DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 222

PRELIMINARY REPORT

ON THE

GROUND WATERS OF SAN JOAQUIN VALLEY, CALIFORNIA

BY

WALTER C. MENDENHALL

WASHINGTON

GOVERNMENT PRINTING OFFICE

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INTRODUCTION.

The agricultural situation in that part of the United States known as the Southwest is peculiar in that within it consumption tends constantly to exceed production. This is due to the large areas of desert, unsuited for agriculture but supporting many other industries. The entire irrigated acreage in the 11 arid States lying for the most part west of the crest of the Rocky Mountains was 7,539,545 acres at the time the Twelfth Census was taken in 1889. Since that date the irrigated acreage has been greatly expanded, and through the operation of the reclamation law and the impulse given by it to private enterprise that expansion will continue; but the population also has grown, and this growth in the future will be even more rapid than it has been in the past.

In the States of Nevada, Arizona, and New Mexico the mining industry becomes yearly of greater importance, and the influx of people engaged in it is increasing correspondingly. The growth of trade with oriental countries and the development of the mineral resources of Alaska have resulted in great accessions to the population of Pacific coast seaports, particularly those about San Francisco Bay and Puget Sound, and in greatly increased demands for food products. Southern California, as that portion of the State lying south of the Tehachapi Mountains is called, is receiving rapid recognition as a playground for the people of the entire United States, and of the thousands of tourists who visit this area each year many become permanent residents.

Of the areas in the Southwest within which food products for its cities, its tourist centers, and its mining regions must be raised, the largest and most promising is the interior lowland known as the Great Central Valley of California. The southern segment of this lowland, the San Joaquin Valley, contains 7,360,000 acres, of which but 750,000 were under irrigation in 1899, and probably not more than 1,125,000 acres are irrigated at present. Southern California contains a million acres of land that would be cultivable if water were applied to it; yet in this region, where all the water resources are utilized, but 225,000 acres are under irrigation, and the remaining area is nonproductive or yields only a small and uncertain crop through dry-farming methods.

Furthermore, the density of population in the irrigated valleys south of the Tehachapi means the consumption there of practically all the staple food products raised. Fruits, especially the citrus varieties, are grown for export, and in some years more grain is produced than is necessary for local needs; but in general the demand in this area for food staples is in excess of the local supply.

The Imperial Valley, in southeastern California, promises to become a very productive area through the utilization of Colorado River water, and many other sections might be mentioned whose acreage will increase the total area under irrigation, but all of them together are smaller than San Joaquin Valley, which, with that of the Sacramento, must become the chief agricultural district of the Southwest.

The agricultural development of this valley is controlled by the distribution of rainfall, the character of the soils, and the possibility of applying other water than that which reaches the valley as a direct result of precipitation upon its surface. Its extreme southern end, in the vicinity of Bakersfield, is strictly arid, the average rainfall there being less than 5 inches. Precipitation increases gradually toward the north, until at Red Bluff, in the northern end of Sacramento Valley, the annual rainfall averages 25.7 inches. Intermediate areas receive an amount of precipitation intermediate between these two extremes; but south of San Francisco Bay the available records indicate a rainfall of less than 16 inches, and over the greater part of this area of less than 12 inches—an amount that is insufficient to insure crops, even of grain, and is entirely inadequate for the other diverse food crops which a dense population demands.

The progressive increase in aridity from the northern toward the southern end of the valley trough prevails to an equally marked extent east of the valley, in the mountain areas from which its surface waters are drawn. The total run-off from the Sierra, according to the best available records, is about 11,500,000 acre-feet annually. Of this amount, 3,000,000 acre-feet are supplied by the streams from Kings River southward and 8,500,000 acre-feet by the streams north of Kings River. The combined drainage area of the streams from Kings River southward is 5,143 square miles; that of the streams north of Kings River is 7,543 square miles. That is, a southern portion of the Sierra, whose area is nearly seven-tenths as large as the northern portion, yields but one-third as much water in the form of stream discharge. Hence in the south end of San Joaquin Valley the acreage which is irrigable by the use of surface waters is very much less than that in the northern end of the valley, and the area available for development here is correspondingly greater than that available farther north.

The question of water supply is, of course, not the only one that confronts those who desire to see the development of the San Joaquin Valley proceed rapidly, although it is properly regarded as the most pressing. The quality of the soil, particularly with reference to the presence of hardpan or of alkali, is of the utmost importance. Extensive alkaline areas exist along the axis of the valley and part way up its eastern slope, especially at points where the ground waters lie close to the surface, and hardpans of at least two types underlie some of the higher and otherwise most valuable lands. These soil problems are being studied systematically by the soil experts of the Department of Agriculture[a] and the reports that are issued should be supplemented as rapidly as possible, until definite information as to soils is available for the entire valley.

CONDITIONS LEADING TO THE PRESENT INVESTIGATION.

The conditions already outlined—namely, the great actual and the much greater prospective importance of the San Joaquin Valley as an agriculturally productive center—have led during the last decade to greatly increased interest in the possibility of adding to the acreage under irrigation, and hence to the output in food products.

Irrigation enterprises, like those of other industries, invariably pass through a pioneer stage, in which only the most easily accessible resources are utilized. In this stage the methods of application of water are wasteful, the land holdings are large, and the agricultural output is low. Only later, when the population becomes much more dense and the need of greater output is clearly recognized, do methods so improve that the ratio of output to area, to resources, and to investment becomes such as to satisfy economic demands.

In Southern California irrigation methods have been carried to a greater degree of refinement than in any other section of the United States. When irrigation began here, during the first third of the nineteenth century, short, crude ditches were constructed by which the waters utilized were diverted from the lower courses of the streams to near-by lands upon which they were turned, and the only products were grain and pasture, by which the flocks and herds were

[a] Lapham, Macy H., and Heileman, W. H., Soil survey of the Hanford area, Cal.: Full operations of the Bureau of Soils for 1901, U. S. Dept. Agr. The results of similar surveys are available for areas about Bakersfield, Fresno, and Stockton.

carried through the dry season. Such methods were in vogue until the late sixties and early seventies, when American settlers entered the country and attempted to utilize lands that had been regarded as entirely worthless. These settlers brought with them capital, and constructed their ditches on higher lines and in a much better manner than did the old Spanish zanjas. They applied water much less lavishly, to larger areas, and with much better unit results, and so by continued improvements of this type all of the surface waters were finally utilized to the best advantage. But settlers continued to flock to the region, and attention was then turned to the underground waters, which were developed at first only to supplement the surface supplies. Such reservoir sites as were available were also filed upon and made use of, and eventually many enterprises were started, some of which depended on a combination of surface and underground waters, and others on underground waters alone. Still later refinements resulted in the reconstruction of many of the old ditches, the replacement of open canals by underground pipes, and the elimination thereby of waste by seepage and evaporation. In the lower lands wells were drilled which yielded flowing water, and stream waters which had previously been utilized on these lower lands were diverted to the bench lands, where products of higher value could be grown.

As a result of this intensity of development it is probable that in no area in the United States are the waters so thoroughly utilized as in the region that lies south of the Tehachapi Mountains. In their passage from the mountains, where they originate in precipitation, to the sea, where they are lost, some portions of these waters are used as many as eight times—in power plants, in irrigation from surface streams, and finally by the recovery of that portion of the surface flow which, sinking in the alluvial fans, augments the supply in the underground reservoirs.

Much of the San Joaquin Valley is still in the pioneer stage of irrigation development, depending almost exclusively on surface waters, and in a large part of the area waste is great, over-use is the rule, and, as a consequence, minimum production results from a maximum use of water. But the pioneer stage is passing. Engineers trained in more refined methods are entering the region and applying their training. Special communities, like those about Portersville and Lindsay, where citrus fruits are raised, have for a decade or more used deep underground waters, whose cost greatly exceeds that of surface waters where the latter are available in other parts of the valley. This relatively high cost is amply justified, however, in the citrus belt by the great value of the products.

In other parts of the valley, as, for example, in the neighborhood of Corcoran, capitalists who had profited in other regions through the use of flowing artesian waters have undertaken to develop colonies by utilizing waters of this type, whose existence had been proved years before by the owners of large cattle ranches, who had put down wells to obtain water for stock.

In still other districts, as about Bakersfield, Stockton, and Fresno, isolated individual pumping plants have been installed within the last decade, and by their use lands whose owners had been unable to secure rights to the limited supply of surface waters have been brought within the productive zone.

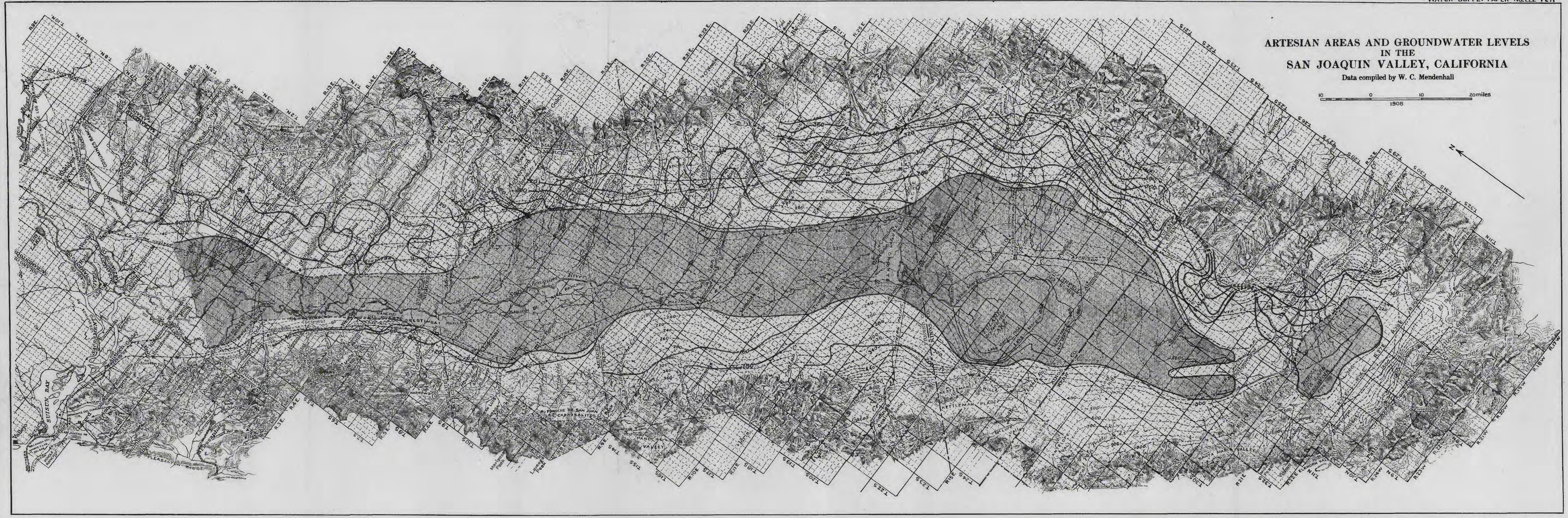
These more or less isolated experiments and their successful outcome have resulted in a widespread recognition of the fact that the productivity of the San Joaquin Valley can be greatly increased by the utilization of the heretofore neglected ground-water resources. This recognition has been followed logically by a desire for specific information as to the quality, occurrence, accessibility, character, and proper use of waters of this type. In response to this demand the Reclamation Service, in 1905, before its separation from the Geological Survey and erection into a separate Bureau of the Department of the Interior, determined to investigate the ground waters of the valley, with the hope that it might become possible to establish there a reclamation project whose water supply should be obtained from the underground reservoirs. Similar investigations were conducted in other parts of the United States during the first three or four years after the passage of the reclamation act, and as a result of these investigations the energies of the Service were concentrated upon those projects which it found most practicable.

The San Joaquin Valley did not afford one of these most practicable projects, and the investigations begun there by the Service were terminated; but the work already carried out had given some idea of the wide extent, the easy accessibility, and the high quality of the underground waters in many parts of the valley, and the Geological Survey decided to continue the work begun by the Reclamation Service. As the appropriations available for this work have not been sufficient to permit it to be carried through in a continuous and systematic manner, its progress has been greatly interrupted, and there has been much delay in the preparation of results.

In the spring of 1905 A. J. Fiske, R. M. Priest, and S. M. Smith were assigned to work in the valley and spent about two months preceding the 1st of July in the collection of preliminary data. The work was resumed in the spring of 1906 by W. N. White and H. R. Boynton, jr., and was continued during the summer of 1907 by Mr. White, who, before the close of the year, had completed the collection of data on the flowing wells, pumping plants, and on many of the domestic wells throughout the valley. During about the same periods H. R. Johnson had been assigned to carry out a geologic study about the borders of the valley, in order to determine its structures, in so far as they might bear upon the occurrence of the ground waters of the valley proper.

Much remains to be done in order that satisfactory data may be procured on all phases of the ground-water problems in the great area and reliable conclusions reached from the study of these data. More definite knowledge is needed as to the cost of developing ground waters under all conditions; the distribution of the alkaline waters that can not be used safely either for drinking purposes or for irrigation is not known with sufficient definiteness; and estimates are needed as to the costs of placing San Joaquin River waters on the arid west-side lands that would be so highly productive could they be irrigated. Nevertheless it seems advisable to issue a preliminary report at this time in order to make available such facts as have been gathered and to call attention to the ground waters as a resource whose more general use will probably be the largest single element in the future development of the valley. Especially will the installation of small pumping plants by individual landowners, who will thereby control their own water supplies, prove of great importance in the future.

