in Otay Valley, directly north of Palm City, at wells O 92, O 38, O 35a, and O 90 (Pl. XX); the first three are 12-inch cased wells and the last is a shallow dug well. The casing of well O 92 is in a pit dug below the water table but sealed off from the gravel stratum penetrated by the casing. Inspection of Plate XXVII shows that wells O 35a and O 38 penetrate and end in a porous stratum below clay at a depth of about 100 feet. The drillers reported that both wells draw from the bottom only. The log of well O 92 could not be obtained accurately, but the well is reported by the driller to be 198 feet deep and to penetrate alternate layers of clay and gravel to a considerable depth. It is to be noted that the fill of Otay Valley at this point is less than 30 feet deep and is underlain by the San Diego formation. Well O 92 is about 1,200 feet from well O 35a, and well O 38 is 1,100 feet from well O 35a. Well O 90 is 200 feet from well O 35a. Well O 92 was equipped with a 4-inch horizontal centrifugal pump, probably raising from 400 to 450 gallons a minute, which was used to lift water to the top of a tower for the purpose of washing gravel. It was in operation about eight hours daily except Sunday or when the plant was for any reason temporarily shut down. Well O 38 was equipped with a 3-inch horizontal centrifugal pump with a capacity of not over 225 gallons a minute. The water was used to irrigate 10 acres of alfalfa and the pump was operated at intervals as needed during the irrigation season. Well O 35a was equipped with a 2½-inch centrifugal pump with a capacity of not more than 150 gallons a minute. The water was used for domestic supply and to irrigate a small garden, the pump being operated for a few hours, at


July
ELEVATION, IN FEET, ABOVE MEAN SEA LEVEL (U.S.G.S. DATUM)
pit
well 0 35e
Pumping at wells 0 35 e and 0 33
Pumping all day
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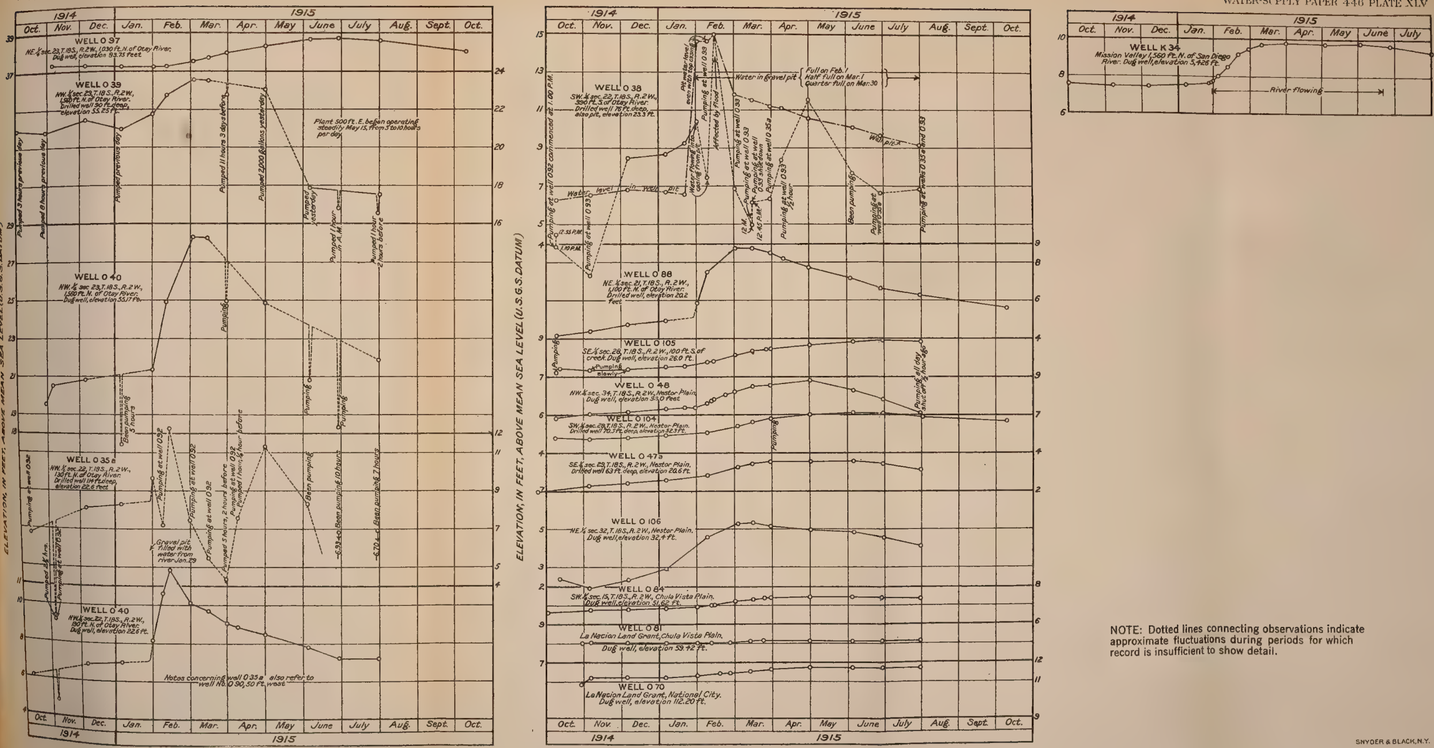
July

IN
EGO



NOTE: Dotted lines connecting observations indicate approximate fluctuations during periods for which record is insufficient to show detail.

SNYDER & BLACK, N.Y.

DIAGRAM SHOWING FLUCTUATIONS OF WATER TABLE IN OBSERVATION WELLS IN SAN DIEGO FORMATION IN VICINITY OF SAN DIEGO BAY 1914-1915

intervals of two or three days, to fill a tank. Observations of water level (Pl. XLV) in well O 90 and in the pit at well O 38 show the normal and regular type of fluctuation for dug wells in shallow valley fill; at well O 35a and in the casing at well O 38, however, fluctuations were very irregular and erratic.

A study of pump operations in connection with these fluctuations shows that the operation of the pump at well O 92 causes much of the erratic fluctuation of wells O 35a and O 38, although pumping at well O 35a seems also to slightly affect well O 38, and probably the latter would be found to affect well O 35a, if observations had been obtained at the proper time. It is difficult from the available data to determine the exact extent to which the pumping of one well lowers the water level in the others, but the lowering may be as much as 6 feet, judging by the marked recovery of water level at wells O 38 and O 35a April 30, when the pump at well O 92 was not operating, as compared with previous observations in March and April, when it was operating, and also the recovery observed December 6, when the pump was not operating as compared with November 6 preceding, when the pump was operating. That this lowering and subsequent recovery is not always instantaneous is shown by the fact that on October 9, 1914, a lowering of 0.72 foot occurred in the casing of well O 38 during the first ten minutes of operation of the pump after an hour's intermission at noon. It is also shown by the fact that on March 15, 1915, the water level rose 1.18 feet in 45 minutes that the pump was shut down. The full lowering or recovery probably requires several hours.

The effect of interference was observed also in well O 39, about 500 feet east of Otay, which penetrates the same gravel bed as well O 38. This well was sunk early in 1915, and beginning May 15, 1915, was pumped steadily from 5 to 10 hours a day at the rate of 60 gallons a minute. Observations at well O 39 (Pl. XLV) indicate that a sudden drop of 5 feet in the water level in well O 39 occurred some time during May, and that this was not recovered during the remainder of the period of record, which ended August 1.

The probability of interference between proposed wells can not be determined except by actual test, owing to the irregularity of the gravel lens. The immediate result of such interference is to increase the cost of pumping to the extent of the increased lift; the ultimate effect would be to drain the gravel lens of its accumulated ground water more rapidly than if one well alone were drawing from it. In the examples described above, however, the local gravels appear to be readily recharged during the run-off season from the overlying valley fill and, except possibly in dry seasons, the supply would not become seriously depleted.

WELL TESTS.

Individual wells vary so widely in yield that it is impossible to make generalizations from which the yield of new wells can be predicted. Three wells on the low terraces between Otay and Tia Juana valleys—considered typical of the best wells of an area that probably affords more favorable conditions for well yield than any other area of Tertiary rocks in San Diego County—were tested. The tests were made as for wells in the valley fill and are described as follows:

Well O 115.—Well O 115, which is owned by W. E. Williams, is at the northern edge of Tia Juana Valley about 1½ miles southeast of Nestor, in sec. 34, T. 18 S., R. 2 W. From the bottom of a dug pit 5 feet square and 7.5 feet deep, curbed with redwood timbers, a drilled well, lined with 10-inch stovepipe casing, is sunk to a depth of 56 feet. The principal water-bearing stratum of gravel is reached 53 feet below the surface, is penetrated 3 feet, and yields water readily. (For log of well see Pl. XXVII.) Water probably enters at the bottom of the casing. The normal water level in the well ranges during the year from about 7.5 feet to 12 feet below the surface of the ground, as shown by measurements made during the season of 1914–15 (Table 30, p. 126). At the time of the test the water stood 8.1 feet below the ground surface. During the test, which lasted 1 hour and 6 minutes, the well was pumped at the rate of 231 gallons a minute; the total drawdown, which was reached 36 minutes after pumping was started and remained constant to the end of the test, was 15.25 feet, so that the water level was 23.35 feet below the surface of the ground. The specific capacity of the well (see p. 158) was therefore a little more than 15 gallons a minute for each foot of drawdown. As the dimensions of the perforated area were not obtained, the specific capacity of the gravels (p. 158) could not be computed.

Well O 47.—Well O 47, owned by Tucker & Evans, is 2 miles west of Nestor, in the SE. ¼ sec. 29, T. 18 S., R. 2 W. It consists of a dug pit, 4 feet 8 inches by 8 feet 6 inches, and 19 feet deep, from the bottom of which a drilled hole, lined with 12-inch stovepipe casing, extends to a depth of 64 feet below the surface of the ground. The casing, which is not perforated, penetrates 14 feet into a good water-bearing stratum composed of gravel with few boulders, and the water enters at the bottom. (For log of well see Pl. XXVII.) In 1914–15 the normal water level ranged from 21 feet to 32 feet below the surface of the ground (Table 30, p. 126). The well was pumped for 1 hour and 38 minutes at a rate of 373 gallons a minute; the resulting drawdown, which was reached 15 minutes after the pump was started, was 21 feet, or to 42 feet below the surface of the ground. The specific capacity of the well was therefore 18 gallons a minute per foot of drawdown.

Well O 102.—Well O 102, owned by R. J. Jaeger, is half a mile northeast of Nestor. It consists of a dug pit, 4 feet square and 110 feet deep, at the bottom of which is drilled a hole 20 feet deep, lined with 12-inch casing that projects 10 feet above the bottom of the pit; the total depth of the well is 130 feet. No very definite information could be obtained as to the log of the well, but the drilled section was said to be mostly in sand and, near the bottom, medium gravel. At the time of the test the normal water level measured 84 feet below the surface of the ground. The well was pumped for 2 hours and 6 minutes at the rate of 116.5 gallons a minute without lowering the water level. It is evident, therefore, that the well was not being pumped to its full capacity, the pump being too small to properly test the well, and the specific capacity could not be determined.

Discussion of well tests.—The results of well tests are summarized in Table 43 (p. 162). The tests of wells O 47 and O 115 indicate that in this area the specific capacity of wells penetrating open gravels is about 15 gallons per minute for each foot of drawdown. A single well penetrating open gravels should therefore yield about 300 gallons a minute for a 20-foot drawdown. Wells such as O 110, O 116, and O 111, which penetrate hardpan and adobe containing boulders and gravel, of which about 30 feet is saturated, would probably yield less than those reaching gravel. Experience with the best of such wells near the edge of Tia Juana Valley indicates that the specific capacity is about 10 gallons a minute per foot of drawdown. Where water is needed to irrigate alfalfa it is customary to drill several such wells in a group. The probable yield of a proposed well should be estimated, if possible, on that of wells in the immediate vicinity which are being pumped to capacity; if such information is not available the figures here given may serve as a rough guide.

WELL CONSTRUCTION.

On the lower benches near San Diego Bay where water may be reached at depths of less than about 100 feet, dug wells are practicable, but such wells can not be constructed profitably on the high mesas, and even on the lower benches drilled wells are likely to be much more satisfactory. Wells 3½ or 4 feet in diameter can be dug at a cost of about $1 a foot.

Very satisfactory results are being obtained on the lower terraces by the use of cased wells 8 to 12 inches in diameter. Where the usual depth to the water plane exceeds 10 feet and ordinary centrifugal pumps are to be installed, pump pits are dug and the casing sunk from the bottom. In the best plants pump pits are lined with concrete. If a deep-well pump is to be installed a pit is not necessary.

Wells are drilled either with the ordinary California rig or some type of portable rig. Occasionally standard pipe is used as well casing instead of stovepipe casing.

Two other general methods of well drilling may be successfully employed in the sedimentary formations of this area—the percussion method and the abrasion or rotary method. The percussion method, which is more commonly used, consists of lifting and dropping, by means of suitable apparatus, a heavy string of drill tools that punch or cut a hole through the unconsolidated materials and break the solid rock into fragments small enough to be readily removed from the hole. When the well is drilled in unconsolidated materials iron pipe or well casing as large in diameter as the hole will admit, usually 6 to 10 inches, is generally driven down as rapidly as the drill descends, each added length of casing being securely screwed to the preceding one to make a tight joint. If the well penetrates hard bedrock the casing should be driven a few feet into the rock to prevent infiltration of water and silt from the overlying deposits. If the well ends in loose material the casing extends to the bottom of the hole and may be perforated or slit at the lower end to admit water more readily. The casing is allowed to extend several inches above the surface of the ground to prevent inflow of surface water, and a flange is fitted to the top to which a pump is attached.

In drilling by the abrasion method hollow drill tools armed with some harder materials, such as diamonds or chilled shot, are rotated on the rock in such a way that a cylindrical core is cut out and brought to the surface in short pieces. The wells sunk by this method are finished in the same way as those made by percussion drilling and the costs practically the same as those sunk by the other method.

Owing to the competition among well drillers there is no standard scale of prices for well drilling. It is customary to charge according to a "sliding scale" a certain amount—$2 or $3 a foot for the first 100 feet and an additional $1 or $2 a foot for each additional 100 feet. Mr. Wilkes James stated that his rates for a 10-inch well are $2 a foot for the first 100 feet, $2.50 a foot for the second 100 feet, and $1 a foot additional for each additional 100 feet. This price, however, does not include casing. In November, 1914, the price of standard 10-inch casing was about 90 cents a foot.

GROUND WATER IN THE HIGHLAND AREA.

By A. J. Ellis and C. H. Lee.

WATER-BEARING FORMATIONS.

The rocks of the highland area may be divided, according to their ability to store and yield water, into four groups: (1) the crystalline rocks; (2) the talus at the bottoms of the mountain slopes; (3) the residuum or weathered material, popularly called "decomposed granite," in the highland basins, described on page 71; (4) the alluvium in the valleys of the principal streams; and (5) the lake deposits in Warners and San Felipe valleys.

WATER IN CRYSTALLINE ROCKS.

None of the wells that were examined in San Diego County obtain water from the crystalline rocks, and this discussion is therefore based on the knowledge of the occurrence of water in crystalline rocks in other areas; but since the underlying principles do not change from one place to another, and since, as will be shown, specific information in regard to rock wells is of very little use in planning future developments except as emphasizing the uncertainties involved, information based on conditions in areas of similar rocks may properly be applied to the crystalline rocks of San Diego County.

Undecomposed crystalline rocks are practically impervious. They absorb some water, but the pores that take up the water are so small that the movement of water through them is exceedingly slow and they are altogether incapable of yielding a water supply when the rocks are penetrated by a drill hole. All such rocks, however, are more or less broken, and fissures of various sizes extend from the surface downward and intersect each other in such a way that a drill hole is able to drain not only the intersected fissures but also others with which these fissures may be connected. Water finding its way into cracks at the surface and passing from one fissure to another as it descends may therefore constitute an important source of supply. Under these conditions obviously the chief factors in the occurrence of water are the number and size of the rock fissures, topography, and the amount of precipitation. In Connecticut,[1] for example, where rock fissures are numerous and the average annual rainfall is 47 inches, the average yield of wells drilled into crystalline rocks is about 15 gallons a minute; but the range is from nothing to more than 100 gallons a minute, and it is a common experience to obtain good wells 100 or 200 feet deep within a few yards of perfectly dry holes of greater depth. It is highly probable that, owing to the low rainfall in San Diego County, the average yield of wells in

[1] Gregory, H. E., and Ellis, E. E., Underground waters of Connecticut, with a study of the occurrence of water in crystalline rocks: U. S. Geol. Survey Water-Supply Paper 232, 1909.

crystalline rocks will be small and that probably a considerable percentage of drill holes will fail to intercept water-bearing fissures and will remain dry. In general supplies larger than those necessary for ordinary domestic use can not be expected from such wells. The most favorable sites for rock wells are where the rocks are most intensely fractured and at low levels where streams or the drainage from surrounding slopes may afford more ample recharge of the rock fissures.

WATER IN TALUS.

Deposits consisting of heterogeneous mixtures of coarse and fine rock débris from the mountain slopes have accumulated along the

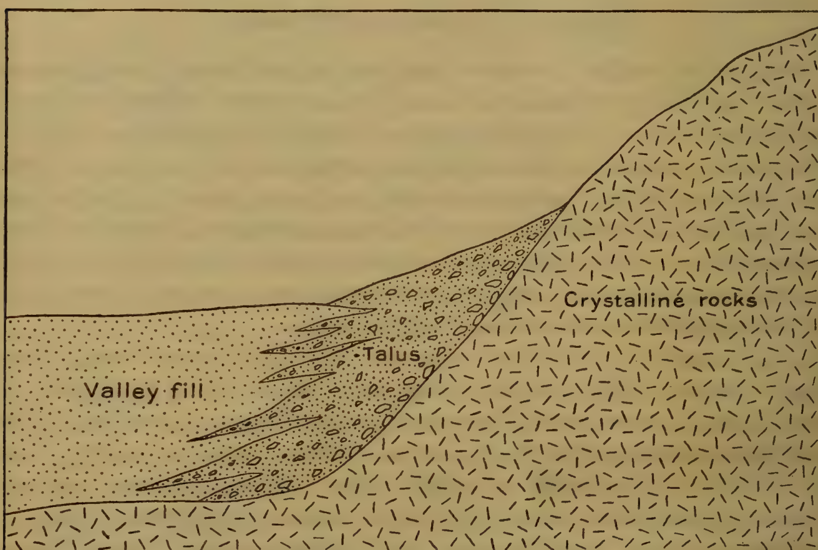


FIGURE 17.—Diagram showing digitate character of contact between talus slope and valley fill; conditions favorable for rapid drainage of talus.

edges of many of the valleys in the highland area. In some places where the valley walls slope gently the coarse and fine materials are somewhat assorted into layers, but as a rule coarse and fine materials have been dropped together without assortment. As the finest material in the talus slopes is usually coarser than the alluvium that is carried out on the valley floors, the talus is particularly well adapted for absorbing water, and its topographic position enables water to reach it readily. Talus deposits grow simultaneously with the accumulation of alluvium on the valley floors, and their bases are interlocked with the alluvium in such a way as to afford especially favorable conditions for the seepage of water from the talus into the alluvium (fig. 17). Owing to its coarseness and its position the talus is not adapted for storing water, and the water that it absorbs sinks rapidly and enters the alluvium. Unless there is a covering of soil on some higher parts of the slope, which absorbs rainfall and discharges it gradually into the talus, or unless the fissures in the rocks themselves afford such a supply the talus is not likely to contain water during dry periods; for this reason it can not in general be regarded as a reliable source of well water. If a well must be sunk into such a deposit it should be placed as near the bottom of the slope as possible; and if it is practicable to choose a site where the well will penetrate alluvium the chances of obtaining a water supply are much better. It should be noted, however, that in some places peculiarities in the talus itself or in the underlying rock slope, or a permanent stream or other source of water may afford conditions favorable to the occurrence of a ground-water reservoir.

WATER IN THE RESIDUUM.

CHARACTER OF THE RESIDUUM.

The most important source of ground water in the highland area is the residuum or, as it is commonly called, the "decomposed granite," which covers the bedrocks in all the highland basins and which occurs more or less generally throughout the area. This material consists of small lumps or grains of the original crystalline rocks that have been disintegrated by the removal or alteration of some of their mineral constituents. The disintegration is most complete at the surface, where in many places the rock has been completely reduced to soil, and it decreases gradually from the surface downward until, at depths ranging from 3 feet to more than 100 feet, it merges with thoroughly indurated rock. Granite is one of the most easily altered crystalline rocks and is the most prevalent rock in this area, so that by far the largest part of the residuum is derived from granite. Figure 18 shows sections of the residuum as determined from well logs.

The porosity of residuum varies greatly as it depends on the degree of disintegration, which is subject to wide variations, both vertically and horizontally. In one place, for example, a well may be easily dug with a pick and shovel to a depth of 50 feet or more, whereas in another place only a few rods distant blasting may be necessary at a depth of 15 to 20 feet. But as a rule the residuum is sufficiently porous and disintegrated to afford storage for water. There are many rock basins, such as El Cajon Valley, Escondido Valley, Bear Valley, Jamul Valley, and Padre Barona Valley, which are nearly water-tight and contain considerable disintegrated material in which water is stored. Ground water may be drained from a large area by sinking wells through the decomposed rock and digging tunnels or boring holes at right angles to the slope of the surface, as explained on page 194.

WATER TABLE.

The water table in the residuum lies at depths ranging from less than 10 to more than 30 feet below the surface of the ground. Fluctuations of ground-water level from September, 1914, to August, 1915, were observed in twelve wells as follows: L 40, G 32, L 92, L 11, H 32, L 24, L 96, P 21, P 2, H 37, H 17, and H 38. Observations since 1912 are also available for wells L 92, L 11, and H 32. The positions of these wells are shown in Plates XXII and XXIV and full information concerning them is given in Table 45. A summary of observations, including dates and elevations of maximum water

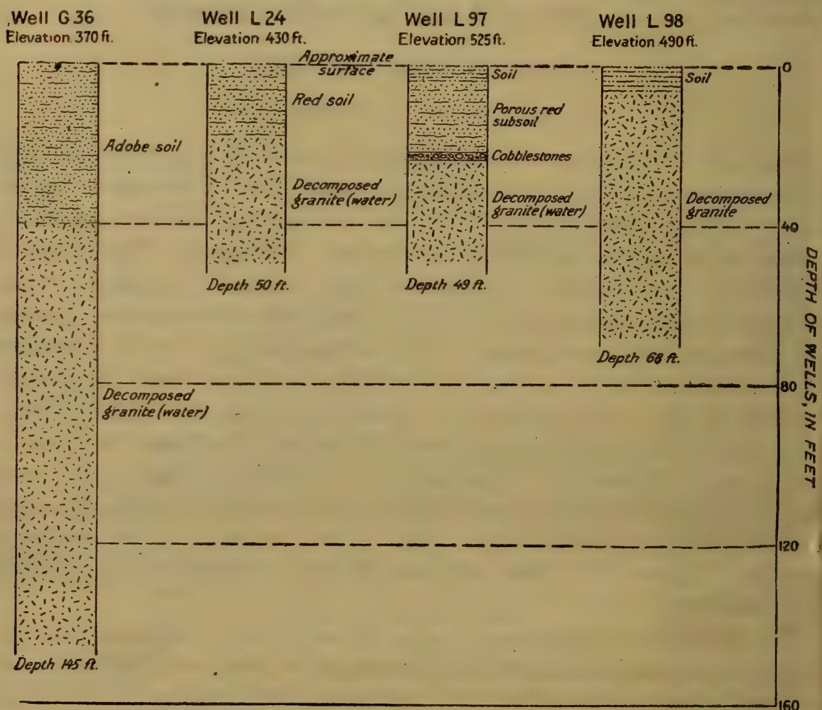


FIGURE 18.—Sections of wells in residuum.

levels, is given in Table 30 (p. 126). The maximum, minimum, and average range of fluctuations observed in wells in 1914–15 are shown in Table 32 (p. 133). The figures there given indicate an annual range of 3.0 to 9.4 feet on an average range of 5.85 feet, although the average probably exceeds 5.85 feet over large areas. The detailed record of fluctuations at eight typical wells, as shown graphically in Plate XLVII, corresponds generally to that of wells in the fill of the major valleys. Wells that show quick rise at the date of the first storm producing run-off, such as well H 87, are near stream channels; in other wells in open valleys and on gentle foothill slopes the water levels are highest in March or April or even as late as May or June.

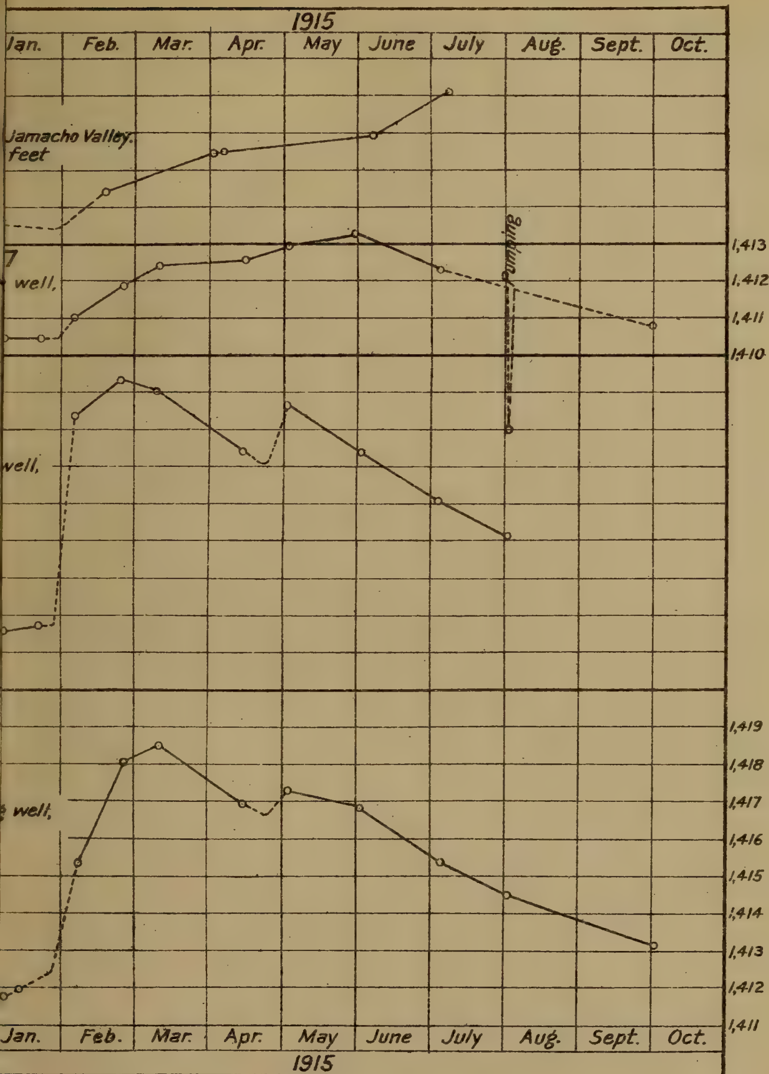


DIAGRAM SHOWING
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1912 - 1915

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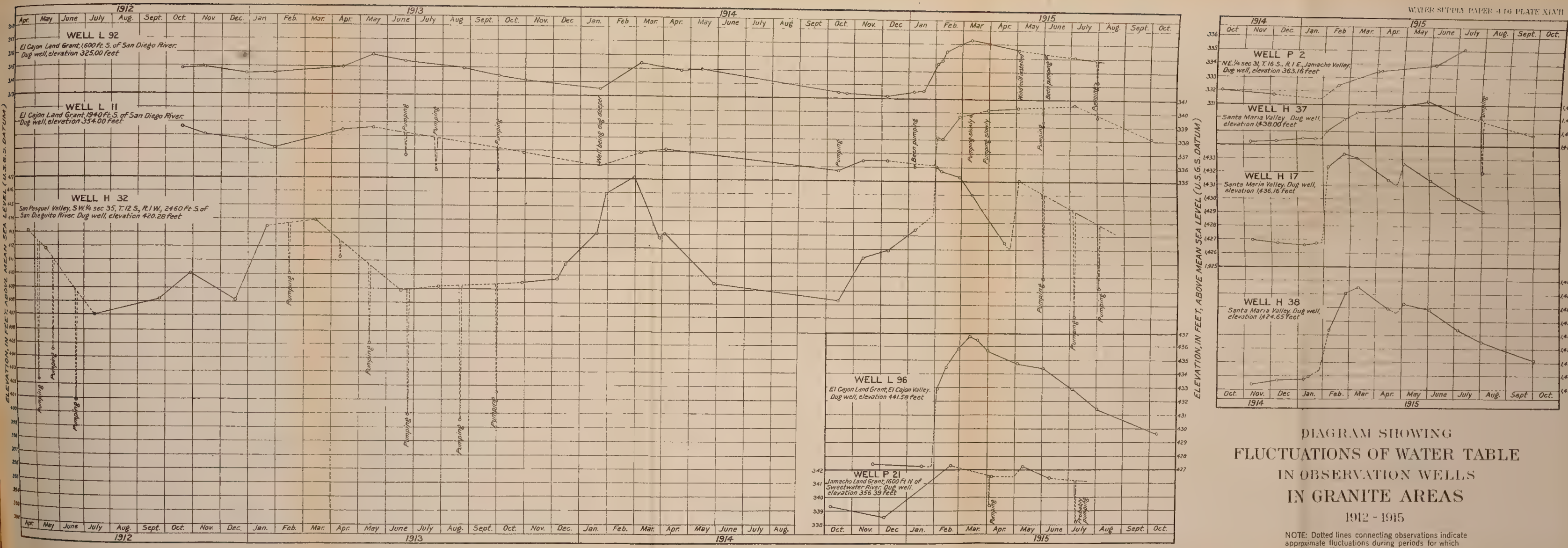

DIAGRAM SHOWING FLUCTUATIONS OF WATER TABLE IN OBSERVATION WELLS IN GRANITE AREAS 1912 - 1915

NOTE: Dotted lines connecting observations indicate approximate fluctuations during periods for which record is insufficient to show detail.

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SOURCES OF WATER.

The water in the residuum or decomposed granite is derived (1) by absorption directly from rainfall, (2) by absorption from streams, and (3) by seepage from irrigated areas.

Water from streams is absorbed only by material adjacent to stream channels. Streams that flow over alluvium recharge the alluvium, which, in turn, contributes to the supply of adjacent residuum. If the period of flow is short, as it usually is in small stream channels, the quantity of water absorbed from this source is small. Seepage from irrigated areas forms a large part of the ground-water supply in regions where irrigation is practiced, especially where the supply is brought in from a distance. As the irrigation season is in the summer, replenishment from this source does not occur during the same period as that from rainfall and run-off. The water-bearing formations are thus recharged throughout the year instead of during the rainy season only. The principal areas of residuum in which irrigation is practiced are in El Cajon and Escondido valleys. The supply of water available from wells in the residuum within and below these irrigated areas is the most plentiful and permanent to be obtained in that formation in San Diego County.

The most general and largest source of water in the residuum is derived from rainfall, although less than 40 per cent reaches the water table. The rainfall map accompanying this report (Pl. XV) shows the relative quantities available for absorption in different places. Except in El Cajon Valley, the average annual precipitation over the larger areas of residuum ranges from 15 to 22 inches, depending on the elevation. In El Cajon Valley it ranges from 12 to 14 inches. In very dry years, two of which may occur in succession, the precipitation may be only half of the above quantities (Table 18, p. 84).

The duty of water for irrigated citrus orchards in this region is about 1 foot per year, and for alfalfa 2 to 3 feet. The supply of water from residuum, where the only source of replenishment is rain, is inadequate for the irrigation of extended overlying areas. Supplies for small isolated areas of a few acres, however, may be obtained from one favorably situated well with sufficient lateral development to permit drawing water from a large surrounding area. The storage of ground water is favored by (1) great depth of residuum, (2) position at the bottom of a slope, near a stream channel or in a ravine, and (3) vegetation and other surface conditions favorable for retarding run-off from the slopes or drainage area above the well.

YIELD OF WELLS.

The yield of wells has been found to range under different conditions from very small quantities to as much as 150 gallons per minute

(Tables 43, p. 162, and 61, p. 275). The smallest yields are obtained from wells without laterals, in shallow decomposed rock or in unaltered rock, on upper slopes or in small ravines, or in other places where conditions are not favorable for large absorption; the largest yields are obtained from wells that penetrate residuum of considerable depth, that are provided with lateral tunnels and auger holes, and that are situated in valleys irrigated with water from an outside source. In general, it may be said that the specific capacity of the best wells in residuum is about 8 gallons a minute per foot of draw down, that for many wells it is as low as 1 gallon per minute per foot of draw down, and that for the poorest wells it is much less than 1 gallon.

METHODS OF SINKING WELLS IN RESIDUUM.

Both dug and drilled wells can be successfully sunk in areas in which ground water is derived from residuum, but drilled wells are not likely to yield much more water than is ordinarily required for domestic use, so that where water is needed for irrigation dug wells should be constructed.

Drilled wells should preferably be 10 or 12 inches in diameter. Storage may be provided by drilling to a depth below that of the decomposed rock, but this method is not likely to increase the specific capacity of the well. Better results may be expected from a well of large diameter drilled to the bottom of the pervious rock than from a well of small diameter in which storage is provided by drilling into the underlying impervious rock.

Dug wells of the kind ordinarily used for domestic water supplies are suitable for that purpose in the areas underlain by the residuum, but they do not yield enough water for irrigation. Wells combining modifications of this type, however, made by digging horizontal tunnels or by boring small lateral auger holes from the bottoms of dug wells, afford supplies as large as can possibly be obtained from residuum. The tunneled wells are usually made in the following manner:

A well about 10 feet in diameter is dug to the depth at which the rock appears to be practically impervious; this depth varies from place to place, but in most places is between 30 and 80 feet. The disintegrated rock is easily excavated near the surface with pick and shovel but it gradually becomes harder with depth and may require blasting through more than half the depth. When the water level is reached pumps are started and are kept in operation as required until all underground work is completed. At the proper depth the work of tunneling is begun. An area about 4 feet wide and 6 feet high is laid out on the wall, the lower side being a few feet above the bottom of the well. A small blast hole, 4 or 5 feet long, is drilled horizontally in the center of the area, and a similar hole, inclined toward the center one, is drilled at each corner. This arrangement of blasts is necessary to insure control of the size and shape of the tunnel and to minimize the consumption of powder. The holes are usually drilled with a small compressed air drill, but at the cost of a little more time and labor they can be bored with hand augers. After the blast is fired the walls of the tunnel are trimmed and new blasts are prepared as before, the tunnel being advanced to its full length in this manner. The tunnels are slightly inclined upward to permit the water to flow freely toward the well. The rock is of such character that the walls and roof stand without timbering, but when blasted from the heading it usually falls in small bits on the floor of the tunnel and is washed along by the natural flow of water to the well where it is shoveled into buckets and hoisted. Smoke produced by blasting is removed by reversed blowers. Tunnels up to 150 feet in length are commonly constructed in this manner. Usually two tunnels are dug in opposite directions from the well, but as many as three or four are sometimes made.

The following charges were made in 1914 for wells constructed by this method: For sinking wells 10 feet in diameter in residuum, $10 a foot for the first 10 feet and $2 a foot additional for each additional 10 feet; for sinking wells in hard unaltered granite, $15 a foot for the first 10 feet and $7 additional for each additional 10 feet; for digging tunnels in residuum, $5 a foot for the first 10 feet and $1 a foot additional for each additional 10 feet.

The chief advantage afforded by wells of this kind is their large storage capacity. A tunnel 4 by 6 feet in cross section has a storage capacity of 180 gallons per foot of length, from which it is evident that wells having an aggregate of several hundred feet of tunnels are capable of furnishing fairly large supplies when the tunnels have become filled.

Wells with lateral auger holes are sunk to the required depth in the usual manner and the laterals are bored 3 or 4 feet from the bottom, or as near to the bottom as it is convenient to work. A 1½-inch or 2-inch auger is used, to which, as it advances, successive sections of hollow pipe are screwed. The length of the sections is limited by the diameter of the well, and each section is perforated by a few small holes to admit water. The auger is directed upward at a slight angle to permit the water to run freely toward the well, and the cuttings, entering the end of the pipe, are carried to the well by the flow of water, so that it is not necessary to withdraw the auger until it has advanced the full distance. Laterals 100 feet long are commonly bored in this manner. Usually several holes are bored in different directions from a well. The cost of laterals ranged in 1914 from 25 to 50 cents a foot, and a workman can make an average of about 40 feet a day where the flow of water is strong enough to remove the cuttings readily.

The advantage in this method of construction lies in the fact that at a very moderate cost the yield of a well may be increased several fold, but of course wells of this type lack the storage capacity that is obtained by tunneling.

DESCRIPTIONS BY AREAS.

FALLBROOK AND VICINITY.

All the wells examined in the vicinity of Fallbrook end in residuum. They range in depth from about 30 feet to more than 100 feet and furnish supplies ranging from meager amounts, barely adequate for domestic needs, to quantities large enough to irrigate 25 acres of land. Ample supplies of good quality are, however, obtained in all the wells that are favorably situated. Dug wells with lateral auger holes or tunnels below the water level (see p. 194) have been found to be much more satisfactory than drilled wells, and there are said to be no drilled wells in use at the present time. A few wells, 8 and 10 inches in diameter, were drilled to depths of 100 feet or more in Fallbrook but they failed to furnish adequate supplies and were abandoned. The depth to water in the wells examined ranges from 10 to 68 feet but exceeds 40 feet only in wells at high elevations, where less favorable ground-water conditions are to be expected. In order to obtain the best results wells should be sunk at low elevations where, by the use of lateral auger holes or tunnels, the underground drainage from long slopes may be intercepted. The following wells are typical of this vicinity. Additional data are given in Table 46 (p. 221).

At Dr. Pratt's ranch (B 4) there are three dug wells 8 feet in diameter, each 40 feet deep, connected at the bottom by tunnels 4 feet wide by 6 feet high, with other tunnels, aggregating about 180 feet in length. These wells end in residuum which was said to extend to a depth of 100 feet, where hard blue granite is reached, and they furnish enough water to irrigate 25 acres of lemon trees. The water stands normally within 10 feet of the top, and it was reported to rise to this level rapidly even after the wells had been pumped empty. No timbers or other supports are used in the tunnels and the wells are curbed to a depth of only 15 feet. Water is pumped at the rate of about 135 gallons a minute at a cost of about 3 cents per 1,000 gallons.

Mr. J. A. Fulwiler's well (B 5), in the NE. ¼ sec. 25, T. 9 S., R. 4 W., is a dug well 55 feet deep and 4 feet in diameter, at the bottom of which is a tunnel 7 feet high, 5 feet wide, and 16 feet long. It penetrated gray residuum which required blasting below the depth of 15 feet, but did not reach solid granite. The well has been pumped at the rate of about 35 gallons a minute, 24 hours a day, for 6 weeks, and the water level stood constantly 52½ feet below the surface, or 2½ feet above the bottom of the well. Very little water is used for irrigation at the present time, but it is believed that the supply is sufficient to irrigate 20 acres. The pumping plant consists of a suction pump with two 3-inch cylinders 22 inches long, and one 4-horsepower gasoline engine.

This well is near the bottom of a slope about one-fourth mile long, near the top of which is a dug well 13 feet deep, containing 5 feet of water and yielding just enough for domestic use. It can be pumped empty in a short time by a windmill operating a 2-inch cylinder. Mr. Fulwiler stated that the well passed through 15 feet of soil at the surface and continued to the depth of 73 feet through residuum.

ESCONDIDO AND VICINITY.

Escondido Creek flows over a deposit of valley fill that extends to a depth of more than 50 feet below the present floor of the valley. This deposit consists of beds of sand and gravel and a few layers of hard clay. Its areal extent has not been accurately determined but it is probably not more than a half mile wide and about 5 miles long. Wells along the creek between Escondido and the north side of the plain derive their water from the valley fill, but all other wells in the vicinity obtain their supplies in residuum.

Well G 1, belonging to A. C. Meyer, is 38 feet deep and 4.5 feet in diameter. Residuum extends from the surface to the bottom of the well where the material is unaltered granite. Two horizontal tunnels, 3 feet wide by 6 feet high, one of which is 165 feet long and the other 38 feet long, extend in opposite directions from the bottom of the well. The pumping plant consists of a 9-horsepower gasoline engine and a No. 3 vertical centrifugal pump. The well can be pumped at the rate of 180 gallons a minute for six hours daily.

George Lehner's well (G 6) is a dug well 61 feet deep and ends in residuum. Two horizontal tunnels, 3 feet wide and 6 feet high, extend from the bottom of the well 60 feet in opposite directions. The pumping plant consists of a 6-horsepower gasoline engine and a suction pump with a cylinder 6 inches in diameter and 36 inches long. The well is said to have a continuous yield of about 18 gallons a minute, but it is allowed to stand idle until it has accumulated considerable water and is then pumped at the rate of about 45 gallons a minute for about 12 hours, when the supply becomes exhausted.

A drilled well (G 8) 51 feet deep, at the home of Mr. J. C. Dickson, about 1¼ miles northeast of Escondido post office and just south of Escondido Creek, penetrated the deposits shown in the following log.

Log of well of J. C. Dickson (G 8), about 1¼ miles northeast of Escondido post office.

	Depth. Ft.	in.
Soil and sand	20	0
Tough plastic clay	21	6
Sand	22	6
Gravel, water bearing	30	6
Tough plastic clay	31	6
Sand and gravel, little water	51	0
Surface of granite bedrock.		

A well about 100 feet south of this well encountered granite at a depth of 5 feet.

Mr. Dickson's principal water supply is obtained from a well drilled about 6 feet from the 51-foot well. It is 31 feet deep and 12 inches in diameter and on November 19, 1914, the water stood 7 feet below the surface. It is cased with stovepipe casing and yields about 165 gallons a minute. Water is lifted by means of a centrifugal pump, operated by a 6-horsepower gasoline engine. A pumping test made November 19, 1914, showed that this plant lifted water at the rate of 106.5 gallons a minute, and that the drawdown after pumping 20 minutes was 10.4 feet. Water is used for domestic supply and to a moderate extent for irrigation.

Well G 10, owned by Mr. John L. Ellis, is about 1 mile southeast of Escondido post office. It is 30 feet deep and yields about 20 gallons a minute. A horizontal auger hole, 1½ inches in diameter and 50 feet long, bored near the bottom of the well, yields a considerable part of the water. The water level is ordinarily about 9 feet below the top of the well but it is lowered to the bottom in three hours by pumping at the rate of 50 gallons a minute. A suction pump with a cylinder 5 inches in diameter and 16 inches long is operated by a gasoline engine. The water is used principally for domestic supply.

The dug well of Mr. D. T. Marlor (G 12), which is about 2 miles west of Escondido, penetrates residuum to the depth of 25 feet. It has no lateral tunnels or auger holes. In April, 1914, the water stood 4.8 feet below the ground surface, and on November 20 it stood 16.8 feet below the surface. This difference in level is believed to represent approximately the average annual fluctuation of the ground-water level at this place. The yield of the well is very small, but is sufficient for domestic needs. A 2,000-gallon tank is filled once a week, the water being lifted by means of a suction pump operated by a 2-horse-power gasoline engine.

Well G 13, belonging to Mr. Benjamin Chubbic, is 29 feet deep and 3 feet in diameter, and on November 20, 1914, the water stood about 22 feet below the surface of the ground.

This well also is without tunnels or auger holes and yields only a small supply. When pumped at the rate of 3.5 gallons a minute, it ususally becomes empty in about an hour.

The combination well (G 14) of Mr. William Riezebus furnishes a supply sufficient for domestic use and stock and for the irrigation of 10 acres of lemon trees. It consists of two vertical shafts, 40 feet deep, 10 feet apart, connected with each other by a 1½-inch auger hole, and with a system of 565 feet of laterals. Horizontal auger holes extend from the bottom of each well, and, to provide storage, a horizontal tunnel 3 feet wide, 6 feet high, and 65 feet long, extends from the bottom of one of the wells. The pumping plant consists of a suction pump and a 6-horsepower gasoline engine. Water is pumped at the rate of 54 gallons a minute. The total cost of the well and the pumping plant was $1,400.

POWAY VALLEY.

Most of the wells in Poway Valley are dug wells, 25 to 50 feet deep, without laterals. They end in coarse alluvium or residuum. These wells generally yield enough water for domestic use but not enough for irrigation. It has been shown, however, by two wells at the head of the valley that supplies adequate for irrigation may be obtained if proper methods are used. These wells were dug by Mr. Rufus Nephew, one of them (K 13) for Mr. A. A. Flint, and the other (K 14), about a half mile east of K 13, for Mr. J. D. Sylvester. Well K 13 is 10 feet in diameter and 66 feet deep and has at the bottom two horizontal tunnels, in most places 4 feet wide and 6 feet high but locally as large as 6 by 10 feet, one of which extends 120 feet north and the other 90 feet south. The well penetrated 12 feet of soil, 24 feet of sand and gravel, and 30 feet of residuum and did not reach unaltered rock. Water was obtained at a depth of 17 feet, and it ordinarily stands at this depth when the pump is not operated. A 3-inch 2-stage vertical centrifugal pump, set 53 feet below the surface, is run by a gasoline engine. The capacity of the pump is 225 to 270 gallons a minute. The water level is lowered from 17 feet to 53 feet below the surface during 11 hours of pumping at full capacity.

Seven acres of alfalfa are now under irrigation from this well, but it is planned to irrigate an additional 15 acres. The water is distributed in the following manner: A line of 6-inch galvanized-iron pipe in convenient lengths is laid along the higher side of the irrigated tract from the well to the lower end of the field and the pump is started. The joints in the pipe line are not tight and a certain amount of water escapes at each joint but, owing to the volume of the stream and the grades, most of it goes through to the end of the line. The workman then returns from the pump to the end of the line, the time required for this trip being sufficient to allow the proper quantity of water to flow from the end of the pipe, and carries each successive length of pipe to a parallel position at a suitable distance, say 50 feet, from its former place. Thus a new line is formed more or less parallel to the first line, and each time a length of pipe is carried to the new line the water escapes one joint nearer to the well in the old line. The quantity of water that escapes while a length of pipe is being moved, with the quantity that previously leaked from the joint, is sufficient to cover the space between the pipe lines. When the length of pipe nearest the well is moved the water begins to flow through the new line and the process of moving is repeated.

The labor involved in this process is reduced as the distance between successive positions of the pipe line is increased, and therefore in order to minimize the labor two or three pipes are repeatedly adjusted at the end of the old line each time it is shortened, in such a way that the end of the old line slowly describes an arc, thus increasing the width of the strip watered. This method of irrigation is employed in many places in San Diego County and it is regarded as particularly applicable where soils are very porous. By telescoping the pipes so as to make fairly tight joints water may be carried over ground at elevations higher than the well. It is said that under favorable conditions lifts of as much as 30 feet can be accomplished, but such high lifts are ordinarily not economical.

The following information in regard to Mr. Sylvester's well (K 14) was obtained from Mr. Flint. This well is 10 feet in diameter and 63 feet deep, with three tunnels 4 feet wide and 6 feet high extending, respectively, 30 feet east, 50 feet south, and 150 feet north. A pump having two 6-inch cylinders set 3 feet below the tops of the tunnels is run by a 10-horsepower gasoline engine. Water is lifted at the rate of 90 gallons a minute and the water level has not been lowered to the tunnels, although this rate of pumping has been continued 15 hours a day for 15 days. Twenty-five acres of lemon and apricot trees are irrigated.

RAMONA AND VICINITY.

A narrow deposit of water-bearing alluvium occurs along Santa Maria Creek, but most of the ground water is obtained from residuum. The following ground-water developments are typical of this vicinity. Data in regard to additional wells are given in Table 46 (p. 221).

Well H 7, on Mr. Ferdinand Hauck's ranch, was under construction when visited, November 23, 1914. It had reached the depth of 23 feet and had encountered water at the depth of 14 feet. It was 6 feet square and was to be sunk to the depth of 75 feet. There are three drilled wells 8 inches in diameter respectively 36, 48, and 60 feet in depth, within a few rods of the dug well. Water was reached at the depth of 10 feet in each well and the yield of each was adequate for domestic use, but the combined yield was insufficient for irrigation. Windmills are installed over two of the wells and water is pumped for domestic use and for stock.

Well H 8, on Mr. W. D. Dukes's ranch, is a dug well 45 feet deep, in the bottom of which is a vertical hole drilled to the depth of 86 feet and ending in residuum. When examined this drill hole was about filed with sediment and yielded no water, but before it became filled it yielded a supply adequate for domestic use. Four 2-inch laterals, respectively 30, 40, 60, and 80 feet long, extend from the well at the depth of 40 feet below the surface. The 60-foot lateral discharges a 2-inch stream of water which reaches to the center of the well. The depth to water below the ground surface on November 23, 1914, was 9 feet. It was said that water can be reached at any place in this vicinity at depths ranging from 6 to 15 feet below the surface. The pumping plant consists of a 4-horsepower gasoline engine and a 1½-inch centrifugal pump. Mr. Dukes stated that in this vicinity the alfalfa crop averaged 4 tons per acre without irrigation and 6 tons per acre with irrigation, but, that, regardless of production or crops, irrigation was practically essential in order to destroy gophers which infest this valley.

A group of four drilled wells (H 12) on the ranch of Mr. W. E. Woodward, 8 inches in diameter and ranging in depth from 34 to 38 feet, yield water for domestic use and for the irrigation of 15 acres of land. These wells are close to Santa Maria Creek and extend through valley fill just to the surface of residuum. The depth to water is about 9 feet, and the entire supply, amounting to about 585 gallons a minute, is derived from the valley fill. The wells are fitted with perforated casings. The pumping plant consists of a 10-horsepower gasoline engine and a 4-inch centrifugal pump.

Three wells (H 11), belonging to Mr. A. U. Woodward, were recently completed a short distance south of H 12, close to Santa Maria Creek. They were drilled, 8 inches in diameter, to depths of from 34 to 36 feet, and just reach the surface of residuum underlying the valley fill. Perforated casings extend to the bottoms of the wells. Water was reached at the depth of 6 feet and a combined yield of 630 gallons a minute was obtained. An 8-horsepower gasoline engine and a 4-inch centrifugal pump have been installed to pump water for domestic use and for irrigation.

EL CAJON VALLEY.

Along the north side of El Cajon Valley water is obtained from the valley fill along San Diego River, as described on page 119. South of the filled valley of the San Diego, however, ground water is obtained principally from residuum. The usual practice in this valley is to dig wells 5 feet in diameter to depths 30 or 40 feet below the water table, then to bore near the bottom three or four horizontal auger holes 2 inches in diameter. It has been found that by boring these holes the yield of a well is increased two or four fold, affording on the average about 45 gallons per minute. A few of the older wells in the valley have lateral tunnels, of large cross section below the water table, but although the advantage of a large storage capacity in this sort of well is recognized, auger holes are now made in preference to larger tunnels because of the great difference in the cost of construction (p. 195). A large number of the wells in El Cajon Valley are equipped with pumps operated by gasoline engines, and it is said that on this account the water table has been very considerably lowered. Mr. H. Culbertson, who has drilled many of the wells in the valley, stated that 50 years ago water was reached at the depth of 8 feet on the east side of the valley where it now stands at a depth of 40 feet. Moreover, the flume owned by the Cuyamaca Flume Co., of San Diego, extends along the east and south sides of the valley and has supplied water for irrigation since 1887, and it is believed that this has contributed materially to the ground-water supply.

At many places in the western part of the valley wells have penetrated beds of marl interbedded with and underlying clay at depths ranging from 8 to 40 feet below the surface. The marl beds have often yielded bitter, salty water, and some wells have been abandoned on this account. The marl beds are not continuous over the entire valley, however, but appear to have been laid down in the depressions on an uneven basement between which masses of granitic residuum rise to the surface of the ground. Water obtained from the granite has invariably been of good quality.

Well L 24, owned by Joseph Miller, is a mile north of El Cajon in El Cajon Valley. The well consists of an open pit, 7.5 feet in diameter and 50 feet deep. About 7 feet up from the bottom of the well, five 2-inch auger holes have been bored, extending out radially from the well and sloping slightly upward for distances ranging from 60 to 131 feet. The total length of these laterals is 541 feet. The log of the well (fig. 18) shows 32 feet of residuum from which the water issues. The normal water level during the year is about 12 feet below the ground surface. In a test covering 20 hours and 48 minutes the well was pumped at the rate of 156 gallons a minute, during which time the water level was lowered 20.8 feet or to a level 30.8 feet below the surface of the ground. The capacity of the well is therefore 7.5 gallons a minute per foot of drawdown.

Well L 98, owned by Charles Bentley, is 2 miles east of El Cajon. It consists of an open pit about 7 feet in diameter for the first 6 feet, 4.5 feet in diameter for the next 20 feet, and 6 feet in diameter for the rest, the total depth being 68.5 feet. It has no lateral tunnels or auger holes. Its log (fig. 18), shows 62.5 feet of residuum, from which the water issues. Its normal water level is about 11 feet below the ground surface. In a test covering 3 hours and 30 minutes the well was pumped at an average rate of about 79 gallons a minute. The total draw down was 24.7 feet or to a level about 36 feet below the surface of the ground. The capacity of the well is therefore only 3.2 gallons a minute for each foot of drawdown, or less than half the specific capacity of well L 24, which has a large system of laterals.

PADRE BARONA VALLEY.

The floor of Padre Barona Valley is composed of residuum which in some places is covered by thin deposits of alluvium and everywhere underlain by hard blue granite. The residuum ranges from 30 to 40 feet in thickness and is saturated with water below a depth of 8 feet from the surface of the ground. A number of wells have been sunk to obtain water for irrigation.

As Barona ranch, owned by Mr. W. H. Jones, includes all the land in the valley, the systematic development of the ground-water resources is unhampered by conflicting rights and requirements. It is planned to dig wells at convenient intervals entirely across the valley and to connect them by tunnels. The description of one of the wells in this proposed series that was under construction when visited on October 27, 1914, is applicable to all the wells now in the valley. This well is 39 feet deep and 10 feet in diameter, with two tunnels 4 feet wide, 6 feet high, and 125 feet long, one extending north and the other south from the bottom of the well. It penetrates residuum and extends to comparatively unaltered rock. This well reached water at a depth of about 8 feet and yielded at the time of examination 45 gallons a minute, although one of the tunnels was only about half completed. The probable quantity of water obtainable from the completed system had not been estimated but it was expected to be sufficient to irrigate all the overlying lands.

WARNERS VALLEY.

No wells have been drilled in Warners Valley to obtain water supplies, but in 1912 and 1913 Mr. Winterhalter sank a number of test holes for the purpose of obtaining information in regard to the position and fluctuation of the water table. The positions of these test holes is shown on Plate II, and the results of the measurements of the depths to water, as furnished by Mr. Williams Post, are shown in the following table:

TABLE 44.—*Depths to the water level in test holes on the Warner ranch.*

Hole E 1.

[Elevation, 2,703 feet; depth, 9 feet.]

Date.	Depth to water level.	Elevation of water level above sea level.	Date.	Depth to water level.	Elevation of water level above sea level.
1913.	*Feet.*	*Feet.*	1913.	*Feet.*	*Feet.*
Jan. 2	Dry		June 17	Dry	
14	do		July 1	do	
24	do		18	do	
Feb. 10	do		Aug. 8	do	
Mar. 3	do		23	do	
18	do		Sept. 5	do	
June 2	do		23	do	

Hole E 2.

[Elevation, 2,729 feet; depth, 8 feet.]

Date.	Depth to water level.	Elevation of water level above sea level.	Date.	Depth to water level.	Elevation of water level above sea level.
1912.			1913.		
Dec. 3	6.1	2,722.9	Mar. 18	1.6	2,727.4
17	6.0	2,723.0	June 3	3.9	2,725.1
1913.			17	4.5	2,724.5
			July 1	5.1	2,723.9
Jan. 2	5.7	2,723.3	18	5.8	2,723.2
14	5.7	2,723.3	Aug. 8	6.2	2,722.8
30	4.4	2,724.6	Sept. 5	7.4	2,721.6
Feb. 10	4.4	2,724.6	23	7.2	2,721.8
Mar. 3	1.3	2,727.7			

TABLE 44.—*Depths to the water level in test holes on the Warner ranch*—Continued.

Hole E 3.

[Elevation, 2,789 feet; depth, 5 feet.]

Date.	Depth to water level.	Elevation of water level above sea level.	Date.	Depth to water level.	Elevation of water level above sea level.
1912.	*Feet.*	*Feet.*	1913.	*Feet.*	*Feet.*
Dec. 3	4.3	2,784.7	June 3	5.0	2,784.0
17	4.2	2,784.8	17	5.3	2,783.7
			July 1	5.3	2,783.7
1913.			18		Dry.
Jan. 2	4.0	2,785.0	28		Do.
14	3.9	2,785.1	Aug. 8		Do.
30	3.2	2,785.8	23		Do.
Feb. 10	3.4	2,785.6	Sept. 5	6.5	2,782.5
Mar. 3	2.1	2,786.9	23	6.3	2,782.7
18	2.3	2,786.7			

Hole E 4.

[Elevation, 2,790 feet; depth, 7.5 feet.]

Date.	Depth to water level.	Elevation of water level above sea level.	Date.	Depth to water level.	Elevation of water level above sea level.
1912.			1913.		
Dec. 3	7.5	2,782.5	June 3	7.1	2,782.9
17	7.5	2,782.5	17	7.3	2,782.7
			July 1	7.4	2,782.6
1913.			18	7.7	2,782.3
Jan. 2	7.5	2,782.5	28	7.7	2,782.3
14	7.5	2,782.5	Aug. 8	7.7	2,782.3
29	7.1	2,782.9	23	7.7	2,782.3
Feb. 10	7.5	2,782.5	Sept. 5	8.3	2,781.7
Mar. 3	6.1	2,783.9	23	1.8	2,788.2
18	5.8	2,784.2			

Hole E 5.

[Elevation, 2,817 feet; depth, 8 feet.]

Date.	Depth to water level.	Elevation of water level above sea level.	Date.	Depth to water level.	Elevation of water level above sea level.
1912.			1913.		
Dec. 3	5.9	2,811.1	Mar. 18	1.9	2,815.1
			June 3	5.5	2,811.5
1913.			17	6.0	2,811.0
Jan. 2	5.7	2,811.3	July 1	6.1	2,810.9
14	5.2	2,811.8	18	6.2	2,810.8
29	4.6	2,812.4	Aug. 8	6.3	2,810.7
Feb. 10	4.0	2,813.0	Sept. 5	6.2	2,810.8
Mar. 3	1.6	2,815.4	23	6.1	2,810.9

Hole E 6.

[Elevation, 2,837 feet; depth, 7 feet.]

Date.	Depth to water level.	Elevation of water level above sea level.	Date.	Depth to water level.	Elevation of water level above sea level.
1912.			1913.		
Dec. 3	1.8	2,835.2	June 3	2.9	2,834.1
17	1.9	2,835.1	17	2.9	2,834.1
			July 1	4.0	2,833.0
1913.			18	4.2	2,832.8
Jan. 2	2.0	2,835.0	28	4.2	2,832.8
14	1.8	2,835.2	Aug. 8	4.4	2,832.6
30	2.0	2,835.0	23	4.8	2,832.7
Feb. 10	2.2	2,834.8	Sept. 5	4.3	2,832.7
Mar. 3	1.6	2,835.4	23	4.5	2,832.5
18	2.3	2,834.7			

TABLE 44.—*Depths to the water level in test holes on the Warner ranch*—Continued.

Hole I 1.

[Elevation, 2,798 feet; depth, 9 feet.]

Date.	Depth to water level.	Elevation of water level above sea level.	Date.	Depth to water level.	Elevation of water level above sea level.
1912.			1913.		
Dec. 3	3.6	2,794.4	Mar. 18	3.1	2,794.9
17	3.6	2,894.4	June 3	4.4	2,793.6
1913.			17	4.7	2,793.3
			July 1	4.7	2,793.3
Jan. 2	3.4	2,794.6	18	4.7	2,793.3
14	3.2	2,794.8	Aug. 8	4.7	2,793.3
29	3.1	2,794.9	Sept. 4	4.5	2,793.5
Feb. 10	3.1	2,794.9	23	5.3	2,792.7
Mar. 3	2.5	2,795.5			

Hole I 2.

[Elevation, 2,986 feet; depth, 9 feet.]

1912.			1913.		
Dec. 3	6.9	2,979.1	Mar. 18	3.3	2,982.7
17	8.1	2,979.9	June 3	5.4	2,980.6
1913.			17	6.0	2,980.0
			July 1	7.1	2,978.9
Jan. 2	6.1	2,979.9	18	7.4	2,978.6
14	5.9	2,980.1	Aug. 8	4.7	2,981.3
29	5.7	2,980.3	Sept. 5	8.1	2,977.9
Feb. 10	5.8	2,980.2	23	8.6	2,977.4
Mar. 3	4.2	2,981.8			

Hole I 3.

[Elevation, 3,095 feet.]

1912.			1913.		
Dec. 3	4.6	3,090.4	Mar. 18	3.1	3,091.9
17	4.2	3,090.8	June 3	5.5	3,089.5
1913.			17	6.2	3,088.8
			July 1	6.5	3,088.5
Jan. 2	4.0	3,091.0	18	6.8	3,088.2
14	3.7	3,091.3	Aug. 8	6.8	3,088.2
24	3.3	3,091.7	Sept. 5	7.8	3,087.2
Feb. 10	3.1	3,091.9	23	7.9	3,087.1
Mar. 3	2.5	3,092.5			

Hole I 4.

[Elevation, 2,713 feet; depth, 7 feet.]

1912.			1913.		
Dec. 3	6.4	2,706.6	Mar. 18	3.6	2,709.4
17	6.5	2,706.5	June 3	4.4	2,708.6
1913.			17	4.7	2,708.3
			July 1	4.8	2,708.2
Jan. 2	6.7	2,706.3	18	4.8	2,708.2
14	6.9	2,706.1	Aug. 8	4.9	2,708.1
29	6.6	2,706.4	23	5.2	2,707.8
Feb. 3	6.9	2,706.1	Sept. 5	5.4	2,707.6
10	6.3	2,706.7	23	5.8	2,707.2
Mar. 3	4.3	2,708.7			

The water table is at shallow depths over a large part of Warners Valley, and springs appear at several places in the valley and along its borders. There is a group of hot springs at Agua Caliente, just above the eastern margin of the valley, which is generally known in southern California as a health resort. The water is sulphurous and reaches the surface of the ground with a temperature of about 148° F.

SAN FELIPE VALLEY.

The following information in regard to the water supply of San Felipe Valley was collected by J. S. Brown, of the United States Geological Survey, during a trip through the valley in 1918.

San Felipe Valley, most of which is included in an early land grant known as San Felipe ranch, comprises 15 to 20 square miles of valley, inclosed by moderately high mountains, in the eastern part of T. 12 S., R. 4 E., and the southwestern part of T. 12 S., R. 5 E. Through Banner Creek on the south, the Arkansas and other canyons on the west, and the headwaters of San Felipe Creek on the northwest, reaching back to the divide by Warner ranch, it receives the drainage from an area approximately twice its size, forming the eastern slope of moderately high mountains along the Peninsular divide. It receives also a small amount of drainage, chiefly intermittent, from the eastern and southern slopes.

Nearly all the western streams are perennial in the mountain region, though at places even there the flow is entirely within the stream gravels. The largest of these streams is Banner Creek, much of whose flow is forced to the surface by a rock dam in the gorge half a mile below Banner. A current-meter measurement made here February 13, 1918, showed 1.04 second-feet of water, which probably represents the usual winter flow. The flow in the upper end of San Felipe Creek is probably nearly as great, and that from the western canyons as much more. The water supply includes also the subsurface flow and the run-off from occasional floods.

The upper end of San Felipe Valley, including a stretch 2 miles long extending about a mile down into the San Felipe ranch, is separated from the larger valley below by low spurs of the inclosing mountains. In the upper half of this tract, which is little more than half a mile wide, the waters of upper San Felipe Creek sink and leave a dry, steeply sloping floor covered with a moderate growth of grass; in the lower half mile, over an area comprising probably 160 acres in the upper end of the ranch, a rank grove of willows and large cottonwoods and increased growth of grass indicate that ground water is near the surface; just below this area a stream nearly equal to Banner Creek bursts up from the valley in numerous groups of springs that flow for a distance over the low natural dam.

This water, together with that from Banner Creek and western canyons, unites to form a body of ground water under a second small valley, whose outer edges grade from rocky fans into grassy slopes and give way finally to a marsh in the tract a mile or so east of the San Felipe ranch house. Shallow wells of good water are easily obtained from the ranch house eastward. One well near the house yields a small flow, and four other wells near by or a little farther east and fitted with windmills and furnish water for stock as well as for the irrigation of small garden plots.

Another low granite ridge, jutting out from the south, constricts the passage of underground waters and separates a third small valley (T. 12 S., R. 5 E.) from the one above. The water rising at this point, some 2 miles east of the ranch house, appears to flow continuously through the lower valley, and ground water is at shallow depths over most of the central area. A heavy growth of mesquite covers the ground and grass is plentiful, making excellent pasturage. Springs that break out at some places indicate a slight pressure on the water beneath. The flow of San Felipe Creek near the middle of this valley was estimated as at least 3 second-feet by comparing its volume with that of Banner Creek. This water at the lower end of the ranch spreads out over an alkali flat, probably half a mile in diameter, and passes out through a narrow gorge at the northwest, from which it sinks into the desert eastward, and does not reappear until well down near the Salton Sea, where at places it breaks out for short distances as a weak flow of vile, bitter water, utterly unfit for any human use.

The creek at many places here flows through cut banks 10 to 20 feet deep which show very evenly stratified fine sands containing great quantities of mica and considerable clay. The possibility that this part of the valley is occupied by lake beds is very strongly suggested, though no direct evidence was obtained.

Little use has heretofore been made of the water, the San Felipe ranch owners preferring to engage in grazing and using the water only for stock. A little of the water that rises over the first natural dam is led over some alfalfa ground in the upper part of the central valley, and a few other plots are irrigated by water from the wells. Several small tracts of excellent soil in different parts of the valley could probably be irrigated by proper conservation of the water available.

All the water, except possibly that obtained in the vicinity of the alkali flat, is of good quality. A sample taken from a stock well near the northwest corner of sec. 34, T. 12 S., R. 5 E., near the lower ranch gate, should represent probably the most saline water in the valley. A slight taste of salt is noticeable.

Five wells have been drilled on the San Felipe grant, none of which reached bedrock or residuum in place. All are situated near the middle of the valley and were intended to furnish water for irrigation. The water is said to be of good quality, but the wells were not tested, and their success as sources of water for irrigation is not known.

Well I 6, at the ranch house, is a drilled well 280 feet deep, lined with 12-inch casing, which was perforated after being inserted. The well penetrated alluvial rock débris, sand, and clay, and ended in a bed of rounded boulders from which a good supply of water was obtained.

Well I 5, half a mile east of I 6, penetrated alluvial soil and gravel to the depth of 90 feet, where it reached a bed of large boulders. This well is 12 inches in diameter and is finished in the same manner as I 6.

The other three wells—I 7, I 8, and I 9—were all similar to those described in the preceding paragraphs.

DETAILED WELL RECORDS.

Tables 45 and 46 give records of all wells and springs examined in San Diego County.

TABLE 45.—*Wells in San Diego County in which series of water-level measurements were made.*

Well No.	Location: Township.	Location: Range.	Location: Section.	Location: Quarter.	Valley or nearest post office.	Owner's name.	Class of well.	Depth of well below bench mark.	Altitude of ground surface above sea level.	Bench mark: Description.	Bench mark: Altitude above sea level.	Geologic source of water.	Vegetation and surface conditions around the well.
								Feet.	*Feet.*		*Feet.*		
B 10	10 S.	4 W.	35	SE.	Bonsall	Not learned	Dug	17.0	111.5	Tack in top of 2 by 3 inch post at southwest corner 5-foot diameter well curb.	113.63	Fill of minor valley.	Dry wash material at mouth of draw, close to granite.
B 11	11 S.	4 W.	4	SE.	San Luis Rey	F. B. and L. A. McClung.	do	19.0	79.3	Tack in top of 6-foot diameter hexagonal wood curb, southeast side.	79.29	Shallow fill of major valley.	Dry wash material at mouth of draw, 250 feet north of river.
C 2	9 S.	2 W.	26	SW.	Pala	U. S. Indian Service.	do	63.0	422.7	Top of 8-foot diameter concrete curb, southwest side.	425.79	Deep fill of major valley.	River sand mixed with gravel and boulders.
C 5	10 S.	3 W.	20	NE.	Bonsall		Auger hole			Top of two stakes of ground surface.		do	Moist sandy soil with salt grass and yerba mansa.
C 6	10 S.	3 W.	20	SW.	do	South Coast Land Co.	Drilled	37.8	165.2	Top of inside section of 12-inch casing at approximate level of ground surface.	164.67	do	Dry, silty soil.
C 7	10 S.	3 W.	20	SW.	do	U. S. G. S.	River gage		155.0	Zero of gage, right bank of river.	152.74	do	Deep river sand; willows on north bank.
C 9	Monserate land grant				Pala	Frank Lower	Driven	7.8	265.0	Top of 1½-inch pipe, 3½ feet above surface.	268.72	do	River sand; willow trees and arrow weed.
C 10	9 S.	2 W.	32	SW.	do	Not learned	Dug	10.8	313.0	Top of 2 by 3 inch in northwest corner at 4 by 4 foot curb.	313.00	do	Silty soil at edge of red soil.
D 2	10 S.	1 W.	35	NW.	Rincon	U. S. Indian Service.	Drilled	46.5	863.0	Top of 16-inch casing.	863.81	do	Dry sandy soil with scattered brush.
D 3	10 S.	1 W.	35	SE.	do	do	Dug	49.0	874.7	Top of 5-foot diameter concrete curb, southeast side.	874.97	do	Coarse and dry sandy soil, with few sycamore and cottonwood trees.
F 3	11 S.	4 W.	18	SW.	San Luis Rey	San Diego County.	do	12.6	32.1	Upper surface of cover, southwest corner 5 by 5 foot wood curb.	35.10	do	Moist adobe soil with salt grass; no cultivation.

TABLE 45.—*Wells in San Diego County in which series of water-level measurements were made*—Continued.

Well No.	Location.				Valley or nearest post office.	Owner's name.	Class of well.	Depth of well below bench mark.	Altitude of ground surface above sea level.	Bench mark.		Geologic source of water.	Vegetation and surface conditions around the well.
	Township.	Range.	Section.	Quarter.						Description.	Altitude above sea level.		
								Feet.	*Feet.*		*Feet.*		
F 4	11 S.	4 W.	4	SE.	San Luis Rey	Fletcher & Hinshaw.	Drilled	168.0	72.7	Top of wood curb, east side of pit, ground surface 4.44 feet above 12-inch casing.	72.88	Deep fill of major valley.	Fine sandy soil, cultivated for beets.
F 10	11 S.	5 W.	22	NE.	Oceanside	H. P. and Mary C. Johnson.	Dug	7.1	8.6	Top of 6 by 6 foot brick curb of northwest corner, at base of plaster course.	9.27	do	Fine sandy soil, formerly salt grass and yerba mansa, now beets.
F 11	11 S.	5 W.	14	SE.	do	do	do	....	12.5	Top of 7 by 6 foot wood curb, southeast corner.	14.36	do	River sand with arrow weed.
F 13	11 S.	4 W.	18	SW.	San Luis Rey	Charles Forman.	do	9.0	26.8	Tack in top of 3 by 3 foot wood curb northwest corner.	28.29	do	Moist adobe soil with salt grass, yerba mansa, alkali surface.
F 16	11 S.	4 W.	18	NE.	do	Wm. and G. A. Osborne.	Drilled	....	41.0	Top of 5-inch casing at ground surface; measurements to water surface made in casing.	41.23	do	Moist adobe soil with salt grass.
F 17	11 S.	4 W.	8	SW.	do	Not learned	Dug	14.8	47.8	Well corner north side of opening 7-foot diameter wood curb.	51.82	do	Dry fine sandy soil, no cultivation.
F 18	11 S.	4 W.	8	SW.	do	do	Drilled	100.0	....	Top of flange at top of casing.	....	do	Dry silty soil, no cultivation.
F 19	11 S.	4 W.	8	NW.	do	Mission Bridge	River bed	....	54.0	Top of third pier from south abutment upstream side of bridge.	64.58	do	Moist river bottom sand.
F 20	11 S.	4 W.	5	SE.	do	Edm. E. Richmond.	Dug	12.3	63.6	Tack in top of curb, northwest corner under cover.	64.55	do	Dry, coarse, sandy soil with few hardy weeds.
F 21	11 S.	4 W.	4	SW.	do	Escondido Mutual Water Co.	do	13.5	66.9	Top of 3 by 4 inch timber under cover south side 4 by 4 foot wood curb.	68.94	do	Dry, coarse, sandy soil.

G 32	San Bernardo land grant.				San Pasqual	A. I. Stewart	....do	15.0	(350.0)	Tack in top of 6-foot octagonal wood curb, northeast side.	350.59	Residuum	Red decomposed granite; edge of irrigated alfalfa field.
H 1	12 S.	1 W.	33	SE.	....do	Not learned	....do	24.5	379.2	Tack in top of curb post, northwest corner, 4 by 4 foot well.	382.73	Deep fill of major valley.	Sandy soil.
H 5	12 S.	1 W.	35	SW.	....do	F. M. Judson	....do	11.0	419.1	Tack in top of 3 by 3 foot wood curb, southwest corner.	419.44	....do	Fine sandy soil, silt.
H 17	Valle de Pamo land grant.				Ramona	Not learned	....do	13.8	1,436.2	Upper edge of inclined 1 by 12 inch well cover at ground surface on west side.	1,436.24	Residuum	Red decomposed granite, cultivated to grain.
H 31	12 S.	1 W.	33	SE.	San Pasqual	H. S. Meyers	....do	7.0	382.0	Tack in top at post, northwest corner, 4 by 4 foot well, wood curb.	384.97	Deep fill of major valley.	Moist silty soil, salt grass, and yerba mansa.
H 32	12 S.	1 W.	35	SW.	....do	F. H. Judson	....do	24.0	420.3	Tack in top of 4 by 4 foot wood curb, north side.	420.78	Residuum	Dark silty soil, with weeds and pepper trees.
H 34	12 S.	1 W.	35	NW.	....do	County Highway Bridge.	River bed	....	425.0	Top of west end of 12 by 12 inch cap second dent from right abutment of bridge.	431.75	Deep fill of major valley.	River sand.
H 36	12 S.	1 W.	36	SE.	....do	Not learned	....do	22.0	462.3	Top of northwest corner post of curb.	464.99	....do	Sand soil with willows and river bottom brush.
H 37	Valle de Pamo land grant.				Ramona	H. A. Miles	....do	32.0	1,438.0	Top of 5-foot diameter concrete curb, southwest side.	1,438.50	Residuum	Red decomposed granite soil; lawn and trees near by.
H 38	....do				....do	Mark Kearney	....do	38.0	1,424.7	Top of 5-foot diameter concrete curb southwest side.	1,424.56	....do	Red decomposed granite; 1 acre alfalfa.
K 31	Ex Mission San Diego				Mission Valley	L. H. Icovich	....do	26.0	94.0	Top of 6-foot diameter concrete curb, east side.	95.70	Deep fill of major valley.	Sandy soil; irrigated alfalfa.
K 33	Pueblo lands of San Diego.				Old Town	G. S. Beach	....do	8.0	11.2	Notch in 2 by 4 inch post, southwest corner.	10.89	....do	Fine river sand; weeds.
K 34	....do				....do	S. C. Bailey	....do	60.0	54.3	Top of 4 by 4 foot wood curb, west side.	54.46	San Diego formation.	Dry mesa soil, small irrigated garden.
K 35	....do				....do	Peter Bobbio	....do	14.3	14.8	Top of 4 by 4 inch upright at southeast corner 6 by 6 foot wood curb.	18.63	Deep fill of major valley.	Sandy soil, cultivated; no irrigation.

TABLE 45.—*Wells in San Diego County in which series of water-level measurements were made*—Continued.

Well No.	Location.				Valley or nearest post office.	Owner's name.	Class of well.	Depth of well below bench mark.	Altitude of ground surface above sea level.	Bench mark.		Geologic source of water.	Vegetation and surface conditions around the well.
	Township.	Range.	Section.	Quarter.						Description.	Altitude above sea level.		
								Feet.	*Feet.*		*Feet.*		
K 44	Pueblo lands of San Diego.				Mission Valley	H. C. Sutemeyer.	Drilled	50.0	23.5	Top of 10-inch screw casing.	18.70	Deep fill of major valley.	Moist sandy soil, with salt grass and willows.
K 46	do				do	E. H. Lusher	do	16.8	44.0	At 2-inch hole in box top of well cover.	44.00	Shallow fill of major valley.	Dry gravelly mesa soil, weeds.
K 48	Ex Mission San Diego				do	L. N. Gibson	do	11.3	54.4	Top of 6 by 6 foot wood curb, north side.	53.87	Deep fill of major valley.	Fine sandy soil, cultivated and irrigated.
K 51	do				do	A. Jousand	do	19.0	72.7	Top of 14-foot diameter wood curb, west side.	72.40	do	Do.
K 52	do				do	Not learned	do	7.0	72.0	Top at wood curb, northeast corner 4 by 4 foot well.	71.93	do	River sand, large cottonwoods and willows.
K 61	Pueblo lands of San Diego.				Old Town	Hodman	do	10.1	14.1	Top of 6 by 6 foot wood curb, northeast corner.	13.33	do	Sandy soil, cultivated; no irrigation.
K 62	do				do		do	14.1	14.2	Top of 6-foot brick curb, northeast side.	14.30	do	Dry river sand and weeds.
K 63	do				Mission Valley	U. S. G. S. Old Town.	River gage		5.7	Zero of gage	0.00	do	River bank and channel, moist sand.
K 65	do				do	City of San Diego.	Drilled	80.0	13.6	Top of 10-inch casing.	13.60	do	Sandy soil with weeds, brush, and willows.
K 70	do				Old Town	do	Dug	27.0	15.3	Top of cover at manhole, 28-foot brick curb well.	17.01	do	Sandy soil; weeds.
K 71	do				do	do	do		13.9	2-inch plank across top 4 by 4 foot dug well wood curb.	12.27	do	Sandy soil; weeds and brush.
K 72	do				do	do	Driven		11.9	Top of 4-inch casing	15.42	do	Do.
K 73	do				Mission Valley	do	Drilled	186.0	14.3	Top of 10-inch casing.	18.20	do	Do.
K 74	do				Old Town	do	Dug	20.5	18.2	Top of board walk level of curb at door of 30-foot diameter brick curb well.	16.46	do	Sandy soil, weeds.

K 75	do	do	do	do	8.0	10.8	Top of 3 by 3 foot wood curb north side.	10.01	do	Sandy soil, weeds, brush and willows.
K 76	do	do	do	do	12.6	8.8	Top of 3 by 3 foot wood curb, south side.	9.72	do	Do.
K 77	do	do	do	do	13.0	9.3	Top of 3 by 3 foot wood curb, east side.	9.80	do	Do.
K 78	do	do	do	do	13.5	12.6	Top of 3 by 3 foot wood curb, west side.	11.87	do	Do.
K 79	do	Mission Valley	do	Drilled	80.0	15.0	Top of 12-inch casing.	16.04	do	Do.
K 80	do	Old Town	Weiss	Dug	14.5	14.8	Top of 10-foot diameter brick curb, northwest side.	17.37	do	Sandy soil, cultivated; no irrigation.
K 81	do	Mission Valley	Not learned	Dug hole	....	17.5	Groove cut in 6-foot by 6-inch post at northeast corner of old windmill frame.	17.04	do	Sandy soil; willows and brush.
K 82	do	do	Henry Gray	Dug	12.3	22.6	Top of 6-foot diameter wood curb, west side, under cover.	24.65	Shallow fill of major valley.	Black adobe soil, moist and formerly supported salt grass and yerba mansa, now cultivated.
K 83	do	do	H. A. Clark	do	28.7	24.0	Top of 6-foot diameter wood curb, southeast side, under cover.	25.49	Deep fill of major valley.	Black adobe soil, irrigated alfalfa.
K 84	do	do	Not learned	do	14.0	28.4	Top of 4 by 4 inch post in southeast corner.	29.39	do	Dry sandy soil, with willows, eucalyptus trees, and weeds.
K 85	do	do	U. S. G. S. Murray Canyon.	River gage	....	(25.0)	Zero of gage	21.23	do	Coarse sand in river bottom.
K 86	do	Murray Canyon	Not learned	Dug	30.0	34.8	Top of 4 by 4 foot wood curb.	36.65	Fill of minor valley.	Dry mesa soil.
K 87	do	Mission Valley	Gus Thierer	do	35.8	57.5	Top of 5-foot diameter brick curb southeast side.	59.35	Shallow fill of major valley.	Dry gravelly mesa soil.
K 88	do	do	City of San Diego	Drilled	....	41.2	Top of 12-inch casing, at joint.	43.55	Deep fill of major valley.	River bottom sand and silt, cultivated to north and southeast.
K 89	do	do	Hong Far	Slough	....	41.9	Three notches on platform to east of pump, south side of platform, over 45° downward turn of suction pipe.	41.93	do	River sand and silt, cultivated all around.

TABLE 45.—*Wells in San Diego County in which series of water-level measurements were made*—Continued.

Well No.	Location.				Valley or nearest post office.	Owner's name.	Class of well.	Depth of well below bench mark.	Altitude of ground surface above sea level.	Bench mark.		Geologic source of water.	Vegetation and surface conditions around the well.
	Township.	Range.	Section.	Quarter.						Description.	Altitude above sea level.		
								Feet.	*Feet.*		*Feet.*		
K 98	Ex Mission San Diego				Mission Valley	City of San Diego	Drilled		46.7	Top of 12-inch casing south side at joint.	49.28	Deep fill of major valley.	Dry sandy soil, mixed with silt, brush, and weeds.
K 99	do				do	China garden	Slough	9.0	47.8	Top of old wood well curb rail, south side.	46.03	do	Coarse river sand, with brush and weeds.
K 106	do				Murphy Canyon	Along county highway.	Creek bed		68.0	Top of 8 by 8 inch beam, under peak of a truss, small bridge to Allen property.	69.61	Fill of minor valley.	Channel overgrown with willows and water-lov ng grasses.
K 107	do				Mission Valley	County highway bridge.	River bed		54.0	Center line, third row rivets, below top first pier from south bank.	55.42	do	Coarse river sand.
K 109	do				do	Not learned	Dug	24.8	76.0	Top of wood curb, west side, 4 by 4 foot well.	78.12	San Diego formation.	Dry mesa soil at foot of bluff, edge of irrigated alfalfa field.
K 114	El Cajon land grant				Santee	E. W. Scripps	Drilled	26.0	317.5	Bottom of 7-inch pipe, 4 inches south of first joint.	315.74	Deep fill of major valley.	Coarse river sand.
K 115	do				do	do	do		318.8	Top of 8-inch casing	320.75	Fill of minor valley.	Black adobe soil; irrigation to north.
K 116	do				do	Not learned	Dug	15.9	325.0	Tack in top of 5 by 5 foot wood curb, north side.	324.70	Residuum	Decomposed granite soil, dry.
K 117	do				do	M. O. Hall	Drilled	15.5	304.0	Top of 8-inch casing, near ground surface.	303.64	Fill of minor valley.	Dry gravelly soil.
K 118	do				do	U. S. G. S. Mission dam.	River gage		270.0	Zero of gage	265.35	Shallow fill of major valley.	River sand, with grass and trees.
L 5	do				Lakeside	G. E. Philbrook.	Dug	19.0	412.0	Tack, top of 7-foot wood curb, west side.	413.40	Deep fill of major valley.	Sandy soil, irrigated alfalfa.
L 7a	do				do	Cuyamaca Water Co.	do		438.2	Three notches, top of curb arc, east side.	435.25	do	Sandy river soil, with weeds.

L 7b	do				do	do	do		437.8	Three notches top of curb arc, north side.	434.76	do	Do.
L 7c	do				do	do	do		437.7	Tack in top of platform.	436.12	do	Do.
L 7d	do				do		do		437.0	Notch in top of well curb, southeast side.	436.38	do	Do.
L 7e	do				do	do	Drilled	70.0	437.20	Top of 6-inch casing, west side.	433.72	do	Do.
L 7f	do				do	do	do	70.0	437.2	do	431.87	do	Do.
L 7g	do				do	do	do	70.0	438.0	Top of connecting bolt, top reducer, north side.	434.35	do	Do.
L 7h	do				do	do	do	70.0	438.2	Top of 6-inch casing, southeast side.	433.12	do	Do.
L 7i	do				do	do	do	70.0	438.6	Top of 6-inch casing, east side.	432.65	do	Do.
L 7j	do				do	do	do	70.0	438.5	Top of 4 by 6 inch block, south side suction pipe.	433.19	do	Do.
L 7k	do				do	do	do	70.0	438.5	Top of cover, north side of pipe.	433.12	do	Do.
L 7l	do				do	do	do	70.0	438.2	Top of 6-inch casing, west side.	429.28	do	Do.
L 7m	do				do	do	do	70.0	437.8	Top of cover, east side of pipe.	432.78	do	Do.
L 7n	do				do	do	do	70.0	438.0	Top of suction pipe, west side.	432.62	do	Do.
L 7o	do				do	do	do	70.0	437.6	Bottom of reducer, south side.	432.38	do	Do.
L 7p	do				do	do	do	70.0	437.6	Top of cover, north side of reducer.	431.75	do	Do.
L 7q	do				do	do	do	70.0	437.4	Top of cover, south side of reducer.	431.64	do	Do.
L 7r	do				do	do	do	70.0	437.6	Top of cover, west side of reducer.	431.61	do	Do.
L 11	do				Santee	James Ballantine.	Dug		354.0	Tack in top of curb, west side, 5 foot-diameter well.	354.61	Residuum	Red granite soil.
L 24	do				El Cajon	Joe Miller	do	25.0	435.0	Top of concrete northeast side, 5-foot concrete curb.		do	Decomposed granite soil, cultivated vineyard.
L 40	16 S.	1 E.	14	SW.	Dehesa	J. M. Owen	do	21.2	501.0	Top of 6-foot curb, west side.	502.45	do	Decomposed dry granite soil.
L 41	16 S.	1 E.	21	SW.	Jamacho	G. M. Hawley	Drilled	40.0	405.9	Top of 8-inch casing, east side.	403.79	Deep fill of major valley.	Rivers and and willow trees east, irrigated land west.
L 42	Jamacho land grant				do	Hawley	Dug	11.0	386.9	Cover of well, north side of hole in center.	388.08	do	Edge of river bottom, surrounded by willow trees.
L 63	El Cajon land grant				Foster	Father Umerman.	Drilled	70.0	428.3	Top of 12-inch casing.	425.09	do	Fine sandy soil. At corner of alfalfa field.

TABLE 45.—*Wells in San Diego County in which series of water-level measurements vcre made*—Continued.

Well No.	Location. Township.	Location. Range.	Location. Section.	Location. Quarter.	Valley or nearest post office.	Owner's name.	Class of well.	Depth of well below bench mark.	Altitude of ground surface above sea level.	Bench mark. Description.	Bench mark. Altitude above sea level.	Geologic source of water.	Vegetation and surface conditions around the well.
								Feet.	*Feet.*		*Feet.*		
L 65	El Cajon land grant				Lakeside	G. E. Philbrook.	Dug		412.0	Tack, top of 7-foot wood curb, east side.	412.20	Deep fill of major valley.	Sandy soil, irrigated alfalfa.
L 66	do				do	do	do	11.2	412.0	Top of 4 by 4 foot wood curb, south side.	412.50	do	Sandy soil.
L 67	do				do	J. M. Philbrook.	do		414.0	Tack, top of 8-foot wood curb, northeast side.	414.95	do	Sandy soil' irrigated alfalfa.
L 68a	do				do	L. Kirkpatrick	Drilled	52.0	408.4	Top of 8-inch casing in pit, east side.	403.26	do	Sandy soil, irrigated orchard.
L 70	do				do	U. S. G. S. Lakeside.	River gage		410.0	Zero of gage	405.00	do	Coarse river sand.
L 71	do				do	El Monte Ranch.	River bed		454.0	Notch in tree north side, witnessed by nail in tin.	453.73	do	Moist river sand with willows and alder trees.
L 72	do				do	do	Dug	16.0	467.4	Underside of cover board at level with top of 6 by 6 foot wood curb.	467.74	do	Sandy soil.
L 75	do				do	do	Drilled	19.8	498.4	Top of 6-inch casing at ground surface.	497.67	do	Sandy soil; oak trees.
L 76	do				do	Theo. Barnes	Excavated		394.0	Head of nail at white arrow on 8 by 8 inch timber.	393.60	do	Sandy soil, irrigated alfalfa to north.
L 78	do				do	Not learned	Drilled	52.8	400.9	Top of 12-inch casing.	401.66	Fill of minor valley.	Sandy soil on top.
L 79	do				do	John H. Gay	Lindo Lake		400.0	Top of 3 by 4 inch pile of intersection of trestle walk on west, and west corner of boathouse house in lagoon, south side of lake.	396.77	do	Decomposed granite; trees and shrubbery.
L 83	do				Santee	San Francisco Savings Union.	Drilled	68.0	363.0	Top of 10-inch casing.	364.48	Deep fill of major valley.	Rivers and, cleared of trees.
L 85	do				do	La Mesa Irrigation District.	Dug	22.8	335.0	Top of curb, west side of 10-foot diameter dug well.	335.00	Shallow fill of major valley.	Sandy soil.

L 86	.....do				.....do	.....do	.....do	6.0	328.0	Top of 3-foot diameter wood curb, east side.	326.75	.....do	Fine river sand and silt.
L 96	.....do				.....do		.....do	26.0	441.6	Top of 6-foot diameter hexagonal wood curb, west side.	441.80	Residuum	Decomposed granite soil; no irrigation.
L 99	16 S.	1 E.	16	NW.	Dehesa	M. C. Allen	.....do	25.0	450.9	Top of 8 foot diameter brick curb, south side.	453.97	Deep fill of major valley.	Sandy loam; irrigated orchard.
L 101	16 S.	1 E.	14	Center.	.....do	C. J. Kurtz	.....do	28.9	507.3	Top of 10-foot diameter wood curb, west side.	507.92	.....do	Sandy river bottom soil; irrigated alfalfa.
L 103	16 S.	1 E.	14	SE.	.....do	G. Rudolph (renter).	Drilled	11.7	512.0	Top of 8-inch (Hawley) wood casing.	512.00	.....do	Coarse river sand, with trees and brush.
L 104	16 S.	1 E.	23	NE.	.....do	.....do	Dug	16.2	516.1	Top of wood curb, northeast corner, 4 by 4 foot well.	517.07	.....do	Sandy soil.
L 105	16 S.	1 E.	24	SW.	.....do	R. S. Babcock	.....do	13.4	....	Top of 12-foot diameter brick curb, south side.	....	Shallow fill of major valley.	Dry sandy soil; oak trees.
O 18	La Nacion land grant				Sunnyside	L. C. Kincaid	.....do	12.7	89.5	Top of 8-foot diameter concrete curb, northwest side.	89.48	Deep fill of major valley.	Sandy river soil, on edge of irrigated field.
O 20	.....do				Sweetwater Junction.	Chas. Dickens	.....do	9.5	28.3	Top of 2 by 4 inch curb post, southwest corner.	31.21	.....do	River bottom; sandy soil.
O 21	.....do				Bonita	R. C. Allen	.....do	12.2	57.8	Top of 3 by 3 foot wood curb, north side.	57.78	.....do	Silty soil near edge of river bottom; salt grass.
O 34	18 S.	2 W.	22	NW.	Otay	Byron Gillette	.....do	....	53.1	5-foot diameter well, timber top of curb, south side.	54.30	San Diego formation.	Dry mesa land; irrigated garden directly east.
O 29	La Nacion land grant				Chulavista	F. M. Winship	.....do	57.0	61.4	Top of 4 by 4 foot wood curb, north side.	62.14	.....do	Cultivated lemon-orchard. Irrigated from S. W. Co. system.
O 35	18 S.	2 W.	22	NW.	Otay	H. Eumellen	.....do	32.0	22.6	Top of curb, south side.	23.40	.....do	Dry mesa soil; no irrigation.
O 35a	18 S.	2 W.	22	NW.	.....do	.....do	Drilled	114.0	22.6	Top of 12-inch casing.	17.00	.....do	Do.
O 38	18 S.	2 W.	22	NW.	.....do	C. R. Johnson	Dug and drilled	100.0	23.2	Top of 6 by 6 foot wood curb, north side.	24.20	Fill of minor valley.	Irrigated alfalfa field to south gravel pit to north.
O 39	18 S.	2 W.	23	NW.	.....do	W. F. Clark	Drilled	90.0	55.3	Top of concrete curb, east side.	56.30	San Diego formation.	Mesa soil; irrigated garden directly southeast of well.
O 40	18 S.	2 W.	23	NW.	.....do	W. S. Clark	Dug	51.5	55.2	Top of wood curb, south side.	56.42	.....do	Do.
O 41	18 S.	2 W.	23	NW.	.....do	W. V. Toner	.....do	25.0	41.0	Top of 2 by 4 inch, across top of well.	41.29	Fill of minor valley.	River bottom, with irrigated vegetable garden west.

TABLE 45.—*Wells in San Diego County in which series of water-level measurements were made*—Continued.

Well No.	Location.				Valley or nearest post office.	Owner's namr.	Class of well.	Depth of well below bench mark.	Altitude of ground surface above sea level.	Bench mark.		Geologic source of water.	Vegetation and surface conditions around the well.
	Township.	Range.	Section.	Quarter.						Description.	Altitude above sea level.		
								Feet.	*Feet.*		*Feet.*		
O 42	18 S.	2 W.	23	SE.	Otay Valley	W. E. Spicer	Drilled, 48 by 19 foot pit.	625.0	57.0	Top of concrete wall, south side.	56.93	Fill of minor valley.	Dry river sand; irrigated land to west.
O 46	18 S.	2 W.	28	NW.	Nestor	G. M. Kimball	Dug and drilled.		41.6	Top of 4 by 4 foot wood curb, northeast side.	41.60	San Diego formation.	Dry mesa soil; cultivated and some irrigation.
O 47	18 S.	2 W.	29	SE.	do	Evans & Tucker	do	68.0	24.1	Top of 12-ich casing at bottom of pit.	6.21	do	Mesa soil to east, irrigated alfalfa west.
O 47a	18 S.	2 W.	29	SE.	do	J. L. Cassidy	do	63.0	20.6	do	12.70	do	Mesa soil.
O 48	18 S.	2 W.	34	NW.	do	I. A. Hanchett	Dug	28.8	33.0	Top of curb north side	33.50	do	Mesa soil, irrigated garden around well.
O 50	18 S.	2 W.	32	SE.	Tia Juana Valley	S. Holderness	Drilled	98.0	9.8	Top of 8-inch casing	11.38	Deep fill of major valley.	Damp silt in river valley surrounded by irrigated land.
O 55	19 S.	2 W.	4	SE.	do	Not learned	Dug	12.9	24.2	Top of cover west side of opening; 8 feet diameter brick curb.	24.40	do	Do.
O 61	19 S.	2 W.	36	SE.	do	J. V. Tavan	Drilled	27.0	58.1	Top of 12-inch casing	56.78	do	Damp silty soil; Yerba mansa and salt grass.
O 70	La Nacion land grant				National City	Cascaras	Dug	110.0	112.2	Top of 3 by 4 inch timber, south side, 3-inch discharge pipe.	111.55	San Diego formation.	Dry mesa.
O 71	do				Sweetwater Junction.		Drilled	4.1	17.36	Top of 24-inch casing north side; 1 by 3 inch stake.	13.36	Deep fill of major valley.	Dry sandy river bank with clump of tall weeds.
O 73	do				do	National Rabbit ranch.	Slough		29.1	Top of nut south end of center crosspiece west side at level of pump house, 5 feet west of 1½-inch centrifugal pump.	29.23	do	Moist silty soil; swamp vegetation.
O 74	do				do	San Diego Land & Town Co.	Dug	9.7	31.0	Top of 4 by 4 inch, south side of 6 by 6 foot wood curb.	30.55	San Diego formatiom.	Fine silty soil; edge of river valley.

O 75	....do....				Bonita....	J. M. Voncida...	....do....	42.0	131.4	Notch in side of 2 by 4 inch curb post, southeast corner.	131.14	....do....	Dry mesa soil in bottom of ravine.
O 76	....do....				....do....	R. C. Allen....	....do....	5.0	63.8	Top of 2 by 4 inch, north side of 2 by 3 foot wood curb.	63.54	Deep fill of major valley.	Moist river sand; irrigated alfalfa field to south.
O 78	....do....				Sunnyside....	Otis....	Driven....	11.8	83.16	Top of 3-inch pipe driven into sand.	84.02	....do....	River bottom, moist sand, willows, etc.
O 79	....do....				....do....	....	Dug....	7.3	86.6	Top of curb post, northwest corner of 3 by 4 foot well.	86.94	....do....	Moist silty soil; willows nearby.
O 80	....do....				....do....	Chinese gardeners.	....do....	19.0	101.6	Top of timber, east side, north of small platform.	99.70	....do....	Fine silty soil irrigated to east.
O 81	....do....				Chula Vista....	Stewart & Klamer.	....do....	53.0	59.4	Top of 2-inch wood cover at ½-inch hole.	59.42	San Diego formation.	Cultivated lemon orchard, irrigated from S. W. Co. system.
O 82	....do....				....do....	V. J. Smith....	Dug and drilled.	104.0	45.5	Top of curb, south side, at ground surface.	45.70	....do....	Do.
O 83	....do....				....do....	San Diego Construction Co.	Dug....	63.0	57.7	Top of timber, south side wood curb.	57.60	....do....	Do.
O 84	18 S.	2 W.	15	SW.	Otay....	Mrs. Stewart....	....do....	54.0	51.6	Top of concrete curb, northwest side.	52.62	....do....	Dry mesa land.
O 86	18 S.	2 W.	21	NE.	....do....	Not learned....	....do....	10.7	12.0	Top of 1½ by 3 inch timber, southwest corner of well curb.	7.58	....do....	Dry mesa land to east of bank and moist salt marsh and typical rank marsh vegetation west.
O 87	18 S.	2 W.	21	SE.	....do....	G. Loustalet....	....do....	15.9	10.9	Top of 3-foot concrete curb; northeast side.	8.90	Fill of minor valley.	Fine dry sand with weeds.
O 88	18 S.	2 W.	21	NE.	....do....	Judge Thomas Robinson.	Dug and drilled.	....	20.2	Top of 12-inch casing in pit.	12.40	San Diego formation.	Dry mesa soil.
O 89	18 S.	2 W.	22	NW.	....do....	Not learned....	Dug....	24.0	22.4	Top 2 by 4 inch upright post, northwest corner well curb.	24.38	....do....	Dry mesa soil in valley bottom; few trees.
O 90	18 S.	2 W.	22	NW.	....do....	H. Eumellen....	....do....	90.0	22.6	Top of 10 by 10 foot wood curb, southeast side.	23.90	....do....	Dry mesa soil; no irrigation.
O 91	18 S.	2 W.	22	SW.	....do....	....	Artificial pit..	48.0	21.7	Three notches on lower crosspiece near top east pile of well derrick, west end of gravel pit.	12.03	Fill of minor valley.	Gravelly dry soil; cultivated field to south.
O 93	18 S.	2 W.	22	NE.	....do....	Not learned....	Dug....	35.0	51.0	Top 4 by 4 inches across well; 6 by 6 foot dug well.	51.86	San Diego formation.	Dry mesa soil; no cultivation.

TABLE 45.—*Wells in San Diego County in which series of water-level measurements were made*—Continued.

Well No.	Location: Township.	Location: Range.	Location: Section.	Location: Quarter.	Valley or nearest post office.	Owner's name.	Class of well.	Depth of well below bench mark.	Altitude of ground surface above sea level.	Bench mark: Description.	Bench mark: Altitude above sea level.	Geologic source of water.	Vegetation and surface conditions around the well.
								Feet.	Feet.		Feet.		
O 97	18 S.	2 W.	23	NE.	Otay	Not learned	Artificial fit		83.8	Top of well cover, center	85.14	San Diego formation.	Dry mesa soil; no irrigation.
O 98	18 S.	2 W.	24	NE.	Otay Valley	do	do		125.8	Top of 3-foot brick curb, south side.	125.26	do	Do.
O 99	18 S.	1 W.	20	NW.	do	do	do	14.0	139.0	Top of 6 by 6 inch timber across 10 by 10 foot curb.	139.00	Fill of minor valley.	Dry wash sand with brush.
O 102	San Dieguito land grant.				San Dieguito Valley	Santa Fe ranch	Drilled		(40)			Deep fill of major valley.	
O 103	18 S.	2 W.	28	NW.	Nestor	Not learned	do	27.0	28.6	Top of 4-inch casing	29.00	San Diego formation.	Dry mesa soil; no irrigation.
O 104	18 S.	2 W.	28	SW.	do	Alfonso Fredricks.	do	70.5	52.3	Top of 12-inch casing between timbers.	53.3	do	Dry mesa soil; irrigation.
O 105	18 S.	2 W.	28	SE.	do	Not learned	Dug	24.3	26.0	Top of 4-foot diameter wood curb, east side.	28.50	do	Dry mesa soil; no irrigation.
O 106	18 S.	2 W.	32	NE.	do	do	do	33.0	32.4	Top of 4 by 4 foot wood curb, west side.	35.20	do	Do.
O 107	18 S.	2 W.	27	SW.	do	E. Hamilton	Drilled	40.0	28.3	Top of concrete around 6-inch casing.	29.30	do	Mesa soil; small garden.
O 109	18 S.	2 W.	33	SW.	do	H. W. George	do	58.0	26.9	Top of 10-inch casing	22.63	do	Black adobe soil; no irrigation.
O 113	18 S.	2 W.	33	NE.	do	K. Walls	do	23.5	22.4	Top of 10-inch casing, south side.	20.80	do	Dry soil near foot of bluff south of mesa.
O 114	18 S.	2 W.	34	NW.	do	Along county road.	Auger hole	9.5	22.3	Bottom of stick laid across two sticks.	17.70	do	Fine silty soil, damp salt grass and sedge; bare soil on general level.
O 115	18 S.	2 W.	34	NW.	do	W. E. Williams.	Dug and drilled.	56.0	27.1	Top of casing in pit, east side.	19.85	do	Sandy loam; irrigation.
O 118	18 S.	2 W.	33	SW.	Tia Juana Valley	Not learned	Driven	16.5	25.0	Top of flange at head of 1½-inch pipe.	26.80	Deep fill of major valley.	Fine silty dry soil.
O 123	19 S.	2 W.	4	NW.	do	F. C. Chase	Drilled	74	19.8	Top of 12-inch casing, west side.	15.60	do	Dry sand in river valley, surrounded by irrigated land.

O 127	19 S.	2 W.	4	NE.	....do....	John Rey....	....do....	73.0	25.5	Top of casing, northwest side.	18.95	....do....	Dry sandy river bottom.
O 130	19 S.	2 W.	4	NE.	....do....	Along county highway.	River bed....	....	21.0	Top of bedplate on south abutment, east side of highway bridge.	29.00	....do....	River sand.
O 136	19 S.	2 W.	2	NW.	....do....	Briar Co....	Driven....	....	38.5	Top of 2½-inch pipe, 2½ feet below ground.	(36.00)	....do....	River sand; field cultivated but not irrigated.
O 137	19 S.	2 W.	2	NW.	....do....	....do....	Drilled....	63.0	(38)	Blaze on telephone pole west side of road in line with 92 A-B-C.	39.71	....do....	Do.
O 139	19 S.	2 W.	2	SW.	....do....	Oscar Lehner...	....do....	30.0	39.6	Top of casing in pit...	32.98	San Diego formation.	Soil is outwash from mesa.
O 140	19 S.	2 W.	1	NW.	....do....	Little Landers Colony.	....do....	30.0	53.4	Top of 12-inch casing 30 feet south of pump house.	52.22	Shallow fill of major valley.	Silty soil of river bottom, salt grass, and weeds.
O 141	19 S.	2 W.	1	SW.	....do....	C. H. Wagner...	....do....	61.0	55.0	Top of 12-inch casing.	55.80	Deep fill of major valley.	Coarse river sand.
P 2	16 S.	1 E.	31	NE.	Jamacho....	Murphy....	Dug....	37.8	363.2	Top of 4 by 6 inch timber across well.	363.86	Residuum....	Decomposed granite soil; small garden.
P 20	Jamacho land grant....				....do....	....	Pond....	....	....	Notch on willow tree.	....	Deep fill of major valley.	Black adobe soil; swampy vegetation and willow trees.
P 21	....do....				....do....	Long....	Dug....	....	331.6	Top of 5-foot diameter brick curb, north side, under board cover.	356.39	Residuum....	Dry decomposed granite soil.
P 22	....do....				....do....	Rickey....	....do....	....	331.6	Top of 4 by 4 inch upright curb post, northwest corner.	331.73	Deep fill of major valley.	Sandy river-bottom soil.
P 23	....do....				....do....	Sefton....	Drilled....	28.0	322.7	Top of 12-inch casing.	322.73	....do....	Coarse river sand; willow brush.
P 25	....do....				....do....	Bennett....	Dug....	6.1	349.3	Top of 3 by 3 inch, southwest corner of pit.	344.90	....do....	River silt with swamp vegetation and willows.
P 26	....do....				....do....	Winterstein....	....do....	12.1	313.0	Timber south side where curb opens into trench.	307.72	....do....	River-bottom sand and willow trees.
P 26a	....do....				....do....	....do....	....do....	....	908.2	Top of post southwest corner, near pump.	307.55	....do....	Do.

QUALITY OF WATER.

By A. J. Ellis.

SCOPE OF WORK.

The investigation of the water resources of San Diego County included a study of the chemical quality of the waters for the purpose of determining their adaptability for use for domestic supplies and for irrigation.

The specific information in this report in regard to the quality of the waters is based on analyses or assays of 111 samples of water collected by A. J. Ellis and C. H. Lee in November and December, 1914, and June, 1915, and of 10 samples collected by F. C. Ebert in 1918. The samples collected in 1914 and 1915 were analyzed or assayed by S. C. Dinsmore, under contract with the United States Geological Survey, and those collected in 1918 were analyzed by Alfred A. Chambers and C. H. Kidwell in the laboratory of the water-resources branch of the United States Geological Survey. The complete analytical data are given in Tables 57, 58, and 59, pages 260–263.

Seven samples of surface waters, collected in March, 1918, by F. C. Ebert, were analyzed by Alfred A. Chambers and C. H. Kidwell and are given in Table 56, page 259.

METHODS OF ANALYSIS AND ACCURACY OF RESULTS.

The analyses (Table 57, pp. 260–261) were made according to the methods outlined in the report on the quality of surface waters in the United States Water-Supply Paper 236 (pp. 9–23), except that "sodium and potassium (Na+K)" was computed by calculating the sum of the reacting values of the acid radicles and subtracting from it the sum of the reacting values of the basic radicles determined. The excess of the acid radicles divided by the reacting value of sodium is considered to be the amount of sodium plus potassium present in parts per million.

Total hardness as $CaCO_3$, scale-forming constituents, foaming constituents, and alkali coefficients were computed according to the formulas given in this report on pages 225, 243 (Nos. 1 and 3), and 234, respectively. The probability of corrosion is based on a computation made by applying formula 4, page 243.

The laboratory assays (Table 58, p. 262) comprise chemically determined values of iron (Fe), carbonate (CO_3), bicarbonate (HCO_3), sulphate (SO_4), chloride (Cl), and total hardness as $CaCO_3$, and computed values for sodium plus potassium (Na+K), total solids, scale-forming and foaming constituents, and alkali coefficient.

The methods used in determining chloride, carbonate, and bicarbonate are the same in the assays as in the analyses. Sulphate was determined by the field method described by R. B. Dole in Water-Supply Paper 398 (pp. 42–43); iron was determined by the field

No. on Pl. II.	Method of lift.[a]	Yield (gallons per minute).	Use of water.[b]	Remarks.
A 1				
A 2				
A 3				
B 1	Gas. eng. suct. p		D; I	
B 2	....do	35	D; I	Tunnels.
B 3	W		D; I	Two tunnels 4 by 6 feet, 8 feet long.
B 4	Dis. eng. suct. p		I	180 feet of tunnels, 4 by 6 feet.
B 5	Gas. eng. suct. p	36	I	16 feet of tunnels, 5 by 7 feet.
B 5a	W	5	D	
B 6		45		One tunnel 3½ by 5½ feet, 12 feet long.
c C 1	Gas. eng. suct. p		D; I	One tunnel 30 feet long.
d C 2	Gas. eng. cent. p	1,600	I	
C 3	Gas. eng. cent. p	540	D; I	
D 1				
E 1				
E 2				
E 3				
E 4				
E 5				
E 6				
f F 1	Stm. eng	1,000	P	
d F 2	Stm. eng	1,800	D; I	
d F 3	W		S	
d F 4	Gas. eng. cent. p	900	I	
F 5	W		D	
F 6				
c F 7				
F 8	Bucket			
c f F 9	Gas. eng., suct. p	10	D	
G 1	Gas. eng., cent. p	e 45	D; I	200 feet of tunne l4 by 6 feet.
G 2			Not used	
G 3	Elec. m. cent. p			
G 3	W	Low.		
G 4	Gas. eng., cent. p		I	
G 5	Gas. eng	189		
G 6	Gas. eng., suct. p	20	P; D; I.	60 feet of tunnel 3 by 6 feet.
c G 7	....do		D	
c G 8	Gas. eng., cent. p		D; I	
G 9				4 tunnels.
G 10	Gas. eng., suct. p			50 feet of 1½-inch auger holes.
G 11	Gas. eng			
c G 12	Gas. eng., suct. p		D	
G 13	....do	Low.	D	
G 14	....do	55	D; I	65 feet of 3 by 6 feet tunnel; 500 feet of 1½-inch auger holes.
c G 15	W		S	
f G 16	W		D; I	
d G 17	Gas. eng., cent. p	400	D; I	
G 17a	....do	270	I	
d G 18	....do	1,800	I	
G 19				
G 20	W			
G 21	Gas. eng., cent. p	900	I	
G 22	....do	495	I	
G 23	....do	990	I	
G 24	....do	150	I	
H 1				
d H 2	....do	900	I	
d H 3	....do	400–900	I	
d H 4	....do	360	I	
d H 5	W		S	
d H 6	W		D	
H 7	W		D	

e corresponding number in Table 59, p. 263.

ıd classification see corresponding number in Table 58, p. 262.

TABLE 46.—*Records of all wells and springs that were examined in San Diego County, Calif.*

[For additional data see Tables 45, 57, 58, and 59.]

No. on Pl. II.	Location: Nearest post office.	Location: Township.	Location: Range.	Location: Section.	Location: Quarter.	Owner or name.	Altitude above sea level.	Type of well or spring.	Depth of well.	Diameter of well.	Geologic horizon.	Water level: Below surface.	Water level: Date of measurement.	Method of lift.[a]	Yield (gallons per minute).	Use of water.[b]	Remarks.
							Feet.		Feet.			Feet.	1914.				
A 1	San Onofre	Las Flores land grant				Barnard Bros	25				Valley fill						
A 2	do	do				do	20				do						
A 3	do	do				do	15				do						
B 1	Fallbrook	9 S.	4 W.	13	SE.	William Williams	700	Dug	57		Residuum	36	November	Gas. eng. suct. p.		D; I.	
B 2	do	9 S.	4 W.	24	SE.	Robert Nesbit	700	do	41	30 inches	do	20.2		do	35	D; I.	Tunnels.
B 3	do	9 S.	4 W.	25	NE.	S. Sproul	660	do	49.8		do	20		W.		D; I.	Two tunnels 4 by 6 feet, 8 feet long.
B 4	do	9 S.	4 W.	25	NW.	Dr. Pratt	690	do	40	96 inches	do	10		Dis. eng. suct. p.		I.	180 feet of tunnels, 4 by 6 feet.
B 5	do	9 S.	4 W.	25	NE.	J. A. Fulwiler	640	do	35	48 inches	do			Gas. eng. suct. p.	36	I.	10 feet of tunnels, 5 by 7 feet.
B 5a	do	9 S.	4 W.	25	NE.	do	690	do	73		do	68		W.	5	D.	
B 6	do	9 S.	4 W.	25	SE.	M. D. Gilman	620	do	51		do	11			45		One tunnel 3½ by 5½ feet, 12 feet long.
[c] C 1	do	9 S.	3 W.	15	SW.	Red Mountain ranch	1,000	do	65	4 by 12 feet	Residuum	40	November	Gas. eng. suct. p.		D; I.	One tunnel 30 feet long.
[d] C 2	Pala	9 S.	2 W.	26	SW.	United States Indian Service	423	do	63	96 inches	Valley fill	[e] 11.3	Jan. 10, 1915[e]	Gas. eng. cent. p.	1,600	I.	
C 3	Monserate ranch	Monserate land grant				Canfield estate	200	Drilled	75		do	4	November	Gas. eng. cent. p.	540	D; I.	
D 1	Pauma Indian Reservation	Pauma land grant					1,000	Cesspool	30		do	Dry					
E 1	Warners ranch	San Jose del Valle land grant					2,703		9								
E 2	do	do					2,729		8								
E 3	do	do					2,789		5								
E 4	do	do					2,700		7.5								
E 5	do	do					2,817		8								
E 6	do	do					2,837		7								
[f] F 1	San Luis Rey Valley	11 S.	5 W.	14	SE.	City of Oceanside	12	2 drilled	150, 204	12 inches	Valley fill	4	November	Stm. eng.	1,000	P.	
[d] F 2	do	11 S.	4 W.	18	SW.	South Coast Land Co.	32	3 drilled	195	11⅛ inches	do	4	do	Stm. eng.	1,500	D; I.	
[d] F 3	do	11 S.	4 W.	18	SW.	San Diego County	32	Dug	9.6	5 by 5 feet	do	5.5	do	W.		S.	
[d] F 4	do	11 S.	4 W.	4	SE.	Fletcher & Henshaw	72.7	Drilled	168	12 inches	do	8.8	Sept. 20[e]	Gas. eng. cent. p.	900	I.	
F 5	Oceanside	11 S.	4 W.	32	NE.		20	Dug	13.9		do	10.1	Oct. 25	W.		D.	
F 6	Encinitas	12 S.	4 W.	26	NW.	Clark	260	Drilled	2,126								
[c] F 7	do	12 S.	4 W.	35	NW.	Pacific Laguna Oil Co.	20	do	1,300								
F 8	do	13 S.	4 W.	2	NE.		65	Dug	15.9	30 by 30 inches	Valley fill	12	Oct. 25	Bucket			
[c f] F 9	do	13 S.	4 W.	16	NE.	Village of Cardiff	25	Drilled	60	8 inches	do	20		Gas. eng., suct. p.	10	D.	
G 1	Escondido	12 S.	2 W.	2	SE.	A. C. Meyer	750	Dug	38	53 inches	Residuum			Gas. eng., cent. p.	[e] 45	D; I.	200 feet of tunnel 4 by 6 feet.
G 2	do	Rincon del Diablo					725	do				5.6				Not used	
G 3	do	12 S.	2 W.	1	SE.	Eureka Ranch Co.	710	Drilled	40	12 inches	Residuum			Elec. m. cent. p.			
G 3	do	12 S.	2 W.	1	SE.	do	710	do	50	12 inches	do			W.	Low.		
G 4	do	Rincon del Diablo				J. S. McClure	685	Dug and drilled	35	48 inches	Valley fill	12		Gas. eng., cent. p.		I.	
G 5	do	do				W. E. Alexander	678	Drilled	32	8 inches	Residuum			Gas. eng.	189		
G 6	do	do				George Lehner	675	Dug	61	12 inches	do			Gas. eng., suct. p.	20	P; D; I.	60 feet of tunnel 3 by 6 feet.
[c] G 7	do	do				Eliza Robinson	665	Dug and drilled	47	42 inches, 12 inches	Valley fill	6	Nov. 20	do		D.	
[c] G 8	do	do				John C. Dickson	680	Drilled	31	12 inches	do	7	Nov. 19	Gas. eng., cent. p.		D; I.	
G 9	do	do				J. A. Whetstone	695	Dug	70		Residuum						4 tunnels.
G 10	do	do				John L. Ellis	718	do	30		do	9.5	Nov. 19	Gas. eng., suct. p.			50 feet of 1½-inch auger holes.
G 11	do	do				do	730		32	84 inches	do	7	do	Gas. eng.			
[c] G 12	do	do				D. T. Marlor	630	Dug	24.7		do	16.8	Nov. 20	Gas. eng., suct. p.		D.	
G 13	do	do				Benjamin Chubbic	675	do	29	36 inches	do	22	do	do	Low.	D.	
G 14	do	do				Wm. Riezebus	675	do	40		do			do	55	D; I.	65 feet of 3 by 6 feet tunnel; 500 feet of 1½-inch auger holes.
[c] G 15	Encinitas	Encinitas land grant					120	do	15.6	60 inches	Valley fill	4.5	Oct. 25	W.		S.	
[f] G 16	Bernardo	San Bernardo land grant				S. C. Smith	315	do	34	96 inches	Residuum	30	Oct. 11	W.		D; I.	
[d] G 17	San Pasqual	12 S.	1 W.	31	NE.	H. B. Pratt	365	3 drilled	77	One 8, two 12 inches.	Fill of minor valley	10	do	Gas. eng., cent. p.	400	D; I.	
G 17a	do	12 S.	1 W.	31	NE.	S. E. Worthington	370	2 drilled	52	12 inches	do	4	do	do	270	I.	
[d] G 18	do	San Bernardo land grant				San Pasqual Ranch Co.	340	8 drilled	40	6 inches	Valley fill	3	do	do	1,800	I.	
G 19	do	do					340										
G 20	Green Valley	13 S.	2 W.	28	NE.		550	Dug	43			38		W.			
G 21	Bernardo	13 S.	2 W.	12	NE.	H. G. Fenton	320	5 drilled	Two, 92; three, 36	12 inches	Valley fill	4	Oct. 10	Gas. eng., cent. p.	900	I.	
G 22	do	San Bernardo land grant				U. S. Weaver	310	2 drilled	45	12 inches	do	5	Oct. 14	do	495	I.	
G 23	do	do				do	305	4 drilled	45	12 inches	do	5	Oct. 10	do	990	I.	
G 24	do	do				M. Barnett	360	7 drilled	100-145	7 inches	Residuum	3	October	do	150	I.	
H 1	San Pasqual	12 S.	1 W.	33			390										
[d] H 2	do	12 S.	1 W.	34	SE.	H. J. Meyers	410	4 drilled	40	12 inches	Valley fill	5	Oct. 11	do	900	I.	
[d] H 3	do	12 S.	1 W.	35	NW.	A. B. Judson	430				do			do	400-900	I.	
[d] H 4	do	12 S.	1 W.	35	NW.	do	440	Drilled	86	12 inches	do	7	Oct. 12	do	360	I.	
[d] H 5	do	12 S.	1 W.	35	SW.	F. M. Judson	419	Dug	11	3 by 3 feet	do	6.5	[e] Oct. 14	W.		S.	
[d] H 6	do	12 S.	1 W.	36	SE.	Ed. Harris	455	Drilled	30	8 inches	do	8	Oct. 12	W.		D.	
H 7	Ramona	Valle de Palmo land grant				Ferdinand Hauck	1,625	3 drilled	36-60	8 inches		10		W.		D.	

[a] Elec. m.=electric motor; Dis. eng.=distillate engine; Gas. eng.=gasoline engine; Stm. eng.=steam engine; W.=windmill; Bucket=rope and bucket; Cent. p.=centrifugal pump; Suct. p.=suction pump; Hand p.=hand pump; Inc.=incomplete.

[b] D=domestic; I=irrigation; P=public.

[c] For chemical composition and classification of water see corresponding number in Table 57, pp. 260-261.

[d] For chemical composition of water see corresponding number in Table 59, p. 263.

[e] See Table 45, p. 209.

[f] For chemical composition of water and classification see corresponding number in Table 58, p. 262.

. on . II.		Method of lift. a	Yield (gallons per minute).	Use of water. b	Remarks.
K 51	M	s. eng., cent. p.		I	
K 52		..do		I	
K 53	L		2	Not used	
K 54		owing		D	Flows 2 gallons a minute.
L 1	P	and p		D	
L 2		c	45	I	250 feet of 4 by 6 feet tunnels.
L 3	F	ec. m., cent. p	1,600	D; I	
L 4		owing		Not used	Flows 2 gallons a minute.
L 5	L	s. eng., cent. p	f 360	I	
L 6		..do	675	I	
L 7		ec. m., cent. p	1,800	D; I	
L 8		and p		D	
L 9	S	s. eng., cent. p	850	I	
L 10		..do	1,300	I	
L 11				D; S	
L 12		ec. m., cent. p	300	I	
L 13	L	s. eng., cent. p	2,250	I	
L 14		..do	1,125–1,260	I; D	
L 15		..do	1,230–1,350	D; I	
L 16				D; I	
L 17	E			D	
L 18			30	D	
L 19					
L 20		as. eng., cent. p	180	I	Wells connected.
L 21					
L 22				D	
L 23		ec. m., cent. p	90	I	Four 2-inch laterals, 276 feet total length.
L 24		..do	161	I	2-inch diameter, 540 feet total length.
L 25		ot equipped		Not used	
L 26					
L 27		as. eng., cent. p	160	P	
L 28				D	
L 29				D	
L 30		as. eng., suct. p		D	Three 2-inch auger holes.
L 31		as eng., suct. p	90	I; D	400 feet of 1½-inch holes.
L 32			45	D	
L 33			45	D	
L 34		ec. m., suct. p	78	D; I	
L 35				D; I	80 feet.
L 36					
L 37					
L 38	D	as eng., cent. p	900	I	
L 39		..do	270	I	
L 40		and p		D	
L 41	J	ec. m., cent. p	720	I; D	
L 42		ucket		D	
L 43	E			D	4 tunnels, 6 by 6 feet.
L 44	L	ec. m., cent. p	225	D; I	
L 45	F	..do	900	D; I	
L 46		..do	540	D; I	
L 47	L	..do	180	D; I	
O 1	S	ec. m., hand p	45		
O 1a		ot equipped	270	D	
O 2			50	D; I	
O 3		s. eng., suct. p		D	
O 4			17	D	
O 5				Inc.	
O 6			1	D	
O 7				D	
O 8			36	D	
O 9				S	
O 10					
O 11					
O 12				D	
O 12				Not used	
O 12				D	
O 13				Not used	
O 14				D	
O 15					
O 16	N S	as. eng., suct. p	70	D; I	
O 17		..do		D; I	
O 18		as. eng., cent. p	240	I	

water see corresponding number in Table 58, pp. 260–261.

water see corresponding number in Table 58, p. 262.