A single small-scale map (Pl. I) accompanies this report. In its preparation, the topographical and engineering map of the San Joaquin Valley issued by the California State engineering department in 1886 was used as a base. Some slight additions and corrections have been made as a result of later surveys, but the earlier map has been used substantially in its original form. Upon this base the area in which flowing wells may be obtained has been outlined with as much accuracy as the information at hand permits. Beyond the limits of the artesian area the attitude of the ground-water plane has been indicated by hydrographic contours, which are based on the elevations of the surface as indicated by the topographic sketch contours of the base map. Neither set of contours is accurate in detail, but it is believed that the relations between the two—that is, the depths to ground water at various points—are correct within a reasonable margin of error, so that the map will be of practical value. It must be remembered, in using this map, that ground-water levels do not everywhere remain constant. On the deltas and in the irrigated areas there is a more or less regular annual variation in level, the plane of saturation rising during the high-water period—the period of maximum irrigation in early summer—and falling during the low-water period in the autumn and early winter. In the past there has been a marked permanent rise in the ground-water level in areas to which water has been applied by the construction of the large canals of the greater irrigation systems. This rise still continues in some localities, to which water has been applied for a number of years, and it will be marked in regions to which canal systems may be extended in the



LEGEND

Artesian areas

Hydrographic contours

future, although the chief changes of this character have doubtless already been brought about. In one or two limited areas there is probably also a general decline in ground-water levels. It is not possible, of course, to indicate a varying water level by a single set of hydrographic contours. Those used indicate about the position and form of the water plane in the period from 1905 to 1907.

GEOGRAPHY OF THE VALLEY.

San Joaquin Valley and Sacramento Valley together constitute the Great Central Valley of California, with an area of nearly 16,000 square miles. This level-floored depression is more than 500 miles long and varies from 20 to 50 miles in width. East of it the Sierra rises to between 14,000 and 15,000 feet above sea level, and west of it the lower coast ranges separate it from the Pacific. The greatest elevation of the Sierra is near its eastern edge and all its important drainage is westward toward the Great Valley, an important fact upon which the greater part of the actual and prospective agricultural value of the valley depends. The coast ranges are a series of parallel ridges of moderate elevation that inclose valleys, like those of the Salinas and Santa Clara, which, when not too arid, are highly productive.

The Great Valley itself exhibits little diversity in its physical aspect. Such differences as exist between its north and south ends are climatic, or, if physical, are directly due to climatic differences. Among local physical features based upon climatic differences may be mentioned the Tulare basin at the south end of the San Joaquin Valley, due to the aridity of the region and the consequent extensive development of alluvial fans. Two of these, extending from Kings River on the east and Los Gatos Creek on the west side of the valley, have coalesced in a low ridge south of which lie the Tulare Lake and Kern Lake depressions. Basins different in character and situation, but originating nevertheless in climatic conditions, are the overflow basins of the Sacramento and the lower San Joaquin valleys, of which the Yolo basin may be mentioned as a type. These basins occupy the lowest portions of the flood plains just outside the ridges that form the immediate river banks.

The central valley opens to San Francisco Bay and thence to the Pacific through Carquinez Straits and the Golden Gate, and the combined drainages of the Sacramento and San Joaquin systems discharge through these gateways. Other passes, like the Tehachapi, the Tejon, and Walker Pass near the south end of San Joaquin Valley, and the Livermore Valley gateway near Carquinez Straits, exist through the mountain barriers that surround the central lowland, but they are not as low nor as pronounced as the central tidal gateway. In general it may be said that the Great Valley is completely inclosed except for this opening.

The larger lobe of the central depression, extending southward from Cosumnes River and Suisun Bay, is generally known as San Joaquin Valley, although it is not all drained directly by San Joaquin River and its tributaries. The southern more arid third of the depression, extending from Kings River delta to the Tehachapi Mountains, has no surface outlet under normal conditions, and the surface waters accumulate in the Tulare Lake depression and the Buena Vista reservoir. Originally Kern Lake received a portion of the excess from Kern River, but through the protection afforded by a restraining dike water is kept out of it except as unusual floods may break the restraining dam, and the original lake bottoms have become valuable wheat lands.

The streams that drain into the valley from the Sierra carry practically all of the water that reaches it. They are in every way more important than those that enter it from the west. They have larger drainage basins, individually and collectively; they have longer courses; and they flow from higher mountains, with a much greater rainfall and a better protective covering of forest and brush; hence their discharge is many times greater and much less erratic than that of the west-side streams.

The total drainage area[a] tributary to the valley from the Sierra is 16,089 square miles; from the Tehachapi and Coast ranges 4,293 square miles, and the area of the valley floor is 11,513 square miles. The total area of the San Joaquin basin is therefore 31,895 square miles.

The average run-off of the principal east-side streams north of Kings River, with a combined drainage area of 7,543 square miles, is about 8,500,000 acre-feet, while that of Kings, Kaweah, Tule, and Kern rivers, discharging into the Tulare basin from a watershed with an area of 5,143 square miles, is about 3,000,000 acre-feet. The total discharge into the valley from 12,686 square miles of Sierra watershed is therefore about 11,500,000 acre-feet.

The preponderance of east-side streams has given the valley floor its well-marked unsymmetrical form. The valley axis, the line of lowest depression, is throughout much nearer the western than the eastern foothills. In places it lies against these hills, but elsewhere, as between Los Gatos and Cantua creeks, the west-side slopes are 15 or 18 miles wide, at least one-half as wide as those of the east side. They are also steeper than those of the east. Grades of 20 or even 40 feet to the mile are not rare, and it is unusual for the grades to be less than 6 or 8 feet per mile. On the east side 30 feet to a mile is about the maximum gradient, while 5 feet or less is perhaps the average.

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[a] Hall, William Ham., Physical data and statistics of California, pp. 396 et seq.

These conditions are due directly to the fact that the valley floor has been built up by the alluvial material eroded by the streams from the mountains east and west of the depression and deposited in it. The larger and more active streams build flatter but more extensive alluvial fans--the type that makes up the east-side slopes; the more erratic and torrential streams of smaller volume build the steeper and less extensive fans that constitute the west-side slopes.

GEOLOGIC OUTLINE.[a]

THE ROCKS OF THE VALLEY BORDERS.

In simplest outline, the geology of the eastern border of San Joaquin Valley consists of the "Bedrock series" of granites and metamorphic sedimentary and igneous masses of pre-Cretaceous age, overlain at the north and south ends of the valley in an interrupted band occupying a zone of low relief between the Sierra proper and the valley proper by a series of Tertiary sediments, entirely unaltered and including beds as old as the Eocene, although the great body of the material seems to be Miocene or Pliocene in age. Between San Joaquin River and Portersville this zone of late sediments is missing, and the sands and gravels of the valley proper lie upon the flanks of the Sierran granite and metamorphic complex. Because of this hiatus the east-side Tertiary is separated into two bodies, of which the northern extends from Fresno River nearly to the Cosumnes, and the southern, conveniently designated as the Bakersfield area, extends from Deer Creek to the Cañada de las Uvas.

The northern area of Tertiary rocks, which is chiefly in the Milton-Merced regions, includes a lower, clayey series that has been called the Ione formation, a middle zone of andesitic sandstone, coarse volcanic breccias, and tuffaceous beds, and an upper gravelly series that is in places auriferous. This upper series usually occurs along the most westerly foothills and merges at many points with the gravels and soils of the valley floor.

The southern area consists of alternating beds of soft sandstone, clay, and gravel, the uppermost beds being coarse, like those of the northern area, and scarcely distinguishable in some places from the alluvium of the valley itself.

The geology of the western margin of the valley contrasts in many ways with that of the eastern border. The oldest rocks of the Mount Diablo Range—the easternmost of the coast ranges—comprise a series of altered igneous and sedimentary rocks known as the Franciscan series, which extend along the axis of the range from a point southwest of Coalinga to San Francisco Bay. Overlying them

[a] Abstract from a manuscript by H. R. Johnson, on the geology of the borders of the San Joaquin Valley.

on the valley side, but not continuously, is a series of sandstones, shales, and conglomerates of Cretaceous and oldest Tertiary age. Succeeding these in turn is a variable series, locally of great thickness and usually but not always present in some of its members, representing the Neocene—that is, the middle and upper Tertiary. These rocks, like the older sediments beneath them, are sandstones, shales, and conglomerates, but usually they are less firmly indurated than the Eocene and Cretaceous rocks. They overlie the latter unconformably and contain many unconformities within themselves, with a resulting variability in thickness and irregularity in extent of individual beds. This series contains the siliceous shales generally spoken of in literature as the "Monterey," besides a great variety and abundance of sandstones and conglomerates. Toward the top of the series are beds that clearly represent fresh water or subaerial deposition, undoubtedly much like that which is now taking place in Tulare lake and in the west-side alluvial fans. As a whole the sedimentary series dips toward the valley, although interruptions like the anticline of the Kettleman and McKittrick hills in places vary the prevailing monoclinal dips. In general the structures of the valley border are more complex at the south end than along the middle portion and at the north.

The valley as a whole is a great structural trough and appears to have been such a basin since well back in Tertiary time. Since it assumed its general troughlike form, gradual subsidence, perhaps interrupted by periods of uplift, has continued and has been accompanied by deposition alternating at least along what is now its western border with intervals of erosion. This interrupted but on the whole continuous deposition seems to have been marine during the early and middle Tertiary; but during the later Tertiary and Pleistocene, when presumably the valley had been at least roughly outlined by the growth of the coast ranges, fresh-water and terrestrial conditions became more and more predominant, until the relations of land and sea, of rivers and lakes, of coast line and interior, of mountain and valley, as they exist now, were gradually evolved. As these conditions developed, the ancestors of the present rivers probably brought to the salt and fresh water bodies that occupied the present site of the valley and its borders, or, in the latest phases of the development, to the land surface itself, the clays, sands, gravels, and alluvium that subsequently consolidated into the shales, sandstones, and conglomerates of the late Tertiary and Pleistocene series, just as the present rivers are supplying the alluvium that is even now accumulating over the valley floor.

The very latest of these accumulations are the sand and silt and gravel beds penetrated by the driller in his explorations for water throughout the valley. They are like the early folded sandstones, shales, and conglomerates exposed along the flanks of the valley, except that they are generally finer, are not yet consolidated or disturbed. The greater part, perhaps all of them, accumulated as stream wash on the valley surface or in interior lakes like the present Tulare Lake, but a proportion of the older sediment that is greater as we delve farther back into the geologic past accumulated in the sea or in salt bays having free connection with the sea. It is these very latest geologic deposits, saturated below the ground-water level by the fresh water supplied chiefly by the Sierran streams, that constitute the reservoirs drawn upon by the wells, whether flowing or pumped, throughout the valley.

The chemical characters of the ground waters, as well as their occurrence and accessibility, are related to geology. If the valley alluvium is derived from the Cretaceous and Tertiary beds of the coast ranges, rich in gypsum and other sulphates and carbonates which are relatively easily soluble, the ground waters that percolate through it will soon dissolve large quantities of the salts. If the alluvium, on the other hand, is derived from the granites and metamorphic rocks of the Sierra, whose potassium, sodium, and calcium compounds are in the form of resistant silicates, the ground waters dissolve out these constituents slowly and under all ordinary conditions remain quite free from salts.

Obviously if the sands and gravels through which the ground waters percolate were deposited under such conditions that salts were deposited with them, as in the salt water of the sea or of bays like San Francisco Bay, or in interior lakes that are saline through evaporation, as is true of Tulare Lake, then the ground waters themselves will quickly become saline, although when they leave the mountains as surface waters, before their absorption by the alluvial fans, they may be as pure natural waters as are known in the world.

ORIGIN OF THE PRESENT VALLEY SURFACE.

The lowland through the heart of California known as the Great Valley, whose origin as a depression appears, in accordance with the facts just outlined, to date well back into Tertiary time, owes its actual surface to more recent action and to more obvious agents. That surface is, in brief, a combination of the surfaces of a great number of alluvial fans, originating at the mouths of the canyons through which the tributary streams discharge from the mountains into the valley.

Each stream that enters the valley brings with it from the mountains a greater or a smaller quantity of sand, gravel, or bowlders. All or a part of this burden is deposited in the valley, and the deposit constitutes the alluvial fan of that particular stream. The apex of each fan is the mouth of the stream canyon. From this apex it broadens and flattens until it coalesces at its periphery with other fans. The stream that built it usually spreads delta-wise over it, discharging through a number of diverging channels into the trough of the valley. As a rule these spreading distributaries flow upon the surface of the fan, but some of the major streams from the San Joaquin northward are incised into the valley floor in shallow trenches 100 feet or less in depth. This must be due to special conditions, such as recent change in volume of stream flow or in elevation of the land relative to the sea—conditions not yet understood.

The fans of different portions of the valley indicate by their mass and form the conditions of volume and distribution of rainfall under which they originated. The west-side fans, particularly those in the middle of the valley and near its southern end, are steep and symmetrical, forms characteristic of areas of low rainfall very irregularly distributed. The east-side fans are of much greater mass and lower slope because the rivers that built them have a greater flow of somewhat less irregular character. The Kern River fan has grown westward against the McKittrick hills until it has isolated the Buena Vista basin south of it. Before dams had been built, interfering with the natural conditions here, a shallow lake occupied the present site of Buena Vista reservoir and the old bed of Kern Lake, and during seasons of unusual rainfall there was overflow northward toward Tulare Lake. The basin occupied by Tulare Lake is likewise due to the aridity of the valley and the consequent development of the Kings River and Los Gatos Creek fans. South of the low, broad ridge due to the coalescing of these two fans is the Tulare basin, in which a part of the surplus waters of the streams south of it accumulate. As a consequence of the flatness of this basin and the very erratic character of the supply that reaches it, the lake fluctuates widely in area during a series of years.

Northward from Tulare Lake basin the discharge of the streams is sufficiently great and sufficiently constant to prevent the formation of delta-dams like those formed by Kings River and Los Gatos Creek fans, and an open channel is maintained from the San Joaquin northward to Suisun Bay.

Along the lower course of the San Joaquin, conditions resemble those in the Sacramento Valley, i. e., they are the conditions usual along rivers draining humid rather than arid regions. Large areas are subject to regular annual inundation during the spring floods or are protected from this inundation only by the construction of artificial levees. The greater part of the water that inundates this area is supplied by the Sacramento system, but the greatest overflow occurs when the floods appear in the two systems at the same time.

The essential fact as to the present valley surface is that it is a direct result of stream action. It has everywhere been built up by deposition from the streams or from the fluctuating lakes that are themselves dependent upon the streams; and it is formed of materials brought by the streams from the mountainous portions of their drainage basins where they are eroding instead of depositing Throughout the south end of the valley its surface is a combination of alluvial fan surfaces; at the north end of the valley these fans, less strikingly and typically developed because of the greater precipitation there, still predominate along the valley borders, while the center of the valley is a flood plain of the usual type.

SOILS.

As the valley surface has been molded by stream action into its present form, so the soils of the valley represent deposition by the rivers of materials washed out of the mountains from which they drain. This soil is modified in various ways after the streams have deposited it—by disintegration of the rock particles where the streams have left them, by the mingling of the products of vegetal decay where vegetation is abundant, or by chemical processes in place, such as the formation of hardpans or the accumulation of alkalies; but the soil foundation, so to speak, reflects pretty closely the type of rock outcropping in the drainage basin of the stream on whose delta the particular soils are found.

For example, the soils of the deltas of Kern and Kings rivers are in large part of granitic derivation, because granitic rocks form the greater part of the mountain drainage basin of each of these rivers. Their coarseness and the distribution of the coarse and fine phases are to a certain extent matters of accident, due to the location of present or past channels of the streams across their deltas; but in steep alluvial fans the coarser and more bowldery soils occur nearer the mountains. In the fans of those east-side streams from the Merced northward, whose lower courses at least are cut through late Tertiary formations containing a large percentage of lavas and derived products, other types of soil result.

The west-side streams, draining mountains practically free from granites and similar rocks but with soft serpentines, shales, and sandstones, deposit fragments of those rocks in their alluvial fans, and the result is a soil type entirely different from that of the east side and south end of the valley. These shale, clay, serpentine, and sandstone fragments disintegrate much more quickly than the granitic sands that contain large proportions of such resistant minerals as quartz and feldspar, and the result is the mellow, loamy soil with its fragments of siliceous shale that makes much of the west slope of the valley and is so productive whenever water can be applied to it.

Soil of another general class occurs at a few localities along the east side of the valley. This soil is not of alluvial fan origin, brought into the valley by the streams from the surrounding mountains, but is due to decay in place of the rocks underlying the particular area where it occurs. Soils of this class are found northeast of Fresno beyond Clovis, and in some of the coves like Clark Valley north of Reedley, and perhaps in other foothill valleys in the Portersville-Lindsay district. Some of the rolling wheat lands found in a zone along the eastern border of Stanislaus and Merced counties may also be regarded as derived from the decay of rock in place rather than from inwashed alluvial fan material, but as the rock is itself a late Tertiary sediment differing but little from the alluvial fan material of the same area, the classification of the soils as residual rather than colluvial has no practical significance.

Another type of soil is neither more nor less than fine beach sand. This type is best developed in a zone surrounding Tulare Lake, and it represents the shore lines of that water body when it contained much more water than at present. In places this sand has been reworked by the wind—blown into inconspicuous dunes, as in the "Sand Ridge" near the Kings-Kern county line.

Finally, there are the soils of the "Tule lands" and the "Islands," the areas subject to overflow particularly along the lower course of the San Joaquin and its tributaries, but present, although less extensively developed, in other areas. These lands are black loams or adobes or impure peats, and are very fertile when reclaimed.

The Bureau of Soils of the Department of Agriculture has made detailed surveys of certain areas in the San Joaquin Valley as the beginning of a general soil mapping of the entire valley. The sheets at present available cover areas about Stockton, Fresno, Hanford, and Bakersfield, and others are in preparation. In the text of the reports and in the maps that accompany them, the soils are classified in great detail on a physical basis, and by a proper study of this classification the geologic origin of most of the soils may be traced.

Another task undertaken by the Bureau of Soils, of even greater immediate value, is the mapping of the alkalies. This work is designed to afford suggestions as to the management and reclamation of alkaline soils and prevention of the rise of the alkalies. When it has been completed for the entire valley it will be of great service in preventing sales of worthless lands to purchasers who buy in good faith with the idea of establishing homes. Many sales of this kind have been made in the valley, and any work that will tend to reduce their number is to be welcomed.

SURFACE WATERS.

The streams of the San Joaquin Valley and their characteristics have been referred to incidentally in the preceding pages. These characteristics depend upon the physical geography of south-central California and the control which it exerts over climate. All of the perennial and important streams flow from the Sierra.

Precipitation within the Sierra district depends upon altitude, latitude, and longitude. Up to a certain limit precipitation increases with increase of altitude; beyond that limit, which at the crossing of the Central Pacific is at Cisco, 6,000 feet above sea and 1,000 feet below the summit, precipitation decreases. Rainfall decreases also southward along the summit of the Sierra as well as in the valleys; and in those parts of the range, principally its southern portion, where altitude does not increase regularly from the western toward the eastern margin, so that the effect of longitude is not obscured by that of altitude, vegetation indicates less rainfall as the desert border of the range is approached.

Under these conditions, therefore, it is evident that the greatest discharge per unit of area will come from those streams with the greater proportion of their drainage basins farthest north in the high part of the Sierra but west of the summit.

From the tables of discharge for 1906, as published by the United States Geological Survey, in Water-Supply Paper 213, the following stream run-off in second-feet per square mile is taken:

Run-off of California rivers in second-feet per square mile.

Feather River	2.72
Yuba River	4.37
American River	4.29
Stanislaus River	3.63
Tuolumne River	3.33
Kings River	3.09
Kaweah River	2.93
Kern River	1.11

Data for the San Joaquin are not available. All these streams except Feather and Kern rivers occupy comparable positions on the western slope of the Sierra and drain the areas of maximum precipitation for their respective latitudes. The rather regular decrease southward from the Yuba to the Kaweah may therefore be assigned with confidence to the effect of latitude on precipitation. The drainage basins of both the Feather and the Kern extend into the very eastern part of the Sierra beyond the zone of maximum precipitation, and the inferiority of run-off from their basins as compared with that of neighboring streams may be assigned, in part at least, to the effect of longitude; i. e., their basins extend so far east as to be measurably affected by desert conditions. Altitude may also be a factor, since each of these streams drains portions of the range which are not so high as areas in the intermediate basins. The discharge of the principal east-side streams and the areas drained by each are summarized in the following table, compiled from the records of the State engineering department of California and from those of the United States Geological Survey.

The number of years of observations from which the average discharge was determined is also given. As several of these records are as short as five years, and one, that of the Kern, as long as seventeen years, it is obvious that they differ in value; but on the whole they supply a concrete indication of the average amount of water discharged into the San Joaquin Valley annually by its chief streams.

Discharge of streams from east side of San Joaquin Valley.

River.	Length of record.	Area of drainage basin.	Average annual discharge.
	Years.	*Sq. miles.*	*Acre-feet.*
Cosumnes	5	580	882,417
Jackson Creek	5	283	161,672
Mokelumne	8	657	1,640,057
Calaveras	5	491	339,306
Stanislaus	11	1,051	1,254,151
Tuolumne	11	1,500	1,011,452
Merced	10	1,076	1,113,754
Chowchilla	5	268	61,834
San Joaquin	12	1,637	1,972,145
Kings	16	1,742	1,790,187
Kaweah	6	619	401,954
Tule	9	437	199,444
Kern	17	2,345	670,611
Total		12,686	11,498,984

The high-water period of the Sierra streams comes during the late spring and early summer months, when the snow accumulated in the winter is melting most rapidly from the mountains; the low-water flow comes during the late summer and fall months after the snows are gone and before the winter rains have begun. These characteristics are illustrated in the following table of monthly discharge of Kings River for 1906, as determined by the United States Geological Survey:[a]

Monthly discharge of Kings River, 1906.

Month.	Discharge in second-feet.			Total in acre-feet.
	Maximum.	Minimum.	Mean.	
January	25,500	205	2,360	144,000
February	2,150	792	1,150	63,900
March	21,000	1,220	5,240	322,000
April	7,760	2,960	4,720	281,000
May	16,800	3,930	10,700	658,000
June	26,600	8,320	17,100	1,020,000
July	22,400	8,180	16,300	1,000,000
August	7,900	1,870	4,300	264,000
September	2,020	682	1,120	66,600
October	682	385	516	31,700
November	610	330	397	23,600
December	2,230	330	700	43,000

Each of the major streams discharges from the mountains upon the eastern edge of the valley in a single channel, but after reaching the valley it usually divides into a number of branches, thus spreading over its delta. This characteristic is most marked in the streams that flow into the southern end of the valley, for many of the northern

[a] Water Supply Paper 213, p. 159.

tributaries are incised in the valley floor and are thus confined between definite banks. This distribution is much more pronounced during the high-water period of early summer than at other seasons of the year. A main channel of sufficient capacity to carry the low-water flow proves inadequate during the flood period, and there is then overflow into the numerous subsidiary channels.

The natural habit of all of the main streams has of course been extensively modified by irrigation. Canal systems now take from the channels practically all of the low-water flow and an important percentage of the maximum early summer flow. These systems have been described by Grunsky.[a]

The west-side streams are practically negligible as factors in the San Joaquin Valley water supply. Only a few of them are perennial, and the late summer flow of these is so slight that a few acres at most can be irrigated by their use. A trifling amount of irrigation of this type is accomplished by utilizing the waters from Los Gatos Creek, Cantua Creek, and others.

UNDERGROUND WATERS.

VALUE FOR IRRIGATION.

Although the underground waters of the valley have been known and used in minor ways practically ever since its settlement, it is nevertheless true that the movement for their extensive utilization as sources of irrigation supply is a late phase of development, for many of the earlier attempts to make use of them resulted in failure.

Among the causes that have contributed to past failures may be mentioned: Application of the developed waters to poor lands, wasteful methods of application; dependence on the continuance of artesian flow; lack of adjustment to the greater cost of pumped waters as compared with that of the gravity waters upon which reliance has heretofore been placed; lack of intensive farming methods and of proper adaptation of crops to soil and locality; too large farm units; and, in a few cases, inadequate transportation facilities.

The most potent of all these causes has been the prevalence of the easy-going methods of the pioneer—the careless, wasteful habits that are a direct inheritance from the grazing and grain-raising period which has not yet passed from the valley. Land and such waters as are utilized have cost little heretofore in the San Joaquin Valley, and things that cost little are lightly valued, no matter what their intrinsic worth. This spirit is fostered by the immense holdings of some of the larger companies. Few of these companies practice intensive cultivation, though their lands are among the best in the valley.

[a] Grunsky, C. E., Water Sup. Papers, U. S. Geol. Survey, Nos. 17, 18, and 19. These papers are no longer available for distribution, but they may be consulted in libraries.

Usually hay and grain are raised to feed through the dry season the stock that is in pasture during the grazing period. But although not as a rule intensely cultivated and by no means producing the maximum of food products or supporting the largest possible population, most of the large holdings are more carefully and successfully managed than the quarter section of the small farmer.

Despite all obstacles and discouragements, however, the use of underground waters is gradually extending. Special, high-priced products like the citrus fruits of the Portersville-Lindsay district justify heavy expenditures for production, and underground water has long been successfully used in this section. One of the highest lifts in the world of water for agricultural and horticultural purposes is that of the Badger Irrigation Company's plant at Exeter, with a maximum lift of 586 feet. This is an experiment, but the success of pumping water to great heights to irrigate the specially early citrus fruits of this region is fully demonstrated, the acreage devoted to these products is constantly extending, and the yield is increasing rapidly as groves planted recently approach maturity.

Irrigation by means of pumped underground water is also proving successful under the entirely different conditions that exist about Lathrop, Lodi, and Stockton, in San Joaquin County. About 200 small pumping plants are in operation in this county, the greater number of which have been installed within a few years. By their use alfalfa, vineyards, and varied crops of fruits and vegetables are successfully grown. Windmills also are extensively used, often with auxiliary gas engines attached to the same well. The area in which this type of irrigation is practiced is closely settled, houses are neat, prosperous looking, and well cared for, the villages and cities which supply the country trade and market the products are flourishing, and altogether there is every evidence of successful endeavor and abundant prosperity.