II

TABLE 46.—*Records of all wells and springs that were examined in San Diego County, Calif.*—Continued.

[For additional data see Tables 45, 57, 58 and 59.]

No. on Pl. II.	Location: Nearest post office.	Township.	Range.	Section.	Quarter.	Owner or name.	Altitude above sea level.	Type of well or spring.	Depth of well.	Diameter of well.	Geologic horizon.	Water level: Below surface.	Water level: Date of measurement.	Method of lift. a	Yield (gallons per minute).	Use of water. b	Remarks.
							Feet.		Feet.			Feet.	1914.				
K51	Mission Valley	Ex Mission San Diego land grant				A. Jaussand	72.6	Dug and drilled	19	14 feet	Valley fill	d 13.2	Oct. 22	Gas. eng., cent. p.		I.	
K52	do	do					72	do	7	4 by 4 feet	do	4	do	do		I.	
K53	La Mesa	do				J. L. Haughawout	420	do	74		Tertiary	25			2	Not used	
K54	do	do					500	Spring			do			Flowing		D.	Flows 2 gallons a minute.
L1	Padre Barona Valley	14 S.	1 E.	28	NW.		1,525	Dug	14			10	Oct. 27	Hand p.		D.	
L2	do	San Vicente land grant				W. H. Jones	1,370	do	30	10 inches	Residuum			Inc.	45	I.	250 feet of 4 by 6 feet tunnels.
L3	Foster	El Cajon land grant				H. L. Weston	445	5 drilled	95	12 inches	Valley fill	14	Oct. 6	Elec. m., cent. p.	1,600	D; I.	
L4	do	15 S.	1 E.	4	SW.		975	Spring					Oct. 27	Flowing		Not used	Flows 2 gallons a minute.
L5	Lakeside	El Cajon land grant				G. E. P. Philbrook	412	Dug	19	84 inches	Valley fill	d 11.8	Oct. 13	Gas. eng., cent. p.	f 360	I.	
L6	do	do				Hugo Thum	420	5 drilled	80–85		do			do	675	I.	
L7	do	do				Cuyamaca Water Co.	438	37 driven	70	6 inches	do	d 5	Sept. 22	Elec. m., cent. p.	1,800	D; I.	
L8	do	do				J. W. Fedders	495	Driven	26		do			Hand p.		D.	
L9	Santee	do				E. W. Scripp	325	15 drilled	26–30	6 inches	do	5	Oct. 22	Gas. eng., cent. p.	850	I.	
L10	do	do				W. H. Dupee	350	9 drilled	40–70	6–8 inches, 3–12 inches.	do			do	1,300	I.	
L11	do	do				James Ballantine	354	Dug		60 inches	Residuum	d 18.9	Oct. 13	W.		D; S.	
L12	do	do				Dr. H. W. Learn	370	3 drilled	20	6 inches	Valley fill			Elec. m., cent. p.	300	I.	
L13	Lakeside	do				John Johnson, jr.	370	8 drilled	60–80	12 inches	do			Gas. eng., cent. p.	2,250	I.	
L14	do	do				Lakeside Farms Co.	380	4 drilled	75	do	do			do	1,125–1,260	I; D.	
L15	do	do				do	395	6 drilled	48–83	do	do			do	1,230–1,350	D; I.	
L16	do	do				Mrs. Price	410	Dug			Residuum			W.		D; I.	
L17	El Cajon Valley	do				Crocker	380	do	40							D.	
L18	do	do					385	do	30		Residuum	15		W.	30	D.	
L19	do	do				G. H. Riddle	400	do	60		do						
L20	do	do				H. Culbertson	400	2 dug			do			Gas. eng., cent. p.	180	I.	Wells connected.
L21	do	do					420	Dug	45		"Marl"						
L22	do	do					425	do	23.6			18.5		W.		D.	
L23	do	do				T. Ballantine	420	do	30	72 inches	Valley fill, residuum	16	October	Elec. m., cent. p.	90	I.	Four 2-inch laterals, 276 feet total length.
L24	do	do				Joseph Miller	435	do	50	90 inches	Residuum	10	June 22, 1915	do	161	I.	2-inch diameter, 540 feet total length.
L25	do	do					440	do	258		do	14.5		Not equipped		Not used	
L26	do	do				High school	525				Marl at 30 feet						
L27	do	do				W. B. Hall	445	Dug	50		Residuum	10	Apr. 15, 1915	Gas. eng., cent. p.	160	P.	
L28	do	do					465	do	28.4	72 inches	do	15.9	1914 Nov. 24			D.	
L29	do	do					465	do	2.8	60 inches		15.4	Nov. 24	W.		D.	
L30	do	do				Morris Ginn	500	do	41			19.8	do	Gas. eng., suct. p.		D.	Three 2-inch auger holes.
L31	do	do				J. D. Hall	525	do	49		Residuum	20	April, 1915	Gas eng., suct. p.	90	I; D.	400 feet of $1\frac{1}{2}$-inch holes.
L32	do	do				Jones	485	do	21.2			12.3	1914. Nov. 24		45	D.	
L33	do	do				Scott	485	do	50						45	D.	
L34	do	do				Chas. Bentley	490	do	68.5	72 inches	Residuum	11.3	April, 1915	Elec. m., suct. p.	78	D; I.	
L35	do	do				Louis Forney	465	do	30			20.2	1914. Nov. 24			D; I.	80 feet.
L36	do	do				do	470	do	28								
L37	do	do					495										
L38	Dehesa	16 S.	1 E.	16	NW.	M. C. Allen	450	4 drilled	45	Three 7 inches, One 6 inches	Valley fill	1–3		Gas eng., cent. p.	900	I.	
L39	do	16 S.	1 E.	14	SW.	J. M. Owen	500	2 drilled	50	6 inches	do			do	270	I.	
L40	do	16 S.	1 E.	14	SW.	do	501	Dug	21.2	72 inches	Residuum	d 17	Oct. 7	Hand p.		D.	
L41	Jamacho	16 S.	1 E.	21	SW.	G. M. Hawley	406	3 drilled	28–34	7 inches	Valley fill	d 6.4	Oct. 6	Elec. m., cent. p.	720	I; D.	
L42	do	Jamacho land grant				Hawley	387	Dug	11	5 by 5 feet	do	d 9	do	Bucket		D.	
L43	El Cajon Valley	El Cajon land grant				Anthony Armitage	385	do	26.5	6 by 6 feet		13.7		W.		D.	4 tunnels, 6 by 6 feet.
L44	Lakeside	do				Wm. McLain	395	2 drilled	76	12 inches	Valley fill			Elec. m., cent. p.	225	D; I.	
L45	Foster	do				R. S. Otto	435	Drilled	78	12 inches	do	10	Oct. 7	do	900	D; I.	
L46	do	do				L. H. Arnold	430	2 drilled	77	12 inches	do	7		do	510	D; I.	
L47	Lakeside	do				S. F. LaMond	415	Drilled	78	12 inches	do			do	180	D; I.	
O1	San Diego	City of San Diego				Y. M. C. A.	75	do	200	8 inches	Tertiary			Elec. m., hand p.	45		
O1a	do	Ex Mission San Diego				Wilkes James	150	do	248	8 inches	do	118		Not equipped	270	D.	
						Charles W. Walker	150	do	184								
O2	do	do				Woodworth	150	Dug	158	8 inches	do				50	D; I.	
O3	do	do				B. G. Estes	175	do	178		do	155.5	Oct. 5	Dis. eng., suct. p.		D.	
O4	do	do				Turner	175		155		do				17	D.	
O5	do	do				L. K. Lanier	175	Drilled	320+		do					Inc.	
O6	do	do				do	200		80		do	40		W.	1	D.	
O7	do	do				Robert Dicks	250		203	10 inches		114				D.	
O8	do	do				San Diego Home Builders Assoc.	400		375	10 inches					36	D.	
O9	do	do					270	Dug	24	96 inches	Valley fill	10	Oct. 5	W.		S.	
O10	do	do				C. B. Stern	50										
O11	do	do					75	Dug	70								
O12	do	do				Albright	95	do	104		Tertiary					D.	
O12	do	do				do	90	Drilled	250		do	60	Oct. 8			Not used	
O12	do	do				Harris	80	Dug	70		do	58	do			D.	
O13	do	do					55	do	60							Not used	
O14	do	do				L. Wiese	100	Dug and drilled	104		Tertiary	62	Oct. 8			D.	
O15	do	do				Ralph Granger	125	Drilled									
O16	National City	La Nacion land grant				G. G. Kimball	65	Dug	61	48 inches	Tertiary	49	Oct. 28	Gas. eng., suct. p.	70	D; I.	
O17	Sunnyside	La Nacion land grant				J. W. Carue	170	Drilled	210	8 inches	do	100	Oct. 5	do		D; I.	
O18	do	do				L. C. Kincaid	89	Dug	12.7	96 inches	Valley fill	d 7.8	do	Gas. eng., cent. p.	240	I.	

a Elec. m.=electric motor; Dis. eng.=distillate engine; Gas eng.=gasoline engine; Stm. eng.=steam engine; W.=windmill; Bucket=rope and bucket; Cent. p.=centrifugal pump; Suct. p.=suction pump; Hand p.=hand pump; Inc.=incomplete.

b D=domestic; I=irrigation; P=public.

c For chemical composition of water see corresponding number in Table 59, p. 263.

d See Table 45, p. 209.

e For chemical composition and classification of water see corresponding number in Table 57, pp. 260-261.

f Statement of C. S. Alverson.

g For chemical composition and classification of water see corresponding number in Table 58, p. 262.

No. o[illegible] Pl. I[illegible]	Method of lift.[a]	Yield (gallons per minute).	Use of water.[b]	Remarks.
c O 1	s. eng., cent. p.	585	I.	
d O 2	ucket		S.	
c O 2	V		D.	
c O 2	lows			Flows 80 to 100 gallons a minute.
O 2			(Test-hole.)	
O 2			do.	
O 2				
O 2			(Test-hole.)	
O 2			do.	
d O 2	V			
d O 2	V		D.	
d O 3	V		D.	
d O 3	V		D.	
d O 3	V		D.	
O 3	uct. p.			
c O 3	V		D; I.	
c O 3	V		D.	
O 3	as. eng., cent. p.	150	D; I.	
d O 3	V		D; I.	
c O 3	lec. m., cent. p.		P.	
d O 3	as. eng., cent. p.	225–300	I.	
O 3	lec. m., cent. p.	400	Washing gravel.	
d O 3	as. eng., suct. p.	90–100	D; I.	
O 3	do	80	I.	
d O 4	V		D.	
c O 4	V		I.	
d O 4	as eng., cent. p.; W		I.	
c O 4	as. eng., cent. p.	56	I; D.	
c O 4	do		I.	
O 4				
d O 4	lec. m., cent. p.		D; I.	
c O 4	do	372	I.	
O 4	as. eng., cent. p.	100	D; S.	
d O 4	as. eng., suct. p., hand p.		D; I.	
O 4	as. eng., cent. p.	225	D; I.	
d O 4	do		I.	
O 4	do	900	I.	
d O 5	do		I.	
O 5	do	900	I.	
c O 5	lec. m., cent. p.	2,700	I.	
c O 5	as. eng., cent. p.		I.	
O 5	do	700	I.	
c O 5	lec. m., cent. p.	450	I; D.	
O 5	do	900	I.	
c O 5	as. eng., cent. p.		I.	
c O 5	V		D; S.	
c O 5	lec. m., cent. p.		I.	
c O 5	do		I.	
O 5	and p.		D.	
d O 5	do		D.	
O 6	V		I; D.	
f O 6	as. eng., cent. p.; W.		I; D.	
d O 6				
O 6				
O 6				
c P	lec. m., cent. p.	2,000	I.	
c P	V		D; I.	
P	and p.		D.	
P	do	6	Bottled.	
P	V		D.	
P	V		S.	
P			Not used.	
P	V		S.	
P			P.	
P		1.2	D; S.	
P 1		p. d. 450	D.	

lassification of water, see corresponding number in Table 57, pp. 260–261.

lassification of water see corresponding number in Table 58, p. 262.

TABLE 46.—*Records of all wells and springs that were examined in San Diego County, Calif.*—Continued.

[For additional data see Tables 45, 57, 58, and 59.]

No. on Pl. II.	Location: Nearest post office.	Location: Township.	Location: Range.	Location: Section.	Location: Quarter.	Owner or name.	Altitude above sea level.	Type of well or spring.	Depth of well.	Diameter of well.	Geologic horizon.	Water level: Below surface.	Water level: Date of measurement.	Method of lift.[a]	Yield (gallons per minute).	Use of water.[b]	Remarks.
							Feet.		Feet.			Feet.	1914.				
[c] O 19	Sweetwater Junction	La Nacion land grant				B. L. Elliott	20	Five drilled	37-60	6 inches	Valley fill	5	Oct. 8	Gas. eng., cent. p.	585	I.	
[c] O 20	do	do				Chas. Dickens	28	Dug	9.5	4 by 4 feet	do	[e] 8.8	Oct. 29	Bucket		S.	
[c] O 21	Bonita	do				R. C. Allen	58	do	12.2	3 by 3 feet	do	[e] 3.5	Oct. 14	W.		D.	
[c] O 22	do	do				H. C. Hammond	64	Drilled	900		Tertiary or older	Flows.		Flows.			Flows 80 to 100 gallons a minute.
O 23	Chula Vista	do				Chula Vista Oil Co.	150	do	678		Tertiary					(Test-hole.)	
O 24	do	do				do	150	do	582		do					do	
O 25	do	do				do	150	do	1,812		do						
O 26	do	do				do	150	do	660		do					(Test-hole.)	
O 27	do	do				do	135	do	643		do					do	
[d] O 28	Coronado	Peninsula					10	Dug	4.3	4 by 5 feet	Sand bar	1.1	Sept. 25	W.			
[d] O 29	Chula Vista	La Nacion land grant				F. M. Winship	61	do	52	4 by 4 feet	Tertiary	[e] 51	Oct. 9	W.		D.	
[d] O 30	do	do				Montgomery	65	do			do			W.		D.	
[d] O 31	do	do				do	60	do	64.6	48 inches	do	58.8	Oct. 8	W.		D.	
[d] O 32	do	do				G. M. Keener	55	do	64	6 by 6 feet	do	52	do	W.		D.	
O 33	do	18 S.	2 W.	16	SE.	Copeland	50	Bored	180					Suct. p.			
[c] O 34	Otay	18 S.	2 W.	22	NW.	Byron Gillette	53	Dug		60 inches	Pleistocene	[e] 50.5	Oct. 2	W.		D; I.	
[c] O 35	do	18 S.	2 W.	22	NW.	H. Eumellen	22.6	do	32	do	Tertiary	19	Oct. 9	W.		D.	
O 35a	do	18 S.	2 W.	22	NW.	do	23	Drilled	114	12 inches	do	16	do	Gas. eng., cent. p.	150	D; I.	
[d] O 36	Palm City	18 S.	2 W.	21	SW.	E. T. Morris	11	Dug and drilled	23	82 inches	Valley fill			W.		D; I.	
[c] O 37	do	18 S.	2 W.	21	NE.	Coronado Water Co.	13	Dug	33.7	21 feet for 20 feet; 14.4 feet for 13.7 feet.	do			Elec. m., cent. p.		P.	
[d] O 38	do	18 S.	2 W.	22	SW.	C. R. Johnson	23	Dug and drilled	100	6 by 6 feet	do	[e] 18	Oct. 9	Gas. eng., cent. p.	225-300	I.	
O 38a	Otay	18 S.	2 W.	22	SW.	Fenton, Sumption & Barnes Co.	23	Drilled	198	12 inches	Tertiary	19.8	Oct. 10	Elec. m., cent. p.	400	Washing gravel.	
[d] O 39	do	18 S.	2 W.	23	NW.	W. F. Clark	55	do	90	do	do	[e] 35.4	Oct. 2	Gas. eng., suct. p.	90-100	D; I.	
O 39a	do	18 S.	2 W.	23	NW.	W. B. Toner	41	do	123	do	do	14	Oct. 30	do	80	I.	
[d] O 40	do	18 S.	2 W.	23	NW.	W. F. Clark	55	Dug	51.5	48 inches	do	[e] 36.9	do	W.		D.	
[c] O 41	do	18 S	2 W.	23	NW.	W. V. Toner	41	do	25	60 inches	Valley fill	14.2	do	W.		I.	
[d] O 42	do	18 S.	2 W.	23	E. ½	W. E. Spicer	57	Drilled	625		do	[e] 15.7	Oct. 2	Gas eng., cent. p.; W.		I.	
[c] O 43	Otay Valley	18 S.	1 W.	19	NW.	R. W. Paul	96	Dug	16		do	6.5	1911 Dec. 5	Gas. eng., cent. p.	56	I; D.	
[c] O 44	do	19 S.	1 W.	20	SE.	Sweetwater Land Co.	152	do			do			do		I.	
O 45	Otay Mesa	18 S.	1 W.	30	NE.	Otay Oil Co.	275	Drilled									
[d] O 46	Palm City	18 S.	2 W.	28	NE.	G. M. Kimball	41.6	Dug and drilled	34.5	48 inches	Tertiary	[e] 35	Oct. 30	Elec. m., cent. p.		D; I.	
[c] O 47	Nestor	18 S.	2 W.	29	SE.	Evans & Tucker	24	do	68	6 by 10 feet	do	[e] 22.2	Sept. 25	do	372	I.	
O 47a	do	18 S.	2 W.	29	SE.	J. L. Cassidy	21	Drilled	63	12 inches	do	18.1	do	Gas eng., cent. p.	100	D; S.	
[d] O 48	do	18 S.	2 W.	34	NW.	I. A. Hanchett	33	Dug	28.8		do	[e] 26.7	Oct. 8	Gas. eng., suct. p., hand p.		D I.	
O 48a	do	18 S.	2 W.	27	SW.	D. Evans	50	Drilled	57	12 inches	do			Gas. eng., cent. p.	225	D; I.	
[d] O 49	do	18 S.	2 W.	33	NE.	Vassar	35	Dug and drilled.	50		do			do		I.	
O 49a	do	18 S.	2 W.	33	NW.	Serrano	23	5 drilled	35	8 inches	do			do	900	I.	
[d] O 50	Tia Juana Valley	18 S.	2 W.	32	SE.	S. Holderness	0.8	Drilled	98	do	Valley fill	[e] 5.5	Sept. 25	do		I.	
O 50a	Nestor	18 S.	2 W.	32	SE.	Joseph Poggi	10	3 drilled	85-99	12 inches	do			do	900	I.	
[c] O 51	Tia Juana Valley	19 S.	2 W.	5	SE.	Guidotti & Pietro	10	8 drilled	73-91	do	do			Elec. m., cent. p.	2,700	I.	
[c] O 52	do	19 S.	2 W.	4	NW.	H. Peary	20	4 drilled	78	do	do			Gas. eng., cent. p.		I.	
O 52a	Nestor	19 S.	2 W.	4	NW.	N. J. Peary	18	5 drilled	Four 84 feet; one 125 feet.	Four 10 inches. One 12 inches.	do			do	700	I.	
[c] O 53	Tia Juana Valley	18 S.	2 W.	33	SW.	J. C. Thompson	25	2 drilled	38	12 inches	Valley fill, Tertiary			Elec. m., cent. p.	450	I; D.	
O 53a	Nestor	18 S.	2 W.	33	SE.	F. L. McMeecham	25	3 drilled	Two 62; one 73.	Two 10 inches. One 12 inches.	Valley fill	9	Oct. 11	do	900	I.	
[c] O 54	Tia Juana Valley	19 S.	2 W.	4	NW.	J. A. McCann	25	Drilled	73	12 inches	Valley fill, Tertiary			Gas. eng., cent. p.		I.	
[c] O 55	do	19 S.	2 W.	4	SE.	D. A. & C. M. Johnson	24	Dug	12.9	96 inches	Valley fill	8	Oct. 9	W.		D; S.	
[c] O 56	do	18 S.	2 W.	34	SE.	C. M. Richardson, Max Mayer	30	Drilled	68		do			Elec. m., cent. p.		I.	
[c] O 57	do	19 S.	2 W.	2	NW.	F. L. McMeachen	35	5 drilled	58-60	12 inches	do			do		I.	
O 58	do	19 S.	2 W.	1	NW.		50	Driven		2 inches	do			Hand p.		D.	
[d] O 59	do	19 S.	2 W.	1	NE.	J. M. Lawson	56	do	Shallow.	do	do			do		D.	
O 60	do	19 S.	2 W.	1	SE.	W. Todd	60	do	do	6 inches	do			W.		I; D.	
[f] O 60a	do	19 S.	2 W.	1	SE.	Mrs. A. W. Jackson		Drilled	18	8 inches	do	5.6	Mar. 15, 1918	Gas. eng., cent. p.; W.		I; D.	
[d] O 61	do	19 S.	1 W.	6	NW.	J. V. Tavan	58	do	27	12 inches	do	[e] 5.6	1914. Oct. 12				
O 62	Otay Mesa	18 S.	1 W.	31	NW.	Lo Tengo Oil Co.	375	do	3,500+		Tertiary						
O 63	Tia Juana Valley	19 S.	2 W.	9	NW.	Tia Juana Valley Oil Co.	70		1,405+								
[c] P 1	Jamacho	Jamacho land grant.				Sefton	320	18 drilled	38	12 inches	Valley fill			Elec. m., cent. p.	2,000	I.	
[c] P 2	do	16 S.	1 E.	31	NE.	Murphy	363	Dug	37.8	48 inches	Residuum	32	Oct. 7	W.		D; I.	
P 3	Jamul	17 S.	1 E.	4	SE.	J. H. Babcock	900	do	13			10		Hand p.		D.	
P 3	do	17 S.	1 E.	4	SE.	do	900	Spring				0		do	6	Bottled.	
P 4	do	17 S.	1 E.	9	NE.		1,000	Dug	32		Residuum	23.5	Oct. 28	W.		D.	
P 5	do	Jamul land grant.					800	do	26.5	4 by 4 feet		23	do	W.		S.	
P 6	do	do				Jamul ranch	800	do				20	do			Not used.	
P 7	Cocatoo Grove	17 S.	1 W.	34	SW.		510	do	29.7	48 inches	Tertiary	22.5		W.		S.	
P 8	Otay Mesa	18 S.	1 W.	27	S.	Loma Alta School	500	Drilled	700		do					P.	
P 9	do	18 S.	1 W.	35	SW.	Roul	490	do	310		do				1 2	D; S.	
P 10	do	19 S.	1 W.	1	NW.	Willpot	500	do	280		do				p d 150	D.	

[a] Elec. m.=electric motor; Dis eng.=distillate engine; Gas. eng.=gasoline engine; Stm. eng.=steam engine; W=windmill; Bucket=rope and bucket; Cent. p.=centrifugal pump; Suct. p.=suction pump; Hand p.=hand pump; Inc.=incomplete.

[b] D=domestic, I=irrigation; P=public.

[c] For chemical composition of water, see corresponding number in Table 59, p. 263.

[d] For chemical composition and classification of water, see corresponding number in Table 57, pp. 260-261.

[e] See Table 45, p. 209.

[f] For chemical composition and classification of water see corresponding number in Table 58, p. 262.

method described by M. O. Leighton in Water-Supply Paper 151 (pp. 45–47); and hardness was determined by the soap method described in the report on standard methods for the examination of water and sewage, third edition (pp. 31–34), published by the American Public Health Association, New York city.

"Sodium and potassium (Na+K)" was computed according to the formula on page 235.

"Total solids" was computed according to the formula at the bottom of page 228; in applying this formula 34 was used as the quantity of silica, the average content of silica determined by analysis in 50 ground waters of San Diego County being 34 parts per million.

The quantities of scale-forming and foaming constituents have been computed according to formulas 1 and 3, respectively, page 243.

The alkali coefficient has been computed according to the same formula as was used for analyses (p. 234).

The probability of corrosion is based on a computation made by applying the formula for assays given in the first paragraph on page 244.

The following discussion of the general quality of water was written by R.B. Dole and is reprinted from "Ground water in San Joaquin Valley, Calif.," by W. C. Mendenhall, R. B. Dole, and Herman Stabler (Water-Supply Paper 398), but matter irrelevant to western San Diego County has been omitted.

STANDARDS FOR CLASSIFICATION.

MINERAL CONSTITUENTS OF WATER.

All natural waters contain dissolved or suspended materials with which they have come into contact. They take up such materials in amounts determined principally by the chemical composition and physical structure of the substances, by the temperature, pressure, and duration of their contact, and by the condition of substances that they have previously incorporated. For purposes of examination the substances that may be present in natural waters are classified as suspended matter, such as particles of clay or leaves; dissolved matter, either of mineral or organic origin; microscopic animals or plants; and bacteria. The presence of very small animals and plants likely to affect the quality of water is determined by microscopic examination, and the chance of contracting disease by drinking the water is ascertained by bacteriologic processes. The amount and nature of the mineral ingredients are most commonly determined by estimating the total suspended matter, total dissolved matter, total hardness, total alkalinity, silica, iron, aluminum, calcium, magnesium, sodium, potassium, carbonate, bicarbonate, sulphate, nitrate, chloride, free carbonic acid, and free hydrogen sulphide, these being the materials most commonly present and most likely to affect the value of the waters.

WATER FOR DOMESTIC USE.

PHYSICAL QUALITIES.

Entirely acceptable domestic supplies are free from suspended matter, color, odor, and taste and are fairly cool when they reach the consumer. The more nearly waters fulfill these conditions the more satisfactory they are for general use. Suspended mineral matter clogs pipes, valves, and faucets, and growths of microscopic plants suspended in water frequently cause odors and stains. The outlets of some artesian wells are surrounded by growths of microscopic organisms, which form tufts or layers in pipes and well casings and sometimes clog them. So far as known, such growths do not cause disease, but they often impart unpleasant odors that make the water objectionable. True color is usually due to dissolved vegetable matter and causes serious objection only when it exceeds 20 to 30 parts per million.

BACTERIOLOGICAL QUALITIES.

Before a water is used for domestic purposes there should be reasonable certainty that it is free from disease-bearing organisms and that it can be guarded against all chances of infection. The disease germs most commonly carried by water are those of typhoid fever. The bacilli enter the supply from some spot infected by the discharges of a person sick with this disease, and, though comparatively short-lived in water, they persist in fecal deposits and retain their power of infection for remarkable lengths of time. Consequently, water from lakes and streams draining from population centers or from irrigated fields should not be used for drinking without purification. Wells should be so located as to be guarded against the entrance of filth of any kind, either over the top or by infiltration. Pumps and piping in the system should also be protected. Water from a carefully cased well more than 20 or 30 feet deep is acceptable if the well is located at a reasonable distance from privies, cesspools, and other sources of pollution. Many open dug wells and pits constructed as reservoirs around the tops of casings are exposed to fecal contamination from above or through cracks in poorly built side walls. Care should be taken that the casings of deep wells do not become leaky near the surface of the ground so as to allow pollution to enter. As a matter of ordinary precaution the ground should be kept clean and water should not be allowed to become foul or stagnant near any well, no matter how deep. If shallow dug wells are necessary, they should be constructed with water-tight walls extending as far as practicable into the well and also a short distance above ground. The floor or curbing should be water-tight, and pumps should be used in preference to buckets for raising the water. Every possible precaution should be taken to prevent feet scrapings and similar dirt from getting into the well. Ground water is not only less likely to become contaminated when protected from surface washings, air, and light, but it keeps better and is less likely to develop microscopic plants that give it an unpleasant taste.

CHEMICAL QUALITIES.

The amounts of dissolved substances permissible in a domestic supply depend much on their nature. No more than traces of barium, copper, zinc, or lead should be present, because these substances are poisonous; however, their occurrence in measurable amounts in ordinary waters is so rare that tests for them are not usually made. Any constituent present in sufficient amount to be clearly perceptible to the taste is objectionable. Water containing 2 parts per million of iron is unpalatable to many people and may cause trouble by discoloring washbowls and tubs and by producing rusty stains on clothes. Tea and coffee can not be made satisfactorily with water containing much iron because a black inky compound is formed. Four or five parts of hydrogen sulphide makes a water unpleasant to the taste, and this gas is objectionable also because it corrodes well strainers and other metal fittings. The amounts of silica and aluminum ordinarily present in well waters have no special significance in relation to domestic supply.

Approximately 250 parts of chloride makes a water "salty," and less than that amount causes corrosion. Where the chloride content runs as low as 5 or 10 parts in normal waters unaffected by animal pollution, the amount of chloride is frequently taken as a measure of contamination. But the establishment of isochlors, or lines of equal chloride, would be of little sanitary value, because many of the ground waters dissolve so much chloride from the silt that the small changes caused by animal pollution are completely masked.

Calcium and magnesium are the chief causes of what is known as the hardness of water. This undesirable quality is indicated by increased soap consumption and by deposition on kettles of scale composed almost entirely of calcium, magnesium, carbonate, and sulphate. Calcium and magnesium, forming with soap insoluble curdy compounds that have no cleansing value, prevent the formation of a lather until these two basic radicles have been precipitated. Hardness is commonly measured by the soap-consuming capacity of a water expressed as an equivalent of calcium carbonate ($CaCO_3$), and it can be determined by actual testing with a standard solution of soap or can be computed from the amounts of calcium (Ca) and magnesium (Mg) by means of the following formula:

$$\text{Total hardness as } CaCO_3 = 2.5\ Ca + 4.1\ Mg.$$

If, as Whipple states,[1] 1 pound of ordinary soap would soften only about 24 gallons of water having a total hardness of 200 parts per million, it can readily be seen that the hardness of water is of intimate concern. Soda ash (sodium carbonate) is used to "break" or soften hard water in order to save soap. Some large cities in other States have found it advisable to soften their public supplies instead of leaving that task to the individual consumer.

MINERAL MATTER AND POTABILITY.

The lower waters are in mineral content the more acceptable they are as sources of supply, yet the amount of dissolved substances that can be tolerated in drinking water is much greater than that allowable in city supplies, for which hardness, corrosion, pipe clogging, and general utility have to be considered. Though there are certain limits above which the common ingredients are intolerable, these limits are not only difficult to ascertain but are also likely to shift. A normal water is not a pure solution of one salt, whose physiologic effect can be measured, but an indeterminate mixture of solutions of several salts whose effects are not easily differentiated. Further, though all animals select for drinking waters that are lowest in solids and avoid those that are highest, the same animals, when transported to districts of poor water, accustom themselves to supplies of far greater mineral content than those which before they would not touch. Consequently any general limits that may be assigned to the various mineral ingredients must be regarded as extremely flexible.

The immediate consequence of drinking waters too high in mineral content is usually diarrhea. Many persons at first afflicted with this trouble become accustomed to the new supply and acquire what may be termed immunity. Whether other disorders result from the continued drinking of such waters is not known; and it is equally uncertain whether cattle and horses that so commonly are reported to have been killed by drinking strong mineral water were killed by the purging produced by the mineral matter in the water or by excessive consumption of water itself. It would appear [2] that alkaline carbonates are most injurious and alkaline sulphates least injurious and that alkaline chlorides occupy an intermediate position. This arrangement corresponds to the order of the same substances in reference to their toxic effect on plants. Waters exceeding 300 parts per million of carbonate, 1,500 parts of chloride, or 2,000 parts of sulphate are apparently intolerable to most people. These limits fortunately are far beyond the points where the substances in solution are clearly perceptible to the ordinary taste. In conclusion it can not be too emphatically stated that the information on this sub-

[1] Whipple, G. C., The value of pure water, p. 26, New York, 1907.

[2] This conclusion is drawn from investigation of quality of waters in San Joaquin Valley by R. B. Dole: U. S. Geol. Survey Water-Supply Paper 398, p. 77, 1916.

ject is fragmentary and uncertain and that any limits of mineral tolerance are modified by individual idiosyncrasy.[1]

INTERPRETATION OF ANALYTICAL DATA IN RELATION TO POTABILITY.

CHEMICAL CHARACTER.

The total amount of mineral matter and the nature of the chief constituents in a water comprise the essential information for judging its potability in respect to mineral ingredients.

Silica is usually present in colloidal form and it is relatively constant in quantity. Calcium and magnesium are similar in many effects and they vary in amount together, calcium usually being the greater. Sodium and potassium are so similar in effect that they are seldom separated in industrial analyses but are reported together as sodium. Carbonate and bicarbonate, representing more or less conventionally different conditions of carbonate in equilibrium, may be considered together under the common term of carbonate (CO_3), to which bicarbonate is translated by dividing by 2.03. These groupings, rendered possible by the usual mode of occurrence of these substances and by their effects, greatly simplify classification of waters. The alkalies, sodium and potassium, can be computed by the Stabler formula already noted. The amounts of the chief acids and bases are used in applying the following classification:

$$\left.\begin{array}{l}\text{Calcium (Ca)}\\ \text{Sodium (Na)}\end{array}\right\}\left\{\begin{array}{l}\text{Carbonate } (CO_3).\\ \text{Sulphate } (SO_4).\\ \text{Chloride (Cl).}\end{array}\right.$$

The designation "calcium" indicates that calcium and magnesium predominate, and "sodium" that sodium and potassium predominate among the bases; the designation "carbonate," "sulphate," or "chloride" shows which acid radicle predominates. Combination of the two terms classifies the water by type, and tabulation of the classification can be abbreviated by use of the symbols. The appellation Na–CO_3, for example, indicates that sodium and potassium predominate among the bases and that carbinate or bicarbonate, or both, predominate among the acids, and that the water would yield on concentration and crystallization more sodium carbonate than any other salt, though this classification does not in any way show the amounts of the salts in solution.

The numerical preponderance of certain acid and basic radicles establishes the nature of many waters, but if further refinement in classification is desired comparison can be made of the reacting values of the radicles, which are the fundamental bases of the effect of the radicles. These values can be computed by multiplying the amount of each constituent by its valence and dividing the product by its

[1] For further data see Dole, R. B., Concentration of mineral water in relation to therapeutic activity: U. S. Geol. Survey Mineral Resources, 1911, pt. 2, pp. 1175–1192, 1912.

molecular weight. The factors given in Table 47 can be used for that purpose. The factor for sodium may be used for the combined values of sodium and potassium.

TABLE 47.—*Factors for computing reacting values.*

Basic radicles.	Factor.	Acid radicles.	Factor.
Calcium (Ca)	0.0499	Carbonate radicle (CO_3)	0.0333
Magnesium (Mg)	.0821	Bicarbonate radicle (HCO_3)	.0164
Sodium (Na)	.0434	Sulphate radicle (SO_4)	.0208
Potassium (K)	.0255	Nitrate radicle (NO_3)	.0161
		Chloride radicle (Cl)	.0282

TOTAL SOLIDS.

Total solids can be computed from the data of an assay in several ways, one of which is to calculate the probable amount of saline residue that would be produced by the acid radicles and to add thereto an arbitrary amount for silica, undetermined substances, and volatile matter. As potassium has the smallest reacting weight of the four common bases the assumptions that equal amounts of sodium and potassium are present and that calcium and magnesium are absent constitute an extreme condition representing a maximum saline residue; similarly, the assumptions that equal parts of calcium and magnesium are present and that the alkalies are absent constitute the condition representing a minimum saline residue. A formula based on an average between these two extremes gives an estimate of total solids (T. S.) within 15 per cent of the exact value for most natural waters.

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

The average content of silica (SiO_2) in ground waters of San Diego County, as determined from 50 analyses, is about 34 parts per million. The estimate of solids should not be expressed more closely than to the nearest 10 parts or with more than two significant figures.

The criteria for classification of water for domestic use includes not only the nature and quantity of each constituent present but also the total quantity of mineral matter. The following table gives an approximate rating for the concentration of water:

TABLE 48.—*Rating of waters by total solids.*

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

WATER FOR IRRIGATION.

SOURCE OF ALKALI.

Many mineral substances are injurious to vegetation, but the only ones that are usually abundant enough to demand attention are compounds of sodium, or, as they are commonly termed, "the alkalies." Though potassium in nominal quantity is a plant food, it is usually not separated from sodium in commercial analyses of water, the two bases being estimated together and reported as sodium; but as the proportion of potassium in highly mineralized waters is commonly low compared with that of sodium this disregard of potassium does not lead to any considerable error in judging the value for irrigation. During the natural decomposition or rotting of rocks and soils salts of the alkalies, easily soluble in water, are formed. These compounds are leached from the soil and washed away in regions where plenty of rain falls, and consequently they do not become concentrated enough to damage crops; but wherever the rainfall is insufficient to effect this removal such materials continually increase, and the proportion of them may become so great that plants are stunted or killed and the ground becomes unproductive.

Accumulations of alkali can also be caused in another way. All waters that penetrate the ground either naturally or as a result of irrigation contain these salts in solution, and evaporation of the water, leaving the salts, adds to the supply that has been formed by decomposition of rock.

OCCURRENCE OF ALKALI.

The soluble salts are not evenly distributed over an area or through a given depth, but are ordinarily concentrated in patches near the surface. Such patches may be found in slight depressions into which mineralized water has seeped or drained and from which it has later evaporated. The underground water drawn to the surface by capillarity also brings alkali, which becomes concentrated in the upper layers of the soil. Where the salts are largely sulphates or chlorides the plots are covered with deposits of so-called "white alkali"—that is, crystals of alkaline chlorides and sulphates, mostly common salt and Glauber's salt; but when much carbonate is present the plots are blackened by solution of humus and are termed spots of "black alkali." It can readily be understood from the manner in which the salts are formed and from the possibility of their introduction by seepage or irrigation that the alkali content of a soil can progressively increase until it reaches a strength that will destroy plants previously unaffected. Conversely, a soil that is normally too high in alkali can be rendered productive by washing part of the soluble salts out of it.

If the alkali content of a soil is excessive the growth of cultures is retarded or entirely prevented. A still greater amount of salts kills the most resistant plants, and the area becomes devoid of vegetation. The chief cause of the poisonous action is commonly considered to be abstraction of water from the plant roots by change of the osmotic pressure, but bad effects are also probably more or less due to corrosion of the plant roots, germicidal action on the soil bacteria, and interference with the food supply through solution of humus.

PERMISSIBLE LIMITS OF ALKALI.

The cause and the manner of the harmful action are, however, not so important at present as the amount of these toxic compounds that can be tolerated by crops, for the limit of resistance in soils fixes in turn the maximum content of waters that can safely be used for irrigation, and it indicates the precautions that must be taken in applying the water. Yet it becomes evident from brief consideration of the problem that limits of tolerance must be very broadly interpreted and that absolute classification of waters in respect to their irrigation value is impracticable.

Many investigators have studied the effect on plant growth of mineral substances in water solutions, and the excellent work of Kearney and Cameron [1] is typical of these. Experimenting with seedlings of white lupine and alfalfa in different strengths of pure solutions, they found that the readily soluble salts common in soils are toxic in the following order: Magnesium sulphate, magnesium chloride, sodium carbonate, sodium sulphate, sodium chloride, sodium bicarbonate, and calcium chloride, the first being 200 times as harmful as the last. But when similar tests were made in the presence of an excess of calcium sulphate and calcium carbonate both the order of toxicity and the maximum concentrations in which the seedlings would grow were entirely changed. The order and the limits for lupine under these conditions are sodium carbonate, 1,560 parts per million; sodium bicarbonate, 4,170 parts; magnesium chloride, 9,600; sodium chloride, 11,600; calcium chloride about 16,000; sodium sulphate, 21,600; and magnesium sulphate, 22,400. Magnesium sulphate, which is most toxic in pure solution, is least harmful in the presence of large amounts of calcium carbonate and sulphate. The chlorides of magnesium, sodium, and calcium follow each other in relative toxicity.

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[1] Kearney, T. H., and Cameron, F. K., Some mutual relations between alkali soils and vegetation: U. S. Dept. Agr. Rept. 71, 1902.

Cameron, F. K., and Breazeale, J. F., The toxic action of acids and salts on seedlings: Jour. Phys. Chemistry, vol. 8, p. 1, 1904.

Jensen, G. H., Toxic limits and stimulation effects of some salts and poisons on wheat: Bot. Gazette, vol. 43, p. 11, 1907.

Kahlenberg, L., and True, R. H., The toxic action of dissolved salts and their electrolytic dissociation: Bot. Gazette, vol. 22, p. 81, 1896.

Heald, F. D., The toxic effect of dilute solutions of acids and salts upon plants: Bot. Gazette, vol. 22 p. 125, 1896.

The sulphate was found to be the least harmful of the sodium salts, sodium chloride being twice and the carbonate fourteen times as poisonous. These alterations are extremely significant, for none of the salts occurs in large amount in soils except in the presence of large quantities of calcium and more or less of all the other harmful salts. Therefore the death point in a simple solution of one salt is not a safe measure of tolerance, for the power of resistance under natural conditions depends on complex reactions between all the components of the soil solution.

Other investigators have shown not only that different cultures have different degrees of resistance but also that the order of toxicity of the various salts is changed. Some species of rather weak tolerance have also been bred to withstand high concentrations, and it is a matter of ordinary observation in regions of alkali that certain crops die on land where others flourish. The vertical position of the soluble salts also is important. Where, as under ordinary conditions, they are concentrated near the surface they can do the greatest amount of damage because they are in contact with the delicate roots. But they may be washed downward out of the danger zone by proper application of water. All these considerations make it evident that the nature of the crops, the manner of cultivation and irrigation, the other mineral components of the soil, and many other factors affect tolerance to alkali; when the effects of reactions between the mineral constituents of the soil and of the applied water are added to these modifying features it must be admitted that all general conclusions regarding the potential value of a water supply for irrigation are subject to much modification in particular cases.

Possibly the best basis for conclusions on the value of water for irrigation is the work of Loughridge,[1] who has endeavored to determine the greatest amounts of alkali in the upper 4 feet of ground in the presence of which cultures grow and come to maturity. In pursuance of this plan observations were made of the condition of fruit trees, shrubs, cereals, and other cultivated plants growing or dying in soils which were then partly analyzed. Loughridge's results are of great practical interest because they are linked with observations on cultures growing under natural conditions on a large scale, and they are here particularly valuable because they represent experiments mostly in the territory covered by this report. Interpretation of the figures is complicated, however, as Loughridge points out, by uncertainty as to whether the observed poor growth was always due to presence of alkali and not to other harmful conditions. As not one alone but all the salts are present in natural soils and as they owe

[1] Loughridge, R. H., Tolerance of alkali by various cultures: California Univ. Agr. Exper. Sta. Bull. 133, 1901. Quoted by Hilgard, E. W., Soils, p. 467, New York, Macmillan Co., 1906. See also California Univ. Agr. Exper. Sta. Bulls. 128, 140, and 169.

their toxic action to the extent to which they are dissociated, the impossibility of determining the exact amounts of the different salts in solution or the share of each acid and each basic radicle in the toxic action is fully apparent. Notwithstanding these doubtful points much can be learned from the studies regarding the relative tolerance of cultures.

The amount of alkali that could be tolerated was found to depend largely on the distribution of the salts in the vertical soil column, the injury usually being greatest in the upper foot, where the feeding roots and the greatest amount of alkali occurred together. The range of tolerance for different cultures is very great. Lemon trees, considered very sensitive, were unaffected in the presence of 5,760 pounds of alkali per acre 4-feet, while grapevines withstood nearly eight times as much, or 45,760 pounds. Sorghum flourished in soil containing 81,360 pounds per acre 4-feet, but rye withstood only 12,480 pounds of alkali. The fact that some plants are more readily affected when they are young is well illustrated by alfalfa, which tolerates more than eight times as much alkali when old as when young. Experiments in vineyards showed that different varieties are affected to different degree by alkali and as a corollary that alkali changes the composition of grapes.

RELATIVE HARMFULNESS OF THE COMMON ALKALIES.

Though various cultures are affected in different degree by sodium in the three common forms of carbonate, chloride, and sulphate, there is some general agreement. Sodium as the carbonate is commonly the most harmful, as the chloride somewhat less so, and as the sulphate least harmful. Hilgard [1] gives the maxima for cereals grown on a certain sandy loam as about 0.1 per cent of sodium carbonate, 0.25 per cent of sodium chloride, and 0.48 per cent of sodium sulphate, corresponding to a toxicity ratio expressed in terms of sodium of 1 : 1.6 : 3.6. The relative harmfulness of sodium in the sulphate, chloride, and carbonate, respectively, can be expressed according to Loughridge's results for 10 standard crops of San Joaquin Valley by the ratio 1 : 5 : 6.6; that is, sodium as the carbonate is 6.6 times as harmful, and sodium as the chloride 5 times as harmful as sodium as the sulphate. A similar ratio for the 15 most sensitive crops is 1 : 5.3 : 6.4. If, therefore, sodium as the sulphate is given a toxicity of 1 a reasonably approximate estimate of the relative toxicity of sodium as the sulphate, chloride, and carbonate, respectively, would be expressed by the ratio 1 : 5 : 6. Stabler has used in his formulas, quoted later, the ratio 1 : 5 : 10 in order to allow for the undesirable puddling of the soil by the carbonate.

[1] Hilgard, E. W., Soils, p. 464, New York, Macmillan Co., 1906.

RELATION BETWEEN APPLIED WATER AND SOILS.

When water used in irrigating evaporates from the surface of the soil it leaves in the ground its content of salts. If all the applied water were to escape by evaporation, constant use of any supply, no matter how pure it might be, would eventually result in an accumulation of alkali that would render the soil unproductive. If, on the other hand, all of a water not too high in mineral content were to seep downward into the deep-lying strata it would leach out the soluble salts of a highly charged area, which would thus be made productive. Such extreme conditions, however, are not natural. Though evaporation greatly exceeds rainfall in arid regions, and the accumulation of alkali is thus facilitated, part of the water seeping away carries with it a load of salts in solution. Various amounts of mineral matter are also taken up by crops and are removed during harvesting; then, too, the sodium in the soil and in the applied water can be prevented by proper methods of irrigation and drainage from accumulating where it will damage the delicate feeding roots of cultures. Consequently, waters of a relatively low mineral content may be applied year after year without inflicting damage, but those exceeding a certain limit of mineral content are useless for irrigation; waters of an intermediate class, normally capable of increasing the alkalies in the soil, may be harmless under judicious usage. This outline of the general relations between the saline content of soils and of waters used on them indicates other allowances that should be made in estimating to what extent the mineral matter in applied waters affects their value for irrigation.

NUMERICAL STANDARDS.

Twelve hundred parts per million of mineral matter is the limit of concentration given by Hilgard [1] for irrigation water in all cases under the ordinary practice in California. This limit is greatly modified by the character of the dissolved salts, and the results of extensive irrigation elsewhere indicate that very much stronger waters can be used on some soils if they are properly applied. Basing his computations on Loughridge's determinations of tolerance,[2] Stabler [3] has developed formulas for rating waters in respect to their value for irrigation. His comparison is made by means of an "alkali coefficient" (k), which is defined as the depth in inches of water which would yield on evaporation sufficient alkali to render a 4-foot depth of soil injurious to the mose sensitive crops. The sodium equiva-

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[1] Op. cit., p. 248.

[2] Loughridge, R. H., Tolerance of alkali by various cultures: California Univ. Exper. Sta. Bull. 133, 1901.

[3] 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, p. 177, 1911. See also Eng. News, vol. 64, p. 57, 1910.

lents of the three common salts of sodium, the sulphate chloride, and carbonate, are assigned relative toxicities of 1, 5, and 10, respectively, and the maximum tolerance of sensitive cultures is taken as 1,500 pounds of sodium in the form of sulphate per acre 4-feet. The correctness of the latter assumption by itself might be questioned in view of the fact that Loughridge's figures for cultures at the lower end of his lists are particularly liable to upward revision after further investigation. Yet this should not lead to appreciable error as the chief value of the formulas rests in the ratio of toxicities and the interpretation of the computed value of k.

If $Na-0.65\ Cl$ is zero or negative, $k=\frac{2,040}{Cl}$.

If $Na-0.65\ Cl$ is positive but not greater than $0.48\ SO_4$, $k=\frac{6,620}{Na+2.6\ Cl}$.

If $Na-0.65\ Cl-0.48\ SO_4$ is positive, $k=\frac{662}{Na-0.32\ Cl-0.43\ SO_4}$.

The alkali coefficient, k, is in inches, as already explained; the symbols SO_4, Cl, and Na represent, respectively, the amounts in parts per million in the water of sulphate, chloride, and alkalies, the latter being commonly grouped under the name of sodium. Consideration of bicarbonate is precluded because estimates of it apparently were not made in the work on which the formulas are based. The three formulas represent the different relations between the alkali and the acid radicles. Under the first condition, with enough, or more than enough, chloride to satisfy sodium, it is assumed that chlorides other than that of sodium are as harmful as that compound. Cameron [1] found that magnesium chloride, sodium chloride, and calcium chloride had relative toxicities of 1.2: 1.0: 0.6, respectively, in the presence of an excess of calcium sulphate or of calcium sulphate and calcium carbonate. Under the second condition, where the chloride and sulphate radicles together are sufficient to satisfy sodium, and under the third, where both chloride and sulphate are insufficient to satisfy sodium, magnesium is assumed to have no deleterious effect. This base loses the greater part of its toxic power when much calcium is present and therefore this assumption seems justifiable as not only is calcium usually high in all soils, but also it commonly exceeds the proportion of magnesium in natural waters. Though the formulas are based on the relative predominance of the radicles, they should not be interpreted as signifying that the acids and bases are combined, but as presenting the maximum possibilities of the deposition of harmful alkali salts in the soil layer. Waters to which the first two formulas are applicable are likely to leave white alkali on evaporation, and those in the third class probably yield black alkali.

[1] Cameron, F. K., and Breazeale, J. F., The toxic action of acids and salts on seedlings: Jour. Phys. Chemistry, vol. 8, p. 1, 1904.

The approximate amount of alkali in a water can be computed from the results of an assay by the following formula:

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

The symbols represent the amounts in parts per million of alkali (sodium and potassium) and the carbonate, bicarbonate, chloride, sulphate, and total hardness found by assay. The equation expresses the theoretical relation that the sum of the reacting values of the acid radicles minus the reacting values of calcium and magnesium, which together are one-fiftieth of total hardness, equals the reacting value of the alkalies; the factor 25 instead of 23, the atomic weight of sodium, is used for safety. Because of the approximate nature of the figures of assays, values of k computed from them should be reported with not more than two significant figures and to the nearest 10 when they exceed 30.

The following ratings for interpreting values of the alkali coefficient are proposed by Stabler:

Value of k (inches).	
Greater than 18	Good.
6 to 18	Fair.
1.2 to 5.9	Poor.
Less than 1.2	Bad.

The value of k, showing the number of inches of water that would yield on evaporation sufficient alkali to inhibit the growth of very sensitive plants, indicates the relative degree of care that is essential in applying a water to irrigated tracts. As defined by Stabler, "good" waters are those that can be used for many years without special care to prevent alkali accumulation. Waters classed as "fair" require special care to prevent gradual concentration of alkali except in loose soils with free natural drainage. In using waters classed as "poor" care in selection of soils has been imperative and artificial drainage has frequently been necessary. The "bad" waters contain so much harmful matter in solution that they are practically valueless for irrigation. These ratings are based on general practice in the arid and semiarid regions of the United States, and so far as they can be checked by comparison with actual experience in the use of waters they answer all practical purposes.

This rating, like any other that might be devised, should be liberally interpreted. It is well to repeat emphatically that it signifies only a comparison of the waters themselves on the basis of their mineral content. It has no reference whatever to the possibility of raising good crops on land to which the waters may be applied, because it does not take into account the alkali content and the texture of the soil, drainage conditions, the method of irrigation, the duty of the water, or the other factors on which agricultural success depends.

REMEDIES FOR ALKALI TROUBLES.

WASHING DOWN THE ALKALI.

The relation between applied water and soils makes it apparent that the farmer can control the alkali content of his ground to great extent by the manner in which he applies water and the care he takes to prevent accumulation of soluble salts near the surface. When a deep, readily pervious soil is covered with water to a proper depth by flooding, the water rapidly soaks into the soil, dissolving the alkali salts concentrated near the surface and carrying them downward beyond the zone of influence on the delicate feeding rootlets. But if the ground is not then protected against surface evaporation the water is drawn upward and alkali again impregnates the top layers. This action can be prevented in some measure by thorough cultivation as soon as possible after irrigation, and the shade afforded by trees and good stands of grass or grain also minimizes it. This shading effect partly explains why well-established growths of some cultures can thrive in soil containing an amount of alkali injurious to younger crops. A good stand of alfalfa, for instance, inhibits surface evaporation and consequent rise of alkali to the feeding roots, though the ground deeper down may contain enough alkali to kill the plants; whereas newly started alfalfa can not prevent evaporation, and the alkali, dissolved by the water and rising with it by capillarity, becomes concentrated where it can do the greatest damage. A shallow soil underlain by hardpan is not benefited by flooding alone, as the leaching is stopped by the impervious layer.

It is a prevalent idea that alkali can be washed from a piece of land by flooding it with large quantities of water and then allowing the surplus to run off. The improvement is, however, not due so much to removal of the comparatively small quantities of material carried away in the off-flow as to depression of the alkali by the downward percolation just described. The results of some experiments by Headden[1] illustrate this well. Two waters, the composition of which is given in columns A and B of Table 49, were used during two successive days to flood a tract of alkali land about 600 feet long. Four samples of the off-flow were taken, two at the beginning of the off-flow and two just before the on-flow was stopped, and the average of the analyses of these four samples is given in column C. Though one of them, taken at the very commencement of the off-flow, carried 1,238 parts per million of dissolved solids, this high content lasted only a few minutes, and comparison of the

[1] Headden, W. P., Colorado irrigation waters and their changes: Colorado Agr. Coll. Exper. Sta. Bull. 82, 1903.

average with the results in columns A and B shows how little the total mineral content of the water that remained above ground and finally flowed off after crossing the entire area was increased by solution of the alkali in the soil.

TABLE 49.—*Effect of flooding on alkali as shown by composition of water.*

[Parts per million.]

Constituents.	A	B	C	D	E
Total solids	328	706	760	1,415	3,278
Organic and volatile matter	27	37	44	92	145
Silica (SiO_2)	10	14	12	23	20
Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	1.0	3.4	.8	1.6	.7
Calcium (Ca)	43	90	93	139	314
Magnesium (Mg)	10	24	30	66	170
Manganese (Mn)	.6	.8	.2	.7	1.0
Sodium (Na)	42	96	102	195	436
Potassium (K)	3.6	3.8	5.6	1.9	6.4
Carbonate radicle (CO_3)	64	106	112	120	149
Sulphate radicle (SO_4)	113	305	335	713	1,885
Chloride radicle (Cl)	10	24	24	60	147

A. Water used in irrigating on Sept. 1.
B. Water used in irrigating on Sept. 2.
C. Average composition of off-flow Sept. 2.
D. Average composition of water from 4 shallow wells Aug. 31.
E. Average composition of water from 4 shallow wells Sept. 2.

Four shallow wells in the plot, protected against entrance of water over the top, were sampled before (column D) and after irrigation (column E). The composition of the ground water portrayed by these averages is typical in showing the downward passage of the alkali salts in the soil. The average amount of mineral matter in the off-flow is only slightly greater than that in the applied water that was used in greater quantity, but the water in the wells increased in dissolved solids from 1,415 parts to 3,278 parts per million, calcium, magnesium, sodium, sulphate, and chloride having been more than doubled. Headden estimates that the ground water gained about 5,000 pounds of mineral matter per acre-foot of water by this irrigation.

The effect of natural precipitation in washing down the soluble salts can be illustrated by analyses of water from the same wells after a long period of heavy rainfall. Just before the rain stopped the water of one well contained 10,360 parts per million of total solids, an amount several times the normal; only eight days later solids had fallen to 6,450 parts; and to 2,030 parts after a month. This decided increase of mineral content after rainfall and the subsequent decrease coincident with the loss of water by evaporation and drainage can be explained by change in position of the soluble salts in the soil column.

Irrigation by shallow furrows from which the water soaks into the ground causes downward transmission of alkali in pervious soils like flooding, with the added advantage that the decreased evaporation lessens the tendency toward surface concentration of alkali. Deep, narrow furrows would undoubtedly still further reduce the proportion of water lost by evaporation and would prevent the rise of alkali by affording deeper circulation of the water supply.

DRAINAGE.

Such downward washing of soluble substances affords no permanent relief, for the alkali, not being removed, may be drawn again to the surface, or may rise as a result of wasteful irrigation, a trouble common in water-logged soils. Downward washing can be safely relied on only when the soils are pervious and have good natural drainage. Application of heavily mineralized water even under such conditions year after year may increase the amount of the harmful ingredients and render them more difficult to handle. The recognized permanent remedy is installation of underdrains, through which the dissolved substances may be removed. The installation of drainage is costly, but it has become an essential part of irrigation systems wherever the soils are very bad or the waters are high in harmful ingredients, for it not only facilitates the removal of the deleterious salts originally in the ground but also affords means for preventing accumulation of alkali when very strong waters are used.

The experimental plots cultivated by the Department of Agriculture in Fresno County where the "rise of the alkali" has spoiled otherwise good ground have been thoroughly reclaimed by underdrainage.[1] The best results with strong saline waters have been obtained by irrigating copiously at frequent intervals. In conjunction with free drainage such operation prevents concentration of alkali salts in the soil, for any accumulation that may form is quickly dissolved and washed downward.

MISCELLANEOUS REMEDIES.

Though it is possible to remove a large proportion of the alkali crust by scraping the surface of the land that method is too expensive to be generally adopted. Growing and completely cropping plants that secrete relatively large quantities of alkali is tedious but fairly successful. The injurious effect of carbonate alkali can be greatly reduced by spreading the ground with gypsum, by action of which carbonate of lime and alkali sulphates are formed. As carbonate alkalies are much more harmful than chlorides or sulphates treatment of this character lessens the toxic action.

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[1] Fortier, Samuel, and Cone, V. M., Drainage of irrigated lands in the San Joaquin Valley, Calif.: U. S. Dept. Agr. Exper. Sta. Bull. 217, 1909.

WATER FOR BOILER USE.

FORMATION OF SCALE.

The most common trouble in boilers is formation of scale, or deposition of mineral matter within the boiler shell. When water is heated under pressure and concentrated by evaporation, as in a boiler, certain substances are thrown out of solution and solidify on the flues and crown sheets or within the tubes. These deposits increase fuel consumption because they are poor conductors of heat and increase the cost of boiler repairs and attendance because they have to be removed. If the amount of scale is great or if it is allowed to accumulate the boiler capacity is decreased and disastrous explosions are likely to occur.

The incrustation (scale) consists of the substances that are insoluble in the feed water or become so within the boiler under conditions of ordinary operation. It includes practically all the suspended matter, or mud; the silica, probably precipitated as the oxide (SiO_2); the iron and aluminum, appearing in the scale as oxides or hydrated oxides; the calcium, precipitated principally as carbonate and sulphate; and the magnesium, found chiefly as oxide but also partly as carbonate. Scale is therefore a mixture, which varies in amount, density, hardness, and composition with the quality of water supply, the steam pressure, the type of boiler, and other conditions of use. Calcium and magnesium are the principal basic substances in the scale, over 90 per cent of which usually is calcium, magnesium, carbonate, and sulphate. If much organic matter is present part of it is precipitated with the mineral scale, as the organic matter is decomposed by heat or by reaction with other substances. If magnesium and sulphate are comparatively low or if suspended matter is comparatively high the scale is soft and bulky and may be in the form of sludge that can be blown or washed from the boiler. On the other hand, a clear water relatively high in magnesium and sulphate may produce a hard, compact scale that is nearly as dense as porcelain, clings to the tubes, and offers great resistance to the transmission of heat. Therefore the value of a water for boiler use depends not only on the quantity but also on the physical structure of the scale produced by it.

CORROSION.

Corrosion or "pitting" is caused chiefly by the solvent action of acids on the iron of the boiler. Free acids capable of dissolving iron occur in some natural waters, especially in the drainage from coal mines, which usually contains free sulphuric acid, and also in some factory wastes draining into streams. Many ground waters contain free hydrogen sulphide, a gas that readily attacks boilers, and some contain dissolved oxygen and free carbon dioxide, which are also corrosive. Organic matter is probably a source of acids, for waters high in organic matter and low in calcium and magnesium are corrosive, though the nature and action of the organic bodies are not well understood. The chief corrosives are acids freed in the boiler by the deposition of hydrates of iron, aluminum, and magnesium, the last-named being the most important as it is the most abundant. The acid radicles that were in equilibrium with these bases may pass into equilibrium with other bases, displacing equivalent quantities of carbonate and bicarbonate; or they may decompose carbonates that have been precipitated as scale; or they may combine with the iron of the boiler, thus causing corrosion; or they may do all three, their action depending on the chemical composition of the water. Even with the most complete analyses this action can be predicted only as a probability. If the acid thus freed exceeds the amount required to decompose the carbonate and bicarbonate radicles it attacks the iron of the boiler and produces pits or tuberculations of the interior surface, leaks, particularly around rivets, and general deterioration.

FOAMING.