Still other communities whose existence depends upon the utilization of ground waters are the recently established colonies in Kings, Tulare, and Kern counties, of which the Corcoran settlement is a type. This particular locality is within the artesian basin, and a group of deep wells yield flowing waters which are utilized for all purposes. As a result, successful dairy farms have been established, sugar beets are raised, and a factory has been built for the manufacture of sugar from them.

It is thus evident that there is a gradual awakening to the value of the ground waters and their usability, although in many localities the advocate of the use of these waters is still met by the statement that they can not be developed and applied at a profit under agricultural conditions as they now exist. It is true that the pumped waters are more expensive than the ditch waters, whose cost as a rule is very low. The average cost of the pumped water used by the Kern County Land Company near Bakersfield, with an average lift of 30 feet, is $1.29 per second-foot for 24 hours on the basis of a charge of 15 cents per horsepower per hour for electric current, whereas the cost of surface water in the same locality is 75 cents per second-foot for twenty-four hours; i. e., the pumped water costs 72 per cent more than the surface water. When it is remembered, however, that almost universally in the San Joaquin Valley water is used in great excess, to the immediate and ultimate injury not only of the lands to which it is applied but of adjacent lands; that on many of the delta lands there is as yet but little intensive cultivation, and that therefore the margin of profit is low; that there is an important proportion of large holdings and absentee ownership dependent upon inefficient hired labor; and above all that, in the midst of the communities in which it is asserted that pumped waters can not be profitably used in agriculture individuals may generally be found who are using them with striking success; when all of these things are taken into consideration, it may be asserted with confidence that the greatest increase in the agricultural development in this valley in the future will be brought about by a utilization of the ground-water supplies, whose development has only begun and whose value is as yet but faintly realized.

It will probably be true in the future, as it has been in the past, that side by side with successful attempts at the utilization of underground waters will be unsuccessful attempts, and that the general movement for full realization upon this asset will be checked here and there by conspicuous failures widely advertised. This is a condition that always arises in any general advance. Each failure should teach its individual lesson as to a particular way *not* to undertake development or to apply water, and should not be interpreted as an argument against the usefulness of the resource under proper conditions, for the fundamental facts remain that ground waters exist beneath the floor of the San Joaquin Valley in immense volume and that over wide areas they are of high quality and very accessible. They are certain, therefore, to be widely used in the future, and by their use hundreds of thousands of acres now arid and unproductive will be brought to yield handsomely.

The development of the ground waters under the conditions that exist at present, when the chief argument against them is their cost as compared with that of the surface waters which have set the standard should follow two or three lines.

In the first place, pumping plants in the higher parts of the delta lands should be used as adjuncts to insufficient gravity supplies. The supply of the gravity waters during the flood months of May, June, and July is from 2 or 3 to 15 or 20 times that available during the months of August, September, and October, when many crops are maturing. As a consequence many owners of late rights to gravity waters secure a proportion of the flow during the early high-water period, but are left without it during the low-water period, when there is only sufficient to satisfy the earliest rights. Such owners often have enough gravity water for one or two early irrigations, but not more. Under present conditions, therefore, the maturing of late crops is a precarious matter with them, and they are confined practically to those products which will yield returns when irrigated only in the spring or early summer. This is a serious handicap, as it greatly limits the range of their agricultural activity and often condemns their land to idleness during half of the year. By the installation of pumping plants, to be operated only when gravity waters are not available, this handicap is removed, and yet the cost of irrigation is much less than where no surface waters are available and pumps must be operated continuously.

In the second place, in districts that have a market for garden products or for those special farm products whose value and yield justify some expense in their production, as sweet potatoes, celery, asparagus, or onions, the small land owner can well afford to install an individual pumping plant independent of surface supplies. The same method will be successful with crops that require only one or two irrigations a year, as, for example, some of the fancy varieties of grapes that are now raised so profitably in the northern part of the valley.

Another line to be followed in development is the utilization of flowing artesian waters. Along the axis of the valley is a zone with an area of about 4,300 square miles within which flowing waters are available. Over perhaps two-thirds of this area the flowing waters are sufficiently pure to be suitable for use in irrigation.

None of these lines along which it is suggested that ground waters may be used are experiments. Each has been followed successfully in some of the communities in the valley, although in other sections quite as favorably situated the investigator will be told that pumped or flowing waters can not be used profitably. Communities, like individuals, fall into ruts, acquire bad habits, and lose the power of initiative. In this condition they may overlook or fail to utilize some of their most valuable assets.

In the course of this investigation nearly 4,000 wells in the valley have been examined and data collected as to depth, yield, cost, etc. Among them are many flowing wells. For most of the wells the data are incomplete, but from the records available the following averages have been determined:

Average size, depth, yield, cost, etc., of flowing wells.

County.	Number averaged.	Average diameter. (inches).	Depth (feet).	Yield (miner's inches).[a]	Average cost.	Annual interest on cost at 8 per cent.	Interest charge per miner's inch per year.
Kern	10	10	621	53.3	$1,545	$123.60	$2.30
Kings	7	9	1,037	30	2,555	204.40	6.81
Tulare	32	8	745	26	1,711	136.88	5.26
Fresno	7	8	936	20	1,540	123.20	6.16
Merced	16	7	350	5½	470	37.60	6.84

[a] A California miner's inch equals 0.02 second-foot.

These are actual averages based upon the experience of owners of wells already drilled and flowing. They therefore have a definite value as a basis for estimating costs of artesian waters to be obtained as a result of future developments. They may be compared with the charge made on the Kern delta for gravity water, namely, 75 cents per second-foot for 24 hours, equivalent to $5.47 per miner's inch per annum.

In comment upon the table it is to be said that the Kern County average is too low, because it happens that among the wells for which sufficiently complete data exist for computing these averages there were one or two of exceptionally great yield that have unduly raised the average yield and reduced the cost, thereby giving a figure lower than that which will probably be realized in future development.

It must be remembered further that the figures are based on the assumption that the entire year's flow will be utilized. This assumption can be realized only by the construction of reservoirs in which the water will be stored during the nonirrigating season for use when wanted. Such construction will add to the cost and will reduce the supply in three ways: (1) By a reduction of flow because of the increased height of delivery necessary to discharge into a reservoir; (2) through loss by evaporation from the surface of the reservoir; (3) through loss by seepage from the reservoir.

The uncertainty as to the amount that will be delivered by any artesian well is another disturbing factor in making exact calculations. The area within which flowing waters are procurable has been outlined with approximate accuracy, but the yield of any well can be determined only after the well has been sunk and the necessary capital invested in it. Some of the wells used in computations have delivered much more than the average supply and so have yielded exceptionally cheap waters; others have delivered less than the average, and their waters are correspondingly expensive.

Another condition that must be realized is this: When the number of wells drawing from the artesian supply is greatly increased in any particular neighborhood, the wells interfere and the yield of each is lessened. When the maximum acreage is dependent on artesian flow under these conditions, the installation of pumping machinery may become necessary in order to insure the continuance of an adequate water supply.

As against these disadvantages, which have been rather fully outlined, as is essential in any frank and therefore useful discussion, is to be placed regularity and relative constancy of the supply and its availability at all times, as compared with the fluctuations of surface waters unavailable except during the flood season to any but the owners of the oldest rights. An added advantage where the landowner owns his well is his complete control over his water supply. He may irrigate when and how he will, and thus most economically, and is not dependent upon the adjustment of supply among a number of users from a common source.

ORIGIN OF THE GROUND WATERS.

The ground waters of the San Joaquin Valley have precisely the same origin as its surface waters—namely, the rainfall and snowfall in the drainage basins tributary to the valley. They are in reality simply that portion of the surface waters that sinks into the sands and gravels of the valley floor and makes the rest of its journey seaward by slow percolation through the pores between the sand grains.

One of three things happens to the water that reaches the earth's surface as precipitation: (1) It returns directly to the air by evaporation from plant, soil, or water surfaces; or (2) it flows to the sea in surface streams; or (3) it sinks into the ground, and joins the body of water that saturates the soil particles below the ground-water level. It is with the latter part of the precipitation on the nearly 32,000 square miles of area included in the San Joaquin Valley and the mountain watershed tributary to it that we have to deal.

In the outline of the geologic history of the valley it has been pointed out that its entire surface is made up of the surfaces of contiguous alluvial fans, and that the valley is underlain to a depth that can not be determined accurately, but that doubtless runs into thousands of feet, by porous, unconsolidated, alluvial-fan material, mingled, in some areas, with lake deposits. This material has been transported from the mountains to the valley by the agency of running water. Many times its own volume of water has passed through and over it in the course of its removal from the mountains to the valley. It was deposited by and in water and has been more or less continuously saturated ever since.

A large but quite undeterminable portion of the run-off from the mountains each year sinks and joins the ground water. Of the 3,000,000 acre-feet discharged annually into the valley south of the Kings River–San Joaquin divide, only the small portion that spills northward from Kings River itself reaches the sea over the surface, because there has been no outflow from Tulare Lake for forty years. The greater part evaporates or sinks to join the underground supply. Northward from Kings River the surface waters are greater in volume than south of it and serve effectually to keep the sands and gravels beneath them saturated.

UNDERGROUND CIRCULATION.

Underground waters near the surface usually move slowly in the direction of the surface slope and at rates that vary with the gradient of the slope and the coarseness of the material through which they percolate. The freedom of the outlet by which they escape is also important. They may be ponded by a restricted outlet just as surface waters may. Measurements of rates of ground water movements in the San Joaquin Valley are not available, but facts stated in the following paragraph indicate pretty plainly the conditions that probably prevail:

(1) The alluvial fans that make up the valley floor are generally of low slope and fine material. The fans of the Cañada de las Uvas and of San Emigdio Creek, at the south end of the valley, and of Pala Prieta and Los Gatos creeks on the west side are exceptions; but the streams that have produced them contribute so small a proportion of the ground waters that they may be disregarded. (2) The general slope of the lowest line of the valley, from the south to the north, is not only not continuous, in that it is interrupted by ridges like that north of the Tulare basin, but it averages only about 1 foot to the mile, a very low gradient for a semi-arid region. (3) The wells drilled throughout the valley prove that the sediments underlying it are all fine. (4) The surface outlet of the San Joaquin and Sacramento drainage is by way of Suisun Bay and the straits of Carquinez to San Francisco Bay; but the straits are restricted, and it is not probable that bedrock lies far beneath the surface in their vicinity. In short, there is no adequate outlet for the underground waters of the Great Valley, which is canoe-shaped, with only a notch in the rim at the straits through which the surface waters spill. All of these conditions favor slow movement of the underground waters about the borders and at the ends of the valley, with their practical stagnation along the lower San Joaquin because there is no adequate outlet for them there. To be sure, capillarity and evaporation afford some slight escape for the ground waters as they approach the surface in their slow movement along the

valley axis. The great alkaline areas of the east slope and of the valley trough indicate escape of underground waters, because it is by this escape that the alkalies are concentrated at the surface; but the outlet provided in this way is of slight consequence when compared with the total body of ground waters.

The belief that there is little movement in the subsurface waters of the lower San Joaquin is strengthened by a consideration of their chemical characteristics. Some of the ground waters of the upper deltas of the east side are among the purest waters of this type known, while those from the shallow flowing wells of the bottom of Tulare Lake and from the deeper wells of the north end of the valley are so heavily charged with mineral matter as not to be potable or suitable for irrigation purposes. Ground waters dissolve the soluble minerals from the rock fragments—the clay, sand, or gravel particles with which they are in contact. The amount thus dissolved depends upon the chemical combinations in which the minerals exist, some being much more soluble than others, and upon the length of time during which the waters are in contact with them. In general, the alkalies in the sands and gravels of the east side are in the most resistant form, the silicates of the granitic débris from the Sierra; the alkalies of the sands and gravels of the west side are in less resistant form, the sulphates and carbonates of the Cretaceous and Tertiary shales and sandstones; hence the ground waters of the high parts of the east slopes of the valley, which move with comparative rapidity, are much purer than the waters from similar situations on the west side. Furthermore, the volume of water poured out upon the east-side fans is many times greater than that discharged upon the west side, so that the alkalies dissolved are greatly diluted. But down in the trough of the valley, especially near its north end, the ground waters contain a much larger percentage of salts, even than those of the west side. If there were rapid circulation of ground waters here, this condition should not exist, for the dissolved salts should have been gradually carried out. The fact that the waters are highly mineralized is regarded then as additional evidence of sluggish circulation, or perhaps practical stagnation.

QUANTITY OF GROUND WATERS.

Little need be said of the quantity of the ground waters in the valley for two reasons: The first is that although it is clear that the quantity is enormous, it is not possible to estimate it with any exactness; the second is that the actual quantity is not of as much importance in its use as its accessibility and the rapidity with which it is restored when withdrawn.

The area of the valley is about 11,500 square miles. The depth of the sands and gravels which are saturated with the ground waters is probably not less than a mile at the maximum, and may be much more. The average depth is equally unknown, but wells 1,000 or 2,000 feet deep, or even more, that are scattered throughout the valley, do not reach the bottom of the unconsolidated sands and gravels; so it may safely be assumed to be one-quarter of a mile and more. At this depth, nearly 3,000 cubic miles are saturated with ground waters, and if the porosity is 20 per cent, the conclusion is reached that 600 cubic miles of water underlies the valley—certainly a conservative estimate. But this includes water of all qualities and those found at great depths. Not all of the former are usable and the latter are not accessible.

ACCESSIBILITY AND AVAILABILITY OF GROUND WATERS.

One of the most important elements in the cost of ground waters, of course, is their accessibility, by which is generally meant the depth at which they stand beneath the surface; but the depth of boring necessary to develop them and, if pumped, the amount that they are drawn down when the pumps are in operation are also important elements.

The cheapest waters in general are those that flow out at the surface, even though deep wells may be necessary to develop them and the initial cost may therefore be great. But these waters may not always be most available, because they are to be had only in the lower parts of the valley, where, because of climatic conditions and alkalinity of soil, many of the lands are less valuable than those farther up the slopes. Generally speaking, about the borders of the valley the ground waters lie at the shallowest depths in the deltas and at the greatest depths in the interareas. The flood channels and the irrigation ditches are the lines along which recharge of the ground waters is effected; hence in their vicinity the ground-water level lies near the surface and the pumping lift is at a minimum.

Beneath the west side slopes, unfortunately, where the waters are most needed, they are not accessible. The conditions here illustrate well the dependence of the ground waters upon local surface supply. Surface run-off is most limited in this area, the ground waters lie at too great depth for profitable utilization, and they are usually too inferior in quality to be desirable even for irrigation.

DEVELOPMENT OF GROUND WATERS.

The development of underground water in the valley is as yet in its infancy. It does not compare in intensity with that in Southern California, where, with an irrigated district of about 225,000 acres, there are nearly 3,000 flowing wells, costing about $675,000 and yielding nearly 200 cubic feet per second of water, and about 1,400 pumping plants in which $2,500,000 are invested, by which an average of nearly 300 cubic feet per second of water are produced. Other minor wells increase the investment, but add little to the product. The total estimated investment in the development of ground waters, exclusive of the distribution systems, is about $5,000,000 in this restricted district and the water produced is approximately 500 cubic feet per second. For comparison with this development south of the Tehachapi, the following estimates have been prepared from the records of the U. S. Geological Survey to indicate the relatively meager development in the San Joaquin Valley.

Ground water development in San Joaquin Valley.

County.	No. artesian wells.	Estimated cost.	Estimated yield, second-feet.	No. pumping plants.	Estimated cost, well and plant.	Estimated capacity, second-feet.	Estimated output.	Total cost.	Total yield.
Kern	112	$161,400	73.46	104	$138,632	225.84	*1/6 capacity.* 42.64	$300,032	116.1
Tulare	124	189,968	23.31	191	244,098	162.72	*1/3 capacity.* 54.24	434,066	77.55
Kings	77	112,959	19.3	3	1,530	1.34	*1/6 capacity.* .24	114,489	19.54
Fresno	40	40,000	7.5	28	....	30	5	....	12.50
Madera	31	13,237	7.81	17	44,931	40.8	6.8	58,168	14.61
Merced	133	48,013	7.95	43	46,700	40.93	6.82	94,713	14.77
Stanislaus	5	3,830	1	9	....	8.35	1.39	....	2.39
San Joaquin	....	....	....	202	123,836	250	41.67	....	41.67
Total	522	569,407	140.33	597	599,727	759.98	158.80	1,001,468	299.13

The data upon which these estimates are based are neither as complete nor as satisfactory as those used in Southern California, and therefore the conclusions must be regarded as suggestive rather than as accurate in detail. As an example of one of the weak points in the estimates, attention may be called to the column in which the output of the pumping plants is recorded. Generally these plants are used in the irrigating of alfalfa or of garden products. Some of them are independent sources of water; others are auxiliary to gravity waters and are used only when the latter are not available; some are in the southern part of the valley, where the rainfall is less than 5 inches; others are in the northern part of the valley, where the rainfall is more than twice as heavy, and where on this account less water need be applied artificially. Of course the pumps are not in constant operation anywhere, but the percentage of the year that they are run varies with local conditions. No exact estimate of this percentage can be made, but it has been assumed in the estimates that the pumps are operated the equivalent of two months continuously, hence that their output for the year is one-sixth of what it would be were they in constant operation. This estimate is more likely to be too high than too low. In one county, Tulare, which includes the Portersville, Exeter, and Lindsay citrus districts, a larger factor is used. Most of the pumps in this county are used for citrus irrigation, and it is assumed here that their output is one-third of what it would be were they in continuous operation. This estimate should not be excessive.

Accepting the estimates, then, as they are, we find that in the San Joaquin Valley there are at present between 500 and 600 flowing wells and a somewhat greater number of pumping plants, representing an investment of between $1,000,000 and $1,500,000, and yielding in the neighborhood of 300 cubic feet of water per second. The number of wells is about one-fourth that of Southern California, the investment is one-third, and the product about one-half, although the total irrigable area of the San Joaquin Valley is nearly ten times that of the southern field and the underground waters available are probably in similar ratio. This comparison, even though the figures upon which it is based are not complete, gives a graphic idea of the development that may yet be accomplished in central California by the full use of the ground-water resources.

COUNTY NOTES.

KERN COUNTY.

GENERAL CONDITIONS.

Kern County, which includes the extreme southern end of the San Joaquin Valley, receives its principal water supply, both surface and underground, from Kern River, which flows out upon the valley floor just above Bakersfield. Minor amounts, chiefly as winter flood waters, are contributed by Poso Creek and the streams that enter the valley from the south and west. The supply in excess of that used by the canal systems flows into Buena Vista reservoir, where it is stored for the irrigation of the Miller and Lux lands along the trough of the valley to the north. During seasons of particularly heavy stream flow, a portion of the water escapes northward along either the main channel or the Goose Slough channel to Tulare Lake.

In the course of its distribution over the delta lands through the canals in irrigation, and by flow through the natural distributaries, a definite portion of the water sinks and so maintains a condition of saturation of the sands and gravels that have been deposited in the course of the growth of the delta. These saturating waters, like the surface waters, move in the direction of the slope of the delta, but at a much slower rate. They circulate more freely through the coarser beds of the delta deposits, and as they pass beneath the finer beds that are more numerous in those parts of an alluvial fan that are most distant from its head, they accumulate pressure. Therefore when the confining beds above them are pierced by a well they rise, and if the pressure is sufficient they flow over the surface. These are the flowing artesian wells of the Kern and Buena Vista lake beds and the region extending some miles north of them, and of the main San Joaquin Valley artesian basin, beginning in the neighborhood of Button Willow and extending thence northward down the San Joaquin Valley to the delta of the San Joaquin and Sacramento rivers. It may connect with the Buena Vista artesian area, although there is no evidence available now to determine this point.

FLOWING WELLS.

In 1905 there were 112 flowing wells in the county that were examined, and there were doubtless a few more that were not seen. The yield of these was in the neighborhood of 70 or 75 second-feet. About one-third of the wells were used for irrigation, the remainder being used for stock or domestic purposes or allowed to waste uselessly. The areas in which they occur are indicated by the outlines of the artesian basins, as shown on Pl. I.

Generally speaking, the artesian pressures have not been seriously affected by the developments that have taken place to date, although there are some wells, as in the Semi-tropic district, whose flow has decreased markedly as a result of the boring of big wells near by, but on lower ground and therefore in more favorable situations. Artesian wells usually deteriorate with age, as a result of any one of several causes, as slow filling with sand, clogging by gelatinous deposits, the growth of miscroscopic organisms, and, finally, by the deterioration of the casing.

The State engineering department of California measured the yield of certain flowing wells in the Kern delta in 1885, and some of these were remeasured in 1905. The remeasured wells show decreases in yield varying from 50 to 100 per cent, but in only one of the wells available for comparison has there been complete cessation of flow. Decrease in yield of individual wells as development progresses is so usual a phenomenon that no community can safely plan its future on the assumption that a cheap supply of this type will remain constant, even in such large basins as those of the San Joaquin. But flowing water should be available for years from those wells whose initial yield is sufficiently large to be of value. Later, when the communities are more thickly settled and the wells are so closely grouped that flow and yield are materially decreased, industrial conditions may have so changed that pumps can profitably be installed to augment the supply. The cost of such pumped waters will usually be particularly low because of the slight lift required to bring them to the surface.

PUMPING PLANTS.

More than 100 pumping plants in Kern County develop underground water for various purposes. Of these about 40 are gas plants, 25 are steam plants, and the rest are electric. The developed waters are used for irrigation, for city supplies, for engine waters, and as supplies for steam plants, as at the pumping stations of the Pacific Coast Oil Company.

In the district about Bakersfield 50 pumping plants are in use to develop irrigation water. Half of these are electrically operated and belong to the Kern County Land Company. Each of these plants is equipped with 30 or 40 horsepower motors directly connected with No. 8, 10, or 12 centrifugal pumps. Each pump is connected with from three to five 13-inch wells, the number being determined by the yield of each well. From the data collected on these wells, the following cost averages were computed, on the basis of the quoted charge of 15 cents per horsepower per 24 hours, for the electric power used.

Data concerning pumping plants in Kern County.

Average depth to the water from the surface, in feet	10
Average suction 20 feet. Average total lift, in feet	30
Total yield of 25 plants, in second-feet	100.34
Total horsepower consumed	860
Total cost per day to develop 100.34 sec. feet, 860 H. P., at 15 cents	$129.00
Cost per second-foot for 24 hours	$1.29
Cost per acre-foot of water developed	$0.65

E. M. Roberts, of Bakersfield, has furnished the following data as to cost of operation on a privately owned steam plant, which has a particularly advantageous location:

Data concerning steam pumping plant at Bakersfield.

Equipment: 30 H. P. steam engine, No. 12 centrifugal pump, five 15-inch wells 40 feet deep; 6 feet to water, 15-foot suction, 21 feet total lift:

Cost of crude oil (fuel) and lubricant for 24 hours	$2.25
Cost of labor 24 hours	$4.00
Total cost	$6.25
Yield of plant	7 second-feet.
Cost per second-foot for 24 hours	$0.89
Cost per acre-foot of water developed	$0.45

Neither of these estimates makes any allowance for interest on investment in well and plant nor for deterioration, hence the costs as given are somewhat too low. It must be remembered, moreover, that Mr. Roberts's plant is in a particularly favorable situation, being close to the banks of the Kern, where the supply is regular and the lift slight. The standard of water costs in this district is set by the price of gravity water from the Kern, 75 cents per second-foot for 24 hours, or about 38 cents per acre-foot, where distribution is affected by sales.

The pumped water therefore costs from 20 to 100 per cent more than the gravity water, and its cost will increase as it is developed from deeper strata with higher lifts. It seems to be quite generally believed locally that water at these prices can not be used profitably.

This may be true with the wasteful methods employed, the excessive amounts of water often applied, the class of crops produced, and the general lack of intensive cultivation; but it has been clearly proved in other communities and by individual experiences in the Bakersfield region itself that with more diversified or better selected crops, smaller individual holdings, and more intensive methods of farming, good profits may be made from the alkali-free lands of the delta and plains by the careful use of water at these or at even higher prices. It is safe to predict that the most important future developments in Kern County will result from the application of these principles.

Under any conditions that are likely to obtain in the near future it is not to be expected that ground waters at greater depths than 25 or 30 feet below the surface as an extreme will be usable for irrigation purposes. Water at this or less depth exists, of course, throughout the artesian areas along the lowest parts of the valley. It is to be found also throughout the greater part of the Kern delta and in the lower parts of the Poso Creek delta from a point about halfway between Famoso and Wasco westward. Near the foothills on each side of the valley, the ground water is not accessible except under unusual conditions, as in the flood plains of the larger rivers, or in areas where particularly valuable products, such as citrus fruits, will justify the expense of pumping to exceptional heights. In the intermediate areas between the deltas of the streams that supply the ground water, it is also apt to be too deep to be accessible. This condition is illustrated in the area between the Kern and Poso Creek deltas, east of Shafter station, on the Santa Fe railroad, and in the region between Delano and the foothills just south of the Tulare county line.

Near the northern edge of the county the main artesian belt of the valley, whose southern end is in the vicinity of Button Willow, expands to a width of 26 or 27 miles measured along the county line. Much of this central portion of the valley along the north edge of Kern County is in large holdings and is therefore but thinly settled, but developments are ample to prove the artesian conditions and to permit outlining the artesian belt with a fair degree of accuracy.

The outlines as determined are shown on the accompanying map (Pl. I), which also shows by means of hydrographic contours the depth to the ground-water level outside the artesian limits.

Although little direct evidence bearing upon this point exists, there can be no doubt that beneath the broad, steeply sloping west-side plains of Kern County the water is too poor in quality to be usable, except perhaps for stock, and that a few miles back from the trough of the valley it is too deep to be accessible. Generally, the water table beneath these west-side plains has but little slope, the depth to it at any point being approximately equal to the elevation of that point above the trough of the valley.

TULARE COUNTY.

GENERAL CONDITIONS.

Tulare County, lying north of Kern and east of Kings, includes the eastern edge of the large central artesian basin at its widest part, all of the delta of Kaweah and Tule rivers and a part of that of Kings River, and the famous citrus region of the foothills and the higher parts of the valley floor about Porterville, Exeter, and Lindsay. It also includes, in the southwestern corner, a part of the old bed of Tulare Lake and a part of the district submerged during the last extremely high water, in 1880. The high water of 1905–1907 did not quite reach the Tulare County line.