Foaming is rising of the water in the boiler and particularly in the steam space normally above the water, and it is intimately connected with priming, which is the passage from the boiler of water mixed with steam. Foaming results when anything prevents the free escape of steam from the water. It is usually ascribed to an excess of dissolved matter that increases the surface tension of the liquid and thereby reduces the readiness with which the steam bubbles break. As sodium and potassium remain dissolved in the boiler water while the greater portion of the other bases is precipitated, the foaming tendency is commonly measured by the degree of concentration of the alkali salts in solution, because this figure in connection with the type of boiler determines to great extent the length of time that a boiler may run without danger of foaming. It is a fact that the worst foaming waters in railroad practice are encountered in the arid and semiarid regions of the Southwest where the quantity of dissolved alkali is greatest. However, it is well known that suspended matter can cause foaming, for certain waters that deposit a moderate amount of scale but do not foam when clear, foam badly when they carry a great quantity of mud. Greth[1] states that foaming is due to condition of boiler, design of boiler, size and shape of water space, steam pipe, irregularity in blowing off, introduction of oil into the feed water from the exhaust steam, neglect to change water periodically, irregularity of load, or improper firing and feeding. He con-

[1] Greth, J. C. W., Water softening and purification for coal-mine operations (paper read before the West Virginia Coal Mining Institute, Bluefield, W. Va., June 7, 1910).

cludes that it is not merely the presence of sodium salts in solution that causes foaming, but the presence of other substances which together with the sodium salts and operating conditions bring about foaming. It is believed that a strong solution of sodium carbonate might not induce excessive foaming in water otherwise pure, but its introduction into a boiler, which under operating conditions invariably contains suspended matter or precipitated sludge, might produce foaming by increasing the suspended matter either by precipitating calcium and magnesium or by loosening previously deposited scale. Under working conditions it is difficult to distinguish the actual cause of the trouble. Experience has shown that the type of boiler, steam pressure, and other operating conditions may greatly accelerate or retard foaming.

REMEDIES FOR BOILER TROUBLES.

The best way of remedying unsatisfactory boiler supplies is to treat them before they enter boilers, but where this is impracticable trouble can be minimized in various ways. Low-pressure large-flue boilers are used in many stationary plants with hard waters, and it is said that the scale formed in them is softer and more flocculent and can therefore be more readily removed than that formed in high-pressure boilers. Blowing off is about the only practical means of preventing foaming, because this trouble is due principally to concentration of substances in the residual water of the boilers. Accumulated sludge, or soft scale, is removed by blowing, particularly in locomotive practice. In condensing systems much of the trouble due to mineral matter in the feed water is obviated because the quantity of raw water supplied is proportionately small. Yet the problem is not completely solved in such systems, because the incrusting or corrosive action is transferred from the boiler to the condenser, which requires more or less cleaning and repairing in proportion to the undesirable qualities of the water supply.

BOILER COMPOUNDS.

Boiler compounds are widely used in regions where hard waters abound, but treatment within the boiler should be given only when it is impossible to purify the supply beforehand or when the supply is relatively pure and requires only minor correction. If previous purification is not practicable some feed waters can be improved by judicious addition of chemicals. Many substances, ranging from flour, oatmeal, and sliced potatoes to barium and chromium salts, have been recommended for such use, but only a few have proved to be really efficient. These substances have been classified[1] according to their action within the boiler. Those that attack chemically the

[1] Cary, A. A., The use of boiler compounds: Am. Machinist, vol. 22, pt. 2, p. 1153, 1899.

scaling and corroding constituents precipitate incrusting matter and neutralize acids. Soda ash, the commercial form of sodium carbonate containing about 95 per cent Na_2CO_3, is the most valauble substance of this character, because it is cheap and its use is attended with the least objectionable results. Tannin and tannin compounds are also used for the same purpose. The addition of limewater to the feed to prevent corrosion and to obviate foaming has been recommended,[1] and it is probable that it would improve waters high in organic matter and very low in incrustants. Such practice increases the incrustants in proportion to lime added but prevents corrosion. Soda ash neutralizes free acids, precipitates the incrusting ingredients as a softer, more flocculent material, which is more easily removed from the boiler, and increases the foaming tendency of the water by increasing its content of dissolved matter. The proper amount to be used depends on the chemical composition of the water and the style of the boiler.

The second class of boiler compounds comprises those that act mechanically on the precipitated crystals of scale-making matter soon after they are formed, surrounding them and robbing them of their cement-like action. Glutinous, starchy, and oily substances belong to this class, but they are not now used to any considerable extent because they thicken and foul the water more than they prevent the formation of hard scale.

The third class comprises compounds that act mechanically like those of the second class and also partly dissolve deposited scale, thus loosening it and aiding in its ready removal. Of these, kerosene is very effective, but graphite is believed to be still better.

Many boiler compounds possessing or supposed to possess one or more of the functions just described are on the market and are widely sold. Some are effective and some are positively injurious. Most of them depend for their chief action on soda ash, petroleum, or a vegetable extract, but all are costly compared with lime and soda ash. Boiler compounds can not reduce the amount of scale and may increase it. Their only legitimate functions are to prevent corrosion and deposition of hard scale and to remove accumulations of scale that have become attached to the boiler. Every engineer should bear in mind that steam boilers are costly and that fuel and boiler repairs are costly and should hesitate to add substances to his feed water without competent advice as to their effect. It is far more economical to have the water supply analyzed and to treat it effectively by well-known chemicals in proper proportion, either within or without the boiler, than to experiment with compounds of unknown composition.

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[1] Palmer, Chase, Quality of the underground waters in the Blue Grass region of Kentucky: U. S. Geol. Survey Water-Supply Paper 233, p. 187, 1909.

NUMERICAL STANDARDS.

Stabler's excellent mathematical discussion of the quality of waters with reference to industrial uses [1] contains several formulas by which the effect of waters may be computed. They have been recalculated in order to obtain the estimates in parts per million. The terms involving iron, aluminum, and free acids have been omitted because these substances are too scarce to call for consideration in such approximate rating; and the terms involving sodium and potassium have been united for simplicity.

(1) $s = Sm + Cm + 2.95\ Ca + 1.66\ Mg$
(2) $h = SiO_2 + 1.66\ Mg + 1.92\ Cl + 1.42\ SO_4 - 2.95\ Na$
(3) $f = 2.7\ Na$
(4) $c = 0.0821\ Mg - 0.0333\ CO_3 - 0.0164\ HCO_3$.

These equations express numerically some of the relations that have been discussed in the preceding sections on scale, corrosion, and foaming. Sm, Cm, SiO_2, Ca, Mg, Na, Cl, SO_4, CO_3, and HCO_3 represent the amounts in parts per million, respectively, of suspended matter, colloidal matter (oxides of silicon, iron, and aluminum), silica, calcium, magnesium, alkalies, chloride, sulphate, carbonate, and bicarbonate.

Formula 1 gives the amount of scale (s) that would probably be formed from the water under ordinary conditions of boiler operation; as the ground waters of San Diego County are practically clear, Sm is equal to zero. Where not determined Cm has been given a value of 34, for waters, the average of SiO_2 in 50 analyses of ground waters in San Diego County.

Formula 2 gives the amount of hard scale forming ingredients (h). The ratio $\frac{h}{s}$ expresses the relative hardness of the scale. If $\frac{h}{s}$ is greater than 0.5 the scale may properly be called hard; if it is less than 0.25 the scale may properly be called soft.

Scale (s) has been estimated from the data of the assays by adding to total hardness (H) the value of Cm used in formula 1 ($s = Cm + H$). (See formula 1 for value of Cm used in assays for San Diego County.) As H theoretically equals $2.5\ Ca + 4.1\ Mg$, and the last two terms of equation 1 are $2.95\ Ca + 1.66\ Mg$, the unknown but variable ratio between calcium and magnesium introduces an uncertain error. Estimates of the scale-forming constituents are, however, always approximate, and experience indicates that this computed value is accurate enough for relative ratings.

Formula 3 gives the amount of the foaming ingredients (f), as estimated from the probable content of alkali salts. The value of sodium

[1] 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, p. 165, 1911. See also Eng. News, vol. 60, p. 355, 1908.

(Na) computed by the formula on page 235 has been used in computing the amount of the foaming ingredients from the results of the assays.

Formula 4 has been used to calculate the corrosive tendency of the water (c). As can be readily seen from the coefficients, it expresses the relation between the reacting values of magnesium and the radicles involving carbonic acid (p. 228). If c is positive, the water is corrosive. If $c + 0.0499$ Ca, the reacting value of calcium, is negative, the mineral constituents will not cause corrosion, but whether organic matter or electrolysis will cause it is uncertain. If $c + 0.0499$ Ca is positive corrosion is uncertain. These conditions of reaction may be restated to conform to the data of the assays thus: If $0.033\ CO_3 + 0.016\ HCO_3$ equals or exceeds 0.02 H the mineral constituents will not cause corrosion. If 0.004 H exceeds $0.033\ CO_3 + 0.016\ HCO_3$ the water is corrosive. One-fiftieth of the total hardness (0.02 H) is equivalent to the reacting value of calcium and magnesium, and H divided by 230 (0.004 H) is equivalent to the reacting value of magnesium on the assumption that $Ca = 6\ Mg$, a ratio in which magnesium is given its smallest probable value in relation to calcium. The reacting values of carbonate and bicarbonate are represented, respectively, by $0.033\ CO_3$ and $0.016\ HCO_3$, the coefficients of which are obtained by dividing the valence of each radicle by its molecular weight.

After these three attributes of boiler feed have been computed rating the water is largely a matter of judgment based on experience. The committee on water service of the American Railway Engineering and Maintenance of Way Association has offered two classifications by which waters in their raw state may be approximately rated, but, as the report states, "it is difficult to define by analysis sharply the line between good and bad water for steam-making purposes." Table 50 gives these classifications with the amounts transformed to parts per million.

TABLE 50.—*Ratings of waters for boiler use according to proportions of incrusting, corroding, and foaming constituents.*

Incrusting and corroding 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.

The quantity of foaming ingredients (f) should always be considered in conjunction with the probable amount of scale or sludge that would be formed, the hardness of the scale, and the tendency toward corrosion. These ratings result in a classification rather more rigid than that usually reported by chemists of railroads in California, and for that reason those who are thoroughly familiar with local conditions and with the chemistry of water will doubtless prefer to disregard the descriptive terms of the classification and to draw their own conclusions regarding the quality of the waters from the figures representing scaling, foaming, and corrosion. The classifications are given principally for the aid of those not thoroughly familiar with such matters, and rather to indicate the limits of usefulness than to define rigidly the value of the waters.

No matter how low a water may be in undesirable constituents it is poor economy to use it if it is much poorer in quality than the average water of the region in which it occurs. On the other hand, if the best available supply is poor the economy of purifying it even at large expense is obvious. Along the Atlantic coast, where waters containing less than 100 parts per million of incrusting ingredients are extremely common, a supply carrying 200 parts of such substances would not be considered fair for boiler use. Throughout most of Mississippi Valley, however, such a supply would be considered good, because in that region natural waters not exceeding 100 parts in scale-forming constituents are rare. This variance in local standards is well illustrated by the opinions on the two sides of San Joaquin Valley as to what constitutes a good boiler water, and because of it numerical standards should be interpreted relatively, not literally. At the same time any classification by nominal ratings must be applied absolutely if the terms are to have comparative significance outside the region where the waters exist. Waters of poor quality can be improved by treatment in softening plants. How bad a water may be used without treatment depends on the cost of softening the water and the relative saving effected by the use of the softened water. A report [1] of the committee on water service of the American Railway Engineering and Maintenance of Way Association sets forth the factors involved. The benefits include the saving in boiler cleaning, repairs, and fuel, the decrease in the time during which the boilers must be withdrawn from service for cleaning and repairs, the decreased depreciation of the boilers, and the value of the materials removed by softening. The cost of softening includes the cost of labor and power for the softening apparatus, the cost of softening chemicals, the interest on the cost of installation, depreciation in the value of the softening plant, and the waste in changing boiler feed due to increased foaming tendency.

[1] Am. Ry. Eng. and Maintenance of Way Assoc. Proc., vol. 8, p. 601, 1907.

In locomotive service it is in general economical to treat waters containing 250 to 850 parts per million of incrustants and to treat those containing less than 250 parts if the scale formed contains much sulphate.[1] As the incrusting solids may commonly be reduced to 80 or 90 parts per million, the economy of treating boiler waters deserves consideration in a region where many supplies contain 300 to 500 parts per million of incrusting matter.

The amount of mineral matter that makes a water unfit for boiler use depends on the combined effect in boilers of the softening reagents used with such waters and of the constituents not removed by softening. Sodium salts added to remove incrustants or to prevent corrosion increase the foaming tendency, and this increase may be great enough to render a water useless for steaming. It is not of much benefit to soften a water containing more than 850 parts per million of nonincrusting material and much incrusting sulphate.[1] Trouble from priming in locomotive boilers begins at a concentration of about 1,700 parts per million of foaming constituents, and the limit of safety for stationary boilers is reached at a concentration of about 7,000 parts. Though waters containing as high as 1,700 parts per million of foaming constituents have been used, it is usually more economical to incur considerable expense in replacing such supplies by better ones.

WATER FOR MISCELLANEOUS INDUSTRIAL USES.

GENERAL REQUISITES.

Many articles are affected by the ingredients of the water used in their manufacture and can be improved by its purification. If by the same process the boiler efficiency of the factory can be increased the expense is often justified when it would not be warranted merely by the increased value of the product. This observation applies particularly to paper, pulp, and strawboard mills, laundries, and other establishments where large quantities of water are evaporated to furnish steam for drying, and to ice factories and similar plants where distilled water is required.

Besides its use for steam making water plays a specific part in many manufacturing processes. In paper mills, strawboard mills, bleacheries, dye works, canning factories, pickle factories, creameries, slaughterhouses, packing houses, nitroglycerin factories, distilleries, breweries, woolen mills, starch works, sugar works, canneries, glue factories, soap factories, and chemical works water becomes a part of the product or is essential in its manufacture. In most of these establishments the principal function of the water is that of a cleansing agent or a vehicle for other substances, and therefore a supply free from color, odor, suspended matter, microscopic organisms

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[1] Am. Ry. Eng. and Maintenance of Way Assoc. Proc., vol. 6, p. 610, 1905.

and especially from bateria of fecal origin, and fairly low in dissolved substances, especially iron, is with few exceptions satisfactory. But water hygienically acceptable is necessary where it comes into contact with or forms part of food materials, as in the making of beverages, sugar, and dairy or meat products. As ideal waters for any use are rare, the manufacturer must ascertain what degree of freedom from impurities is necessary to prevent injury to his machinery or to his output and whether the cost of obtaining such purity is counterbalanced by decreased cost of production and increased value of product.

EFFECTS OF DISSOLVED AND SUSPENDED MATERIALS.

The effects in some industries of the substances most commonly found in water are outlined in the following pages, the object being to offer approximate standards for classification.

FREE ACIDS.

Free mineral acids, such as the sulphuric acid in drainage from coal mines or the hydrochloric acid in the effluents of some industrial establishments, are especially injurious and nearly always have to be neutralized before the waters containing them can be used industrially. In paper mills, cotton mills, bleacheries, and dye works waters containing a measureable amount of free mineral acid decompose chemicals, streak and rot fabrics, and corrode and rapidly destroy metal screens, strainers, and pipes.

SUSPENDED MATTER.

Suspended matter in surface waters may be of vegetable, mineral, or animal origin, as it consists of particles of sewage, bits of leaves, sticks and sawdust, and sand and clay. The fine silt so common in rivers of the West is largely derived from clay. Few well waters contain suspended animal or vegetable matter, but many carry finely divided sand and clay, and many become turbid by precipitation of dissolved ingredients. Suspended matter is objectionable in all processes in which water is used for washing or comes into contact with food materials, because it is likely to stain or spot the product. Suspended matter due to precipitated iron is especially injurious even in small amount. Suspended vegetable or animal matter liable to decomposition or to partial solution is much more objectionable, even in small amount (10 to 20 parts per million), than equal quantities of mineral matter. For these reasons water should be freed from suspended matter before being used for laundering, bleaching, wool scouring, paper making, dyeing, starch and sugar making, brewing, distilling, and similar processes. In making the coarser grades of paper, such as strawboard, a small amount of suspended matter is not especially injurious, but for the finer white and colored varieties clear water is essential.

COLOR.

Color in water is due principally to solution of vegetable matter. Materials bleached, washed, or dyed light shades in colored water are likely to become tinged. Highly colored waters can be used in making wrapping or dark-tinted papers but not in making the white grades, and paper manufacturers are put to great expense for water purification on that account. The lower waters are in color, therefore, the more desirable they are for use in bleacheries, dye works, paper mills, and other factories where brown tints in the products are undesirable.

IRON.

Iron is the most undesirable dissolved constituent, and its presence in comparatively small quantities necessitates purification. Many ground waters contain 1 to 20 parts per million of iron, which may be precipitated by exposure to the air and by release of hydrostatic pressure, causing the waters to become turbid, and many such waters develop rusty-looking gelatinous growths that may interfere in industrial operations. In all cleansing processes, especially if soap or alkali is used, precipitated iron is likely to cause rusty or dull spots. In contact with materials containing tannin compounds iron forms greenish or black substances that discolor the product. Therefore many waters containing amounts even as small as 1 or 2 parts per million of iron have to be purified before they can be used industrially. In water for dye works iron is especially objectionable and commonly prevents the use of the water without purification.[1] Iron in the water supply of paper mills may be precipitated on the pulp, giving a brown color, or during sizing or tinting, giving spotty effects. Water containing much iron can not be used in bleaching fabrics because salts that spot the goods are formed. The dark-colored compounds that iron forms with tannin discolor hides in tanning.

CALCIUM AND MAGNESIUM.

Calcium and magnesium are similar in their industrial effects. In water their amounts bear a more or less definite relation to each other, most waters carrying 10 to 50 per cent as much magnesium as calcium. Both are precipitated on whatever is boiled in water containing them, forming a deposit that may interfere with later operations. They also decompose equivalent amounts of many chemicals employed in technical operations, causing waste and forming alkaline-earth compounds that interfere with the later treatment of fabrics. These are the strongest incentives to preliminary softening. Some of the chemicals used to disintegrate the fibers in making pulp are consumed by the calcium and magnesium in the water supply, though the loss from this source is not nearly so great as that which occurs later when the

[1] Sadtler, S. P., A handbook of industrial organic chemistry, p. 483, Philadelphia, 1900.

resin soap used in sizing the paper is decomposed by the calcium and magnesium. The insoluble soaps thus created do not fix themselves on the fibers, but form clots and streaks. Similar decomposition of valuable cleansing materials and subsequent deposition of insoluble compounds take place in laundering, wool scouring, and similar processes. In the manufacture of soap, calcium and magnesium form with the fatty acids curdy precipitates that are insoluble in water and therefore have no cleansing value. They interfere with many dyeing operations, neutralizing chemicals and changing the reactions of the baths, besides forming insoluble compounds with many dyes. Very soft water, on the other hand, is said to be undesirable in paper mills for loading papers with any form of calcium sulphate because such waters dissolve part of the loading materials.[1] Probably waters high in chlorides would also be bad for this purpose, because chlorides increase the solubility of calcium sulphate.

CARBONATE.

The effects of carbonate and bicarbonate in waters used in industrial processes are commonly not differentiated. It is not unusual to estimate the combined carbonic acid and to state it as the carbonate without distinguishing between carbonate and bicarbonate, though in many natural waters the carbonate radicle is absent and the combined carbonic acid is in the form of bicarbonate. If hard waters proportionately high in carbonate and low in sulphate are boiled, the bicarbonate radicle is decomposed, free carbonic acid is given off, and the greater part of the calcium and magnesium is precipitated. Consequently waters of that character are generally more desirable for industrial operations than waters high in sulphate and low in carbonate, whose hardening constitutents are not greatly reduced by boiling.

SULPHATE.

Hard waters with sulphate predominating are desirable in tanning heavy hides, because they swell the skins, exposing more surface for the action of the tan liquors.[2] Sulphate interferes with crystallization in sugar making by increasing the amount of sugar retained in the mother liquor.

CHLORIDE.

High chloride is usually accompanied by high alkalies. Appreciable amounts of chloride are injurious in many industrial processes. Beverages and food products, of course, can not be treated with waters very high in chloride without becoming salty. In tanning, chloride causes the hides to become thin and flabby.[2] Animal charcoal used in clarifying sugar is robbed of its bleaching power by

[1] Cross, C. F., and Bevan, E. J., A textbook of paper making, p. 294, New York, 1900.

[2] Parker, H. N., and others, The Potomac River basin: U. S. Geol. Survey Water-Supply Paper 192, p. 194, 1907.

absorption of salt. The quality of sugars is affected by chloride-bearing waters, because saline salts are incorporated in the crystals.[1] The only commercially developed way of removing chloride from water is distillation. As the cost of this process has been greatly reduced by use of multiple-effect evaporators, it is worth consideration where chloride-bearing waters must be used.

ORGANIC MATTER.

Organic matter of fecal origin is, of course, dangerous in any water that comes into contact with food products, and water so polluted should be purified before being used. Care in this respect is particularly necessary in creameries, slaughterhouses, canneries, pickle factories, and sugar factories. Organic matter not necessarily capable of producing disease is further undesirable in industrial supplies because it induces decomposition in other organic materials, like cloth, yarn, sugar, starch, meat, or paper, rotting and discoloring them, and because it causes slime spots on fabrics by supporting algæ growths.

HYDROGEN SULPHIDE.

Hydrogen sulphide (H_2S), a gas with an odor like that of rotten eggs, occurs dissolved in some ground waters. It is corrosive even in small quantities, and it also injures materials by discoloring and rotting them.

MISCELLANEOUS SUBSTANCES.

Silica and aluminum are usually not present in sufficient quantity appreciably to affect any industrial process, except those in which water is evaporated. Large quantities of sodium and potassium, by adding to the amount of dissolved matter, are objectionable in some manufacturing operations. Phosphates, nitrates, and some other substances not noted in this outline interfere with industrial chemical reactions, but they are present in few natural waters in sufficient quantity to have noticeable effect.

QUALITY IN RELATION TO GEOLOGIC SOURCE.

GENERAL RELATIONS.

The wells in the part of San Diego County covered by this paper derive their supplies from (1) pre-Cretaceous crystalline rocks and the residuum resulting from their decomposition, (2) Tertiary and older sedimentary formations, and (3) Quaternary valley fill. Of the 121 samples of ground water that were analyzed or assayed, 17 were derived from the residuum, 26 from Tertiary or older sedimentary formations, and 78 from valley fill. (See pp. 251–258 and Table 46, opposite p. 222.)

Table 51 shows the range in total dissolved solids and the average content of dissolved solids in the samples analyzed from each of the

[1] De la Coux, M. A. J., L'eau dans l'industrie, p. 152, Paris, 1900.

three geologic divisions. Only analyses of samples from wells supplying water are included in the results given in Tables 51 and 54 and in the discussion following, samples from oil wells (F7, K16, and K37) being excluded. Analyses of water from wells F7, K16, and K37 are given in Table 57, pages 260–261.

TABLE 51.—*Comparison of quantities of total dissolved solids* [a] *in waters analyzed from different geologic sources.*

Geologic source.	Number of samples.	Total dissolved solids in parts per million.	
		Range.	Average.
Residuum	5	392–2,552	1,125
Tertiary and older sediments	17	274–3,409	1,183
Valley fill	25	320–5,060	1,516

[a] Taken from analyses published in this report.

The table shows a wide range in mineral content in the waters within each of the three groups and the average mineral content in all of them is rather high. As the formations differ from each other both in origin and in composition, it might reasonably be expected that the waters obtained from them would show considerable differences in quality, but the differences are not very marked.

The similarity between the waters from the different geologic sources is evident also when the quantities of different chemical constituents are compared; and they are, moreover, similar in that they show about equally wide range in chemical composition. Of the 47 well waters analyzed 43 are of the sodium-chloride type, 3 are calcium-carbonate, and 1 is sodium-carbonate. The average chloride content of all the 47 waters analysed is 496 parts per million, the average for waters from valley fill being 566 parts, for waters from Tertiary and older sediments 450 parts, and for waters from residuum 304 parts per million.

The analyses of ground waters from this area, as given in Table 57, pages 260–261, show so wide a range in chemical composition, regardless of location or geologic source, that it is not possible accurately to predict the quality of a water that may be found in any part of the area. However, rather highly mineralized sodium-chloride waters, fairly satisfactory for use for domestic supplies and for irrigation, and very bad for use in boilers, are greatly predominant in San Diego County and may be regarded as typical for the area.

WATER FROM RESIDUUM.

The residuum of the highland basins, as described on page 71, is derived mainly from coarse granitic rocks by the chemical alteration of some of their mineral components and by the solution and removal of some chemical constituents by percolating water. During the early stages of rock decomposition the only apparent change consists of a granulation of the surficial parts of a formation whereby, instead of a dense, hard rock, there remains a disintegrated mass that crumbles at a touch of the hand and yields readily to excavation by means of a pick and shovel. The pore spaces are enlarged and the water-bearing capacity of the rock is greatly increased by decomposition, so that where topographic conditions are favorable and disintegration extends to a considerable depth, material of this kind may be an important source of ground water. The residuum in many of the highland valleys is favorably situated, and the disintegration reaches depths of as much as 100 feet, and in many places the formation yields sufficient water for the irrigation of farm lands.

The chemical quality of the water in residuum is determined by the solubility of the mineral substances in the residuum and the length of time that the waters remain in contact with these substances, except where the residuum has been contaminated by sea water, by highly mineralized surface water, or by water issuing from sedimentary deposits that contain much soluble mineral. The waters in the residuum take mineral matter into solution very slowly, and, except where they have been contaminated from other sources, they may be expected to contain only small quantities of dissolved solids. There are probably many places in San Diego County at which waters of low mineral content may be obtained from residuum, but only two samples were collected for analysis during this investigation.

Analyses of these two samples, which are believed to fairly represent the quality of water in uncontaminated residuum, and their classification for use as domestic supplies for irrigation or in boilers are given in Table 52.

TABLE 52.—*Partial analyses and classification of two samples of water from uncontaminated residuum.*

[Parts per million. S. C. Dinsmore, analyst. Numbers at head of columns refer to corresponding numbers on Plate II.]

	C 1 [a]	H 18 [b]
Silica (SiO_2)	57	47
Iron (Fe)	.10	.03
Calcium (Ca)	62	38
Magnesium (Mg)	28	26
Sodium and potassium (Na+K) [c]	15	87
Carbonate radicle (CO_3)	.0	.0
Bicarbonate radicle (HCO_3)	229	171
Sulphate radicle (SO_4)	14	13
Chloride radicle (Cl)	66	157
Nitrate radicle (NO_3)	10	19
Total dissolved solids at 180° C	392	490
Total hardness as $CaCO_3$ [c]	270	202
Chemical character	Ca-CO_3.	Na-Cl.
Quality for domestic use	Fair.	Good.
Quality for irrigation	Good.	Fair.
Quality for boiler use	Poor.	Fair.
Date of collection (1914)	Nov. 21.	Nov. 24.

[a] Dug well 65 feet deep on Red Mountain ranch, 3 miles east of Fallbrook, in SW. ¼ sec. 15, T. 9 S., R. 3 W.; see also corresponding number in Table 46, opposite p. 222.
[b] Drilled well 74 feet deep, of Nick Anderson, in Santa Maria Valley, about 1½ miles south of Ramona post office; see also corresponding number in Table 46, opposite p. 222.
[c] Calculated.

These samples do not afford conclusive evidence of the quality of water in the residuum of the highland area, but they are at least consistent with the belief that such waters generally contain only small or moderate quantities of dissolved mineral matter; and in the absence of more information it is reasonable to expect that wells in highland valleys underlain by residuum or decomposed granite will furnish water of good quality, similar to the samples described above, provided no highly mineralized water passes into the residuum from deposits of valley fill or other sources, a possibility indicated by the results of analyses of water from residuum in highland basins.

Waters that have circulated through valley fill or the older sedimentary formations of this area are generally highly mineralized, but it is also probable that some residuum waters may owe their high mineral content to prolonged contact with mineral substances of the residuum itself. The residuum is almost as porous as valley fill, and it is more porous than most of the Tertiary sediments, so that the amount of surface presented to the solvent action of percolating water is very great. The movement of ground water is generally slow, even under most favorable conditions, and in the flat-floored basins of the highland area it is in some places hardly appreciable. In such places ground water may remain in contact with the rock particles long enough to permit the solution of considerable quantities of mineral matter. So far as this investigation has shown, long contact is the only reasonable explanation of the presence of mineral substances in solution in waters from the residuum where they are obviously not contaminated by seepage from sedimentary formations; it is certainly responsible in some measure for the quality of residuum waters, whether there is seepage from sediments or not. It is possible that the high mineralization of some of the waters from residuum in this county is also due to prolonged contact.

WATER FROM THE TERTIARY AND OLDER SEDIMENTARY FORMATIONS.

Most of the Tertiary and underlying Cretaceous formations that are penetrated by wells in the western part of San Diego County were deposited in sea water, and as shown by the record of the Balboa oil well (see p. 55), which penetrated sedimentary formations to a depth more than a mile below sea level, most of the beds, at least nine-tenths of the known section, still lie below sea level. Moreover some of the beds that now lie above the level of the sea have been submerged in Quaternary time. It is to be expected, therefore, that waters derived from the beds which still lie below sea level and from those above sea level that are most resistant to the leaching action of percolating water will yield waters containing large quantities of mineral matter.

In addition to mineral substances derived from sea water, there are the soluble salts contained in the materials that make up the formations. Where shales and sandstones, especially those of the San Diego formation, are exposed in section they are commonly coated with a white efflorescence due to leaching and deposition by water that percolates through the beds and evaporates on the exposed surfaces. These coatings are concrete evidences of readily soluble mineral matter in the deposits and explain the high mineral content of waters derived from them.

Partial analyses were made of 20 samples from wells that draw their supplies from Tertiary and older sedimentary formations. The results (excluding analyses from oil wells, F 7, K 16, and K 37) show a high average concentration, 1,183 parts per million of total dissolved solids. There is a very wide range in quantities of total dissolved solids, from 283 to 3,409 parts per million, and there are correspondingly wide ranges in the quantities of the different mineral constituents, so that it is not practicable to indicate a water that would typically represent Tertiary supplies (see Table 54). The quality does not vary consistently with depth or location but depends on local stratigraphic conditions at individual wells. As, however, most of the waters already obtained from this source are highly mineralized sodium-chloride waters, fair or poor for domestic use, poor for irrigation, and very bad for boilers, water of this type may in general be expected from new wells.

Most of the wells that draw their supplies from Tertiary beds are on terraces where the soil is heavy and much less pervious than the soils in areas underlain by valley fill. These soils are not naturally well drained and it is not probable therefore that waters classified as poor for irrigation can be successfully applied on them unless adequate means are provided for artificial soil drainage.

Of the 17 water-well samples analyzed from Tertiary beds 10 were classified as poor for irrigation, 6 as fair and 1 as good. It is a matter of interest that the sample classified as good for irrigation was obtained from a well (K 30) that had been drilled especially to provide water for irrigation, and that although this water comes from a stratum 620 feet below the surface, nearly 1,000 feet below the top of the San Diego formation, it is one of the least mineralized waters obtained in the county. The contrast between this water and the water obtained from the Balboa oil well (K 37), which at present draws its supply from different horizons between the depths of 900 and 5,000 feet, is shown in the following table:

TABLE 53.—*Partial analyses and classification of waters of extreme types from Tertiary deposits.*

[Parts per million.]

	K 30.[a][b]	K 37.[a][c]
Silica (SiO_2)	32	44
Iron (Fe)	1.3	Tr.
Calcium (Ca)	22	550
Magnesium (Mg)	10	27
Sodium and potassium (Na+K)[d]	36	2,565
Carbonate radicle (CO_3)	.0	.0
Bicarbonate radicle (HCO_3)	69	26
Sulphate radicle (SO_4)	20	1,381
Chloride radicle (Cl)	62	3,965
Nitrate radicle (NO_3)	12	.00
Total dissolved solids at 180° C	274	8,764
Total hardness as $CaCO_3$ [d]	96	1,490
Chemical character	Na-Cl	Na-Cl.
Quality for domestic use	Good	Unfit.
Quality for irrigation	do	Bad.
Quality for boiler use	do	Very bad.
Date of collection	Mar. 16, 1918	June 9, 1915.
Analyst	Alfred A. Chambers and C. H. Kidwell.	S. C. Dinsmore.

[a] Number on Plate II.
[b] Drilled well of Roger Topp, Ex Mission San Diego, Murphy Canyon, Calif.; see also corresponding number in Table 46, opposite p. 222.
[c] Oil well of Balboa Oil Co., Pueblo Lands of San Diego, Calif.; see also corresponding number in Table 46, opposite p. 222.
[d] Calculated.

Waters as good as that from well K 30 probably can not be commonly expected from this source, and, on the other hand, waters as bad as that from well K 37 are not likely to be encountered in many wells. Table 54 presents the averages of analyses of Tertiary waters.

TABLE 54.—*Average quantities of certain constituents in 17 waters analyzed from Tertiary and older formations.*[a][b]

	Parts per million.
Bicarbonate radicle (HCO_3)	224
Sulphate radicle (SO_4)	128
Chloride radicle (Cl)	450
Total hardness as $CaCO_3$ [c]	395
Total dissolved solids at 180° C	1,183
Range of total dissolved solids	[d] 283–3,409

[a] Based on analyses published in this report.
[b] Omitting analyses of oil wells, map Nos. F 7, K 16, and K 37.
[c] Computed.
[d] Total solids in water from Balboa oil well, map No. K 37 (Table 57, pp. 260–261)=8,764 parts per million.

WATER FROM VALLEY FILL.

The valley fill in the area covered by this report is found principally in the valleys of the major streams (see p. 111) and consists mainly of unconsolidated sand and silt. Layers of coarse materials, such as gravel and boulders, are encountered in some places, particularly at or near the bottom of the valley fill, but constitute a very small part of the deposit. The valley fill occupies ancient steep-walled valleys, and is therefore sharply bounded on the sides and bottom by the formations in which the valleys were cut. In the highland area the bodies of valley fill are surrounded by crystalline rocks and residuum; in the coastal belt they are for the most part surrounded by Tertiary deposits. The major stream valleys cross both the highland area and the coastal belt, and the valley fill occurs, not in continuous deposits but in isolated bodies separated by bedrock exposures, as shown on the geologic map, Plate III, so that along some drainage courses water passes successively over several distinct deposits of fill. The drainage carried by Hatfield Creek, for example, is collected in a catchment area underlain by crystalline rocks and is discharged into Santa Maria Creek, whose valley contains a large deposit of valley fill. This deposit extends down Santa Maria Creek only as far as the west side of the Valle de Palmo. The creek then passes over a crystalline rock bed, carries water that has traversed valley fill in the Ramona basin, and empties into San Dieguito River in San Pasqual Valley. San Pasqual Valley contains a deep deposit of valley fill which extends west to the foot of Bernardo Mountain. From Bernardo Mountain to the head of San Dieguito Valley, which begins at the western edge of the highland area, San Dieguito River flows over a crystalline rock floor, and finally, through San Dieguito Valley it flows over valley fill. Sources of recharge in valley fill near the coast are:

(1) Direct rainfall on the valley fill, (2) surface drainage, (3) springs and underground drainage from crystalline rocks and granitic residuum, and (4) springs and underground drainage from the Tertiary sedimentary formations.

Passing eastward from the coast, drainage from the Tertiary sediments first ceases to be a source of recharge; and finally, as the highest valley-fill deposits are reached, drainage from other valley fill. Thus in the highland basins the sources of recharge in valley fill are: (1) direct rainfall, (2) surface drainage, and (3) springs and underground drainage from crystalline rocks and granitic residuum.

The chemical composition of the water in any deposit of valley fill is determined by the mingling of waters from all the different sources of recharge, and by the solution of mineral substances contained in the valley fill itself. Twenty-five samples of water obtained from wells that draw their supplies from valley fill were analyzed; of these 19 came from fill in the coastal belt and 6 from fill in highland basins.

The following table gives the averages of some of the constituents:

TABLE 55.—*Average quantities of certain constituents in waters analyzed from valley fill in coastal belt and in highland basins.*[a]

[Parts per million unless otherwise stated.]

	Coastal belt.	Highland basins.
Number of samples averaged	19	6
Bicarbonate radicle (HCO_3)	363	219
Sulphate radicle (SO_4)	215	69
Chloride radicle (Cl)	689	179
Total hardness as $CaCO_3$[b]	513	269
Total dissolved solids at 180° C.	1,801	614
Range of total dissolved solids	320–5,060	352–871

[a] Based on analyses published in this report. [b] Computed.

Thus, so far as shown by the analyses, the water from the fill of the principal valleys in the coastal belt contains about three times as much dissolved solids as the water from the fill of the major valleys in the highland area. According to the results of the analyses the waters from the fill of the highland area range in total dissolved solids from 352 to 871 parts per million and average about 614 parts per million, whereas the waters from the fill in the coastal belt have a much wider range—from 320 to 5,060 parts per million—and average 1,801.

Though there is wide variation in the quality of water from valley fill, it has not been possible to discover any consistent relation between this variation and the depth or location of the wells, except as indicated above. The analyses indicate that in the valleys of the coastal belt waters from wells ending in valley fill are likely to be rather highly mineralized, sodium-chloride waters, fair or poor for irrigation, and very bad for boilers. The waters of the coastal belt vary widely in their quality for domestic use; of the 19 samples analyzed 2 are classed as good, 5 as fair, 5 as poor, 4 as bad, and 3 as unfit for domestic use. The analyses in this report indicate that waters from wells sunk in valley fill in the highland valleys may be expected to yield sodium-chloride waters of moderate mineral content, fair for domestic use, fair for irrigation, and ranging from fair to very bad for boiler use.

With regard to the quality of these waters for irrigation, however, it should be remembered that, as stated on pages 234–235, the classification is based on the quantities of dissolved salts harmful to plants, but that the texture of the soil and conditions affecting drainage of the soil may entirely prevent accumulation of alkali, so that under favorable conditions waters classified as poor for irrigation may be used successfully. A large number of wells are now being pumped for irrigation and the results have been sufficiently encouraging to stimulate active interest in the use of ground water supplies for this purpose. That some care is necessary to insure success in the use of highly mineralized waters is, however, illustrated by a more or less accidental result obtained in Sweetwater Valley, where a well (O 22) drilled in Sweetwater Valley to the depth of 900 feet encountered an artesian flow of very salty water (see Table 59, p. 263) in Tertiary beds underlying the valley fill. Being unfit for use it was permitted to run unchecked for a number of years, and it is said that land for a considerable distance down the valley became seriously damaged by salt water. The water in this well is said to have gradually decreased in salinity, however, and the flow was finally stopped. According to information obtained from gardeners in the vicinity the land that had been damaged by this well has gradually improved. Owing to the high porosity of valley fill in this area and the favorable conditions for soil drainage, and especially owing to the natural flushing of the lowlands during flood seasons, it is believed that in general the use of valley-fill waters for irrigation will cause no serious alkali trouble.

QUALITY IN RELATION TO USE FOR IRRIGATION.

Irrigation at the present time is almost entirely confined to areas underlain by valley fill and residuum, which together comprise an exceedingly small part of the region and are naturally so well adapted to irrigation that injurious effects of poor waters are likely to be slow to manifest themselves. Valley fill and residuum lands are much better adapted to the use of highly mineralized waters than are the terrace or mesa lands underlain by Tertiary deposits, because both the valley fill and the residuum are much more porous, and in most places they are naturally well drained, so that there is probably no serious danger of the soils becoming so highly impregnated with alkali as to inhibit the growth of plants.

The lands on Linda Vista and Otay mesas, however, owing to the density of the soils and underlying rocks, may present difficult problems if ways are found to bring them under irrigation. These lands, reaching in unbroken stretches over hundreds of square miles, constitute by far the largest part of the coastal belt. (See Pl. II.) They are covered by tillable soils, probably as good and in some places even better than valley lands now cultivated, but they remain almost entirely unoccupied because of the absence of water. Water is, of course, the first need; its quality, provided it is not unfit for irrigation, being a minor consideration and the chemical problems that may be encountered in irrigation will no doubt appear trifling after overcoming the difficulties of obtaining the water.

QUALITY OF SURFACE WATERS.

This investigation did not afford an opportunity to make a detailed study of the quality of surface waters. However, seven samples were obtained from selected localities and the results of their analysis are given in the following table:

TABLE 56.—*Partial analyses*[a] *of surface waters.*

[Parts per million. Alfred A. Chambers and C. H. Kidwell, analysts.]

Constituents.	1	2	3	4	5	6	7
Suspended matter	278	42	2.7	120	56	52	12
Silica (SiO_2)	13	34	34	32	37	32	39
Iron (Fe)	.18	1.4	.06	.42	.09	.06	.04
Calcium (Ca)	23	18	33	31	40	37	50
Magnesium (Mg)	7.0	7.1	17	12	12	18	19
Sodium and potassium (Na+K)[b]	33	18	26	56	64	49	77
Carbonate radicle (CO_3)	.0	.0	.0	.0	7.2	.0	5.8
Bicarbonate radicle (HCO_3)	119	79	129	145	183	188	251
Sulphate radicle (SO_4)	23	21	50	32	32	40	30
Chloride radicle (Cl)	26	18	36	68	65	55	87
Nitrate radicle (NO_3)	Tr.	.40	Tr.	.22	Tr.	.16	Tr.
Total dissolved solids at 180° C.	188	176	264	307	346	323	429
Date of collection (1918)	Mar. 16	Mar. 8	Mar. 7	Mar. 16	Mar. 10	Mar. 10	Mar. 10

[a] For methods used in anlyses and accuracy of results, see pp. 222–223. [b] Computed.

1. San Luis Rey River (Escondido canal intake, sec. 32, T. 10 S., R. 1 E.), about 3 miles east of Rincon Indian Agency, Calif.
2. Santa Ysabel Creek about 7 miles northeast of Ramona, Calif. (SW. ¼ sec. 17, T. 12 S., R. 2 E.). 35 second-feet in creek Mar. 6, 1918.
3. San Diego River about 15 miles northeast of Lakeside, Calif. (NE. ¼ sec. 2, T. 14 S., R. 2 E.). 7.8 second-feet in river Mar. 7, 1918.
4. San Diego River at Mission dam, about 7 miles west of Lakeside, Calif. (at bench mark near west boundary of El Cajon land grant). 189 second-feet in river Mar. 16, 1918.
5. Sweetwater River at Dehesa, Calif. (sec. 14, T. 16 S., R. 1 E.). 14 second-feet in river Mar. 10, 1918.
6. Jamul Creek about 6 miles west of Dulzura, Calif. (southwest portion of Jamul land grant). Sample collected at point below entrance of aqueduct from Cottonwood Creek—sample is a mixture of waters from Jamul and Cottonwood creeks. The raw water forms part of the public water supply for San Diego, Calif.
7. Cottonwood Creek about 5 miles southeast of Dulzura, Calif. (N. ½ sec. 26, T. 18 S., R. 2 E.). Water from Cottonwood Creek is diverted at Barrett dam into Jamul Creek. 5 second-feet in river Mar. 10, 1918.

TABLE 57.—*Partial analyses* [a] *and classification of water from wells and springs.*

[Parts per million unless otherwise designated; analyzed by S. C. Dinsmore. For records of wells and springs see corresponding numbers in Table 46, opposite p. 222.]

Well No. [b]	Date of collection.	Determined quantities. Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K). [c]	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chloride radicle (Cl).	Nitrate radicle (NO_3).	Total dissolved solids at 180° C.	Computed quantities. Total hardness as $CaCO_3$.	Scale-forming ingredients.	Foaming ingredients.	Alkali coefficient (inches). [d]	Classification. Mineral content.	Chemical character.	Probability of corrosion. [e]	Quality for boiler use.	Quality for domestic use.	Quality for irrigation.
	1914.																					
C 1	Nov. 21	57	0.10	62	28	15	0.0	229	14	66	10	392	270	290	40	31	Moderate	Ca-CO3..	(?)	Poor..	Fair.	Good
F 7	Nov. 25	17	.06	75	5.0	357	.0	46	425	356	.00	1,277	208	250	960	5.2	High....	Na-Cl...	(?)	Very bad.	..do..	Poor
F 9	...do...	46	.09	107	29	164	.0	215	96	331	.00	955	386	410	440	6.2	...do.....	...do.....	(?)	...do...	Poor	Fair.
G 7	Nov. 19	66	1.0	50	33	91	.0	163	29	203	10	575	260	270	250	10	...do.....	...do.....	C	Poor..	Fair.	Do.
G 8	...do...	53	Tr.	63	35	174	.0	361	46	235	3.0	871	301	300	470	8.4	...do.....	...do.....	(?)	Very bad.	..do..	Do.
G 12	...do....	50	.10	50	29	176	.0	75	61	298	100	912	244	250	480	6.8	...do.....	...do.....	C	...do...	..do..	Do.
G 15	Nov. 25	23	.20	221	83	1,274	.0	769	576	1,722	.00	4,398	893	810	3,400	1.2	Very high	...do.....	(?)	...do...	Unfit	Poor
H 18	Nov. 24	47	.03	38	26	87	.0	171	13	157	19	490	202	200	240	13	Moderate	...do.....	(?)	Fair...	Good	Fair
K 1	Nov. 25	22	.06	267	33	582	.0	559	719	609	.00	2,552	803	860	1,600	3.1	Very high	...do.....	(?)	Very bad.	Bad.	Poor
K 3	...do...	27	.20	247	100	344	.0	341	557	647	1.5	2,262	1,030	920	930	3.2	...do.....	...do.....	C	...do...	..do..	Do.
K 7	...do...	38	.07	50	9.0	43	.0	190	16	53	10	320	162	200	120	35	Moderate	Ca-CO3..	(?)	Fair...	Good	Good
K 8	...do...	36	.40	50	54	379	.0	276	221	505	.00	1,410	346	270	1,000	3.9	High....	Na-Cl..	(?)	Very bad.	Poor	Poor
K 10	...do....	40	.06	131	52	347	.0	214	186	656	.00	1,604	541	510	940	3.1	...do.....	...do.....	C	...do...	..do..	Do.
K 16	...do....	18	.09	39	21	228	.0	378	118	174	.80	789	184	170	620	5.5	...do.....	Na-CO3.	N	...do...	Fair.	Do.
	1918.																					
K 30 [f]	Mar. 16	32	1.3	22	10	36	.0	69	20	62	12	274	96	110	97	33	Moderate	Na-Cl...	(?)	Good..	Good	Good
	1915.																					
K 31	June 11	28	Tr.	77	30	96	.0	251	65	177	1.0	628	316	300	260	12	High....	...do.....	(?)	Bad...	Fair.	Fair
K 32	June 9	26	Tr.	68	53	990	9.8	1,033	371	878	60	3,012	387	310	2,700	2.3	Very high	...do.....	N	Very bad.	Bad.	Poor
K 34	...do....	42	Tr.	244	116	733	24	288	658	1,214	6.0	3,409	1,090	950	2,000	1.7	...do.....	...do.....	C	...do...	Unfit	Do.
K 37	...do....	44	Tr.	550	27	2,565	.0	26	1,381	3,965	.00	8,764	1,490	1,700	6,900	.5	...do.....	...do.....	C	...do...	..do..	Bad
K 40	...do ...	21	Tr.	72	28	367	.0	273	164	494	.00	1,259	295	280	990	4.0	High....	...do.....	(?)	...do..	Poor	Poor
K 44	...do....	36	Tr.	165	72	301	.0	310	420	475	.00	1,644	708	640	810	4.3	...do.. ..	...do.....	C	...do...	..do..	Do.
K 45	...do....	20	Tr.	174	80	392	.0	351	283	731	3.0	1,988	763	670	1,100	2.7	...do.....	...do.....	C	...do...	Bad	Do.
K 47	...do....	24	Tr.	57	17	54	.0	151	81	85	1.0	394	212	220	150	24	Moderate	Ca-CO3.	(?)	Poor..	Good	Good
L 3	June 11	38	Tr.	41	19	70	.0	139	28	128	12	352	180	190	190	16	...do.....	Na-Cl...	(?)	Fair...	..do..	Fair
L 7	...do....	43	Tr.	61	26	72	.0	224	92	96	.00	490	259	270	190	21	...do.....	Na-CO3.	(?)	Poor..	Fair.	Good
L 9	June 10	37	Tr.	77	35	151	.0	219	122	252	1.0	811	336	320	410	8.1	High....	Na-Cl...	(?)	Very bad.	..do..	Fair
L 13	June 11	37	Tr.	65	28	100	.0	208	95	160	.00	584	277	280	270	13	...do.....	...do.....	(?)	Bad...	..do..	Do.

L 35	1914. Nov. 24	55	.00	93	59	255	.0	407	86	389	70	1,280	474	430	700	5.2	...do.....	...do.....	(?)	Very bad.	Poor	Poor
O 3	Dec. 2	18	.30	52	20	95	.0	249	19	139	.80	473	212	200	260	14	Moderate	$Na-CO_3$.	(?)	Bad...	Good	Fair
O 14	Dec. 3	21	.20	41	28	191	.0	249	58	260	1.4	721	217	190	520	7.7	High	Na-Cl...	(?)	Very bad.	Fair.	Do.
O 16	...do....	40	.40	58	28	120	.0	195	38	226	3.0	608	260	260	320	9.0	...do.....	...do.....	(?)	Bad...	..do..	Do.
O 17	1915. June 4	12	Tr.	54	22	201	.0	300	37	267	.00	735	225	210	540	6.6	...do.....	...do.....	N	Very bad.	..do..	Do.
O 18	June 8	35	Tr.	71	31	93	.0	212	73	176	10	624	305	300	250	12	...do.....	...do.....	(?)	Poor..	..do..	Do.
O 20	June 4	33	Tr.	160	137	1,223	.0	603	329	1,974	Tr.	4,285	962	730	3,300	1.0	Very high	...do.....	C	Very bad.	Unfit	Bad
O 28	1914. Dec. 2	10	.40	147	139	1,536	.0	219	248	2,719	.00	5,060	937	670	4,200	.8	...do.....	...do.....	C	...do...	..do..	Do.
O 29	1915. June 4	14	Tr.	46	26	165	.0	137	67	281	.00	708	222	190	440	7.3	High....	...do.....	(?)	...do...	Fair.	Fair
O 30	June 7	45	Tr.	118	40	280	.0	195	210	485	4.0	1,372	459	460	760	4.2	...do.....	...do.....	C	...do...	Poor	Poor
O 31	1914. Dec. 2	55	.30	125	46	189	.0	234	91	443	.00	1,356	501	490	510	4.6	...do.....	...do.....	(?)	...do...	..do..	Do.
O 32	...do...	41	Tr.	94	90	317	.0	180	83	750	1.0	1,533	604	470	860	2.7	...do.....	...do.....	C	...do...	Bad	Do.
O 36	1915. June 4	35	Tr.	87	52	389	.0	312	170	597	1.0	1,543	431	380	1,000	3.4	...do.....	...do.....	(?)	...do...	Poor	Do.
O 38	...do....	39	Tr.	65	31	169	.0	195	66	304	Tr.	813	290	280	460	6.7	...do.....	...do.....	(?)	...do...	Fair.	Fair
O 39	June 5	36	Tr.	46	20	135	.0	161	30	230	3.0	614	197	200	360	8.9	...do.....	...do.....	(?)	Bad...	..do..	Do.
O 40	...do....	42	Tr.	94	50	309	7.2	137	84	630	14	1,399	440	400	830	3.2	...do.....	...do.....	(?)	Very bad.	Poor	Poor
O 42	...do....	32	Tr.	51	24	115	.0	256	30	166	Tr.	543	226	220	310	12	...do.....	...do.....	(?)	Bad...	Fair.	Fair
O 46	June 4	67	.80	85	43	255	.0	249	117	437	.00	1,184	389	390	690	4.7	...do.....	...do.....	(?)	Very bad.	Poor	Poor
O 48	1914. Dec. 2	43	.30	110	57	367	.0	327	188	592	15	1,556	509	460	990	3.4	...do.....	...do.....	(?)	...do...	..do..	Do.
O 49	...do....	32	.20	106	47	304	.0	358	138	481	1.4	1,303	458	420	820	4.2	...do.....	...do.....	(?)	...do...	..do..	Do.
O 50	1915. June 7	32	Tr.	68	26	149	.0	273	72	213	.00	723	277	280	400	9.4	...do.....	...do.....	(?)	Bad...	Fair.	Fair
O 59	June 5	29	Tr.	120	44	427	.0	539	217	521	5.0	1,655	480	460	1,200	3.7	...do.....	...do.....	(?)	Very bad.	Poor	Poor
O 61	1914. Dec. 2	8.0	.70	143	68	485	.0	410	203	809	.00	1,961	636	540	1,300	2.5	...do.....	...do.....	(?)	...do...	Bad	Do.

[a] For methods used in analyses and accuracy of results, see pp. 222-223.
[b] See also records corresponding in number in Table 46, opposite p. 222.
[c] Sodium and potassium results are computed according to method on p. 222, but are included under determined quantities in order to maintain the usual arrangement of bases and acids.
[d] Depth in inches of water which would yield on evaporation sufficient alkali to render a 4-foot depth of soil injurious to the most sensitive crops.
[e] Based on computed quantity; N=noncorrosive; C=corrosive; (?)=corrosion uncertain.
[f] Analyzed by Alfred A. Chambers and C. H. Kidwell, U. S. Geol. Survey.

TABLE 58.—*Laboratory assays*[a] *and classification of water from wells.*

[Parts per million except as otherwise designated. Alfred A. Chambers and C. H. Kidwell, analysts. Numbers at heads of columns refer to corresponding well numbers on Pl. II; see also records corresponding in number, Table 46, opposite p. 222.]

	F 1	F 9	G 16	K 1	K 39a	K 41	L 34	O 3	O 60a
Determined quantities:									
Iron (Fe)	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.
Carbonate radicle (CO_3)	0.0	0.0	0.0	4.8	0.0	0.0	46	12	0.0
Bicarbonate radicle (HCO_3)	224	178	340	516	304	204	56	229	312
Sulphate radicle (SO_4)	45	108	40	640	112	74	28	18	89
Chloride radicle (Cl)	98	329	338	592	492	188	196	90	280
Total hardness as $CaCO_3$	180	325	389	757	468	318	264	179	374
Computed quantities:[b]									
Sodium and potassium (Na+K)	95	200	210	590	300	120	83	88	190
Total dissolved solids	450	880	930	2,400	1,300	680	520	420	890
Scale-forming constitutents	210	360	420	790	500	350	290	210	400
Foaming constituents	260	540	570	1,600	810	320	220	240	510
Alkali coefficient (inches)[c]	15	6.2	6.0	3.1	4.1	11	10	13	7.2
Classification:									
Mineral content	Mod.	High	High	Very high	High	High	High	Mod.	High
Chemical character	Na–CO_3	Na–Cl	Na–Cl	Na–Cl	Na–Cl	Ca–Cl	Ca–Cl	Na–CO_3	Na–Cl
Probability of corrosion[d]	N	(?)	(?)	(?)	(?)	(?)	(?)	N	(?)
Quality for boiler use	Bad	Very bad	Very bad	Very bad	Very bad	Poor	Poor	Poor	Very bad
Quality for domestic use	Good	Poor	Poor	Bad	Poor	Fair	Fair	Good	Poor
Quality for irrigation	Fair	Fair	Fair	Poor	do	do	do	Fair	Fair
Date of collection (1918)	Mar. 6	Mar. 6	Mar. 16	Mar. 6	Mar. 6	Mar. 9	Mar. 15	Mar.15	Mar. 15

[a] For methods used in assays and accuracy of results, see pp. 222–223.
[b] See page 223.
[c] Depths in inches of water which would yield on evaporation sufficient alkali to render a 4-foot depth of soil injurious to the most sensitive crops.
[d] Based on computed quantity; N=noncorrosive; (?)=corrosion uncertain.

TABLE 59.—*Incomplete laboratory assays of water from wells and springs.*

[Parts per million; samples collected June, 1915; assayed by S. C. Dinsmore. For records of wells and springs, see corresponding numbers in Table 46, opposite p. 222.]

No. on Pl. II.	Iron (Fe).	Carbonate radicle (CO_3).	Bicarbonate radicle HCO_3).	Sulphate radicle (SO_4).	Chloride radicle (Cl).
C 2	Tr.	0	168	84	39
F 2	Tr.	0	217	37	85
F 3	Tr.	0	639	431	703
F 4	Tr.	0	346	35	188
G 17	Tr.	0	344	50	515
G 18	Tr.	0	346	104	167
H 2	Tr.	0	234	Tr.	42
H 3	Tr.	0	224	Tr.	46
H 4	Tr.	0	161	Tr.	50
H 5	Tr.	0	217	Tr.	39
H 6	Tr.	0	193	Tr.	50
K 24	Tr.	0	56	Tr.	60
K 33	Tr.	0	227	74	213
K 35	Tr.	0	471	103	348
K 36	Tr.	0	256	176	238
K 38	Tr.	0	395	406	1,050
K 42	Tr.	0	364	481	813
K 43	Tr.	0	112	56	135
K 46	Tr.	0	461	456	788
K 48	Tr.	0	476	181	177
K 49	Tr.	0	283	56	181
K 50	Tr.	0	146	Tr.	60
K 51	Tr.	0	315	108	366
K 52	Tr.	0	168	Tr.	99
L 5	Tr.	0	390	215	419
L 6	Tr.	0	159	49	60
L 8	Tr.	0	168	Tr.	64
L 10	Tr.	0	163	38	85
L 11	Tr.	0	154	Tr.	209
L 12	Tr.	0	361	168	426
L 14	Tr.	0	271	64	149
L 15	Tr.	0	163	56	121
L 16	Tr.	0	398	42	284
L 20	Tr.	0	190	Tr.	106
L 23	Tr.	0	171	61	501
L 24	Tr.	0	188	66	486
L 27	Tr.	0	178	46	586
L 31	Tr.	0	266	50	256
L 38	Tr.	0	178	Tr.	60
L 39	Tr.	0	293	Tr.	163
L 40	Tr.	0	307	37	202
L 41	Tr.	0	263	37	96
L 42	Tr.	0	476	140	518
O 19	Tr.	0	288	36	217
O 21	0.34	0	686	104	1,160
O 22	Tr.	0	30	138	1,300
O 34	Tr.	0	144	49	440
O 35	Tr.	0	183	61	422
O 37	Tr.	0	251	30	199
O 41	Tr.	0	249	Tr.	170
O 43	Tr.	0	266	Tr.	156
O 44	Tr.	0	249	Tr.	170
O 47	Tr.	0	300	256	1,260
O 51	Tr.	0	354	222	511
O 52	Tr.	0	298	97	195
O 53	Tr.	0	429	229	387
O 54	Tr.	0	271	108	217
O 55	Tr.	0	53	Tr.	124
O 56	Tr.	0	290	82	177
O 57	.09	0	288	81	185
P 1	Tr.	0	337	83	199
P 2	Tr.	0	207	36	249

TESTS OF PUMPING PLANTS.

By C. H. Lee.

PURPOSE OF TESTS.

Examinations and tests of pumping plants of various types were made by the writer in June, 1915, to determine under actual conditions on the farm the efficiency of pumps and the over-all efficiency of pumping plants and the cost of pumping water for irrigation.

The efficiency of a pump is the percentage of the useful work done to the total power delivered to the pump. The difference between the efficiency and 100 per cent represents the power which is wasted by friction in the pump but which must be paid for by the owner of the plant, who should therefore understand clearly the conditions that tend to increase or decrease the proportion of power wasted. The efficiency of a pump as measured at the well is very commonly much below that claimed by the manufacturer's catalogue and the sales agent, chiefly because the pump is operated under conditions entirely different from those for which its efficiency was determined for the manufacturer's catalogue. Thus, although the manufacturer's rated efficiency can probably be realized under the prescribed conditions of head, speed, and discharge, the actual efficiency realized under the conditions prevailing where the pump is used may be much lower.

Moreover, the efficiency of the pump may be much greater than the over-all efficiency of the plant, owing to loss of energy in transmission from the motor or engine to the pump. The efficiency of pumps and plants can be shown only by tests made on plants actually installed. Such tests not only assist the owners of pumping plants to determine whether their plants are operating efficiently and economically, but also furnish a basis for rules that should be followed in selecting and installing new plants.

The result of such tests that is perhaps the most valuable to the irrigator is the determination of the cost of pumping water for irrigation. In this day, when so much is said and written to show what enormous profits may be made by irrigation with pumped water, there is great need of careful investigation to determine as accurately as possible the most economical method of pumping for irrigation under every set of local conditions. To the farmer who contemplates putting in a pumping plant for irrigation, the investigation furnishes a means of determining whether it is likely to be a paying investment; to the farmer who is already operating a plant, a comparative study of the cost of pumping in other plants may indicate whether his water is costing too much and may suggest methods by which the cost can be decreased and the profits increased.

The pumping plants selected for tests were only those which could be considered representative of type of well, formations penetrated, and choice and manner of installation of machinery, plants of very poor design or in bad repair being, so far as possible, avoided. Tests were made of seven motor-driven plants and of one gasoline-engine plant, but as the test of the gasoline-engine plant did not prove satisfactory the results were rejected. The owners and operators of the plants cooperated heartily, and the success of the tests is due in no small degree to the valuable assistance and information they so cheerfully furnished.

METHODS USED IN TESTS.

EQUIPMENT.

The following equipment was carried and used as required to supplement permanent equipment found at the plants:

1 0–300-pound pressure gage.
1 vacuum gage.
1 small Price current meter.
1 Fahrenheit thermometer.
1 100-foot steel tape.
1 stop watch.
2 speed indicators.
1 small spirit level.
1 hand level.
1 4-foot folding rule.
1 hook gage, reading to 0.001 foot.
1 Cippoletti weir board, with 24-inch crest.
Miscellaneous small tools, such as drills, pliers, screw driver, wrenches, ¼-inch pipe nipples, and fittings for use with gages.