Kings, Kaweah, and Tulare rivers are the chief sources of such additions to the ground waters as are made in this county, as they are the sources of the surface waters used by the various canal systems.[a] Each of these streams has a distinct though rather flat delta, and the attitude of the ground-water plane indicates that the stream channels and canals along the crests of the deltas are the direct sources of the ground waters in the higher portion of the valley within Tulare County, and that from these lines of supply the waters percolate toward the lower parts of the valley and toward the areas between the deltas. These interareas receive only the slight direct supply from rainfall and from the minor streams that drain the foothills.

Within the artesian basin south and west of Tulare the ground waters, although receiving local additions within the county, are a part of the general body of ground waters of the central valley, stored there as a result of accumulation from all sources during centuries past, and are in general slow in motion northward along the valley axis.

[a] An account of these systems was published in Water-Supply Papers, U. S. Geol. Survey, Nos. 17 and 18. These papers are not now obtainable, but may be consulted in libraries.

FLOWING WELLS.

In the 365 or 370 square miles of artesian-water land within the county there were about 125 flowing wells in 1905, representing an investment of between $150,000 and $200,000. Nearly 100 of these wells were used for irrigation, and the combined yield of all of them was estimated at less than 25 second-feet. The greater number of them are 7 inches or more in diameter, while a few old wells are of smaller bore. They are most numerous on the Kaweah delta west of Tulare and somewhat farther south, west of Tipton and Pixley. Pasture lands, alfalfa, gardens, deciduous fruits, and vineyards are irrigated by the use of the waters developed.

PUMPING PLANTS.

Irrigation by the use of pumped water is more extensively practiced in Tulare County than anywhere else in the valley. This is due to the development of citrus culture along the foothills between Tulare River and Kaweah River, where methods in vogue in the citrus districts south of the Tehachapi have been introduced. There were in all about 170 pumping plants in use for irrigation in 1905 while a number of others were in use for domestic or town supplies. Of the total number, 125 were electrically driven and procured their power from one company; 45 were gas or steam plants.

These plants are adapted to a wide variety of conditions, some of them pumping from wells in which the water stands at the surface, and others lifting it from a depth of 100 feet. In the irrigation of some of the hillside citrus groves water is forced to heights of several hundred feet, usually from a reservoir into which it is pumped from the wells. The best equipped plants that overcome lifts of less than 75 or 80 feet use centrifugal pumps directly connected with motors; when the lifts are greater some form of deep-well plunger pump is used.

In the Lindsay district the ground-water level varies greatly each year, falling during the pumping season and rising again in the winter and spring. To keep the pumps and motors within the suction limit during the low-water period, and at the same time prevent their submersion during the winter season, some of the ranchers have adopted the plan of placing the machinery in a tank. In one plant examined, the motor and pump were fastened to a movable platform that could be raised or lowered in adjustment to the varying ground-water level.

The Badger Irrigation Company at Exeter has a particularly interesting plant because of the high lift of waters for irrigation purposes. There are three substations in the lowlands that deliver water to several citrus tracts at the base of the foothills, and to a large reservoir. From this reservoir the water is forced on up the hill by a special design triple-plunger pump operated by a 75 horsepower motor. This pump has a capacity of 75 miner's inches from the 66-foot lateral to the 247-foot lateral; of 53 miner's inches from the 300-foot lateral to the 400-foot lateral; and of 36 miner's inches from the 530-foot lateral to the 586-foot lateral.

Difficulty was experienced when the plant was first installed because the pipe used was too light to resist the great pressure. At present three-eighths inch cast iron pipe of 6, 8, and 10 inch diameter is in successful use.

COST OF PUMPED WATER.

The charge made for power in this district by the Mount Whitney Power Company is $50 per year per horsepower for current used continuously, which equals 13.7 cents per horsepower for 24 hours; $30 per year per horsepower for current used in daylight only, which equals 8.8 cents per horsepower per day of 12 hours.

Estimates were made of the yield and cost of water from 50 plants using power on the first basis, with the following results:

Cost of water at fifty plants.

Average lift, in feet	79
Total yield of 50 plants, in second-feet	24.5
Total horsepower consumed	509.6
Total cost per day, 509.6 horsepower at 13.7 cents	$69.81
Cost per second-foot per day	$2.85
Cost per acre-foot	$1.43
Cost to lift 1 second-foot 1 foot for 24 hours	$0.036

Another estimate is given below of the cost of water from another group of 8 plants in the same district:

Cost of water at eight plants.

Average lift, in feet	30
Total yield, in second-feet	8.44
Total horsepower consumed	106.9
Total cost per day, 106.9 horsepower at 13.7 cents	$14.65
Cost per second-foot per day	$1.75
Cost per acre-foot	$0.88
Cost to lift 1 second-foot 1 foot for 24 hours	$0.058

These estimates indicate in a general way what irrigators are doing in this district under present conditions.

PERMANENCE OF THE GROUND-WATER SUPPLY.

Most artesian basins are very sensitive to development, old wells decreasing in yield as new ones are installed, the shallow wells and those about the upper, outer edge of the basin being the first to show signs of failure. Diminution in the flow of the less favorably situated wells will take place in actual practice long before the basin is overtaxed, hence some alarm is likely to be felt and some individual loss may occur before alarm is justified by conditions. In addition to the normal diminution of flow in wells due to physical deterioration in casing or to other causes not related to a general loss of head and reduction in supply, a new well drilled in the neighborhood of an old one, or so situated as to draw in part from the same general zone of saturated porous materials, will affect the yield of the first, although the combined yields of the two are much greater than that of either alone and much less than the supply.

Until wells are withdrawing water from an area more rapidly than it is supplied, even though there may be reduction in the yield of individual wells, there is no cause for alarm. It is difficult to determine when this point is reached in an artesian basin because diminution in flowing wells begins soon after development has begun, but when waters are pumped it is less difficult to tell. The continued lowering of the ground-water level in a pumped well, through years of average or abundant rainfall with gradually increasing lifts and correspondingly increasing costs, indicates overuse.

A comparison of the flows of a number of artesian wells in Tulare County, measured first by the California State engineering department in 1885, and twenty years later by the United States Geological Survey, indicates, as is to be expected, a general diminution of yield, this decrease varying from 40 to 90 per cent. A part of it is undoubtedly due to the installation of new wells in recent years, but much of it is to be accounted for by the clogging and filling of the wells and the rusting of the casing. In any event the losses are not serious, and in view of the immensity of the basin and the large supplies that reach it annually, it can not be considered to have approached the point of overuse.

This observation, however, does not hold for some of the areas in which pumping is most intense. The lands favorable for citrus culture are distributed along a frost-free belt on the lower foothills and adjacent high parts of the valley floor. The zone of most intense pumping is along the eastern edge of the valley, between the deltas of Tulare and Kaweah rivers. The ground waters here receive some slight accessions from local run-off from the foothills and from minor streams that flow out from them, but their principal source is the constant supply that sinks in the deltas of the major streams and percolates thence slowly in all directions.

On the deltas themselves, especially along their lower portions, where so much damage has been done in recent years as a result of over-irrigation, the consequent rise of the ground-water plane and with it the alkali, pumping is most helpful; in fact, pumping will doubtless be one of the means by which the damage done by over-irrigation in the past will be remedied in the future; but in Tulare

County pumping thus far has been concentrated, upon those points remote from the deltas and from the trough of the valley, where supplies are least rapidly replenished. As a result there has been a noticeable lowering of the water plane in recent years and an increased cost of the water product. As a matter of safety to the orchards already producing, means should be taken to prevent the installation of additional pumping plants in those parts of the citrus belt where development is now most intense and the effects upon the ground water have been most clearly discerned, for it is obviously more important to protect the orchards that are already producing than to plant more.

KINGS COUNTY.

GENERAL CONDITIONS.

The valley portion of Kings County includes the present and past Tulare Lake bottoms and the southern slope of the lower Kings River delta. Tulare basin is the lowest point in the southern section of the valley and is the area in which all surplus waters from Kings River southward accumulate. The flood waters of Kings River are divided on its delta, part of them flowing northward to join the San Joaquin drainage, while the other part flows into Tulare Lake. During years of low or moderate snowfall and rainfall in the Sierra, practically all the flow of Kern, Tulare, Kaweah, and Kings rivers is used in irrigation, and there is but little excess to escape to the basin; but during years of heavy precipitation great volumes of water accumulate in the Tulare lowlands. This basin is very shallow. Its shores have gentle slopes, hence the area of the lake fluctuates widely, with slight changes in the depth of the water in it. Since settlement began in the San Joaquin Valley it has had a complex history. Grunsky has summarized what is known of its earlier history in Water-Supply Paper No. 17,[a] pp. 16 and 17. From his account that part of the following résumé which deals with conditions prior to 1897 is condensed:

Résumé of history of Tulare Lake.

1853. High.
1853–1861. Subsidence; elevation of surface in 1861, 204 feet.
1861–1863. Rapid rise to highest known stage, 220 feet above sea level, overflowing into San Joaquin River; area about 800 square miles.
1863–1867. Decline to about 208 or 209 feet above tide.
1867–1868. Filled again to about 220 feet above tide.
1872–1876. Fluctuated between 211 and 217 feet.
1876–1883. Decline to 192 feet; lowest stage then known.
1883–1897. Fluctuating; generally low.
1897–1905. Decline; dry in autumn of 1905.
1905–1907. Rise; elevation of water surface in summer of 1907, 193 feet; area of water surface summer of 1907, 300 square miles.

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[a] This paper is not now available for distribution.

A knowledge of the history of this lake makes clear the origin and character of the soils of all except the northern part of Kings County, where the alluvial-fan or "delta" conditions so general in the San Joaquin valley prevail.

Evidences of the former occupancy of the lowlands by the lake appear everywhere. Faintly marked sandy beaches encircle the depression at various elevations and over these beaches are strewn the shells of the mollusks that lived in the lake. In its lowest parts, dry and planted in grain in 1905, the fine sediments that settled in the lake bottom make a fertile alluvial soil.

It is to be presumed that the history of the lake for many centuries has been like that part of it which we know directly, i. e., that it has fluctuated in area and depth, occasionally drying out completely, then filling to the point of overflow. Under such conditions relatively little of the water which it has contained can have escaped by surface overflow; the greater part of it has evaporated or has been absorbed by the sands and silts of the lake bottom.

With the shrinking of the lake during the years preceding the inflow of 1906, its old floor was placed under cultivation and valuable crops of grain were produced. This successful grain culture proves the nonalkaline character of the present surface of the old lake bottom, but the saline waters yielded by numerous shallow flowing wells within it indicate the presence of alkalies at slight depths. The few wells available as evidence in and about the borders of the old lake, however, indicate that the deeper wells obtain the better water.

Most of those that extend to depths of 1,000 feet or more develop waters sufficiently pure for irrigation or for drinking purposes.

FLOWING WELLS.

There are probably as yet less than 100 flowing wells in Kings County (77 were visited by Geological Survey representatives in 1905), yielding approximately 20 second-feet. Probably not more than one-third of the wells are used for irrigation, a large number of small-bore shallow wells being used for stock and for domestic purposes. The northern part of the county, in the vicinity of Hanford, Armona, and Lemoore, is well supplied with surface water by the canal systems that head in Kings River, and is a most productive, thoroughly cultivated area. Ground waters are not needed and no serious attempt has been made to utilize them here.

In the vicinity of Corcoran, Waukena, and Angiola, however, a successful colony has been established that depends almost entirely upon ground waters. A number of deep wells have been put down to depths of 900 to 1,600 feet, which yield flowing waters in amounts ranging from 5 to 40 miner's inches. Shallow wells have also been bored and pumping plants have been installed over them. The tract includes about 30,000 acres, and alfalfa, cereals, sugar beets, dairy and garden products, and fruits are produced successfully.

FRESNO COUNTY.

GENERAL CONDITIONS.

Because of the fact that San Joaquin River forms the boundary that separates it from Madera County, Fresno County extends 25 or 30 miles farther north along the trough of the valley and along the west side than along the east slope. Thus the greater part of its lowland area is in arid west-side plains and in the relatively thinly settled central valley between Kings River at Lemoore and Laton and San Joaquin River at Mendota and Jameson.

Its best known, most densely populated, and most productive area is, of course, that about the city of Fresno, on the middle east-side plains, on the Kings River delta. This rich and populous region is irrigated by gravity water, distributed by a network of canals that take their supply from the river. These irrigation systems have been fully described by Grunsky.[a]

A later Water-Supply Paper, by Lippincott,[b] dealing with the possibility of storage and the development of water power on Kings River, embodies the results of a close study of the ground waters and their relation to alkaline conditions by Louis Mesmer and Thomas H. Means. From this report the following quotations are taken:

> The natural drainage of these lands is toward the southeast at the rate of about 6 feet to the mile. The soil is largely granitic sand, and below an average depth of 10 or 15 feet it is saturated with water. The surface water is somewhat alkaline and therefore it is not advisable to pump it for irrigation. Water below a depth of 50 feet can be considered satisfactory for irrigation. This is based on tests of more than 800 wells in the district, some of them being in sections where there were the strongest surface alkaline indications. In every case this lower water was found to be good, and when the strata near the surface are penetrated it rises to the elevation stated. There have been few attempts to pump water in larger quantity than is required for domestic purposes. A 2-inch screw pipe, put down to an average depth of 50 feet, landing the pipe on a stratum of clay, and then boring through the clay and allowing the water to come in from the bottom of the hole, is always ample for this purpose.
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> * * * * * * *
>
> A few small pumping plants have been installed—one 5 miles east of Fresno, on the Minnewawa ranch; several around Selma, and two near Wildflower—which yield at least 0.5 second-foot to a 7-inch unperforated well not more than 70 feet deep; with a lift not to exceed 20 feet in any case. Wells of 10-inch or 12-inch casing should be put down to a depth of about 100 feet on an average and should not be perforated above 50 feet below the surface, thus shutting off all possible chance of drawing from the more or less alkaline surface water. It is probable that wells of this size and depth would each furnish 1.5 second-feet. * * *

[a] Water-Supply Paper, U. S. Geol. Survey, No. 18, p. 39 et seq. Out of print. May be consulted in libraries.

[b] Water-Supply Paper, U. S. Geol. Survey, No. 58. Out of print. May be consulted in libraries.

The result of pumping, * * * would be to improve the conditions rather than to increase the troubles from alkali. The water table would be lowered sufficiently to permit the washing down of the alkali salts, and the salts, instead of being confined to the surface layers of the soil, would gradually be distributed * * * and thus rendered harmless. The lowering of the water table would be of the greatest assistance in the reclamation of the lands already alkaline, and would probably permit this reclamation without extensive underdrains.

In a report by Lewis A. Hicks on the "Generation and transmission of electric power and installation of pumping plants," included in Water-Supply Paper No. 58, an estimate has been made of the cost of water pumped from the ground-water supply by electric power generated on Kings River. The estimates are made on the basis of 100 pumping stations, each with a maximum capacity of 5 second-feet and an average lift of 45 feet, and the probable cost of the water produced is given as 50 cents per acre-foot when the pumping plants operate 328½ days per year and $1.43 when the pumping plants operate 100 days per year.

Among the conclusions reached by Mr. Lippincott after a thorough investigation of conditions on the Kings River delta are the following:

(5) Pumping plants can be established and operated which will furnish 1,000 acre-feet of water every day at a cost not much greater than that now paid for gravity water from the canals, to supplement the present summer supply or to extend the irrigated areas.

(6) The operation of the pumping plants will partially, if not wholly, prevent the rising of alkali to the surface of irrigated lands.

The rise of the ground waters presents a difficult problem in practically all of the delta lands of the San Joaquin Valley, and is merely particularly well exemplified in the Kings River delta in Fresno County. Mr. Grunsky states that the rise in ground waters since the beginning of irrigation is from 10 to as much as 50 feet in parts of the delta. One great difficulty that arises in dealing with the problem is due to the fact that the injury is done in one locality while a large part of the cause may be in another. The lower part of the delta lands are the chief sufferers from the rise of the ground waters, but the cause is to be found in the irrigation on the higher lands as well as on those affected. Over portions of the central artesian basin and about its borders the ground waters have always stood close to the surface, and much of the land was alkaline before there was any settlement in the valley. The effect of the irrigation on the higher lands has been to extend this saturated and alkaline zone slowly up the slope toward the eastern margin of the valley. As a result of this extension it has encroached to a certain extent upon lands that were valuable.

Without storage the gravity waters will not serve an acreage greatly in excess of that supplied by them now, and the pumping plants that must be installed to secure future growth will in addition serve a most valuable function in drainage, tending to prevent the extension of alkaline conditions and aiding in the reclamation of lands already alkaline.

FLOWING WELLS.

The flowing wells of the artesian belt of Fresno County are sparsely scattered over a broad area along the trough of the valley. There are only about 40 of them, all told, and they range in depth from less than 100 to 1,500 feet, the latter being the depth of one of the wells belonging to the Johns estate, north of Summit Lake. In the district adjacent to Lemoore, south of Kings River, small flows, sufficient for stock and domestic purposes, are obtained at 150 feet and less; but farther north no shallow wells are found.

Those on the James and Herminghause ranches, south of the San Joaquin River, are 600 to 800 feet deep. The flowing wells of the larger ranches were bored generally to obtain a supply of water for stock at times when none is available in the sloughs and irrigating ditches. Irrigation in these large holdings is as yet accomplished only during the flood season when abundant gravity water is available for lavish use. The possibility of using ground waters for such purposes is scarcely considered, although on one of the James ranches the water from a flowing well is used to irrigate about 50 acres of alfalfa.

The waters west of the San Joaquin River in Fresno County, whether within or without the flowing-well area, contain large proportions of salts in solution. This is a condition that is true of west-side waters everywhere within the valley, and apparently of all very deep waters near its northern end. South of Mendota, where the river no longer forms the eastern border of the county, the area within which waters of the east-side type appear extends 5 or 6 miles east of the valley axis. All of the waters of the upper east slope are very pure, but as they approach the lowest part of the valley they gradually assume the character of the waters there. In addition to the increase in the percentage of dissolved solids from the east toward the west across the valley, there seems likewise to be an increase from the south northward. The shallow flowing wells of Lemoore and vicinity contain very moderate amounts of salts in solution, while those in the vicinity of Mendota and Firebaugh and farther north carry from 1,000 to 20,000 or more parts per million.

The great west-side plains, with their productive soil, freedom from hardpan, good drainage, and favorable situation, are nonproductive because of their aridity, and must remain so until water can be applied to them. The ground waters beneath them are poor in quality and are deep. The ground-water plane seems to be nearly horizontal, such evidence as is at hand indicating a slope of only about 2 to 5 feet per mile; hence it is nearly as far to ground water beneath any part of these plains as the plains themselves are above the lowest part of the valley. If experiments should prove that they will successfully produce citrus fruits or other high-priced products, then it may be that water can be pumped to them from the valley and the venture made commercially practicable despite the great expense involved, for it is to be remembered that water is pumped to heights of several hundred feet in Tulare and San Bernardino counties in localities where it can be used on good citrus lands with an excellent margin of profit.

At present the west slope is nearly without permanent residents. There are perhaps a dozen settlers between Panoche Creek and the Coalinga Branch of the Southern Pacific. Sheep camps, occupied temporarily in winter, are scattered over them. In the early nineties a few seasons of heavy rainfall led to settlement about Huron, and two or three crops of grain were harvested, but since then there has not been sufficient rainfall to mature a crop, and the plains have been abandoned to the sheep men who rent the grazing privileges from the large landholders, notably the Southern Pacific Railway Company, for 6 cents per acre per annum.

MADERA COUNTY.

GENERAL CONDITIONS.

The valley portion of Madera County is limited on the south and west by San Joaquin River and on the north by the Chowchilla. Irrigation by the use of surface water is practiced about Madera through the utilization of Fresno River waters in the early summer, when they are available, and about Minturn, near the north edge of the county, by the similar use of Chowchilla River waters. Both of these streams have small mountain drainage basins, so that the flow from them is not prolonged late into the summer.

The extreme western edge of the county is also under irrigation from gravity waters. The Chowchilla canal heads on the north side of the San Joaquin, about 6 miles east of Mendota, and runs northward, generally parallel to the river, for about 20 miles, commanding a strip 5 or 6 miles wide between it and the river. The greater part of the rest of the county is as yet grain land or pasture land, intensive cultivation being practiced only locally.

FLOWING WELLS.

The ground waters have not been drawn upon to any extent for irrigation in the developments that have taken place thus far. There are about 30 flowing wells in the 350 square miles of artesian water-bearing land in the county, and these are practically all used for watering stock on the Chowchilla ranch and the Miller and Lux properties. The total yield for all of the flowing wells is estimated to be less than 8 cubic feet per second, although at least one of the individual wells yields more than 1 cubic foot per second. These wells are generally shallow, depths of 200 to 400 feet being usual. Some of them are among the oldest in California, having been drilled nearly forty years ago, and while there has been some lessening in yield it is undoubtedly due to deterioration of the casing and to clogging. A table of measurements made at different periods is appended:

Yield of flowing wells in Madera County.

Location.	Yield in miner's inches.		
	1871.	1884.	1905.
Sec. 21-10-14	20	13	10
Sec. 4-11-15	22	18	11
Sec. 25-10-15	4	6	....
Sec. 16-10-14	1.1	3	12
Sec. 23-10-13	....	5	2
Sec. 14-10-13	....	23	12

The well in section 16–10–14 was recently cleaned and responded with a stronger flow than it had ever yielded before. The fact of a well-maintained pressure and supply is further indicated by the strong flows of new wells put down in the vicinity of older ones, tapping the same water bearing beds.

It is evident that these cheap waters can be developed in large volume in the western part of Madera County if it is desired.

PUMPING PLANTS.

About 15 pumping plants in the county are used for irrigation. Most of these are in the vicinity of Borden, where the ground-water level lies at a depth of from 10 to 20 feet. The pumps pull the water level down locally 15 or 20 feet, so that the total lift is usually 25 to 40 feet. Irrigators estimate that under these conditions they can deliver water for about 75 cents per acre-foot for fuel and labor. Even lower figures are given for the best equipped plants. The following estimates are recorded from the plant of A. L. Sayre:

Estimated cost of pumping water in Madera County.

Equipment, 60 horsepower gas engine, No. 10 centrifugal pump. Three 10 and 12 inch wells, 110 feet deep; depth to water, 16 feet; suction, 22 feet; total lift, 38 feet.

Cost of fuel per day of 24 hours	$5. 47
Cost of labor per day of 24 hours	3. 35
Total	8. 82
Yield of plant, second-feet	6. 23
Cost per second-foot for 24 hours	$1. 41
Cost per acre-foot	$0. 71

Interest on investment and deterioration of plant, of course, increase this cost somewhat; yet, it is certainly well within the limits of profitable use. Practically everywhere within that part of the county west of the Southern Pacific, except near the bluffs of San Joaquin River, pumping waters are accessible. As the foothills are approached, depth to ground water increases and the lift necessary in their development increases correspondingly.

MERCED COUNTY.

GENERAL CONDITIONS.

Merced County, unlike Madera County, extends entirely across the San Joaquin Valley and thus includes both east-side and west-side conditions. The gradual amelioration northward of the aridity of the south end of the San Joaquin Valley becomes noticeable at this latitude; hence, the raising of grain without irrigation, which is possible on the east side as far south as Fresno County, is usually successful on the west side in the northern part of Merced County.

Irrigation by surface waters is accomplished principally by the utilization of San Joaquin and Merced River waters. The lower line of the San Joaquin and Kings River canal, which leaves the river near Mendota in Fresno County, extends entirely across the west side of Merced County and into Stanislaus County. The high-line canal of the same system also extends from the southern to within a few miles of the northern edge of the county. This irrigation work commands much the larger portion of the west-side plain. The zone of unwatered land, between the high-line canal and the foothills, is relatively narrow.

The most important east-side system is the Crocker-Huffman canal, which taps Merced River about 2 miles below Merced Falls and serves an extensive section east and north of the county seat. The Stevenson-Mitchell canal heads in San Joaquin River about 14 miles southwest of Merced and commands a belt from 3 to 4 miles wide between this point and the mouth of Merced River. The principal settlement below this canal, the Stevenson colony, is between the lower Merced and the San Joaquin.

North of Merced River, the Turlock irrigation district extends into Merced County from Tuolumne County, in which lie the greater part of the lands covered by the system. In addition to these major systems, there are a number of minor canals along the Merced River bottoms. On the whole, however, the county is thinly settled and but a small portion of it is under irrigation. Perhaps three-fourths of the valley lands are devoted to dry farming, the production of hay and grain, or to pasturage.

The territory east and north of Merced, the Plainsburg and Le Grand districts in the southeastern part of the county, much of the foothill area, and the greater part of the strip on the north side of Merced River are producing hay and grain, while the greater part of the area between the Southern Pacific Railway (main line) and San Joaquin River is in pasture. Part of this pasture land was at one time tilled, but for various reasons, among them the rise of alkali, tillage has ceased, and the lands have been returned to pasture. On the west side the strip above the canals and between them and the hills is generally in grain from Dos Palos northward. South of Dos Palos this strip is utilized principally as sheep range.

FLOWING WELLS.

The use of ground waters, like surface irrigation, is more usual in Merced than in Madera County, although it has not as yet become extensive in either area. The total number of flowing wells in the county is between 125 and 150. The greater number of these wells are shallow, from 100 to 400 feet deep, and their yield is correspondingly small. As the most of them were drilled twenty or twenty-five years ago, not for irrigation but for domestic purposes and for stock, they fulfill the function for which they were intended. Of the 133 wells of which the Geological Survey has records, but 15 are reported as used for irrigation, and even these are generally used on a small alfalfa patch or garden of but little importance. The total yield of all the flowing wells in the county is estimated at less than 8 second-feet. That large yields may be secured is indicated by the experience of the Crocker-Huffman Company in sinking a 2,000-foot test well for oil in the spring of 1902 in sec. 15, T. 7 S., R. 13 E. No oil was found, but this well, although near the eastern edge of the flowing well area, as indicated by the shallow developments to date, yielded what is reported to have been the largest flow in the Merced district. When the casing was pulled the flow ceased, doubtless because of leakage into the upper strata. The water is said to have been soft and of fine quality.