The pressure gage was calibrated against a standard and was found to be correct when registering more than 9 feet of water pressure. The vacuum gage was new and checked closely with one known to be correct. The current meter, which had been recently rated, was in excellent condition. The Cippoletti weir board was made of 1-inch redwood and was 6 feet long and 2 feet wide; the notch was 7 inches deep and 24 inches long on the bottom; galvanized sheet iron was fastened to the upstream face of the notch with screws and nails, and the wooden edge was beveled on the downstream side so as to insure a free fall of the water. A burlap apron was tacked to the board on each side to prevent the water from leaking around the weir.

MEASUREMENTS AND COMPUTATIONS.

Discharge.—Wherever possible the discharge, or the quantity of water being lifted by the pump, was measured by the portable Cippoletti weir, a temporary pond with earth banks being prepared and the weir board placed at one end and thoroughly puddled into the bank. A hook gage fastened to a stake driven upstream from the weir was used for reading the head of water over the crest of the weir. The discharge was then determined from standard tables of discharge for Cippoletti weirs. In two tests the discharge was measured with the current meter; in two others it was determined by measuring the change in depth of water in a circular reservoir during the period of the test.

Head.—The head against which a pump must operate is often erroneously considered as the vertical distance between the water surface in the well during pumping and the point of free discharge or, when the discharge is submerged, the level of the water in the reservoir or standpipe. The actual head, however, is always greater than this static head, for the pump must also operate against a head made up of the losses due to friction in the discharge and suction pipes. Pump efficiency computed from static head alone is therefore too low. In these tests the total head was obtained, where possible, by installing pressure and vaccum gages and observing the pressure heads and suction heads, and adding to this observed head the measured vertical distance between the center of the pressure gage and the point of insertion of the vacuum gage. This method gives the true total head against which the pump operates and includes the difference of elevation through which the water is lifted as well as the head due to losses by friction in the suction and discharge pipes. It does not include the head represented by the velocity of discharge, and although engineers differ in opinion as to whether it should be credited to the pump, it was not taken into account in these tests.

Where it was impossible to install the pressure and vacuum gages, the total head was determined by adding to the difference in elevation between the surface of the water in the well and the point of discharge, the head lost by friction in pipe and bends, computed by the usual hydraulic formulas.

Speed.—The speed of motors and pumps was measured by means of a speed counter and stop watch. In plants provided with belt transmission from motor to pump, loss of power in transmission was determined by measuring the speed of both drive and pump pulleys as nearly simultaneously as possible. Several readings were made during each test, and the mean result was taken as the determined speed.

Water horsepower.—"Water horsepower," as the term is used in these tests, is the product of the discharge in gallons per minute by the weight of a gallon of water in pounds by the total head in feet, divided by 33,000, the number of foot-pounds per minute equivalent to one horsepower. Total head is the head made up of the static head plus head due to losses by friction in suction and discharge pipes.

Power input.—The power input of the pumping plants, all of which were motor-driven electrical plants, was measured in kilowatts at the beginning and the end of the test by reading the watt meters installed by the power company. The difference between these readings gave the number of kilowatt-hours of power used during the period of the test, from which, the meter constant and the duration of the test in hours being known, the power input in kilowatts was computed and reduced to horsepower. In all the tests the speed of the meter disk was read and the power input in kilowatts was computed as a check on that obtained from the meter readings. The number of kilowatts as derived from the meter readings was used in all the tests except one, as it gave a better average determination for the power input, from which the plant efficiency was determined.

Horsepower input at pump.—The horsepower input at the pump, used in determining pump efficiency, was computed by subtracting from the electrical horsepower input at the motor the power lost in the motor and in the transmission from motor to pump. The power lost in the motor was computed from the efficiency of the motor as shown by the efficiency curves furnished by the manufacturers. Part of the loss in belt transmission was determined by comparing the measured speed of the pump pulley with its theoretical speed as computed from the measured speed of the drive pulley and the ratio of pulley diameters. Other belt losses are small and no attempt was made to determine them. The loss in gear transmission was computed by Goodman's empirical formula for efficiency of toothed gears.

Pump efficiency.—The pump efficiency is the ratio of the water horsepower to the horsepower input at the pump. In many efficiency tests of installed irrigation pumps the loss in transmission between motor or engine and pump has been charged to the pump. This practice is manifestly unfair to the pump, and care was taken in these tests and computations to obtain as closely as possible the actual power input at the pump.

Plant efficiency.—The plant efficiency is the ratio of the water horsepower to the electrical horsepower input at the motor, as determined from the watt-meter readings of power consumed during the test. It differs from pump efficiency in that it includes, besides such losses as those in pump and piping, the losses in the motor and in transmission from motor to pump.

RESULTS OF TESTS.

PUMPING PLANT AT WELL O 132.

The plant at well O 132 is in Tia Juana Valley, 2 miles southeast of Nestor, in sec. 34, T. 18 S., R. 2 W., and is owned by C. M. Richardson. It was tested June 19, 1915, at which time it had been in operation two years.

The equipment consisted of a 20-horsepower, 3-phase, 220-volt motor, rated at 1,200 revolutions per minute, direct-connected to a 6-inch centrifugal pump, rated at 900 gallons per minute at 1,120 revolutions per minute when operating against a 40-foot head. The discharge pipe was 8 inches in diameter and 19.5 feet long.

Pump and motor were placed in the bottom of a circular concrete pit, 12 feet in diameter and 12 feet deep, a shed housing all. On a level with the bottom of the pit was a horizontal suction pipe, 8 inches in diameter and 76 feet long, from which vertical connections 9 feet long were dropped into each of two drilled wells, 72 feet apart, sunk to a depth of 68 feet below the surface of the ground, lined to the level of the horizontal suction pipe with 12-inch casing perforated along the lower 12 feet.

The pressure gage could not be used with the low head existing, so that the total head was obtained by adding the suction head as observed with the vacuum gage, the measured vertical distance between vacuum gage and point of discharge, and the estimated head lost by friction in the discharge pipe. The discharge was measured with the current meter in a wooden flume that carried the water from the pump. The power input was obtained from readings of the watt meter at the beginning and the end of the test.

Summary of results of test at well O 132.

Duration....hours..	1
Speed of motor....revolutions per minute..	1,120
Speed of pump....do....	1,120
Depth of normal water level below the ground surface (approximate)....feet..	9
Drawdown (estimated)....do....	27
Total head (estimated)....do....	44.5
Discharge....gallons per minute..	1,120
Water horsepower....	12.6
Power input....kilowatt hours..	14
Power input....horsepower..	18.75
Motor efficiency....per cent..	88
Horsepower input at pump....	16.5
Pump efficiency....per cent..	76.5
Plant efficiency....do....	68.5

PUMPING PLANT AT WELL K 41.

The plant at well K 41 is in Mission Valley, about 5 miles northeast of San Diego, and is owned by C. A. Van Houten. It had been in operation six months when the test was made, June 21, 1915.

The equipment included a 20-horsepower 3-phase 220-volt motor, rated at 1,200 revolutions per minute, direct-connected to an 8-inch centrifugal pump having a discharge pipe 10 inches in diameter and 16.7 feet long. The suction line ranged from 8 inches to 4 inches in diameter, the horizontal part being composed of 120 feet of 8-inch, 60 feet of 6-inch, and 60 feet of 4-inch pipe.

Pump and motor were in the bottom of a circular concrete pit, 8 feet in diameter and 9.5 feet deep. From the horizontal part of the suction line, which extended out from and on a level with the bottom of the pit, a 4-inch pipe, 35 feet long, extended into each of five drilled wells, spaced 60 feet apart, sunk to an average depth of 80 feet, and lined with 10-inch standard screw casing which was perforated with drilled holes along the lower 10 feet in each well; the well casings extended only to the suction line. One of the wells was directly below the bottom of the pit and the others were outside. The well farthest from the pump was in an open pit extending from the horizontal suction pipe to the surface of the ground; the other wells were buried.

Two test runs were made. The pressure gage could not be used at the low head existing, and the total head was obtained by adding the suction head as observed with the vacuum gage, the measured vertical distance between the vacuum gage and point of discharge, and the estimated head lost by friction in the discharge pipe. The pump was leaking air badly during both tests, and just at the conclusion of the second run entirely stopped delivering water. The discharge in the first run was measured by current meter in the ditch that carried water from the plant; for the second run it was measured by both weir and current meter, the two determinations checking closely. The power input for both runs was obtained from readings of the speed of disk in the watt meter.

Summary of results of test of well K 41.

	First run.	Second run.
Duration ... hours..	1.32	1.35
Speed of motor ... revolutions per minute..	1,170	1,170
Speed of pump ... do....	1,170	1,170
Depth of normal water level below ground surface (approximate) ... feet..	8	....
Drawdown [a] (approximate) ... do....	....	22
Total head (estimated) ... do....	32.7	36.7
Discharge ... gallons per minute..	529.5	614.
Water horsepower ...	4.4	5.7
Power input ... kilowatt hours..	15.4	16.9
Power input ... horsepower..	15.65	17.21
Motor efficiency ... per cent..	87	87
Power input at pump ... horsepower..	13.6	15.0
Pump efficiency ... per cent..	32	38
Plant efficiency ... do....	28	33

[a] Final drawdown at end of second run after five hours continuous pumping; the rest of the data for the two runs being taken during this time.

PUMPING PLANT AT WELL O 115.

The plant at well O 115 is 1½ miles south of Nestor, on the north edge of Tia Juana Valley, in sec. 34, T. 18 S., R. 2 W., and is owned by W. E. Williams. The test was made June 24, 1915, at which time the plant had been in operation two years.

The equipment consisted of a 5-horsepower 3-phase 60-cycle 220-volt motor, rated at 1,800 revolutions per minute, belted with 3½-inch 4-ply stitched canvas belt to a centrifugal pump with 3½-inch suction. The discharge pipe was 4 inches in diameter and 21.5 feet long. The suction pipe was 4 inches in diameter and 27 feet long.

The motor was on the ground-surface level, housed in a shed, and the pump was set in the bottom of an open-dug pit, 5 feet square and 7.5 feet deep, curbed with redwood boards. The belt connecting pump and motor ran through an inclined trench, the motor and pump being spaced 17.8 feet, center to center. From the bottom of the pit a single drilled well, lined with unperforated 10-inch casing and drawing water only from the bottom, was sunk to a depth of 56 feet.

The plant was in poor running order. The curbing was in bad condition, a result of the wet weather of 1914–15. The bottom of the pit was a bog of quicksand, silt, and water, and streams of water were entering the well casing. The slush and water with which the pump pulley and belt were in continuous contact caused much slippage in the belt and very uneven discharge. The discharge was measured with the 2-foot Cippoletti weir. Owing to the impossibility of installing the vacuum and pressure gages, the total head was estimated by adding the measured distance from the average drawdown of the water level to the point of discharge and the estimated loss of head due to friction in pipe and bends. The power input was obtained from readings of the watt meter at the beginning and the end of the test.

Summary of results of test at well O 115.

Duration	hours	1.1
Speed of motor	revolutions per minute	1,783
Speed of pump	do	795
Depth of normal water level below ground surface	feet	8.1
Drawdown	do	15.25
Total head (estimated)	do	28.7
Discharge	gallons per minute	231.0
Water horsepower		1.7
Power input	kilowatt hours	5.3
Power input	horsepower	6.45
Motor efficiency	per cent	86
Belt efficiency (assumed)	do	90
Power input at pump	horsepower	4.99
Pump efficiency	per cent	34
Plant efficiency	do	26

PUMPING PLANT AT WELL O 47.

The plant at well O 47 is 1½ miles west of Nestor, in the SW. ¼ sec. 29, T. 18 S., R. 2 W., and is owned by Tucker and Evans. The test was made June 18, 1915, at which time the plant had been operated two years.

The equipment consisted of a 10-horsepower 3-phase 60-cycle 220-volt motor, rated at 1,800 revolutions per minute, direct-connected to a 4-inch centrifugal pump with rated discharge of 400 gallons per minute at 1,740 revolutions per minute. The discharge pipe was 6 inches in diameter and 25 feet long. The suction pipe was 6 inches in diameter and 30 feet long.

The plant is of modern design, the pump and motor being placed in a concrete pit 4.7 feet by 8.5 feet and 19 feet deep, a shed housing the whole. From the bottom of the pit a drilled well, with 12-inch casing, extended to a depth of 68 feet below the surface of the ground. The casing was said to be without perforations, the water being drawn into the well at the bottom.

The total head was obtained by readings of the vacuum and pressure gages. The discharge was measured by the portable 2-foot Cippoletti weir. The power input was obtained from readings of the watt meter at the beginning and the end of the test.

Summary of results of test at well O 47.

Duration	hours..	1.63
Speed of motor	revolutions per minute..	1,732
Speed of pump	do....	1,732
Depth of normal water level below ground surface	feet..	21
Drawdown	do....	21
Total head	do....	53.1
Discharge	gallons per minute..	373.0
Water horsepower		5.01
Power input	kilowatt hours..	13.0
Power input	horsepower..	10.67
Motor efficiency	per cent..	87
Power input at pump	horsepower..	9.27
Pump efficiency	per cent..	54.0
Plant efficiency	do....	47.3

PUMPING PLANT AT WELL O 102.

The plant at well O 102 is 1 mile east of Nestor, in the SE. ¼ sec. 27, T. 18 S., R. 2 W., and is owned by R. J. Jaeger. The test was made June 18, 1915, when the plant had been in operation two years.

The equipment included a 10-horsepower 3-phase 220-volt motor, rated at 800 revolutions per minute, geared to a deep-well reciprocating pump with 8-inch cylinders and 15-inch stroke, whose rated capacity was 243 gallons per minute at 40 strokes per minute. The discharge line was made up of 90 feet of 10-inch pipe and 112 feet of 6-inch pipe. The suction pipe was 8 inches in diameter and 18 feet long.

Pump head and motor were placed at the ground-surface level and were supported on timbers spanning an open dug pit, 4 feet square and 110 feet deep, curbed with concrete. From the bottom of the pit a drilled well, lined with 12-inch casing, extended to a depth of 20 feet below the bottom of the pit, the casing protruding 10 feet above the bottom of the pit.

The total head was obtained by adding the measured distance from the water level in the pit during pumping to the point of discharge and the estimated head due to losses from friction in the discharge and suction lines. The discharge was obtained by measuring the depth of water at the beginning and end of the test in a concrete circular reservoir. The power input was obtained from readings of the watt meter at beginning and end of test.

Summary of the results of test at well O 102.

Duration	hours	2.1
Speed of motor	revolutions per minute	862.2
Speed of pump	strokes per minute	25.4
Depth of normal water level below ground surface	feet	84.0
Drawdown		Inappreciable.
Total head (estimated)	feet	97.4
Discharge	gallons per minute	116
Water horsepower		2.9
Power input	kilowatt hours	13.0
Power input	horsepower	8.32
Motor efficiency	per cent	86
Power input at pump	horsepower	7.15
Pump efficiency [a]	per cent	40.6
Plant efficiency	per cent	35.0

PUMPING PLANT AT WELL L 24.

The plant at well L 24 is about half a mile north of El Cajon and is owned by Joseph Miller. The test was made June 22, 1915, when the plant was only 3 months old.

The equipment consisted of a 5-horsepower 3-phase 60-cycle 220-volt motor, rated at 1,700 revolutions per minute, direct-connected to a centrifugal pump rated at 225 gallons per minute when pumping against a 40-foot head. The pump suction was 2½ inches in diameter, and the suction pipe was 4 inches in diameter and 26 feet long. The discharge pipe was 3 inches in diameter and 32.85 feet long.

The plant was thoroughly modern and well equipped. Pump and motor were set in the bottom of a water-tight concrete pit, 5 feet in diameter and 25 feet deep, protected by shed housing, and distant about 8 feet from the open dug well, 7.5 feet in diameter and 50 feet deep, curbed with concrete. The normal water level was thus always above the level of the pump and hence no priming was required. About 7 feet up from the bottom of the well five 2-inch

[a] Pump efficiency includes loss in gears of pump head, which is standard equipment of the manufacturing concern, and therefore is a loss whose effect should be included in the pump efficiency.

auger-hole borings extended radially from the well, for distances ranging from 60 to 131 feet, into the water-bearing residuum.

The head was obtained by readings of the vacuum and pressure gages. The discharge was measured by means of the 2-foot Cippoletti weir. The power input was obtained by readings of the wattmeter at beginning and end of test.

Summary of the results of test at well L 24.

Duration	hours	20.8
Speed of motor (average)	revolutions per minute	1,714
Speed of pump	do	1,714
Depth of normal water level below ground surface	feet	9.5
Drawdown	do	20.8
Total head	do	46.35
Discharge	gallons per minute	156
Water horsepower		1.83
Power input	kilowatt hours	73.6
Power input	horsepower	4.74
Motor efficiency	per cent	85
Power input at pump	horsepower	4.04
Pump efficiency	per cent	45.3
Plant efficiency	do	39.3

PUMPING PLANT AT WELL L 98.

The plant at well L 98 is 2 miles east of El Cajon and is owned by Charles Bentley. The test was made June 23 and 24, 1915, at which time the plant had been in operation 11 months.

The equipment consisted of a 5-horsepower 3-phase 60-cycle 220-volt motor, rated at 1,800 revolutions per minute, connected by a very short 3-inch leather belt to the pump head of a duplex displacement pump, with cylinders 5 inches in diameter and stroke 27 inches. There were 61.2 feet of 6-inch suction and discharge pipe and 47.7 feet of 4-inch discharge pipe.

The well was a dug pit, 7 feet 2 inches in diameter for the first 6 feet (where it was curbed), 4 feet 6 inches in diameter to a depth of 20 feet, and 6 feet in diameter for the remainder to a total depth of 68 feet. There were no laterals. Pump and motor were supported on a platform over the pit and the whole was housed by a shed. The pulley wheel to which the motor was belted operates a train of gears which finally operates the connecting rods of the pump cylinders. The belt showed much tendency to slipping. Considerable vibration of the pump rods was observed.

Tests were made for three runs. The total head in each run was determined by adding the measured distance from the average water level in the well to the point of discharge and the estimated head lost in friction. The discharge was determined by measuring the depth, at the beginning and end of the test, in the circular wooden tank that received the water. The power input was obtained from readings of the wattmeter at beginning and end of test.

Summary of results of test at well L 98.

	First run.	Second run.	Third run.
Duration....hours..	1.2	0.45	0.98
Speed or motor....revolutions per minute..	1,769	1,766	1,750
Speed of drive pulley on pump....do....	258	258	262
Depth of normal water level below ground surface (approximate)...feet..	11		
Drawdown [a]....do....	....	24.73	....
Total head....do....	62.9	77.1	56.5
Discharge....gallons per minute..	82.0	75.2	79.9
Water horsepower....	1.3	1.5	1.1
Power input....kilowatt hours..	3.05	1.1	2.55
Power input....horsepower..	3.41	3.27	3.37
Efficiency of motor....per cent..	84	84	84
Efficiency of belt....do....	90.0	90.2	89.9
Power input at pump....horsepower..	2.57	2.48	2.54
Pump efficiency....per cent..	51	60	45
Plant efficiency....do....	38	45	34

[a] Drawdown reached at end of second run after 3 hours and 35 minutes continuous pumping, during which other data for runs 1 and 2 were obtained.

DISCUSSION OF TESTS AND COST OF PUMPING.

ESTIMATES OF FIXED CHARGES.

The results of the foregoing tests are summarized in Table 61, in which are included also data concerning the cost of pumping at each plant.

Information as to the cost of the plant and well, the cost of repairs and attendance, the number of hours during the year each plant was run, and the unit cost of fuel was obtained from the owners of the plants. For estimating the fixed charges of interest, depreciation, repairs and maintenance, taxes and insurance, it was assumed that the percentages in Table 60 represent nearly the actual costs under these heads for the average pumping plant in San Diego County.

TABLE 60.—*Assumed fixed charges for pumping plants, expressed as per cent of total cost of plant.*

	Gasoline-engine plant.	Motor-driven plant.
Depreciation....	8	5
Interest....	6	6
Repairs and maintenance....	3	1
Taxes and insurance....	1	1
	18	13

TABLE 61.—*Summary of pumping plant tests and cost of pumping.*

Well No.	Size of motor (horse-power).	Measured speed of motor (revolutions per minute).	Electrical horse-power input at motor.	Brake horse-power at motor.	Horse-power input at pump.	Kind and size of pump.	Measured speed of pump (revolutions per minute).	Total[a] head (feet).	Discharge (gallons per minute).	Water horse power[1].	Pump efficiency[1].	Plant efficiency[1].	Power input (kilowatts).	Kilowatts per water horse-power.	Total number hours plant runs per year.	Total kilowatt hours per year.
K 41	20	1,170	17.21	15.0	15.0	Centrifugal (8-inch suction)	1,170	36.7	614.0	5.7	38	33	12.85	2.25	1,590	20,400
L 98	5	1,769	3.41	2.86	2.57	Duplex	258	62.9	82.0	1.3	51	38	2.54	1.95	1,920	4,880
L 24	5	1,714	4.74	4.04	4.04	Centrifugal (2½-inch suction)	1,714	46.35	156.0	1.83	45.3	39.3	3.54	1.93	2,312	8,190
O 47	10	1,732	10.67	9.27	9.27	Centrifugal (4-inch suction)	1,732	53.1	373.0	5.01	54.0	47.3	7.96	1.59	672	5,350
O 102	10	862.2	8.32	7.15	6.28	Deep-well	25.4	97.4	116.5	2.9	46	35	6.2	2.14	1,728	10,700
O 115	5	1,783	6.45	5.55	4.99	Centrifugal (3½-inch suction)	795	28.7	231.0	1.7	34	26	4.82	2.84	230	1,158
O 132	20	1,120	18.75	16.5	16.5	Centrifugal (6-inch suction)	1,120	44.5	1,120.0	12.6	76.5	68.5	14.0	1.1	793	11,100

Well No.	Unit cost of electricity.	Total area irrigated (acres).	Total quantity of water pumped (acre feet).	Total cost of plant.	Annual costs.			Annual cost per water horsepower.[1]			Annual cost per acre-foot pumped.			Annual cost per acre-foot per foot of lift.		
					Fixed charges estimated at 13 per cent.	Electricity.	Total.	Fixed charges.	Electricity.	Total.	Fixed charges.	Electricity.	Total.	Fixed charges.	Electricity.	Total.
K 41	$240 minimum; 2.78 cents per kilowatt hour.	30	[2] 180.0	$2,672.00	$347.00	$568.00	$915.00	$61.00	$99.50	$160.50	$1.93	$3.15	$5.08	$0.052	$0.086	$0.138
L 98	$100 minimum; 3.89 cents per kilowatt hour.	18	29.0	1,165.00	151.50	190.00	341.50	116.50	146.25	262.75	5.23	6.55	11.78	0.083	0: 104	0.187
L 24	2.50 cents per kilowatt hour	28	66.5	916.50	119.00	205.00	324.00	65.00	112.00	177.00	1.79	3.08	4.87	0.039	0.066	0.105
O 47	$120 minimum; 3.33 cents per kilowatt hour.	10	46.1	816.00	106.00	178.00	284.00	21.20	35.60	56.80	2.30	3.86	6.16	0.043	0.073	0.116
O 102	$180 minimum; 2.78 cents per kilowatt hour.	21	37.1	[b] 1,905.00	248.00	297.00	545.00	85.50	102.50	188.00	6.69	8.00	14.69	0.069	0.082	0.151
O 115	$60 minimum; 3.89 cents per kilowatt hour.	10	9.8	532.00	69.00	45.00	114.00	40.50	26.50	67.00	7.04	4.59	11.63	0.245	0.160	0.405
O 132	$300 minimum; 2.78 cents per kilowatt hour.	27	164.0	2,491.00	324.00	309.00	633.00	25.70	24.55	50.25	1.98	1.88	3.86	0.045	0.042	0.087

a Including friction head. *b* Estimated.

The rate of depreciation of pumping plants varies through an enormous range, not only as a whole but in its several parts. It depends mainly on the skill and care of the attendant. The assumed percentages give a fair estimate of cost of depreciation where reasonable care in attendance is exercised. The actual cost of repairs and maintenance is difficult, and for some plants impossible to determine, owing to the fact that few owners of pumping plants keep accurate account of such expenses, and even if a record has been kept it does not cover a sufficient number of years to give a figure that will represent the average annual cost of repairs and maintenance. The percentage assumed is, therefore, based largely on data gathered in previous investigations of the cost of pumping in other localities.

None of the owners of tested plants reported expense of attendance as part of the cost. This failure to report it does not mean that the plant required no attendance, but that the owner himself spends as much time as is necessary in caring for the plant during his odd moments. Strictly speaking, charge for the time spent by the farmer in that way should be added to the annual cost, for though motor-driven plants require little or no attendance while running, gasoline-engine plants sometimes require a great deal of attendance. However, if the plant is in good running order the amount of necessary attendance is small and its cost is usually negligible.

The investigations of plant and pump efficiency and cost of pumping, summarized in Table 61, cover only in part the range of conditions of installation of pumping plants; for, so far as possible, plants were selected which were in good repair and of good design. They do, however, cover the range of capacities and equipment commonly found in small pumping plants used for irrigation, and the results, therefore, indicate those that may be obtained in plants which are of reasonably good design and are maintained in good running order. A study of the table brings out some very interesting facts.

PUMP EFFICIENCY.

Centrifugal pumps ranged in efficiency from 34 per cent for a $3\frac{1}{2}$-inch pump to 76.5 per cent for a 6-inch pump, the efficiency increasing, other things being equal, with the size of the pump. The efficiency of 76.5 per cent for the 6-inch pump (well O 132) and 45 per cent for the $2\frac{1}{2}$-inch pump (well L 24) is unusually high for pumps of these sizes, and shows not only that the plants have been well designed and are in good running order, but that during the last few years the manufacturers have greatly improved the design of centrifugal pumps for small pumping plants for irrigation. The efficiency of 38 per cent for the 8-inch centrifugal pump (well K 41) is low for a pump of that size, but is due to the fact that the pump was leaking air badly during the test. The efficiency of 34 per cent for the $3\frac{1}{2}$-inch pump (well O 115) is also lower than it should be, but the reason is not apparent from the data obtained, except that the whole plant was in poor running order.

The efficiency given by the tests of the reciprocating pumps may be considered fair and to fall within the limits of efficiency generally given by pumps of this type.

PLANT EFFICIENCY.

The table shows plant efficiency ranging from 26 per cent to 68.5 per cent, the less efficient being, as was to be expected, the smaller plants. The range is that generally found in practice, although 68.5 per cent is unusually high. The efficiency of the plants equipped with reciprocating pumps is not relatively high, that of the plant with the duplex pump (well L 98) being much lower than it should have been, on account of the excessive loss in transmission due to belt slippage. The deep-well pump at well O 102 might have shown greater efficiency in both plant and pump if it had been operating more nearly at its rated capacity and speed and for conditions more nearly suited to a pump of this type.

In regard to power consumed, the summary shows that under the best conditions the larger motor-driven plants consume 1.1 kilowatts per water horsepower and the smaller plants about 1.9 kilowatts. In this connection attention is called to the great increase in consumption of power due to poor repair or poor design of plant, as is clearly shown in the tests of wells K 41 and O 115. The pump at well K 41 was leaking air badly at the time of the test; the pump at well O 115 was either of poor design or in poor running order, and, moreover, was handicapped by excessive slippage of the belt. The owners of such plants are paying much more for the water pumped than is necessary and could greatly reduce costs by making the necessary improvements or repairs, the expense of which would probably be small as compared with the loss resulting from running a plant in poor repair or of poor design.

COST OF PUMPING.

In regard to the cost of pumping—total and in detail—Table 61 furnishes information of much interest. The cost of electricity for motor-driven plants is not so great a part of the expense of pumping as is commonly believed. For the plants tested, the relation of the annual cost of electrical power to the total annual cost ranged from 40 to 63 per cent, the average being 55 per cent. This relation, of course, depends on the unit cost of electrical power and on the length of time during which the plant is operated during the year, and may vary with the locality. The figures, therefore, indicate only the relation that may exist for conditions similar to those in San Diego County.

The annual cost per water horsepower furnishes the best means of comparing the economy of pumping plants as machines for pumping water. For any type of centrifugal pump, the larger the pump the smaller the cost per water horsepower.

The annual cost per acre-foot of water pumped was, perhaps, the item of greatest interest to the owners of the plants tested, and it affords also a basis for rough estimate of the total annual cost of pumping for any known area and duty of water. The annual cost per acre-foot for the plants tested ranges from $3.86 for a plant having a lift of 44.5 feet and a discharge of 120 gallons per minute to $14.69 for a plant having a lift of 97 feet and a discharge of 116.5 gallons per minute. Out of thirteen motor-driven pumping plants near Pomona, Cal., tested in 1905,[1] the annual cost per acre-foot of water pumped ranged from $1.96 for a pump having a head of 22.5 feet and discharging 992 gallons per minute to $19.20 for a plant having a head of 122.4 feet and discharging 494 gallons per minute.

For the plants using centrifugal pumps, the annual cost of pumping per acre-foot of lift ranges from about $0.09 to $0.40. For four of the seven plants tested the costs range from $0.09 to $0.14, amounts that are more nearly representative of the usual range in cost of pumping water for plants of this type. Out of seven motor-driven plants equipped with centrifugal pumps near Pomona, Calif., tested in 1905,[2] the annual cost of pumping per acre-foot of water per foot of lift ranged between $0.07 and $0.45, but in five of these tests the cost was less than $0.16. The high cost of pumping at well O 115—$0.40 per acre-foot per foot—is a striking illustration of the large increase in cost due to poor repair or poor design of plant. The cost at well O 115 is about four times as large as at well L 24, in which the pump is smaller. The same relation is shown in less degree at well K 41, where the annual cost per acre-foot per foot of lift is about $0.14, whereas at well O 132, which is equipped with a pump of about the same size, the cost is $0.09.

Another cause contributing to the high cost of pumping at well O 115—a cause which must be taken into consideration—is the relatively small time during the year in which the plant is operated. The fixed charges, which make up a large part of the annual cost of pumping, continue at about the same rate whether the plant is being operated or not, and all computations in this report are based on the assumption that they do continue at the same rate. Therefore, other things being equal, the longer the period of operation during

[1] Le Conte, J. N., and Tait, C. E., Mechanical tests of pumping plants in California: U. S. Dept. Agr. Office Exper. Sta. Bull. 181, p. 56, 1907.

[2] Idem, p. 60.

the year the smaller will be the unit cost of pumping the water. If, for example, the plant at well O 115 was operated 3,000 hours during the year instead of 230 hours, the total number of acre-feet pumped per year would be 127.7, the cost of electricity would be $563.50, and the total annual cost $632.50; the cost per acre-foot per foot of lift would then be about $0.17. This illustration shows clearly how great a factor the length of the pumping season is in the total cost of an acre-foot of water. There is ordinarily more or less opportunity for choice between a pump of small capacity to be operated for a long period and a pump of larger capacity to be operated for a shorter period. The first cost of a plant of small capacity is less than that of a larger one, and hence the annual fixed charges are smaller. There are, of course, other factors of equal importance in the selection of pumping machinery which are not to the advantage of the small plant. For example, the use of a small plant requires a longer period of irrigation and of attendance in operation than the use of a larger plant and also gives a lower efficiency.

The cost per acre-foot of pumping with the reciprocating pumps is shown by the results of these tests to be high compared with that for the centrifugal pumps. The tests made are not strictly comparable, however, on account of differences in lift and capacity, but they show the limitation in head and capacity for which reciprocating pumps can be economically used. The lifts under which these pumps were operating are too small for their economical use. Pumps of this type are best suited for pumping small quantities of water from depths of 100 feet or more.

SELECTION AND INSTALLATION OF PUMPING MACHINERY.

GENERAL CONSIDERATIONS.

The following suggestions are offered as a guide to the successful selection and installation of small pumping plants for irrigation. They are based on the best experience and practice, not only in San Diego County but throughout the regions in which ground water is pumped for irrigation.

The problem of selecting and installing pumping machinery is much more difficult than many suppose. Acting on the advice of some sales agent who has little or no knowledge of the proper selection and installation of pumps, many farmers have bought pumps that are not well adapted for the conditions of head and discharge under which they must operate, or have selected and installed a gasoline engine or an electric motor which has either too little power and thus will not operate the pump at the desired capacity, or has much more power than is necessary and thus causes undue loss of energy in operation at part load. In many plants that use belt transmission between pump and motor or engine the pulleys are improperly proportioned or there is excessive belt slippage, so that the pump, or the engine, or the motor, or possibly all, may be running at improper speed. The problem not only includes a choice of the proper size and type of the various units of the plant, but a choice of a method of installation that will insure operation at the highest efficiency and furnish the desired quantity of water at a minimum cost.

Mistakes in selecting and installing pumping machinery are expensive, and anyone who contemplates installing a pumping plant that involves an expenditure of $600 or more for equipment would do well to consult some reputable engineer, experienced in the design, selection, and installation of pumping plants for irrigation.

PUMPS.

CAPACITY OF PUMP.

The capacity of the pump required to furnish water for irrigation depends on the area to be irrigated, the total depth of water necessary for properly irrigating the crop, and the length of the period of operation. The advantages and disadvantages of continuous operation with pumps of small size as compared with a shorter period of operation with pumps of larger size have been briefly discussed on page 279. As a rule, a period of operation from one-half to one-third the length of the irrigation season is most desirable. Unless reservoirs are used, the pump should be large enough to give a stream sufficient to irrigate without great loss. To irrigate even the smallest orchard the discharge should be at least 5 to 10 miner's inches (45 to 90 gallons a minute), and for a crop of alfalfa on the sandy soils usual in San Diego County 50 to 75 miner's inches (450 to 675 gallons per minute) would be a minimum. On the other hand, the capacity of the pump is limited by the maximum yield obtainable from the well.

To illustrate the problem of determining the necessary capacity of pumps: Assume a 40-acre farm planted to alfalfa, which requires 3 acre-feet of water per acre for an irrigation season of six months, a quantity equal to an application of a total depth of 6 inches of water each month. For continuous operation, 24 hours a day, the necessary capacity of the pump would be 150 gallons per minute (16.6 miner's inches); for half-time operation, or fifteen 24-hour days during the month, a stream twice as large, or 300 gallons per minute (33.3 miner's inches), would be required; and for a one-third period, a stream three times as large, or 450 gallons per minute (50 miner's inches) would be required. If it were desired to run only 10 hours a day and to operate 15 days a month a pump capacity of 720 gallons per minute (80 miner's inches) would be required. For the usual sandy soil on which alfalfa is grown in San Diego County it would probably be found best to put on only a 3 or 4 inch depth of water at each irrigation and to use a head as large as would be economically feasible. A good practice would be to irrigate twice a month with about 3 inches each time, each irrigation period lasting twelve 10-hour days, the six days interveinng between successive irrigating periods being used for making any needed repairs to the plant. On this schedule of irrigation a pump capable of supplying 450 gallons per minute (50 miner's inches) would be required. Such a pump would furnish a stream large enough to be used economically with the common method of irrigation by portable pipes.

The size of pump of the type selected must be determined from a study of the manufacturers' catalogues. In selecting the size of pump the fitness of the pump for the conditions of head and discharge under which it is to operate should be carefully considered. As a rule, each manufacturer makes only one size of stock pump that will give the highest efficiency when operating under the given conditions of head and discharge, and this pump must be run at the one speed corresponding to the head pumped against. The kind of power and the manner of connection between pump and motor must also be borne in mind, as either may limit the speed at which the pump is to operate. Thus, if a centrifugal pump is to be direct-connected to a motor, a pump must be selected which will operate at the high speed at which motors generally run and which will at the same time give a high efficiency under the given conditions of discharge and head; if the pump is to be belt-connected to a gasoline engine, one run at a lower speed would probably be best suited to the conditions.

TYPE OF PUMP.

Classification of types.—The required capacity of the pump having been determined, the type of pump must next be selected. Although pumps of many types are used for pumping water for irrigation, three main types, which will cover all combinations of conditions, have been found most suitable—the centrifugal pump, the power plunger or piston pump, and the deep-well reciprocating pump. Rotary pumps of certain types are used in a few plants but are adapted only for pumping water that is clean and free from sand. Air lifts are feasible only for large plants and, because of their low efficiency, should be used only under special conditions; they are not suited for use in small pumping plants for irrigation.

Each of these types of pumps is particularly adapted to a certain set of conditions, the limits of which are well recognized, notwithstanding the fact that some manufacturers of pumps of one special type may claim that their pump is suitable for use under all conditions, without regard to economy in operation, capacity, head, or practical difficulties of operation.

Power plunger pumps.—Power plunger pumps, either duplex or triplex, are adapted to pumping small quantities of water, usually less than 150 to 200 gallons per minute, against heads exceeding 75 feet, where the depth of water in the well below the ground surface during pumping does not exceed about 25 feet. For such conditions the cost of fuel or electricity used for pumping is relatively small and the plunger pumps are more efficient than centrifugal pumps of such small capacity. The first cost of the plunger pump per unit capacity is high compared to that of centrifugal pumps. If a capacity much over 200 gallons a minute is required the advantage of cheaper fuel or electricity may be more than offset by the higher fixed charges on the first cost, and hence a centrifugal pump of lower first cost per unit capacity may become cheaper. Again, in order that it may be within suction lift of the water level, it is usually necessary to set a pump of this type in an open pit; therefore if the depth to water level becomes much greater than 25 feet, the first cost of the pit may offset the cheaper cost of fuel or electricity, and a vertical centrifugal pump, or perhaps a deep-well centrifugal pump, inclosed in a steel casing may become cheaper on account of lower total first cost. The economical capacity of the power plunger pump is usually too small for irrigation of alfalfa and is best adapted to irrigating small orchards or truck gardens.

Deep-well reciprocating pumps.—Deep-well reciprocating pumps are adapted to pumping small quantities of water, usually not more than 200 or 300 gallons a minute, from depths ranging from 100 to 400 feet below the surface of the ground. Under such conditions a pump of this type is more efficient than a centrifugal pump and the cost of fuel or electricity is less. However, the first cost of this pump is high per unit capacity as compared with that of the centrifugal pump, and hence, if the required capacity is much more than 200 gallons a minute, a vertical centrifugal deep-well pump inclosed in a steel casing may be found cheaper, on account of a smaller first cost. Most pumps of this type are too small for economical irrigation of alfalfa and they are best adapted to the irrigation of small orchards or truck gardens.

Centrifugal pumps.—The centrifugal pump in its various forms has an adaptability wider by far than that of pumps of any other type and it is more commonly used for pumping water for irrigation than all other types together. It is adapted to pumping water in quantities ranging from 20 to several thousand gallons per minute, against heads ranging from a few feet to several hundred feet. Except where it is required to pump small quantities of water—up to 200 or 300 gallons a minute—either from depths below the ground surface of at least 100 feet or to heights above the ground surface of more than 75 feet, some form of centrifugal pump will usually be found cheapest and best to install and operate. The centrifugal pump must always be placed within easy suction lift of the water level in the well, care being taken to allow for the drawdown of the water level in the well during pumping as well as for natural fluctuations of the ground-water level. In practice the suction lift should never exceed 20 feet and it should preferably be less.

In general, where conditions are such that either a vertical or a horizontal centrifugal pump can be used, the horizontal is to be preferred because of its higher efficiency and more perfect running conditions. The horizontal form can ordinarily be used only where the water level in the well is not more than 40 feet below the surface and where its fluctuations during the season are small. In pumping from wells where the depth to water is so great that the pump must be placed in a pit more than 25 feet deep, or where there is a large fluctuation in the water level, or where both these conditions occur together, the vertical form of centrifugal pump is best adapted. The vertical form requires a smaller pit than the horizontal form, and the motor or engine and belt connection, if used, are on the surface of the ground, so that the pump may be run submerged. Even if the depth to the water were less than 40 feet, if fluctuations in water level were large the successful operation of a horizontal centrifugal pump might require that it be placed in a water-tight concrete pit to keep the motor or the belt from becoming wet. The expense and difficulty of constructing such a water-tight pit might therefore make the use of the vertical form more desirable. The open-pit type of vertical centrifugal pump should not be used where the depth to ground-water level during pumping exceeds 75 feet.

Single-stage centrifugal pumps, especially designed and driven at a sufficiently high rate of speed, may be used to pump against total heads considerably more than 100 feet, but usually the stock pump obtainable from the manufacturers is not suitable for heads greater than 75 feet for the large sizes and 50 feet for the smaller sizes. For greater heads compound or multi-stage centrifugal pumps are used, allowing 75 to 125 feet head for each stage.

During the last few years a new form of vertical centrifugal pump, commonly called the turbine or deep-well centrifugal pump, has been devised for pumping from deep wells without the necessity of a pit. It is similar in form to the multi-stage pump except that the diameter of runner is generally made smaller, 12 to 30 feet of head being allowed for each stage, the lower limit corresponding to the smaller capacities. As the pump is always placed below the water level and run submerged no priming is necessary. The pump parts and vertical shafting are installed inside a steel casing 12 to 30 inches in diameter, and this casing, which is usually larger than the well casing, is connected to the well casing just below the bottom stage of the pump. Power is supplied above the ground surface. Pumps of this type are adapted to pumping quantities of water ranging from 200 to 2,000 gallons or more a minute from depths ranging from 75 feet to 400 feet below the surface of the ground. Many defects in the original design and operation of centrifugal pumps of this form have been remedied by the manufacturers, and pumps of the larger capacities—900 to 1,000 gallons a minute—are now giving efficiencies as high as 70 per cent. Where the water level is more than 250 feet below the surface of the ground serious difficulties are still involved in the operation of pumps of this design. The hydraulic downthrust on the pump runners, which it is difficult and usually impracticable to balance hydraulically in a centrifugal pump of this form, is taken up by the support bearing in the pump head at the ground surface, from which the pump and shafting are suspended. This method creates a tensional stress in the vertical shaft, which is thereby elongated, and with long shafts and large pumps the elongation may become so great as to close up the clearance space allowed between the pump runners and casing and thus make operation impossible. Only the smaller sizes of pumps of this form, capable of furnishing not more than about 500 gallons a minute, seem at present adapted to use in wells in which the water level is 300 or 400 feet below the surface of the ground. Such pumps are now being used in many wells under conditions for which the ordinary form of vertical centrifugal pump was formerly considered best suited. The deep-well centrifugal pump is also used to advantage in getting a maximum yield from a poor well by placing the pump far below the water level in the well, thus allowing a much greater drawdown than would ordinarily be possible with a pump of any other type.

POWER.

TYPE OF POWER.

The choice of power for small irrigation pumping plants will usually lie between the internal combustion engine and the electric motor. In the last few years a modified form of the gasoline engine and a few special types of internal combustion engines have been developed which are capable of using the heavier distillates. Some of these engines have proved very successful and are of great value because of their use of cheap fuel. The cost of power in gasoline-engine plants and in motor-driven plants varies locally with the price of gasoline and of electric power. It must be borne in mind, however, that the cost of power is not the only matter to be considered. Motors are cheaper in first cost per unit horsepower, depreciate less rapidly, are more efficient, and are more convenient to operate than gasoline engines. A gasoline engine may cost but little (though this is somewhat uncertain) for attendance if kept in good running order, whereas a motor generally costs little for attendance and repairs.

If a gasoline engine is selected care should be taken to install only one made by a reliable manufacturer. The cheaper engines are not only flimsy and weak in certain parts but they are also overrated, that is, rated at a horsepower which they can attain only at speeds that are so high as to cause excessive depreciation. The speed of an engine of 6 horsepower or less should not exceed 300 revolutions per minute; for sizes above 6 horsepower the speed should decrease to 200 revolutions per minute or less.

SIZE OF ENGINE OR MOTOR.

The size of the engine or motor depends on the quantity of water to be pumped, the total head to be pumped against—which must include not only the static head but the head due to losses by friction in the discharge and suction pipes—and the efficiency of the pump.

The water horsepower must first be computed as the product of the quantity of water pumped, in gallons per minute, by the weight of a gallon of water in pounds (1 gallon of water weighs 8.34 pounds), by the total head in feet, divided by 33,000. The horsepower input necessary at the pump is then obtained by dividing this water horsepower by the pump efficiency. The efficiency of the pump should be determined from an actual test of the pump, and the high estimates of efficiency made by some manufacturers should be accepted with caution.

Motors and gasoline engines are rated on brake horsepower. If the motor or engine is direct-connected to the pump, the input at the pump will be the required brake horsepower of the motor or engine; if the motor or engine is connected to the pump by belt, chain, or gear, the required brake horsepower must be determined by dividing the input at the pump by the estimated efficiency of the transmission. It will usually be safe to estimate the efficiency of belt transmission at 90 to 95 per cent.

PIPING AND CONNECTIONS.

There are many seemingly unimportant details in connection with the installation of pumping machinery which, if neglected, cause needless loss of energy and increase in cost of pumping. Many pumping plants give low efficiency simply because of defects in such details.

In general, the more direct the connection between the pump and engine or motor the better. For motor-driven plants the ideal method of applying power to the pump is by direct connection between motor and pump, as it eliminates the loss of power, more or less large, which is always involved in indirect transmission. Although this method is not always feasible, it should be adopted wherever possible. If belt transmission between pump and motor or engine is used the loss in power should be made as small as possible by decreasing the amount of slippage in the belt. The pulleys ordinarily found on centrifugal pumps are so small that it is impossible to prevent undue slippage. Larger pulleys than are usually furnished for both pump and motor should be specified in ordering, say, not less than a 12-inch pulley on a 4-inch pump. It is, of course, necessary to have the pulleys on pump and motor of the proper proportionate size so as to insure proper speed of both motor and pump. Idler pulleys and countershafts should be avoided, as they increase the loss in power. The belt connection should be not less than 16 feet center to center of pulleys.

The foot valves installed in many pumping plants at the bottom of the suction pipe usually interfere very materially with the flow of water into the pipe, and their use should be avoided. In their stead a check valve should be used, placed immediately above the discharge opening of the pump, or, better still, a flap valve which can be lowered over the upper end of the discharge pipe, as in this way the pump can be quickly primed before starting by means of an ordinary pitcher pump connected to the top of the pump casing.

The suction and discharge pipes should be materially larger than the pump openings. The loss in friction depends on the size of the pipe. Doubling the diameter of the pipe, other things being equal, reduces the internal friction head in the pipe to one thirty-second of its former value and reduces the head lost in discharge to one-sixteenth of its former value. The size of pipe should be at least 1 inch larger for sizes of pump less than 4 inches. The losses at entrance to the suction and exit from the discharge pipes may be greatly reduced by installing a tapering pipe at the ends thereof, of a length about two and one-half times the diameter of pipe, and gradually increasing the diameter of the pipe to about one and three-fourth times at the end. The pipe should have as few bends as possible, and sharp bends and turns in the piping should be avoided. All elbows and tees should be of the "long-sweep" form, which may be obtained from the regular stock of the larger dealers at no greater cost than the fittings with sharp bends.

CONVENIENT EQUIVALENTS.

The following list and tables of equivalents will be found convenient for use in hydraulic computations.

TABLE 62.—*Conversion table—Rates of flow.*

Cubic feet per second.	Miner's inches (southern California standard).	U. S. gallons per minute.	Acre-feet per day of 24 hours.	Acre-feet per year of 365 days.	U. S. gallons per day of 24 hours.
1	50	448.83	1.9835	723.97	646,317
.02	1	8.976	.0397	14.48	12,926
.002,228	.1114	1	.00442	1.613	1,440
.504	25.21	226.29	1	365	325,851
.001,38	.0691	.62	.00274	1	890
1.547	77.36	694.44	3.07	1,120.14	1,000,000

TABLE 63.—*Conversion table—Pressure units.*

Pounds per square inch.	Inches of mercury.	Feet of water.
1	2.037	2.308
.4910	1	1.133
.4333	.8826	1

1 cubic foot of water weighs 62.4 pounds.
1 U. S. gallon of water weighs 8.34 pounds.
1 cubic foot equals 7.48 U. S. gallons.
1 acre-foot equals 43,560 cubic feet, equals 325,851 U. S. gallons.
1,000,000 cubic feet equal 22.95 acre-feet.
1 second-foot equals 50 miner's inches (southern California standard).
1 second-foot equals 40 miner's inches (California statute).
1 second-foot equals about 1 acre-inch per hour.
1 horsepower equals 0.746 kilowatts.
1 kilowatt equals 1.34 horsepower.

$$\text{Water horsepower equals} \frac{\text{second-feet of water} \times 62.4 \times \text{total head in feet}}{550}$$

$$\text{or } \frac{\text{gallons of water per minute} \times 8.34 \times \text{total head in feet}}{33{,}000}$$

Required brake horsepower of motor or engine equals

$$\frac{\text{water horsepower}}{\text{efficiency of pump} \times \text{efficiency of transmission.}}$$

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DETAILED PRECIPITATION RECORDS.

Table 64.—*Monthly and annual precipitation at 106 stations in or near San Diego County.*

[For summary of records see Table 17, p. 79. All the means were computed by C. H. Lee.]

Warner dam site (1): elevation, 2,702 feet.

[Authority, Volcan Land & Water Co., W. S. Post, engineer.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1911–12	0.87	0.00	0.39	0.37	0.13	1.98	0.71	0.05	15.60	4.68	1.34	0.19	26.31
1912–13	.15	.68	.00	2.77	1.49	.08	3.79	7.67	1.58	.83	.30	.24	19.58
1913–14	.47	.88	.15	.23	3.64	1.70	10.71	8.05	3.10	2.54	.09	.21	31.77
1914–15	2.04	.00	.06	.76	1.13	5.07	11.15	11.22	2.30	6.67	3.23	.07	43.70
4-year means	.88	.39	.02	1.03	1.59	2.21	6.58	6.75	5.62	3.68	1.24	.18	30.34

Damrons (2); elevation, 2,725 feet.

[Authority, Volcan Land & Water Co., W. S. Post, engineer.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1911–12	a0.45	0.00	0.16	0.20	0.07	1.81	0.67	Tr.	16.08	4.94	1.47	0.30	26.15
1912–13	.03	.27	.00	2.20	2.52	.02	3.78	9.12	3.62	1.14	.44	.32	23.46
1913–14	.34	3.19	.34	.06	4.11	2.01	11.51	7.96	2.08	2.71	.12	.54	34.97
1914–15	.44	.00	.00	.25	1.32	6.33	11.14	13.89	.93	6.60	5.40	.09	46.39
4-year means	.32	.87	.13	.68	2.01	2.54	6.78	7.74	5.68	3.85	1.86	.31	32.74

Monkey Hill (3); elevation, 2,810 feet.

[Authority, Volcan Land & Water Co.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1911–12	a0.50	0.00	0.30	0.14	Tr.	0.69	0.28	Tr.	6.03	2.19	1.37	0.18	11.68
1912–13	.40	a.40	.00	1.92	.60	.00	1.60	3.86	.30	.33	.05	.17	9.63
1913–14	.46	1.84	.05	.08	1.37	1.05	5.21	3.96	1.28	1.06	.00	.09	16.45
1914–15	.56	.00	.00	.59	1.21	3.33	7.21	5.05	.45	3.16	.74	.04	22.34
4-year means	.49	.56	.09	.68	.79	1.27	3.58	3.22	2.02	1.69	.54	.12	15.03

a Estimated.

TABLE 64.—*Monthly and annual precipitation at 106 stations in or near San Diego County*—Continued.

Warner summer road (4); elevation, 2,805 feet.

[Authority, Volcan Land & Water Co., W. S. Post, engineer.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1911–12	a0.50	0.00	0.35	0.14	0.07	0.83	0.46	Tr.	8.48	2.80	1.43	0.20	15.26
1912–13	.50	.42	.00	2.04	.79	.38	2.45	3.97	.79	.35	.08	.16	11.93
1913–14	.34	1.44	.02	.06	1.79	.89	6.77	5.18	1.27	1.41	.00	.14	19.31
1914–15	.93	.00	.00	.66	1.47	2.87	8.01	7.28	.50	4.77	1.21	.06	27.76
4-year means	.57	.47	.09	.73	1.03	1.24	4.42	4.11	2.76	2.33	.68	.14	18.57

Puerta La Cruz (5); elevation, 2,772 feet.

[Authority, Volcan Land & Water Co., W. S. Post, engineer.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1911–12	a0.50	0.00	0.23	0.15	0.12	0.98	0.23	Tr.	7.82	2.85	1.05	0.27	14.20
1912–13	.20	.53	.00	2.11	.50	.02	2.42	3.97	1.17	.40	.06	.15	11.53
1913–14	.41	1.47	Tr.	.12	1.48	.75	6.42	5.25	1.20	2.21	.00	.21	19.52
1914–15	.56	.00	Tr.	.63	.98	4.14	7.62	7.03	.48	5.43	1.12	.07	28.06
4-year means	.42	.50	.06	.75	.77	1.47	4.17	4.06	2.67	2.72	.56	.18	18.33

Deadmans Hole (6); elevation, 3,200 feet.

[Authority, Volcan Land & Water Co., W. S. Post, engineer.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1911–12	a0.75	0.00	0.65	0.20	Tr.	1.20	0.21	0.05	9.81	3.48	1.54	0.17	18.06
1912–13	.15	.58	.00	1.73	.61	.00	1.50	5.77	1.18	.50	.10	.07	12.19
1913–14	.33	2.13	.04	.05	2.46	1.09	7.42	6.79	1.76	1.59	.06	.09	23.81
1914–15	.06	.04	.05	.57	.94	4.45	9.64	8.26	2.44	4.28	1.62	.10	32.45
4-year means	.11	.83	2.46	3.80	5.22	4.69	1.69	1.00	.64	.19	.69	.32	21.63

Pamo (7); elevation, 1,050 feet.

[Authority, Volcan Land & Water Co., W. S. Post, engineer.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1911–12	a0.75	0.00	0.46	0.32	0.11	1.37	0.70	0.00	9.21	3.67	1.97	0.14	18.70
1912–13	.04	.20	.09	2.08	1.25	.10	2.14	4.71	1.79	.95	.22	.16	13.73
1913–14	.26	.00	.06	.35	3.21	1.47	(b)	(b)	(b)	(b)	(b)	(b)	(b)
2-year means	.39	.10	.27	1.20	.68	.74	1.42	2.26	5.50	2.31	1.09	.15	16.21

Santa Ysabel ranch (8); elevation, 3,000 feet.

[Authorities: 1900 to 1910–11, S. Rotanzi; 1911–1915, Volcan Land & Water Co., W. S. Post, engineer.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1900–1901	......	......	......	......	......	......	......	......	......	......	......	......	21.45
1901–2	......	......	......	......	......	......	......	......	......	......	......	......	18.65
1902–3	......	......	......	......	......	......	......	......	......	......	......	......	20.75
1903–4	......	......	......	......	......	......	......	......	......	......	......	......	11.00
1904–5	......	......	......	......	......	......	......	......	......	......	......	......	31.00
1905–6	......	......	......	......	......	......	......	......	......	......	......	......	42.00
1906–7	......	......	......	......	......	......	......	......	......	......	......	......	24.70
1907–8	......	......	......	......	......	......	......	......	......	......	......	......	24.00
1908–9	......	......	......	......	......	......	......	......	......	......	......	......	25.25
1909–10	......	......	......	......	......	......	......	......	......	......	......	......	22.85
1910–11	......	......	......	......	......	......	......	......	......	......	......	......	a20.00
1911–12	a0.35	0.00	0.60	0.45	a0.30	1.85	1.10	0.10	12.25	4.05	1.85	0.32	23.22
1912–13	2.50	.50	.00	3.50	1.75	.05	2.95	2.57	3.20	1.25	.55	.50	19.32
1913–14	.38	.75	.00	.00	3.47	2.44	8.25	6.00	1.40	3.29	.00	.90	26.88
1914–15	.00	.00	.05	1.74	1.05	4.41	10.70	9.00	3.45	7.00	1.80	.00	39.20
4-year means	.81	.06	.16	1.42	1.64	2.19	5.75	4.42	5.08	3.90	1.05	.43	24.68

a Estimated.

b Abandoned; see No. 63, 2 miles south of Volcan Land & Water Co.

TABLE 64.—*Monthly and annual precipitation at 106 stations in or near San Diego County*—Continued.

Santa Ysabel Store (9); elevation, 2,983 feet.

[Authority, Volcan Land & Water Co., W. S. Post, engineer.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1911-12	a0.35	0.00	a0.60	a0.45	a0.30	2.05	1.15	Tr.	13.97	4.12	2.00	0.35	25.34
1912-13	.00	.60	.00	3.70	a1.75	a .05	a2.95	a2.57	a3.20	a1.25	a .55	a .50	17.12
1913-14	.69	.78	.00	.00	3.06	2.03	8.48	6.25	1.51	2.53	.00	a .90	26.23
1914-15	1.20	.00	Tr.	1.59	1.28	3.70	8.63	10.38	2.68	5.43	5.98	.00	40.87
4-year means	.56	.45	.15	1.44	1.60	1.96	5.30	4.80	5.34	4.44	2.13	.44	27.39

Witch Creek (10); elevation, 2,800 feet.

[Authority, J. Woods.]

1909-10	......	......	......	......	......	......	......	......	......	......	......	......	25.40
1910-11	......	......	......	......	......	......	......	......	......	......	......	......	23.55
1911-12	a0.35	0.00	0.64	0.65	0.35	2.00	1.40	0.00	14.20	4.95	1.40	0.30	26.24
1912-13	.15	.60	.00	4.00	1.60	.00	3.50	6.05	2.55	.75	.55	.50	20.25
1913-14	.30	.40	.00	.00	3.90	2.40	8.80	6.25	1.45	3.10	.00	.70	27.30
1914-15	.00	.00	.10	1.30	.90	5.40	9.75	10.30	2.30	6.00	4.35	.00	40.40
4-year means	.20	.25	.19	1.49	1.69	2.45	5.86	5.65	5.13	3.70	1.58	.38	27.19

Ramona (Verlaque) (11); elevation, 1,440 feet.

[Authorities: 1896 to 1910-11, R. L. Verlaque; 1911-1915, Volcan Land & Water Co., W. S. Post, engineer.

1896-97	0.00	0.00	0.00	1.95	1.37	1.90	4.93	5.93	2.88	0.00	0.00	0.00	18.96
1897-98	.00	.00	.00	1.55	.00	.96	3.25	.25	1.95	.00	1.35	.00	9.31
1898-99	.00	.00	.00	.00	.75	1.10	2.80	1.05	1.35	.00	.00	1.00	8.05
1899-1900	.00	.00	.00	.75	1.50	1.25	4.85	.15	.85	1.80	1.90	.00	13.05
1900-1901	.00	.00	.00	.00	3.55	.00	2.15	6.10	.50	.00	1.42	.00	13.72
1901-2	.00	.00	.00	.40	.37	.10	2.35	2.83	3.50	.80	.00	.00	10.35
1902-3	.25	.00	.00	.20	2.30	2.25	1.45	3.60	2.51	3.70	.35	.00	16.61
1903-4	.00	.00	.15	.35	.00	.00	.32	2.26	4.25	.63	.35	.00	8.31
1904-5	.00	.00	.00	.55	.00	2.30	4.70	9.82	7.98	1.13	2.12	.00	28.60
1905-6	.00	.00	.32	.20	5.50	1.13	2.30	4.17	11.80	2.10	1.13	.00	28.65
1906-7	.00	.25	.30	.20	2.25	5.42	5.75	1.28	3.49	.53	.52	.25	20.24
1907-8	.00	.00	.00	3.59	.45	1.10	5.04	3.96	1.92	.77	.47	.00	17.30
1908-9	.00	.00	.30	.45	.65	1.30	7.45	4.85	3.05	.00	.00	.00	18.05
1909-10	.00	1.10	.00	.00	3.85	7.30	3.25	.55	2.07	.45	.00	.00	18.57
1910-11	.00	.00	.00	1.05	1.55	.40	5.25	5.60	1.75	1.35	.00	.00	16.95
1911-12	a .20	.00	.45	.28	.00	1.75	.75	.00	9.80	4.02	1.85	.20	19.30
1912-13	.00	.33	.00	1.35	.80	.00	2.30	4.79	1.40	.20	.37	.30	11.84
1913-14	.20	.00	.00	.55	2.60	1.50	7.85	4.75	.75	a2.02	.30	.00	20.52
1914-15	.00	.00	.00	1.15	1.45	3.10	8.65	6.95	.97	4.36	2.65	.00	29.28
19-year means	.03	.09	.08	.77	1.52	1.73	3.96	3.63	3.31	1.25	.76	.09	17.25

Ramona (Sentinel) (12); elevation, 1,440 feet.

[Authority, Reed, Sentinel newspaper.]

1911-12	a0.20	0.00	a0.40	a0.25	0.00	1.52	0.67	0.00	8.62	3.75	2.03	Tr.	17.44
1912-13	.00	.40	.00	1.35	.32	.00	1.85	4.50	.37	a .20	a .37	a .30	9.66
1913-14	a .20	.00	.15	.50	2.85	1.20	6.35	3.87	.60	2.02	.62	.23	18.59
1914-15	.00	.00	Tr.	1.01	1.34	3.15	6.78	a7.00	1.30	4.97	1.89	.00	27.44
4-year means	.10	.10	.14	.78	1.13	1.47	3.91	3.84	2.72	2.73	1.23	.13	18.28

Rose Glen (13); elevation, 2,300 feet.

[Authority: Mrs. S. Rotanzi.]

1911-12	a0.37	0.00	a0.70	a0.45	a0.20	2.15	1.17	0.02	9.96	4.28	2.50	0.55	22.35
1912-13	a .10	.50	.00	2.55	1.45	.05	2.57	4.71	2.51	.83	.50	.50	16.27
1913-14	.25	.72	.00	1.50	3.27	2.09	7.18	4.55	1.33	2.78	.46	.80	24.93
1914-15	.00	.00	.00	1.27	1.05	3.08	7.57	8.01	1.55	5.32	a1.73	.00	29.58
4-year means	.18	.31	.18	1.44	1.49	1.84	4.62	4.32	3.84	3.30	1.30	.46	23.26

a Estimated.

TABLE 64.—*Monthly and annual precipitation at 106 stations in or near San Diego County*—Continued.

Mesa Grande (U. S. W. B.) (14); elevation, 3,450 feet.

[Authorities: 1905 to Jan., 1909, Ed. H. Davis; 1909 to 1914–15, U. S. Weather Bureau. Three-inch Southern Pacific Co. gage used, 1905 to Oct., 1908; subsequently U. S. Weather Bureau standard gage.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1905–6	......	......	......	......	......	......	......	......	......	......	......	......	47.03
1906–7	......	......	......	......	......	......	......	......	......	......	......	......	33.66
1907–8	......	......	......	......	......	......	......	......	......	......	......	......	27.67
1908–9	......	......	......	......	......	......	15.65	8.84	4.34	0.69	0.14	0.00	36.67
1909–10	Tr.	1.73	Tr.	0.00	5.48	10.00	6.30	1.32	3.92	.73	.07	.00	29.55
1910–11	0.10	.00	0.42	1.46	2.19	.68	8.99	7.30	3.49	2.92	.20	.00	27.75
1911–12	.37	.00	.73	.47	.39	2.17	1.14	.00	15.31	4.60	2.13	.29	27.60
1912–13	.24	.43	.09	3.58	1.82	.18	4.07	8.70	3.28	1.90	.60	.75	25.64
1913–14	.23	.68	.48	.26	4.28	1.86	10.86	7.13	1.96	3.07	.18	.78	31.77
1914–15	.05	.00	.07	1.51	1.23	5.20	10.85	10.79	2.83	5.59	6.34	.00	44.46
6-year means	.17	.47	.30	1.21	2.56	3.35	8.26	6.29	5.02	2.79	1.38	.26	33.18

Mesa Grande (Angels) (15); elevation, 3,450 feet.

[Authority, Volcan Land & Water Co., W. S. Post, engineer.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1911–12	a0.40	0.00	a0.80	a0.50	a0.40	a2.30	1.30	0.07	15.88	5.30	2.03	a0.30	29.28
1912–13	.30	.91	a .00	3.33	1.56	.00	9.81	8.57	3.65	1.57	.78	.67	31.15
1913–14	.26	1.10	.00	.00	5.45	2.89	12.47	7.50	2.70	3.48	.16	.88	36.89
1914–15	.00	.00	.00	1.64	1.50	4.98	9.44	11.88	a3.50	3.68	a6.50	a .05	43.17
4-year means	.24	.50	.20	1.37	2.23	2.54	8.25	7.01	6.43	3.51	2.37	.48	35.12

Nellie (16); elevation, 5,350 feet.

[Authorities: 1901 to Jan., 1909, T. O. Bailey; 1909 to 1914–15, U. S. Weather Bureau. Interpolations by using seasonal ratios from 5 nearby stations.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1901–2	a0.00	a0.00	a0.76	2.55	1.75	0.55	17.60	7.34	10.21	2.20	0.25	0.00	a43.21
1902–3	.06	.00	.22	.85	5.32	5.26	......	......	......	......	......	......	......
1903–4	.00	.00	a .30	.78	.01	.00	1.42	6.77	12.37	2.50	.71	.00	a24.86
1904–5	Tr.	.90	Tr.	1.18	Tr.	3.10	11.46	15.09	14.48	2.43	6.07	.00	54.71
1905–6	.00	Tr.	.44	.27	9.99	2.68	7.62	8.70	36.88	3.86	6.65	.31	77.40
1906–7	.41	1.39	.66	.25	4.57	10.91	......	......	......	......	......	......	......
1907–8													
1908–9	a .10	a3.10	a2.20	a1.40	a1.60	a2.70	23.10	11.27	6.51	.19	.14	.00	a52.31
1909–10	.11	1.70	.17	.00	7.78	17.34	7.76	1.40	6.87	1.08	.00	.00	44.21
1910–11	Tr.	Tr.	.44	2.20	3.64	1.25	10.80	13.93	10.25	2.20	.25	Tr.	44.96
1911–12	.47	.00	.76	.75	.60	3.65	1.45	.00	21.35	7.90	1.95	.18	39.06
1912–13	Tr.	.05	.00	3.30	2.90	.00	4.45	14.20	9.45	1.95	1.20	1.09	38.59
1913–14	.45	.87	.15	a .05	a3.20	a3.30	17.68	12.95	3.61	4.56	.47	1.44	48.73
1914–15	3.75	a0.00	a0.00	2.24	1.53	6.72	13.89	16.78	5.08	9.94	7.21	.05	a67.19
11-year means	.44	.60	.47	1.34	3.00	3.75	10.66	9.86	12.47	3.53	2.26	.28	48.66

Mendenhall Valley (17); elevation, 4,500 feet.

[Authority, Volcan Land & Water Co., W. S. Post, engineer.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1911–12	a0.30	0.00	a0.40	0.54	a0.00	2.26	0.39	0.10	19.18	5.41	1.50	a0.30	30.38
1912–13	.70	.83	.00	2.17	.98	.47	3.95	11.01	2.10	1.01	.50	.33	24.05
1913–14	.27	.75	.30	.00	5.66	3.10	12.37	9.17	3.10	1.98	.20	.50	37.40
1914–15	.25	.00	.00	1.28	1.41	6.44	13.42	6.50	1.08	9.04	2.43	.15	42.00
4-year means	.38	.39	.18	1.00	2.01	3.07	7.53	6.69	6.36	4.36	1.16	.32	33.46

Oak Grove (18); elevation, 2,750 feet.

[Authority: U. S. Weather Bureau.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1911–12	0.44	0.00	0.94	0.49	0.02	1.17	0.18	0.08	9.53	3.76	1.20	0.24	18.05
1912–13	.33	.29	.00	.99	.49	a .00	2.41	4.39	a1.06	.19	.10	a .10	10.35
1913–14	......	......	......	......	......	......	7.29	6.02	1.69	1.28	......	......	......
1914–15	......	......	......	......	......	3.24	8.13	6.70	2.32	2.28	2.12	.00	......
2-year means	.39	.15	.47	.74	.25	.59	1.29	2.24	5.29	1.98	.65	.17	14.20

a Estimated.

TABLE 64.—*Monthly and annual precipitation at 106 stations in or near San Diego County*—Continued.

Chihuahua Mountain (19)[a]; elevation, 4,200 feet.

[Authority, Volcan Land & Water Co., W. S. Post, engineer.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1911-12	[b]0.60	0.00	[b]0.30	0.15	0.00	0.73	0.04	0.00	10.15	2.52	1.25	0.35	16.09
1912-13	.00	.65	.00	2.62	.87	.00	2.25	5.01	1.30	.32	.30	.21	13.53
1913-14	1.08	3.15	.00	.05	2.68	1.39	6.75	6.75	1.52	2.35	.30	.00	26.02
1914-15	.00	.00	.00	[b]1.90	[b]3.00	4.82	9.36	5.28	2.08	4.00	[b]2.20	.03	[b]32.67
4-year means	.42	.95	.08	1.18	1.64	1.74	4.60	4.26	3.76	2.29	1.01	.15	22.08

Eagles Nest (20); elevation, 4,500 feet.

[Authority, Volcan Land & Water Co., W. S. Post, engineer.]

1911-12	[b]0.14	0.00	[b]0.50	[b]0.20	0.09	1.22	0 24	0.00	5.14	2.54	0.81	0.00	10.88
1912-13	.51	.28	.00	3.99	[b]1.10	.00	1.36	3.34	.33	.15	.09	.17	11.32
1913-14	.41	2.82	.00	.00	1.12	1.09	4.45	3.19	1.79	2.26	.00	.04	17.17
1914-15	.16	.00	Tr.	1.35	1.56	5.85	9.28	6.80	.60	4.02	2.72	.03	32.37
4-year means	.31	.78	.13	1.38	.97	2.04	3.83	3.33	1.97	2.24	.91	.06	17.94

Warner Springs (21); elevation, 3,165 feet.

[Authority, U. S. Weather Bureau.]

1900-1901	......	......	......	......	1.93	......	2.58	5.98	0.35	0.20	0.97	......	......
1906-7	1.12	1.72	0.21	0.23	2.46	5.09	6.13	1.48	4.40	.25	.14	0.00	23.23
1907-8	.00	1.13	.00	3.73	.05	1.08	3.95	3.61	1.37	.60	.39	.00	15.91
1908-9	.16	2.11	.81	.80	.49	.76	5.78	4.31	2.38	.08	.00	.00	17.68
1909-10	1.26	3.25	1.41	.00	2.66	7.93	2.90	.25	2.67	.12	.00	.00	22.45
1910-11	1.61	Tr.	.73	.79	1.77	.49	4.61	4.71	2.36	.38	.02	.02	17.49
1911-12	.14	.00	.54	.25	.08	1.10	.16	Tr.	7.29	3.19	1.09	.22	14.06
1912-13	.66	.39	.00	3.07	.98	.00	2.37	4.80	1.04	.29	.08	.13	13.81
1913-14	.44	2.10	.05	.18	1.52	.98	6.07	4.23	1.11	1.49	.10	.21	18.48
1914-15	.16	.00	.01	.46	1.22	4.03	7.24	4.89	2.45	3.80	2.90	Tr.	27.16
9-year means	.62	1.20	.42	1.06	1.25	2.38	4.36	3.14	2.78	1.13	.52	.06	18.92

Warner ranch house (22); elevation, 2,894 feet.

[Authority, Volcan Land & Water Co., W. S. Post, engineer.]

1911-12	[b]0.50	0.00	[b]0.35	0.18	0.00	0.83	0.35	0.00	7.52	2.99	1.29	Tr.	14.01
1912-13	[b] .50	.62	.00	1.85	.82	.00	2.60	3.89	.37	.75	.13	.11	11.64
1913-14	.51	2.30	.00	.00	1.54	.85	7.64	4.73	1.15	1.50	.00	[b] .14	[b]20.36
1914-15	.51	.00	Tr.	.63	1.30	2.89	8.02	5.54	2.09	4.04	4.76	.00	29.78
4-year means	.51	.73	.09	.67	.92	1.14	4.65	3.54	2.53	2.32	1.55	.06	18.95

San Felipe (23); elevation, 3,600 feet.

[Authority, Volcan Land & Water Co., W. S. Post, engineer.]

1911-12	[b]0.50	0.00	[b]0.40	0.10	0.05	1.85	0.30	0.00	14.50	2.32	1.55	0.25	21.82
1912-13	.80	.35	.00	2.80	.33	.05	2.34	6.00	1.80	.65	.24	.20	15.56
1913-14	.50	1.75	.00	.25	2.33	1.32	8.05	7.80	1.90	2.30	.00	.22	26.42
1914-15	.50	.00	.11	.40	1.30	2.14	9.15	8.40	3.20	4.75	2.26	.00	32.21
4-year means	.58	.53	.13	.89	1.00	1.34	4.96	5.55	5.35	2.50	1.01	.17	24.00

[a] Abandoned. [b] Estimated.

TABLE 64.—*Monthly and annual precipitation at 106 stations in or near San Diego County*—Continued.

Matagual (24); elevation, 3,200 feet.

[Authority, Volcan Land & Water Co., W. S. Post engineer.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1911–12	a0.50	0.00	0.40	0.29	0.03	1.24	0.21	Tr.	11.19	3.56	1.50	0.33	19.2
1912–13	.30	.44	.00	2.80	.89	.25	3.24	6.16	1.58	.63	a.50	.14	16.95
1913–14	.27	1.95	Tr.	.10	2.56	.95	8.14	6.17	1.50	2.48	.00	.62	24.73
1914–15	.00	.00	Tr.	.69	1.24	5.08	9.52	9.76	.82	6.16	1.86	.00	35.14
4-year means	.27	.60	.10	.97	1.18	1.88	5.28	5.52	3.77	3.21	.97	.27	24.01

Volcan Mountain (25); elevation, 4,800 feet.

[Authority, Volcan Land & Water Co., W. S. Post, engineer.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1911–12	a0.50	0.00	a0.60	a0.40	a0.30	2.05	1.45	0.00	17.18	7.65	2.30	a0.50	32.93
1912–13	.50	1.06	.20	4.54	2.01	.89	4.80	12.35	3.80	1.25	.78	.71	32.83
1913–14	.98	1.75	.00	.11	4.60	3.33	9.19	7.31	1.54	2.43	.60	.93	32.77
1914–15	.00	.00	.10	1.72	1.70	7.21	8.67	9.40	6.23	7.10	4.68	.09	46.90
4-year means	.49	.70	.22	1.69	2.65	3.37	6.03	7.27	7.19	4.61	2.08	.56	36.36

Pine Mountain (26); elevation, 2,500 feet.

[Authority, Volcan Land & Water Co., W. S. Post, engineer.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1911–12	a0.75	0.00	a0.46	a0.32	a0.11	1.41	0.61	Tr.	11.86	2.95	1.24	a0.10	19.81
1912–13 b	......	......	......	......	......	......	......	......	......	......	......	......	......
1913–14 b	......	......	......	......	......	......	......	......	......	......	......	......	......
1914–15 b	......	......	......	......	......	......	......	......	......	......	......	......	......

Aguanga (27); elevation, 1,988 feet.

[Authority, U. S. Weather Bureau.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1908–9	......	1.05	0.51	0.14	0.07	0.50	4.44	3.28	1.95	0.00	0.00	0.00	11.94
1909–10	0.15	1.61	.43	.00	1.90	4.16	4.49	.72	1.82	.14	.00	.00	15.42
1910–11	.19	.00	.13	.68	1.53	.16	4.76	3.89	1.42	.57	.00	.00	13.33
1911–12	.14	.00	.54	.25	.00	.63	.34	.00	6.92	2.94	1.05	.02	12.83
1912–13	.32	.44	.00	1.37	.49	.00	1.61	3.10	.65	.16	.00	.05	8.19
1913–14	.16	1.07	.82	.16	1.26	.23	5.68	3.97	.82	.96	.12	.18	15.43
1914–15	.00	.00	.22	.58	.99	2.27	5.37	5.91	1.57	2.20	1.58	.00	20.69
7-year means	.14	.60	.38	.45	.89	1.13	3.82	2.98	2.16	1.00	.39	.04	13.98

Julian (28); elevation, 4,200 feet.

[Authority, U. S. Weather Bureau.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1879–80	0.00	0.00	0.00	0.00	2.13	4.50	1.50	5.75	9.25	7.50	0.00	0.00	30.63
1880–81	.00	.00	.00	.00	2.25	2.75	5.13	4.88	8.13	2.75	.00	.00	25.89
1881–82	.00	.00	.00	.00	1.88	6.88	5.13	3.38	7.13	4.88	.00	.00	29.28
1882–83	.00	.00	.00	.00	5.13	6.25	10.04	6.63	9.13	4.13	.00	.00	41.31
1883–84	.00	.00	.00	2.75	.00	6.00	2.25	20.63	15.63	10.63	3.63	.00	61.52
1890–91	......	......	......	......	......	......	4.70	3.00	12.00	6.80	2.50	.00	......
1891–92	.00	.00	.10	.00	.00	.00	3.70	2.40	7.00	3.10	5.50	.45	22.25
1892–93	.00	.00	.00	1.00	1.00	1.60	4.40	3.20	13.00	.00	.90	.00	25.10
1893–94	2.00	.40	.00	1.70	7.00	.00	15.00	12.50	2.00	.00	.50	.20	41.30
1894–95	.00	.00	.00	.00	.00	9.50	15.50	3.30	2.00	1.25	.50	.00	31.70
1895–96	.00	.00	.00	.00	2.00	2.50	1.00	.00	3.00	3.50	.00	.00	12.00
1896–97	.00	.00	.00	2.00	.00	.00	3.50	4.20	5.60	6.00	1.10	.00	22.40
1897–98	.00	.00	.00	2.00	.00	.00	.00	2.00	2.00	2.50	5.00	.00	13.50
1898–99	.00	.00	.00	.00	.00	3.00	.00	.00	5.75	.00	2.00	.00	10.75
1899–1900	.00	.00	.00	2.50	1.50	1.00	4.00	.00	1.00	6.75	3.50	.00	20.25
1900–1901	.00	.00	1.00	.00	6.00	.00	7.00	8.00	.75	.00	2.00	.00	24.75
1901–2	.00	.00	.00	1.00	1.00	.10	6.00	5.75	8.00	2.60	.00	.00	24.45
1902–3	2.00	.00	.00	1.00	3.00	3.25	2.50	8.00	10.50	.00	.50	.00	30.75
1903–4	.00	.00	.00	.50	.00	.00	.50	2.00	2.25	8.25	1.75	.00	15.25
1904–5	1.50	.00	.00	.50	.00	2.25	6.75	11.50	12.25	1.25	4.70	.00	40.70

a Estimated. b Abandoned.

TABLE 64.—*Monthly and annual precipitation at 106 stations in or near San Diego County*—Continued.

Julian (28); elevation, 4,200 feet—Continued.

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1905–6	.00	.00	.25	.00	11.50	.00	5.00	4.50	17.00	5.00	2.00	.25	45.50
1906–7	.00	.00	.00	.00	3.00	8.00	9.00	4.25	6.00	1.00	.75	.50	32.50
1907–8	.00	.00	.00	2.50	1.00	.50	5.75	8.25	3.25	2.75	.50	.00	24.50
1908–9	2.60	.50	1.15	1.10	1.00	1.50	8.90	7.00	4.05	.00	.00	.00	27.80
1909–10	1.45	1.40	.00	.00	4.30	6.05	7.10	.70	2.15	.70	.00	.00	23.85
1910–11	2.35	.00	.00	1.50	2.55	.65	8.35	8.25	4.00	.70	.00	.00	28.35
1911–12	.50	.00	.30	.60	.40	2.15	1.60	.00	15.90	3.10	1.95	.20	26.70
1912–13	.85	.45	.00	3.41	2.11	.40	3.88	3.73	3.56	1.26	.62	.55	20.82
1913–14	.58	2.40	.00	.65	4.08	3.06	11.04	6.96	2.01	3.96	.35	.42	35.51
1914–15	.21	.05	.11	1.05	1.22	7.70	13.25	12.78	3.42	4.83	7.76	Tr.	52.38
29-year means	.48	.18	.10	.89	2.21	2.74	5.77	5.54	6.40	3.05	1.57	.09	29.02

Cuyamaca (29); elevation, 4,677 feet.

[Authority, U. S. Weather Bureau.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1888–89	0.93	0.04	[a]0.09	3.82	8.33	13.30	[a]3.34	[a]4.62	12.85	3.44	2.22	0.00	52.98
1889–90	.00	1.71	.03	[a]4.27	[a]2.94	[a]20.73	[a]13.56	[a]21.16	[a]5.58	1.02	3.92	.00	74.92
1890–91	.09	.90	1.45	.58	3.62	12.14	.00	34.70	1.87	3.50	3.69	.00	62.54
1891–92	.04	.30	.69	.00	.45	6.75	7.23	6.47	7.76	3.35	5.90	.67	39.61
1892–93	.00	.00	.00	.30	2.87	3.76	5.55	9.13	[a]20.40	1.00	1.00	.00	44.01
1893–94	1.20	.30	.00	1.90	3.30	3.75	[a]4.36	[a]3.36	2.90	.00	1.00	.50	22.57
1894–95	.00	.50	.30	.00	.00	12.80	[a]30.98	4.60	5.89	1.10	1.16	.00	57.33
1895–96	.00	.00	.03	1.03	6.01	1.66	5.77	.20	7.91	1.78	.92	.00	25.31
1896–97	1.29	.87	1.06	4.73	3.45	3.74	6.32	[a]10.27	[a]9.56	.22	.38	.00	41.89
1897–98	.00	.00	.36	5.09	1.07	[a]3.36	[a]7.77	1.97	[a]5.04	1.24	5.97	.00	31.87
1898–99	.00	1.32	.00	.00	.88	[a]2.56	[a]7.13	[a]2.73	7.23	.98	.47	2.96	26.26
1899–1900	.04	Tr.	.00	4.51	[a]4.54	2.49	3.62	.26	2.51	6.69	4.03	.10	28.79
1900–1901	.28	.00	.92	.74	11.97	.04	8.17	13.26	2.32	1.24	3.87	.00	42.81
1901–2	Tr.	.09	.08	1.94	1.48	.52	8.17	7.50	13.82	2.09	.14	.17	36.00
1902–3	1.54	.00	Tr.	1.01	5.09	3.66	3.96	[a]6.30	6.13	8.21	.69	.00	36.59
1903–4	.00	.28	1.28	.53	.04	.16	.78	3.76	12.75	2.64	1.15	.00	23.37
1904–5	.20	1.25	.15	1.18	.00	2.95	9.87	15.91	15.63	3.64	7.11	.00	57.89
1905–6	.00	Tr.	1.01	Tr.	10.15	2.78	5.44	7.40	22.41	3.54	3.37	.14	56.24
1906–7	.10	3.00	.90	.80	3.68	9.13	9.48	3.22	11.38	1.71	.64	.87	44.91
1907–8	.00	.00	.00	3.40	1.31	1.80	6.67	9.30	3.25	2.77	1.85	.00	30.35
1908–9	Tr.	2.87	1.82	2.30	1.24	.70	15.16	12.50	8.85	.21	.00	.00	45.65
1909–10	.16	1.30	.30	.06	6.07	11.76	6.33	1.35	5.19	.92	.00	.00	33.44
1910–11	1.50	.09	.33	1.86	2.62	1.12	10.19	8.26	4.39	1.79	Tr.	.00	32.15
1911–12	.64	Tr.	.29	.68	.26	2.35	1.30	.02	19.87	4.38	1.69	.42	31.90
1912–13	.84	.64	.01	5.53	2.40	.07	5.38	11.88	2.12	.93	.51	.71	31.02
1913–14	.52	2.38	.02	.34	4.86	3.33	9.75	6.94	2.35	3.80	.04	.49	34.82
1914–15	.04	1.33	.20	1.63	1.18	8.31	11.48	12.32	3.67	7.41	8.22	.00	55.79
27-year means	.35	.71	.42	1.79	3.33	5.03	7.69	8.13	8.28	2.58	2.22	.26	40.78

Escondido (30); elevation, 657 feet.

[Authorities: 1875 to 1886–87, Maj. Merriam; 1887 to 1896–97, Escondido Land & Town Co.; 1897 to 1914–15, U. S. Weather Bureau.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1875–76	0.00	0.00	2.50	0.00	3.51	0.42	6.04	4.03	3.12	0.38	0.81	0.00	20.81
1876–77	.00	.00	.00	.05	.16	.07	3.80	2.87	1.00	.42	.00	.00	8.37
1877–78	.00	.00	.03	.09	.78	4.03	3.95	7.90	2.49	5.66	1.40	.47	26.80
1878–79	.00	.00	.00	.28	.35	.98	3.26	1.34	.41	1.59	.18	.33	8.72
1879–80	.00	.00	.00	.45	3.50	4.38	1.50	2.10	2.65	5.00	.25	.00	19.83
1880–81	.00	.10	.00	.75	.75	4.05	.91	.70	2.75	.66	.00	.00	10.67
1881–82	.00	.00	.10	1.20	.25	.60	3.80	2.87	1.00	.30	.20	.00	10.32
1882–83	.00	.00	.08	.68	.84	.20	1.03	1.40	1.30	.87	1.30	.00	7.70
1883–84	.00	.00	.00	1.45	.00	3.58	2.22	9.83	8.68	3.26	2.00	1.05	32.07
1884–85	.00	.00	.00	.30	.48	4.96	.45	.60	.00	2.61	.00	.00	9.40
1885–86	.00	.00	.00	.00	4.68	.75	7.33	.80	4.71	2.60	.00	.00	20.87
1886–87	.00	.00	.00	.20	2.72	.20	.12	4.73	.00	1.85	.70	.00	10.52
1887–88	.00	.00	.00	.25	2.45	3.60	3.45	1.90	3.70	.50	.00	.00	15.85
1888–89	.00	.00	.00	.62	3.08	5.70	1.75	1.07	5.75	.50	.00	.00	18.47
1889–90	.00	.00	1.00	3.25	1.25	4.55	3.98	4.11	1.75	.50	.50	.00	20.89
1890–91	.00	.00	.00	.75	.50	3.00	.10	8.57	.78	1.25	.00	.00	14.95
1891–92	.00	.00	.00	.00	.50	1.25	1.75	2.50	3.03	.40	2.17	.00	11.60
1892–93	.00	.00	.00	.01	2.60	1.50	2.20	3.00	8.63	.42	.00	.00	18.36
1893–94	.00	.00	.00	.65	.65	2.55	.80	.50	.75	.00	.00	.00	5.90

[a] Record as published by U. S. Weather Bureau does not include snow; latter has been added from records of Cuyamaca Water Co., by W. S. Post, engineer.

TABLE 64.—*Monthly and annual precipitation at 106 stations in or near San Diego County*—Continued.

Escondido (30); elevation, 657 feet—Continued.

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1894-95	.00	.00	.00	.10	.00	4.51	10.26	1.25	1.35	.75	.35	.00	18.57
1895-96	.00	.00	.00	.25	1.42	.25	2.42	.00	3.48	.10	.00	.00	7.92
1896-97	.00	.00	.00	2.30	1.05	1.85	3.95	4.75	1.60	.00	.00	.00	15.50
1897-98	.00	Tr.	Tr.	1.52	.05	.75	2.48	.68	1.53	.48	1.19	.00	8.68
1898-99	.00	.00	.01	.00	.11	1.48	3.23	1.13	2.11	.29	.15	.96	9.47
1899-1900	.00	Tr.	.00	.61	1.99	1.62	5.18	.20	.79	2.23	1.27	Tr.	13.89
1900-1901	Tr.	.00	.03	.30	4.05	.00	2.86	5.21	.52	.18	1.31	.00	14.46
1901-2	Tr.	.04	00	.62	.43	.05	2.59	3.54	3.68	.67	.00	.04	11.66
1902-3	.15	.00	.00	.28	2.35	3.04	1.58	3.67	2.78	3.84	Tr.	.00	17.69
1903-4	.00	.00	.32	.12	.03	.05	.41	2.66	3.79	.47	.30	.00	8.15
1904-5	.00	.00	a.02	.53	.00	1.68	3.97	9.29	5.75	.45	1.80	.00	23.49
1905-6	.00	.00	.00	.13	4.45	.82	2.78	2.14	11.98	1.59	1.46	.08	25.43
1906-7	.00	.03	.19	.07	1.34	5.51	4.96	1.60	3.48	.43	.09	.19	17.89
1907-8	.00	.00	.00	1.98	.14	.98	5.07	3.31	1.05	.77	.22	.00	13.52
1908-9	.00	1.00	.46	.45	.73	1.07	7.23	4.38	2.76	.00	.13	.00	18.21
1909-10	.00	.22	.05	.00	3.93	7.71	4.03	.49	1.82	.58	.00	.00	18.83
1910-11	.25	Tr.	.00	1.08	1.27	.20	4.96	4.26	2.04	1.38	Tr.	.00	15.44
1911-12	.11	.00	.02	.05	.10	.94	.67	.00	8.04	3.11	1.58	.08	14.70
1912-13	.00	.37	.14	.56	.79	.02	1.79	4.21	1.46	.70	.17	.10	10.31
1913-14	.07	.00	.07	Tr.	2.54	1.11	6.53	5.62	1.57	1.22	.24	.14	19.11
1914-15	.00	.00	Tr.	.92	1.41	2.95	7.06	5.41	1.55	3.72	2.35	.00	25.37
40-year means	.01	.04	.13	.57	1.43	2.07	3.31	3.12	2.89	1.29	.55	.09	15.51

Head of Escondido ditch (31); elevation, 1,986 feet.

[Authority, Escondido Mutual Water Co.

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1896-97	......	......	......	2.75	1.17	2.10	7.35	7.02	4.50	0.00	0.00	......	24.89
1897-98	......	......	......	1.60	1.85	1.25	3.80	.70	2.42	.10	......	......	11.72
1898-99	......	......	......	......	.26	1.45	1.35	1.80	2.92	.40	.00	1.35	9.53
1899-1900	......	......	......	......	......	b4.55	2.60	.03	1.30	2.72	1.92	......	13.12
1900-1901	......	......	......	......	4.97	.00	3.70	7.05	1.55	.25	......	......	17.52
1901-2	......	......	......	......	......	......	......	......	......	......	......	......	......
1902-3	......	......	......	......	3.19	3.40	2.10	3.60	4.40	5.15	.00	......	21.84
1903-4	......	......	......	......	......	......	......	......	......	......	......	......	......
1904-5	......	......	......	......	1.25	......	......	1.80	9.55	1.40	4.25	......	......
1905-6	......	......	......	......	5.45	......	2.30	3.93	21.15	......	......	......	......
1906-7	......	......	......	.10	2.75	3.05	7.00	1.70	6.00	1.15	.35	......	22.10
1907-8	......	......	......	5.46	.91	1.50	6.65	5.45	2.30	1.25	.75	......	24.27
1908-9	......	1.00	0.35	.55	.80	1.48	11.10	4.25	4.22	.13	.17	......	24.05
1909-10	......	......	......	......	4.85	8.83	4.05	.45	5.15	.50	......	......	23.83
1910-11	......	......	......	.70	1.63	.33	5.02	6.97	4.48	1.43	.03	......	20.59
1911-12	......	......	......	.07	.25	2.00	.60	......	12.80	3.80	2.25	......	21.77
1912-13	0.25	......	......	......	......	......	2.90	6.75	.55	1.02	.55	.41	12.43
1913-14	......	......	......	......	......	2.10	10.70	10.20	2.70	2.45	.28	.40	28.83
1914-15	......	......	......	......	......	6.76	8.85	10.40	2.52	5.28	3.44	.05	37.30
15-year means	.02	.07	.02	.75	1.51	2.59	5.18	4.42	3.85	1.71	.65	.15	20.92

Hot Springs Mountain (32); elevation, 6,200 feet.

[Authority, Volcan Land & Water Co. and U. S. Forest Service, W. S. Post, engineer.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1912-13	a0.51	a0.28	0.00	a4.00	a1.10	0.00	3.27	4.26	0.56	a0.15	a0.09	a0.17	14.39
1913-14	2.00	3.06	.20	.08	3.46	1.08	3.55	3.70	.77	.90	.00	.00	18.80
1914-15	.03	.10	.65	.95	1.20	2.79	3.70	4.04	.43	4.08	2.21	.00	20.18
3-year means	.85	1.15	.28	1.68	1.92	1.29	3.51	4.00	.59	1.71	.77	.06	17.79

Elsinore (33); elevation, 1,234 feet.

[Authority, U. S. Weather Bureau.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1886-87	......	......	......	......	......	......	0.16	7.01	0.06	1.54	0.02	0.05	......
1887-88	Tr.	0.00	0.16	0.32	1.72	4.04	6.09	.80	5.87	.08	.09	.00	19.17
1888-89	0.10	.00	.06	.69	2.93	5.37	1.41	......	......	......	......	......	......
1896-97	......	......	......	......	......	......	a2.49	a1.76	a.77	.00	.03	.00	......
1897-98	.00	.29	.26	1.06	Tr.	.19	2.29	.15	.82	.23	1.32	.01	6.62
1898-99	.00	.00	.00	.00	.04	1.38	3.43	.48	.96	.00	Tr.	.18	6.47

a Estimated. b Total to date.

TABLE 64.—*Monthly and annual precipitation at 106 stations in or near San Diego County*—Continued.

Elsinore (33); elevation, 1,234 feet—Continued.

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1899–1900	.00	Tr.	Tr.	.98	.69	.55	1.56	.00	.39	.77	1.04	.00	5.98
1900–1901	Tr.	Tr.	Tr.	.06	5.04	.00	3.59	4.61	.42	.10	.47	Tr.	14.29
1901–2	.00	.74	.00	1.08	.35	.00	2.30	2.03	2.64	.30	Tr.	.21	9.65
1902–3	.08	.00	.00	.13	1.26	3.04	.81	2.50	6.55	1.71	Tr.	.00	16.08
1903–4	a.02	a.05	.40	.05	.00	Tr.	.19	1.49	4.14	.28	.03	.00	6.65
1904–5	.00	1.12	.82	Tr.	.00	.91	5.32	7.72	4.36	.30	.92	.00	21.47
1905–6	.00	.00	Tr.	.12	5.61	.20	2.78	2.14	11.98	1.59	1.46	.08	25.96
1906–7	.00	.03	.19	.07	1.34	5.51	4.80	2.24	3.68	.07	.04	.05	18.02
1907–8	Tr.	.00	.00	2.99	.08	.41	4.93	2.80	.47	.18	.04	.00	11.90
1908–9	.00	.73	.30	.53	.24	.82	6.51	3.57	2.29	.00	.00	.04	15.03
1909–10	.00	.55	.00	.09	1.43	6.65	3.74	.14	1.19	.35	.00	.00	14.14
1910–11	.09	.00	Tr.	.53	.19	.14	5.81	3.24	1.38	.25	.00	.00	11.63
1911–12	.00	.00	.58	.15	.20	.80	.08	.00	6.73	1.80	.13	.00	10.47
1912–13	Tr.	.10	.00	.87	a.40	.00	......	......	......	......	......	......	......
1913–14 a	......	......	......	......	......	......	......	......	......	......	......	......	......
16-year means	.01	.22	.17	.51	1.13	1.54	3.39	2.12	3.37	.50	.35	.04	13.34

Oceanside (34).

[Authorities: 1892 to 1908–9, J. A. Tulip; 1908–9, H. D. Brodie; 1909 to 1914–15, U. S. Weather Bureau.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1892–93	0.00	0.00	0.00	0.27	1.85	3.07	1.33	1.92	2.41	2.25	0.00	0.00	13.10
1893–94	.00	.00	.58	.55	.85	2.29	1.14	.00	1.54	.00	.00	.00	6.95
1894–95	.00	.00	.43	.00	.00	3.98	8.10	.00	.95	.52	.35	.00	14.33
1895–96	.00	.00	.00	.00	1.85	.00	2.92	.00	2.35	.00	.00	.00	7.12
1896–97	.00	.00	.00	1.05	1.14	1.98	4.70	4.66	2.55	.00	.00	.00	16.08
1897–98	.00	.00	.00	2.19	.00	.00	2.84	.37	1.05	.46	.00	.00	6.91
1898–99	.00	.00	.00	.00	.00	.76	2.75	.30	.90	.07	.21	.00	4.99
1899–1900	.00	.00	.00	.74	1.74	1.65	2.69	.10	.33	1.07	1.29	.00	9.61
1900–1901	.00	.00	.00	.33	2.16	.00	3.08	3.43	.20	.00	.00	.00	9.20
1901–2	.00	.00	.00	.29	.84	.18	3.92	.00	3.00	.53	.00	.00	8.76
1902–3	.14	.00	.00	.27	1.85	3.97	1.33	1.92	2.41	2.25	.00	.00	14.14
1903–4	.00	.00	.00	.00	.00	.15	.19	1.39	2.45	.19	.15	.00	4.52
1904–5	.00	.00	.00	1.50	.00	1.72	2.92	6.16	2.58	.20	1.21	.00	16.29
1905–6	.00	.00	.00	.00	3.51	.00	2.60	1.53	6.62	.73	.46	.00	15.45
1906–7	.00	.00	.00	.00	1.47	3.27	3.54	.00	2.78	.27	.00	.00	11.33
1907–8	.00	.00	.00	1.59	.00	1.13	3.21	2.17	.69	.62	.00	.00	9.41
1908–9	.00	1.10	.00	.00	.78	.72	3.41	2.23	2.28	.00	.05	.00	10.57
1909–10	.00	.00	.00	.00	2.72	4.78	1.62	.11	1.76	.07	Tr.	.06	11.12
1910–11	.28	.01	.05	.66	.77	.37	3.94	3.59	1.65	.91	.03	Tr.	12.26
1911–12	.15	Tr.	.23	.33	.07	.56	.71	.42	5.78	2.36	.74	.32	11.67
1912–13	.02	.05	Tr.	.44	.68	Tr.	1.44	2.78	.53	.24	.16	.16	6.50
1913–14	.05	Tr.	Tr.	.05	2.00	1.04	5.55	2.99	1.27	.66	.25	.29	14.15
1914–15	Tr.	Tr.	Tr.	1.41	1.29	3.42	6.51	5.75	.50	2.73	.51	Tr.	22.12
23-year means	.03	.05	.06	.51	1.11	1.52	3.06	1.81	2.03	.70	.24	.03	11.15

Poway (35); elevation, 460 feet.

[Authority, U. S. Weather Bureau.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1878–79	......	......	......	......	......	1.57	2.88	1.50	0.00	1.30	0.08	0.20	......
1879–80	0.00	0.00	0.00	0.30	2.75	4.72	1.13	1.54	1.76	3.10	.09	.00	15.39
1880–81	.06	.16	Tr.	.74	.30	3.56	1.16	.60	2.86	1.14	.03	.00	10.61
1881–82	.00	.04	.03	1.17	.20	.73	6.40	2.69	1.13	.84	.04	.09	13.36
1882–83	.00	.01	.04	.29	.60	.27	.88	1.76	1.87	1.36	1.34	.00	8.42
1883–84	.00	Tr.	.00	1.59	.00	2.40	1.59	9.40	6.96	4.81	2.26	.44	29.45
1884–85	.00	Tr.	Tr.	.24	.38	5.91	.72	.35	.34	2.05	.63	.07	10.69
1885–86	.00	Tr.	.00	.06	2.71	.90	6.34	.77	3.24	2.78	.00	.00	16.80
1886–87	Tr.	.02	.00	.10	1.50	.20	.09	4.87	.34	2.01	.34	.00	9.47
1887–88	.00	Tr.	.63	.00	2.04	2.70	4.01	.89	4.85	.10	.51	.00	15.73
1892–93	......	......	......	......	1.45	1.37	1.78	2.42	8.26	.51	.00	Tr.	......
1893–94	.00	.00	.06	.19	1.36	2.49	.79	1.29	1.64	.14	.21	.15	8.32
1894–95	.00	.06	Tr.	Tr.	.00	3.06	12.65	1.08	1.24	.46	.26	.00	18.81
1895–96	.00	Tr.	.00	.25	1.44	.57	2.50	Tr.	4.73	.96	.31	.00	10.76
1896–97	Tr.	.08	.00	1.51	1.54	2.42	4.30	4.91	2.89	.00	.12	.00	17.77
1897–98	.00	.00	.02	1.70	.08	.72	2.78	.22	1.75	.33	1.55	.00	9.15
1898–99	.00	Tr.	.05	.00	.29	1.87	2.98	.61	1.16	.05	.44	.51	7.96
1899–1900	.00	.00	.00	.78	1.29	1.29	3.89	.32	.69	1.48	1.48	.05	11.27

a Estimated.
b Abandoned.
c Gage on bluff above ocean at 30 feet elevation 1892–1909, and half a mile back from ocean at 67 feet elevation 1910–1915.

TABLE 64.—*Monthly and annual precipitation at 106 stations in or near San Diego County*—Continued.

Poway (35); elevation, 460 feet—Continued.

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1900–1901	.00	.00	Tr.	.25	3.19	.00	2.28	5.82	.34	.61	.65	.01	13.15
1901–2	Tr.	.02	Tr.	.24	.46	.22	2.47	2.64	3.13	.59	.10	.01	9.88
1902–3	.80	.00	.00	.38	3.03	2.27	2.22	2.83	2.96	1.95	.11	.00	16.55
1903–4	.00	Tr.	.17	.14	.02	.06	.47	2.95	3.74	.41	.28	.00	8.24
1904–5	Tr.	Tr.	Tr.	.19	.00	1.85	4.25	7.99	3.24	.42	1.90	.00	19.84
1905–6	.00	.00	.32	.17	4.43	.84	2.25	2.88	8.55	1.06	1.27	Tr.	21.77
1906–7	Tr.	Tr.	.36	.03	1.16	6.34	4.67	1.13	2.45	.30	.09	.20	16.73
1907–8	.00	.00	Tr.	1.66	.48	.76	3.95	3.56	1.09	.75	.44	.00	12.69
1908–9	.08	.47	.30	.48	1.23	.85	7.49	4.48	2.64	Tr.	Tr.	.00	18.02
25-year means	.04	.03	.08	.50	1.22	1.88	3.29	2.62	2.62	1.11	.57	.06	14.01

Sweetwater dam (36); elevation, 310 feet.

[Authority, Sweetwater Water Co., J. F. Covert, engineer.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1888–89	0.00	0.00	0.48	0.36	2.81	3.22	1.56	1.85	2.84	0.36	0.21	0.33	14.02
1889–90	.01	.09	.00	2.60	.10	8.05	2.26	2.73	.74	.13	.41	.00	17.12
1890–91	.00	.07	.87	.00	.93	2.43	.62	5.29	.23	1.27	.83	.09	12.63
1891–92	.00	.03	.04	.02	.13	1.75	1.57	3.47	1.20	.28	1.46	.00	9.95
1892–93	.00	.02	.00	.15	.68	1.48	1.01	1.17	6.50	.27	.20	.00	11.48
1893–94	.16	.00	.00	.33	.84	2.08	.36	.71	1.69	.04	.15	.00	6.36
1894–95	.00	.00	.00	.04	.00	3.03	10.06	1.09	1.18	.79	.00	.00	16.19
1895–96	.00	.00	.02	.45	1.45	.43	1.70	.00	2.52	.65	.05	.00	7.27
1896–97	.05	.11	.04	.69	1.14	1.69	3.11	2.95	2.27	.00	.02	.00	12.07
1897–98	.00	.00	.00	1.50	.06	.45	2.23	.13	1.50	.39	.79	.00	7.05
1898–99	.00	.00	.00	.00	.07	.76	2.40	.70	.89	.23	.11	.58	5.74
1899–1900	.00	.00	.00	.41	1.66	.77	.57	.00	.37	1.06	1.66	.00	6.50
1900–1901	.00	.00	.00	.25	1.63	.00	1.75	4.22	.54	.11	.74	.00	9.24
1901–2	.00	.00	.03	.43	.19	.00	1.96	1.60	2.39	.49	.00	.00	7.09
1902–3	.90	.00	.00	.11	1.29	2.80	.77	2.41	1.28	.89	.00	.00	10.45
1903–4	.00	.00	.00	.25	.00	.12	.11	1.85	2.30	.14	.34	.00	5.11
1904–5	.00	.00	.00	.34	.00	2.15	2.02	6.02	3.47	.35	1.05	.00	15.40
1905–6	.19	.00	.50	.24	3.69	.43	.99	2.66	5.46	1.67	.85	.00	16.68
1906–7	.00	.00	.25	.03	1.20	4.37	3.67	.56	2.35	.18	.08	.39	13.08
1907–8	.00	.00	.00	1.85	.08	.31	3.10	3.21	1.06	.65	.25	.00	10.51
1908–9	.00	.67	.56	.48	.82	.70	4.06	2.07	2.73	.00	.00	.00	12.09
1909–10	.01	.00	.00	.00	2.54	4.00	1.85	.24	1.24	.41	.00	.00	10.29
1910–11	.00	.00	.00	1.05	.74	.20	2.86	3.54	2.07	.80	.01	Tr.	11.27
1911–12	.19	.00	.35	.45	.02	1.54	.77	.00	4.80	2.29	.54	.44	11.39
1912–13	.02	.24	.00	.82	.48	.04	1.52	3.02	.65	.13	.12	.13	7.17
1913–14	.14	.15	.00	.00	2.59	1.06	3.78	2.05	.57	1.29	.14	.09	11.86
1914–15	.00	.00	.06	.87	.75	2.75	4.38	3.16	.89	1.77	1.13	.00	15.76
27-year means	.06	.05	.12	.51	.96	1.73	2.26	2.10	1.99	.62	.41	.07	10.88

Descanso (37); elevation, 3,400 feet.

[Authority, U. S. Weather Bureau.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1895–96	[a]0.00	[b]0.00	[a]Tr.	[a]0.38	[a]4.37	[a]1.00	2.93	0.10	8.04	1.14	0.17	0.00	18.13
1896–97	.30	1.38	.03	2.71	2.12	2.43	6.48	6.27	5.21	.16	.21	.01	27.31
1897–98	.62	.04	.56	2.83	.40	2.90	5.28	.89	4.11	.90	2.35	.00	20.88
1898–99	.15	.83	.00	.00	.35	1.00	3.49	1.69	2.73	.25	1.45	.00	11.94
1899–1900	.15	.38	.00	1.62	.25	1.06	4.00	.75	1.25	4.25	2.69	.06	16.46
1900–1901	.00	Tr.	.25	.63	6.50	.15	3.25	11.00	1.40	.57	1.53	.00	25.28
1901–2	Tr.	.78	Tr.	1.25	.87	.12	4.47	4.52	8.00	1.50	.06	.00	21.57
1902–3	.45	.00	......	......	......	......	......	......	......	......	......	......	......
1908–9	......	......	......	......	......	......	11.03	6.53	4.97	.06	.00	.00	......
1909–10	.00	2.62	.00	.00	5.12	7.79	6.06	1.36	4.01	.58	.00	.00	27.54
1910–11	.72	.00	.36	1.86	2.26	.80	4.62	6.22	2.73	2.08	.00	.00	21.65
1911–12	.77	.00	.23	.57	.00	2.35	.65	.00	13.84	3.83	1.04	.12	23.40
1912–13	.00	.30	.00	1.50	.30	.00	3.27	6.65	2.62	.60	.40	.38	16.02
1913–14	.00	.57	1.27	.06	3.42	1.59	7.64	3.76	1.78	2.83	.22	.32	23.46
1914–15	.60	.00	.00	1.57	.97	4.82	8.88	9.05	2.02	4.50	4.75	.00	37.16
13-year means	.21	.53	.21	1.15	2.07	2.00	4.69	4.02	4.44	1.79	1.14	.07	22.35

[a] Estimated. [b] See Water-Supply Paper 81, U. S. Geological Survey.

TABLE 64.—*Monthly and annual precipitation at 106 stations in or near San Diego County*—Continued.

Valley Center (38); elevation, 1,360 feet.

[Authorities: 1872 to 1898–99, S. G. Antony; 1911 to 1914–15, Volcan Land & Water Co.; W. S. Post, Engineer.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1872–73	......	......	......	......	......	......	......	......	......	......	......	......	11.65
1873–74	......	......	......	......	......	......	......	......	......	......	......	......	37.80
1874–75	......	......	......	......	......	......	......	......	......	......	......	......	13.30
1875–76	......	......	......	......	......	......	......	......	......	......	......	......	19.40
1876–77	......	......	......	......	......	......	......	......	......	......	......	......	8.80
1877–78	......	......	......	......	......	......	......	......	......	......	......	......	26.51
1878–79	......	......	......	......	......	......	......	......	......	......	......	......	8.49
1879–80	......	......	......	......	......	......	......	......	......	......	......	......	24.55
1880–81	......	......	......	......	......	......	......	......	......	......	......	......	16.03
1881–82	......	......	......	......	......	......	......	......	......	......	......	......	16.61
1882–83	......	......	......	......	......	......	......	......	......	......	......	......	11.94
1883–84	......	......	......	......	......	......	......	......	......	......	......	......	50.50
1884–85	......	......	......	......	......	......	......	......	......	......	......	......	13.36
1885–86	......	......	......	......	......	......	......	......	......	......	......	......	30.55
1886–87	......	......	......	......	......	......	......	......	......	......	......	......	13.71
1887–88	......	......	......	......	......	......	......	......	......	......	......	......	22.80
1888–89	......	......	......	......	......	......	......	......	......	......	......	......	26.50
1889–90	......	......	......	......	......	......	......	......	......	......	......	......	30.48
1890–91	......	......	......	......	......	......	......	......	......	......	......	......	26.56
1891–92	......	......	......	......	......	......	......	......	......	......	......	......	18.07
1892–93	......	......	......	......	......	......	......	......	......	......	......	......	20.60
1893–94	......	......	......	......	......	......	......	......	......	......	......	......	9.90
1894–95	......	......	......	......	......	......	......	......	......	......	......	......	24.70
1895–96	......	......	......	......	......	......	......	......	......	......	......	......	11.94
1896–97	......	......	......	......	......	......	......	......	......	......	......	......	24.00
1897–98	......	......	......	......	......	......	......	......	......	......	......	......	10.93
1898–99	......	......	......	......	......	......	......	......	......	......	......	......	11.74
1911–12	[a]0.09	[a]0.00	[a]0.01	[a]0.04	[a]0.08	[a]0.79	[a]0.56	0.00	6.50	3.00	1.20	[a]0.06	12.33
1912–13	......	......	......	......	......	......	1.90	3.80	.88	.66	.23	.23	......
1913–14	.18	Tr.	.01	.05	2.40	1.18	7.08	6.22	1.64	1.48	.27	.30	20.81
1914–15	Tr.	.00	Tr.	1.25	1.73	3.15	8.17	6.41	1.61	4.12	1.43	Tr.	27.87
Means	.09	.00	.00	.45	1.40	1.71	5.27	4.21	3.25	2.87	.97	.12	19.74

San Diego (39); elevation, 93 feet.

[Authority, U. S. Weather Bureau.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1849–50	......	......	......	......	......	......	0.00	1.13	1.00	0.09	0.00	0.68	......
1850–51	0.00	0.00	0.00	0.19	2.82	1.93	.03	1.51	.34	.87	.71	.01	8.41
1851–52	.00	.00	.02	.01	.25	3.74	.58	1.84	1.87	.85	.32	.00	9.48
1852–53	.00	.40	.00	.06	1.45	4.50	.50	.20	1.52	.25	2.10	.05	11.03
1853–54	.00	.21	.00	.00	1.28	1.77	.99	2.56	1.88	.89	.18	.01	9.77
1854–55	.07	1.36	.09	.27	.04	3.29	1.97	3.59	1.30	1.52	.06	.00	13.56
1855–56	.00	.04	.00	.11	2.15	.41	1.27	1.86	1.59	2.17	.29	.00	9.89
1856–57	.00	.00	.07	.00	1.22	1.30	.26	1.76	.00	.04	.08	.03	4.76
1857–58	.00	.02	.01	.49	2.16	1.30	1.52	.44	1.24	.17	.00	.19	7.54
1858–59	.00	.04	.10	.47	.28	3.10	.00	1.89	.20	.36	.17	.00	6.61
1859–60	.02	.00	.00	.18	1.49	1.79	.72	1.49	.15	.65	.04	.05	6.58
1860–61	.14	.00	.00	.00	2.88	2.99	.82	.79	.05	.04	.00	.19	7.90
1861–62	.00	.00	1.59	.05	1.19	3.20	5.56	1.39	.97	1.05	.16	.48	15.64
1862–63	.11	.00	.00	.89	.05	.93	.32	1.09	.33	.13	.02	.00	3.87
1863–64	.00	.00	.36	.00	.73	.04	.04	2.50	.20	.01	1.25	.01	5.14
1864–65	.11	.00	.00	.04	2.41	1.04	1.28	3.00	.00	.56	.00	.01	8.45
1865–66	1.29	.00	.00	.02	.52	.84	5.05	3.43	1.47	.11	.09	.00	12.82
1866–67	.00	.10	.00	.00	.24	1.82	2.32	.85	7.88	.48	.04	.00	13.73
1867–68	.00	.30	.00	.34	.45	3.06	3.37	1.63	.73	1.20	.15	.00	11.23
1868–69	.51	.00	.05	.00	2.00	1.52	2.88	1.88	1.98	.53	.33	.00	11.68
1869–70	.05	.00	.00	.05	2.32	.94	.54	.77	.33	.20	.28	.00	5.48
1870–71	.04	.07	.00	1.54	.18	.42	.52	1.35	.01	.70	.34	.00	5.17
1871–72	.00	.00	.00	.00	1.33	1.39	.99	2.63	.46	.26	.12	.00	7.18
1872–73	.00	.18	.00	.00	.00	1.43	.44	4.21	.11	.10	.03	.00	6.50
1873–74	.00	1.95	.00	.00	.77	5.46	3.11	3.73	1.20	.34	.32	.00	16.88
1874–75	.12	.00	.13	.53	.88	.55	2.38	.37	.45	.12	.20	.02	5.75
1875–76	.00	.21	.39	.00	2.25	.41	2.47	2.44	1.78	.06	.05	.05	10.11
1876–77	.03	.06	.03	.08	.04	.15	1.05	.18	1.44	.26	.43	Tr.	3.75
1877–78	.00	.00	.00	.81	.06	3.89	1.45	4.83	1.41	2.91	.58	.16	16.10
1878–79	.00	.00	.00	.96	.00	1.57	3.54	1.04	.10	.60	Tr.	.07	7.88
1879–80	.00	.00	.00	.29	2.77	6.30	.61	1.50	1.43	1.34	.06	.06	14.36
1880–81	.09	.32	.00	.53	.28	4.15	.52	.45	1.88	1.35	.04	.05	9.66
1881–82	.00	.01	.04	.24	.12	.30	4.53	2.55	1.02	.45	.18	.07	9.51
1882–83	.00	Tr.	.01	.41	.39	.13	1.09	.95	.41	.31	1.14	.08	2.94

[a] Estimated.

TABLE 64.—*Monthly and annual precipitation at 106 stations in or near San Diego County*—Continued.

San Diego (39): elevation, 93 feet—Continued.

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1883–84	.00	.00	.00	2.01	.20	1.82	1.34	9.05	6.23	2.84	2.17	.31	25.97
1884–85	.00	Tr.	.07	.35	.11	5.12	.35	.02	.78	1.20	.61	.06	8.67
1885–86	Tr.	.13	Tr.	.31	1.56	.71	6.95	1.51	3.73	1.95	.04	.07	16.96
1886–87	Tr.	Tr.	.00	.05	.95	.10	.04	4.51	.02	2.14	.47	.04	8.32
1887–88	.01	Tr.	Tr.	Tr.	2.08	1.14	1.96	1.48	2.79	.10	.22	.04	9.82
1888–89	.01	Tr.	.04	.26	1.83	2.84	1.72	1.80	2.20	.19	.03	.10	11.02
1889–90	Tr.	.04	Tr.	2.12	.12	7.71	2.79	1.70	.41	.05	.08	.00	15.02
1890–91	.00	Tr.	.65	.01	.72	1.61	1.21	4.84	.27	.76	.35	.05	10.47
1891–92	Tr.	.00	.08	.04	.10	1.29	1.58	2.96	.96	.41	1.15	.13	8.70
1892–93	.00	.05	Tr.	.22	.91	.69	.78	.47	5.50	.22	.39	Tr.	9.26
1893–94	Tr.	.00	.00	.11	.91	1.91	.29	.49	1.05	.11	.09	.01	4.97
1894–95	.00	.04	.01	Tr.	.00	2.26	7.33	.53	1.43	.11	.19	.00	11.90
1895–96	.00	.00	.01	.27	1.19	.27	1.27	.02	2.89	.25	.03	.01	6.21
1896–97	Tr.	.13	Tr.	.97	.98	2.18	3.13	2.72	1.53	.02	.12	Tr.	11.78
1897–98	.01	Tr.	Tr.	1.06	.02	.32	1.71	.06	.91	.22	.66	.02	4.99
1898–99	.00	.00	.07	.00	.15	.87	2.34	.30	.85	.29	.10	.27	5.24
1899–1900	.00	.07	.00	.35	.86	.65	.69	.03	.53	1.26	1.45	.08	5.97
1900–1901	.00	Tr.	Tr.	.30	1.43	.00	2.08	4.77	1.07	.01	.77	.02	10.45
1901–2	Tr.	Tr.	.06	.28	.41	.02	1.70	1.57	1.86	.21	.06	Tr.	6.17
1902–3	.92	Tr.	Tr.	.06	1.53	3.58	.69	2.27	1.17	1.40	.14	Tr.	11.76
1903–4	.00	Tr.	Tr.	.07	Tr.	.35	.04	1.50	2.17	.15	.12	.00	4.40
1904–5	.00	Tr.	Tr.	.17	.00	2.46	2.16	5.90	2.98	.30	.35	Tr.	14.32
1905–6	.16	.00	.50	.25	3.38	.38	.98	2.62	4.68	.98	.72	.03	14.68
1906–7	Tr.	.10	.12	.03	.62	4.02	3.27	.45	1.62	.13	.07	.19	10.62
1907–8	.03	.00	.00	1.71	.05	.43	2.80	2.41	.61	.35	.16	.00	8.55
1908–9	.00	.64	.20	.15	1.00	.27	3.57	1.76	2.62	.02	Tr.	Tr.	10.23
1909–10	Tr.	Tr.	.02	.00	2.39	3.76	2.00	.19	1.30	.08	.05	.00	9.79
1910–11	.01	.05	.17	1.35	.40	.15	3.35	4.92	.92	.65	.01	.01	11.99
1911–12	.12	.00	.10	.28	.02	1.39	.66	.00	5.72	2.13	.17	.16	10.72
1912–13	.14	.26	.00	.89	.40	.03	1.19	2.40	.42	.08	.07	.09	5.97
1913–14	.06	.02	.02	Tr.	2.23	.72	3.59	1.90	.36	.85	.08	.00	9.83
1914–15	.00	.00	Tr.	1.05	.86	2.21	4.91	3.62	.33	1.15	.28	Tr.	14.41
65-year means	.06	.10	.08	.36	.96	1.80	1.86	1.99	1.48	.64	.32	.05	9.69

El Cajon (40); elevation, 570 feet.

[Authority, U. S. Weather Bureau.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1875–76	......	......	......	......	1.99	1.01	3.83	2.71	2.53	0.11	0.02	0.02	......
1876–77	0.07	......	......	......	.14	.07	......	......	1.00	.40	......	......	......
1899	......	......	......	......	......	......	2.15	.55	1.15	.08	.04	.52	......
1899–1900	0.00	Tr.	0.00	0.67	1.39	.87	1.33	.11	.71	1.30	1.48	.19	8.05
1900–1901	.00	.00	Tr.	.40	2.61	.00	1.89	2.66	2.57	.69	.67	.11	11.60
1901–2	.10	.11	.00	.32	.28	.43	2.28	2.49	2.81	.33	.04	.00	9.19
1902–3	.75	.00	.00	.20	1.73	2.21	.84	2.97	1.33	1.29	.14	Tr.	11.46
1903–4	.00	.00	Tr.	.20	.00	.10	.17	2.19	2.66	.10	.29	.00	5.71
1904–5	.00	Tr.	Tr.	.27	.00	2.73	2.67	9.22	4.23	.36	1.02	.00	20.50
1905–6	.03	.01	.57	.25	4.89	.55	1.20	2.13	6.56	1.66	.73	.04	18.62
1906–7	Tr.	.13	.30	Tr.	1.52	4.14	4.35	.85	3.06	.44	.20	.25	15.24
1907–8	.00	.00	.00	2.10	.62	.57	4.58	3.39	1.34	.69	.23	.00	13.52
1908–9	.16	.89	.32	.59	.84	1.19	5.31	2.83	3.37	.00	.00	.00	15.50
1909–10	.00	.15	.00	.00	2.87	4.75	2.72	.35	2.21	.24	.00	.00	13.29
1910–11	.34	.00	.15	.94	.88	.33	4.74	4.00	1.30	1.07	.00	.00	13.75
1911–12	.06	.00	.46	.28	.00	1.59	.50	.00	7.80	2.42	1.29	.70	15.10
1912–13	.00	.32	.00	.77	.76	.05	1.50	3.10	1.09	.19	.16	.10	8.04
1913–14	.20	.33	.00	.02	2.83	1.03	4.56	4.00	.60	1.25	.27	.16	15.25
1914–15	.00	.00	.10	1.09	1.35	2.85	6.49	4.22	1.33	2.86	1.42	.00	21.71
16-year means	.10	.12	.12	.51	1.41	1.46	2.82	2.78	2.69	.93	5.00	1.00	13.53

Lakeside (41); elevation, 500 feet.

[Authority, San Diego & Southeastern Ry. Co.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1909–10	0.00	0.00	0.00	0.00	3.06	3.96	3.76	0.35	1.72	0.10	0.00	0.00	12.95
1910–11	.00	.00	.00	.75	1.00	.43	3.56	4.95	1.38	.77	.00	.00	12.82
1911–12	.00	.00	.50	.15	.00	1.72	.50	.00	6.77	3.22	.85	.70	14.41
1912–13	.00	.22	.00	.62	.00	.00	1.87	3.37	.98	.43	.20	.04	7.73
1913–14	.00	.04	.00	.00	2.62	1.06	4.46	3.02	.54	1.24	.19	.02	13.19
1914–15	.00	.00	.03	1.03	1.60	3.04	5.82	3.98	1.12	2.17	1.82	.00	20.61
6-year means	.00	.04	.09	.42	1.38	1.70	3.33	2.61	2.09	1.32	.51	.13	13.62

TABLE 64.—*Monthly and annual precipitation at 106 stations in or near San Diego County*—Continued.

End of flume near La Mesa (42); elevation, 640 feet.