By far the greater number of the flowing wells in the county are on the east side, south and west of Merced. The west-side developments are very meager. This is doubtless due in part to the fact that the San Joaquin and Kings River canal system supplies plenty of cheap gravity water to this district, but it is affected also by the fact that the west-side underground waters are of inferior quality. The flowing wells particularly, which must be deep, yield very bad waters. Some of them are too saline for irrigation. A few of the shallow wells near the main canals or the large laterals supply water sufficiently soft for any purpose. Most of the deeper waters along the axis of the valley, as well as those along the west side, are alkaline. The experience of some of the irrigators in the Stevenson colony, who have found that the waters from certain flowing wells can not be used safely in the irrigation of fruit, proves this. In general, it may be said that the best ground waters are found well up the east slope, and that there is a progressive deterioration westward.

PUMPING PLANTS.

There are between 40 and 50 pumping plants in the county, most of them equipped with gas engines. More than half of these are used to develop irrigating waters, and the remainder are used chiefly for domestic or town supplies. Grain, fruit, alfalfa, berries, sweet potatoes, etc., are the principal crops raised by the ranchers, who use pumping plants for irrigation. They express themselves as satisfied with the results and convinced that pump irrigation in many parts of Merced County may be made highly successful.

In the Atwater and Livingston districts, as well as about Plainsburg and Le Grand, plants have already proved practicable. Throughout much of the east side, to the west, south, and east of Merced, the ground-water level is within 20 feet or less of the surface, and where soils are favorable, such accessible ground waters may be utilized to advantage in pumping operations.

Merced, like other east-side counties, includes a belt between the trough of the valley and the foothills that contains more or less alkali because of the proximity of the ground waters to the surface. In certain parts of this belt alkalinity has increased in recent years as the result of irrigation by means of gravity waters supplied by the Crocker-Huffman system. In such areas, if the lands are still productive, pumping, either as an independent source of irrigation water, or as an auxiliary to the gravity system, is most to be desired. It results in benefit to the community in several ways. In the first place, it is a method of drainage. The water that is supplied to the land is drawn from beneath it. The tendency of the ground waters to rise with irrigation is thereby counteracted and the ground water level is kept down. In the second place, there is no overuse. Each acre-foot of water developed costs a fixed sum. Under these conditions more will not be used than is needed and the usual tendency of the ground-water plane to rise with irrigation will not be manifest. Again, pumping and the use of relatively high-priced water encourages intensive cultivation and this again reduces the quantity of water necessary. Frequent cultivation and the creation thereby of a mulch at the surface has long been recognized as one of the effective means of prevention of loss of water by evaporation from the surface. Whether lands already damaged by alkali as a result of the application of too much water can be reclaimed and utilized by pumping, under the economic conditions that now exist, is an unsettled question; but there is no doubt that the irrigation of undamaged lands whose water plane lies within 20 or 25 feet can be carried out successfully where intensive farming methods are used, and that the rise of alkalies in such lands will be prevented.

STANISLAUS COUNTY.

GENERAL CONDITIONS.

Stanislaus County, like Merced, extends entirely across San Joaquin Valley, and therefore both east-side and west-side conditions are represented within it. The valley in this latitude is contracted somewhat, so that its width is greater both to the north and to the south than here.

South of Tuolumne River and east of the San Joaquin, the canals of the Turlock irrigation district supply gravity water to a large part of the valley; and north of the Tuolumne the canals of the Modesto district supply the west-central part of the county from a point about 8 miles east of Modesto to San Joaquin River. West of the San Joaquin the lower line of the San Joaquin and Kings River canal system extends to the vicinity of Crows Landing. Under these canal systems much alfalfa is raised, dairying is an important and growing industry, and there is an increasing acreage devoted to fruit raising and diversified farming. Outside of the irrigated district the greater part of the valley lands are in grain, both wheat and barley being raised, although here, as in other parts of the Great Valley, the production is less than formerly. Along the San Joaquin the flooded bottoms and the neighboring alkali lands are used for grazing.

Less use is made of underground waters in this county than in any part of the valley. The rainfall is sufficient, so that grain raising has been successful in the past, and irrigation, therefore, has not been absolutely necessary in order that the valley lands might be utilized, and the pressure for irrigation therefore has not been as intense as in the more strictly arid sections farther south. Furthermore, the surface supply is more nearly adequate than in many of the counties, and the limits of productivity through the use of the cheap gravity waters have not been reached, because the Turlock and Modesto districts are not yet fully developed. The needs that result from a combination of such complete aridity that crop production is impossible without irrigation and full utilization of all surface waters that are available, are not as yet operative in Stanislaus County, and there has not yet been an influx of the type of settler who is content to develop small farm units intensively in the way that is resulting in such successful use of small pumping plants as prevails about Stockton and Lodi.

FLOWING WELLS.

The Survey has records of only 5 flowing wells in the county. These are near the southern boundary, and most of them are west of San Joaquin River. Only one, that on the McDermott estate, northeast of Newman, is used for irrigation. The others furnish supplies for stock. The water from all of these wells contains an excess of saline matter in solution, so that it must be used with care.

Because of the meager development, the limits of the area within which flowing waters are to be expected can not be determined with certainty. Nor are these limits of as much importance here as farther south in the valley, because the flowing wells will yield rather meagerly, their waters will be of poor quality generally, and the flowing-well area will be confined to a zone of low land along the axis of the valley, much of which is subject to overflow and some of which is alkaline.

The settlers along the west side—owners of fertile, alkali-free soils, capable of immense production if water could be applied to them, but practically limited under present conditions to dry crops—are as a matter of course deeply interested in the possibility of securing irrigation water from any source. The streams that flow from the west-side hills toward the valley are wet-weather streams of slight flow and can not be considered as sources of irrigation water.

The San Joaquin and Kings River canal system may be capable of slight extension when irrigation practice on the lands under it improves; but at best it can serve only a small additional acreage. It is probable that pumping systems will eventually be installed to lift water directly from the San Joaquin to apply to those west-side lands that are within 40 or 50 feet of the low-water level in the river. Pumping plants may also be installed in the lower west-side lands to pump ground waters, but the lift will be nearly as great as from the river and the water will be of inferior quality, since all of the west-side ground waters contain notable quantities of salts and some of them approach the limit of usability for irrigation.

PUMPING PLANTS.

Pumping plants for irrigation are practically unknown in this county, but one or two being in operation. They are used, however, to supply the stations of the Pacific Coast Oil Company, the railroads, and the domestic supply for the city of Modesto. Ground waters are accessible with moderate lifts throughout the west half of the east slope of the valley, and as irrigation progresses under the gravity systems and the water plane rises, it will become increasingly desirable as a means of drainage as well as a source of auxiliary or independent gravity waters. That intensive cultivation and careful methods will make it as practicable here as it is elsewhere in the valley, scarcely needs affirmation.

SAN JOAQUIN COUNTY.

GENERAL CONDITIONS.

San Joaquin County is, with the exception of small areas in Alameda and Contra Costa, the northernmost of those counties whose valley lands belong to the southern division of the great central lowland of California. Because of its latitude and its position near the gateway that opens to the Pacific, it differs greatly climatically from the southern counties of the valley. Its temperatures are not as high and do not fluctuate through as wide a range (monthly averages vary from 46.5° in January to 72.5° in July and August), its rainfall is greater, amounting to about 15.5 inches, and its percentage of foggy days exceeds that of Kern, Tulare, and other of the southern counties. Furthermore, situated as it is along the lower San Joaquin, it includes a tidal section of that stream and a large area that is subject to inundation when the Sacramento is in flood, and a still larger section subject to overflow when floods in the San Joaquin and its tributaries occur at the same time as those of the Sacramento. The county, therefore, includes a part of that Central California area, whose problems of reclamation, drainage, and navigation involve in so complete and fascinating a way all of the phases of hydraulic engineering. The rivers must be improved and controlled for navigation purposes, the lowlands must be protected from floods and drained, while the higher bordering parts of the valley lands, too dry to produce the more valuable crops although suited to grain raising, require irrigation for their fullest development. This threefold problem belongs typically to the Sacramento Valley, but it requires solution also in that of the lower San Joaquin.

The Stanislaus Water Company takes its supply of water from the Stanislaus near Knights Ferry and irrigates an area of several thousand acres along the southern border of the county in the Escalon and Manteca districts. In the Lodi and Stockton districts the systems of the Stockton and Mokelumne Irrigating Company and the Woodbridge Canal and Irrigation Company supply surface waters to limited areas. Within the island district, west and north of Stockton, where reclamation has been accomplished by the construction of protective levees, water is sometimes admitted within the dikes during high-water periods in the streams for irrigation purposes, but as subirrigation is effectual throughout the greater part of these areas, surface irrigation is rarely necessary. The higher lands of the valley slopes, both along the east and west sides, are devoted to grain raising, as some of them have been for almost half a century. No water is applied to them. There is no uniformity as to practice among the vineyardists, some of them irrigating their vines, others preferring that they be not irrigated.

FLOWING WELLS.

San Joaquin County includes the northern portion of the great central artesian zone of the valley, but as this zone is less important in its northern part, both because of the inferior yield of wells there and because of the greater proportion of water of poor quality obtained from them, there has been relatively little development for irrigation purposes or domestic supply. Twenty-nine records have been obtained and these are believed to include all of the flowing wells in the country districts and nearly all of those in the city of Stockton. Only six of these supply water that is suitable for irrigating purposes and the yield of these is small. By far the greater number of the flowing wells have been drilled for the gas they yield. In all such wells, the water with which the gas occurs is saline and is allowed to waste, since it is not usable for drinking purposes or for irrigation.

The few artesian wells that furnish water of good quality not only yield small supplies but are expensive because of their considerable depth. Those of which records are available are from 975 to 1,200 feet deep. Wells of lesser depths do not yield flows, and those with greater depths, at least in the Stockton neighborhood, yield saline waters and gas. Farther west than Stockton, nearer the axis of the valley, it is probable that the water, even from shallow wells, would be alkaline. It will be realized that under these conditions flowing wells are not of value for irrigation purposes in the county, despite the rather large area over which flows may be obtained.

PUMPING PLANTS.

During the last few years irrigation by the use of pumped waters has become an important factor in the development of the east side of San Joaquin County. Around Lathrop and French Colony, in the district east of Stockton and in the country about Lodi, a large number of plants have been installed and new wells are being sunk and new plants put in operation constantly.

This development is of a most promising type. Most of the plants are small and the acreage irrigated by each is limited. This means small holdings, intensive cultivation, and eventually relatively dense settlement. The average recorded horsepower of 193 plants is only 6.2. Of the 193 plants 138 develop from 2 to 8 horsepower, while 42 are equipped with engines developing from 10 to 15 horsepower. One hundred and eighty-seven gas engines are in use, thirteen plants use motors, and two are operated by steam.

One hundred and thirty-seven owners of plants report a total of 1,455 acres, an average of only 10.6 acres each. The cost of 106 of the plants is reported by the owners as $64,983, an average cost of $613 each. These facts indicate the small scale and individualistic character of the development.

The power companies charge a uniform rate of 3⅓ cents per horsepower per hour. This is higher than the fuel charge in the gas plants, the reported average in 12 plants for the summer of 1906 being 1.45 cents per horsepower per hour, but labor and installation, both of which are heavier charges in the gas plants, tend to equalize the difference. Water as developed in these small plants seems to cost the users from $1.50 to as much as $3 or $4 per acre-foot.

Generally water is delivered from the pumping plants to the acreage served through earth ditches, and where the soil is sandy and porous this method results in much waste.

The pumping-plant wells are comparatively shallow, and hence are very much cheaper than the deep wells necessary to secure artesian flows. The average depth of somewhat more than 100 wells, taken at random from the records, is about 80 feet. Another group of 20 wells average only 40 feet in depth. These latter wells are equipped with small pumping plants, developing an average of 5 horsepower each, and the water which they yield is ample.

The wells are particularly cheap because it has been found that in many parts of the area it is not necessary to case them, or at least they must be cased only to slight depths. Twelve pumping-plant wells are reported as without any casing; 24 others were only partially cased, the pipe in these varying in length from a few joints to three-fourths or seven-eighths of the entire depth of the well.

The windmill has been an important factor in the past in irrigation in the Stockton district, and although it is being rapidly superseded by the small pumping plant, it is still extensively used, especially in the vegetable garden and fruit districts east and northeast of Stockton. Its chief disadvantage, of course, is the uncertainty of the wind. It is not unusual to see a well equipped both with a small gas engine and a large windmill, the engine being used when the wind fails. The wheels used are of wood and of local manufacture, from 18 to 22 feet in diameter, and cost complete with the tower from $175 to $200.

Much of the gardening and fruit for the San Francisco market is in the hands of Italian immigrants, who, after giving the windmill a thorough trial, are now abandoning it in favor of the more reliable small gas engine.

Irrigation by pumping, of the general type practiced about Stockton and Lodi, could be extended with great advantage throughout a large acreage, now without water, between the Mokelumne and Tejon Pass, but to be practiced successfully it will require a different spirit from that which as yet largely dominates the West. The promoting and speculative spirit, the desire to get rich overnight, to control large holdings, and to avoid personal labor, will have to be superseded by a willingness to be satisfied with sure but moderate returns, to be content with small farm units, and to attain personal independence through individual effort. It is to be hoped that the American citizen of the generations to come will prove willing to accept these conditions and that in the future dependence need not be placed upon our adopted citizens for detailed development of this desirable type.

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