[Authority, Cuyamaca Water Co., W. S. Post, engineer.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1899–1900	0.00	0.00	0.00	0.62	1.35	0.81	1.28	0.00	0.70	1.39	1.45	0.00	7.60
1900–1901	.00	.00	.01	.31	2.76	.00	2.90	6.06	.70	.75	.19	.00	13.68
1901–2	.00	.00	.00	.39	.37	.27	2.44	2.90	2.24	.20	.17	.00	8.98
1902–3	.86	.00	.00	.20	2.17	2.70	1.07	2.77	1.83	1.53	.04	.00	13.17
1903–4	.00	.00	.03	.04	.00	.10	.18	1.83	3.00	.12	.23	.00	5.53
1904–5	.00	.00	.00	.23	.00	3.21	2.69	7.76	4.05	.42	1.23	.00	19.59
1905–6	.00	.00	.35	.12	3.08	.65	1.35	2.08	6.64	1.78	.63	.00	16.68
1906–7	.00	.00	.42	.00	1.35	4.91	4.40	.96	3.24	.31	.20	.35	16.14
1907–8	.00	.00	.00	1.07	.40	.66	3.57	3.46	1.35	.82	.42	.00	11.75
1908–9	.00	.90	.41	.07	.11	.73	5.47	2.99	3.10	.05	.05	.00	13.88
1909–10	.00	.18	.00	.02	3.06	5.83	2.38	.22	1.80	.45	.00	.00	13.94
1910–11	.47	.00	.00	.99	1.10	.25	4.57	4.72	1.41	1.27	.00	.06	14.84
1911–12	.27	.00	.10	.24	.05	1.53	.74	.00	7.58	2.66	.59	.42	14.18
1912–13	.00	.24	.00	.44	.46	.00	1.70	3.21	1.12	.21	.29	.11	7.78
1913–14	.20	.00	.00	.00	3.79	1.07	4.30	3.72	.53	1.61	.20	.11	15.53
1914–15	.00	.00	.03	1.28	1.06	3.36	7.34	6.53	1.86	2.94	1.61	.00	26.01
16-year means	.11	.08	.08	.38	1.32	1.57	2.89	3.08	2.57	1.03	.45	.06	13.69

Los Coches Creek (43); elevation, 710 feet.

[Authority, Cuyamaca Water Co., W. S. Post, engineer.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1900–1901	......	......	......	......	......	9.34	......	......	......	0.50	0.47	0.00	10.31
1901–2	0.02	0.00	0.00	0.22	0.32	.08	2.35	2.03	3.44	.49	.06	.00	9.01
1902–3	.61	.00	.00	.40	1.73	2.38	1.13	3.20	1.96	1.21	.05	.00	12.67
1903–4	.00	.00	.13	.19	.00	.12	.25	2.35	2.53	.20	.75	.00	6.52
1904–5	.00	.00	.00	.51	.00	1.98	2.52	9.77	4.70	.46	1.03	.00	20.97
1905–6	.00	.00	.93	.25	4.08	.60	1.23	1.98	6.36	1.56	.83	.01	17.83
1906–7	.00	.04	.35	.05	2.09	5.78	4.58	.93	2.69	.16	.16	.12	16.95
1907–8	.00	.00	.00	1.44	.56	.48	3.98	3.44	1.48	.68	.19	.00	12.25
1908–9	.00	.52	.65	.53	.65	1.38	4.01	2.77	2.50	.06	.03	.00	13.10
1909–10	.00	.27	.00	.03	3.17	4.78	2.25	.43	2.15	.10	.00	.00	13.18
1910–11	.10	.00	.03	.68	.99	.43	4.18	3.71	1.19	.65	.00	.00	11.96
1911–12	.00	.00	.08	.28	.06	1.44	.47	.00	6.94	2.62	1.20	.54	13.63
1912–13	.00	.38	.00	.74	.58	.00	1.57	3.47	.87	.22	.26	.22	8.31
1913–14	.10	.22	.01	.04	2.80	.89	4.80	4.10	.74	1.32	.16	.12	15.30
1914–15	.00	.00	.09	1.03	1.60	2.96	6.43	5.91	1.38	2.62	1.34	.00	23.36
15-year means	.06	.10	.16	.45	1.33	1.67	2.84	3.15	2.79	.88	.43	.07	13.69

Chocolate Creek (44); elevation, 760 feet.

[Authority, Cuyamaca Water Co., W. S. Post, engineer.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1899–1900	0.00	0.00	0.00	0.00	0.00	1.00	2.99	0.00	0.96	2.06	1.65	0.00	8.66
1900–1901	.00	.00	.00	.15	4.08	.00	2.88	8.08	1.20	.60	.63	.00	17.62
1901–2	.00	.00	.00	.00	.40	.05	3.19	2.26	4.33	.85	.06	.00	11.14
1902–3	.36	.00	.00	.35	1.95	2.21	1.78	4.08	2.03	1.45	.06	.00	14.27
1903–4	.00	.00	.14	.17	.00	.00	.30	2.87	3.65	.40	.24	.00	7.77
1904–5	.00	.00	.00	.52	.00	2.04	4.07	9.61	5.76	.44	1.32	.00	23.76
1905–6	.00	.00	.81	.07	3.38	1.15	1.96	4.43	8.68	1.59	1.30	.05	23.42
1906–7	.00	.25	.49	.05	1.96	5.98	5.39	1.53	3.41	.62	.23	.43	20.34
1907–8	.00	.00	.00	1.92	1.18	.71	4.16	4.73	2.11	1.38	.47	.00	16.66
1908–9	.00	.67	.64	1.20	.80	.69	8.17	4.42	3.36	.22	.05	.00	20.22
1909–10	.00	.89	.00	.00	3.55	6.56	2.79	.87	2.48	.33	.00	.00	17.47
1910–11	.31	.00	.28	.80	1.37	.66	4.38	4.20	1.37	1.29	.00	.00	14.66
1911–12	.00	.00	.12	.30	.10	1.84	.53	.00	9.75	3.10	1.67	.50	17.91
1912–13	.04	.63	.00	1.05	.80	.00	2.38	5.03	1.43	.49	.36	.22	12.43
1913–14	.05	.12	.00	.04	3.13	1.86	5.50	5.22	.97	2.47	.20	.17	19.73
1914–15	.00	.00	.06	1.09	1.22	3.07	6.51	7.56	1.45	3.89	2.20	.00	27.05
16-year means	.05	.16	.16	.48	1.49	1.74	3.56	4.05	3.31	1.35	.65	.08	17.07

TABLE 64.—*Monthly and annual precipitation at 106 stations in or near San Diego County*—Continued.

Diverting dam (45); elevation, 820 feet.

[Authority, Cuyamaca Water Co., W. S. Post, engineer.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1899-1900	0.00	0.00	0.00	0.80	1.65	0.90	3.95	0.05	0.37	1.62	1.18	0.00	10.52
1900-1901	.00	.00	.00	.07	4.33	.00	2.72	6.69	1.28	.44	1.03	.00	16.56
1901-2	.00	.03	.00	.25	.37	.00	2.70	2.26	4.22	.78	.02	.00	10.63
1902-3	.40	.00	.00	.35	2.24	2.11	1.21	4.37	3.20	2.25	.08	.00	16.21
1903-4	.00	.00	.19	.11	.00	.00	.27	2.23	3.76	.30	.23	.00	7.09
1904-5	.00	.00	.00	.25	.00	1.30	2.97	10.06	6.55	.95	2.38	.00	24.46
1905-6	.00	.00	.38	.23	3.43	.98	2.21	4.20	11.87	1.75	1.32	.00	26.37
1906-7	.11	.95	.66	.64	2.19	7.10	6.01	1.71	4.07	.40	.19	.34	24.37
1907-8	.00	.00	.00	2.74	.26	.50	4.08	3.99	1.84	.99	.65	.00	15.05
1908-9	.00	.58	.57	.35	.62	.93	5.71	4.50	3.06	.06	.00	.00	16.38
1909-10	.52	.68	.00	.00	2.82	5.93	3.41	.51	2.68	.30	.00	.00	16.85
1910-11	.11	.00	.28	1.10	1.62	.75	5.40	4.09	1.47	1.10	.00	.00	15.92
1911-12	.00	.00	.13	.30	.10	1.13	.44	.00	10.13	3.29	1.84	.53	17.89
1912-13	.03	.36	.00	1.05	.61	.00	2.36	3.91	1.40	.19	.19	.08	10.18
1913-14	.11	.11	.11	.04	2.99	1.11	5.69	4.11	.81	2.32	.34	.20	17.94
1914-15	.02	.00	.00	1.30	1.09	3.34	6.62	6.35	1.65	2.86	2.30	.00	25.53
16-year means	.08	.17	.14	.59	1.52	1.63	3.59	3.69	3.65	1.22	.74	.07	16.99

East Cuyamaca (46); elevation, 4,600 feet.

[Authority, Cuyamaca Water Co., W. S. Post, engineer.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1912-13	[a]0.42	[a]0.32	[a] Tr.	[a]2.76	[a]1.20	0.04	[b]2.52	6.20	1.86	1.03	0.22	0.13	16.70
1913-14	.72	.21	2.10	.22	3.18	1.75	4.86	5.16	1.05	.77	.50	.10	20.62
1914-15	.00	.46	.43	.46	1.38	3.53	8.74	6.81	1.01	3.22	2.44	.00	28.48
3-year means	.38	.33	.84	1.15	1.92	1.77	5.37	2.72	1.31	1.67	1.05	.08	21.93

Schilling (47); elevation, 4,550 feet.

[Authority, Cuyamaca Water Co., W. S. Post, engineer.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1912-13	[a]0.42	[a]0.32	[a] Tr.	[a]2.76	[a]1.20	0.04	[b]1.06	5.61	[a]1.79	1.05	0.51	0.29	15.05
1913-14	.86	1.35	.60	.14	5.66	2.46	8.08	5.94	1.68	2.70	.17	.46	30.10
1914-15	.00	.20	.08	.83	1.41	5.35	11.09	9.83	.96	4.94	3.90	.00	38.59
3-year means	.43	.62	.23	1.24	2.76	2.62	6.74	7.13	1.48	2.90	1.53	.25	27.91

Campo (48); elevation, 2,543 feet.

[Authority, U. S. Weather Bureau.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1876-77	......	......	......	......	......	......	2.42	4.74	2.29	1.08	0.91	0.00	......
1877-78	0.50	0.00	0.00	0.35	1.50	2.44	1.79	5.45	1.84	5.75	.41	.00	20.03
1878-79	2.32	.01	.00	.31	.55	1.29	2.18	1.32	.60	2.01	.00	.00	10.59
1879-80	.00	.00	.00	.00	3.00	2.23	3.00	2.15	3.56	4.00	.00	.00	17.94
1880-81	.12	.41	.01	.68	.85	4.85	1.74	.53	5.00	1.52	.12	.04	15.87
1881-82	.07	1.27	.02	.73	.11	.24	3.10	4.57	1.01	1.10	.18	.26	12.66
1882-83	.62	.53	.02	.46	1.57	2.59	......	......	......	......	......	......	......
1888-89	......	......	......	......	......	......	2.42	4.65	4.00	1.90	.45	.10	......
1889-90	.53	2.50	.50	1.10	1.67	9.34	2.40	7.25	1.69	1.86	.90	.16	29.90
1890-91	2.26	2.67	1.80	.44	.95	2.80	.00	13.30	.50	1.20	.75	.00	26.67
1891-92	.00	16.10	.00	.00	.25	3.21	.75	4.55	3.30	1.25	2.75	.35	32.51
1892-93	.00	.00	.00	.12	.71	.50	3.55	3.65	7.19	1.54	.41	.00	17.67
1893-94	.00	.00	.57	.11	3.38	2.08	5.89	5.83	1.01	.80	4.38	1.26	25.31
1894-95	.00	.00	.25	.46	1.57	2.59	......	......	......	......	......	......	......
1899-1900	.24	.60	1.61	1.15	2.65	.10	.55	2.07	1.04	.10	......	......	......
1900-1901	.00	.00	.05	.28	4.47	.00	2.03	8.22	.69	.54	1.18	.00	17.46
1901-2	.61	.63	.00	1.02	.43	.23	4.28	4.72	4.00	1.33	.07	.12	17.44
1902-3	2.24	.00	.00	.03	2.27	3.04	1.85	4.93	2.30	3.23	.11	Tr.	20.00
1903-4	.00	.00	.47	.03	.00	.00	.41	2.68	4.19	.49	.52	.00	8.79
1904-5	.85	1.59	.64	.13	.00	1.82	4.32	11.94	6.87	.92	2.53	.00	31.61
1905-6	.00	.25	.68	Tr.	5.85	1.12	2.98	3.69	10.20	1.60	.70	.00	27.07
1906-7	.18	2.12	.90	.10	3.23	7.15	5.24	1.67	3.91	.25	.41	.26	25.42
1907-8	.00	.00	.00	2.46	.25	.12	4.21	4.90	1.91	.71	1.01	.00	15.57
1908-9	.26	.00	.40	1.72	.77	1.83	8.41	5.43	4.05	.00	.00	.00	22.87

[a] Estimated. [b] Probably low. Shows actual catch of snow.

TABLE 64.—*Monthly and annual precipitation at 106 stations in or near San Diego County*—Continued.

Campo (48); elevation, 4,550 feet—Continued.

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1909-10	.00	.00	.00	.00	3.44	5.82	4.93	.66	2.25	.32	.00	.00	17.42
1910-11	3.44	.00	1.94	1.03	1.12	.15	4.65	5.70	1.40	.96	.00	.00	20.39
1911-12	.40	.00	.00	.00	.10	2.08	.64	.00	10.67	3.51	1.52	.15	19.07
1912-13	.15	.20	.00	.98	.92	.00	2.75	5.27	1.90	.33	.13	.20	12.83
1913-14	.36	1.77	.00	.05	2.39	1.49	5.85	4.07	.92	2.34	.78	.00	20.02
1914-15	.75	.00	.22	.88	.76	3.99	6.36	4.47	1.74	1.50	2.56	.00	23.23
25-year means	.60	1.18	.33	.50	1.56	2.31	3.33	4.68	3.31	1.56	.86	.11	20.33

Buckman Springs (49); elevation, 5,450 feet (?).

[Authority, Cuyamaca Water Co., W. S. Post, engineer.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1914-15	.70	.00	.68	.91	.68	5.06	8.76	6.55	1.67	1.73	4.89	.00	31.63

Morena dam (50); elevation, 3,000 feet.

[Authority, Southern California Mountain Water Co.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1906-7	......	......	......	......	......	......	6.44	1.59	4.71	0.84	0.39	0.88	......
1907-8	0.00	0.00	0.00	2.64	0.41	0.61	5.61	4.98	1.90	1.18	.92	.00	18.25
1908-9	.00	.86	1.31	1.29	1.31	1.20	10.90	5.55	4.22	.17	.00	.00	26.81
1909-10	.06	1.64	.00	.00	3.99	5.64	5.69	.98	2.78	.38	.00	.00	21.16
1910-11	.97	.00	.47	1.36	1.91	.46	4.33	6.39	2.04	1.59	.00	.00	19.52
1911-12	.96	.00	.06	.71	.14	1.75	1.09	.06	12.07	3.59	1.25	.14	21.82
1912-13	.43	.30	.00	1.19	1.18	.48	3.11	4.86	2.71	.59	.28	.31	15.44
1913-14	.43	1.64	.26	.00	2.40	2.00	5.54	4.76	1.02	1.94	.41	.27	20.67
1914-15	.00	.00	.10	1.38	.61	4.26	8.00	5.78	2.34	4.08	4.13	.00	30.68
8-year means	.36	.56	.25	1.07	1.49	2.05	5.53	4.17	3.64	1.69	.87	.09	21.79

La Jolla Indian Reservation (51); elevation, 3,800 feet.

[Authority, U. S. Weather Bureau.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1911-12	a0.80	a0.00	a0.40	a0.40	a0.10	a2.00	1.18	Tr.	12.05	4.73	2.10	0.05	23.81
1912-13	.18	.96	.00	2.35	1.33	.78	3.02	7.64	2.67	1.43	.73	.62	21.71
1913-14	.14	.60	.14	.05	3.41	3.46	10.08	8.97	2.45	3.18	.10	.94	33.52
1914-15	.00	.00	.00	2.23	1.19	4.56	11.05	11.94	3.48	6.90	4.63	.00	45.98
4-year means	.28	.39	.14	1.26	1.51	2.70	6.33	7.14	5.16	4.06	1.89	.40	31.26

Laguna (52); elevation, 5,440 feet.

[Authority, Arch. Campbell. Copied from U. S. Geological Survey records.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1884-85	......	......	......	......	......	......	......	......	......	2.10	1.36	0.17	......
1885-86	0.00	1.87	......	0.44	2.71	0.60	......	......	......	......	......	......	......
1886-87	.21	2.43	0.00	.29	1.40	......	......	......	......	......	......	......	......
1890-91	......	......	......	......	......	......	......	......	......	......	.60	.00	......
1894-95	1.15	2.83	.00	.00	.00	9.97	17.44	2.87	2.70	.00	.45	.00	37.41
1895-96	.00	.00	.00	......	6.40		3.55		5.60	1.55	.25	.00	17.35
1896-97	1.50	3.83	.00	3.35	2.48	2.74	3.60	1.08	.00	.00	.00	.00	18.58
1897-98	.00	.00	.03	2.50	.00	1.80		8.10		4.44		.00	16.87
1898-99	.00	.00	.00	.00	a.00	a.00		16.00			.00	.00	16.00
1899-1900	.00	.00	.00	1.85	2.70	1.65	3.30	.37	1.00	3.80	2.19	.30	17.16
1900-1901	.00	.00	.20	.40	6.20	.00	5.60	8.60	.95	.71	2.09	.00	24.75
1901-2	.42	1.25	.00	1.42	.54	.35	.40	.35	6.15	1.05	.11	.21	12.25
1902-3	2.32	.00	.00	.48	3.23	2.95		b2.00		3.20	.54	.15	14.87
1903-4	.00	.45	1.08	.00	.00	.05	.55	a6.00		2.00	.50	.00	10.63
1904-5	1.67	6.95	.21	.57	.00	......	......	......	......	......	......	......	......
1914-15	......	......	......	......	......	......	13.10	6.50	.68	8.40	.54	.00	......
10-year means	.54	.84	.13	1.21	1.73	2.16	4.00	2.54	2.68	1.85	.84	.06	18.59

a Estimated.

TABLE 64.—*Monthly and annual precipitation at 106 stations in or near San Diego County*—Continued.

Barrett dam (53); elevation, 1,600 feet.

[Authority, Southern California Mountain Water Co.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1908-9	......	......	......	......	......	......	6.88	4.71	3.83	0.04	0.00	0.00	....
1909-10	0.00	1.07	0.00	0.00	3.10	4.91	4.39	.76	2.13	.28	.00	.00	16.64
1910-11	.53	.00	.53	1.03	1.10	.55	3.01	5.34	1.54	.69	.00	.00	14.32
1911-12	.68	.00	.06	.34	.08	1.70	.48	.07	10.93	3.30	1.25	.08	18.97
1912-13	.05	.11	.00	.81	.62	.05	2.44	5.04	1.91	.35	.18	.21	11.77
1913-14	.26	.63	.75	.00	1.80	1.17	4.28	4.37	.78	1.72	.38	.11	16.25
1914-15	.00	.00	.00	2.23	1.19	4.56	11.05	11.94	3.48	6.90	4.63	.00	45.98
6-year means	.25	.30	.22	.74	1.32	2.16	4.27	4.59	3.46	2.21	1.07	.07	20.66

Jamul Store (54); elevation, 1,040 feet.

[Authority, city of San Diego.]

1914-15	0.00	0.00	0.11	0.92	1.15	3.13	6.57	4.85	1.49	2.70	......	......	....

El Cajon Valley—Sweetwater Pass (55); elevation, 670 feet.

[Authority, Cuyamaca Water Co., W. S. Post, engineer.]

1908-9	0.00	0.71	0.21	0.89	0.82	1.67	3.14	2.30	3.08	0.00	0.06	0.00	12.88
1909-10	.00	.09	.00	.00	2.81	4.17	1.95	.20	1.69	.16	.00	.00	11.07
1910-11	.22	.00	.10	1.81	.86	.27	3.59	2.99	.90	.61	.00	.00	11.35
1911-12	.00	.00	.52	.18	.05	1.27	.27	.00	.00	1.97	1.03	.72	6.01
1912-13	.00	.25	.00	.86	.41	.00	1.42	2.78	1.12	.15	.25	.13	7.37
1913-14	.15	.14	.02	.02	3.01	.62	4.73	3.80	.59	1.26	.31	.09	14.74
1914-15	.00	.00	.09	1.21	1.14	3.13	5.58	5.28	1.08	2.33	1.25	.00	21.09
7-year means	.05	.17	.13	.71	1.30	1.59	2.95	2.48	1.21	.92	.41	.31	12.07

Pine Hills Hotel (56); elevation, 4,100 feet.

[Authority, Volcan Land & Water Co., W. S. Post, engineer.]

1913-14	*a*0.40	1.45	*a*0.00	0.10	7.80	2.75	10.20	7.65	2.10	4.00	0.00	0.50	*a* 36.95
1914-15	.67	.00	.30	1.85	1.20	5.96	11.05	13.00	2.88	6.20	*a*5.70	.00	*a* 48.81
2-year means	.53	.72	.15	.97	4.50	4.35	10.62	10.32	2.49	5.10	2.85	.25	42.88

Fallbrook (57); elevation 700 feet.

[Authority, U. S. Weather Bureau.]

1875-76	......	......	......	......	......	......	6.17	3.78	2.77	0.15	0.61	0.00	....
1876-77	0.15	0.00	0.20	0.23	0.07	0.08	3.41	.59	2.28	.55	1.11	.00	8.67
1877-78	.00	Tr.	.00	.59	.58	4.02	3.19	8.01	2.08	4.63	1.41	.33	24.84
1878-79	.00	Tr.	.00	.32	.25	1.64	3.21	.90	.29	.83	.03	.23	7.70
1879-80	.00	.05	.00	.42	3.61	5.87	1.46	1.86	2.12	4.99	.05	.02	20.45
1880-81	.03	.26	.11	.74	1.27	3.22	3.51	.73	2.93	.67	.00	.00	13.47
1881-82	.00	.00	.00	.57	.24	.35	2.65	4.02	2.42	1.64	.09	.26	12.24
1882-83	Tr.	.12	.03	.70	1.01	.33	3.46	2.68	1.89	1.23	1.87	.00	13.32
1883-84	.00	.00	.00	2.96	.00	3.32	3.56	15.36	10.90	3.13	1.02	.52	40.77
1884-85	.00	.02	.20	.53	.54	7.07	.92	.13	.29	2.60	.29	.11	12.70
1885-86	.00	.02	.00	.00	5.92	1.13	9.76	1.13	4.70	3.43	.00	.14	26.23
1886-87	Tr.	.11	.12	.04	1.95	.30	.28	5.65	.05	2.02	.24	.06	10.82
1887-88	.05	.00	.83	.20	2.03	3.56	3.89	2.55	5.88	.28	.81	.02	20.10
1888-89	.03	.00	.00	.80	3.48	6.13	1.49	2.35	7.97	.63	.47	.11	23.46
1889-90	.00	.07	.05	2.11	.58	15.53	5.14	2.22	.80	.09	.30	.02	26.91
1890-91	.00	.26	.49	.00	.58	3.22	.40	11.93	.56	1.35	.89	.00	19.68
1891-92	.02	.00	.13	.02	.01	2.64	1.10	4.59	2.71	.62	1.46	.19	13.49
1892-93	.00	.00	.00	.32	2.85	2.14	3.40	3.72	8.06	.49	.29	.00	21.27
1893-94	.13	.00	.06	.86	1.46	3.58	.87	1.10	1.36	.08	.31	.00	9.81
1894-95	.04	.18	.38	.06	.00	6.09	12.52	1.59	2.14	.61	.24	.00	23.85
1895-96	.00	.00	.00	.06	1.46	.47	3.45	Tr.	3.44	.26	.13	.00	9.27
1896-97	.05	.05	.00	2.68	1.22	2.13	4.20	6.61	4.37	.06	.21	.00	21.58

a Estimated.

TABLE 64.—*Monthly and annual precipitation at 106 stations in or near San Diego County*—Continued.

Fallbrook (57); elevation, 700 feet—Continued.

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1897–98	.01	Tr.	Tr.	2.82	.17	.38	2.65	.71	1.48	.46	2.23	.07	10.98
1898–99	Tr.	Tr.	Tr.	.00	.02	1.04	3.51	.66	2.23	.16	.18	.90	8.70
1899–1900	.00	.03	.00	1.25	2.90	2.22	3.26	.29	.76	1.00	1.76	Tr.	13.47
1900–1901	.00	.00	.06	.23	5.06	.00	4.24	5.17	.42	.10	1.26	.06	16.60
1901–2	.00	.08	Tr.	.87	.75	Tr.	2.84	3.48	3.52	.75	.11	.05	12.45
1902–3	.23	.00	.00	.29	2.86	4.00	3.11	3.33	5.19	4.35	.08	.05	23.49
1903–4	.00	.00	.15	.11	.05	.05	.48	2.94	......	......	......	......	....
27-year means	.03	.05	.10	.73	1.51	2.98	3.39	3.38	2.99	1.37	.62	.12	17.27

Divide between Santa Ysabel and Warners (58); elevation, 3,200 feet.

[Authority, Volcan Land & Water Co., W. S. Post, engineer.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1912–13	[a]0.10	[a]0.70	[a]0.00	[a]3.00	[a]1.80	[a]0.10	[a]3.00	6.76	3.06	0.99	0.54	0.48	20.53
1913–14	.26	1.31	Tr.	.32	3.51	2.37	9.52	6.53	1.73	3.36	.00	.82	29.73
1914–15	.03	.00	Tr.	1.54	1.22	5.35	13.17	10.21	1.10	9.36	2.26	.08	44.32
3-year means	.13	.67	.00	1.62	2.18	2.61	8.56	7.83	1.96	4.57	.93	.46	31.53

Rincon or Warner's ranch (59); elevation, 2,975 feet.

[Authority, Volcan Land & Water Co., W. S. Post, engineer.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1912–13	[a]0.20	[a]0.40	[a]0.00	[a]2.20	[a]0.80	[a]0.10	[a]3.00	7.92	2.09	0.49	0.18	0.32	17.70
1913–14	.26	.90	.00	.40	2.74	1.71	8.75	8.24	2.00	1.98	.00	.22	27.20
1914–15	.53	.00	Tr.	.94	1.00	4.91	11.69	12.98	1.69	7.54	1.29	.14	42.71
3-year means	.33	.43	.00	1.18	1.51	2.24	7.81	9.71	1.93	3.34	.49	.23	29.20

La Mesa dam (60); elevation, 500 feet.

[Authority, Cuyamaca Water Co., W. S. Post, engineer.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1912–13	[a]0.00	[a]0.25	[a]0.00	[a]0.60	[a]0.40	[a]0.00	1.43	2.61	1.04	0.20	0.30	0.09	6.92
1913–14	.12	.00	.00	.00	2.99	1.01	4.13	3.12	.61	1.34	.30	.19	13.81
1914–15	.00	.00	.00	1.35	1.17	2.67	6.50	5.14	1.24	2.83	1.12	.00	22.02
3-year means	.04	.08	.00	.65	1.52	1.23	4.02	3.62	.96	1.46	.57	.09	14.25

Sutherland dam site (61); elevation, 1,900 feet.

[Authority, Volcan Land & Water Co., W. S. Post, engineer.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1913–14	......	......	......	......	......	......	8.48	5.54	1.54	3.82	0.70	0.45	....
1914–15	0.00	0.00	0.00	1.34	1.86	3.96	9.58	5.78	3.27	6.23	5.35	.00	37.37

Santa Maria dam site (62); elevation, 1,400 feet.

[Authority, Volcan Land & Water Co., W. S. Post, engineer.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1913–14	......	......	......	......	......	......	5.83	4.05	0.93	2.21	0.70	0.38	....
1914–15	0.00	0.00	0.00	1.09	1.15	4.01	8.76	5.85	2.10	2.65	2.81	0.00	28.42

Pamo camp (63); elevation, 975 feet.

[Authority, Volcan Land & Water Co., W. S. Post, engineer.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1913–14	......	......	......	......	......	......	4.50	4.33	1.14	1.37	0.53	0.24	......
1914–15	0.00	0.00	0.02	0.90	1.65	2.73	7.45	6.34	1.65	3.13	4.31	.00	28.18

[a] Estimated.

TABLE 64.—*Monthly and annual precipitation at 106 stations in or near San Diego County*—Continued.

Carroll dam site (64); elevation, 250 feet.

[Authority, Volcan Land & Water Co., W. S. Post, engineer.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1914–15	......	......	......	......	......	12.77	9.04	10.29	2.80	6.44	4.89	0.00	......

Point Loma (65); elevation, 302 feet.

[Authority, U. S. Weather Bureau.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1903–4	......	......	......	......	......	......	0.05	2.27	2.26	0.24	0.15	0.01	......
1904–5	Tr.	Tr.	0.04	0.18	0.00	1.51	3.35	5.03	2.27	.55	.51	.02	13.46
1905–6	0.15	0.00	.28	.20	3.31	.21	1.16	1.92	5.05	.54	.77	.08	13.67
1906–7	.04	.10	.21	.05	.74	3.11	3.09	.52	1.76	.18	.01	.33	10.14
1907–8	.10	.00	.00	1.59	.12	.62	3.05	2.29	.53	.28	.10	Tr.	8.68
1908–9	.04	1.26	.38	.47	1.03	.42	3.39	1.93	2.31	.02	.04	.03	11.32
1909–10	.01	.00	.07	.02	3.10	3.19	2.92	.21	1.35	.18	.02	Tr.	11.13
1910–11	.03	Tr.	.08	2.33	.69	.40	3.07	4.56	1.19	.45	.01	.03	12.84
1911–12	.10	.06	.25	.50	.05	1.04	.69	.16	4.67	2.37	.16	.22	10.27
1912–13	.17	.41	.01	.43	.47	.06	1.19	2.24	.42	.13	.18	.16	5.87
1913–14	.05	.02	.03	.04	2.02	.87	4.76	2.22	.76	.80	.15	.14	11.86
1914–15	.00	.00	.02	.90	.77	2.34	5.53	3.86	.49	1.73	.42	Tr.	16.06
11-year means	.06	.17	.13	.61	1.12	1.25	2.93	2.26	1.89	.66	.22	.09	11.39

Otay (66); elevation, 90 feet.

[Authority, George G. Downes. Gage has good exposure.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1908–9	0.00	0.00	0.00	0.43	1.08	0.39	2.72	2.31	4.64	0.09	0.00	0.00	11.66
1909–10	.00	.00	.02	3.79	5.40	2.54	.50	1.44	.49	.00	.00	.00	14.18
1910–11	.00	.00	Tr.	1.51	.70	.37	2.76	3.10	.66	.44	.00	.00	9.54
1911–12	.07	.00	.22	.23	.19	1.20	.49	.00	5.17	1.93	.12	.19	9.81
1912–13	.20	.28	.00	.43	.56	.00	1.50	2.64	.48	.14	.10	.12	6.45
1913–14	.04	.00	.00	.00	1.96	.92	3.47	2.07	.70	.36	.18	.00	9.70
1914–15	.00	.00	.07	1.76	1.22	2.33	5.24	3.11	.68	1.32	.45	.00	16.18
7-year means	.04	.04	.04	1.16	1.59	1.11	2.38	2.09	1.83	.61	.12	.05	11.07

Lower Otay reservoir (67); elevation 486 feet.

[Authorities: 1905 to 1914, Southern California Mountain Water Co.; 1914–15, city of San Diego.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1905–6	......	......	......	......	......	......	0.74	5.39	3.12	2.75	0.72	0.00	......
1906–7	0.00	0.08	0.00	0.02	1.31	3.31	4.54	.74	2.85	.35	.09	.22	13.51
1907–8	.00	.00	.00	.78	.00	.35	4.35	2.52	2.00	.73	.05	.00	10.78
1908–9	.00	1.20	.14	.35	.80	.00	3.94	2.39	2.20	.00	.00	.00	11.02
1909–10	.00	.00	.00	.00	1.50	4.74	1.85	.05	1.56	.52	.00	.00	10.22
1910–11	.00	.00	.00	1.34	1.39	.33	3.13	3.59	1.21	.64	.00	.00	11.63
1911–12	.03	.00	.16	.24	.06	1.19	.79	.00	7.29	2.49	1.13	.29	13.67
1912–13	.01	.20	.00	1.26	1.97	.16	1.51	3.89	.67	.15	.04	.23	10.09
1913–14	.10	.05	.00	.01	2.17	1.63	2.98	2.17	.85	.78	.15	.00	10.89
1914–15	.00	.00	.00	.80	.63	2.58	2.77	3.97	.87	1.79	1.00	.00	14.41
9-year means	.02	.17	.03	.53	1.09	1.58	2.87	2.15	2.16	.83	.27	.08	11.80

Los Padres ranch (68); elevation, 490 feet.

[Authorities: 1901 to 1910–11, U. S. Weather Bureau; 1912 to 1914–15, M. G. Allen.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1901–2	0.00	0.00	0.20	0.30	0.50	0.40	3.10	2.60	3.30	0.30	0.00	0.00	10.70
1902–3	.70	.00	.00	.90	1.25	2.40	.75	3.50	1.05	1.50	.00	.00	12.05
1903–4	.00	.00	.30	.00	.35	2.50	.10	2.33	3.22	.25	.23	.00	9.28
1904–5	.00	.00	.40	.00	.00	2.85	3.27	9.62	5.05	.58	.66	.00	22.43
1905–6	.00	.00	.20	.45	4.85	.70	1.32	2.93	7.73	2.16	1.17	.00	21.51
1906–7	.00	.00	.35	.00	2.26	5.27	5.12	1.50	3.73	.39	.30	.00	18.92
1907–8	.00	.46	.00	1.57	.87	.00	5.05	3.71	1.77	1.09	.98	.00	15.50
1908–9	.00	1.28	.49	.76	.82	1.82	5.55	3.58	5.55	.00	.00	.00	19.85
1909–10	.00	.00	.36	.00	3.49	5.02	3.63	.57	2.57	.33	.00	.00	15.97
1910–11	.00	.00	.34	.81	1.46	.60	4.02	5.05	1.39	1.02	1.02	.00	15.71
1912–13	.00	.00	.70	.00	.70	.00	1.60	4.02	1.00	.00	.00	.00	8.02
1913–14	.00	.00	.00	.00	2.50	1.06	4.70	3.97	.70	1.05	.17	.00	14.15
1914–15	.00	.00	.00	1.06	1.42	2.76	6.05	5.66	1.08	1.94	2.30	.00	22.27
13-year means	.05	.13	.26	.45	1.57	1.95	3.40	3.76	2.93	.82	.53	.00	15.87

TABLE 64.—*Monthly and annual precipitation at 106 stations in or near San Diego County*—Continued.

Bonita (69); elevation, 110 feet.

[Authorities: 1899 to 1913–14, G. A. Norton; 1914–15, R. M. Allen and U. S. Weather Bureau. Mr. Norton let water of each storm accumulate until end of storm; used redwood stick but was very careful to read quickly and so eliminated crawl. Record kept at residence of R. C. Allen, of the Sweetwater Fruit Co. Rain gage is U. S. Weather Bureau standard.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1899–1900	0.00	0.00	0.00	0.36	1.21	0.79	0.45	0.05	0.47	0.99	1.45	0.00	5.77
1900–1901	.00	.00	.00	.28	1.36	.00	1.53	3.65	.44	Tr.	.74	.00	8.00
1901–2	.00	.00	.00	.37	.00	.11	1.94	1.37	2.61	.32	Tr.	Tr.	6.72
1902–3	1.15	.00	.00	.04	1.30	2.97	.91	2.28	1.17	1.12	.00	.00	10.94
1903–4	.00	.00	.00	.14	.00	.12	.12	1.98	2.05	.21	.27	.00	4.89
1904–5	.00	.00	.00	.26	.00	2.16	1.80	6.64	2.93	.26	.92	.00	14.97
1905–6	.00	.00	.69	.30	4.12	.58	1.12	2.32	5.69	1.77	.79	.07	17.45
1906–7	.00	.00	.00	.00	1.39	4.20	4.12	.97	2.01	.16	.00	.00	12.85
1907–8	.00	.00	.00	1.79	.00	.37	3.50	2.96	1.14	.42	.16	.00	10.34
1908–9	.00	.72	.08	.20	1.00	.56	3.73	2.21	3.65	.00	.00	.00	12.15
1909–10	.00	.00	.00	.00	2.66	3.69	2.19	.38	1.22	.46	.00	.00	10.60
1910–11	.00	.00	.00	.87	.84	.20	2.97	3.47	.76	.50	.00	.00	9.61
1911–12	.00	.00	.25	.64	.00	1.61	.81	.00	5.17	2.28	.96	.32	12.04
1912–13	.00	.15	.00	.75	.38	.00	1.88	2.78	.64	.17	.00	.12	6.87
1913–14	.00	.00	.00	Tr.	2.06	.75	4.30	2.21	.78	.77	.08	.00	10.95
1914–15	.00	.00	.08	1.06	.81	2.24	4.64	3.32	.95	1.73	.71	.00	15.54
16-year means	.07	.05	.07	.44	1.07	1.27	2.25	2.29	1.98	.70	.38	.03	10.61

Rockwood ranch (70); elevation, 430 feet.

[Authority, L. D. Rockwood. Exposure of gage is good. It is on slope 250 feet northeast of house and 250 feet northwest of barn. Measurements taken with stick graduated in inches and hundredths. Readings made daily since October, 1901. Prior to this, weekly or for storms, readings being made oftener during big storms.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1893–94	0.00	0.00	0.00	0.62	0.62	2.50	0.75	0.62	1.00	0.00	0.00	0.00	6.11
1894–95	.00	.00	.00	.00	.00	3.88	10.25	1.00	.12	.00	.00	.00	15.25
1895–96	.00	.00	.00	.00	2.00	.50	3.25	.00	4.50	.00	.00	.00	10.25
1896–97	.00	.00	.00	1.25	.75	2.00	3.75	4.50	2.00	.00	.00	.00	14.25
1897–98	.00	.00	.00	.62	.00	.00	1.75	.25	1.75	.00	1.00	.00	6.37
1898–99	.00	.00	.00	.50	.00	1.00	2.25	1.00	2.12	.00	.00	.00	6.87
1899–1900	.00	.00	.00	.95	1.68	1.24	5.25	.00	.41	1.16	1.05	.00	11.74
1900–1901	.00	.00	.00	.15	3.05	.00	1.62	5.22	.00	.00	1.90	.00	11.94
1901–2	.00	.00	.00	.20	.40	.00	1.99	[a]2.64	4.02	.50	.00	.00	9.75
1902–3	.00	.00	.00	.25	2.27	1.89	.82	3.43	2.79	3.53	.00	.00	14.98
1903–4	.00	.00	.00	.00	.00	.00	.10	1.28	3.18	.55	.21	.00	5.32
1904–5	.00	.00	.00	.50	.00	1.58	3.05	6.60	6.45	.86	.90	.00	19.94
1905–6	.00	.00	.00	.00	2.18	.40	2.14	2.42	8.27	1.60	1.09	.00	18.10
1906–7	.00	.00	.00	.00	1.26	4.38	4.77	1.30	3.17	.25	.00	.00	15.13
1907–8	.00	.00	.00	2.33	.62	.63	2.92	3.46	1.18	.75	.22	.00	12.11
1908–9	.00	1.50	.00	.00	.60	.78	6.12	3.72	2.00	.00	.00	.00	14.72
1909–10	.00	1.50	.00	.00	3.45	6.88	.90	.30	1.46	.00	.00	.00	14.40
1910–11	.00	.00	.00	.97	1.41	.33	4.55	4.88	1.83	.71	.00	.00	14.68
1911–12	.00	.00	.30	.30	.33	1.67	.85	.00	7.56	3.25	1.28	.00	15.54
1912–13	.00	.78	.00	1.16	.00	.28	1.75	3.71	1.11	.67	.00	.00	9.46
1913–14	.00	.00	.00	.00	2.29	1.12	5.57	3.63	1.26	1.43	.00	.00	15.30
1914–15	.00	.00	.00	1.20	1.16	2.52	6.92	5.19	1.21	4.37	2.12	.00	24.69
22-year means	.00	.17	.01	.55	1.10	1.53	3.24	2.51	2.61	.90	.44	.00	13.04

Boulder Creek (71); elevation, 2,990 feet.

[Authority, Volcan Land & Water Co., W. S. Post, engineer.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1914–15	......	......	......	......	......	12.77	9.04	10.29	2.80	6.44	4.89	0.00	......

Harvey ranch (72); elevation, 514 feet.

[Authority, A. M. Logan.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1913–14	......	......	......	......	......	......	3.77	2.74	0.72	0.98	0.15	0.00	......
1914–15	0.00	0.00	0.03	0.84	1.00	2.21	4.51	3.66	.94	......	......	......	......

[a] Storm of Feb. 2 not included.

TABLE 64.—*Monthly and annual precipitation at 106 stations in or near San Diego County*—Continued.

Jamul ranch (73); elevation, 800 feet.

[Authority, Thos. Popplewell.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1911–12	......	......	......	......	......	......	0.60	0.00	10.34	2.83	1.15	0.00	....
1912–13	0.00	0.00	0.00	0.90	0.80	0.00	*a*3.00	4.96	1.44	.19	.18	.00	*a*11.47
1913–14	......	......	......	......	2.33	1.22	4.89	3.54	.90	1.15	.20	.00	....
1914–15	.00	.00	.00	.87	.92	2.37	6.66	4.18	2.48	2.68	1.90	.00	22.06
2-year means	.00	.00	.00	.88	.81	1.19	4.83	4.57	1.96	1.44	1.04	.00	16.77

Dulzura (74); elevation, 1,075 feet.

[Authority, Clark Bros.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1913–14	......	......	......	......	1.64	1.13	5.41	4.47	0.83	1.67	0.00	0.00	....
1914–15	0.00	0.00	0.00	1.35	.90	2.22	7.65	5.68	2.02	3.33	.88	.00	24.03

Marron Valley (75); elevation, 575 feet.

[Authority, Donohoe Bros.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1913–14	......	......	......	......	......	1.73	4.26	3.20	0.56	1.51	0.22	0.00	....
1914–15	0.00	0.00	0.00	.82	.64	2.82	5.51	3.42	.53	3.04	1.41	.00	18.19

Winetka Valley (76); elevation, 2,500 feet.

[Authority, L. Harvey.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1913–14	......	......	......	......	......	......	6.73	5.00	1.35	2.06	0.25	0.00	....
1914–15	0.00	0.00	0.00	1.60	1.17	3.09	7.86	7.40	2.52	4.71	......	......	....

Lyon Peak (77); elevation, 3,755 feet.

[Authority, R. Wueste.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1913–14	......	......	......	......	......	......	......	......	......	2.22	0.34	0.27	....
1914–15	0.00	0.00	0.10	1.58	1.61	3.55	6.35	7.00	1.32	6.00	2.51	.00	30.02

Lyon Valley (78); elevation, 2,200 feet.

[Authority, R. Wueste.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1913–14	......	......	......	......	......	......	......	......	......	2.27	0.20	0.25	....
1914–15	0.00	0.00	0.10	1.33	1.45	4.34	7.95	9.14	2.66	6.13	3.49	.00	36.59

The Willows (79); elevation, 2,300 feet.

[Authority, F. B. Walker.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1913–14	......	......	......	......	......	......	......	......	0.97	2.09	0.16	0.21	....
1914–15	0.00	0.00	0.06	1.33	1.16	3.43	7.06	8.09	.84	......	......	......	....

Cottonwood (80); elevation, 875 feet.

[Authority, L. W. Smith.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1913–14	......	......	......	......	......	......	......	4.02	0.67	1.29	0.31	0.00	....
1914–15	0.17	0.00	0.00	0.60	0.79	3.29	6.28	5.05	1.84	1.98	2.65	.00	22.65

TABLE 64.—*Monthly and annual precipitation at 106 stations in or near San Diego County*—Continued.

Tecate (81); elevation, 1,775 feet.

[Authority, G. F. Robinson.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1913–14	......	......	......	......	......	......	5.72	3.81	0.66	2.05	0.57	0.00	....
1914–15	0.00	0.00	0.37	0.63	0.62	3.80	6.41	5.04	1.50	2.62	2.74	.00	23.73

Petrero (82); elevation, 2,390 feet.

[Authority, G. Nelson.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1913–14	......	......	......	......	......	......	7.12	4.75	0.96	1.93	0.34	0.11	....
1914–15	0.00	0.00	0.15	0.87	0.90	3.78	7.23	6.65	2.05	2.68	3.03	.00	27.34

Skye Valley (83); elevation, 2,550 feet.

[Authority, G. F. Korte.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1912–13	......	......	......	......	......	......	......	3.33	1.55	......	0.21	0.10	....
1913–14	1.00	0.40	1.10	0.06	1.95	1.35	5.72	4.92	1.05	1.69	.21	.00	19.45
1914–15	.10	.00	.08	.85	1.26	3.33	5.04	6.16	1.80	5.55	......	......	....

Grigsby's ranch (84); elevation, 2,690 feet.

[Authority, A. B. Grigsby.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1912–13	......	......	......	......	......	......	......	5.50	2.32	0.40	0.00	0.24	....
1913–14	0.35	2.42	[a]1.50	[a]0.33	2.20	1.38	5.71	4.35	1.02	2.23	.64	.00	[a]22.13
1914–15	1.32	.00	.05	.81	.86	4.36	7.31	6.15	2.16	2.28	3.28	.00	28.58
2-year means	.84	1.21	.77	.57	1.53	2.92	6.51	5.25	1.59	2.26	1.96	.00	25.36

El Cajon (city) (85); elevation, 482 feet.

[Authority, T. J. Cox.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1881–82	......	......	......	......	......	......	0.83	1.71	1.07	1.10	1.04	0.00	....
1882–83	0.00	0.00	0.09	0.20	0.49	0.29	1.89	9.66	7.06	3.58	2.65	.40	26.31
1883–84	.00	.00	.00	1.67	.10	2.64	.54	.58	.75	1.88	.28	.00	8.44
1884–85	.00	.00	.00	.24	.13	6.48	7.29	2.90	2.11	2.26	.00	.00	21.41
1885–86	.00	.00	.00	.08	1.67	.47	.00	4.47	.16	1.97	.13	.00	8.95
1886–87	.00	.00	.00	.13	1.91	.20	3.62	1.30	4.17	.36	.00	.00	11.69
1887–88	.00	.00	.00	.00	2.33	3.07	1.54	2.40	4.44	.33	.28	.00	14.39
1888–89	.00	.00	.35	.65	2.16	4.16	2.38	2.89	.68	.05	.21	.00	13.53
1889–90	.00	.18	.00	3.77	.18	8.54	.60	6.14	.89	1.35	1.01	.00	22.66
1890–91	.00	.00	.91	.03	.80	2.56	1.34	3.19	2.04	.25	1.89	.00	13.01
1891–92	.00	.00	.00	.00	.11	2.05	1.26	1.39	7.94	.32	.08	.00	13.15
1892–93	.00	.00	.00	.35	1.02	1.10	.59	.84	1.79	.00	.22	.15	6.08
1893–94	.00	.00	.00	.31	.97	2.12	11.32	1.06	1.62	.17	.18	.00	17.75
1894–95	.00	.00	.00	.00	.00	3.16	......	......	......	......	......	......	....
12-year means	.00	.02	.11	.62	.99	2.81	2.70	3.07	2.80	1.04	.58	.05	14.78

Buckman Springs (86); elevation, 3,400 feet.

[Authority, W. O. Wolin.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1912–13	......	......	......	......	0.53	0.46	2.94	5.59	0.96	0.13	0.07	0.06	....
1913–14	0.34	1.45	0.17	0.14	......	1.51	......	......	1.05	1.73	.22	.03	....
1914–15	.70	.00	.68	.91	.68	5.06	8.76	6.55	1.67	2.53	2.93	.00	30.47

Descanso Valley (87); elevation, 3,500 feet.

[Authority, G. O. Brenner.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1913–14	......	......	......	......	......	......	......	......	......	1.09	0.33	0.29	....
1914–15	0.82	0.00	0.11	1.56	0.75	4.82	9.03	9.83	2.54	5.52	5.33	.00	40.31

[a] Estimated.

TABLE 64.—*Monthly and annual precipitation at 106 stations in or near San Diego County*—Continued.

Laguna ranger station (88); elevation, 5,475 feet.

[Authority, Leo Morris.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1914–15	......	......	......	......	......	......	12.52	5.84	0.36	8.27	0.45	0.00	......

Bonita (89); elevation, 60 feet.

[Authority, J. M. Voneida.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1913–14	......	......	......	......	......	......	3.28	1.88	0.68	0.75	0.11	0.01	......
1914–15	0.00	0.00	0.10	0.80	0.78	2.35	4.37	2.62	.95	1.32	.67	.01	13.97

Chollas Heights (90); elevation, 350 feet.

[Authority, F. William Blatchford.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1913–14	......	......	......	......	......	......	3.48	2.51	0.61	1.05	0.04	0.16	......
1914–15	0.00	0.00	0.00	1.47	1.11	3.22	5.44	4.71	.74	1.74	.86	.01	19.30

Campbell's ranch (91); elevation, 2,575 feet.

[Authority, Arch. Campbell.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1913–14	......	......	......	......	......	......	......	......	0.74	1.79	0.64	0.00	......
1914–15	0.75	0.00	0.75	0.37	0.60	3.88	6.36	4.26	1.72	......	......	......	......

Kitchen Valley (92); elevation, 5,250 feet.

[Authority, Seth Swenson.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1914–15	......	......	......	......	......	......	12.02	8.80	1.00	8.05	0.66	0.00	......

Dehesa (93); elevation, 580 feet.

[Authority, J. H. Whitaker.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1913–14	......	......	......	......	......	......	......	......	......	2.05	0.14	0.17	......
1914–15	0.00	0.00	0.09	0.98	1.69	2.66	5.84	5.62	1.38	1.97	5.36	.00	25.59

La Presa (94); elevation, 300 feet.

[Authority, J. S. Dressler.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1914–15	0.00	0.00	0.00	1.01	0.88	2.67	5.11	3.73	0.78	2.02	0.93	0.00	17.13

Nobles mine (96); elevation, 4,200 feet.

[Authority, Thos. Noble, jr.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1912–13	......	......	......	......	......	......	3.70	5.60	1.95	0.60	0.30	0.17	......
1913–14	0.45	0.74	0.33	0.21	2.29	1.60	5.73	4.15	1.31	2.28	.30	.15	19.54
1914–15	.45	.30	.68	.97	.98	......	......	......	......	......	......	......	......

TABLE 64.—*Monthly and annual precipitation at 106 stations in or near San Diego County*—Continued.

Japatul (97); elevation, 2,725 feet.

[Authority, R. J. Grouse.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1913–14	......	......	......	......	......	......	......	......	......	1.17	0.54	0.17	....
1914–15	0.16	0.00	0.11	0.79	1.08	3.95	8.06	6.33	2.02	3.24	3.14	.00	28.88

Pueblo farm (98); elevation, 400 feet.

[Authority, Max Watson.]

1913–14	......	......	......	......	......	......	3.80	0.20	......	......	......	0.00	....
1914–15	0.00	0.00	......	......	......	......	6.05	......	......	2.50	......	......	....

Modigajuat (99); elevation, 3,150 feet.

[Authority, Charles Hook.]

1914–15	0.00	0.00	0.00	0.87	0.63	4.17	7.84	5.93	2.40	3.09	3.45	0.00	28.38

Rattlesnake Valley (100); elevation, 4,775 feet.

[Authority, J. D. Harper.]

1914–15	......	......	......	......	......	3.32	8.41	5.79	1.99	3.19	3.09	0.19	....

La Posta (101); elevation, 3,300 feet.

[Authority, R. S. Benton.]

1914–15	......	......	......	......	......	......	7.75	6.06	2.03	2.37	2.78	......	....

Viejas (102).

[Authority, City of San Diego.]

1914–15	......	......	......	......	......	......	......	8.09	0.84	4.01	2.93	......	....

Miramar (103); elevation, 660 feet.

[Authority, G. A. Riley.]

1901–2	0.00	0.00	0.00	0.45	0.60	0.00	1.85	1.45	3.20	0.60	0.20	0.00	8.35
1902–3	.00	.00	.00	.45	3.05	2.85	1.30	3.20	1.60	1.30	.00	.00	13.75
1903–4	.00	.00	.00	.20	.00	.15	.30	2.50	3.13	.25	.25	.00	6.78
1904–5	.80	.00	.00	.30	.00	2.45	3.55	6.95	2.60	.45	.90	.00	18.00
1905–6	.00	.00	.20	.15	4.40	.65	1.80	3.35	7.45	.95	1.10	.10	20.15
1906–7	.00	.00	.25	.00	1.05	5.25	3.85	.80	2.35	.10	.30	.28	14.23
1907–8	.00	.00	.00	.20	1.65	.55	3.60	2.70	1.00	.50	.25	.00	10.45
1908–9	.00	.50	.35	35	1.05	.75	4.67	3.17	2.32	.00	.30	.00	13.46
1909–10	.00	.00	.00	.00	3.45	5.90	3.50	.45	2.05	.30	.00	.00	15.65
1910–11	1.00	.00	.00	1.10	.85	.30	4.45	5.10	1.65	1.20	.00	.17	15.82
1911–12	.00	.00	.10	.22	.00	1.50	.97	.00	5.90	3.15	1.20	.20	13.24
1912–13	.00	.45	.00	1.15	.55	.05	1.50	3.45	1.15	.40	.30	.05	9.05
1913–14	.05	.00	.15	.00	2.15	1.20	5.35	3.45	1.00	1.05	.30	.35	15.05
1914–15	.00	.00	.00	1.25	1.55	3.60	8.95	5.15	1.10	1.04	1.50	.00	24.14
14-year means	.13	.07	.08	.42	1.45	1.80	3.16	2.98	2.61	.81	.47	.08	14.15

TABLE 64.—*Monthly and annual precipitation at 106 stations in or near San Diego County*—Continued.

Santa Fe ranch (104); elevation, 55 feet.

[Authority, M. H. Crawford.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1911-12	a0.00	a0.00	a0.10	a0.12	a0.00	a0.75	0.00	0.00	5.39	2.81	1.10	0.00	a10.27
1912-13	.15	.00	.00	.00	.90	.00	1.50	2.17	.56	.00	.00	.00	5.28
1913-14	.00	.00	.00	.00	1.80	.60	4.19	3.48	.00	.48	.00	.00	10.55
1914-15	.00	.00	.00	.40	1.13	1.80	5.27	4.52	1.27	1.77	.19	.00	16.35
4-year means	.04	.00	.03	.13	.96	.79	2.74	2.79	1.81	1.27	.32	.00	10.61

Scripps Biological Institute (105); elevation, 50 feet.

[Authority, G. F. McEwen.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1914-15	......	......	......	......	......	......	5.95	1.05	1.65	1.42	1.20	Tr.	......

Lauterbaughs (106).

[Authority, city of San Diego.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1914-15	0.03	0.00	0.04	0.46	0.66	3.69	6.96	6.11	2.37	2.21	3.11	0.00	25.64

Idyllwild, Riverside County.

[Authority, U. S. Weather Bureau.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1901	......	......	......	......	......	......	3.47	5.81	1.23	0.37	1.22	0.00	......
1901-2	0.34	3.44	0.00	1.03	0.69	0.34	2.42	5.25	5.53	.09	.20	.10	19.43
1902-3	.33	.00	Tr.	.10	3.80	2.00	3.82	3.00	6.76	6.10	.48	.09	26.48
1903-4	.00	.57	2.21	.47	.00	.00	.80	2.70	4.59	2.19	1.42	.00	14.95
1904-5	Tr.	2.45	Tr.	.25	.00	.98	6.85	8.43	10.07	2.21	3.77	.00	35.01
1905-6	.03	.17	.38	Tr.	8.38	1.93	3.34	5.32	16.15	3.19	2.73	.04	41.66
1906-7	.73	2.77	.14	.03	2.15	5.25	7.30	2.71	6.78	.89	1.48	.43	30.66
1907-8	.05	.00	Tr.	4.55	1.11	2.64	3.96	3.85	1.67	2.34	1.14	.00	21.31
1908-9	1.50	2.73	3.11	1.85	.70	1.05	12.16	7.27	4.56	.26	.15	.00	35.34
1909-10	1.00	1.87	.40	.00	4.34	8.53	5.20	.60	3.08	.33	.00	.00	25.35
1910-11	.55	.21	15	1.43	2.40	.10	9.35	6.26	6.03	1.34	.00	Tr.	27.82
1911-12	1.02	.00	.80	.43	.15	2.10	......	......	12.77	3.01	1.56	......	......
10-year means	.45	1.42	.64	.97	2.36	2.28	5.52	4.54	6.52	1.89	1.14	.07	27.80

San Jacinto, Riverside County; elevation, 1,550 feet.

[Authority, U. S. Weather Bureau.]

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Total.
1893-94	0.03	0.00	0.51	0.66	0.80	3.16	0.67	0.96	0.89	0.10	1.15	0.00	8.93
1894-95	.13	.03	.04	.04	.00	5.30	7.81	1.53	.99	.51	.26	.03	16.67
1895-96	Tr.	Tr.	.00	Tr.	2.09	.34	2.04	.10	3.70	.71	.22	.00	9.20
1896-97	.07	Tr.	.40	1.76	1.20	1.70	3.55	3.74	2.24	a.71	.14	a.00	15.51
1897-98	a.08	a.10	.16	3.38	.34	.47	2.25	.49	.81	a.71	a.67	a.00	a9.46
1898-99	.22	.54	.00	.00	.18	1.38	2.38	.69	1.63	a.71	a.67	a.00	a8.40
1899-1900	a.08	a.10	.00	.81	1.83	.75	1.42	.00	.76	1.97	1.86	.00	a9.58
1900-1901	.01	.00	.01	.42	4.57	.00	2.86	4.62	.33	.03	.55	.00	13.40
1901-2	.00	1.53	.06	.61	.06	Tr.	1.55	1.57	2.31	.53	0.1	.01	8.24
1902-3	.10	.00	.00	.06	1.25	2.12	1.32	1.37	4.54	4.99	.00	Tr.	15.75
1903-4	.00	.11	1.16	.00	.00	a1.64	.32	a1.15	3.02	.35	.15	.00	a7.90
1904-5	.00	.32	.00	.13	.00	1.02	3.46	6.48	4.89	1.03	1.26	.00	18.59
1905-6	.00	.37	.00	.24	2.54	.22	1.42	1.99	6.50	.94	.57	.00	14.79
1906-7	.52	Tr.	.12	.00	2.43	4.79	5.11	2.03	2.98	.04	.00	.00	18.02
1907-8	.00	.00	.00	3.30	.11	.57	3.81	2.92	1.61	.35	.00	.00	12.67
1908-9	.17	.45	.45	.91	.20	.58	3.96	3.25	3.64	.00	.15	.00	13.76
1909-10	.18	.23	.00	.00	1.70	4.89	2.99	.24	2.29	.00	.00	.00	12.52
1910-11	.00	.00	.00	.90	2.94	.00	4.71	3.19	2.31	1.39	.00	.00	15.44
1911-12	.00	.00	.50	.28	.00	.00	.15	.00	7.29	3.24	1.18	.00	12.64
1912-13	.00	.50	.00	1.33	.48	.00	1.07	3.50	.97	.61	.00	.16	8.62
1913-14	.20	.40	.00	.00	2.13	1.34	5.55	3.84	1.03	4.07	.06	.25	18.87
1914-15	.00	.00	.00	.08	.55	2.59	4.65	7.05	.21	2.13	.00	.00	17.26
22-year means	.08	.22	.16	.68	1.15	1.49	2.87	2.31	2.50	1.14	.40	.02	13.01

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SNYDER & BLACK, N.Y.

A, SHOWI

Scale $\frac{1}{250,000}$

4 6 8

2 4 6 8 10 K

ur interval 250 feet.

um is mean sea level.

1919

MAP OF THE SAN DIEGO AREA, CALIFORNIA, SHOWING TOPOGRAPHY AND LOCATION OF WELLS

Contour interval 250 feet
Datum is mean sea level
1919

OF SAN

Geology by A.J. Ellis

Scale $\frac{1}{250,000}$

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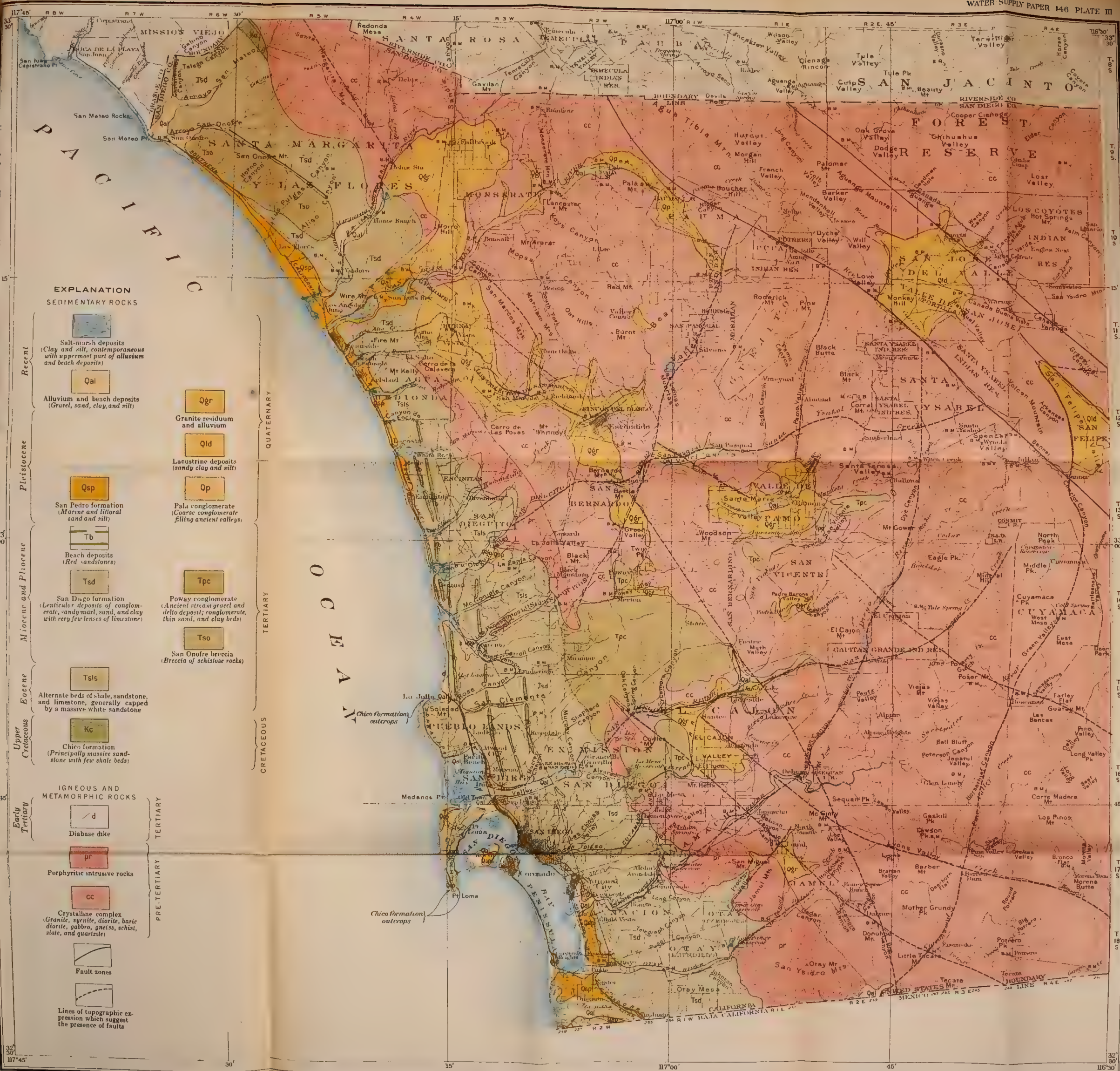
m is mean sea level.

1919.



PRELIMINARY GEOLOGIC MAP OF SAN DIEGO COUNTY, CALIFORNIA

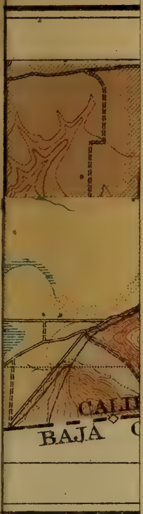
Geology by A. J. Ellis

SNYDER & BLACK, N.Y.

Contour interval 250 feet

Datum is mean sea level

1919



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ne sour

3

4

MAP OF SAN DIEGO QUADRANGLE, CALIFORNIA

Showing marine terraces and marine soundings

Contour interval 25 feet

1919

SNYDER & BLACK, N.Y.

AN DIEGO

age areas ab

le $\frac{1}{250000}$

4 6 8

4 6 8 10 K

terval 250 feet.

mean sea level.

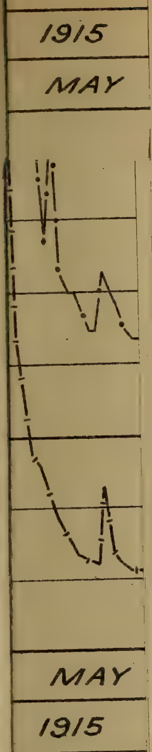
1919.

MAP OF WESTERN PART OF SAN DIEGO COUNTY, CALIFORNIA

Showing precipitation and drainage areas above gaging stations

Contour interval 250 feet

1919



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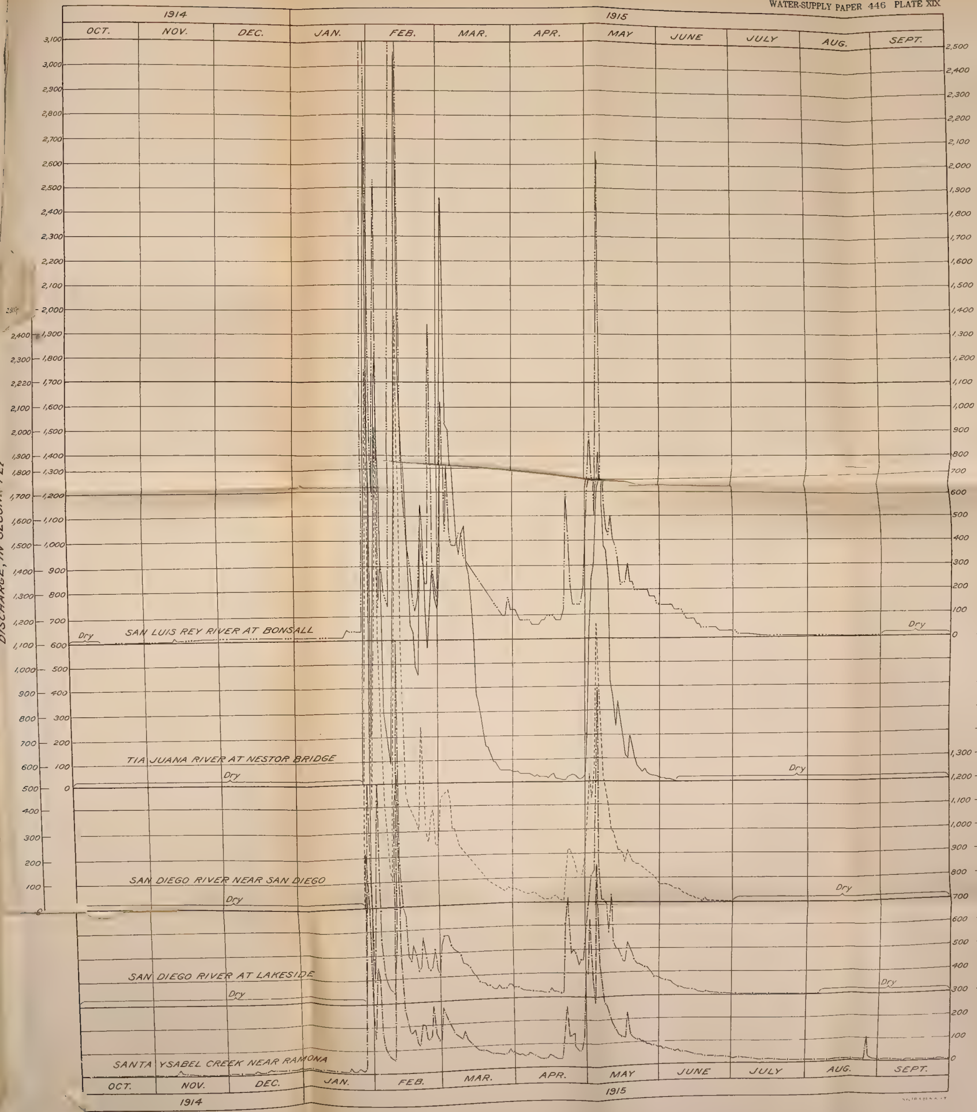
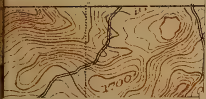
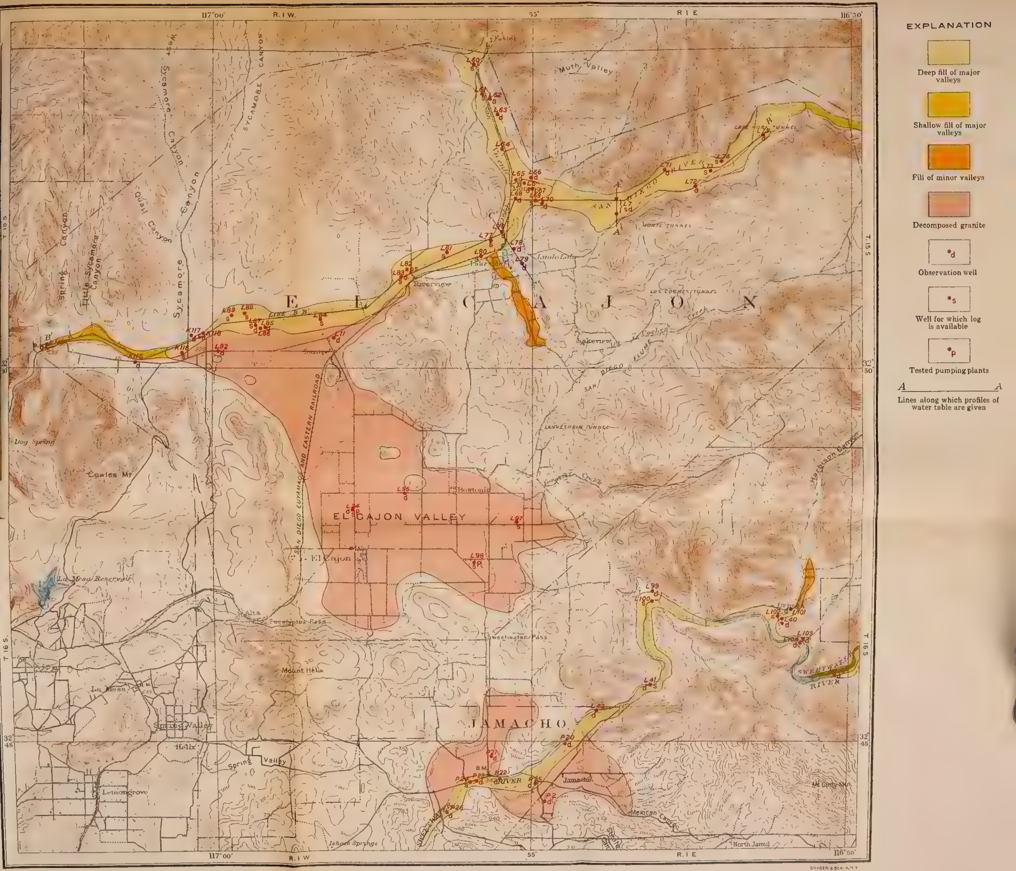


DAILY HYDROGRAPHS OF PRINCIPAL STREAMS IN SAN DIEGO COUNTY AT U. S. GEOLOGICAL SURVEY GAGING STATIONS, 1914-1915.


1700

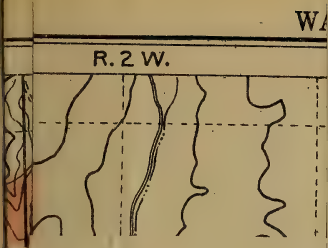


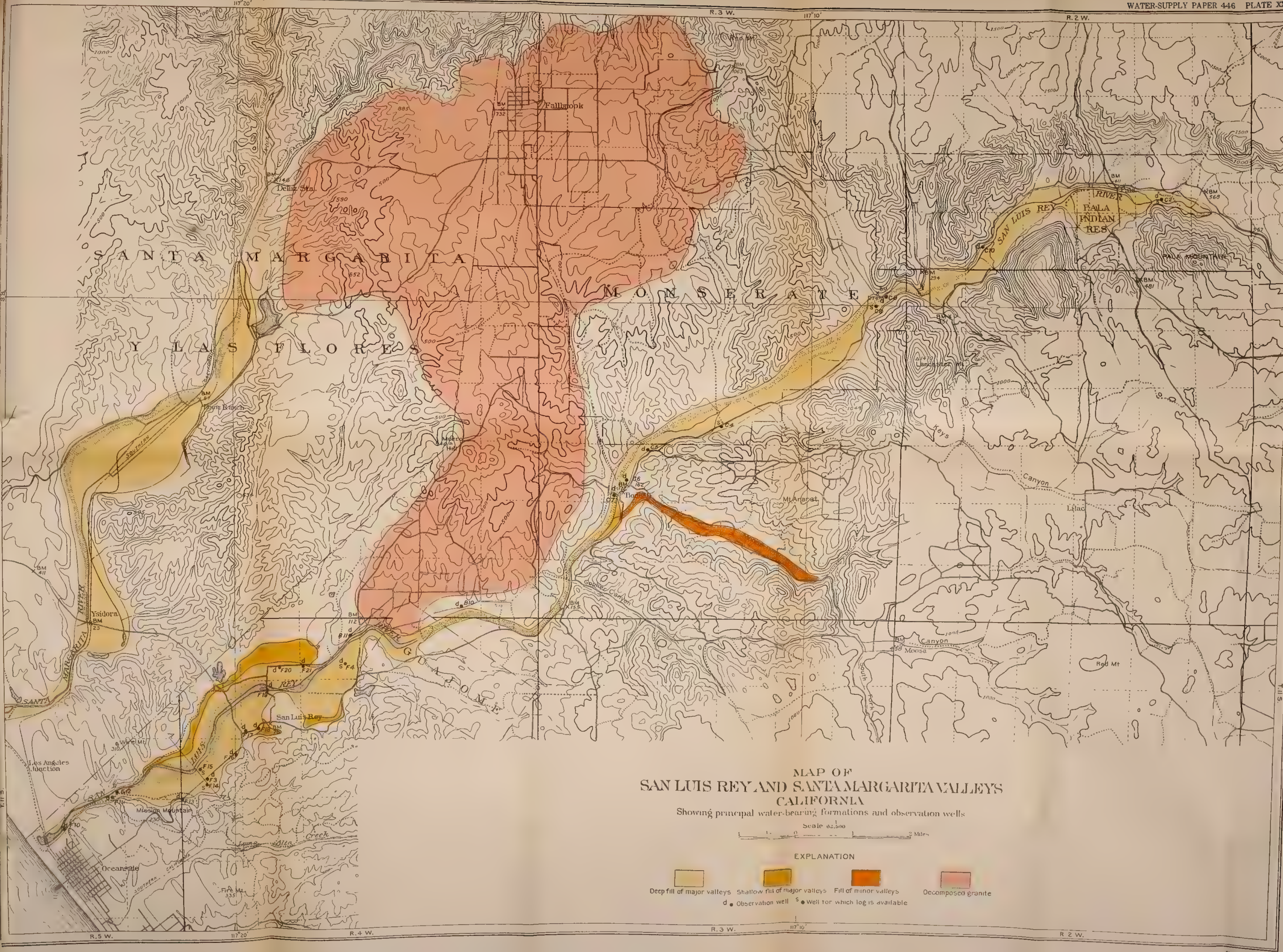
MAP OF EL CAJON VALLEY AND VICINITY, CALIFORNIA

Showing principal water-bearing formations, observation wells, and tested pumping plants

Scale $\frac{1}{62500}$

Contour interval 25 feet
(Lower part 100 feet)
Datum is mean sea level
1919


WA
R. 2 W.



MAP OF
SAN LUIS REY AND SANTA MARGARITA VALLEYS
CALIFORNIA

Showing principal water-bearing formations and observation wells

Scale 62,500

EXPLANATION

Deep fill of major valleys

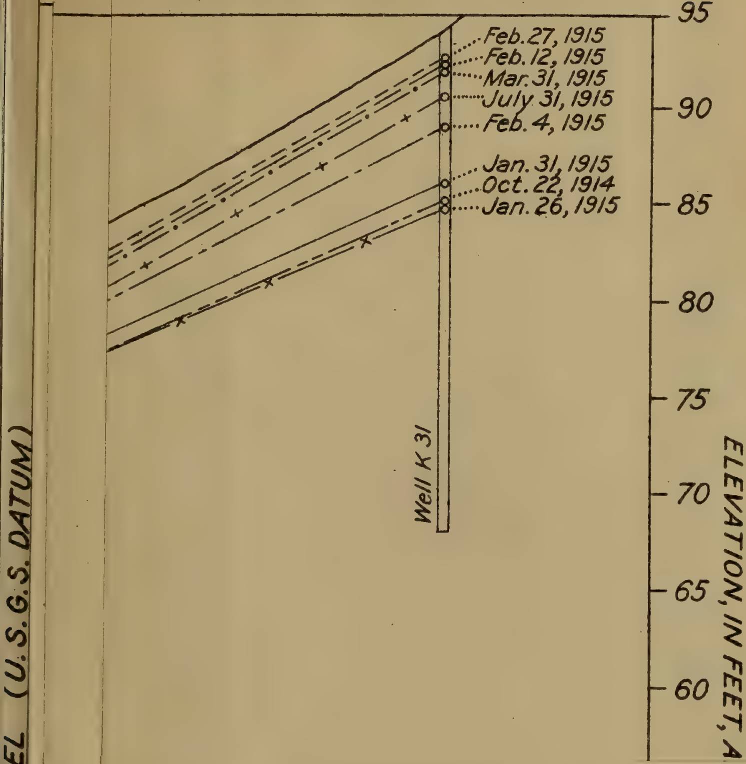
Shallow fill of major valleys

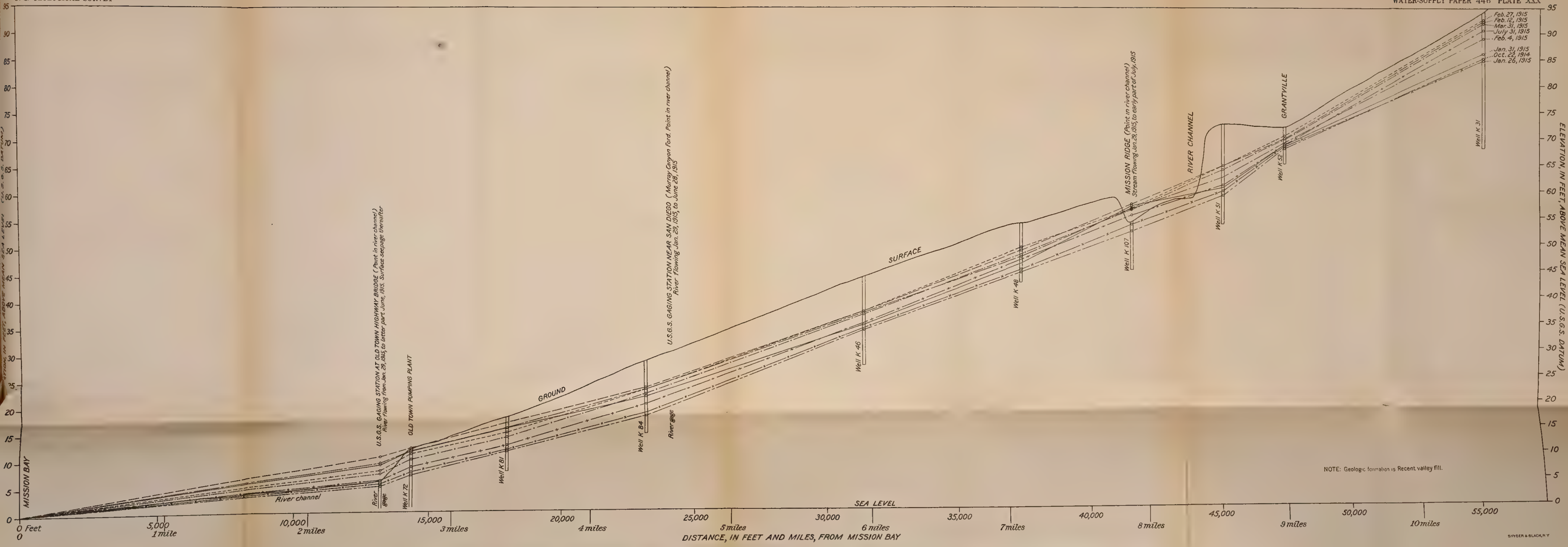
Fill of minor valleys

Decomposed granite

d ● Observation well s ● Well for which log is available

SNYDER & BLACK N.Y.


95
Feb. 27, 1915
Feb. 12, 1915
Mar. 31, 1915
July 31, 1915
90
Feb. 4, 1915
Jan. 31, 1915
Oct. 22, 1914
85
Jan. 26, 1915
80
75
Well K 31
70
65
60
ELEVATION, IN FEET, A
VEL (U.S.G.S. DATUM)



LONGITUDINAL PROFILE OF MISSION VALLEY, SHOWING POSITION OF WATER TABLE IN DIFFERENT SEASONS OF THE YEAR, 1914-1915.

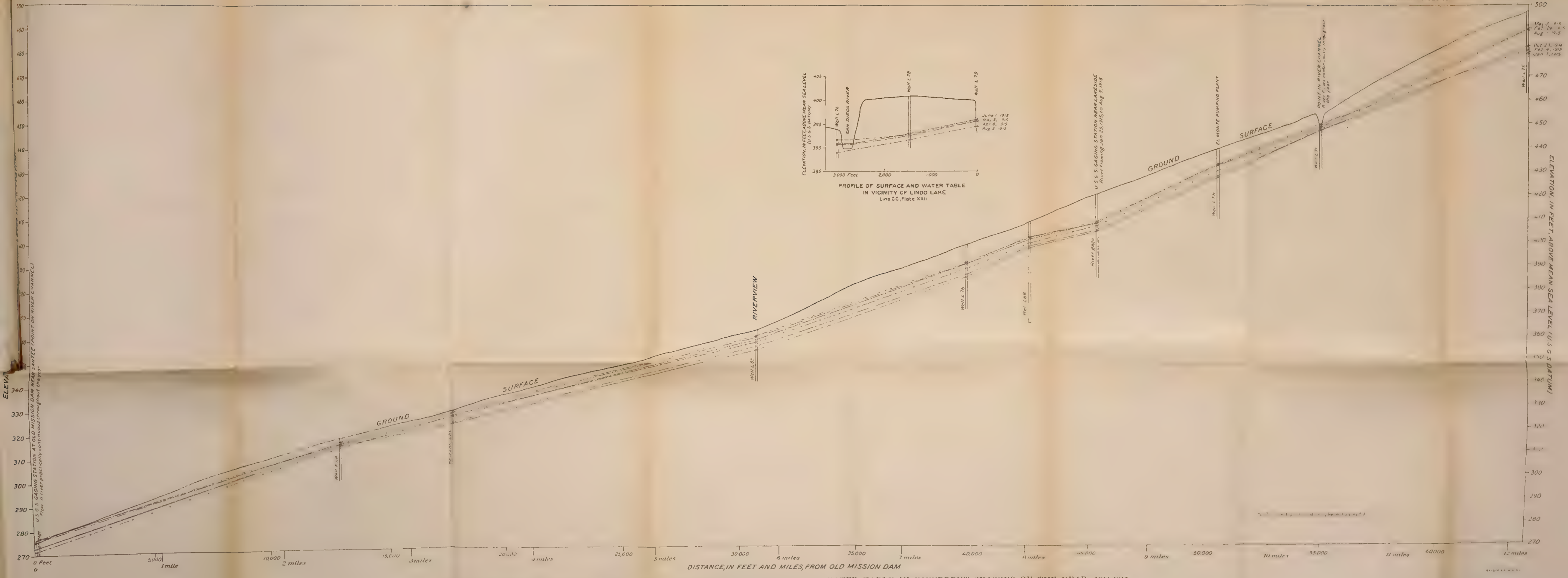
(Red line B-B, Plate XXI)

5

4

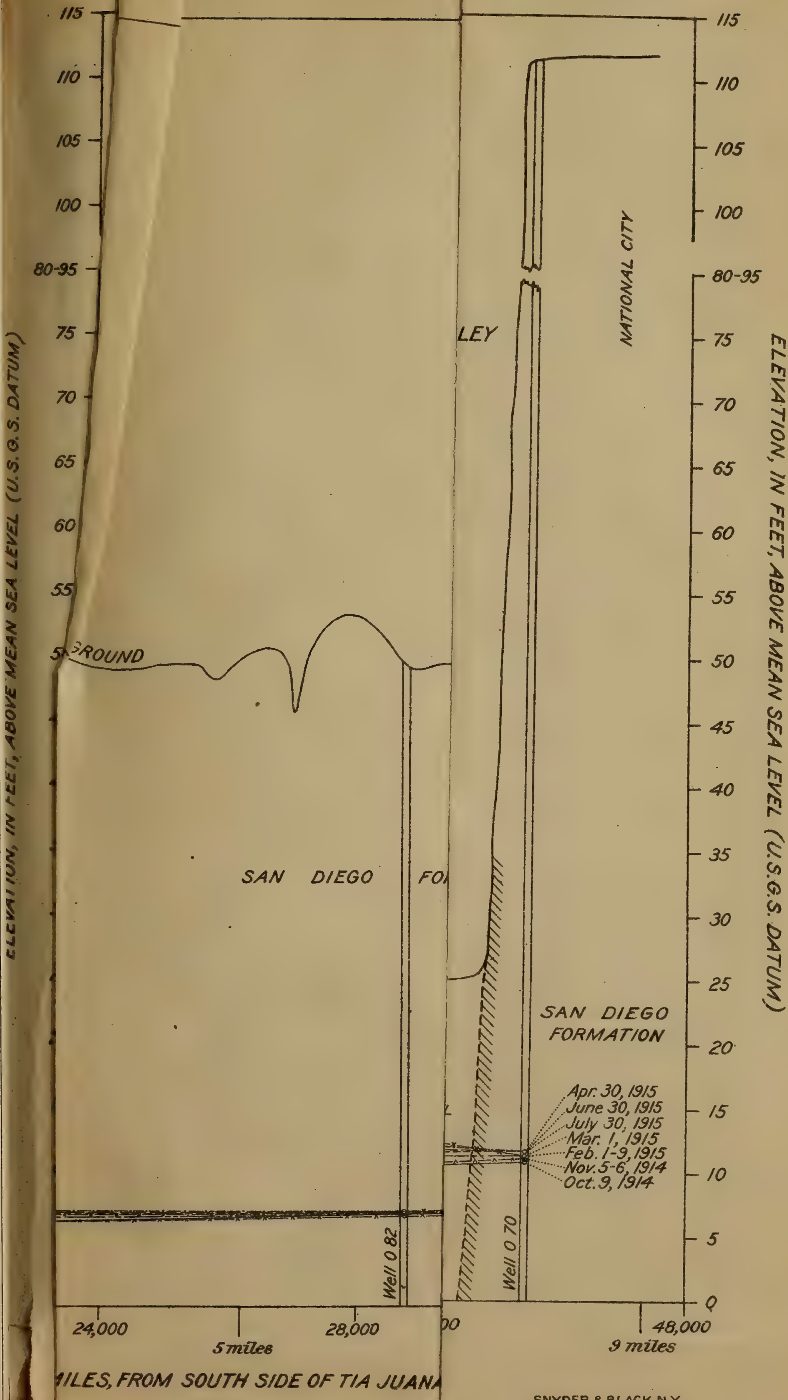
4

4



LONGITUDINAL PROFILE OF SAN DIEGO RIVER VALLEY, SHOWING POSITION OF WATER TABLE IN DIFFERENT SEASONS OF THE YEAR. 1914-1915.

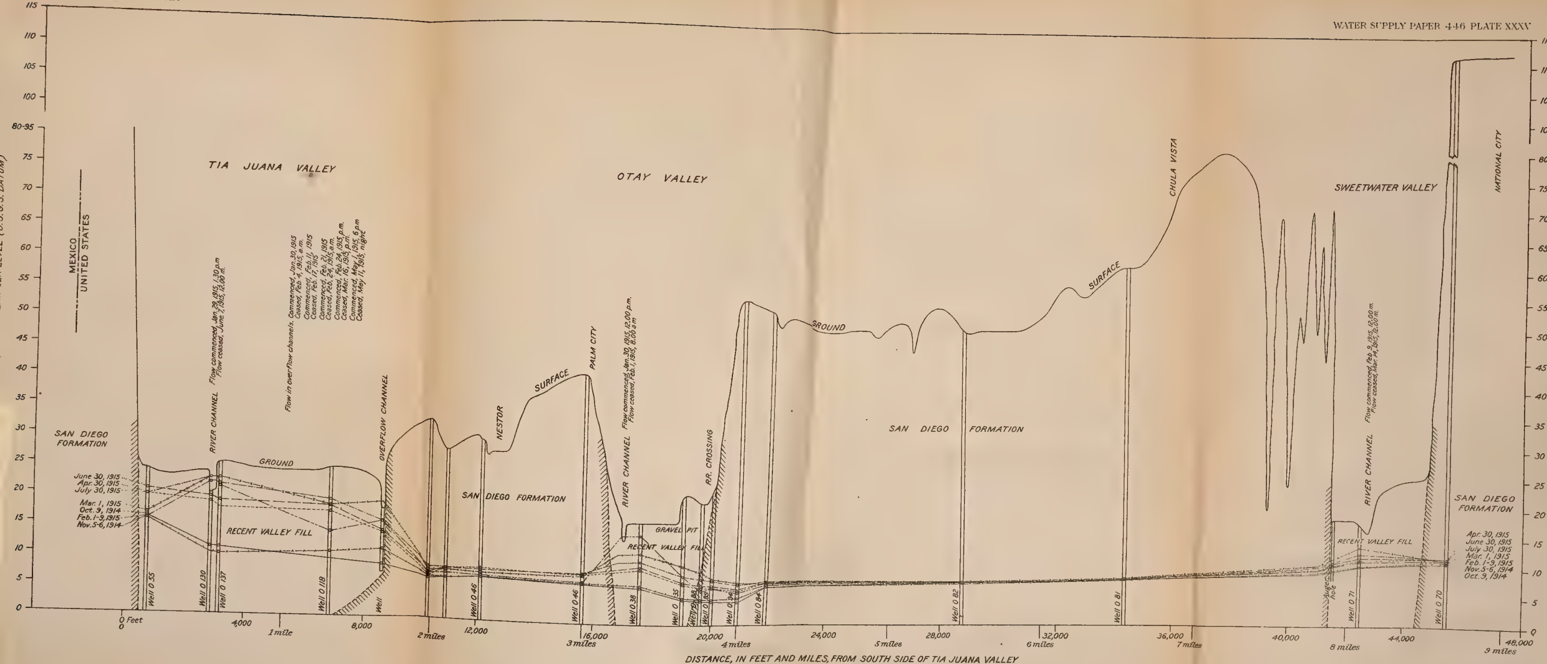
(Line B-B, Plate XXII)



SNYDER & BLACK, N.Y.

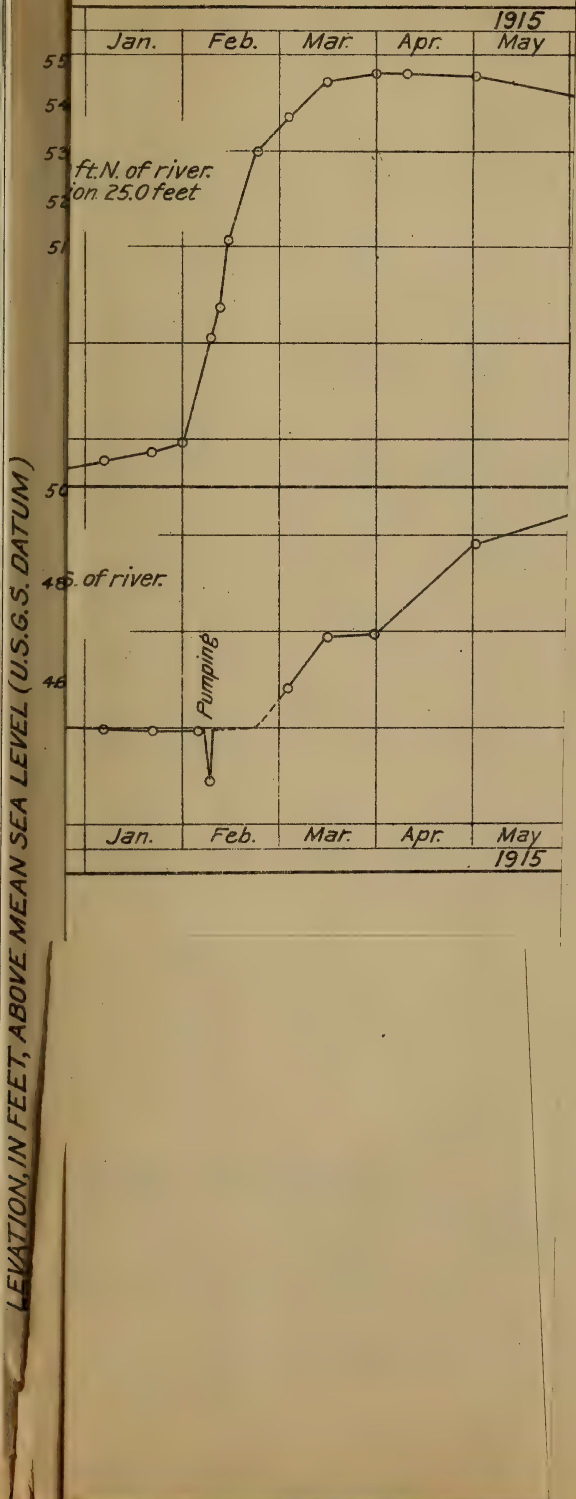
ING FLUCTUATION

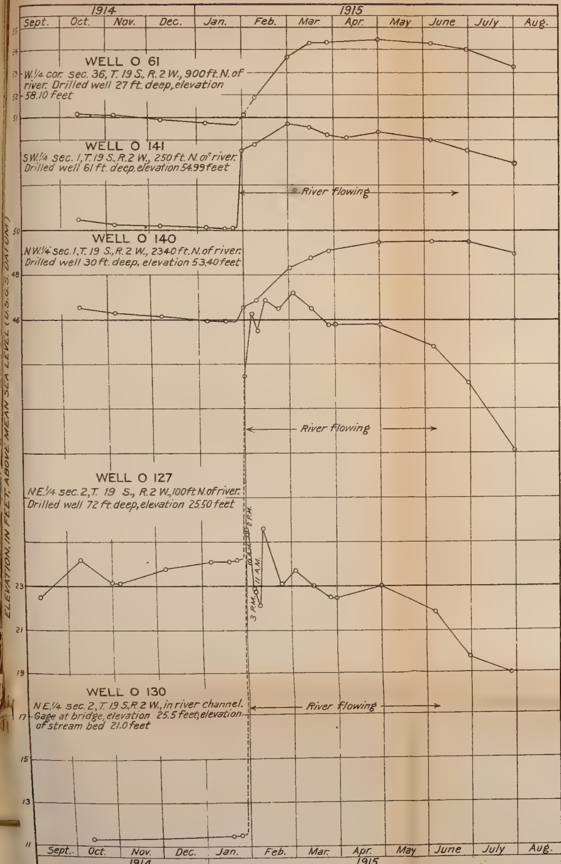
Plate XX)



SECTION FROM TIA JUANA VALLEY TO NATIONAL CITY, SHOWING FLUCTUATIONS OF WATER TABLE, SEASON 1914-1915.

(Red line A-A, Plate XX)


1915
Jan.
Feb.
Mar.
Apr.
May
55
54
53
ft.N. of river.
ion 25.0 feet
51
50
48
S. of river.
Pumping
46
1915
ELEVATION, IN FEET, ABOVE MEAN SEA LEVEL (U.S.G.S. DATUM)



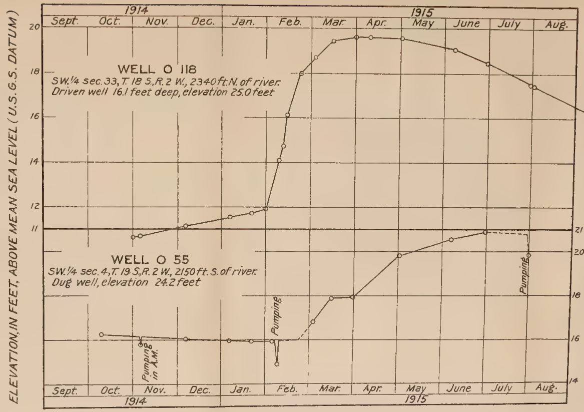


DIAGRAM SHOWING
FLUCTUATIONS OF WATER TABLE IN OBSERVATION WELLS IN TIA JUANA VALLEY
1914-1915

NOTE: Dotted lines connecting observations indicate approximate fluctuations during periods for which record is insufficient to show detail.

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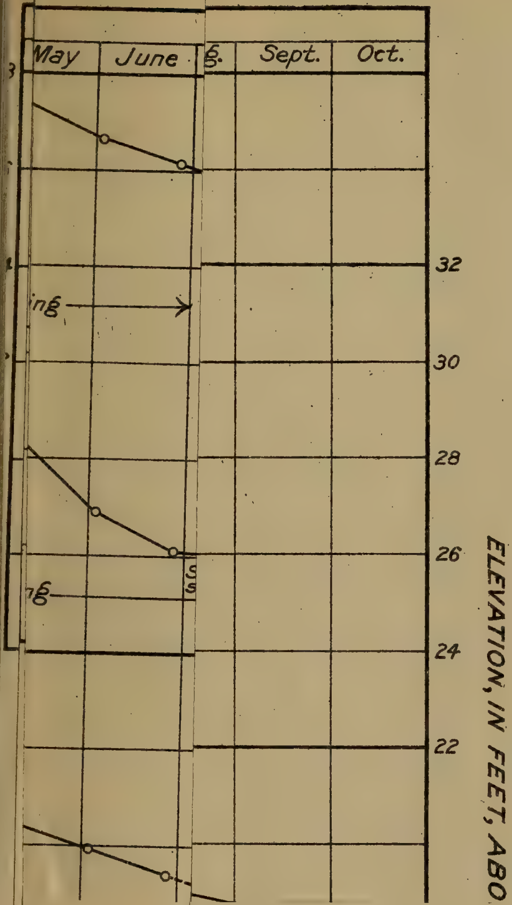
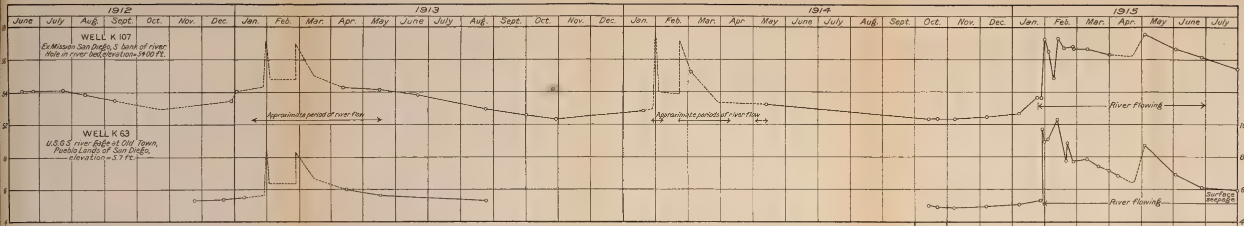
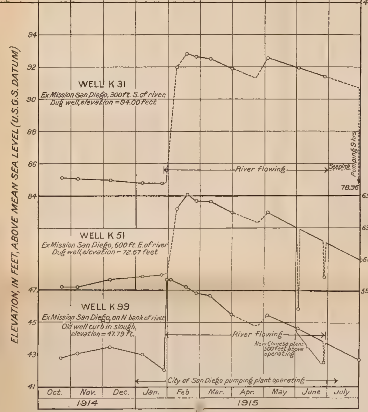

May
June
Sept.
Oct.
ing
32
30
28
26
24
22
ELEVATION, IN FEET, ABO





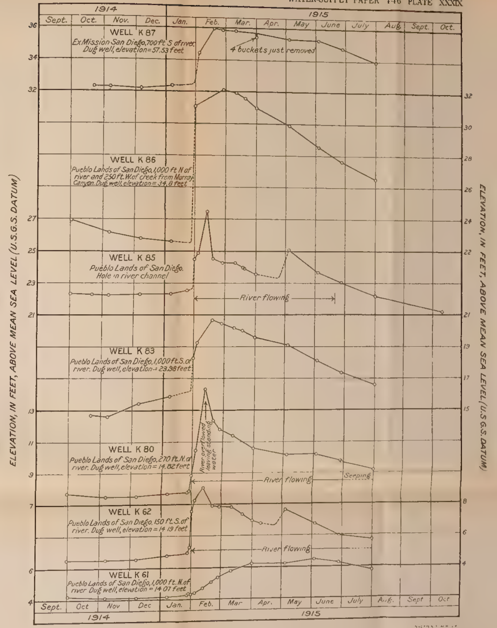


DIAGRAM SHOWING
FLUCTUATIONS OF WATER TABLE
IN OBSERVATION WELLS
IN MISSION VALLEY
1912 - 1915

NOTE. Dotted lines connecting observations indicate approximate fluctuations during periods for which record is insufficient to show detail.

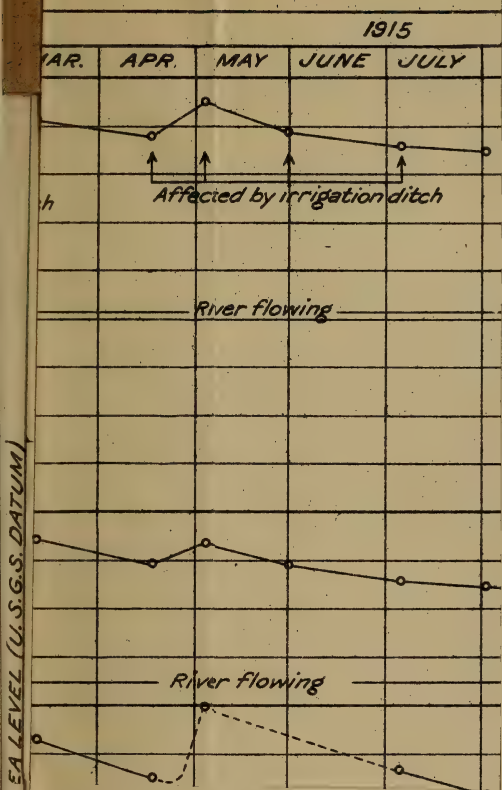
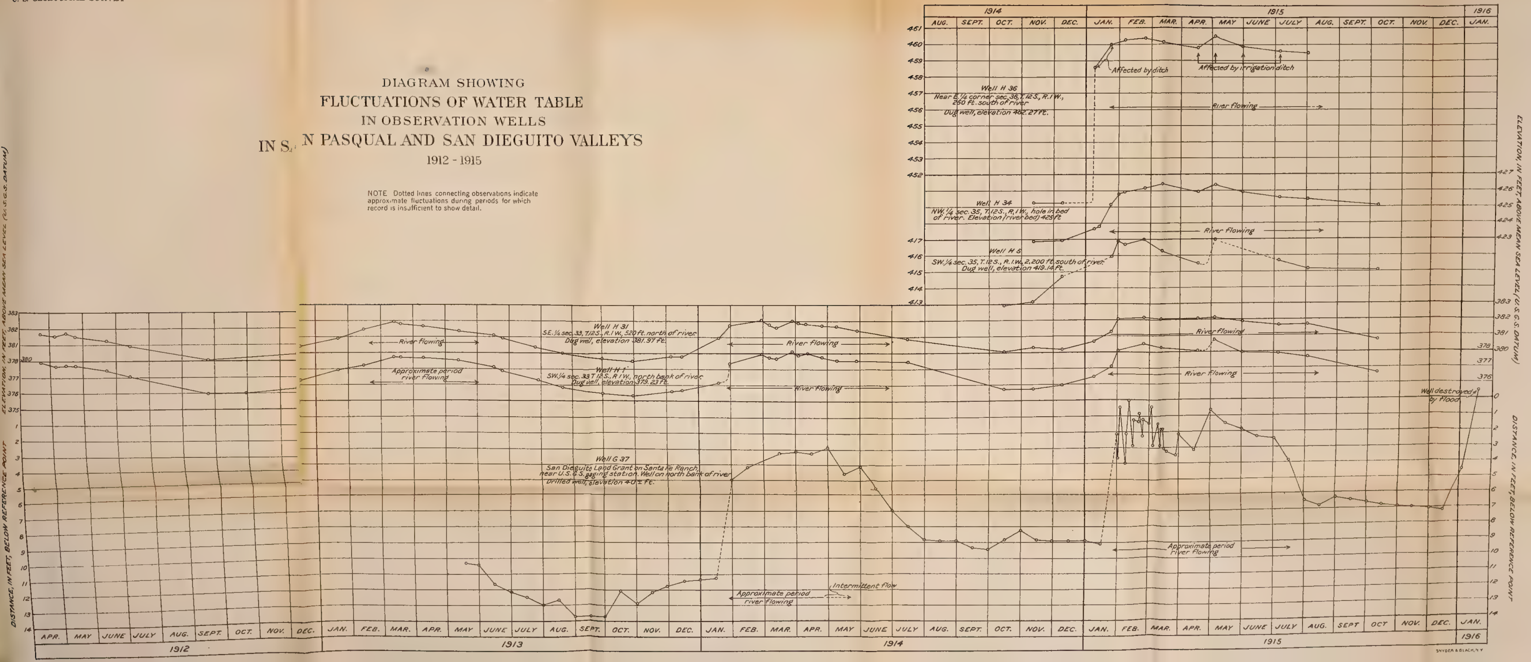

1915
AR.
APR.
MAY
JUNE
JULY
Affected by irrigation ditch
River flowing
River flowing
EA LEVEL (U.S.G.S. DATUM)

DIAGRAM SHOWING
FLUCTUATIONS OF WATER TABLE
IN OBSERVATION WELLS
IN SAN PASQUAL AND SAN DIEGUITO VALLEYS
1912 - 1915

NOTE. Dotted lines connecting observations indicate approximate fluctuations during periods for which record is insufficient to show detail.



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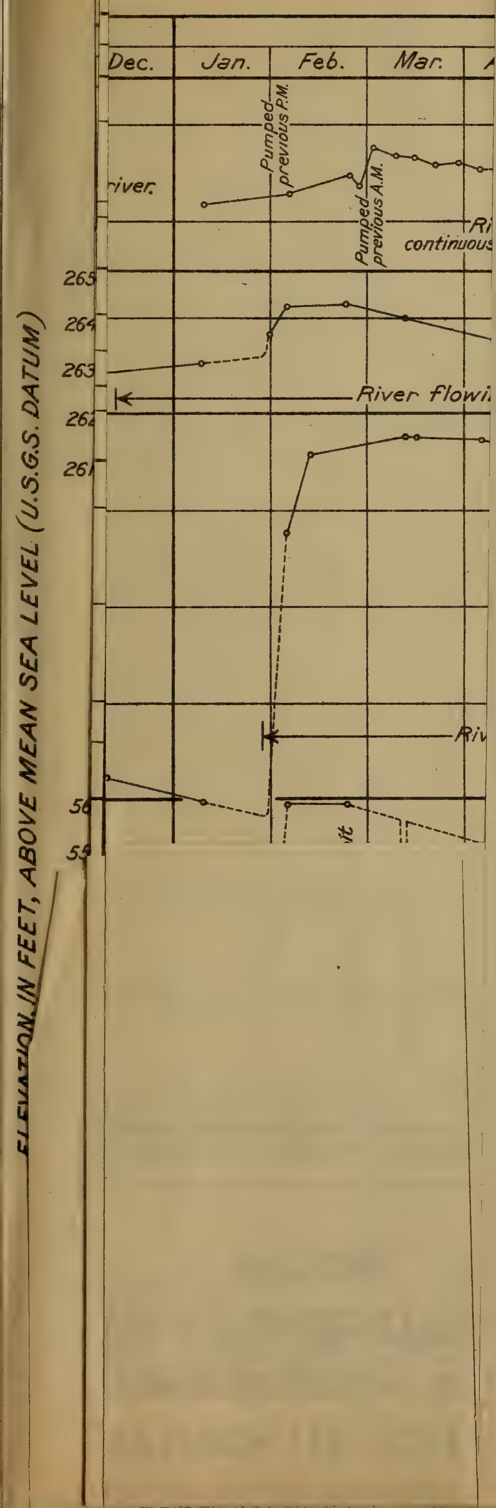

ELEVATION IN FEET, ABOVE MEAN SEA LEVEL (U.S.G.S. DATUM)
Dec.
Jan.
Feb.
Mar.
Pumped previous P.M.
Pumped previous A.M.
continuous
River
265
263

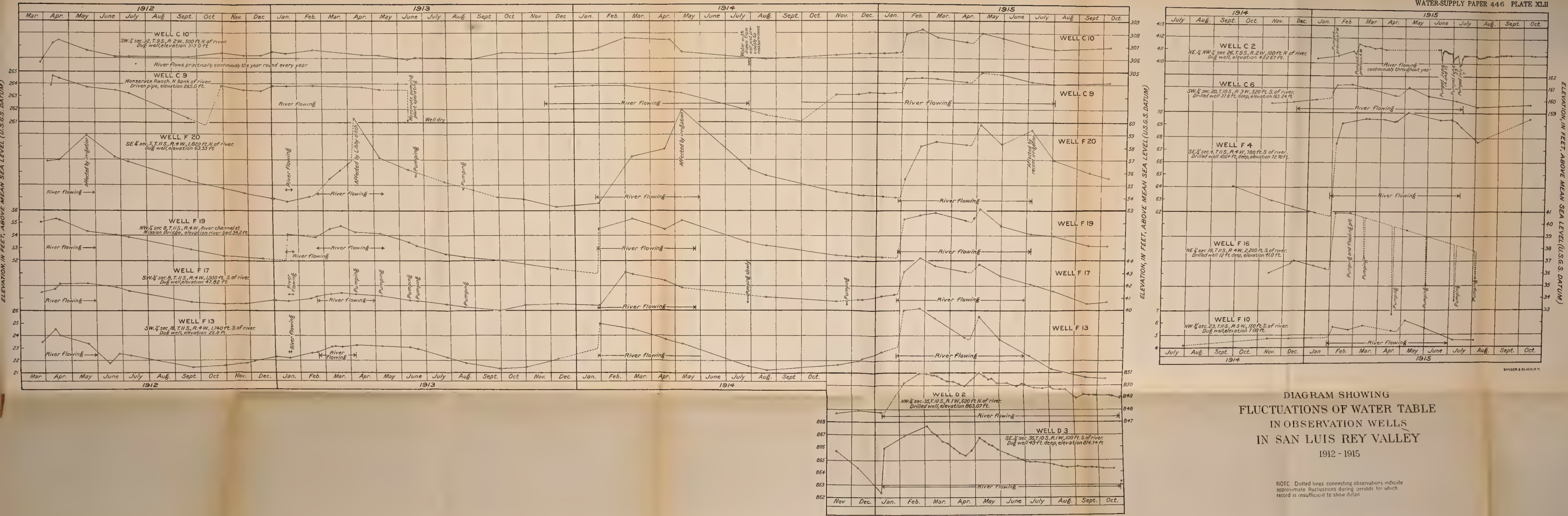
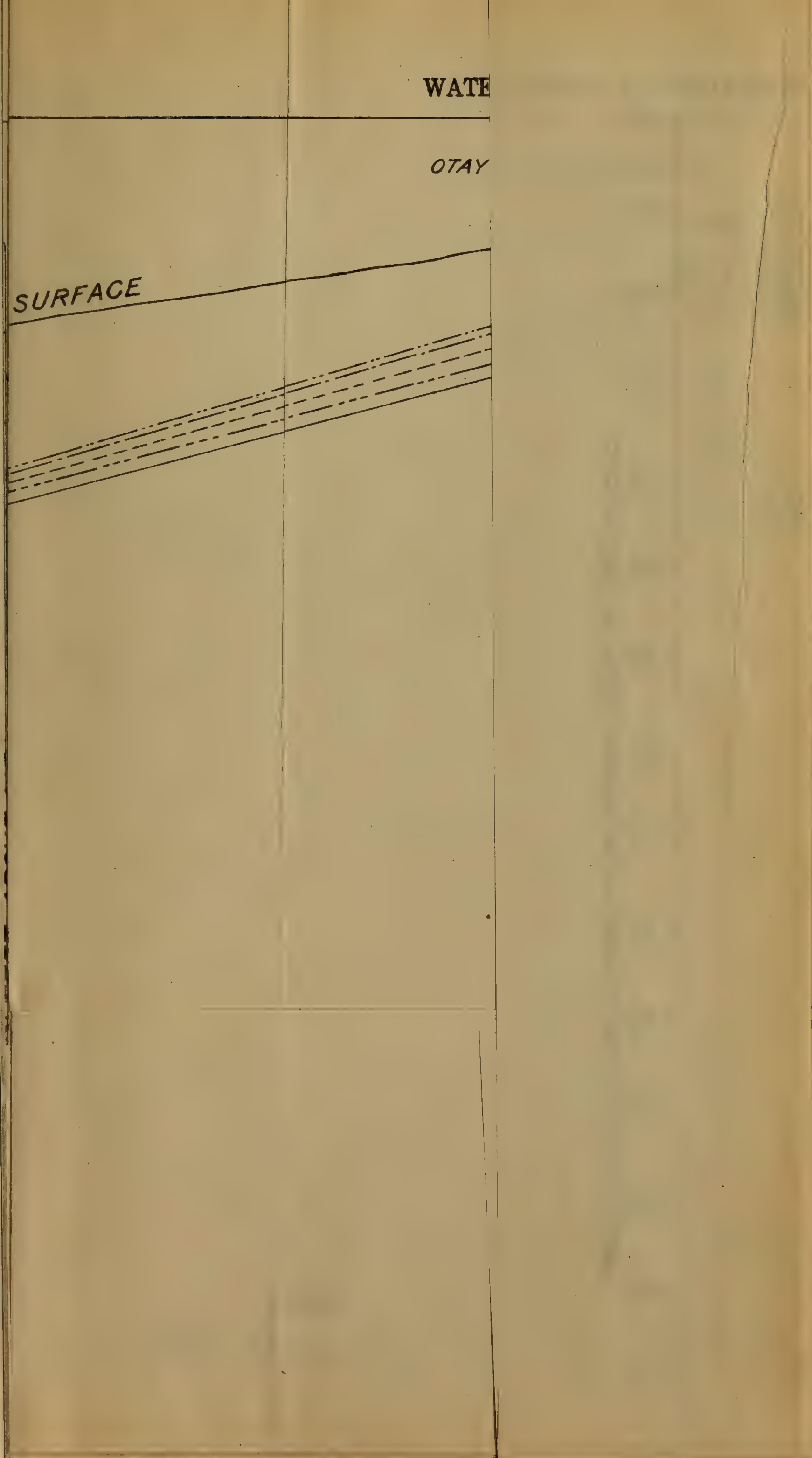
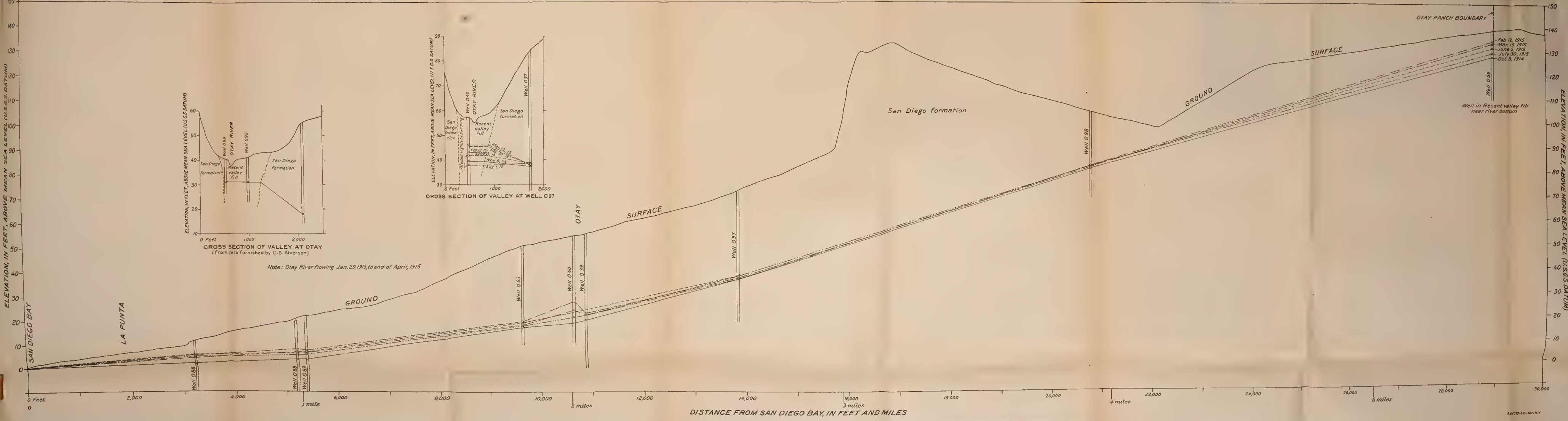


DIAGRAM SHOWING FLUCTUATIONS OF WATER TABLE IN OBSERVATION WELLS IN SAN LUIS REY VALLEY 1912-1915

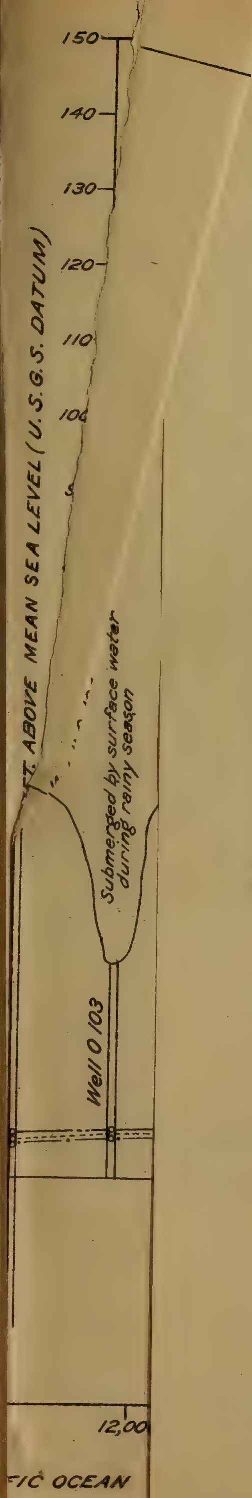
NOTE. Dotted lines connecting observations indicate approximate fluctuations during periods for which record is insufficient to show detail.


WATE
OTAY
SURFACE

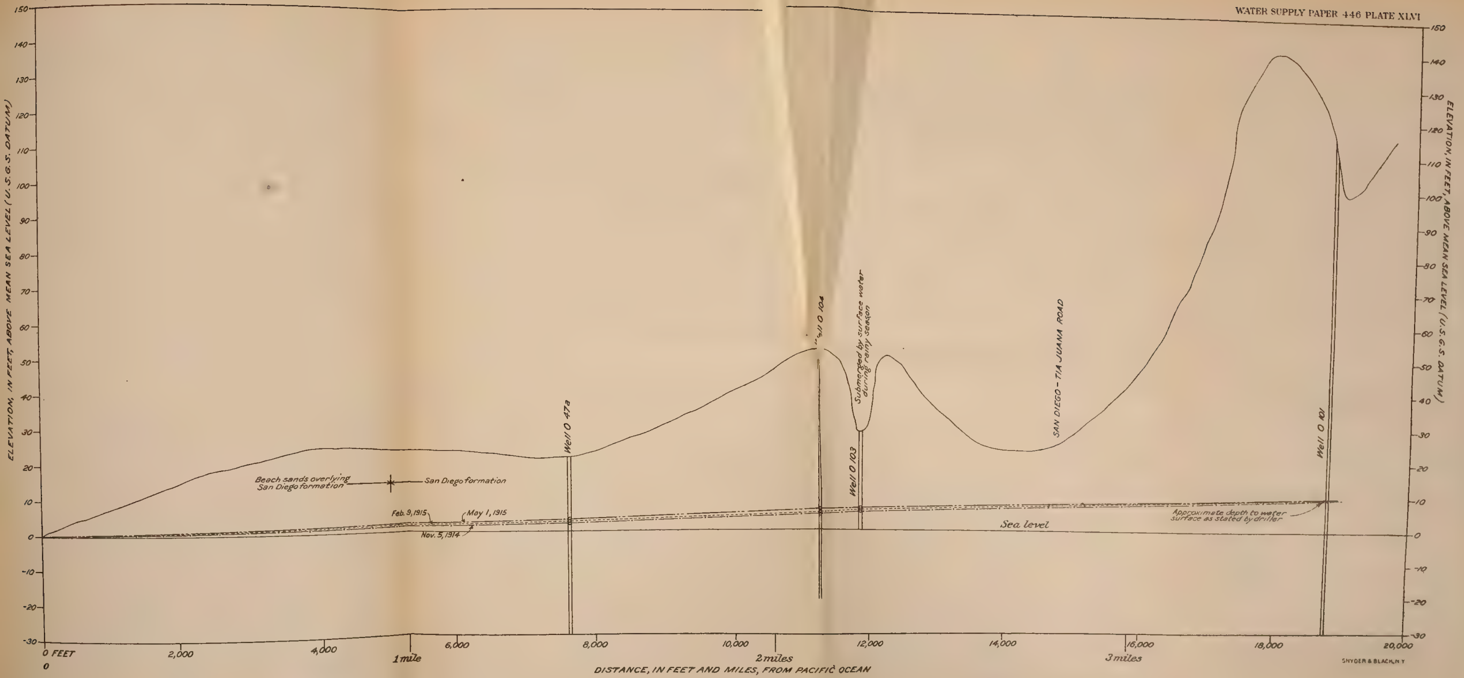


SECTIONS ACROSS OTAY VALLEY AND PARALLEL TO IT, SHOWING FLUCTUATIONS OF WATER TABLE, SEASON 1914-1915.

(Red line D-D, Plate XX)


150
140
130
120
110
FT. ABOVE MEAN SEA LEVEL (U.S.G.S. DATUM)
Submerged by surface water during rainy season
Well O 103
12,00
FIC OCEAN

ONS OF
)



SECTION THROUGH NESTOR TERRACE, SHOWING FLUCTUATIONS OF WATER TABLE, SEASON 1914-1915.
(Red line C-C, Plate XX)